SECTION 5—DESIGN

5.1 Joints

5.1.1 Definitions

The definitions in 5.1.1.1 through 5.1.1.8 apply to tank joint designs. (See 9.1 for definitions that apply to welders and welding procedures. See Section 3 for additional definitions.)

5.1.1.1
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.

5.1.1.2
double-welded butt joint
A joint between two abutting parts lying in approximately the same plane that is welded from both sides.

5.1.1.3
double-welded lap joint
A joint between two overlapping members in which the overlapped edges of both members are welded with fillet welds.

5.1.1.4
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.

5.1.1.5
full-fillet weld
A fillet weld whose size is equal to the thickness of the thinner joined member.

5.1.1.6
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.

5.1.1.7
single-welded lap joint
A joint between two overlapping members in which the overlapped edge of one member is welded with a fillet weld.

5.1.1.8
tack weld
A weld made to hold the parts of a weldment in proper alignment until the final welds are made.

5.1.2 Weld Size

5.1.2.1 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).

5.1.2.2 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.

5.1.3 Restrictions on Joints

5.1.3.1 Restrictions on the type and size of welded joints are given in 5.1.3.2 through 5.1.3.8.

5.1.3.2 Tack welds shall not be considered as having any strength value in the finished structure.

5.1.3.3 The minimum size of fillet welds 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.).

5.1.3.4 Single-welded lap joints are permissible only on bottom plates and roof plates.

5.1.3.5 Lap-welded joints, as tack-welded, shall be lapped as follows.

— Double-welded joints shall be lapped at least five times the nominal thickness of the thinner plate joined, or 50 mm (2 in.), whichever is smaller.

— Single-welded joints shall be lapped at least five times the nominal thickness of the thinner plate joined, or 25 mm (1 in.), whichever is smaller.

5.1.3.6 Weld passes are restricted as follows:

● **5.1.3.6.1** For bottom plate welds and roof plate welds for all materials, and for shell-to-bottom welds for Groups I, II, III, and IIIA materials, the following weld size requirements apply:

a) For manual welding processes, fillet weld legs or groove weld depths greater than 6 mm ($^1/_4$ in.) shall be multipass, unless otherwise specified on the Data Sheet, Line 15.

b) For semi-automatic, machine, and automatic welding processes, fillet weld legs or groove weld depths greater than 10 mm ($^3/_8$ in.) shall be multipass, unless otherwise specified on the Data Sheet, Line 15.

5.1.3.6.2 For Groups IV, IVA, V, or VI shell-to-bottom welds for all welding processes, all welds shall be made using a minimum of two passes.

5.1.3.7 Attachments to tank exterior surfaces shall be as follows.

a) Except as provided in item b. below, all attachments to tank exterior surfaces shall be completely seal welded (no intermittent welding) to minimize rust streaking.

b) If specified on the Data Sheet, intermittent welding is permitted for:

1) wind girders as described in 5.1.5.8;

2) attachments to surfaces that will be covered by insulation;

3) attachments to surfaces of corrosion-resistant materials, including but not limited to stainless steel (See Annex S and Annex X) and aluminum (See Annex AL).

● **5.1.3.8** Except as permitted in 5.1.5.5 and 5.1.5.6, permanent weld joint backing strips are permitted only with the approval of the Purchaser.

5.1.4 Welding Symbols

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

5.1.5 Typical Joints

5.1.5.1 General

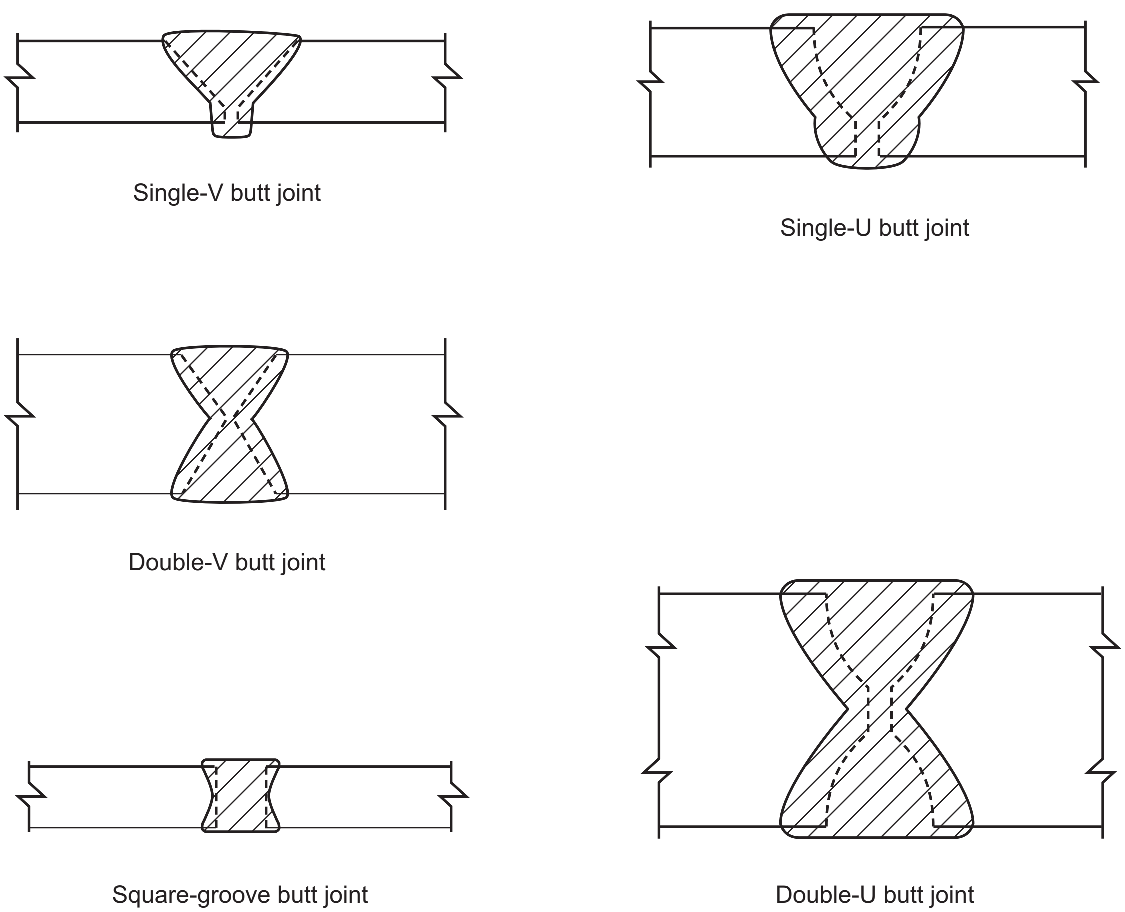
a) Typical tank joints are shown in Figure 5.1, Figure 5.2, Figure 5.3a, Figure 5.3b, and Figure 5.3c.

b) The top surfaces of bottom welds (butt-welded annular plates, butt-welded sketch plates, or Figure 5.3b joints) shall be ground flush where they will contact the bottoms of the shell, insert plates, thickened insert plates, or reinforcing plates.

5.1.5.2 Vertical Shell Joints

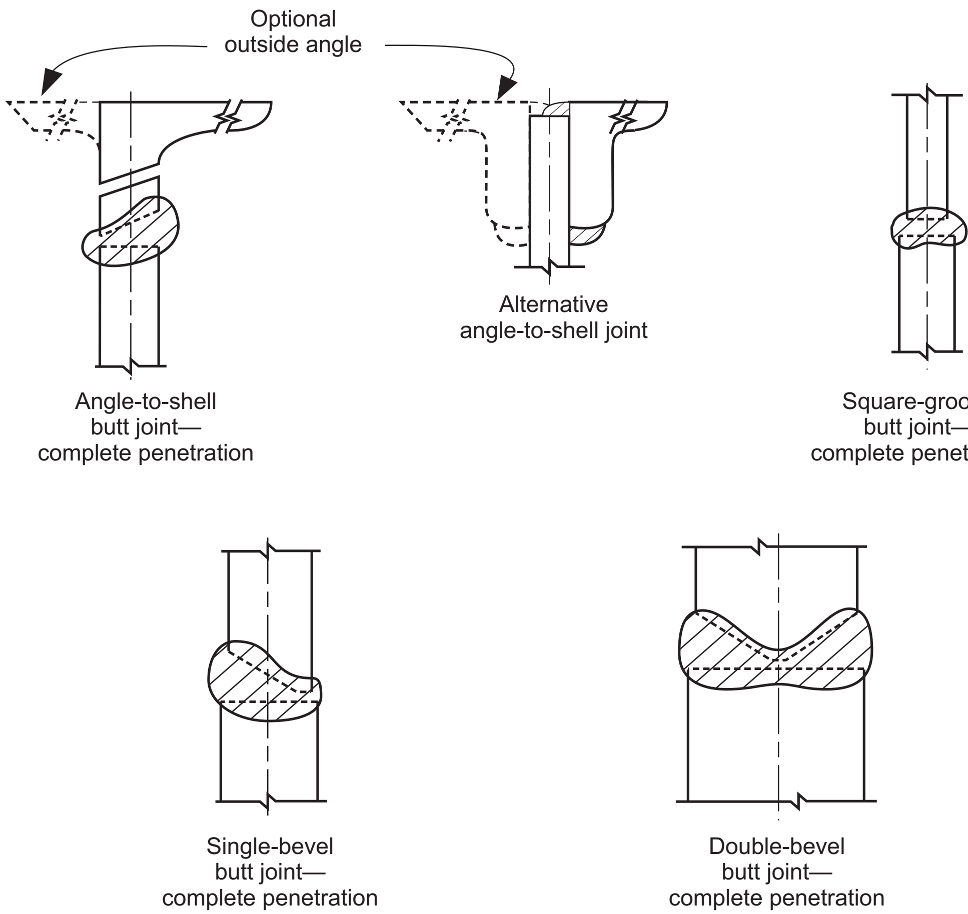
a) Vertical shell joints shall be butt joints with complete penetration and complete fusion attained by double welding or other means that will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to meet the requirements of 7.2.1 and 7.2.3. The suitability of the plate preparation and welding procedure shall be determined in accordance with 9.2.

b) 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.



NOTE See 5.1.5.2 for specific requirements for vertical shell joints.

Figure 5.1—Typical Vertical Shell Joints



NOTE See 5.1.5.3 for specific requirements for horizontal shell joints.

Figure 5.2—Typical Horizontal Shell Joints

5.1.5.3 Horizontal Shell Joints

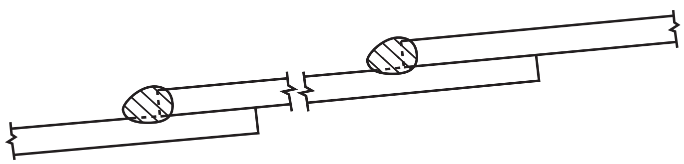
a) Horizontal shell joints shall have complete penetration and complete fusion; however, as an alternative, top angles may be attached to the shell by a double-welded lap joint. The suitability of the plate preparation and welding procedure shall be determined in accordance with 9.2.

● b) Unless otherwise specified, abutting shell plates at horizontal joints shall have a common vertical centerline.

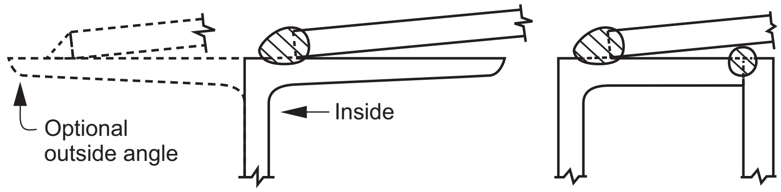
5.1.5.4 Lap-Welded Bottom Joints

● **5.1.5.4.1** Lap-welded bottom plates shall be reasonably rectangular. Additionally, plate may be either square cut or may have mill edges. Mill edges to be welded shall be relatively smooth and uniform, free of deleterious deposits, and have a shape such that a full fillet weld can be achieved. Unless otherwise specified by the Purchaser, lap welded plates on sloped bottoms shall be overlapped in a manner to reduce the tendency for liquid to puddle during draw-down.

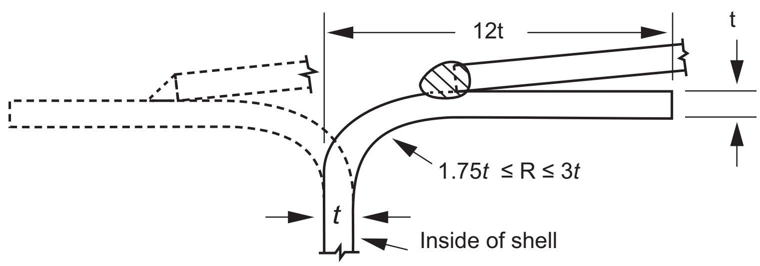
5.1.5.4.2 Three-plate laps in tank bottoms shall be at least 300 mm (12 in.) from each other, from the tank shell, and from joints between annular plates and the bottom. A three-plate lap is created where three plates come together and all plates are joined to one another by lap welds. A location where two bottom plates are lap-welded to each other and are lapped onto or under an annular plate constitutes a three-plate lap, but lapping a single bottom plate onto or under a butt-welded annular plate splice does not constitute a three-plate lap weld since the two annular plates are not joined together by a lap weld. Lap joint connections to butt-welded annular plates are illustrated in Figure 5.3d.



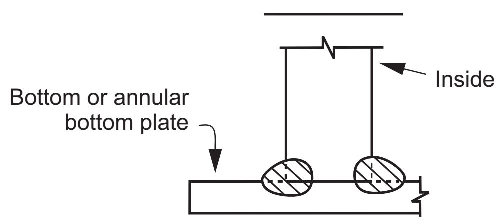
Roof-Plate Joint



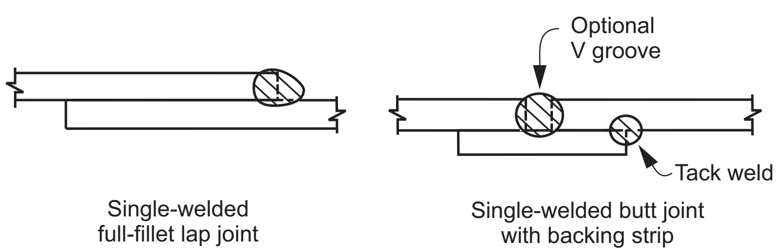
Roof-to-Shell Joints



Alternative Roof-to-Shell Joint
(See Note 2)



Bottom-to-Shell Joint



Bottom-Plate Joints

NOTE 1 See 5.1.5.4 through 5.1.5.9 for specific requirements for roof and bottom joints.
NOTE 2 The alternative roof-to-shell joint is subject to the limitations of 5.1.5.9, Item f.

Figure 5.3a—Typical Roof and Bottom Joints

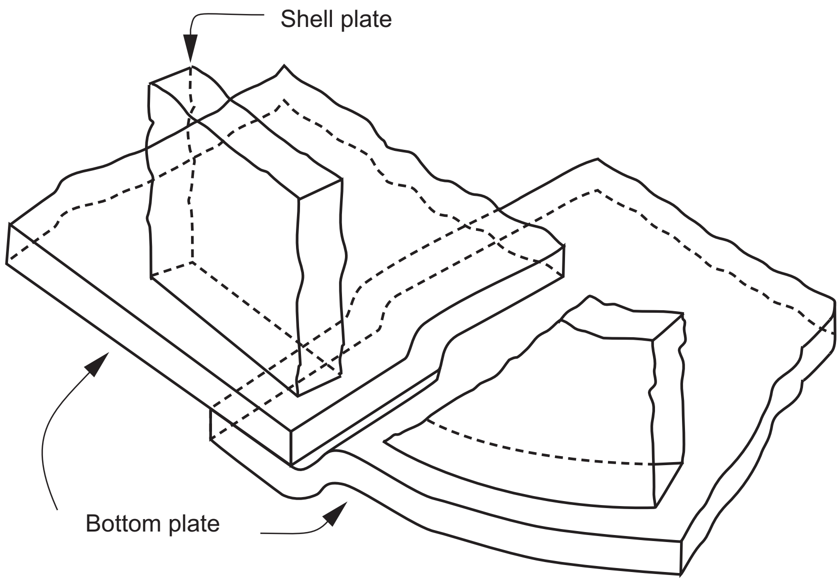
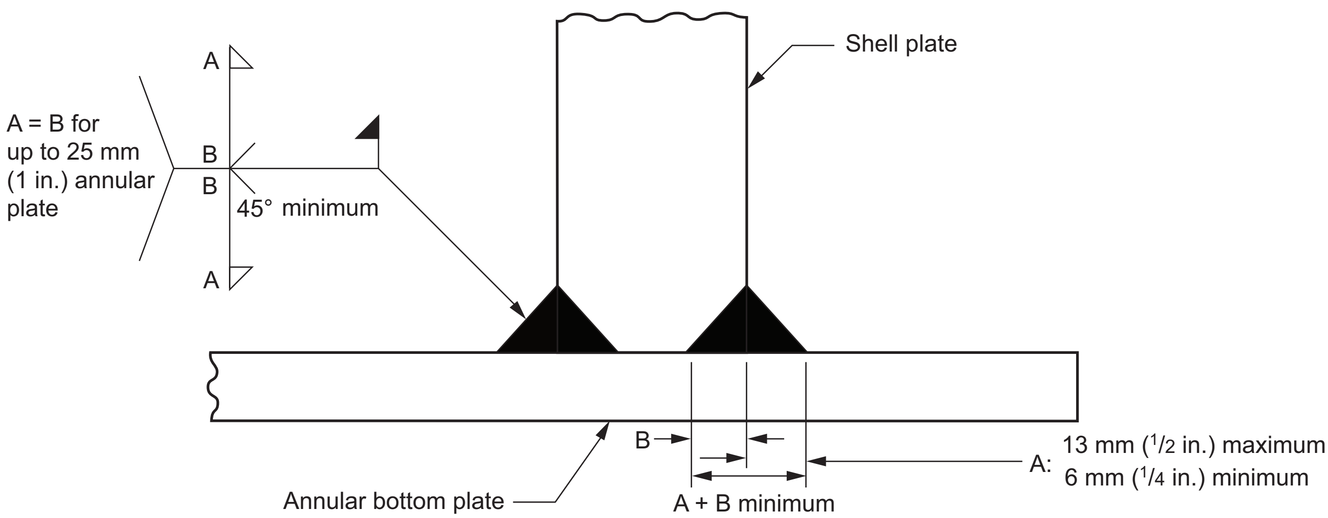


Figure 5.3b—Method for Preparing Lap-welded Bottom Plates under Tank Shell (See 5.1.5.4)



NOTE 1 A = Fillet weld size limited to 13 mm (1/2 in.) maximum.

NOTE 2 A + B = Thinner of shell or annular bottom plate thickness.

NOTE 3 Groove weld B may exceed fillet size A only when annular plate is thicker than 25 mm (1 in.).

Figure 5.3c—Detail of Double Fillet-groove Weld for Annular Bottom Plates with a Nominal Thickness Greater than 13 mm (1/2 in.) (See 5.1.5.7, Item b)

5.1.5.4.3 Bottom plates need to be welded on the top side only, with a continuous full-fillet weld on all seams. Lap-welded bottom plates under the bottom shell ring shall have the outer ends of the joints fitted and lap-welded to form a smooth bearing surface for the shell plates, as shown in Figure 5.3b. Lap-welded bottom plates shall be seal-welded to each other on the exposed outer periphery of their lapped edges.

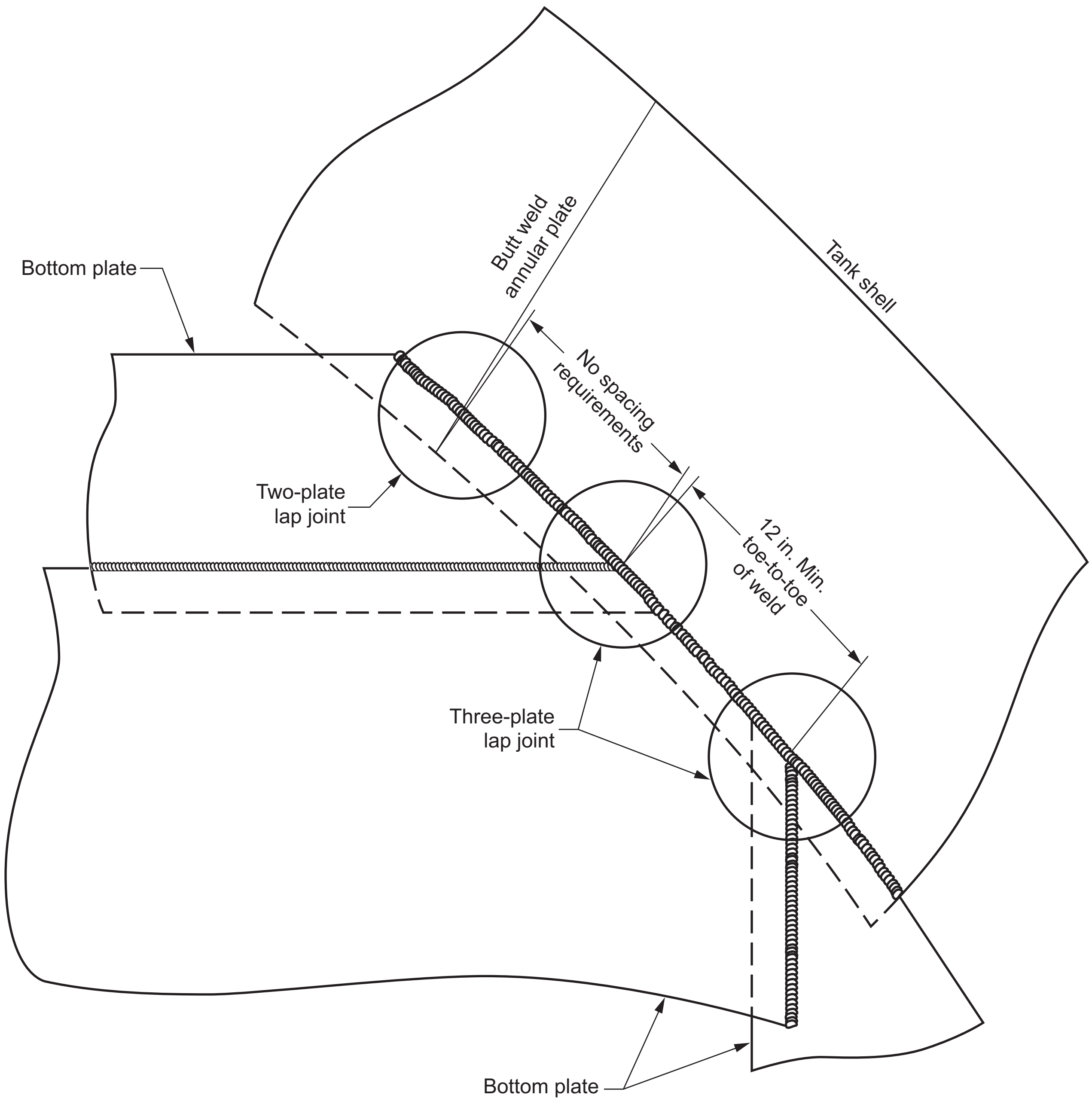


Figure 5.3d—Spacing of Three-Plate Welds at Annular Plates

• 5.1.5.5 Butt-Welded Bottom Joints

Butt-welded bottom plates shall have their parallel edges prepared for butt welding with either square or V grooves. Butt-welds shall be made using an appropriate weld joint configuration that yields a complete penetration weld. Typical permissible bottom butt-welds without a backing strip are the same as those shown in Figure 5.1. The use of a backing strip at least 3 mm ($^1/_8$ in.) thick tack welded to the underside of the plate is permitted. Butt-welds using a backing strip are shown in Figure 5.3a. If square grooves are employed, the root openings shall not be less than 6 mm ($^1/_4$ in.). 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.

5.1.5.6 Bottom Annular-Plate Joints

Bottom annular-plate radial joints shall be butt-welded in accordance with 5.1.5.5 and shall have complete penetration and complete fusion. The backing strip, if used, shall be compatible for welding the annular plates together.

5.1.5.7 Shell-to-Bottom Fillet Welds

a) For bottom and annular plates with a nominal thickness 13 mm (1/2 in.), and less, the attachment between the bottom edge of the 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 13 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	> 0.1875 to 0.75	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 13 mm (1/2 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 (see Figure 5.3c), but shall not exceed the shell plate thickness.

c) The attachment weld between low-type reinforcing pads and the bottom or annular plates shall be a fillet weld as shown in Figure 5.8, Details A and B. The size of the fillet weld shall not be less than the nominal thickness of the thinner of the two plates joined, shall not be less than the values shown in the table in the paragraph above, and shall not be more than 13 mm (1/2 in.).

d) The attachment weld between shell insert plates or thickened insert plates and the bottom or annular plates shall be sized as required by paragraphs a) or b), above.

e) The bottom or annular plates shall be sufficient to provide a minimum 13 mm (1/2 in.) from the toe of the fillet weld referenced in 5.1.5.7c to the outside edge of the bottom or annular plates.

5.1.5.8 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 unless specified otherwise by the Purchaser.

5.1.5.9 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) For frangible roofs, roof plates shall be attached to the top angle of a tank with a continuous fillet weld on the top side only, as specified in 5.10.2.6. For non-frangible roofs, alternate details are permitted.

c) The top-angle sections, tension rings, and compression rings shall be joined by butt-welds having complete penetration and fusion. Joint efficiency factors need not be applied when conforming to the requirements of 5.10.5 and 5.10.6.

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 in 5.9, for tanks with frangible joints per 5.10.2.6, for self-supporting roofs in 5.10.5, and 5.10.6, and for tanks with the flanged roof-to-shell detail described in Item f below, tank shells shall be supplied with top angles of not less than the following sizes:

Tank Diameter (D)	**Minimum Top Angle Size[a] (mm)**	**Minimum Top Angle Size[a] (in.)**
$D \leq$ 11 m, ($D \leq$ 35 ft)	50 × 50 × 5	2 × 2 × 3/16
11 m < $D \leq$ 18 m, (35 ft < $D \leq$ 60 ft)	50 × 50 × 6	2 × 2 × 1/4
D > 18 m, (D > 60 ft)	75 × 75 × 10	3 × 3 × 3/8

[a] Approximate equivalent sizes may be used to accommodate local availability of materials.

Roof-to-shell connection details per Figure F.2 are permissible provided that the design effective area (cross-hatched section) is greater than or equal to the design effective area provided by the minimum top angle size listed above.

For fixed roof tanks equipped with full shell height insulation or jacketing, the horizontal leg of the top shell stiffener shall project outward. For insulation system compatibility, the Purchaser shall specify if the horizontal leg is to be larger than specified above.

f) For tanks with a diameter less than or equal to 9 m (30 ft) and a supported cone roof (see 5.10.4), 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 Figure 5.3a. This construction may be used for any tank with a self-supporting roof (see 5.10.5 and 5.10.6) 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.

5.2 Design Considerations

5.2.1 Loads

Loads are defined as follows.

• a) **Dead Load (D_L):** The weight of the tank or tank component, including any corrosion allowance unless otherwise noted.

• b) **Design External Pressure (P_e):** Shall not be less than 0.25 kPa (1 in. of water) except that the Design External Pressure (P_e) shall be considered as 0 kPa (0 in. of water) for tanks with circulation vents meeting Annex H requirements. Refer to Annex V for design external pressure greater than 0.25 kPa (1 in. of water). Requirements for design external pressure exceeding this value and design requirements to resist flotation and external fluid pressure shall be a matter of agreement between the Purchaser and the Manufacturer (see Annex V). Tanks that meet the requirements of this standard may be subjected to a partial vacuum of 0.25 kPa (1 in. of water), without the need to provide any additional supporting calculations.

c) **Design Internal Pressure (P_i):** Shall not exceed 18 kPa (2.5 lbf/in.^{2}).

d) **Hydrostatic Test (H_t):** The load due to filling the tank with water to the design liquid level.

e) **Internal Floating Roof Loads:**

1) Dead load of internal floating roof (D_f) including the weight of the flotation compartments, seal and all other floating roof and attached components.

2) Internal floating roof uniform live load (L_{f1}) (0.6 kPa [12.5 lbf/ft^2]) if no automatic drains are provided, [0.24 kPa (5 lbf/f^2)] if automatic drains are provided).

3) Internal floating roof point load (L_{f2}) of at least two men walking anywhere on the roof. One applied load of 2.2 kN [500 lbf] over 0.1 m^2 [1 ft^2] applied anywhere on the roof addresses two men walking.

4) Internal floating roof design external pressure (P_{fe}) of (0.24 kPa [5 lbf/ft^2]) minimum.

f) **Minimum Roof Live Load (L_r):** 1.0 kPa (20 lb/ft^2) on the horizontal projected area of the roof. The minimum roof live load may alternatively be determined in accordance with ASCE 7, but shall not be less than 0.72 kPa (15 psf). The minimum roof live load shall be reported to the Purchaser.

• g) **Seismic (E):** Seismic loads determined in accordance with E.1 through E.6 (see Data Sheet, Line 8).

• h) **Snow (S):** The ground snow load shall be determined from ASCE 7, Figure 7-1 or Table 7-1 unless the ground snow load that equals or exceeds the value based on a 2 % annual probability of being exceeded (50-year mean recurrence interval) or a national standard (such as the National Building Code of Canada) is specified by the Purchaser.

1) The balanced design snow load (S_b) shall be 0.84 times the ground snow load. Alternately, the balanced design snow load (S_b) shall be determined from the ground snow load in accordance with ASCE 7. The balanced design snow load shall be reported to the Purchaser.

2) The unbalanced design snow load (S_u) for cone roofs with a slope of 10° or less shall be equal to the balanced snow load. The unbalanced design snow load (S_u) for all other roofs shall be 1.5 times the balanced design snow load. Unbalanced design snow load shall be applied over a 135° sector of the roof plan with no snow on the remaining 225° sector. Alternately, the unbalanced snow load shall be determined from the ground snow load in accordance with ASCE 7

3) The balanced and unbalanced design snow loads shall be reported to the Purchaser.

• i) **Stored Liquid (F):** The load due to filling the tank to the design liquid level (see 5.6.3.2) with liquid with the design specific gravity specified by the Purchaser.

j) **Test Pressure (P_t):** As required by F.4.4 or F.8.3.

• k) **Wind (W):** The design wind speed (V) shall be either:

— the 3-sec gust design wind speed determined from ASCE 7-05 multiplied by $\sqrt{I}$, Figure 6-1; or

— the 3-sec gust design wind speed determined from ASCE 7-10 for risk category specified by the Purchaser (Figure 26.5-1A, Figure 26.5-1B, or Figure 26.5-1C) multiplied by 0.78; or

— the 3-sec gust design wind speed specified by the Purchaser, which shall be for a 3-sec gust based on a 2 % annual probability of being exceeded (50-year mean recurrence interval).

The 3-sec gust wind speed used shall be reported to the Purchaser.

• 1) Design wind pressure (P_{WS} and P_{WR}) using design wind speed (V): The design wind pressure on shell (P_{WS}) shall be 0.89 kPa $(V/190)^2$, [(18.6 lbf/ft^2)$(V/120)^2$] on vertical projected areas of cylindrical surfaces. The design wind uplift pressure on roof (P_{WR}) shall be 1.48 kPa $(V/190)^2$, [(31 lbf/ft^2)$(V/120)^2$] (see item 2) on horizontal projected areas of conical or doubly curved surfaces. For supported cone roofs meeting the requirements of 5.10.4, P_{WR} shall be taken as zero.

P_{WS} = the design wind pressure on the shell in kPa (lbf/ft^2),

P_{WR} = the design wind uplift pressure on the roof in kPa (lbf/ft^2), and

V = the design wind speed in km/hr (mph).

These design wind pressures are in accordance with ASCE 7-05 for wind exposure Category C. As alternatives, pressures may be determined in accordance with:

a) ASCE 7-05 (exposure category and importance factor provided by Purchaser); or

b) ASCE 7-10 (exposure category and risk category provided by Purchaser) with either velocity multiplied by 0.78 or the ASCE 7-10 pressure multiplied by 0.6; or

c) a national standard for the specific conditions for the tank being designed.

2) The design uplift pressure on the roof (wind plus internal pressure) need not exceed 1.6 times the design pressure P determined in F.4.1.

3) Windward and leeward horizontal wind loads on the roof are conservatively equal and opposite and therefore they are not included in the above pressures.

4) Fastest mile wind speed times 1.2 is approximately equal to 3-sec gust wind speed (V).

NOTE ASCE 7-10 wind velocities now have LRFD load factors and risk category (importance factors) built in, whereas API 650 uses the working stress. The 0.78 factor applied to the ASCE 7-10 wind speed provides a conversion to working stress levels.

• l) **External Loads:**

• 1) 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) Unless otherwise specified, seismic design shall be in accordance with Annex E.

• 3) Design for localized wind induced forces on roof components shall be a matter of agreement between the Purchaser and the Manufacturer.

4) Localized loads resulting from items such as ladders, stairs, platforms, etc., shall be considered.

5) The Purchaser shall state the magnitude and direction of any external loads other than normal personnel access for which the roof manholes and openings shall be designed. The design for such loadings shall be a matter of agreement between the Purchaser and the Manufacturer.

5.2.2 Load Combinations

Loads shall be combined as follows. Design rules in this Standard use these load combinations, including the absence of any load other than D_L in the combinations:

a) Fluid and Internal Pressure: $D_L + F + P_i$

b) Hydrostatic Test: $D_L + H_t + P_t$

c) Wind and Internal Pressure: $D_L + W + F_p\, P_i$

d) Wind and External Pressure: $D_L + W + F_{pe}\, P_e$

e) Gravity Loads:

1) $D_L + (L_r \text{ or } S_u \text{ or } S_b) + F_{pe}\, P_e$

2) $D_L + P_e + 0.4(L_r \text{ or } S_u \text{ or } S_b)$

f) Seismic: $D_L + F + E + 0.1S_b + F_p\, P_i$

g) Gravity Loads for Fixed Roofs with Suspended Floating Roofs:

1) $D_L + D_f + (L_r \text{ or } S) + P_e + 0.4(P_{fe} \text{ or } L_{f1} \text{ or } L_{f2})$

2) $D_L + D_f + (P_{fe} \text{ or } L_{f1} \text{ or } L_{f2}) + 0.4[(L_r \text{ or } S) + F_{pe} P_e]$

- The internal pressure combination factor (F_p) is defined as the ratio of normal operating internal pressure to design internal pressure, with a minimum value of 0.4.
- The external pressure combination factor (F_{pe}) is defined as the ratio of normal operating external pressure to design external pressure, with a minimum value of 0.4.

5.2.3 Design Factors

- The Purchaser shall state the design metal temperature (based on ambient temperatures), the maximum design temperature, the design specific gravity, the corrosion allowance (if any), and the seismic factors.

• 5.2.4 Protective Measures

The Purchaser shall consider foundations, corrosion allowance, hardness testing, and any other protective measures deemed necessary. For example, for insulated tanks, means to prevent infiltration of water into the insulation shall be specified, especially around penetrations of the insulation and at the roof-to-shell junction.

5.2.5 Tank Capacity

• **5.2.5.1** The Purchaser shall specify the maximum capacity and the overfill protection level (or volume) requirement (see API 2350).

5.2.5.2 Maximum capacity is the volume of product in a tank when the tank is filled to its design liquid level as defined in 5.6.3.2 (see Figure 5.4).

5.2.5.3 The net working capacity is the volume of available product under normal operating conditions. The net working capacity is equal to the maximum capacity (see 5.2.5.2) less the minimum operating volume remaining in the tank, less the overfill protection level (or volume) requirement (see Figure 5.4).

5.3 Special Considerations

5.3.1 Foundation

• **5.3.1.1** The selection of the tank site and the design and construction of the foundation shall be given careful consideration, as outlined in Annex B, to ensure adequate tank support. The adequacy of the foundation is the responsibility of the Purchaser. Foundation loading data shall be provided by the Manufacturer on the Data Sheet, Line 13.

5.3.1.2 Sliding friction resistance shall be verified for tanks subject to lateral wind loads or seismic loads (see 5.11.4 and E.7.6).

5.3.2 Corrosion Allowances

• **5.3.2.1** The Purchaser, after giving consideration to the total effect of the liquid stored, the vapor above the liquid, and the atmospheric environment, shall specify in the Data Sheet, Table 1 and Table 2, any corrosion allowances to be provided for all components, including each shell course, for the bottom, for the roof, for nozzles and manholes, and for structural members.

5.3.2.2 Excluding nozzle necks, corrosion allowances for nozzles, flush-type cleanouts, manholes, and self-supporting roofs shall be added to the design thickness, if calculated, or to the minimum specified thickness.

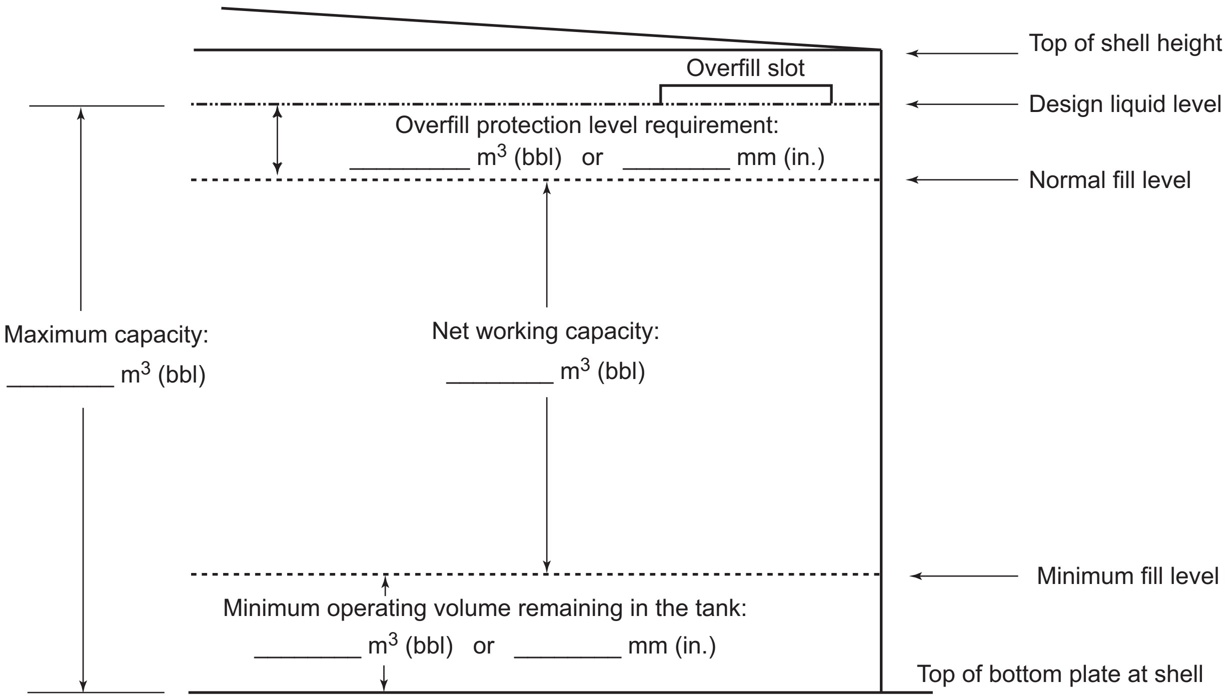


Figure 5.4—Storage Tank

- **5.3.2.3** For nozzle necks, any specified nozzle neck corrosion allowance shall, by agreement between the Purchaser and the Manufacturer, be added to either the nominal neck thickness shown in Table 5.6a and Table 5.6b (or Table 5.7a and Table 5.7b), or to the minimum calculated thickness required for pressure head and mechanical strength. In no case shall the neck thickness provided be less than the nominal thickness shown in the table.

5.3.2.4 Corrosion allowance for anchor bolts shall be added to the nominal diameter.

5.3.2.5 Corrosion allowance for anchor straps and brackets shall be added to the required strap and bracket thickness.

- **5.3.2.6** For internal structural members, the corrosion allowance shall be applied to the total thickness unless otherwise specified.

5.3.3 Service Conditions

- The Purchaser shall specify any applicable special metallurgical requirements pertaining to the selection of materials and the fabrication processes as required by any anticipated 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 in 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. See the Data Sheet, Line 5.

• **5.3.4 Weld Hardness**

a) Weld metal and Heat Affected Zone (HAZ) hardnesses shall comply with the H_2S Supplemental Specification listed on the Data Sheet, Line 5, when specified by the Purchaser.

b) 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.

1) 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.

2) All welds deposited by machine or 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.

• **5.3.5 Thickness**

When 6 mm ($^1/_4$ in.) thick material is specified, 0.236 in. thick material may be used in the US Customary rule set with Purchaser approval. Similarly when 5 mm ($^3/_{16}$ in.) thick material is specified, 4.8 mm. thick material may be used in the SI rule set with Purchaser approval. The design calculations shall be based on thickness used.

5.4 Bottom Plates

• **5.4.1** All bottom plates shall have a corroded thickness of not less than 6 mm (0.236 in.) [49.8 kg/m^2 (9.6 lbf/ft^2) (see 4.2.1.2)]. 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 nominal width of not less than 1800 mm (72 in.).

5.4.2 Bottom plates or annular plates of sufficient size shall be ordered so that, when trimmed, at least a 50 mm (2 in.) width will project beyond the outside surface of the shell plate or meet the requirements given in 5.1.5.7 e, whichever is greater.

5.4.3 Bottom plates shall be welded in accordance with 5.1.5.4 or 5.1.5.5.

• **5.4.4** Unless otherwise specified on the Data Sheet, Line 12, tank bottoms requiring sloping shall have a minimum slope of 1:120 upwards toward center of the tank.

• **5.4.5** If specified on the Data Sheet, Line 12, a foundation drip ring shall be provided to prevent ingress of water between the tank bottom and foundation. Unless the Purchaser specifies otherwise, the ring shall meet the following requirements (see Figure 5.5).

1) Material shall be carbon steel, 3 mm ($^1/_8$ in.) minimum thickness.

2) All radial joints between sections of the drip rings, as well as between the drip ring and the annular plate or bottom, shall be continuously seal-welded.

3) The drip ring shall extend at least 75 mm (3 in.) beyond the outer periphery of the foundation ringwall and then turn down (up to 90°) at its outer diameter.

4) The top and bottom of the drip ring, and the top of the tank bottom edge projection beyond the shell, and a portion of the tank shell shall be coated if specified by the Purchaser.

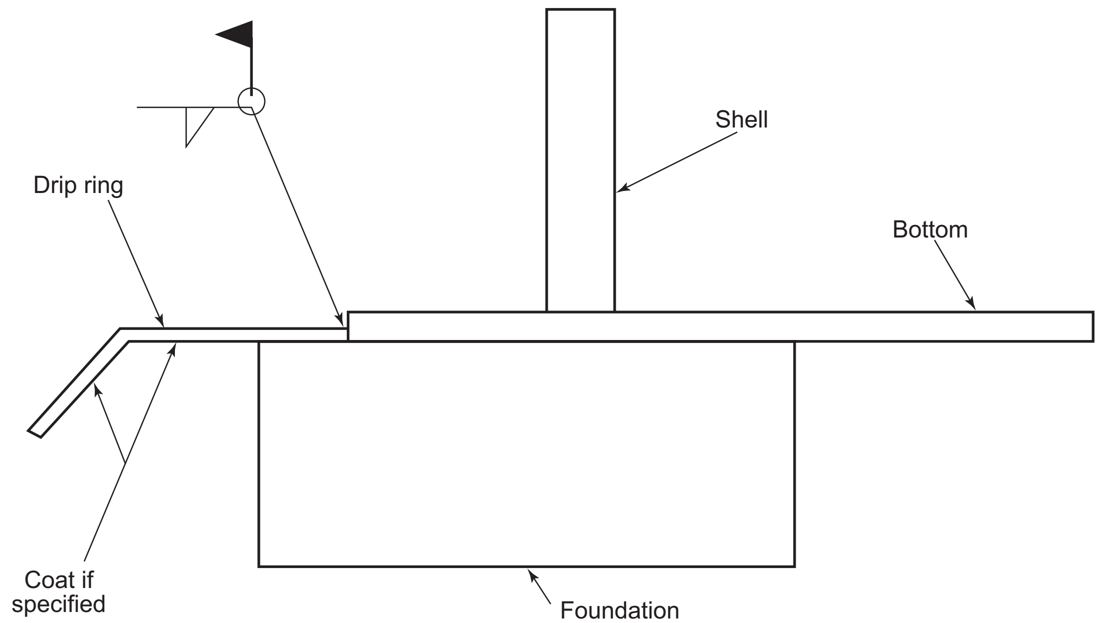


Figure 5.5—Drip Ring (Suggested Detail)

5.5 Annular Bottom Plates

5.5.1 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 (see 5.1.5.6). When the bottom shell course is of a material in Group IV, IVA, V, or VI and the maximum product stress (see 5.6.2.1) for the first shell course is less than or equal to 160 MPa (23,200 lbf/in.^{2}) or the maximum hydrostatic test stress (see 5.6.2.2) for the first shell course is less than or equal to 171 MPa (24,900 lbf/in.^{2}), lap-welded bottom plates (see 5.1.5.4) may be used in lieu of butt-welded annular bottom plates. When annular bottom plates are not required by this standard, lap-welded or butt-welded bottom plates cut into annular shapes may be installed under the shell, but they would not be considered annular bottom plates (see 3.1).

5.5.2 Annular bottom plate projection outside the shell shall meet the requirements of 5.4.2. If annular plates are required by either 5.5.1, AL.5.2.1, M.4.1, S.3.1.3, or X.3.2, the annular plate minimum radial width shall be needed to provide L as calculated using the following formula:

$$L = 2\ t_b \sqrt{\frac{F_y}{2 \Upsilon G H}}$$, but not less than 600 mm (24 in.)

where

L is the minimum radial distance as measured from inside edge of the shell to the edge of the plate in the remainder of the bottom, mm (inch);

F_y is the minimum yield strength of the annular plate at ambient temperature, MPa (psi);

NOTE This applies to Annex-M, Annex-AL, Annex-S, and Annex-X tanks, as well.

t_b is the nominal thickness of the annular plate (see 5.5.3), mm (in.);

H is the maximum design liquid level (see 5.6.3.2), m (ft);

G is the design specific gravity of the liquid to be stored, as specified by the Purchaser, not greater than 1.0;

Υ is the density factor of water. MPa per meter, (psi per foot) SI: 9.81/1000, USC: 62.4/144.

NOTE Derivation of the equation is from "Structural Analysis and Design of Process Equipment" by Jawad and Farr and L.P. Zick and R.V. McGrath, "Design of Large Diameter Cylindrical Shells."

Alternatively, if thickened annular plates are being solely provided as wind or seismic overturning resistance, the minimum radial distance between the inside of the shell and the edge of the plate in the remainder of the bottom shall be in accordance with 5.11.2.3 or E.6.2.1.1.3, respectively.

5.5.3 The thickness of the annular bottom plates shall not be less than the greater thickness determined using Table 5.1a and Table 5.1b for product design (plus any specified corrosion allowance) or for hydrostatic test design. Table 5.1a and Table 5.1b are applicable for effective product height of $H \times G \leq 23$ m (75 ft). Beyond this height an elastic analysis must be made to determine the annular plate thickness.

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 = $((t_d - CA)/$ corroded $t)$ (S_d)

Hydrostatic Test Stress = $(t_t$ / 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.

5.5.4 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. These pieces shall be welded in accordance with 5.1.5.6 and 5.1.5.7, Item b.

5.5.5 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 in 5.5.2.

5.6 Shell Design

5.6.1 General

5.6.1.1 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.)
< 15	< 50	5	3/16
15 to < 36	50 to < 120	6	1/4
36 to 60	120 to 200	8	5/16
> 60	> 200	10	3/8

• NOTE 1 Unless otherwise specified by the Purchaser, the nominal tank diameter shall be the centerline diameter of the bottom shell-course plates.

NOTE 2 The thicknesses specified are based on erection requirements.

• NOTE 3 When specified by the Purchaser, plate with a nominal thickness of 6 mm may be substituted for 1/4-in. plate.

NOTE 4 For diameters less than 15 m (50 ft) but greater than 3.2 m (10.5 ft), the nominal thickness of the lowest shell course shall not be less than 6 mm (1/4 in.).

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 = $((t_d - CA)$/ corroded t) (S_d)

Hydrostatic Test Stress = $(t_t$ / 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.

5.6.1.2 Unless otherwise agreed to by the Purchaser, 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.

5.6.1.3 The calculated stress for each shell course shall not be greater than the stress permitted for the particular material used for the course. When the allowable stress for an upper shell course is lower than the allowable stress of the next lower shell course, then either a or b shall be satisfied.

a) The lower shell course thickness shall be no less than the thickness required of the upper shell course for product and hydrostatic test loads by 5.6.3 or 5.6.4.

b) The thickness of all shell courses shall be that determined from an elastic analysis per 5.6.5 using final plate thicknesses.

The inside of an upper shell course shall not project beyond the inside surface of the shell course below (except within tolerances provided in 7.2.3.2).

5.6.1.4 The tank shell shall be checked for stability against buckling from the design wind speed in accordance with 5.9.6. If required for stability, intermediate girders, increased shell-plate thicknesses, or both shall be used.

5.6.1.5 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.

5.6.2 Allowable Stress

5.6.2.1 The maximum allowable product design stress, S_d, shall be as shown in Table 5.2a and Table 5.2b. The corroded plate thicknesses 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.

5.6.2.2 The maximum allowable hydrostatic test stress, S_t, shall be as shown in Table 5.2a and Table 5.2b. The nominal plate thicknesses 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 5.2a—Permissible Plate Materials and Allowable Stresses (SI)

Plate Specification	Grade	Nominal Plate Thickness t mm	Minimum Yield Strength MPa	Minimum Tensile Strength MPa	Product Design Stress S_d MPa	Hydrostatic Test Stress S_t MPa
ASTM Specifications						
A283M	C		205	380	137	154
A285M	C		205	380	137	154
A131M	A, B		235	400	157	171
A36M	—		250	400	160	171
A131M	EH 36		360	490[a]	196	210
A573M	400		220	400	147	165
A573M	450		240	450	160	180
A573M	485		290	485[a]	193	208
A516M	380		205	380	137	154
A516M	415		220	415	147	165
A516M	450		240	450	160	180
A516M	485		260	485	173	195
A662M	B		275	450	180	193

Table 5.2a—Permissible Plate Materials and Allowable Stresses (SI) (Continued)

Plate Specification	Grade	Nominal Plate Thickness t mm	Minimum Yield Strength MPa	Minimum Tensile Strength MPa	Product Design Stress S_d MPa	Hydrostatic Test Stress S_t MPa
A662M	C		295	485[a]	194	208
A537M	1	$t \le 65$ $65 < t \le 100$	345 310	485[a] 450[b]	194 180	208 193
A537M	2	$t \le 65$ $65 < t \le 100$	415 380	550[a] 515[b]	220 206	236 221
A633M	C, D	$t \le 65$ $65 < t \le 100$	345 315	485[a] 450[b]	194 180	208 193
A737M	B		345	485[a]	194	208
A841M	Class 1, Grades A and B		345	485[a]	194	208
A841M	Class 2, Grades A and B		415	550[a]	220	236
CSA Specifications						
G40.21M	260W		260	410	164	176
G40.21M	260 WT		260	410	164	176
G40.21M	300W		300	440	176	189
G40.21M	300WT		300	440	176	189
G40.21M	350W		350	450	180	193
G40.21M	350WT	$t \le 65$ $65 < t \le 100$	350 320	450[a] 450[a]	180 180	193 193
National Standards						
	235		235	365	137	154
	250		250	400	157	171
	275		275	430	167	184

Table 5.2a—Permissible Plate Materials and Allowable Stresses (SI) (Continued)

Plate Specification	Grade	Nominal Plate Thickness t mm	Minimum Yield Strength MPa	Minimum Tensile Strength MPa	Product Design Stress S_d MPa	Hydrostatic Test Stress S_t MPa
ISO Specifications						
ISO 630	S275C, D	$t \leq 16$	275	410	164	176
		$16 < t \leq 40$	265	410	164	176
	S355C, D	$t \leq 16$	355	470[a]	188	201
		$16 < t \leq 40$	345	470[a]	188	201
		$40 < t \leq 50$	335	470[a]	188	201
EN Specifications						
EN 10025	S 275J0, J2	$t \leq 16$	275	410	164	176
		$16 < t \leq 40$	265	410	164	176
	S 355J0, J2, K2	$t \leq 16$	355	470[a]	188	201
		$16 < t \leq 40$	345	470[a]	188	201
		$40 < t \leq 50$	335	470[a]	188	201

● [a] By agreement between the Purchaser and the Manufacturer, the tensile strength of ASTM A537M, Class 2, and A841M, Class 2 materials may be increased to 585 MPa minimum and 690 MPa maximum. The tensile strength of the other listed materials may be increased to 515 MPa minimum and 620 MPa maximum. When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

● [b] By agreement between the Purchaser and the Manufacturer, the tensile strength of ASTM A537M, Class 2 materials may be increased to 550 MPa minimum and 690 MPa maximum. The tensile strength of the other listed materials may be increased to 485 MPa minimum and 620 MPa maximum. When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

5.6.2.3 Annex A permits an alternative shell design with a fixed allowable stress of 145 MPa (21,000 lbf/in.^{2}) and a joint efficiency factor of 0.85 or 0.70. This design may only be used for tanks with shell thicknesses less than or equal to 13 mm ($^1/_2$ in.).

5.6.2.4 Structural design stresses shall conform to the allowable working stresses given in 5.10.3.

5.6.3 Calculation of Thickness by the 1-Foot Method

5.6.3.1 The 1-foot method calculates the thicknesses required at design points 0.3 m (1 ft) above the bottom of each shell course. Annex A permits only this design method. This method shall not be used for tanks larger than 61 m (200 ft) in diameter.

● **5.6.3.2** The required minimum thickness of shell plates shall be the greater of the values computed by the following formulas:

In SI units:

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

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

Table 5.2b—Permissible Plate Materials and Allowable Stresses (USC)

Plate Specification	Grade	Nominal Plate Thickness t in.	Minimum Yield Strength psi	Minimum Tensile Strength psi	Product Design Stress S_d psi	Hydrostatic Test Stress S_t psi
ASTM Specifications						
A283	C		30,000	55,000	20,000	22,500
A285	C		30,000	55,000	20,000	22,500
A131	A, B		34,000	58,000	22,700	24,900
A36	—		36,000	58,000	23,200	24,900
A131	EH 36		51,000	71,000[a]	28,400	30,400
A573	58		32,000	58,000	21,300	24,000
A573	65		35,000	65,000	23,300	26,300
A573	70		42,000	70,000[a]	28,000	30,000
A516	55		30,000	55,000	20,000	22,500
A516	60		32,000	60,000	21,300	24,000
A516	65		35,000	65,000	23,300	26,300
A516	70		38,000	70,000	25,300	28,500
A662	B		40,000	65,000	26,000	27,900
A662	C		43,000	70,000[a]	28,000	30,000
A537	1	$t \le 2^1/_2$ $2^1/_2 < t \le 4$	50,000 45,000	70,000[a] 65,000[b]	28,000 26,000	30,000 27,900
A537	2	$t \le 2^1/_2$ $2^1/_2 < t \le 4$	60,000 55,000	80,000[a] 75,000[b]	32,000 30,000	34,300 32,100
A633	C, D	$t \le 2^1/_2$ $2^1/_2 < t \le 4$	50,000 46.000	70,000[a] 65,000[b]	28,000 26,000	30,000 27,900
A737	B		50,000	70,000[a]	28,000	30,000
A841	Class 1, Grades A and B		50,000	70,000[a]	28,000	30,000
A841	Class 2, Grades A and B		60,000	80,000[a]	32,000	34,300
CSA Specifications						
G40.21	38W		38,000	60,000	24,000	25,700
G40.21	38WT		38,000	60,000	24,000	25,700

Table 5.2b—Permissible Plate Materials and Allowable Stresses (USC) (Continued)

Plate Specification	Grade	Nominal Plate Thickness t in.	Minimum Yield Strength psi	Minimum Tensile Strength psi	Product Design Stress S_d psi	Hydrostatic Test Stress S_t psi
G40.21	44W		44,000	64,000	25,600	27,400
G40.21	44WT		44,000	64,000	25,600	27,400
G40.21	50W		50,000	65,000	26,000	27,900
G40.21	50WT	$t \le 2^1/_2$	50,000	65,000[a]	26,000	27,900
		$2^1/_2 < t \le 4$	46,000	65,000[a]	26,000	27,900
National Standards						
	235		34,000	52,600	20,000	22,500
	250		36,000	58,300	22,700	25,000
	275		40,000	62,600	24,000	26,800
ISO Specifications						
ISO 630	S275C, D	$t \le {}^5/_8$	39,900	59,500	23,800	25,500
		${}^5/_8 < t \le 1^1/_2$	38,400	59,500	23,800	25,500
	S355C, D	$t \le {}^5/_8$	51,500	68,100[a]	27,200	29,200
		${}^5/_8 < t \le 1^1/_2$	50,000	68,100[a]	27,200	29,200
		$1^1/_2 < t \le 2$	48,600	68,100[a]	27,200	29,200
EN Specifications						
EN 10025	S 275J0, J2	$t \le {}^5/_8$	39,900	59,500	23,800	25,500
		${}^5/_8 < t \le 1^1/_2$	38,400	59,500	23,800	25,500
	S 355J0, J2, K2	$t \le {}^5/_8$	51,500	68,100[a]	27,200	29,200
		${}^5/_8 < t \le 1^1/_2$	50,000	68,100[a]	27,200	29,200
		$1^1/_2 < t \le 2$	48,600	68,100[a]	27,200	29,200

• [a] By agreement between the Purchaser and the Manufacturer, the tensile strength of ASTM A537M, Class 2, and A841M, Class 2 materials may be increased to 85,000 psi minimum and 100,000 psi maximum. The tensile strength of the other listed materials may be increased to 75,000 psi minimum and 90,000 psi maximum. When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

• [b] By agreement between the Purchaser and the Manufacturer, the tensile strength of ASTM A537M, Class 2 materials may be increased to 80,000 psi minimum and 100,000 psi maximum. The tensile strength of the other listed materials may be increased to 70,000 psi minimum and 90,000 psi maximum. When this is done, the allowable stresses shall be determined as stated in 5.6.2.1 and 5.6.2.2.

where

t_d is the design shell thickness, in mm;

t_t is the hydrostatic test shell thickness, in mm;

D is the nominal tank diameter, in m (see 5.6.1.1, Note 1);

- H is the design liquid level, in m:

  is the 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 is the design specific gravity of the liquid to be stored, as specified by the Purchaser;

- CA is the corrosion allowance, in mm, as specified by the Purchaser (see 5.3.2);

S_d is the allowable stress for the design condition, in MPa (see 5.6.2.1);

S_t is the allowable stress for the hydrostatic test condition, in MPa (see 5.6.2.2).

In USC units:

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

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

where

t_d is the design shell thickness, in inches;

t_t is the hydrostatic test shell thickness, in inches;

D is the nominal tank diameter, in ft (see 5.6.1.1, Note 1);

- H is the design liquid level, in ft:

  is the 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 is the design specific gravity of the liquid to be stored, as specified by the Purchaser;

- CA is the corrosion allowance, in inches, as specified by the Purchaser (see 5.3.2);

S_d is the allowable stress for the design condition, in lbf/in.^{2} (see 5.6.2.1);

S_t is the allowable stress for the hydrostatic test condition, in lbf/in.^{2} (see 5.6.2.2).

5.6.4 Calculation of Thickness by the Variable-Design-Point Method

NOTE This procedure normally provides a reduction in shell-course thicknesses and total material weight, but more important is its potential to permit construction of larger diameter tanks within the maximum plate thickness limitation. For background information, see L.P. Zick and R.V. McGrath, "Design of Large Diameter Cylindrical Shells."[15]

• **5.6.4.1** Design by the variable-design-point method gives shell thicknesses at design points that result in the calculated stresses being relatively close to the actual circumferential shell stresses. This method may only be used when the Purchaser has not specified that the 1-foot method be used and when the following is true:

In SI units:

$$\frac{L}{H} \leq \frac{1000}{6}$$

where

L equals $(500\ Dt)^{0.5}$, in mm;

D is the tank diameter, in m;

t is the bottom-course corroded shell thickness, in mm;

H is the maximum design liquid level (see 5.6.3.2), in m.

In USC units:

$$\frac{L}{H} \leq 2$$

where

L equals $(6\ Dt)^{0.5}$, in inches;

D is the tank diameter, in ft;

t is the bottom-course corroded shell thickness, in inches;

H is the maximum design liquid level (see 5.6.3.2), in ft.

5.6.4.2 The minimum plate thicknesses for both the design condition and the hydrostatic test condition shall be determined as outlined. Complete, independent calculations shall be made for all of the courses for the design condition and for the hydrostatic test condition. The required shell thickness for each course shall be the greater of the design shell thickness plus any corrosion allowance or the hydrostatic test shell thickness, but the total shell thickness shall not be less than the shell thickness required by 5.6.1.1, 5.6.1.3, and 5.6.1.4. When a greater thickness is used for a shell course, the greater thickness may be used for subsequent calculations of the thicknesses of the shell courses above the course that has the greater thickness, provided the greater thickness is shown as the required design thickness on the Manufacturer's drawing (see W.3).

5.6.4.3 To calculate the bottom-course thicknesses, preliminary values t_{pd} and t_{pt} for the design and hydrostatic test conditions shall first be calculated from the formulas in 5.6.3.2.

5.6.4.4 The bottom-course thicknesses t_{1d} and t_{1t} for the design and hydrostatic test conditions shall be calculated using the following formulas:

[15] L.P. Zick and R.V. McGrath, "Design of Large Diameter Cylindrical Shells," *Proceedings*—Division of Refining, American Petroleum Institute, New York, 1968, Volume 48, pp. 1114 – 1140.

In SI units:

$$t_{1d} = \left(1.06 - \frac{0.0696D}{H}\sqrt{\frac{HG}{S_d}}\right)\left(\frac{4.9HDG}{S_d}\right) + CA$$

In USC units:

$$t_{1d} = \left(1.06 - \frac{0.463D}{H}\sqrt{\frac{HG}{S_d}}\right)\left(\frac{2.6HDG}{S_d}\right) + CA$$

NOTE For the design condition, t_{1d} need not be greater than t_{pd}.

In SI units:

$$t_{1t} = \left(1.06 - \frac{0.0696D}{H}\sqrt{\frac{H}{S_t}}\right)\left(\frac{4.9HD}{S_t}\right)$$

In USC units:

$$t_{1t} = \left(1.06 - \frac{0.463D}{H}\sqrt{\frac{H}{S_t}}\right)\left(\frac{2.6HD}{S_t}\right)$$

NOTE For the hydrostatic test condition, t_{1t} need not be greater than t_{pt}.

5.6.4.5 To calculate the second-course thicknesses for both the design condition and the hydrostatic test condition, the value of the following ratio shall be calculated for the bottom course:

$$\frac{h_1}{(rt_1)^{0.5}}$$

where

- h_1 is the height of the bottom shell course, in mm (in.);
- r is the nominal tank radius, in mm (in.);
- t_1 is the calculated corroded thickness of the bottom shell course, in mm (in.), used to calculate t_2 (design). The calculated hydrostatic thickness of the bottom shell course shall be used to calculate t_2 (hydrostatic test).

If the value of the ratio is less than or equal to 1.375:

$$t_2 = t_1$$

If the value of the ratio is greater than or equal to 2.625:

$$t_2 = t_{2a}$$

If the value of the ratio is greater than 1.375 but less than 2.625:

$$t_2 = t_{2a} + (t_1 - t_{2a})\left[2.1 - \frac{h_1}{1.25(rt_1)^{0.5}}\right]$$

where

t_2 is the minimum design thickness of the second shell course, in mm (in.);

t_{2a} is the corroded thickness of the second shell course, in mm (in.), as calculated for an upper shell course as described in 5.6.4.6, 5.6.4.7, and 5.6.4.8. In calculating second shell course thickness (t_2) for design case and hydrostatic test case, applicable values of t_{2a} and t_1 shall be used.

The preceding formula for t_2 is based on the same allowable stress being used for the design of the bottom and second courses. For tanks where the value of the ratio is greater than or equal to 2.625, the allowable stress for the second course may be lower than the allowable stress for the bottom course when the methods described in 5.6.4.6 through 5.6.4.8 are used.

5.6.4.6 To calculate the upper-course thicknesses for both the design condition and the hydrostatic test condition, a preliminary value t_u for the upper-course corroded thickness shall be calculated using the formulas in 5.6.3.2, and then the distance x of the variable design point from the bottom of the course shall be calculated using the lowest value obtained from the following:

In SI units:

$$x_1 = 0.61\,(rt_u)^{0.5} + 320\,CH$$

$$x_2 = 1000\,CH$$

$$x_3 = 1.22\,(rt_u)^{0.5}$$

where

t_u is the corroded thickness of the upper course at the girth joint, in mm;

C equals $[K^{0.5}\,(K - 1)]/(1 + K^{1.5})$;

K equals t_L / t_u;

t_L is the corroded thickness of the lower course at the girth joint, in mm;

• H is the design liquid level (see 5.6.3.2), in m.

In USC units:

$$x_1 = 0.61\,(rt_u)^{0.5} + 3.84\,CH$$

$$x_2 = 12\,CH$$

$$x_3 = 1.22\,(rt_u)^{0.5}$$

where

t_u is the corroded thickness of the upper course at the girth joint, in inches;

C equals $[K^{0.5}\,(K - 1)]/(1 + K^{1.5})$;

K equals t_L / t_u;

t_L is the corroded thickness of the lower course at the girth joint, in inches;

• H is the design liquid level (see 5.6.3.2), in ft.

5.6.4.7 The minimum thickness t_x for the upper shell courses shall be calculated for both the design condition (t_{dx}) and the hydrostatic test condition (t_{tx}) using the minimum value of *x* obtained from 5.6.4.6:

In SI units:

$$t_{dx} = \frac{4.9D\left(H - \frac{x}{1000}\right)G}{S_d} + CA$$

$$t_{tx} = \frac{4.9D\left(H - \frac{x}{1000}\right)}{S_t}$$

In USC units:

$$t_{dx} = \frac{2.6D\left(H - \frac{x}{12}\right)G}{S_d} + CA$$

$$t_{tx} = \frac{2.6D\left(H - \frac{x}{12}\right)}{S_t}$$

5.6.4.8 The steps described in 5.6.4.6 and 5.6.4.7 shall be repeated using the calculated value of t_x as t_u until there is little difference between the calculated values of t_x in succession (repeating the steps twice is normally sufficient). Repeating the steps provides a more exact location of the design point for the course under consideration and, consequently, a more accurate shell thickness.

5.6.4.9 There are two examples provided in Annex K. Example #1 are step-by-step calculations illustrating an application of the variable-design-point method to a tank with a diameter of 85 m (280 ft) and a height of 19.2 m (64 ft) to determine shell-plate thicknesses for the first three courses for the hydrostatic test condition only. Example #2 demonstrates the variable-design-point design method in US Customary units for a tank with a diameter of 280 ft and a height of 40 ft with varying corrosion allowances and varying materials for both the design and hydrostatic test conditions.

5.6.5 Calculation of Thickness by Elastic Analysis

For tanks where L/H is greater than 1000/6 (2 in USC units), the selection of shell thicknesses shall be based on an elastic analysis that shows the calculated circumferential shell stresses to be below the allowable stresses given in Table 5.2a and Table 5.2b. The boundary conditions for the analysis shall assume a fully plastic moment caused by yielding of the plate beneath the shell and zero radial growth.

5.7 Shell Openings

5.7.1 General

5.7.1.1 The following requirements for shell openings are intended to restrict the use of appurtenances to those providing for attachment to the shell by welding. See Figure 5.6.

5.7.1.2 The shell opening designs described in this standard are required, except for alternative designs allowed in 5.7.1.8.

5.7.1.3 Flush-type cleanout fittings and flush-type shell connections shall conform to the designs specified in 5.7.7 and 5.7.8.

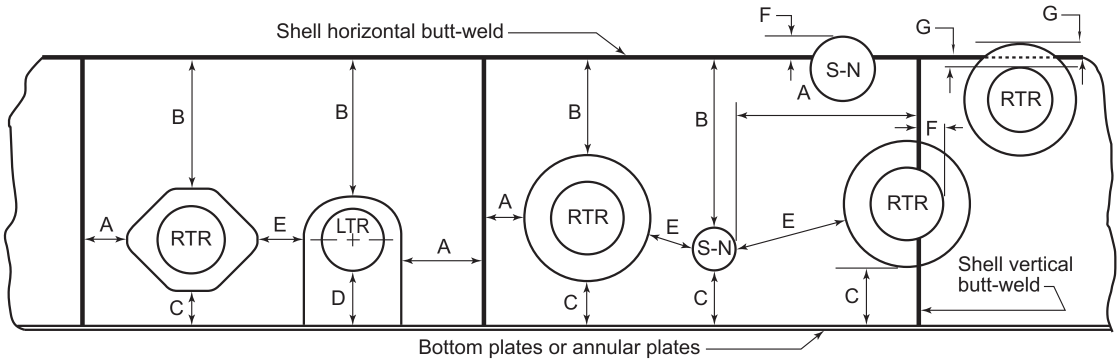
● **5.7.1.4** When a size intermediate to the sizes listed in Tables 5.3a through 5.12b is specified by the Purchaser, the construction details and reinforcements shall conform to the next larger opening listed in the tables. The size of the opening or tank connection shall not be larger than the maximum size given in the appropriate table.

5.7.1.5 Openings near the bottom of a tank shell will tend to rotate with vertical bending of the shell under hydrostatic loading. Shell openings in this area that have attached piping or other external loads shall be reinforced not only for the static condition but also for any loads imposed on the shell connections by the restraint of the attached piping to the shell rotation. The external loads shall be minimized, or the shell connections shall be relocated outside the rotation area. Annex P provides a method for evaluating openings that conform to Table 5.6a and Table 5.6b.

5.7.1.6 Sheared or oxygen-cut surfaces on manhole necks, nozzle necks, reinforcing plates, and shell-plate openings shall be made uniform and smooth, with the corners rounded except where the surfaces are fully covered by attachment welds.

5.7.1.7 Shell openings may be reinforced by the use of an insert plate/reinforcing plate combination or thickened insert plate per Figure 5.7b. A rectangular insert plate or thickened insert plate shall have rounded corners (except for edges terminating at the tank bottom or at joints between shell courses) with a radius which is greater than or equal to the larger of 150 mm (6 in.) or $6t$ where t is the thickness of the shell course containing the insert plate or thickened insert plate. The insert plate or thickened insert plate may contain multiple shell openings. The thickness and dimensions of insert plate or thickened insert plate shall provide the reinforcing required per 5.7.2. The weld spacing shall meet the requirements of 5.7.3. The periphery of thickened insert plates shall have a 1:4 tapered transition to the thickness of the adjoining shell material when the insert plate thickness exceeds the adjacent shell thickness by more than 3 mm ($^{1}/_{8}$ in.).

● **5.7.1.8** The shape and dimensions of the shell opening reinforcement, illustrated in Figure 5.7a, Figure 5.7b,and Figure 5.8 and dimensioned in the related tables may be altered as long as the reinforcement meets the area, welding, and weld spacing requirements outlined in 5.7.2 and 5.7.3. For reinforcing plates greater than $^{1}/_{2}$ in. thick, with approval of the Purchaser, reinforcement and welding (excluding weld spacing) of shell openings that comply with API 620, Section 5 are acceptable. These statements of permissible alternatives of shell opening reinforcement and welding do not apply to flush-type cleanout fittings, flush-type shell connections or similar configurations.



KEY

RTR = Regular-Type Reinforced Opening (nozzle or manhole) with diamond or circular shape reinforcing plate, or insert plate, or thickened insert plate, that does not extend to the bottom (see Figure 5.7A and Figure 5.8).

LTR = Low-Type Reinforced Opening (nozzle or manhole) using tombstone type reinforcing plate, insert plate, or thickened insert plate that extends to the bottom [see Figure 5.8, Detail (a) and Detail (b)].

S-N = Shell openings with neither a reinforcing plate nor with a thickened insert plate (i.e. integrally reinforced shell openings; or openings not requiring reinforcing).

Variables		**Reference**	**Minimum Dimension Between Weld Toes or Weld Centerline** (Notes 1, 2, 3, and 4)						
Shell t	**Condition**	**Paragraph Number**	**A**	**B**	**C**	**D (5 only)**	**E**	**F (6)**	**G (6)**
$t \le 13$ mm ($t \le 1/2$ in.)	As welded or PWHT	5.7.3.2	150 mm (6 in.)	75 mm (3 in.)			75 mm (3 in.)		
		5.7.3.3			75 mm (3 in.)				
		5.7.3.3							
		5.7.3.3				Table 5.6a and Table 5.6b			
		• 5.7.3.4						Lesser of $8t$ or $1/2\ r$	
		• 5.7.3.4							$8t$
$t > 13$ mm ($t > 1/2$ in.)	As Welded	5.7.3.1.a	$8W$ or 250 mm (10 in.)	$8W$ or 250 mm (10 in.)					
		5.7.3.1.b					$8W$ or 150 mm (6 in.)		
		5.7.3.3			$8W$ or 250 mm (10 in.)				
		5.7.3.3			75 mm (3 in.) for S-N				
		5.7.3.3				Table 5.6a and Table 5.6b			
		• 5.7.3.4						Lesser of $8t$ or $1/2\ r$	
		• 5.7.3.4							$8t$
$t > 13$ mm ($t > 1/2$ in.)	PWHT	5.7.3.2	150 mm (6 in.)	75 mm (3 in.) or $(2\,1/2)\ t$			75 mm (3 in.) or $(2\,1/2)\ t$		
		5.7.3.3			75 mm (3 in.) or $(2\,1/2)\ t$				
		5.7.3.3			75 mm (3 in.) for S-N				
		5.7.3.3				Table 5.6a and Table 5.6b			
		• 5.7.3.4						Lesser of $8t$ or $1/2\ r$	
		• 5.7.3.4							$8t$

NOTE 1 If two requirements are given, the minimum spacing is the greater value, unless otherwise noted.

NOTE 2 Weld spacings are measured to the toe of a fillet-weld, the centerline of an insert or thickened insert plate butt-weld, or the centerline of a shell butt-weld.

NOTE 3 t = shell nominal thickness; r = radius of opening

NOTE 4 W = the largest weld size around the periphery of the fitting(s): for fillet welds the leg length along the tank shell, for butt welds the thickness of the insert plate at the weld joint.

NOTE 5 D = spacing distance established by minimum elevation for low-type reinforced openings from Table 5.6a and Table 5.6b, column 9.

NOTE 6 Purchaser option to allow shell openings to be located in horizontal or vertical shell butt-welds. See Figure 5.9.

Figure 5.6—Minimum Weld Requirements for Openings in Shells According to 5.7.3

Table 5.3a—Thickness of Shell Manhole Cover Plate and Bolting Flange (SI)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Max. Design Liquid Level m H	Equivalent Pressure[a] kPa	Minimum Thickness of Cover Plate[b] (t_c), mm				Minimum Thickness of Bolting Flange After Finishing[b] (t_f), mm			
		500 mm Manhole	600 mm Manhole	750 mm Manhole	900 mm Manhole	500 mm Manhole	600 mm Manhole	750 mm Manhole	900 mm Manhole
5	49	8	10	12	13	6	7	9	10
6.5	64	10	11	13	15	7	8	10	12
8.0	78	11	12	14	17	8	9	11	14
9.5	93	12	13	16	18	9	10	13	15
11	108	12	14	17	20	9	11	14	17
13	128	13	15	18	21	10	12	15	18
16	157	15	17	20	23	12	14	17	20
19	186	16	18	22	26	13	15	19	23
23	225	18	20	24	28	15	17	21	25

[a] Equivalent pressure is based on water loading.

[b] For addition of corrosion allowance, see 5.7.5.2.

[c] Cover Plate and Flange thickness given can be used on Manholes dimensioned to ID or OD.

[d] For table calculations S_d set per 5.7.5.6.

NOTE See Figure 5.7a.

Table 5.3b—Thickness of Shell Manhole Cover Plate and Bolting Flange (USC)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Max. Design Liquid Level ft H	Equivalent Pressure[a] lbf/in.^{2}	Minimum Thickness of Cover Plate[b] (t_c), in.				Minimum Thickness of Bolting Flange After Finishing[b] (t_f), in.			
		20 in. Manhole	24 in. Manhole	30 in. Manhole	36 in. Manhole	20 in. Manhole	24 in. Manhole	30 in. Manhole	36 in. Manhole
18	7.8	3/8	7/16	1/2	9/16	1/4	5/16	3/8	7/16
20	8.7	3/8	7/16	1/2	9/16	1/4	5/16	3/8	7/16
24	10.4	7/16	7/16	9/16	5/8	5/16	5/16	7/16	1/2
32	13.8	7/16	9/16	5/8	3/4	5/16	7/16	1/2	5/8
36	15.6	1/2	9/16	11/16	3/4	3/8	7/16	9/16	5/8
44	19.1	9/16	5/8	3/4	7/8	7/16	1/2	5/8	3/4
52	22.5	9/16	11/16	13/16	15/16	7/16	9/16	11/16	13/16
60	26.0	5/8	3/4	7/8	1	1/2	5/8	3/4	7/8
75	32.5	11/16	13/16	15/16	1 1/8	9/16	11/16	13/16	1

[a] Equivalent pressure is based on water loading.

[b] For addition of corrosion allowance, see 5.7.5.2.

[c] Cover Plate and Flange thickness given can be used on Manholes dimensioned to ID or OD.

[d] For table calculations S_d set per 5.7.5.6.

NOTE See Figure 5.7a.

Table 5.4a—Dimensions for Shell Manhole Neck Thickness (SI)

Dimensions in millimeters

Thickness of Shell (t) [a]	Minimum Neck Thickness (t_n) [b]			
	For Manhole Diameter 500 mm	For Manhole Diameter 600 mm	For Manhole Diameter 750 mm	For Manhole Diameter 900 mm
5	5	5	5	5
6	6	6	6	6
8	6	6	8	8
10	6	6	8	10
11	6	6	8	10
12.5	6	6	8	10
14	6	6	8	10
16	6	6	8	10
18	6	6	8	10
19	6	6	8	10
21	8	6	8	10
22	10	8	8	10
24	11	11	11	11
25	11	11	11	11
27	11	11	11	11
28	13	13	13	13
30	14	14	14	14
32	16	14	14	14
33	16	16	16	16
35	17	16	16	16
36	17	17	17	17
38	20	20	20	20
40	21	21	21	21
41	21	21	21	21
43	22	22	22	22
45	22	22	22	22

[a] If a shell plate thicker than required is used for the product and hydrostatic loading (see 5.6), the excess shell-plate thickness, within a vertical distance both above and below the centerline of the hole in the tank shell plate equal to the vertical dimension of the hole in the tank shell plate, may be considered as reinforcement, and the thickness T of the manhole reinforcing plate may be decreased accordingly. In such cases, the reinforcement and the attachment welding shall conform to the design limits for reinforcement of shell openings specified in 5.7.2.

[b] The minimum neck thickness shall be the required corroded thickness of the shell plate or the minimum flange thickness of the bolting flange (see Table 5.3a), whichever is thinner. If the neck thickness is greater than the required minimum, the manhole reinforcing plate thickness may be deceased accordingly. In such cases the reinforcement and the attachment welding shall conform to the design limits of the reinforcement of the shell opening in 5.7.2.

Table 5.4b—Dimensions for Shell Manhole Neck Thickness (USC)

Dimensions in inches

Thickness of Shell (t) [a]	Minimum Neck Thickness (t_n) [b]			
	For Manhole Diameter 20 in.	For Manhole Diameter 24 in.	For Manhole Diameter 30 in.	For Manhole Diameter 36 in.
3/16	3/16	3/16	3/16	3/16
1/4	1/4	1/4	1/4	1/4
5/16	1/4	1/4	5/16	5/16
3/8	1/4	1/4	5/16	3/8
7/16	1/4	1/4	5/16	3/8
1/2	1/4	1/4	5/16	3/8
9/16	1/4	1/4	5/16	3/8
5/8	1/4	1/4	5/16	3/8
11/16	1/4	1/4	5/16	3/8
3/4	1/4	1/4	5/16	3/8
13/16	5/16	1/4	5/16	3/8
7/8	3/8	5/16	5/16	3/8
15/16	7/16	7/16	7/16	7/16
1	7/16	7/16	7/16	7/16
1 1/16	7/16	7/16	7/16	7/16
1 1/8	1/2	1/2	1/2	1/2
1 3/16	9/16	9/16	9/16	9/16
1 5/16	5/8	9/16	9/16	9/16
1 3/8	5/8	5/8	5/8	5/8
1 3/8	11/16	5/8	5/8	5/8
1 7/16	11/16	11/16	11/16	11/16
1 1/2	3/4	3/4	3/4	3/4
1 9/16	13/16	13/16	13/16	13/16
1 5/8	13/16	13/16	13/16	13/16
1 11/16	7/8	7/8	7/8	7/8
1 3/4	7/8	7/8	7/8	7/8

[a] If a shell plate thicker than required is used for the product and hydrostatic loading (see 5.6), the excess shell-plate thickness, within a vertical distance both above and below the centerline of the hole in the tank shell plate equal to the vertical dimension of the hole in the tank shell plate, may be considered as reinforcement, and the thickness T of the manhole reinforcing plate may be decreased accordingly. In such cases, the reinforcement and the attachment welding shall conform to the design limits for reinforcement of shell openings specified in 5.7.2.

[b] The minimum neck thickness shall be the required corroded thickness of the shell plate or the minimum flange thickness of the bolting flange (see Table 5.3b), whichever is thinner. If the neck thickness is greater than the required minimum, the manhole reinforcing plate thickness may be deceased accordingly. In such cases the reinforcement and the attachment welding shall conform to the design limits of the reinforcement of the shell opening in 5.7.2.

Table 5.5a—Dimensions for Bolt Circle Diameter D_b and Cover Plate Diameter D_c for Shell Manholes (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3
Manhole Diameter *OD*	**Bolt Circle Diameter D_b**	**Cover Plate Diameter D_c**
500	667	730
600	768	832
750	921	984
900	1073	1137
NOTE See Figure 5.7a.		

Table 5.5b—Dimensions for Bolt Circle Diameter D_b and Cover Plate Diameter D_c for Shell Manholes (USC)

Dimensions in inches.

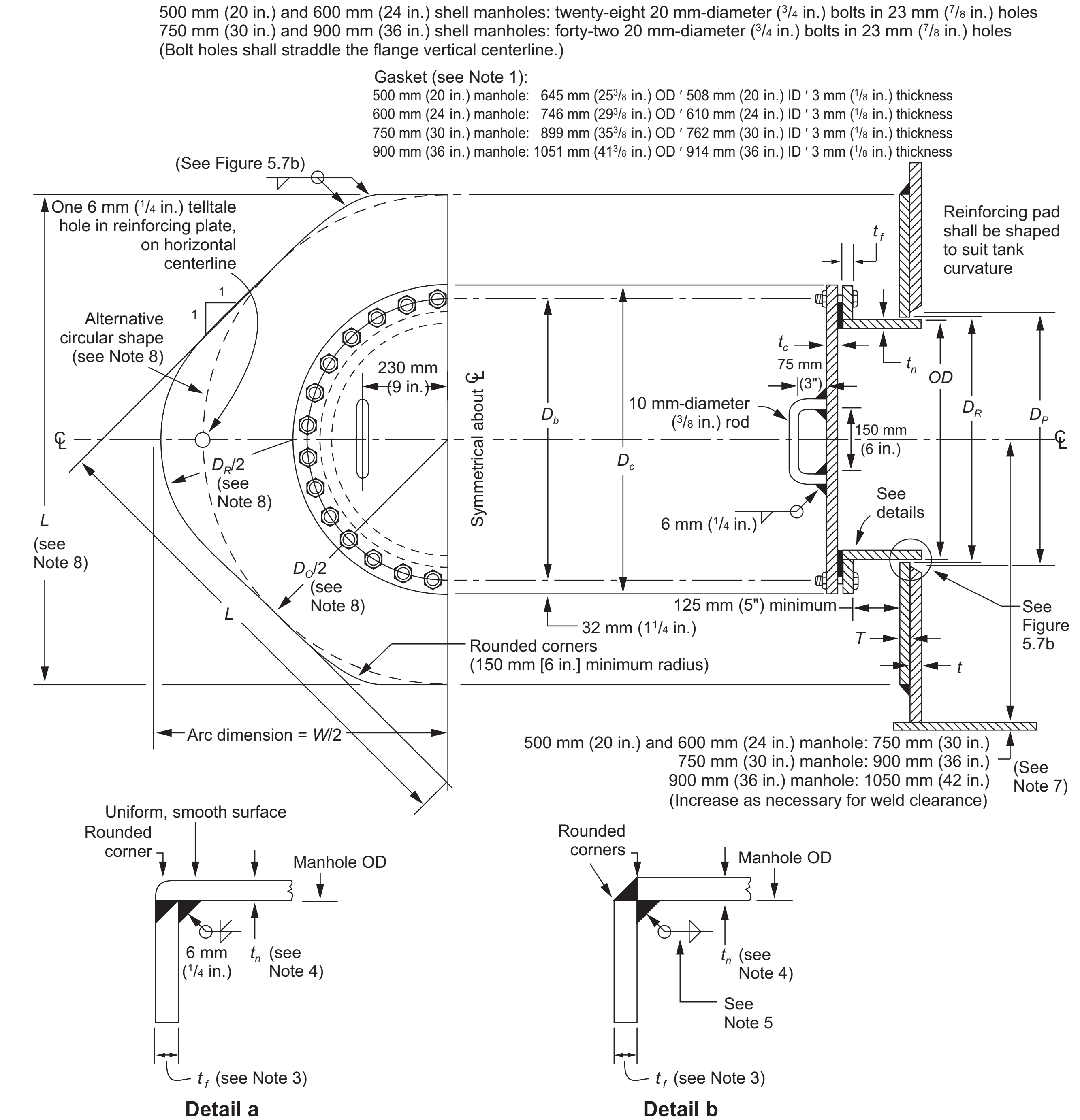
Column 1	Column 2	Column 3
Manhole Diameter *OD*	**Bolt Circle Diameter D_b**	**Cover Plate Diameter D_c**
20	$26^1/_4$	$28^3/_4$
24	$30^1/_4$	$32^3/_4$
30	$36^1/_4$	$38^3/_4$
36	$42^1/_4$	$44^3/_4$
NOTE See Figure 5.7a.		

5.7.1.9 The flange facing shall be suitable for the gasket and bolting employed. Gaskets shall be selected to meet the service environment so that the required seating load is compatible with the flange rating and facing, the strength of the flange, and its bolting (see 4.9).

5.7.2 Reinforcement and Welding

5.7.2.1 Openings in tank shells larger than required to accommodate a NPS 2 flanged or threaded nozzle shall be reinforced. The minimum cross-sectional area of the required reinforcement shall not be less than the product of the vertical diameter of the hole cut in the shell and the nominal plate thickness, but when calculations are made for the maximum required thickness considering all design and hydrostatic test load conditions, the required thickness may be used in lieu of the nominal plate thickness. The cross-sectional area of the reinforcement shall be measured vertically, coincident with the diameter of the opening.

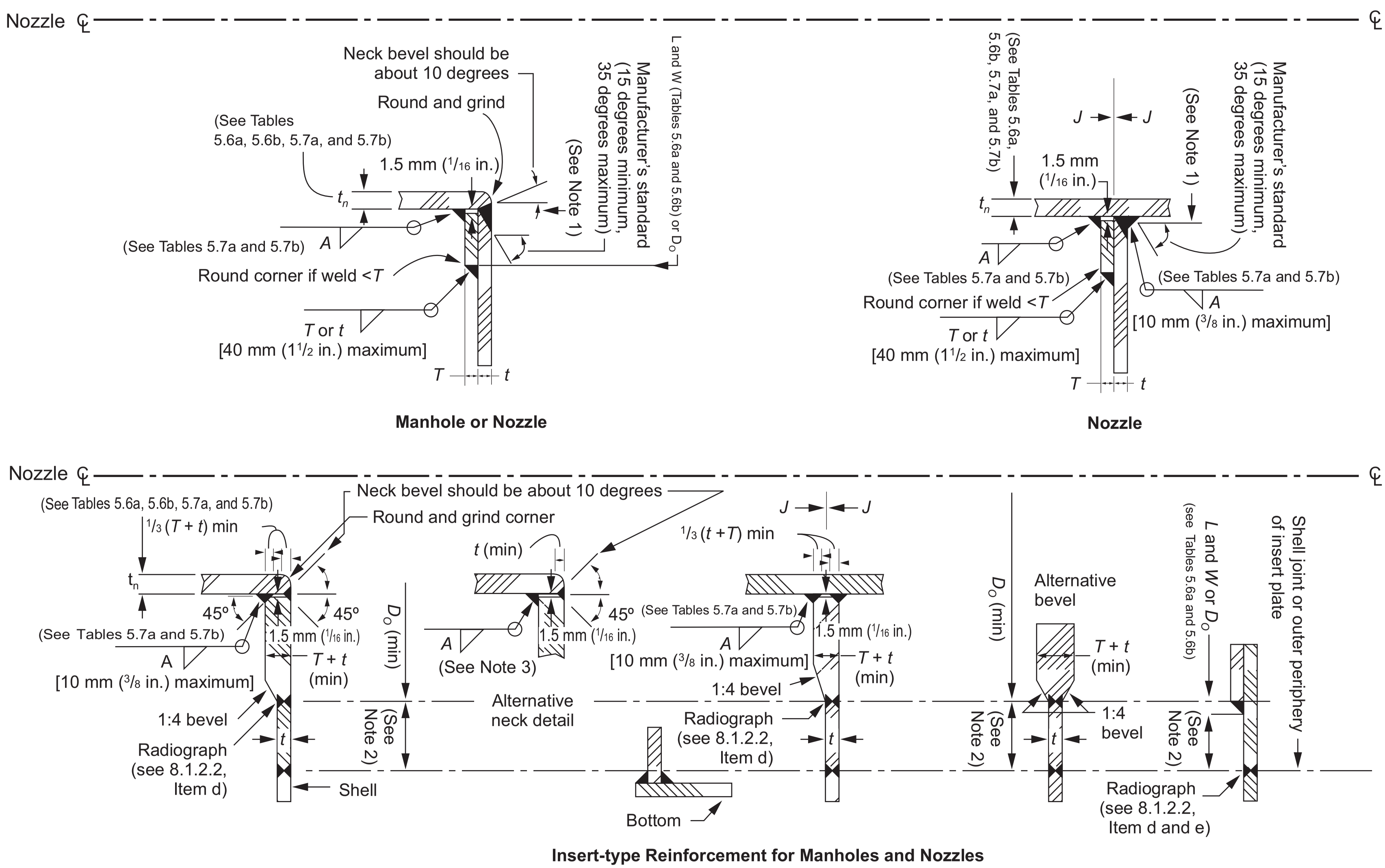
• **5.7.2.2** The only shell openings that may utilize welds having less than full penetration through the shell are those that do not require reinforcement and those that utilize a thickened insert plate as shown in Figure 5.7b and Figure 5.8. However, any openings listed in Table 3 of the Data Sheet that are marked “yes” under “Full Penetration on Openings” shall utilize welds that fully penetrate the shell and the reinforcement, if used.



NOTES

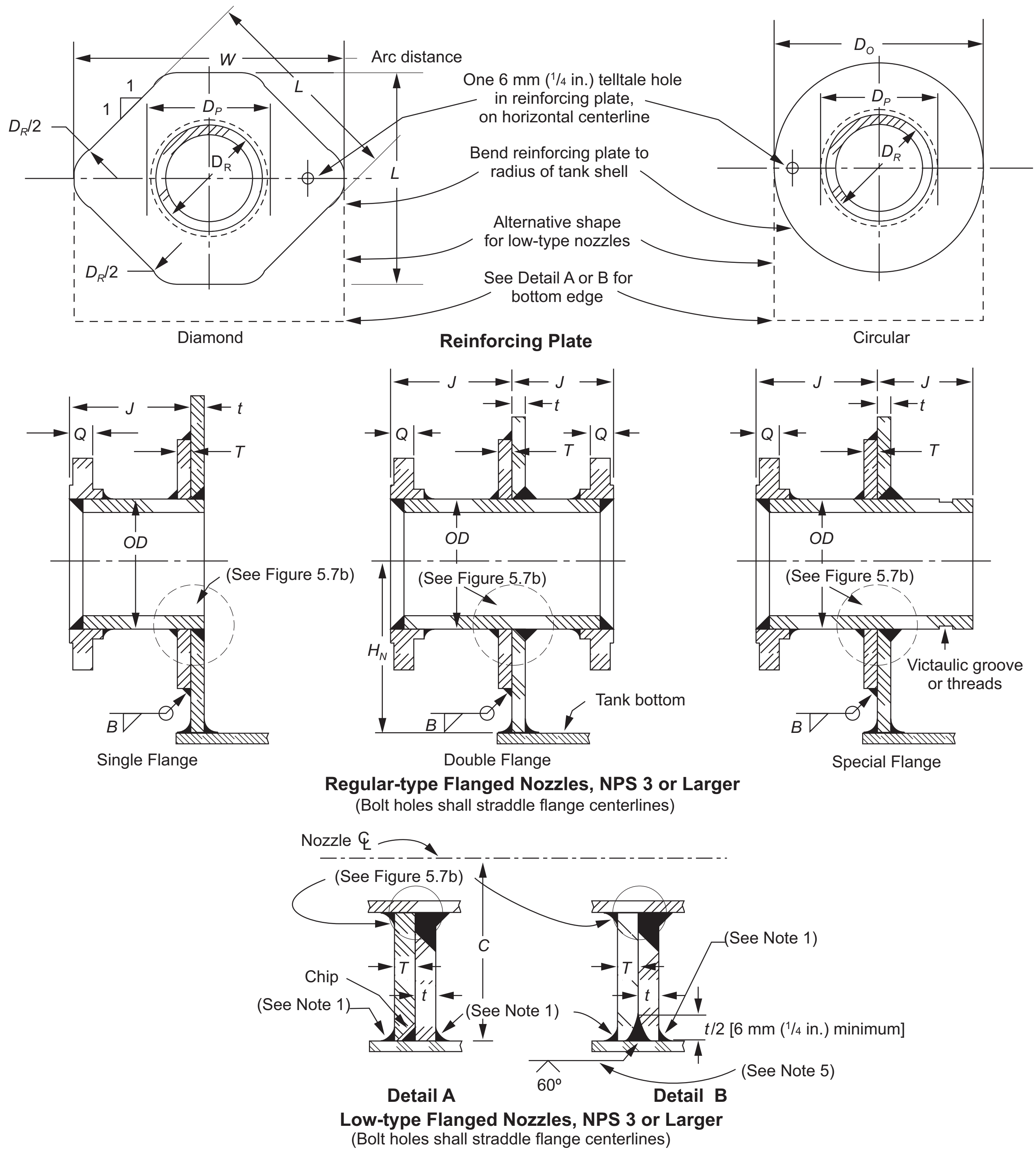
1. Gasket material shall be specified by the Purchaser. See 5.7.5.4.
2. (Deleted).
3. See Table 5.3a and Table 5.3b.
4. See Table 5.4a and Table 5.4b.
5. The size of the weld shall equal the thickness of the thinner member joined.
6. The shell nozzles shown in Figure 5.8 may be substituted for manholes.
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



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 or thickened 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.

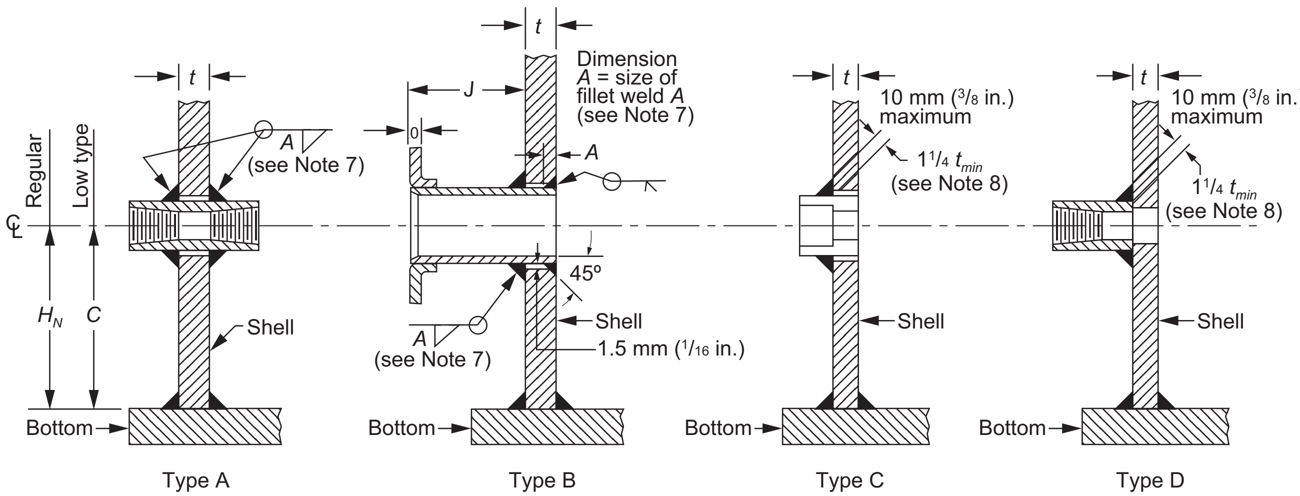
Figure 5.7b—Details of Shell Manholes and Nozzles



NOTES

1. See 5.1.5.7 for information on the size of welds.
2. See 5.8.9 for information on the couplings used in shell nozzles.
3. Nozzles NPS 3 or larger require reinforcement.
4. ● Details of welding bevels may vary from those shown if agreed to by the Purchaser.
5. Shop weld not attached to bottom plate.
6. See 5.7.6.2 for information on supplying nozzles flush or with an internal projection.

Figure 5.8—Shell Nozzles (see Tables 5.6a, 5.6b, 5.7a, 5.7b, 5.8a, and 5.8b)



Couplings and Flanged Fittings, NPS 3/4 Through NPS 2 (see Note 3)

NOTES (continued)
7. See Table 5.7a and Table 5. 7b, Column 6.
8. t_{min} shall be 19 mm (3/4 in.) or the thickness of either part joined by the fillet weld, whichever is less.
9. The construction details apply to unreinforced threaded, non-threaded, and flanged nozzles.

Figure 5.8—Shell Nozzles (continued)

Table 5.6a—Dimensions for Shell Nozzles (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9[c]
NPS (Size of Nozzle)	Outside Diameter of Pipe *OD*	Nominal Thickness of Flanged Nozzle Pipe Wall[a] t_n	Diameter of Hole in Reinforcing Plate D_R	Length of Side of Reinforcing Plate[b] or Diameter $L = D_o$	Width of Reinforcing Plate *W*	Minimum Distance from Shell-to-Flange Face *J*	Minimum Distance from Bottom of Tank to Center of Nozzle	
							Regular Type[d] H_N	Low Type *C*
Flanged Fittings								
60	1524.0	e	1528	3068	3703	400	1641	1534
54	1371.6	e	1375	2763	3341	400	1488	1382
52	1320.8	e	1324	2661	3214	400	1437	1331
50	1270.0	e	1274	2560	3093	400	1387	1280
48	1219.2	e	1222	2455	2970	400	1334	1230
46	1168.4	e	1172	2355	2845	400	1284	1180
44	1117.6	e	1121	2255	2725	375	1234	1125
42	1066.8	e	1070	2155	2605	375	1184	1075
40	1016.0	e	1019	2050	2485	375	1131	1025
38	965.2	e	968	1950	2355	350	1081	975
36	914.4	e	918	1850	2235	350	1031	925
34	863.6	e	867	1745	2115	325	979	875
32	812.8	e	816	1645	1995	325	929	820
30	762.0	e	765	1545	1865	300	879	770

Table 5.6a—Dimensions for Shell Nozzles (SI) (Continued)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9[c]
NPS (Size of Nozzle)	Outside Diameter of Pipe OD	Nominal Thickness of Flanged Nozzle Pipe Wall[a] t_n	Diameter of Hole in Reinforcing Plate D_R	Length of Side of Reinforcing Plate[b] or Diameter $L = D_o$	Width of Reinforcing Plate W	Minimum Distance from Shell-to-Flange Face J	Minimum Distance from Bottom of Tank to Center of Nozzle	
							Regular Type[d] H_N	Low Type C
28	711.2	[e]	714	1440	1745	300	826	720
26	660.4	[e]	664	1340	1625	300	776	670
24	609.6	12.7	613	1255	1525	300	734	630
22	558.8	12.7	562	1155	1405	275	684	580
20	508.0	12.7	511	1055	1285	275	634	525
18	457.2	12.7	460	950	1160	250	581	475
16	406.4	12.7	410	850	1035	250	531	425
14	355.6	12.7	359	750	915	250	481	375
12	323.8	12.7	327	685	840	225	449	345
10	273.0	12.7	276	585	720	225	399	290
8	219.1	12.7	222	485	590	200	349	240
6	168.3	10.97	171	400	495	200	306	200
4	114.3	8.56	117	305	385	175	259	150
3	88.9	7.62	92	265	345	175	239	135
2[f]	60.3	5.54	63	—	—	150	175	[h]
1 1/2[f]	48.3	5.08	51	—	—	150	150	[h]
1[f]	33.4	6.35	—	—	—	150	150	[h]
3/4[f]	26.7	5.54	—	—	—	150	150	[h]
Threaded and Socket-welded Couplings								
3[g]	108.0	Coupling	111.1	285	360	—	245	145
2[f]	76.2	Coupling	79.4	—	—	—	175	[h]
1 1/2[f]	63.5	Coupling	66.7	—	—	—	150	[h]
1[f]	44.5	Coupling	47.6	—	—	—	150	[h]
3/4[f]	35.0	Coupling	38.1	—	—	—	150	[h]

[a] For extra-strong pipe, see ASTM A53M or A106M for other wall thicknesses; however, piping material must conform to 4.5.

[b] The width of the shell plate shall be sufficient to contain the reinforcing plate and to provide clearance from the girth joint of the shell course.

● [c] Low type reinforced nozzles shall not be located lower than the minimum distance shown in Column 9. The minimum distance from the bottom shown in Column 9 complies with spacing rules of 5.7.3 and Figure 5.6.

[d] Regular type reinforced nozzles shall not be located lower than the minimum distance H_N shown in Column 8 when shell thickness is equal to or less than 12.5 mm. Greater distances may be required for shells thicker than 12.5 mm to meet the minimum weld spacing of 5.7.3 and Figure 5.6.

[e] See Table 5.7a, Column 2.

[f] Flanged nozzles and couplings in pipe sizes NPS 2 or smaller do not require reinforcing plates. D_R will be the diameter of the hole in the shell plate, and Weld A will be as specified in Table 5.7a, Column 6. Reinforcing plates may be used if the construction details comply with reinforced nozzle details.

[g] A coupling in an NPS 3 requires reinforcement.

[h] See 5.7.3 and Figure 5.6.

NOTE See Figure 5.8.

Table 5.6b—Dimensions for Shell Nozzles (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9[c]
NPS (Size of Nozzle)	Outside Diameter of Pipe OD	Nominal Thickness of Flanged Nozzle Pipe Wall[a] t_n	Diameter of Hole in Reinforcing Plate D_R	Length of Side of Reinforcing Plate[b] or Diameter $L = D_o$	Width of Reinforcing Plate W	Minimum Distance from Shell-to-Flange Face J	Minimum Distance from Bottom of Tank to Center of Nozzle	
							Regular Type[d] H_N	Low Type C
Flanged Fittings								
60	60	e	60 1/8	120 3/4	145 3/4	16	64 5/8	60 3/8
54	54	e	54 1/8	108 3/4	131 1/2	16	58 5/8	54 3/8
52	52	e	52 1/8	104 3/4	126 1/2	16	56 5/8	52 3/8
50	50	e	50 1/8	100 3/4	121 3/4	16	54 5/8	50 3/8
48	48	e	48 1/8	96 3/4	117	16	52 5/8	48 3/8
46	46	e	46 1/8	92 3/4	112	16	50 5/8	46 3/8
44	44	e	44 1/8	88 3/4	107 1/4	15	48 5/8	44 3/8
42	42	e	42 1/8	84 3/4	102 1/2	15	46 5/8	42 3/8
40	40	e	40 1/8	80 3/4	97 3/4	15	44 5/8	40 3/8
38	38	e	38 1/8	76 3/4	92 3/4	14	42 5/8	38 3/8
36	36	e	36 1/8	72 3/4	88	14	40 5/8	36 3/8
34	34	e	34 1/8	68 3/4	83 1/4	13	38 5/8	34 3/8
32	32	e	32 1/8	64 3/4	78 1/2	13	36 5/8	32 3/8
30	30	e	30 1/8	60 3/4	73 1/2	12	34 5/8	30 3/8
28	28	e	28 1/8	56 3/4	68 3/4	12	32 5/8	28 3/8
26	26	e	26 1/8	52 3/4	64	12	30 5/8	26 3/8
24	24	0.50	24 1/8	49 1/2	60	12	29	24 3/4
22	22	0.50	22 1/8	45 1/2	55 1/4	11	27	22 3/4
20	20	0.50	20 1/8	41 1/2	50 1/2	11	25	20 3/4
18	18	0.50	18 1/8	37 1/2	45 3/4	10	23	18 3/4
16	16	0.50	16 1/8	33 1/2	40 3/4	10	21	16 3/4
14	14	0.50	14 1/8	29 1/2	36	10	19	14 3/4
12	12 3/4	0.50	12 7/8	27	33	9	17 3/4	13 1/2
10	10 3/4	0.50	10 7/8	23	28 1/4	9	15 3/4	11 1/2
8	8 5/8	0.50	8 3/4	19	23 1/4	8	13 3/4	9 1/2
6	6 5/8	0.432	6 3/4	15 3/4	19 1/2	8	12 1/8	7 7/8
4	4 1/2	0.337	4 5/8	12	15 1/4	7	10 1/4	6
3	3 1/2	0.300	3 5/8	10 1/2	13 1/2	7	9 1/2	5 1/4
2[f]	2 3/8	0.218	2 1/2	—	—	6	7	h

Table 5.6b—Dimensions for Shell Nozzles (USC) (Continued)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9[c]
NPS (Size of Nozzle)	Outside Diameter of Pipe *OD*	Nominal Thickness of Flanged Nozzle Pipe Wall[a] t_n	Diameter of Hole in Reinforcing Plate D_R	Length of Side of Reinforcing Plate[b] or Diameter $L = D_o$	Width of Reinforcing Plate *W*	Minimum Distance from Shell-to-Flange Face *J*	Minimum Distance from Bottom of Tank to Center of Nozzle: Regular Type[d] H_N	Minimum Distance from Bottom of Tank to Center of Nozzle: Low Type *C*
1 1/2[f]	1.90	0.200	2	—	—	6	6	[h]
1[f]	1.315	0.250	—	—	—	6	6	[h]
3/4[f]	1.05	0.218	—	—	—	6	6	[h]
Threaded and Socket-Welded Couplings								
3[g]	4.250	Coupling	4 3/8	11 1/4	14 1/4	—	9 5/8	5 5/8
2[f]	3.000	Coupling	3 1/8	—	—	—	7	[h]
1 1/2[f]	2.500	Coupling	2 5/8	—	—	—	6	[h]
1[f]	1.750	Coupling	1 7/8	—	—	—	6	[h]
3/4[f]	1.375	Coupling	1 1/2	—	—	—	5	[h]

[a] For extra-strong pipe, see ASTM A53 or A106 for other wall thicknesses; however, piping material must conform to 4.5.

[b] The width of the shell plate shall be sufficient to contain the reinforcing plate and to provide clearance from the girth joint of the shell course.

● [c] Low type reinforced nozzles shall not be located lower than the minimum distance shown in Column 9. The minimum distance from the bottom shown in Column 9 complies with spacing rules of 5.7.3 and Figure 5.6.

[d] Regular type reinforced nozzles shall not be located lower than the minimum distance H_N shown in Column 8 when shell thickness is equal to or less than 1/2 in. Greater distances may be required for shells thicker than 1/2 in. to meet the minimum weld spacing of 5.7.3 and Figure 5.6.

[e] See Table 5.7b, Column 2.

[f] Flanged nozzles and couplings in pipe sizes NPS 2 or smaller do not require reinforcing plates. D_R will be the diameter of the hole in the shell plate, and Weld *A* will be as specified in Table 5.7b, Column 6. Reinforcing plates may be used if the construction details comply with reinforced nozzle details.

[g] A coupling in an NPS 3 requires reinforcement.

[h] See 5.7.3 and Figure 5.6.

NOTE See Figure 5.8.

Table 5.7a—Dimensions for Shell Nozzles: Pipe, Plate, and Welding Schedules (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Thickness of Shell and Reinforcing Plate[a] *t* and *T*	Minimum Pipe Wall Thickness of Flanged Nozzles[b] t_n	Maximum Diameter of Hole in Shell Plate (D_p) Equals Outside Diameter of Pipe Plus	Size of Fillet Weld *B*	Size of Fillet Weld *A*: Nozzles Larger Than NPS 2	Size of Fillet Weld *A*: NPS 3/4 to 2 Nozzles
5	12.7	16	5	6	6
6	12.7	16	6	6	6
8	12.7	16	8	6	6
10	12.7	16	10	6	6
11	12.7	16	11	6	6
13	12.7	16	13	6	8
14	12.7	20	14	6	8

Table 5.7a—Dimensions for Shell Nozzles: Pipe, Plate, and Welding Schedules (SI) (Continued)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Thickness of Shell and Reinforcing Plate[a] t and T	Minimum Pipe Wall Thickness of Flanged Nozzles[b] t_n	Maximum Diameter of Hole in Shell Plate (D_p) Equals Outside Diameter of Pipe Plus	Size of Fillet Weld B	Size of Fillet Weld A	
				Nozzles Larger Than NPS 2	NPS $^3/_4$ to 2 Nozzles
16	12.7	20	16	8	8
17	12.7	20	18	8	8
20	12.7	20	20	8	8
21	12.7	20	21	10	8
22	12.7	20	22	10	8
24	12.7	20	24	10	8
25	12.7	20	25	11	8
27	14	20	27	11	8
28	14	20	28	11	8
30	16	20	30	13	8
32	16	20	32	13	8
33	18	20	33	13	8
35	18	20	35	14	8
36	20	20	36	14	8
38	20	20	38	14	8
40	21	20	40	14	8
41	21	20	40	16	8
43	22	20	40	16	8
45	22	20	40	16	8

[a] If a shell plate thicker than required is used for the product and hydrostatic loading (see 5.6), the excess shell-plate thickness, within a vertical distance both above and below the centerline of the hole in the tank shell plate equal to the vertical dimension of the hole in the tank shell plate, may be considered as reinforcement, and the thickness T of the nozzle reinforcing plate may be decreased accordingly. In such cases, the reinforcement and the attachment welding shall conform to the design limits for reinforcement of shell openings specified in 5.7.2.

[b] This column applies to flanged nozzles NPS 26 and larger. See 4.5 for piping materials.

NOTE See Figure 5.8.

5.7.2.3 Except for flush-type openings and connections, all effective reinforcements shall be made within a distance above and below the centerline of the shell opening equal to the vertical dimension of the hole in the tank shell plate. Reinforcement may be provided by any one or any combination of the following:

a) The attachment flange of the fitting.

• b) The reinforcing plate. Reinforcing plates for manholes, nozzles, and other attachments shall be of the same nominal composition (i.e. same ASME P-number and Group Number) as the tank part to which they are attached, unless approved otherwise by the Purchaser (refer to 9.2.1.3).

Table 5.7b—Dimensions for Shell Nozzles: Pipe, Plate, and Welding Schedules (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Thickness of Shell and Reinforcing Plate[a] t and T	Minimum Pipe Wall Thickness of Flanged Nozzles[b] t_n	Maximum Diameter of Hole in Shell Plate (D_p) Equals Outside Diameter of Pipe Plus	Size of Fillet Weld B	Size of Fillet Weld A	
				Nozzles Larger Than NPS 2	NPS 3/4 to 2 Nozzles
3/16	1/2	5/8	3/16	1/4	1/4
1/4	1/2	5/8	1/4	1/4	1/4
5/16	1/2	5/8	5/16	1/4	1/4
3/8	1/2	5/8	3/8	1/4	1/4
7/16	1/2	5/8	7/16	1/4	1/4
1/2	1/2	5/8	1/2	1/4	5/16
9/16	1/2	3/4	9/16	1/4	5/16
5/8	1/2	3/4	5/8	5/16	5/16
11/16	1/2	3/4	11/16	5/16	5/16
3/4	1/2	3/4	3/4	5/16	5/16
13/16	1/2	3/4	13/16	3/8	5/16
7/8	1/2	3/4	7/8	3/8	5/16
15/16	1/2	3/4	15/16	3/8	5/16
1	1/2	3/4	1	7/16	5/16
1 1/16	9/16	3/4	1 1/16	7/16	5/16
1 1/8	9/16	3/4	1 1/8	7/16	5/16
1 3/16	5/8	3/4	1 3/16	1/2	5/16
1 1/4	5/8	3/4	1 1/4	1/2	5/16
1 5/16	11/16	3/4	1 5/16	1/2	5/16
1 3/8	11/16	3/4	1 3/8	9/16	5/16
1 7/16	3/4	3/4	1 7/16	9/16	5/16
1 1/2	3/4	3/4	1 1/2	9/16	5/16
1 9/16	13/16	3/4	1 1/2	9/16	5/16
1 5/8	13/16	3/4	1 1/2	5/8	5/16
1 11/16	7/8	3/4	1 1/2	5/8	5/16
1 3/4	7/8	3/4	1 1/2	5/8	5/16

[a] If a shell plate thicker than required is used for the product and hydrostatic loading (see 5.6), the excess shell-plate thickness, within a vertical distance both above and below the centerline of the hole in the tank shell plate equal to the vertical dimension of the hole in the tank shell plate, may be considered as reinforcement, and the thickness T of the nozzle reinforcing plate may be decreased accordingly. In such cases, the reinforcement and the attachment welding shall conform to the design limits for reinforcement of shell openings specified in 5.7.2.

[b] This column applies to flanged nozzles NPS 26 and larger. See 4.5 for piping materials.

NOTE See Figure 5.8.

Table 5.8a—Dimensions for Shell Nozzle Flanges (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
								Diameter of Bore		Minimum Diameter of Hub at Point of Weld	
NPS (Size of Nozzle)	Minimum Thickness of Flange[d] Q	Outside Diameter of Flange A	Diameter of Raised Face D	Diameter of Bolt Circle C	Number of Holes	Diameter of Holes	Diameter of Bolts	Slip-On Type: Outside Diameter of Pipe Plus B	Welding Neck Type[a] B_1	Slip-On Type[b] E	Welding Neck Type[c] E_1
60	79.4	1854	1676	1759	52	48	45	6.4	a	b	c
54	76.2	1683	1511	1594	44	48	45	6.4	a	b	c
52	73	1626	1461	1537	44	48	45	6.4	a	b	c
50	70	1569	1410	1480	44	48	45	6.4	a	b	c
48	70	1510	1360	1426	44	42	40	6.4	a	b	c
46	68	1460	1295	1365	40	42	40	6.4	a	b	c
44	67	1405	1245	1315	40	42	40	6.4	a	b	c
42	67	1345	1195	1257	36	42	40	6.4	a	b	c
40	65	1290	1125	1200	36	42	40	6.4	a	b	c
38	60	1240	1075	1150	32	42	40	6.4	a	b	c
36	60	1170	1020	1036	32	42	40	6.4	a	b	c
34	59	1110	960	1029	32	42	40	6.4	a	b	c
32	57	1060	910	978	28	42	40	6.4	a	b	c
30	54	985	855	914	28	33	30	6.4	a	b	c
28	52	925	795	864	28	33	30	6.4	a	b	c
26	50	870	745	806	24	33	30	6.4	a	b	c
24	48	815	690	750	20	33	30	4.8	a	b	c
22	46	750	640	692	20	33	30	4.8	a	b	c
20	43	700	585	635	20	30	27	4.8	a	b	c
18	40	635	535	577	16	30	27	4.8	a	b	c
16	36	595	470	540	16	27	24	4.8	a	b	c
14	35	535	415	476	12	27	24	4.8	a	b	c
12	32	485	380	432	12	25	22	3.2	a	b	c
10	30	405	325	362	12	25	22	3.2	a	b	c
8	28	345	270	298	8	23	20	3.2	a	b	c
6	25	280	216	241	8	23	20	2.4	a	b	c
4	24	230	157	190	8	19	16	1.6	a	b	c
3	24	190	127	152	4	19	16	1.6	a	b	c
2	20	150	92	121	4	19	16	1.6	a	b	c
$1^1/_2$	17	125	73	98	4	16	12	1.6	a	b	c

[a] B_1 = inside diameter of pipe.

[b] E = outside diameter of pipe + $2t_n$.

[c] E_1 = outside diameter of pipe.

● [d] Corrosion allowance, if specified, need not be added to flange and cover thicknesses complying with ASME B16.5 Class 150, ASME B16.1 Class 125, and ASME B16.47 flanges.

NOTE See Figure 5.8. The facing dimensions for slip-on and welding-neck flanges in NPS $1^1/_2$ through 20 and NPS 24 are identical to those specified in ASME B16.5 for Class 150 steel flanges. The facing dimensions for flanges in NPS 30, 36, 42, 48, 50, 52, 54, and 60 are in agreement with ASME B16.1 for Class 125 cast iron flanges. The dimensions for large flanges may conform to Series B of ASME B16.47.

Table 5.8b—Dimensions for Shell Nozzle Flanges (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
NPS (Size of Nozzle)	Minimum Thickness of Flange[d] Q	Outside Diameter of Flange A	Diameter of Raised Face D	Diameter of Bolt Circle C	Number of Holes	Diameter of Holes	Diameter of Bolts	Diameter of Bore		Minimum Diameter of Hub at Point of Weld	
								Slip-On Type: Outside Diameter of Pipe Plus B	Welding Neck Type[a] B_1	Slip-On Type[b] E	Welding Neck Type[c] E_1
60	3 1/8	73	66	69 1/4	52	17/8	1 3/4	0.25	a	b	c
54	3	66 1/4	59 1/2	62 3/4	44	17/8	1 3/4	0.25	a	b	c
52	2 7/8	64	57 1/2	60 1/2	44	17/8	1 3/4	0.25	a	b	c
50	2 3/4	61 3/4	55 1/2	58 1/4	44	17/8	1 3/4	0.25	a	b	c
48	2 3/4	59 1/2	53 1/2	56	44	1 5/8	1 1/2	0.25	a	b	c
46	2 11/16	57 1/2	51	53 3/4	40	1 5/8	1 1/2	0.25	a	b	c
44	2 5/8	55 1/4	49	51 3/4	40	1 5/8	1 1/2	0.25	a	b	c
42	2 5/8	53	47	49 1/2	36	1 5/8	1 1/2	0.25	a	b	c
40	2 1/2	50 3/4	44 1/4	47 1/4	36	1 5/8	1 1/2	0.25	a	b	c
38	2 3/8	48 3/4	42 1/4	45 1/4	32	1 5/8	1 1/2	0.25	a	b	c
36	2 3/8	46	40 1/4	42 3/4	32	1 5/8	1 1/2	0.25	a	b	c
34	2 5/16	43 3/4	37 3/4	40 1/2	32	1 5/8	1 1/2	0.25	a	b	c
32	2 1/4	41 3/4	35 3/4	38 1/2	28	1 5/8	1 1/2	0.25	a	b	c
30	2 1/8	38 3/4	33 3/4	36	28	1 3/8	1 1/4	0.25	a	b	c
28	2 1/16	36 1/2	31 1/4	34	28	1 3/8	1 1/4	0.25	a	b	c
26	2	34 1/4	29 1/4	31 3/4	24	1 3/8	1 1/4	0.25	a	b	c
24	1 7/8	32	27 1/4	29 1/2	20	1 3/8	1 1/4	0.19	a	b	c
22	1 13/16	29 1/2	25 1/4	27 1/4	20	1 3/8	1 1/4	0.19	a	b	c
20	1 11/16	27 1/2	23	25	20	1 1/4	1 1/8	0.19	a	b	c
18	1 9/16	25	21	22 3/4	16	1 1/4	1 1/8	0.19	a	b	c
16	1 7/16	23 1/2	18 1/2	21 1/4	16	1 1/8	1	0.19	a	b	c
14	1 3/8	21	16 1/4	18 3/4	12	1 1/8	1	0.19	a	b	c
12	1 1/4	19	15	17	12	1	7/8	0.13	a	b	c
10	1 3/16	16	12 3/4	14 1/4	12	1	7/8	0.13	a	b	c
8	1 1/8	13 1/2	10 5/8	11 3/4	8	7/8	3/4	0.10	a	b	c
6	1	11	8 1/2	9 1/2	8	7/8	3/4	0.10	a	b	c
4	15/16	9	6 3/16	7 1/2	8	3/4	5/8	0.06	a	b	c
3	15/16	7 1/2	5	6	4	3/4	5/8	0.06	a	b	c
2	3/4	6	3 5/8	4 3/4	4	3/4	5/8	0.07	a	b	c
1 1/2	11/16	5	2 7/8	3 7/8	4	5/8	1/2	0.07	a	b	c

[a] B_1 = inside diameter of pipe.

[b] E = outside diameter of pipe + $2t_n$.

[c] E_1 = outside diameter of pipe.

• [d] Corrosion allowance, if specified, need not be added to flange and cover thicknesses complying with ASME B16.5 Class 150, ASME B16.1 Class 125, and ASME B16.47 flanges.

NOTE See Figure 5.8. The facing dimensions for slip-on and welding-neck flanges in NPS 1 1/2 through 20 and NPS 24 are identical to those specified in ASME B16.5 for Class 150 steel flanges. The facing dimensions for flanges in NPS 30, 36, 42, 48, 50, 52, 54, and 60 are in agreement with ASME B16.1 for Class 125 cast iron flanges. The dimensions for large flanges may conform to Series B of ASME B16.47.

Table 5.9a—Dimensions for Flush-type Cleanout Fittings (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Height of Opening *h*	Width of Opening *b*	Arc Width of Shell Reinforcing Plate *W*	Upper Corner Radius of Opening r_1	Upper Corner Radius of Shell Reinforcing Plate r_2	Edge Distance of Bolts *e*	Flange Width[a] (Except at Bottom) f_3	Bottom Flange Width f_2	Special Bolt Spacing[b] *g*	Number of Bolts	Diameter of Bolts
203	406	1170	100	360	32	102	89	83	22	20
610	610	1830	300	740	38	102	95	89	36	20
914	1219	2700	610	1040	38	114	121	108	46	24
1219[c]	1219	3200	610	1310	38	114	127	114	52	24

[a] For neck thicknesses greater than 40 mm, increase f_3 as necessary to provide a 1.5 mm clearance between the required neck-to-flange weld and the head of the bolt.

[b] Refers to spacing at the lower corners of the cleanout-fitting flange.

[c] Only for Group I, II, III, or IIIA shell materials (see 5.7.7.2).

NOTE See Figure 5.12.

Table 5.9b—Dimensions for Flush-type Cleanout Fittings (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Height of Opening *h*	Width of Opening *b*	Arc Width of Shell Reinforcing Plate *W*	Upper Corner Radius of Opening r_1	Upper Corner Radius of Shell Reinforcing Plate r_2	Edge Distance of Bolts *e*	Flange Width[a] (Except at Bottom) f_3	Bottom Flange Width f_2	Special Bolt Spacing[b] *g*	Number of Bolts	Diameter of Bolts
8	16	46	4	14	$1^1/_4$	4	$3^1/_2$	$3^1/_4$	22	$^3/_4$
24	24	72	12	29	$1^1/_2$	4	$3^3/_4$	$3^1/_2$	36	$^3/_4$
36	48	106	24	41	$1^1/_2$	$4^1/_2$	$4^3/_4$	$4^1/_4$	46	1
48[c]	48	125	24	$51^1/_2$	$1^1/_2$	$4^1/_2$	5	$4^1/_2$	52	1

[a] For neck thicknesses greater than $1^9/_{16}$ in., increase f_3 as necessary to provide a $^1/_{16}$ in. clearance between the required neck-to-flange weld and the head of the bolt.

[b] Refers to spacing at the lower corners of the cleanout-fitting flange.

[c] Only for Group I, II, III, or IIIA shell materials (see 5.7.7.2).

NOTE See Figure 5.12.

Table 5.10a—Minimum Thickness of Cover Plate, Bolting Flange, and Bottom Reinforcing Plate for Flush-type Cleanout Fittings[f] (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
		Size of Opening $h \times b$ (Height × Width)							
		200 × 400		600 × 600		900 × 1200		1200 × 1200	
Maximum Design Liquid Level, m H	Equivalent Pressure[a] kPa	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[b] t_{br}	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[c] t_{br}	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[d] t_{br}	Thickness of Bolting Flange and CoverPlate t_c	Thickness of Bottom Reinforcing Plate[e] t_{br}
6	60	10	13	10	13	15	20	16	22
10	98	10	13	11	13	19	25	20	27
12	118	10	13	13	14	21	27	22	29
16	157	10	13	14	16	24	31	25	33
18	177	10	13	15	17	25	33	27	35
19.5	191	11	13	16	17	26	34	28	36
22	216	11	13	17	18	28	36	30	38

[a] Equivalent pressure is based on water loading.
[b] Maximum of 25 mm.
[c] Maximum of 28 mm.
[d] Maximum of 40mm.
[e] Maximum of 45 mm.
[f] See 5.7.7.7 when corrosion allowance is specified.
[g] S_d set to maximum value for table calculations, see 5.7.7.7.
NOTE See Figure 5.12.

Table 5.10b—Minimum Thickness of Cover Plate, Bolting Flange, and Bottom Reinforcing Plate for Flush-type Cleanout Fittings[f] (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
		Size of Opening $h \times b$ (Height × Width)							
		8 × 16		24 × 24		36 × 48		48 × 48	
Maximum Design Liquid Level, ft H	Equivalent Pressure[a] lbf/in.^{2}	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[b] t_{br}	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[c] t_{br}	Thickness of Bolting Flange and Cover Plate t_c	Thickness of Bottom Reinforcing Plate[d] t_{br}	Thickness of Bolting Flange and CoverPlate t_c	Thickness of Bottom Reinforcing Plate[e] t_{br}
24	10.4	3/8	1/2	3/8	1/2	11/16	7/8	11/16	15/16
30	13.0	3/8	1/2	7/16	1/2	3/4	1	3/4	1 1/16
40	17.4	3/8	1/2	1/2	9/16	13/16	1 1/8	7/8	1 3/16
48	20.9	3/8	1/2	9/16	5/8	15/16	1 3/16	1	1 1/4
54	23.5	3/8	1/2	9/16	5/8	1	1 1/4	1 1/16	1 5/16
60	26.9	7/16	1/2	5/8	11/16	1	1 5/16	1 1/16	1 3/8
72	31.2	7/16	1/2	11/16	3/4	1 1/8	1 7/16	1 3/16	1 1/2

[a] Equivalent pressure is based on water loading.
[b] Maximum of 1 in.
[c] Maximum of 1 1/8 in.
[d] Maximum of 1 1/2 in.
[e] Maximum of 1 3/4 in.
[f] See 5.7.7.7 when corrosion allowance is specified.
[g] S_d set to maximum value for table calculations, see 5.7.7.7
NOTE See Figure 5.12.

Table 5.11a—Thicknesses and Heights of Shell Reinforcing Plates for Flush-type Cleanout Fittings (SI)

Dimensions in millimeters

Thickness of Lowest Shell Course t, t_d[a] mm	Maximum Design Liquid Level[c] H m	Height of Shell Reinforcing Plate for Size of Opening $h \times b$ (Height × Width) mm			
		200 × 400	600 × 600	900 × 1200	1200 × 1200[b]
All	< 22	350	915	1372	1830

[a] Dimensions t_d and L may be varied within the limits defined in 5.7.7.

[b] 1200 × 1200 flush-type cleanout fittings are not permitted for tanks with greater than 38 mm lowest shell course thickness.

[c] See 5.6.3.2.

Table 5.11b—Thicknesses and Heights of Shell Reinforcing Plates for Flush-type Cleanout Fittings (USC)

Dimensions in inches

Thickness of Lowest Shell Course t, t_d[a] in.	Maximum Design Liquid Level[c] H ft	Height of Shell Reinforcing Plate for Size of Opening $h \times b$ (Height × Width) mm			
		8 × 16	24 × 24	36 × 48	48 × 48[b]
All	< 72	14	36	54	72

[a] Dimensions t_d and L may be varied within the limits defined in 5.7.7.

[b] 48 × 48 flush-type cleanout fittings are not permitted for tanks with greater than $1^1/_2$ in. lowest shell course thickness.

[c] See 5.6.3.2.

c) The portion of the neck of the fitting that may be considered as reinforcement according to 5.7.2.4.

d) Excess shell-plate thickness. Reinforcement may be provided by any shell-plate thickness in excess of the thickness required by the governing load condition within a vertical distance above and below the centerline of the hole in the shell equal to the vertical dimension of the hole in the tank shell plate as long as the extra shell-plate thickness is the actual plate thickness used less the required thickness, calculated at the applicable opening, considering all load conditions and the corrosion allowance.

e) The material in the nozzle neck. The strength of the material in the nozzle neck used for reinforcement should preferably be the same as the strength of the tank shell, but lower strength material is permissible as reinforcement as long as the neck material has minimum specified yield and tensile strengths not less than 70 % and 80 %, respectively, of the shell-plate minimum specified yield and tensile strengths. When the material strength is greater than or equal to the 70 % and 80 % minimum values, the area in the neck available for reinforcement shall be reduced by the ratio of the allowable stress in the neck, using the governing stress factors, to the allowable stress in the attached shell plate. No credit may be taken for the additional strength of any reinforcing material that has a higher allowable stress than that of the shell plate. Neck material that has a yield or tensile strength less than the 70 % or 80 % minimum values may be used, provided that no neck area is considered as effective reinforcement.

5.7.2.4 The following portions of the neck of a fitting may be considered part of the area of reinforcement, except where prohibited by 5.7.2.3, Item e:

a) The portion extending outward from the outside surface of the tank shell plate to a distance equal to four times the neck-wall thickness or, if the neck-wall thickness is reduced within this distance, to the point of transition.

b) The portion lying within the shell-plate thickness.

c) The portion extending inward from the inside surface of the tank shell plate to the distance specified in Item a.

5.7.2.5 The aggregate strength of the weld attaching a fitting to the shell plate, an intervening reinforcing plate, or both shall at least equal the proportion of the forces passing through the entire reinforcement that is calculated to pass through the fitting.

5.7.2.6 The aggregate strength of the welds attaching any intervening reinforcing plate to the shell plate shall at least equal the proportion of the forces passing through the entire reinforcement that is calculated to pass through the reinforcing plate.

5.7.2.7 The attachment weld to the shell along the outer periphery of a reinforcing plate or proprietary connection that lap welds to the shell shall be considered effective only for the parts lying outside the area bounded by vertical lines drawn tangent to the shell opening; however, the outer peripheral weld shall be applied completely around the reinforcement. See 5.7.2.8 for allowable stresses. All of the inner peripheral weld shall be considered effective. The strength of the effective attachment weld shall be considered as the weld's shear resistance at the stress value given for fillet welds in 5.7.2.8. The size of the outer peripheral weld shall be equal to the thickness of the shell plate or reinforcing plate, whichever is thinner, but shall not be greater than 40 mm ($1^1/2$ in.). When low-type nozzles are used with a reinforcing plate that extends to the tank bottom (see Figure 5.8), the size of the portion of the peripheral weld that attaches the reinforcing plate to the bottom plate shall conform to 5.1.5.7. The inner peripheral weld shall be large enough to sustain the remainder of the loading.

5.7.2.8 The reinforcement and welding shall be configured to provide the required strength for the forces covered in 5.7.2.5 and 5.7.2.6.

The allowable stresses for the attachment elements are the following.

a) For outer reinforcing plate-to-shell and inner reinforcing plate-to-nozzle neck fillet welds: $S_d \times 0.60$.

b) For tension across groove welds: $S_d \times 0.875 \times 0.70$.

c) For shear in the nozzle neck: $S_d \times 0.80 \times 0.875$.

where

S_d is the maximum allowable design stress (the lesser value of the base materials joined) permitted by 5.6.2.1 for carbon steel, or by Tables S.2a and S.2b for stainless steel.

Stress in fillet welds shall be considered as shear on the throat of the weld. The throat of the fillet shall be assumed to be 0.707 times the length of the shorter leg. Tension stress in the groove weld shall be considered to act over the effective weld depth.

5.7.2.9 When two or more openings are located so that the outer edges (toes) of their normal reinforcing-plate fillet welds are closer than eight times the size of the larger of the fillet welds, with a minimum of 150 mm (6 in.), they shall be treated and reinforced as follows:

a) All such openings shall be included in a single reinforcing plate that shall be proportioned for the largest opening in the group.

b) If the normal reinforcing plates for the smaller openings in the group, considered separately, fall within the area limits of the solid portion of the normal plate for the largest opening, the smaller openings may be included in the normal plate for the largest opening without an increase in the size of the plate, provided that if any opening intersects the vertical centerline of another opening, the total width of the final reinforcing plate along the vertical centerline of either opening is not less than the sum of the widths of the normal plates for the openings involved.

c) If the normal reinforcing plates for the smaller openings in the group, considered separately, do not fall within the area limits of the solid portion of the normal plate for the largest opening, the group reinforcing-plate size and shape shall include the outer limits of the normal reinforcing plates for all the openings in the group. A change in size from the outer limits of the normal plate for the largest opening to the outer limits of that for the smaller opening farthest from the largest opening shall be accomplished by uniform straight taper unless the normal plate for any intermediate opening would extend beyond these limits, in which case uniform straight tapers shall join the outer limits of the several normal plates. The provisions of Item b with respect to openings on the same or adjacent vertical centerlines also apply in this case.

5.7.2.10 Each reinforcing plate for shell openings shall be provided with a 6 mm (1/4 in.) diameter telltale hole. The hole shall be located on the horizontal centerline and shall be open to the atmosphere.

5.7.3 Spacing of Welds around Connections

See Figure 5.6 for spacing requirements listed in 5.7.3.1, 5.7.3.2, 5.7.3.3, and 5.7.3.4.

NOTE 1 Additional weld spacing requirements exist in this standard. Other paragraphs and tables dealing with nozzles and manholes may increase the minimum spacing.

NOTE 2 Whenever stress relief or thermal stress relief is used in this standard, it shall mean post-weld heat treatment.

5.7.3.1 For non-stress-relieved welds on shell plates over 13 mm (1/2 in.) thick, the minimum spacing between penetration connections and adjacent shell-plate joints shall be governed by the following.

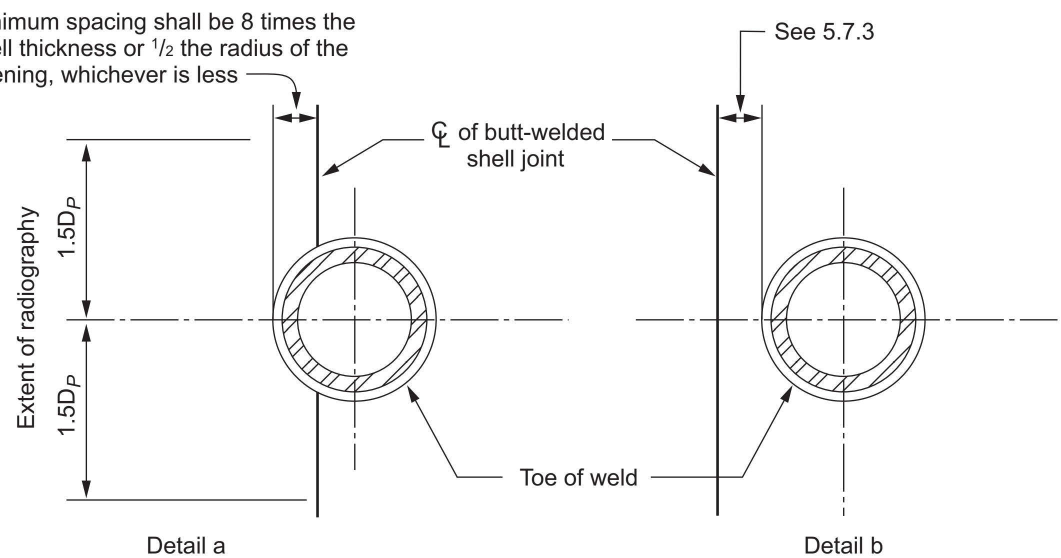
a) The toe of the fillet weld around a non-reinforced penetration or around the periphery of a reinforcing plate, and the centerline of a butt-weld around the periphery of a thickened insert plate or insert plate, shall be spaced at least the greater of eight times the weld size or 250 mm (10 in.) from the centerline of any butt-welded shell joints, as illustrated in Figure 5.6, dimensions A or B.

b) The toe of the fillet weld around a non-reinforced penetration or around the periphery of a reinforcing plate, and the centerline of a butt-weld around the periphery of a thickened insert plate or insert plate, shall be spaced at least the greater of eight times the larger weld size or 150 mm (6 in.) from each other, as illustrated in Figure 5.6, dimension E.

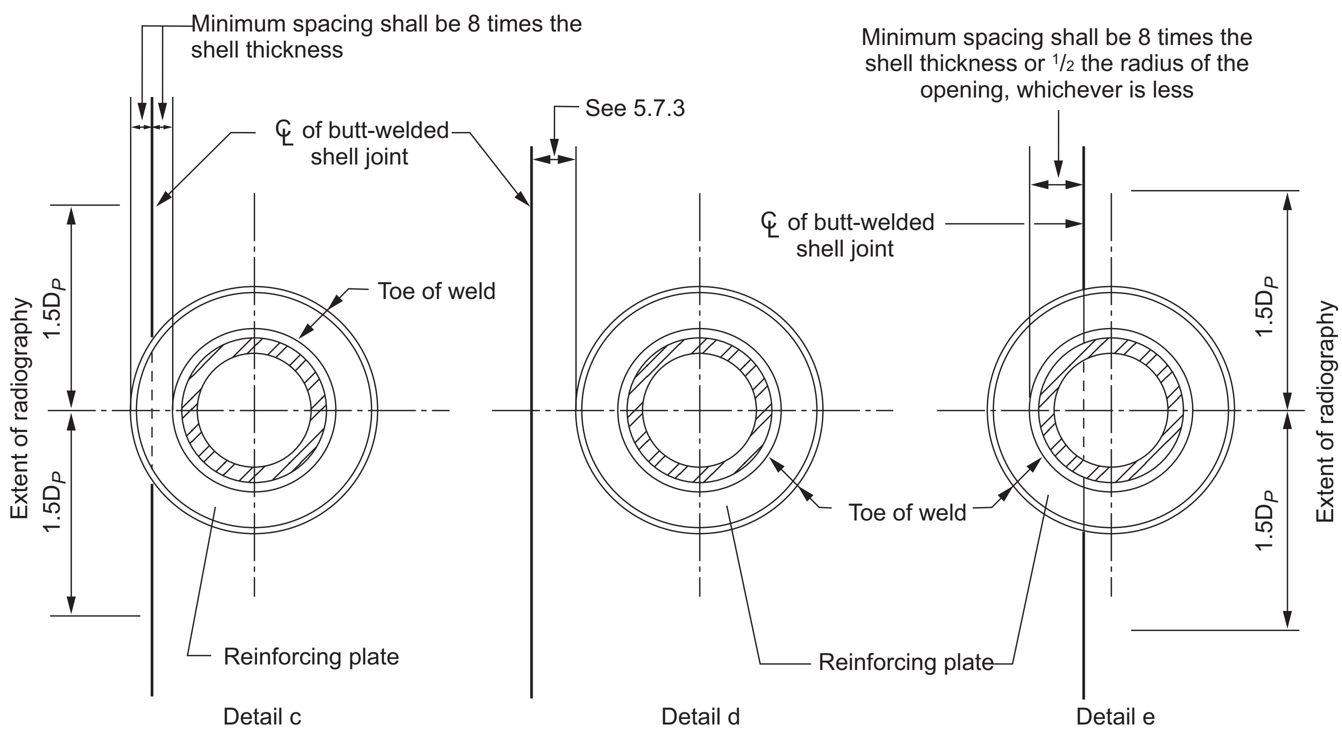
5.7.3.2 Where stress-relieving of the periphery weld has been performed prior to welding of the adjacent shell joint or where a non-stress-relieved weld is on a shell plate which is less than or equal to 13 mm (½ in.) thick, the minimum weld spacing may be reduced to 150 mm (6 in.) from vertical joints, as illustrated in Figure 5.6, dimension A or to the greater of 75 mm (3 in.) or 2½ times the shell thickness from horizontal joints, as illustrated in Figure 5.6, dimension B. The spacing between the welds around the periphery of a thickened insert plate, around the periphery of an insert plate with a reinforced penetration, around a reinforcing plate, or around a non-reinforced penetration, shall be the greater of 75 mm (3 in.) or 2½ times the shell thickness, as illustrated in Figure 5.6, dimension E.

5.7.3.3 The rules in 5.7.3.1 and 5.7.3.2 shall also apply to the bottom-to-shell joint (dimension C in Figure 5.6) unless, as an alternative, the thickened insert plate, insert plate, or reinforcing plate extends to the bottom-to-shell joint and intersects it at approximately 90 degrees, as illustrated in Figure 5.6, dimension D. A minimum distance of 75 mm (3 in.) shall be maintained between the toe of a weld around a non-reinforced penetration (see 5.7.2.1) and the toe of the shell-to-bottom weld.

• **5.7.3.4** Nozzles and manholes should not be placed in shell weld seams and reinforcing pads for nozzles and manholes should not overlap plate seams (i.e. Figure 5.9, Details a, c, and e should be avoided). If there is no other feasible option and the Purchaser accepts the design, circular shell openings and reinforcing plates (if used) may be located in a horizontal or vertical butt-welded shell joint provided that the minimum spacing dimensions are met and a radiographic examination of the welded shell joint is conducted. The welded shell joint shall be fully radiographed for a length equal to three times the diameter of the opening, but the weld seam being removed need not be radiographed. Radiographic examination shall be in accordance with 8.1.3 through 8.1.8.



Penetration Without Reinforcing Plate



Penetration With Reinforcing Plate

Note: D_p = diameter of opening.

Figure 5.9—Minimum Spacing of Welds and Extent of Related Radiographic Examination

5.7.4 Thermal Stress Relief

5.7.4.1 All flush-type cleanout fittings and flush-type shell connections shall be thermally stress-relieved as an assembly prior to installation in the tank shell or, alternatively, after installation into the tank shell if the entire tank is stress-relieved. The stress relief shall be carried out within a temperature range of 600 °C to 650 °C (1100 °F to 1200 °F) (see 5.7.4.5 for quenched and tempered materials) for 1 hour per 25 mm (1 in.) of shell thickness. The assembly shall include the bottom reinforcing plate (or annular plate) and the flange-to-neck weld.

5.7.4.2 For non-flush-type nozzles and manways, when the shell material is Group I, II, III, or IIIA, all openings NPS 12 or larger in nominal diameter in a shell plate, insert plate, or thickened insert plate more than 25 mm (1 in.) thick shall be prefabricated into the shell plate, insert plate, or thickened insert plate, and the prefabricated assembly shall be thermally stress-relieved within a temperature range of 600 °C to 650 °C (1100 °F to 1200 °F) for 1 hour per 25 mm (1 in.) of thickness prior to installation.

5.7.4.3 For non-flush-type nozzles and manways, when the shell material is Group IV, IVA, V, or VI, all openings larger than NPS 2 in. nominal diameter in a shell plate, insert plate, or thickened insert plate more than 13 mm ($^1/_2$ in.) thick shall be prefabricated into the shell plate, insert plate, or thickened insert plate, and the prefabricated assembly shall be thermally stress relieved within a temperature range of 600 °C to 650 °C (1100 °F to 1200 °F) for 1 hour per 25 mm (1 in.) of thickness prior to installation.

5.7.4.4 For non-flush-type nozzles and manways, the stress-relieving requirements do not apply to the weld of the shell, insert plate, or thickened insert plate to the bottom annular plate. Further, the stress-relieving requirements need not include the flange-to-neck welds or other nozzle-neck and manhole-neck attachments, provided the following conditions are satisfied:

a) The welds are outside the reinforcement (see 5.7.2.4).

b) The throat dimension of a fillet weld in a slip-on flange does not exceed 16 mm ($^5/_8$ in.), or the butt joint of a welding-neck flange does not exceed 19 mm ($^3/_4$ in.). If the material is preheated to a minimum temperature of 90 °C (200 °F) during welding, the weld limits of 16 mm ($^5/_8$ in.) and 19 mm ($^3/_4$ in.) may be increase to 32 mm and 40 mm (1$^1/_4$ in. and 1$^1/_2$ in.), respectively.

5.7.4.5 When openings are installed in quenched and tempered material, the maximum thermal stress-relieving temperature shall not exceed the tempering temperature for materials in the prefabricated stress-relieving assembly.

5.7.4.6 The thermal stress relief procedure shall be as outlined in the following:

a) The temperature of the furnace shall not exceed 425 °C (800 °F) at the time the part or section of the tank is placed in it.

b) The rate of heating above 425 °C (800 °F) shall be not more than 220 °C (400 °F) per hour divided by the maximum metal thickness, in inches, of the wall plate being heated, but in no case shall it be more than 220 °C (400 °F) per hour.

c) During the heating period, the temperature throughout the portion of the tank being heated shall not vary more than 140 °C (250 °F) within any 4.6 m (15 ft) interval of length and, when at the hold temperature, not more than 85 °C (150 °F) throughout the portion of the tank being heated. A minimum temperature of 595 °C (1100 °F) (except as permitted in 5.7.4.8) shall be maintained for a period of one hour per inch of metal thickness (maximum metal thickness of the tank wall plates affected). During the heating and holding periods, the furnace atmosphere shall be controlled to avoid excessive oxidation of the surface of the material being treated. The furnace shall be designed to prevent direct impingement of the flame on the material.

d) At temperatures over 425 °C (800 °F), cooling shall be done in a closed furnace or cooling chamber at a rate not greater than 280 °C (500 °F) per hour divided by the maximum metal thickness, in inches, of the plates affected, but in no case shall the rate be more than 280 °C (500 °F) per hour. At temperatures below 425 °C (800 °F), the material may be cooled in still air.

5.7.4.7 Examination after stress relief shall be in accordance with 7.2.3.7 or 7.2.3.8.

• **5.7.4.8** When it is impractical to stress relieve at a minimum temperature of 600 °C (1100 °F), it is permissible, subject to the Purchaser's agreement, to carry out the stress-relieving operation at lower temperatures for longer periods of time in accordance with the tabulation below. The lower temperature/longer time PWHT may not provide material toughness and residual stresses equivalent to that using the higher temperature/shorter time PWHT; therefore, a review by a knowledgeable metallurgist and possible verification by mill testing of heat-treated coupons and/or testing of welded plates shall be considered. See Line 23 of the Data Sheet for any Purchaser-specified requirements applicable to this heat-treatment option.

Minimum Stress-relieving Temperature		Holding Time (hours per 25 mm [1 in.] of thickness)	See Note
(°C)	(°F)		
600	1100	1	1
570	1050	2	1
540	1000	4	1
510	950	10	1, 2
480 (min.)	900 (min.)	20	1, 2

NOTE 1 For intermediate temperatures, the time of heating shall be determined by straight line interpolation.

NOTE 2 Stress relieving at these temperatures is not permitted for A537 Class 2 material.

5.7.4.9 When used in stress-relieved assemblies, the material of quenched and tempered steels A537, Cl 2, and of TMCP steel A841, shall be represented by test specimens that have been subjected to the same manner of heat treatment as that used for the stress relieved assembly.

5.7.5 Shell Manholes

5.7.5.1 Shell manholes shall conform to Figure 5.7a and Figure 5.7b and Table 5.3a through Table 5.5b (or Table 5.6a through Table 5.8b), but other shapes are permitted by 5.7.1.8. Cover plate and bolting flange thickness equations are provided in the equation in 5.7.5.6. Typical thickness values are shown in Table 5.3. Each manhole reinforcing plate shall be provided with a 6 mm (1/4 in.) diameter telltale hole (for detection of leakage through the interior welds). The hole shall be located on the horizontal centerline and shall be open to the atmosphere.

• **5.7.5.2** Manholes shall be of built-up welded construction. The dimensions are listed in Tables 5.3a through 5.5b. The dimensions are based on the minimum neck thicknesses listed in Tables 5.4a and 5.4b. When corrosion allowance is specified to be applied to shell manholes, corrosion allowance is to be added to the minimum neck, cover plate, and bolting flange thicknesses of Table 5.3a, Table 5.3b, Table 5.4a, and Table 5.4b.

5.7.5.3 The maximum diameter D_p of a shell cutout shall be as listed in Column 3 of Table 5.7a and Table 5.7b. Dimensions for required reinforcing plates are listed in Table 5.6a and Table 5.6b.

5.7.5.4 Unless otherwise specified by the Purchaser, shell manhole flanges shall be machine finished, and provided a minimum gasket width of 19 mm (3/4 in.) for ring style and full face gaskets. The gasket facing surface finish for both the cover plate and the flange shall have a roughness value that complies with the roughness tolerances referenced in the ASME PCC-1 standard, Appendix C, and also have a flatness tolerance that complies with the flatness tolerances referenced in the ASME PCC-1 standard, Appendix D. In the case of non-circular manholes, the maximum deviation from any reference plane shall not occur within less than a 150 mm (6 in.) distance. The gasket materials shall meet service requirements based on the product stored, maximum design temperature, and fire resistance.

Gasket dimensions, when used in conjunction with thin-plate flanges described in Figure 5.7a, have proven effective when used with soft gaskets, such as non-asbestos fiber with suitable binder. When using hard gaskets, such as solid metal, corrugated metal, metal-jacketed, and spiral-wound metal, the gasket dimensions, shell manhole flange, and shell manhole cover shall be designed per API Standard 620, Section 5.20 and Section 5.21. See 4.9 for additional requirements.

5.7.5.5 In lieu of using Figure 5.7a or design per API 620, forged flanges and forged blind flanges may be furnished per 4.6.

5.7.5.6 The required minimum thickness of manhole cover plate and bolting flange shall be the greater of the values computed by the following formulas:

In SI units:

$$t_c = D_b \times \sqrt{\frac{C\Upsilon HG}{S_d}} + CA$$

$$t_f = t_c - 3$$

t_c is the minimum nominal thickness of cover plate (not less than 8), in mm;

t_f is the minimum nominal thickness of bolting flange (not less than 6), in mm;

D_b is the bolt circle diameter (see Table 5.5), in mm;

C is the coefficient for circular plates and equals 0.3;

Υ is the water density factor 0.00981, in MPa/m;

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

G is the specific gravity of stored product not less than 1.0;

S_d is the design stress equal to 0.5 S_y (S_y is the yield strength equal to 205), in MPa;

NOTE Materials with higher a yield strength of 205 MPa may be used, but for thickness calculations S_y shall be less than or equal to 205 MPa, to maintain a leak tight bolted joint.

CA is the corrosion allowance, in mm.

In USC units:

$$t_c = D_b \times \sqrt{\frac{C\Upsilon HG}{S_d}} + CA$$

$$t_f = t_c - \frac{1}{8}$$

where

t_c is the minimum nominal thickness of cover plate (not less than $^5/_{16}$), in inches;

t_f is the minimum nominal thickness of bolting flange (not less than 1/4), in inches;

D_b is the bolt circle diameter (see Table 5.5), in inches;

C is the coefficient for circular plates and equals 0.3;

Υ is the water density factor 0.433, in psi/ft;

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

G is the specific gravity of stored product not less than 1.0;

S_d is the design stress equal to 0.5 S_y, in lbf/in.^{2}, (S_y is the yield strength equal to 30,000), in lbf/in.^{2};

NOTE Materials with higher a yield strength of 30,000 psi may be used, but for thickness calculations S_y shall not be greater than 30,000 psi, to maintain a leak tight bolted joint.

CA is the corrosion allowance, in inches.

EXAMPLE (SI) using a 23 m tall tank with 500 mm manway.

$$t_c = 667 \times \sqrt{\frac{0.3\left(\frac{9.81}{1000}\right)23 \times 1.0}{0.5 \times 205}} + 0 = 17.14 \text{ mm}$$

EXAMPLE (USC) using 75 ft tall tank with 20 in manway.

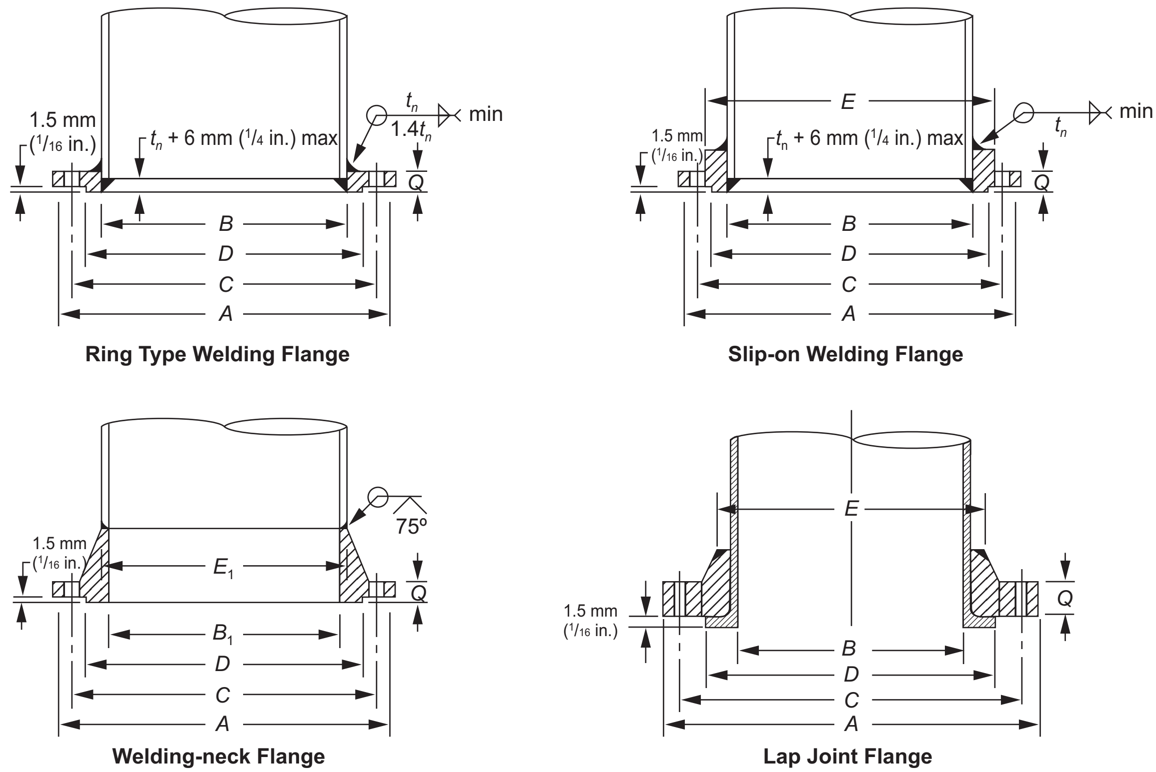
$$t_c = 26.25 \times \sqrt{\frac{0.3\left(\frac{62.4}{144}\right)75 \times 1.0}{0.5 \times 30{,}000}} + 0 = 0.6692 \text{ in.}$$

5.7.5.7 A cover plate with a nozzle attachment for product-mixing equipment shall have a thickness (t_c) of at least √2 times the thickness required by Table 5.3a and Table 5.3b (excluding corrosion allowance) or √2 times the calculated thickness, excluding corrosion allowance, per equation 5.7.5.6. The added thickness (or pad plate) for replacement of the opening cutout in the cover plate shall be based on Table 5.3a and Table 5.3b. The increased thickness of the cover plate within a radius of one diameter of the opening may be included as part of the area of replacement required. The mixer-nozzle attachment to the cover plate shall be a full-penetration weld. The manhole bolting-flange thickness (t_f) shall not be less than √2 times the thickness required by Table 5.3a and Table 5.3b (excluding corrosion allowance) or √2 times calculated thickness per the equation in 5.7.5.6, excluding corrosion allowance. The manhole nozzle neck shall be designed to support the mixer forces with a minimum thickness of not less than the requirements of Table 5.4a and Table 5.4b without comparison to the increased bolting-flange thickness noted in this section.

5.7.6 Shell Nozzles and Flanges

• **5.7.6.1.a** Unless otherwise specified, shell nozzle flanges, excluding manholes, in sizes NPS 1 1/2 through NPS 20 and NPS 24 shall meet the requirements of ASME B16.5. For sizes larger than NPS 24 but not greater than NPS 60, flanges shall meet the requirements of ASME B16.47, Series A or Series B. Series A and Series B flanges are not compatible in all sizes and must be carefully selected to match the mating flange. If diameters, materials of construction, and flange styles of ASME B16.47 are unavailable, fabricated flanges with drilling template (bolt circle diameter, number of holes, and hole diameter) matching Series A or Series B shall be used. These fabricated flanges shall be designed in accordance with the ASME *Boiler and Pressure Vessel Code,* Section VIII, Division 1, Section UG-34 and Annex 2. The allowable stresses for design shall be a matter of agreement between the Purchaser and the Manufacturer. Bolt holes shall straddle the vertical centerline of the flange.

• **5.7.6.1.b** Shell nozzles (and flanges, if specified by the Purchaser as an alternate to a. above) shall conform to Figure 5.7b, Figure 5.8, and Figure 5.10 and Tables 5.6a through 5.8b, but other shapes are permitted by 5.7.1.8. An alternative connection design is permissible for the nozzle end that is not welded to the shell, if it provides equivalent strength, toughness, leak tightness, and utility and if the Purchaser agrees to its use in writing.



NOTE The t_n designated for weld thickness is the nominal pipe wall thickness (see Tables 5.6a, 5.6b, 5.7a, and 5.7b).

Figure 5.10—Shell Nozzle Flanges (see Table 5.8a and Table 5.8b)

• **5.7.6.2** Unless shell nozzles are specified to be flush on the inside of the tank shell by the Purchaser, shell nozzles without internal piping in a tank without a floating roof may be supplied flush or with an internal projection at the option of the Manufacturer. In floating roof tanks, shell nozzles without internal piping within operating range of the floating roof shall be supplied flush on the inside of the tank shell unless agreed otherwise between the Manufacturer and the Purchaser.

• **5.7.6.3** The details and dimensions specified in this standard are for nozzles installed with their axes perpendicular to the shell plate. A nozzle may be installed at an angle other than 90 degrees to the shell plate in a horizontal plane, provided the width of the reinforcing plate (W or D_o in Figure 5.8 and Table 5.6a and Table 5.6b) is increased by the amount that the horizontal chord of the opening cut in the shell plate (D_p in Figure 5.8 and Table 5.7a and Table 5.7b) increases as the opening is changed from circular to elliptical for the angular installation. In addition, nozzles not larger than NPS 3—for the insertion of thermometer wells, for sampling connections, or for other purposes not involving the attachment of extended piping—may be installed at an angle of 15 degrees or less off perpendicular in a vertical plane without modification of the nozzle reinforcing plate.

5.7.6.4 The minimum nominal thickness of nozzle necks to be used shall be equal to the required thickness as identified by the term t_n in Table 5.6a and Table 5.6b, Column 3.

5.7.7 Flush-Type Cleanout Fittings

• **5.7.7.1** Flush-type cleanout fittings shall conform to the requirements of 5.7.7.2 through 5.7.7.12 and to the details and dimensions shown in Figure 5.12 and Figure 5.13 and Tables 5.9a through 5.11b. When a size intermediate to the sizes given in Tables 5.9a through 5.11b is specified by the Purchaser, the construction details and reinforcements shall conform to the next larger opening listed in the tables. The size of the opening or tank connection shall not be larger than the maximum size given in the appropriate table.

5.7.7.2 The opening shall be rectangular, but the upper corners of the opening shall have a radius (r_1) as shown in Table 5.9a and Table 5.9b. When the shell material is Group I, II, III, or IIIA, the width or height of the clear opening shall not exceed 1200 mm (48 in.); when the shell material is Group IV, IVA, V, or VI, the height shall not exceed 900 mm (36 in.).

5.7.7.3 The reinforced opening shall be completely preassembled into a shell plate, and the completed unit, including the shell plate at the cleanout fitting, shall be thermally stress-relieved as described in 5.7.4 (regardless of the thickness or strength of the material).

5.7.7.4 The required cross-sectional area of the reinforcement over the top of the opening shall be calculated for Design Condition as well as Hydrostatic Test Condition as follows:

$$A_{cs} \geq \frac{K_1 h t}{2}$$

where

A_{cs} is the required cross-sectional area of the reinforcement over the top of the opening, in mm^2 (in.^{2});

K_1 is the area coefficient from Figure 5.11;

h is the vertical height of clear opening, in mm (in.);

t is the calculated thickness of the lowest shell course, in mm (in.), required by the formulas of 5.6.3, 5.6.4, or A.4.1 (with joint efficiency E = 1.0), including corrosion allowance, where applicable.

5.7.7.5 The nominal thickness of the shell plate in the flush-type cleanout fitting assembly shall be at least as thick as the adjacent shell plate nominal thickness in the lowest shell course. The nominal thickness of the shell reinforcing plate and the neck plate shall be, as a minimum, the thickness of the shell plate in the cleanout-opening assembly.

The reinforcement in the plane of the shell shall be provided within a height L above the bottom of the opening. L shall not exceed 1.5h except that, in the case of small openings, $L - h$ shall not be less than 150 mm (6 in.). Where this exception results in an L that is greater than 1.5h, only the portion of the reinforcement that is within the height of 1.5h shall be considered effective. The reinforcement required may be provided by any one or any combination of the following.

a) The shell reinforcing plate.

b) Any thickness of the shell plate in the flush-type cleanout fitting assembly that is greater than the required thickness of lowest shell course, as determined by 5.6.3, 5.6.4, or A.4.1 (with joint efficiency E = 1.0).

c) The portion of the neck plate having a length equal to the nominal thickness of the reinforcing plate.

Reinforcing area provided shall be adequate for Design Conditions as well as Hydrostatic test Conditions.

Vertical axis in SI units:

$$\left[\frac{(H + 8.8)D + 71.5}{1.408h}\right]\left[\frac{123t}{4.9D\,(H - 0.3)}\right]^{0.5}$$

Vertical axis in US Customary units:

$$\left[\frac{(H + 29)D + 770}{385h}\right]\left[\frac{17{,}850t}{2.6D\,(H - 1)}\right]^{0.5}$$

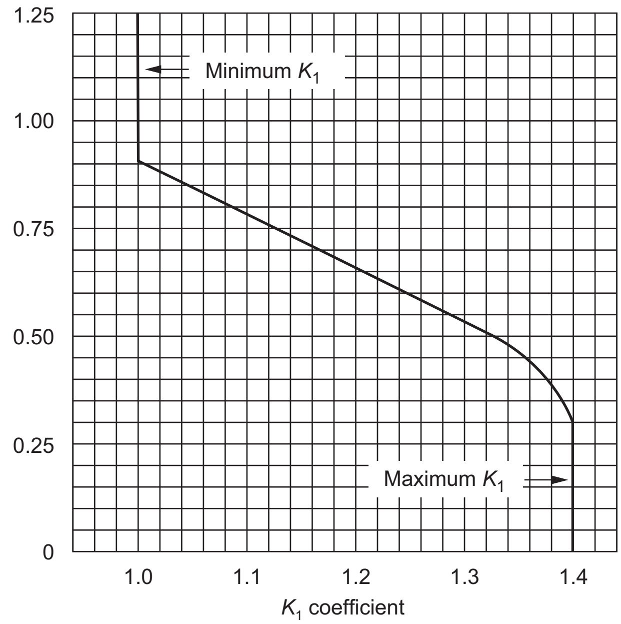


Figure 5.11—Area Coefficient for Determining Minimum Reinforcement of Flush-type Cleanout Fittings

5.7.7.6 The minimum width of the tank-bottom reinforcing plate at the centerline of the opening shall be 250 mm (10 in.) plus the combined nominal thickness of the shell plate in the cleanout-opening assembly and the shell reinforcing plate. When corrosion allowance is specified, it is to be added to the thickness of the bottom-reinforcing plate.

The nominal thickness of the bottom reinforcing plate shall be not less than that determined by the following equation:

In SI units:

$$t_{br} = \frac{0.0004027h^2}{S_d} + b\sqrt{\frac{0.5YHG}{S_d}} + \mathrm{CA}$$

where

t_{br} is the minimum thickness of the bottom reinforcing plate, (not less than 13), in mm (maximum 25 mm for 200 × 400, maximum 28 mm for 600 × 600, maximum 40 mm, for 900 ×1200, and maximum 45 mm for 1200 × 1200);

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

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

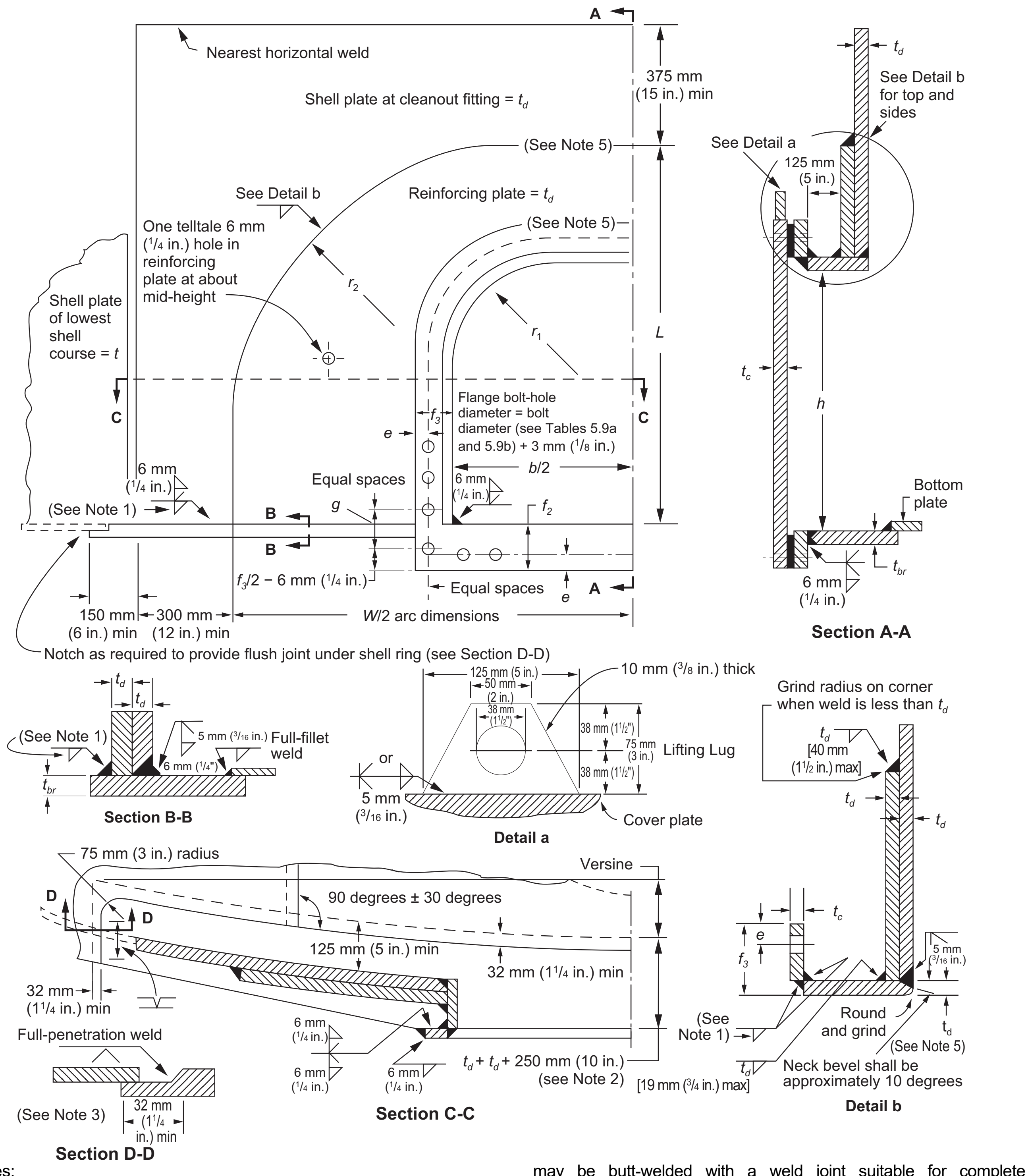
H is the maximum design liquid level (see 5.6.3.2), in m;

G is the design specific gravity; for the purposes of this equation, shall not be less than 1.0.

Y is the water density factor .00981 = (9.81/1000), in MPa/m;

S_d is the design stress of 145, in MPa; ≤ 0.7 S_y;

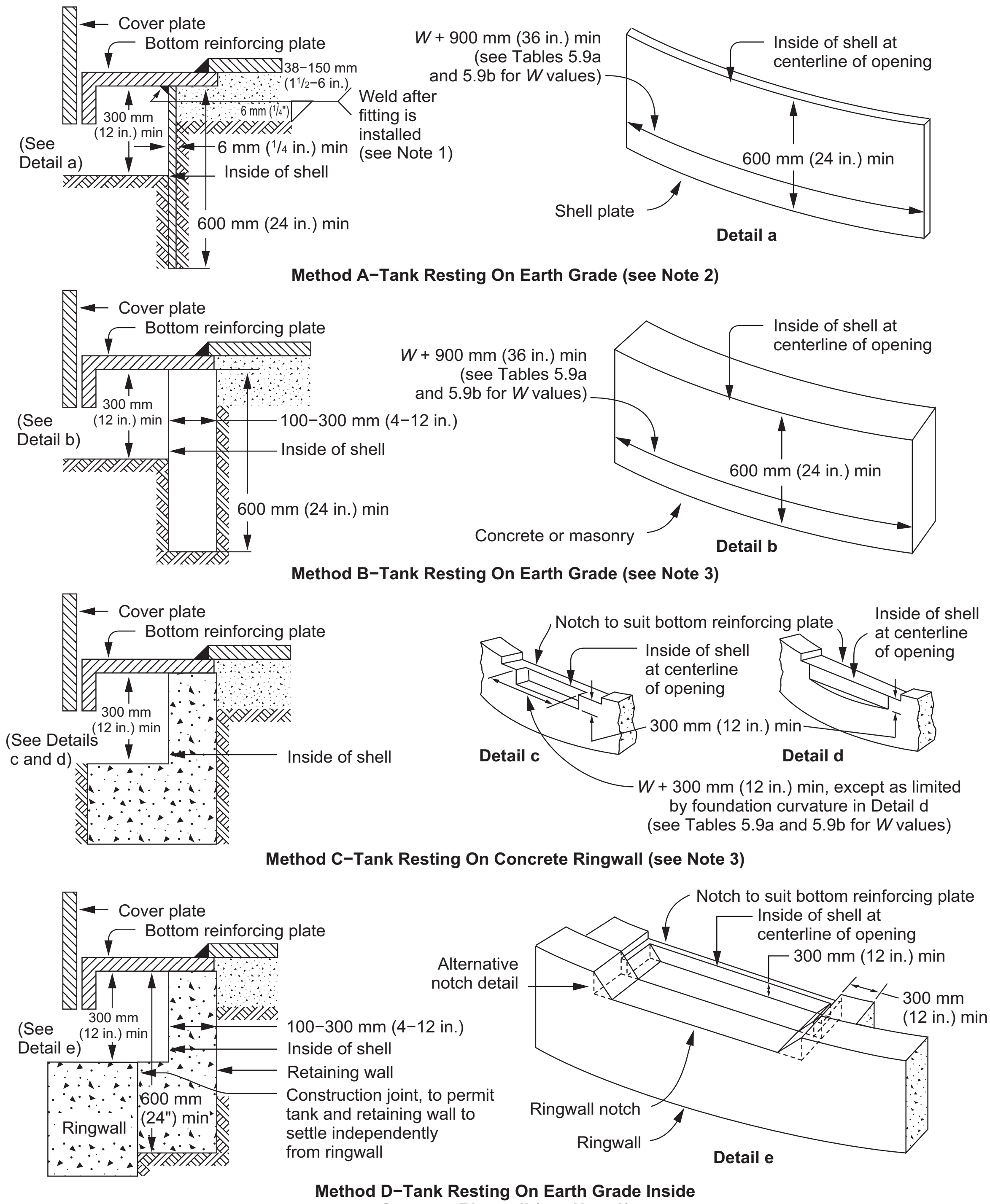
NOTE Materials with a design stress greater than 145 MPa may be used, but for thickness calculations, S_d shall not be greater than 145 MPa.



Notes:

1. Thickness of thinner plate joined (13 mm [1/2 in.] maximum).
2. When an annular plate is provided, the reinforcing plate shall be regarded as a segment of the annular plate and shall be the same width as the annular plate.
3. When the difference between the thickness of the annular ring and that of the bottom reinforcing plate is less than 6 mm (1/4 in.), the radial joint between the annular ring and the bottom reinforcing plate may be butt-welded with a weld joint suitable for complete penetration and fusion.
4. ● Gasket material shall be specified by the Purchaser. The gasket material shall meet service requirements based on product stored, design metal temperature, maximum design temperature and fire resistance.
5. The thickness (t_d) of the shell plate at the cleanout opening, the reinforcing plate, and the neck plate, shall be equal to or greater than the thickness (t) of the shell plate of the lowest shell course.

Figure 5.12—Flush-Type Cleanout Fittings (see Tables 5.9a, 5.9b, 5.10a, 5.10b, 5.11a, and 5.11b)



Notes:

1. This weld is not required if the earth is stabilized with portland cement at a ratio of not more than 1:12 or if the earth fill is replaced with concrete for a lateral distance and depth of at least 300 mm (12 in.).
2. When Method A is used, before the bottom plate is attached to the bottom reinforcing plate, (a) a sand cushion shall be placed flush with the top of the bottom reinforcing plate, and (b) the earth fill and sand cushion shall be thoroughly compacted.
3. When Method B, C, or D is used, before the bottom plate is attached to the bottom reinforcing plate, (a) a sand cushion shall be placed flush with the top of the bottom reinforcing plate, (b) the earth fill and sand cushion shall be thoroughly compacted, and (c) grout shall be placed under the reinforcing plate (if needed) to ensure a firm bearing.

Figure 5.13—Flush-type Cleanout Fitting Supports (see 5.7.7)

S_y is the yield strength at design temperature; ≤ 205 MPa;

CA is the corrosion allowance, in mm.

In USC units:

$$t_{br} = \frac{1.5h^2}{S_d} + b\sqrt{\frac{0.5YHG}{S_d}} + \mathrm{CA}$$

where

t_{br} is the minimum thickness of the bottom reinforcing plate (not less than 0.5), in inches (maximum 1 in. for 8 × 16, maximum 1 1/8 in. for 24 × 24, maximum 1 1/2 in. for 24 × 36, and maximum 1 3/4 in. for 48 × 48);

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 design specific gravity; for the purposes of this equation, shall not be less than 1.0.

Y is the water density factor 0.433 = (62.4/144), in psi/ft;

S_d is the design stress of 21,000, in lbf/in.^{2}; ≤ 0.7 S_y;

NOTE Materials with a design stress greater than 21,000 lbf/in.^{2} may be used, but for thickness calculations, S_d shall not be greater than 21,000 lbf/in.^{2}.

S_y is the yield strength at design temperature; ≤ 30,000 psi;

CA is the corrosion allowance, in mm.

5.7.7.7 The dimensions of the cover plate, bolting flange, and bolting shall conform to equations below. Some values have been calculated in Table 5.9a, Table 5.9b, Table 5.10a, and Table 5.10b. Minimum cover plate and flange thickness shall be 10 mm or 0.375 in. When corrosion allowance is specified, it is to be added to the cover plate and bolting flange thicknesses.

In SI units:

$$t_c = (h + 150)\sqrt{\frac{C\Upsilon HG}{S_d}} + CA$$

where

t_c is the minimum nominal thickness of cover plate and bolting flange (not less than 10), in mm;

h is the vertical opening height of the cleanout, in mm;

C is the coefficient $= \dfrac{1}{2 \times \left(1 + 0.623 \times \left(\dfrac{h}{b}\right)^6\right)}$, for $\dfrac{h}{b} > 0.5$ (b is opening width of clean out, in mm);

C is the coefficient $= \dfrac{1}{1.34 \times \left(1 + 1.61 \times \left(\frac{h}{b}\right)^3\right)}$, for $\dfrac{h}{b} \leq 0.5$ (b is opening width of clean out, in mm);

Υ is the water density factor 0.00981, in MPa/m;

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

G is the specific gravity of stored product, not less than 1.0;

S_d is the design stress of 145, in MPa;

NOTE Materials with a higher design stress of 145 MPa can be used, but for thickness calculations S_d shall not be greater than 145 MPa to limit deflection for a leak tight bolted joint.

CA is the corrosion allowance, in mm.

EXAMPLE For a 22 m tall tank with 200 mm tall cleanout.

$$t_c = (200 + 150) \times \sqrt{\frac{C \times \left(\frac{9.81}{1000}\right) \times 22 \times 1.0}{145}} + 0 = 10.64 \text{ mm}$$

where

$$C = \frac{1}{1.34 \times \left(1 + 1.61 \times \left(\frac{200}{400}\right)^3\right)} = 0.6212$$

In USC units:

$$t_c = (h + 6)\sqrt{\frac{C\Upsilon HG}{S_d}} + CA$$

where

t_c is the minimum nominal thickness of cover plate and bolting flange (not less than 0.375), in inches;

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

C is the coefficient $= \dfrac{1}{2 \times \left(1 + 0.623 \times \left(\frac{h}{b}\right)^6\right)}$, for $\dfrac{h}{b} > 0.5$ (b is opening width of clean out, in inches);

C is the coefficient $= \dfrac{1}{1.34 \times \left(1 + 1.61 \times \left(\frac{h}{b}\right)^3\right)}$, for $\dfrac{h}{b} \leq 0.5$ (b is opening width of clean out, in inches);

Υ is the water density factor 0.433, in psi/ft;

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

G is the specific gravity of stored product, not less than 1.0;

S_d is the design stress of 21,000, in lbf/in.^{2};

NOTE Materials with a higher design stress of 21,000 lbf/in.^{2} can be used, but for thickness calculations S_d shall not be greater than 21,000 lbf/in.^{2} to limit deflection for a leak tight bolted joint.

CA is the corrosion allowance, in inches;

EXAMPLE For a 72 ft tall tank with 8 in. tall cleanout:

$$t_c = (8+6) \times \sqrt{\frac{C \times \left(\frac{62.4}{144}\right) \times 72 \times 1.0}{21{,}000}} + 0 = 0.425 \text{ in.}$$

where

$$C = \frac{1}{1.34 \times \left(1 + 1.61 \times \left(\frac{8}{16}\right)^3\right)} = 0.6212$$

5.7.7.8 All materials in the flush-type cleanout fitting assembly shall conform to the requirements in Section 4. The shell plate containing the cleanout assembly, the shell reinforcing plate, the neck plate, and the bottom reinforcing plate shall meet the impact test requirements of 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 cover plate shall be based on the governing thickness as defined in 4.5.4.3 using Table 4.3a, Table 4.3b, and Figure 4.1. Additionally, the yield strength and the tensile strength of the shell plate at the flush-type cleanout fitting, the shell reinforcing plate, and the neck plate shall be equal to, or greater than, the yield strength and the tensile strength of the adjacent lowest shell course plate material.

5.7.7.9 The dimensions and details of the cleanout-opening assemblies covered by this section are based on internal hydrostatic loading with no external-piping loading.

5.7.7.10 When a flush-type cleanout fitting is installed on a tank that is resting on an earth grade without concrete or masonry walls under the tank shell, provision shall be made to support the fitting and retain the grade by either of the following methods:

a) Install a vertical steel bulkhead plate under the tank, along the contour of the tank shell, symmetrical with the opening, as shown in Figure 5.13, Method A.

b) Install a concrete or masonry retaining wall under the tank with the wall's outer face conforming to the contour of the tank shell as shown in Figure 5.13, Method B.

5.7.7.11 When a flush-type cleanout fitting is installed on a tank that is resting on a ringwall, a notch with the dimensions shown in Figure 5.13, Method C, shall be provided to accommodate the cleanout fitting.

5.7.7.12 When a flush-type cleanout fitting is installed on a tank that is resting on an earth grade inside a foundation retaining wall, a notch shall be provided in the retaining wall to accommodate the fitting, and a supplementary inside retaining wall shall be provided to support the fitting and retain the grade. The dimensions shall be as shown in Figure 5.13, Method D.

5.7.8 Flush-type Shell Connections

• **5.7.8.1** Tanks may have flush-type connections at the lower edge of the shell. Each connection may be made flush with the flat bottom under the following conditions (see Figure 5.14).

a) The shell uplift from the internal design and test pressures (see Annex F) and wind and earthquake loads (see Annex E) shall be counteracted so that no uplift will occur at the cylindrical-shell/flat-bottom junction.

b) The vertical or meridional membrane stress in the cylindrical shell at the top of the opening for the flush-type connection shall not exceed one-tenth of the circumferential design stress in the lowest shell course containing the opening.

c) The maximum width, b, of the flush-type connection opening in the cylindrical shell shall not exceed 900 mm (36 in.).

d) The maximum height, h, of the opening in the cylindrical shell shall not exceed 300 mm (12 in.).

e) The nominal thickness t_a of the bottom transition plate in the assembly shall be the greatest of:

1) 13 mm ($^1/_2$ in.), exclusive of corrosion allowance;

2) the nominal annular ring thickness; or

3) the nominal thickness of the bottom plate attached to the tank shell.

5.7.8.2 The details of the connection shall conform to those shown in Figure 5.14, and the dimensions of the connection shall conform to Table 5.12a and Table 5.12b and to the requirements of 5.7.8.3 through 5.7.8.11.

Table 5.12a—Dimensions for Flush-type Shell Connections (SI)

Dimensions in millimeters

Class 150 Nominal Height of Flange Size	Height of Opening h	Width of Opening b	Arc Width of Shell Reinforcing Plate W	Upper Corner Radius of Opening r_1	Lower Corner Radius of Shell Reinforcing Plate r_2
8	200	200	950	OD of 8 NPS[a]	350
12	300	300	1300	OD of 12 NPS[a]	450
16	300	500	1600	150	450
18	300	550	1650	150	450
20	300	625	1725	150	450
24	300	900	2225	150	450

[a] For circular openings, this value will be $^1/_2$ of the ID based on the nozzle neck specified.

NOTE See Figure 5.14.

5.7.8.3 The reinforced connection shall be completely preassembled into a shell or insert plate. The completed assembly, including the shell or insert plate containing the connection, shall be thermally stress-relieved at a temperature of 600 °C to 650 °C (1100 °F to 1200 °F) for 1 hour per 25 mm (1 in.) of shell-plate thickness, t_d (see 5.7.4.1 and 5.7.4.2).

5.7.8.4 The reinforcement for a flush-type shell connection shall meet the following requirements:

a) The cross-sectional area of the reinforcement over the top of the connection shall not be less than $K_1ht/2$ (see 5.7.7.4).

Table 5.12b—Dimensions for Flush-type Shell Connections (USC)

Dimensions in inches

Class 150 Nominal Height of Flange Size	Height of Opening h	Width of Opening b	Arc Width of Shell Reinforcing Plate W	Upper Corner Radius of Opening r_1	Lower Corner Radius of Shell Reinforcing Plate r_2
8	8 5/8	8 5/8	38	4[a]	14
12	12 3/4	12 3/4	52	4[a]	18
16	12	20	64	6	18
18	12	22	66	6	18
20	12	25	69	6	18
24	12	36	89	6	18

[a] For circular openings, this value will be 1/2 of the ID based on the nozzle neck specified.

NOTE See Figure 5.14.

b) The nominal thickness of the shell or insert plate, t_d, for the flush-connection assembly shall be at least as thick as the adjacent shell or insert plate nominal thickness, t, in the lowest shell course.

c) The nominal thickness of the shell reinforcing plate shall be, as a minimum, the nominal thickness of the shell or insert plate in the flush-connection assembly.

d) The reinforcement in the plane of the shell shall be provided within a height L above the bottom of the opening. L shall not exceed 1.5h except that, in the case of small openings, $L - h$ shall not be less than 150 mm (6 in.). Where this exception results in an L that is greater than 1.5h, only the portion of the reinforcement that is within the height of 1.5h shall be considered effective.

e) The required reinforcement may be provided by any one or any combination of the following:

1) the shell reinforcing plate;

2) any thickness of the shell or insert plate in the flush-type shell connection assembly that is greater than the required thickness of lowest shell course, as determined by 5.6.3, 5.6.4, or A.4.1 (with joint efficiency E = 1.0); and

3) the portion of the neck plate having a length equal to the thickness of the reinforcing plate.

Reinforcing area provided shall be adequate for Design Conditions as well as Hydrostatic Test Conditions.

f) The width of the tank-bottom reinforcing plate at the centerline of the opening shall be 250 mm (10 in.) plus the combined nominal thickness of the shell or insert plate in the flush-connection assembly and the shell reinforcing plate. The thickness of the bottom reinforcing plate shall be calculated using the equations in 5.7.7.6.

The minimum value of t_{br} 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.).

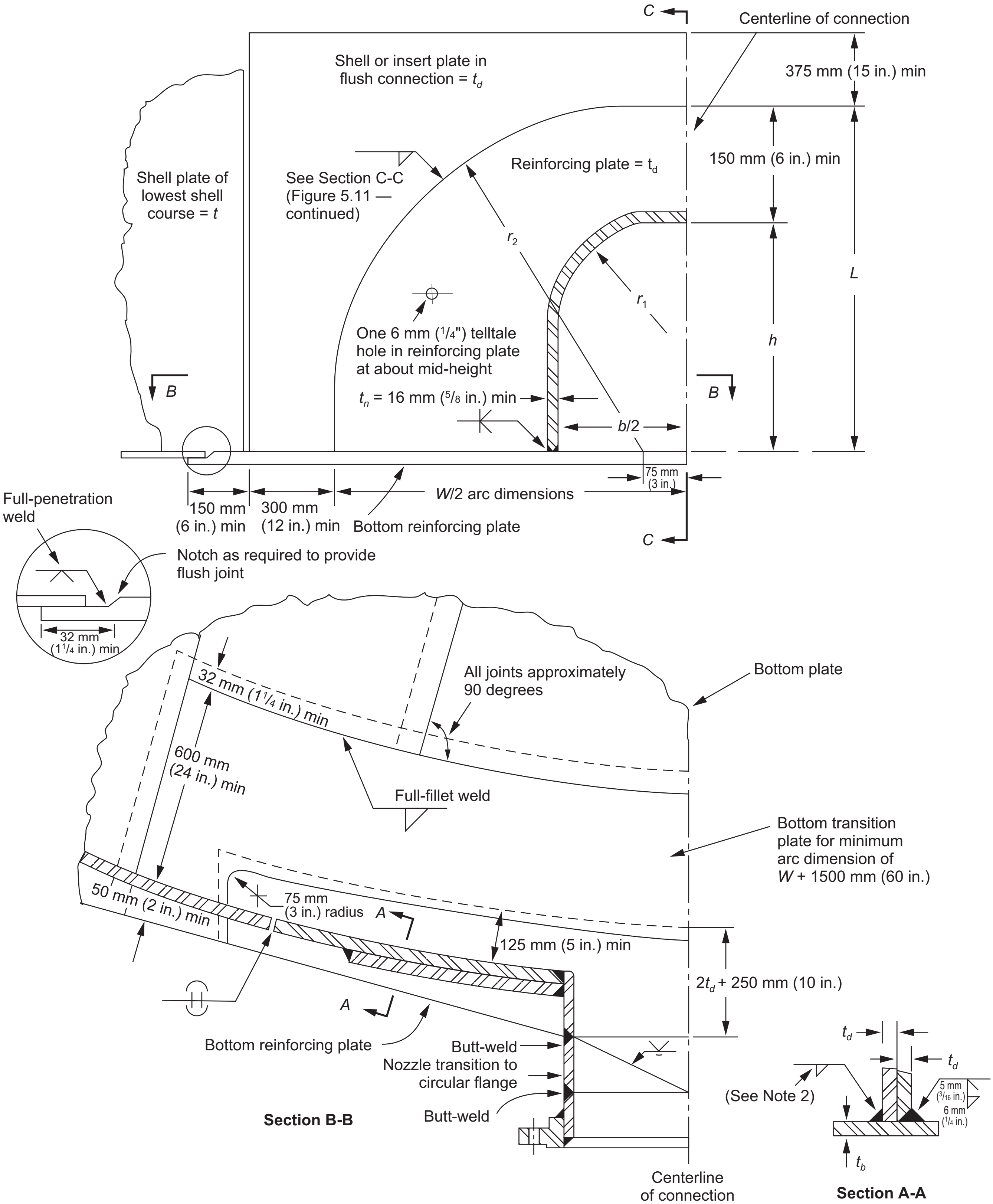
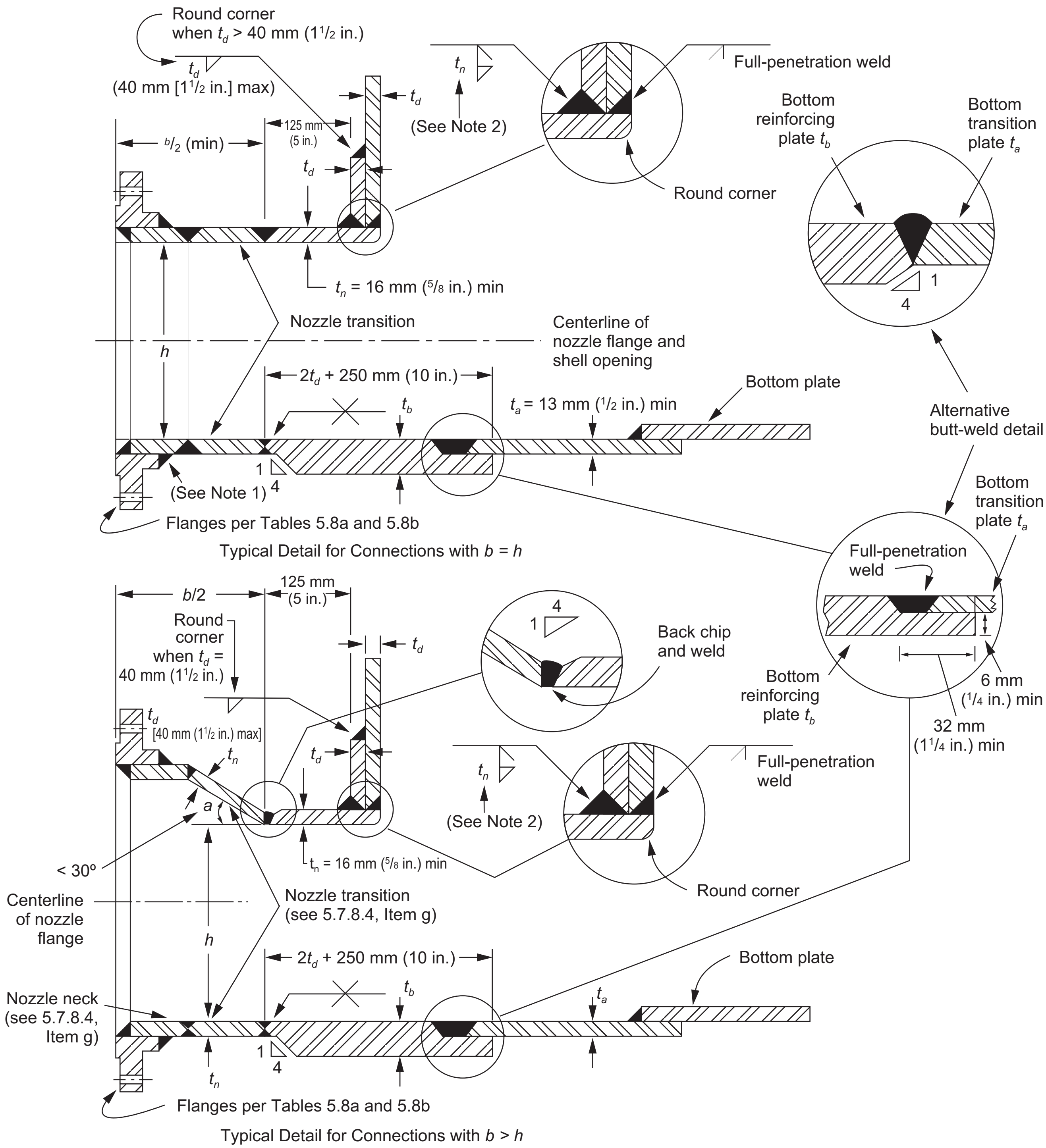


Figure 5.14—Flush-type Shell Connection



Section C-C

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 (1/2 in.) maximum.

Figure 5.14—Flush-type Shell Connection (Continued)

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 or insert 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 4.5.4.3 and used in Figure 4.1. Additionally, the yield strength and the tensile strength of the shell or insert 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.

5.7.8.10 Flush-type connections may be installed using a common reinforcing pad; however, when this construction is employed, the minimum distance between nozzle centerlines shall not be less than 1.5 [b_1 + b_2 + 65 mm (2$^1/_2$ in.)], where b_1 and b_2 are the widths of adjacent openings, or 600 mm (24 in.), whichever is greater. The width of each opening, b, shall be obtained from Table 5.12a and Table 5.12b for the respective nominal flange size. Adjacent shell flush-type connections that do not share a common reinforcing plate shall have at least a 900 mm (36 in.) clearance between the ends of their reinforcing plates.

5.7.8.11 All longitudinal butt-welds in the nozzle neck and transition piece, if any, and the first circumferential butt-weld in the neck closest to the shell, excluding neck-to-flange weld, shall receive 100 % radiographic examination (see 8.1). The nozzle-to-tank-shell and reinforcing plate welds and the shell-to-bottom reinforcing plate welds shall be examined for their complete length by magnetic particle examination (see 8.2). The magnetic particle examination shall be performed on the root pass, on every 13 mm ($^1/_2$ in.) of deposited weld metal while the welds are made, and on the completed welds. The completed welds shall also be visually examined. The examination of the completed welds shall be performed after stress-relieving but before hydrostatic testing (see 8.2 and 8.5 for the appropriate inspection and repair criteria).

5.8 Shell Attachments and Tank Appurtenances

5.8.1 Shell Attachments

5.8.1.1 Shell attachments shall be made, inspected, and removed in conformance with Section 7.

a) Permanent attachments are items welded to the shell that will remain while the tank is in its intended service. These include items such as wind girders, stairs, gauging systems, davits, walkways, tank anchors, supports for internal items such as heating coils and other piping supports, ladders, floating roof supports welded to the shell, exterior piping supports, grounding clips, insulation rings, and electrical conduit and fixtures. Items installed above the maximum liquid level of the tank are not permanent attachments.

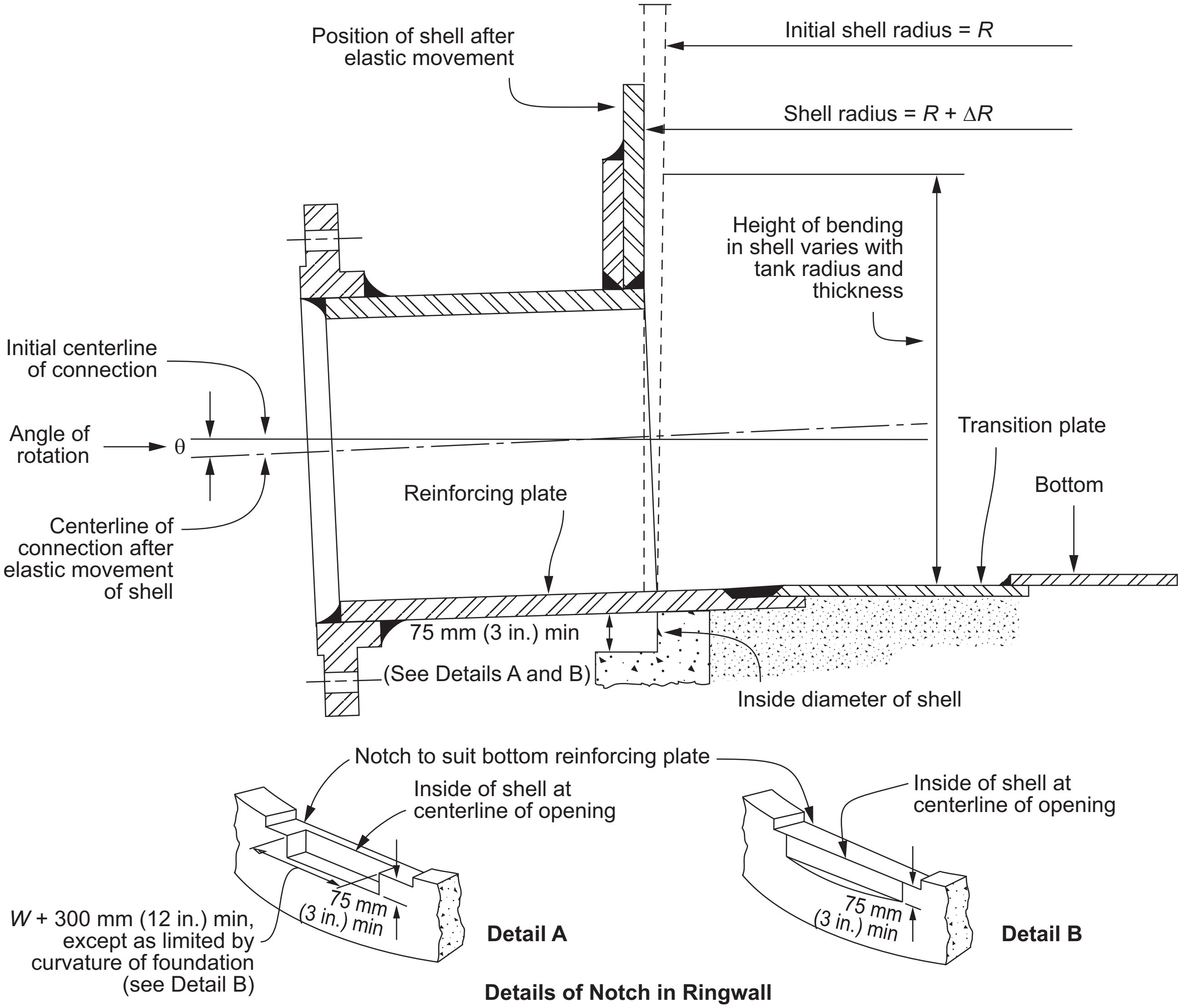


Figure 5.15—Rotation of Shell Connection

b) Temporary attachments are items welded to the shell that will be removed prior to the tank being commissioned into its intended service. These include items such as alignment clips, fitting equipment, stabilizers, and lifting lugs.

5.8.1.2 When attachments are made to shell courses of material in Group IV, IVA, V, or VI, the movement of the shell (particularly the movement of the bottom course) under hydrostatic loading shall be considered, and the attachments shall meet the following requirements:

a) Permanent attachments may be welded directly to the shell with fillet welds having a maximum leg dimension of 13 mm (1/2 in.). The edge of any permanent attachment welds shall be at least 75 mm (3 in.) from the horizontal joints of the shell and at least 150 mm (6 in.) from the vertical joints, insert-plate joints, thickened insert plate joints, or reinforcing-plate fillet welds. Permanent attachment welds may cross shell horizontal or vertical butt welds providing the welds are continuous within these limits and the angle of incidence between the two welds is greater than or equal to 45 degrees. Additionally, any splice weld in the permanent attachment shall be located a minimum of 150 mm (6 in.) from any shell weld unless the splice weld is kept from intersecting the shell weld by acceptable modifications to the attachment.

b) The welding and inspection of permanent attachments to these shell courses shall conform to 7.2.3.6.

c) Temporary attachments to shell courses should be made prior to welding of the shell joints. Weld spacing for temporary attachments made after welding of the shell joints shall be the same as that required for permanent attachments. Temporary attachments to shell courses shall be removed, and any resulting damage shall be repaired and ground to a smooth profile.

• **5.8.2 Bottom Connections**

Connections to the tank bottom are permitted subject to agreement between the Purchaser and the Manufacturer with respect to details that provide strength, tightness, and utility equal to the details of shell connections specified in this standard.

5.8.3 Cover Plates

5.8.3.1 Unreinforced openings less than or equal to NPS 2 pipe size are permissible in flat cover plates without increasing the cover plate thickness if the edges of the openings are not closer to the center of the cover plate than one-fourth the height or diameter of the opening. Requirements for openings NPS 2 pipe size and smaller that do not satisfy the location requirement and for larger reinforced openings are given in 5.8.3.2 through 5.8.3.4.

5.8.3.2 Reinforced openings in the cover plates of shell manholes and flush-type clean outs shall be limited to one-half the diameter of the manhole or one-half the least dimension of the flush-type clean out opening but shall not exceed NPS 12 pipe size. The reinforcement added to an opening may be a reinforcing plate or an increased thickness of the cover plate, but in either case, the reinforcement shall provide an added reinforcing area no less than the cutout area of the opening in the cover plate.

For cover plates with nozzle attachments for product mixing, see 5.7.5.7.

5.8.3.3 When cover plates (or blind flanges) are required for shell nozzles, the minimum thickness shall be that given for flanges in Table 5.8a and Table 5.8b. Reinforced openings in the cover plates (or blind flanges) of shell nozzles shall be limited to one-half the diameter of the nozzle. The reinforcement added to an opening may be an added pad plate or an increased thickness of the cover plate, but in either case, the reinforcement shall provide an added reinforcing area no less than 50 % of the cutout area of the opening in the cover plate. Mixer nozzles may be attached to cover plates.

5.8.3.4 Openings in the cover plates of flush-type cleanout fittings shall be located on the vertical centerline of the cover plate and shall be in accordance with 5.8.3.1 and 5.8.3.2. Adequate provisions should be made for free movement of connected piping to minimize thrusts and moments on the cover plate to 2225 N (500 lbs) and 60 N-m (500 ft-lbs). Analysis or load leak test may be used to accept greater loads or moments.

5.8.3.5 Shell manhole covers shall have two handles. Those covers weighing more than 34 kg (75 lb) shall be equipped with either a hinge or davit to facilitate the handling of the manhole cover plate. The davit support arm shall not be welded directly to the shell without a reinforcing plate.

5.8.4 Roof Manholes

Roof manholes shall conform to Figure 5.16 and Table 5.13a and Table 5.13b. The effects of loads (other than normal personnel access) applied at the roof manhole and supporting roof structure shall be considered. Examples of such loads may include fall protection anchorage, hoisting, or personnel retrieval. The roof structure and plate around the manhole shall be reinforced as necessary.

5.8.5 Roof Venting

5.8.5.1 Tanks designed in accordance with this standard and having a fixed roof shall be vented for both normal conditions (resulting from operational requirements, including maximum filling and emptying rates, and atmospheric

Table 5.13a—Dimensions for Roof Manholes (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Size of Manhole	Diameter of Neck ID[a]	Diameter of Cover Plate D_C	Diameter of Bolt Circle D_B	Number of Bolts	Diameter of Gasket		Diameter of Hole in Roof Plate or Reinforcing Plate D_P	Outside Diameter of Reinforcing Plate D_R
					Inside	Outside		
500	500	660	597	16	500	660	524	1050
600	600	762	699	20	600	762	625	1150

[a] Pipe may be used for neck, providing the minimum nominal wall thickness is 6 mm (ID and D_p shall be adjusted accordingly.)

NOTE See Figure 5.16.

Table 5.13b—Dimensions for Roof Manholes (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Size of Manhole	Diameter of Neck ID[a]	Diameter of Cover Plate D_C	Diameter of Bolt Circle D_B	Number of Bolts	Diameter of Gasket		Diameter of Hole in Roof Plate or Reinforcing Plate D_P	Outside Diameter of Reinforcing Plate D_R
					Inside	Outside		
20	20	26	$23^1/_2$	16	20	26	$20^5/_8$	42
24	24	30	$27^1/_2$	20	24	30	$24^5/_8$	46

[a] Pipe may be used for neck, providing the minimum nominal wall thickness is $^1/_4$ in. (ID and D_p shall be adjusted accordingly.)

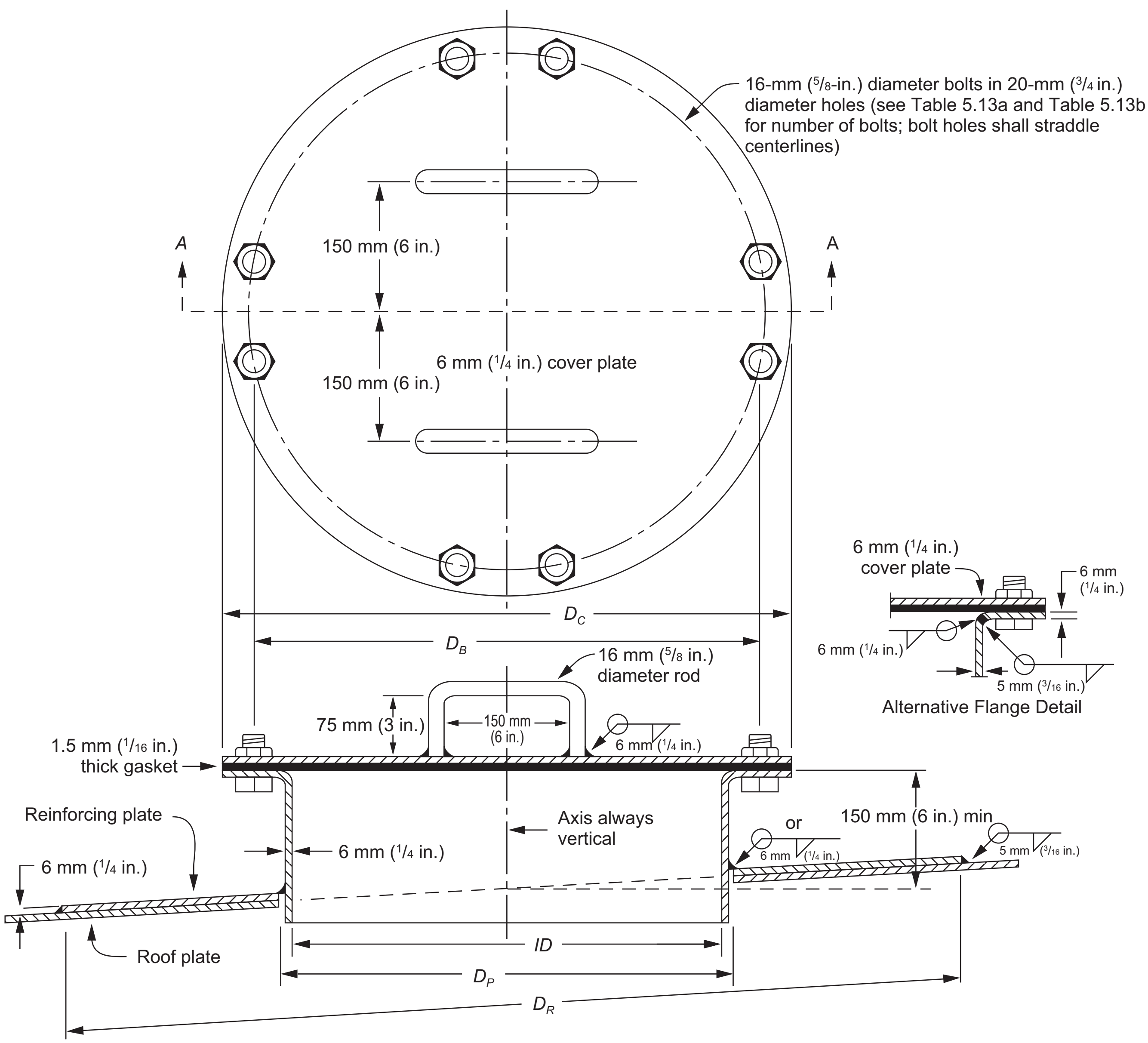
NOTE See Figure 5.16.

temperature changes) and emergency conditions (resulting from exposure to an external fire). Tanks with both a fixed roof and a floating roof satisfy these requirements when they comply with the circulation venting requirements of Annex H. All other tanks designed in accordance with this standard and having a fixed roof shall meet the venting requirements of 5.8.5.2 and 5.8.5.3.

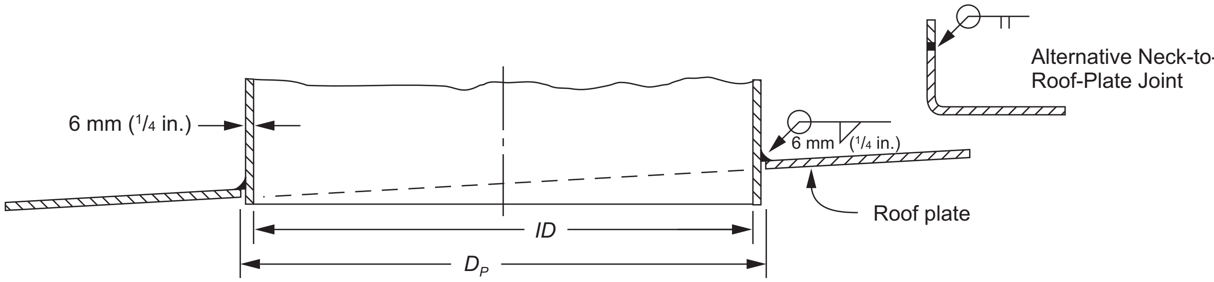
5.8.5.2 Normal venting shall be adequate to prevent internal or external pressure from exceeding the corresponding tank design pressures and shall meet the requirements specified in API 2000 for normal venting.

• **5.8.5.3** Emergency venting requirements are satisfied if the tank is equipped with a weak roof-to-shell attachment (frangible joint) in accordance with 5.10.2.6, or if the tank is equipped with pressure relief devices meeting the requirements specified in API 2000 for emergency venting. When pressure relief devices are used to satisfy the emergency venting requirements, they shall achieve the flow rates specified in API 2000 without exceeding the following limits on internal pressure.

a) For self-anchored tanks, the pressure relief devices shall be adequate to prevent internal pressure from exceeding the tank design pressure as determined in F.4.1 (subject to the limitations in F.4.2 and F.4.3, as applicable). In calculating limitations per F.4.2, use M_W or M_{WS} = 0.



Section A-A—Roof Manhole With Reinforcing Plate



Base For Roof Manhole Without Reinforcing Plate

Figure 5.16—Roof Manholes (see Table 5.13a and Table 5.13b)

b) For mechanically-anchored tanks, except those designed to F.1.3, the pressure relief devices shall be adequate to prevent internal pressure from exceeding the tank design pressure as determined in F.4.1 (subject to the limitations in F.4.3, as applicable).

c) For tanks designed to F.1.3 (mechanically-anchored tanks), the pressure relief devices shall be adequate to prevent internal pressure from exceeding the design pressure specified by the Purchaser.

• **5.8.5.4** The filling and emptying rates are specified on the Data Sheet, Line 7. See the Data Sheet, Table 3 for venting devices, which shall be specified by the Purchaser and verified by the Manufacturer.

• **5.8.5.5** All free vents shall be provided with corrosion-resistant coarse-mesh bird screens of a maximum opening size of (19 mm [$^3/_4$ in.] nominal opening). It is recommended that in areas where snow drifting or icing may be an issue, special attention to vent details (such as profile, diameter, capacity, arrangement, or increased screen size) should be made. In these situations, the Purchaser shall specify modified venting requirements based on anticipated needs for a specific environment. The smallest dimension of the opening in any mesh used for bird screen is the governing size for the opening.

5.8.5.6 Flanged roof nozzles shall conform to Figure 5.19 and Table 5.14a and Table 5.14b. Slip-on flanges and weld neck flanges shall conform to the requirements of ASME B16.5 for Class 150 plate-ring flanges shall conform to all of the dimensional requirements for slip-on welding flanges with the exception that it is acceptable to omit the extended hub on the back of the slip-on or weld neck flanges. Raised face flanges shall be provided for nozzles with attached piping. Flat face flanges shall be provided for roof nozzles used for the mounting of tank accessories.

5.8.5.7 Threaded roof nozzles shall conform to Figure 5.20 and Table 5.15a and Table 5.15b.

5.8.6 Rectangular Roof Openings

5.8.6.1 Rectangular roof openings shall conform to Figure 5.17 and Figure 5.18 and/or this section. The effects of loads (other than normal personnel access) applied at the roof opening and supporting roof structure shall be considered. Examples of such loads may include fall protection anchorage, hoisting, or personnel retrieval. The roof structure and plate around the opening shall be reinforced as necessary.

5.8.6.2 The cover plate thickness and/or structural support shall be designed to limit maximum fiber stresses in accordance with this standard, however, cover plate thickness shall not be less than 5 mm ($^3/_{16}$ in.). In addition to other expected design loads, consider a 112 kg (250 lb) person standing in the center of the installed/closed cover. The designer shall consider wind in the design of hinged openings and how removed covers will be handled without damage (adequate rigidity).

5.8.6.3 Rectangular openings, other than shown in Figure 5.17 and Figure 5.18, and openings larger than indicated shall be designed by an engineer experienced in tank design in accordance with this standard. Hinged covers prescribed in Figure 5.18 may not be used on roofs designed to contain internal pressure. Flanged covers prescribed in Figure 5.17 may not be used on tanks with internal pressures (acting across the cross sectional area of the tank roof) that exceed the weight of the roof plates. This section applies only to fixed steel roofs.

• 5.8.7 Water Drawoff Sumps

Water drawoff sumps shall be as specified in Figure 5.21 and Table 5.16a and Table 5.16b unless otherwise specified by the Purchaser.

5.8.8 Scaffold-Cable Support

The scaffold-cable support shall conform to Figure 5.22. Where seams or other attachments are located at the center of the tank roof, the scaffold support shall be located as close as possible to the center.

Table 5.14a—Dimensions for Flanged Roof Nozzles (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5
Nozzle NPS	**Outside Diameter of Pipe Neck**	**Diameter of Hole in Roof Plate or Reinforcing Plate** D_P	**Minimum Height of Nozzle** H_R	**Outside Diameter of Reinforcing Plate**[a] D_R
1 1/2	48.3	50	150	125
2	60.3	65	150	175
3	88.9	92	150	225
4	114.3	120	150	275
6	168.3	170	150	375
8	219.1	225	150	450
10	273.0	280	200	550
12	323.8	330	200	600

[a] Reinforcing plates are not required on nozzles NPS 6 or smaller but may be used if desired.

NOTE See Figure 5.19.

Table 5.14b—Dimensions for Flanged Roof Nozzles (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5
Nozzle NPS	**Outside Diameter of Pipe Neck**	**Diameter of Hole in Roof Plate or Reinforcing Plate** D_P	**Minimum Height of Nozzle** H_R	**Outside Diameter of Reinforcing Plate**[a] D_R
1 1/2	1.900	2	6	5
2	2 3/8	2 1/2	6	7
3	3 1/2	3 5/8	6	9
4	4 1/2	4 5/8	6	11
6	6 5/8	6 3/4	6	15
8	8 5/8	8 7/8	6	18
10	10 3/4	11	8	22
12	12 3/4	13	8	24

[a] Reinforcing plates are not required on nozzles NPS 6 or smaller but may be used if desired.

NOTE See Figure 5.19.

Table 5.15a—Dimensions for Threaded Roof Nozzles (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4
Nozzle NPS	**Coupling NPS**	**Diameter of Hole in Roof Plate or Reinforcing Plate D_P**	**Outside Diameter of Reinforcing Plate[a] D_R**
3/4	3/4	36	100
1	1	44	110
1 1/2	1 1/2	60	125
2	2	76	175
3	3	105	225
4	4	135	275
6	6	192	375
8	8	250	450
10	10	305	550
12	12	360	600

[a] Reinforcing plates are not required on nozzles NPS 6 or smaller but may be used if desired.

NOTE See Figure 5.20.

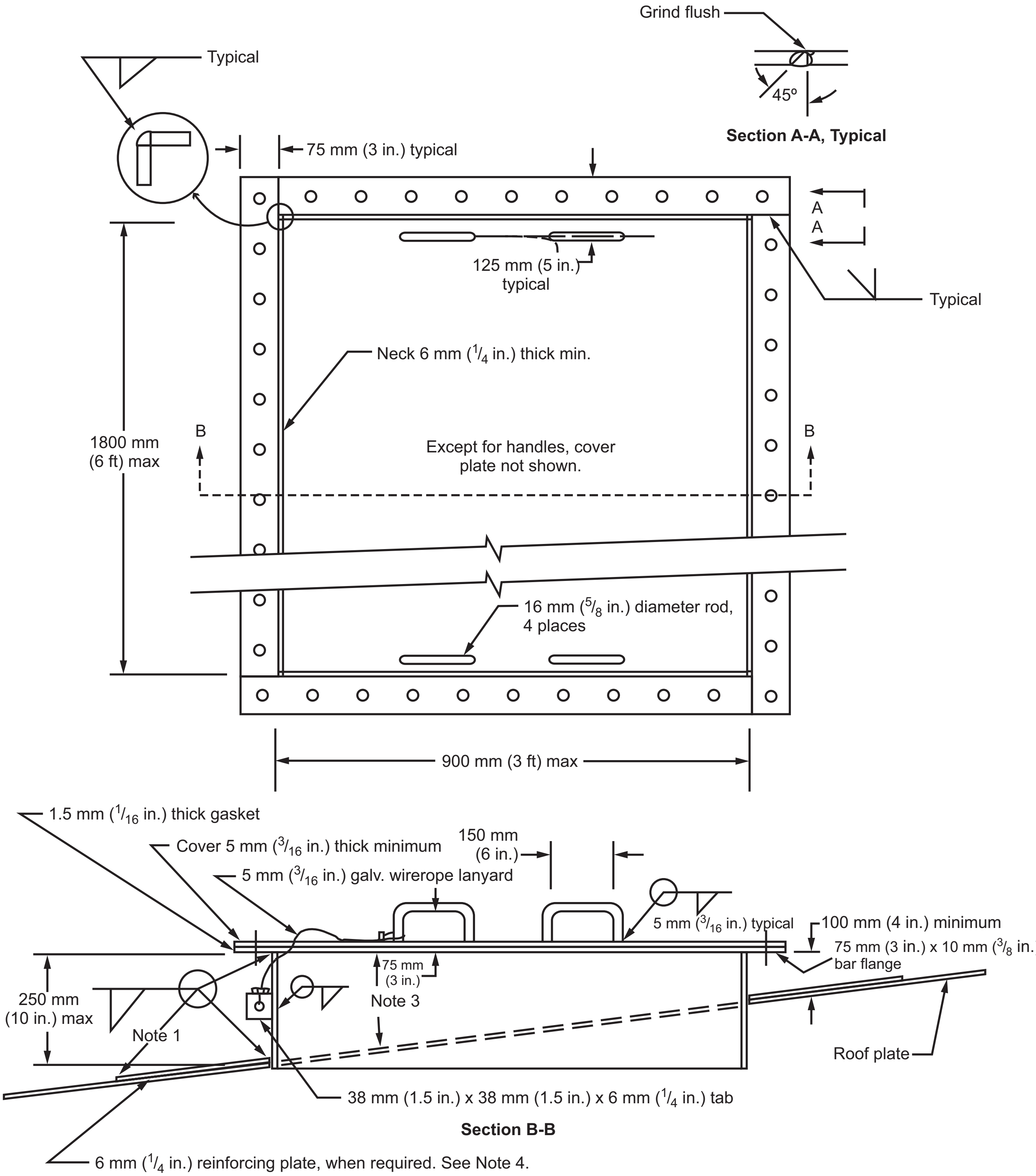
Table 5.15b—Dimensions for Threaded Roof Nozzles (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4
Nozzle NPS	**Coupling NPS**	**Diameter of Hole in Roof Plate or Reinforcing Plate D_P**	**Outside Diameter of Reinforcing Plate[a] D_R**
3/4	3/4	1 7/16	4
1	1	1 23/32	4 1/2
1 1/2	1 1/2	2 11/32	5
2	2	3	7
3	3	4 1/8	9
4	4	5 11/32	11
6	6	7 17/32	15
8	8	9 7/8	18
10	10	12	22
12	12	14 1/4	24

[a] Reinforcing plates are not required on nozzles NPS 6 or smaller but may be used if desired.

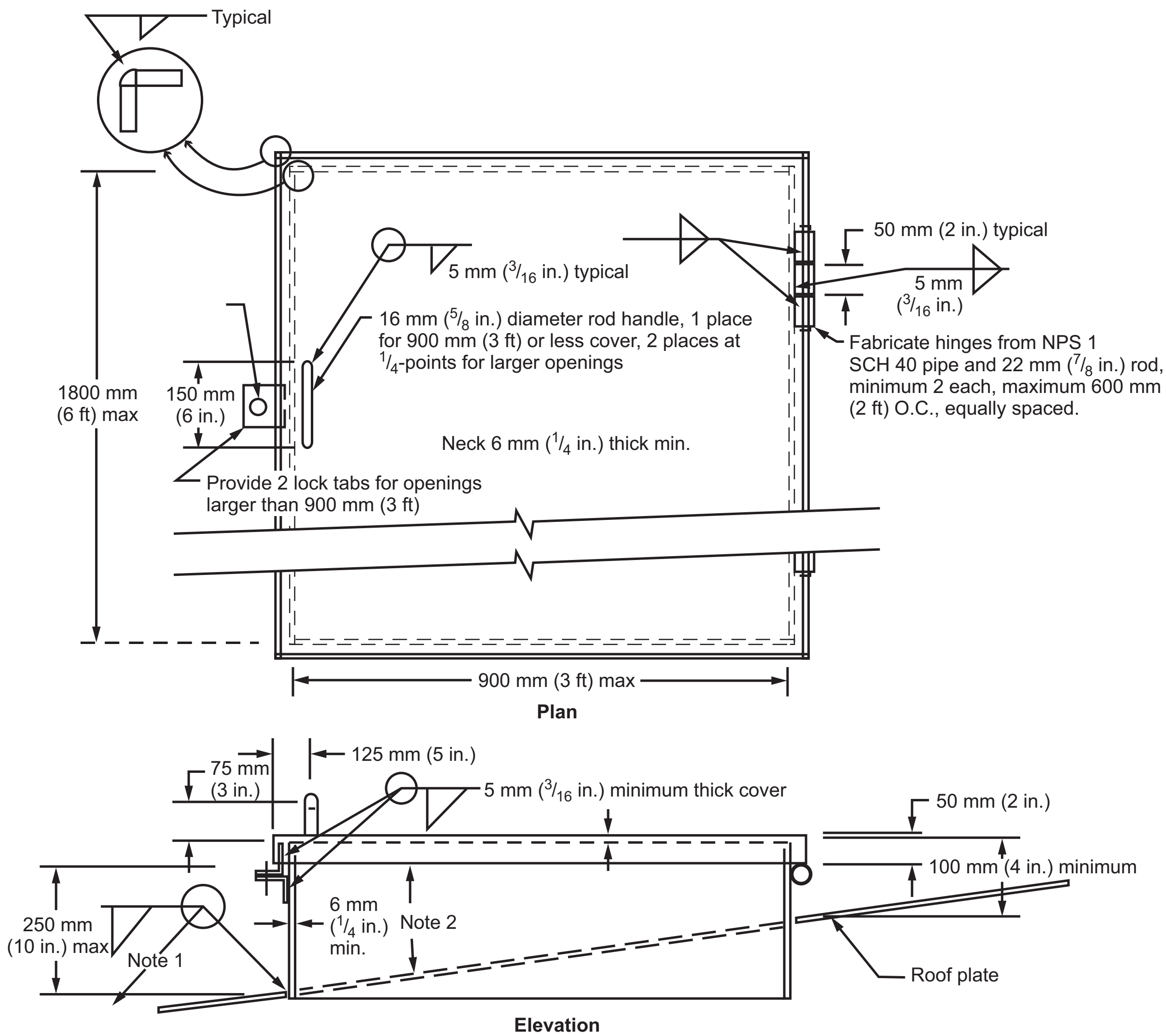
NOTE See Figure 5.20.



Notes:
1. Weld size shall be the smaller of the plate thicknesses being joined.
● 2. Cover may be either parallel to roof or horizontal. Opening may be oriented as desired.
3. Bolts shall be 16-mm ($^{5}/_{8}$-in.) diameter in 20-mm ($^{3}/_{4}$-in.) holes, which shall be equally spaced and shall not exceed 125-mm (5 in.) on center.
4. When required, provide 6-mm ($^{1}/_{4}$-in.) reinforcing plate. Width at least $^{1}/_{2}$ smallest opening dimension. Round outside corners with 75 mm (3 in.) radius, minimum. Seams shall be square groove butt-welded.

15

Figure 5.17—Rectangular Roof Openings with Flanged Covers



Notes:
1. Weld size shall be the smaller of the plate thicknesses being joined.
2. Cover may be either parallel to roof or horizontal. Opening may be oriented as desired.
3. Reinforcement, when required, shall be as shown in Figure 5.19.
4. Not for use on roofs designed to contain internal pressure.

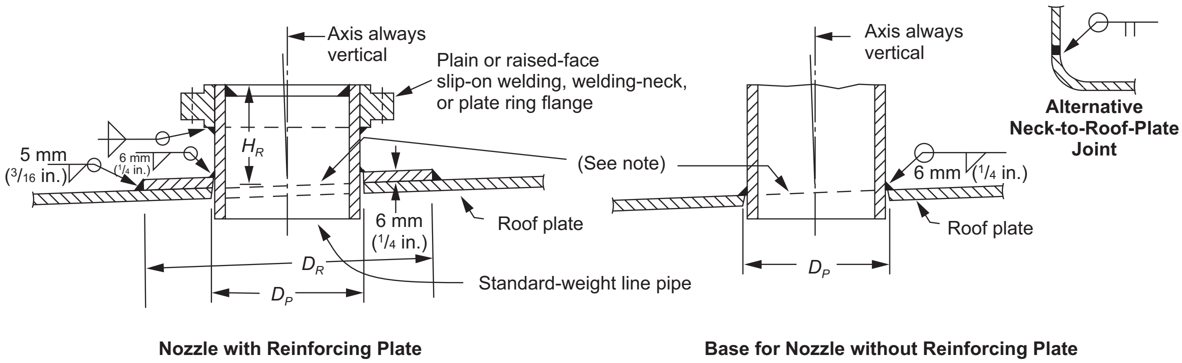
Figure 5.18—Rectangular Roof Openings with Hinged Cover

5.8.9 Threaded Connections

Threaded piping connections shall be female and tapered. The threads shall conform to the requirements of ASME B1.20.1 for tapered pipe threads.

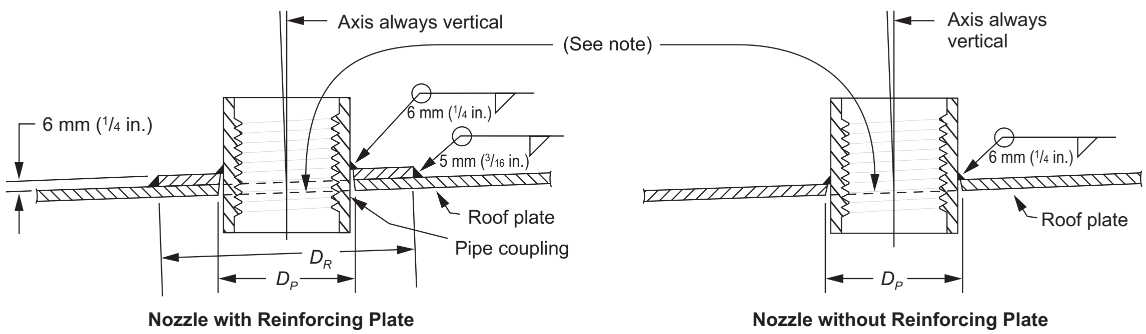
5.8.10 Platforms, Walkways, and Stairways

a) Platforms, walkways, and stairways shall be in accordance with Table 5.17 and Table 5.18 unless more demanding rules are provided by the applicable national safety standards for the location, such as OSHA 29 CFR 1910, Subpart D, or equivalent. Where no local safety standards are mandated, the requirements of OSHA are recommended..



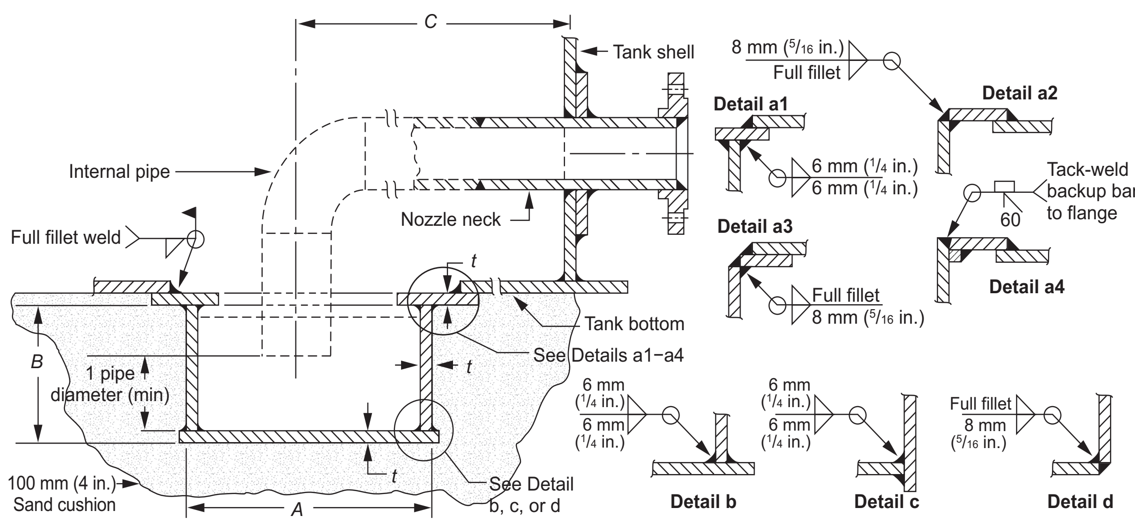
NOTE When the roof nozzle is used for venting, the neck shall be trimmed flush with the roofline.

Figure 5.19—Flanged Roof Nozzles (see Table 5.14a and Table 5.14b)



NOTE See 5.8.9 for requirements for threaded connections. When the roof nozzle is used for venting, the neck shall be trimmed flush with the roofline.

Figure 5.20—Threaded Roof Nozzles (see Table 5.15a and Table 5.15b)



NOTE The erection procedure shall be performed by one of the following methods or by an alternate design approved by a Storage Tank Engineer:

a) For sumps being placed in the foundation before bottom placement, the sump shall be placed in position with at least 100 mm (4 in.) of thoroughly compacted sand, or other suitable fill material, around the sump. The sump then shall be welded to the bottom.

b) For sumps being placed in the foundation after bottom placement, sufficient bottom plate shall be removed to allow for the sump to be placed in position with at least 100 mm (4 in.) of thoroughly compacted sand, or other suitable fill material, around the sump. The sump shall then be welded to the bottom.

Figure 5.21—Drawoff Sump (see Table 5.16a and Table 5.16b)

Note: NPS 4 Schedule 40 pipe (wall thickness = 6.02 mm [0.237 in.]; outside diameter = 114.3 mm [4.5 in.]).

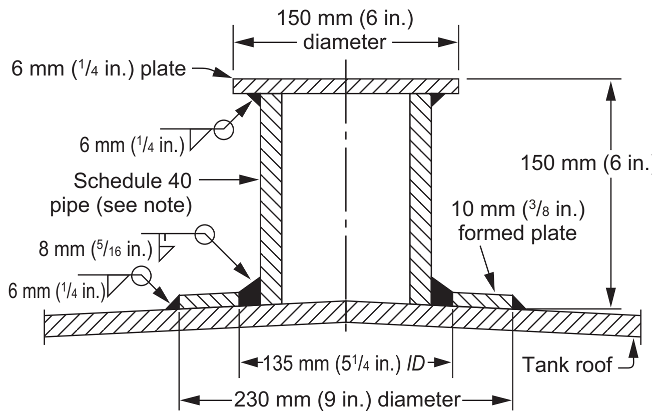


Figure 5.22—Scaffold Cable Support

Table 5.16a—Dimensions for Drawoff Sumps (SI)

NPS	Diameter of Sump mm *A*	Depth of Sump mm *B*	Distance from Center Pipe to Shell m *C*	Thickness of Plates in Sump mm *t*	Minimum Internal Pipe Thickness mm	Minimum Nozzle Neck Thickness mm
2	610	300	1.1	8	5.54	5.54
3	910	450	1.5	10	6.35	7.62
4	1220	600	2.1	10	6.35	8.56
6	1520	900	2.6	11	6.35	10.97
NOTE See Figure 5.21.						

Table 5.16b—Dimensions for Drawoff Sumps (USC)

NPS	Diameter of Sump in. *A*	Depth of Sump in. *B*	Distance from Center Pipe to Shell ft *C*	Thickness of Plates in Sump in. *t*	Minimum Internal Pipe Thickness in.	Minimum Nozzle Neck Thickness in.
2	610 (24)	12	3 1/2	5/16	0.218	0.218
3	910 (36)	18	5	3/8	0.250	0.300
4	1220 (48)	24	6 3/4	3/8	0.250	0.337
6	1520 (60)	36	8 1/2	7/16	0.250	0.432
NOTE See Figure 5.21.						

b) For details on guardrails, handrails, and tread rise/run, follow OSHA 29 CFR 1910, Subpart D, or equivalent national standard.

c) The completed structure must also be designed for the loads listed in OSHA, or an equivalent national safety standard.

d) For examples of acceptable details, see Process Industry Practices standard details PIP STF05501, PIP STF05520, and PIP STF05521 (see www.pip.org).

e) Unless declined on the Data Sheet, Line 24, a roof edge landing or gauger's platform shall be provided at the top of all tanks.

Table 5.17—Requirements for Platforms and Walkways

1.	All parts shall be made of metal, unless an alternate material is specified by the Purchaser.
2.	The minimum width of the walkway shall be 610 mm (24 in.), after making adjustments at all projections.
3.	Flooring shall be made of grating or nonslip material.
4.	The completed structure shall be capable of supporting a moving concentrated load of 4450 N (1000 lbf).
5.	Guardrails shall be on all exposed sides of the platform, but shall be discontinued where necessary for access.
6.	At guardrail openings, any space wider than 150 mm (6 in.) between the tank and the platform should be floored.
7.	A tank runway that extends from one part of a tank to any part of an adjacent tank, to the ground, or to another structure shall be supported so that free relative movement of the structures joined by the runway is permitted. This may be accomplished by firm attachment of the runway to one tank and the use of a slip joint at the point of contact between the runway and the other tank.

Table 5.18—Requirements for Stairways

1.	All parts shall be made of metal, unless an alternate material is specified by the Purchaser.
2.	The minimum width of the stairs shall be 710 mm (28 in.).
3.	The nose of the treads shall align or overlap the back edge of the tread below. For spiral stairs, the minimum stair run shall be 190 mm (7.5 in.) measured at 300 mm (12 in.) radially from the tread edge nearest the shell. Riser height shall be uniform throughout the height of the stairway.
4.	Treads shall be made of grating or nonslip material.
5.	The top railing shall join the platform handrail without offset, and the height measured vertically from tread level at the nose of the tread shall be 1070 mm (42 in.). If OSHA is applicable, a separate handrail shall be provided from 760 mm to 970 mm (30 in. to 38 in.).
6.	The completed structure shall be capable of supporting a moving concentrated load of 4450 N (1000 lbf).
7.	Guardrail systems shall be on both sides of straight stairs; guardrail systems shall also be on both sides of spiral stairs when the clearance between the tank shell and the stair stringer exceeds 200 mm (8 in.).
8.	Spiral stairways shall be supported on the shell of the tank, and the ends of the stringers shall be clear of the ground. Stairways shall extend from the bottom of the tank (or ground) up to a roof edge landing or gauger's platform.
9.	The minimum vertical clearance is 2030 mm (80 in.) above any stair tread to any overhead obstruction as measured from the leading edge of the tread.

5.8.11 Other Appurtenances and Attachments

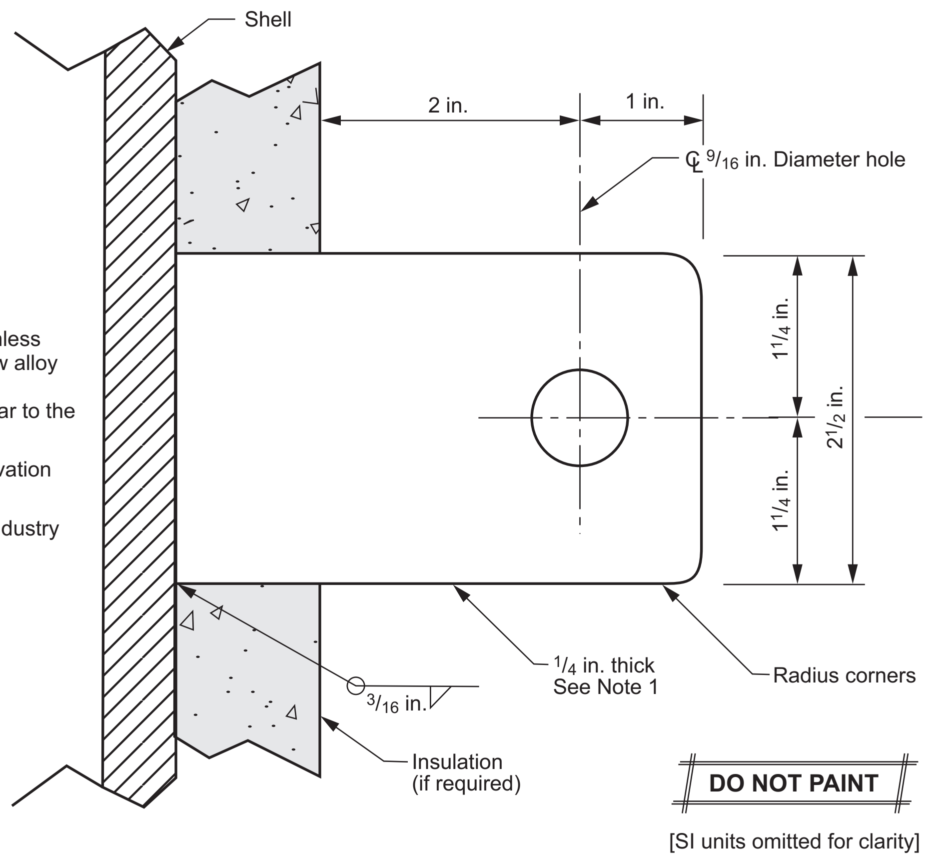
5.8.11.1 Floating suction lines shall be provided when specified on the Data Sheet, Table 4. Floating suction lines using rigid articulated (having one or more swing joints) pipe shall be designed to travel in a vertical plane and prevent damage to the floating roof and the suction line through its design range of travel. These lines shall be designed so that the vertical plane is as close as possible to, and in no case greater than 10 degrees off, a radial line from the tank centerline to the nozzle. Adjustments shall be made to clear internal structures.

• **5.8.11.2** Inlet diffusers shall be provided when specified by the Purchaser or the floating roof manufacturer. Traditional diffuser sizing to limit exit velocity to 3 ft/sec provides protection for tank internal components and reduces static electricity build up due to splashing and misting however does not limit static electricity build up in tanks due to higher velocity product flow in external inlet and outlet piping. See API 2003. Requirements shall be included in the Data Sheet (Table 4 or Table 5).

● **5.8.11.3** If required by the Purchaser, grounding lugs shall be provided in the quantity specified on the Data Sheet, Table 4 (see page L-24), and comply with Figure 5.23. The lugs shall be equally spaced around the base of the tank. Provide a minimum of four lugs. The suggested maximum lug spacing is 30 m (100 ft).

NOTE Tanks that rest directly on a foundation of soil, asphalt or concrete are inherently grounded for purposes of dissipation of electrostatic charges. The addition of grounding rods or similar devices will not reduce the hazard associated with electrostatic charges in the stored product. API Recommended Practice 2003 contains additional information about tank grounding issues as well as comments about lightning protection.

5.8.11.4 All non-circular miscellaneous pads shall have rounded corners with a minimum radius of 50 mm (2 in.). Pads that must cover shell seams shall be provided with a 6 mm ($^1/_4$ in.) telltale hole (see 5.7.3.4).



Notes:
1. Lug material shall be austenitic stainless steel when attached to carbon or low alloy steel parts. When attached to other materials, lug material shall be similar to the material to which attached.
2. See tank drawing/data sheet for elevation and orientation.
3. Drawing courtesy of PIP (Process Industry Practices).

Figure 5.23—Grounding Lug

5.8.11.5 Tanks shall have a liquid level measurement system, unless otherwise specified on the Tank Data Sheet, line item 20. The Purchaser shall specify type of measurement system required. The following shall be considered:

a) Access for maintenance and repair.

b) Level gauge shall be located with consideration to avoid turbulence.

c) The bottom of the float well shall be approximately 150 mm (6 in.) above the tank bottom when the floating roof is at its lowest position unless otherwise specified by the Purchaser.

d) Gauge float wells shall be equipped with a gasketed cover that is not bolted closed unless required by the Purchaser. See C.1.3 or H.1.2 regarding Purchaser specification of jurisdictional requirements.

5.9 Top and Intermediate Stiffening Rings (Wind Girders)

5.9.1 General

5.9.1.1 Stiffening ring requirements for wind loading (wind girders) are addressed in this section. Stiffening ring requirements for external pressure (vacuum) loading and vacuum loading in combination with wind loading, are addressed in Annex V.

5.9.1.2 Open-top tanks shall be provided with a top wind girder to maintain roundness when the tank is subjected to wind loads. See 5.9.5.

5.9.1.3 All tanks shall be stiffened by intermediate wind girders when required by 5.9.6. Vacuum stiffeners, when required by Annex V, may be considered to also act as wind girders when the spacing and stiffeners meet all other requirements of both this section and Annex V.

5.9.1.4 This design for rings used as wind girders also applies to floating-roof tanks covered in Annex C. The top angle and the wind girders shall conform, in material and size, to the requirements of this standard.

5.9.2 Types of Stiffening Rings

Stiffening rings may be made of structural sections, formed plate sections, sections built up by welding, or combinations of such types of sections assembled by welding. The outer periphery of stiffening rings may be circular or polygonal (see Figure 5.24).

5.9.3 Restrictions on Stiffening Rings

5.9.3.1 The minimum size of angle for use alone or as a component in a built-up stiffening ring shall be 65 × 65 × 6 mm ($2^1/_2 \times 2^1/_2 \times {}^1/_4$ in.). The minimum nominal thickness of plate for use in formed or built-up stiffening rings shall be 6 mm (0.236 in.).

• **5.9.3.2** Rings that may trap liquid shall be provided with adequate drain holes. Uninsulated tanks having rings shall have small water-shedding slopes and/or drain holes or slots unless the Purchaser approves an alternate means of drainage. If drain holes are provided, they shall be at least 25 mm (1 in.) diameter (or slot width) on 2400 mm (8 ft) centers or less. Insulated tanks where the rings function as insulation closures shall have no drain holes or slots.

5.9.3.3 Welds joining stiffening rings to the tank shell may cross vertical tank seam welds. Any splice weld in the ring shall be located a minimum of 150 mm (6 in.) from any vertical shell weld. Stiffening rings may also cross vertical tank seam welds with the use of coping (rat hole) of the stiffening ring at the vertical tank seam. Where the coping method is used, the required section modulus of the stiffening ring and weld spacing must be maintained.

5.9.4 Supports for Stiffening Rings

Supports shall be provided for all stiffening rings when the dimension of the horizontal leg or web exceeds 16 times the leg or web thickness. The supports shall be spaced at the intervals required for the dead load and vertical live load; however, the spacing shall not exceed 24 times the width of the outside compression flange.

5.9.5 Top Wind Girder

5.9.5.1 The top wind girder shall be located at or near the top of the top shell course, preferably on the outside of the tank shell.

5.9.5.2 When the top wind girder is located more than 0.6 m (2 ft) below the top of the shell, the tank shall be provided with a 65 x 65 x 6 mm ($2^1/_2$ x $2^1/_2$ x $^3/_{16}$ in.) top curb angle for shells 5 mm ($^3/_{16}$ in.) thick, with a 75 x 75 x 6 mm (3 x 3 x $^1/_4$ in.) top curb angle for shells more than 5 mm ($^3/_{16}$ in.) thick, or with other members of equivalent section modulus.

5.9.5.3 The required minimum section modulus of the top wind girder shall be determined by the following equation:

In SI units:

$$Z = \frac{6H_2D^2}{0.5F_y}\left(\frac{P_{wd}}{1.72}\right)$$

where

- Z is the required minimum section modulus, in cm^3;
- D is the nominal tank diameter (for tanks in excess of 61 m diameter, the diameter shall be considered to be 61 m when determining the section modulus), in meters (m);
- H_2 is the height of the tank shell, in meters, including any freeboard provided above the maximum filling height as a guide for a floating roof;
- F_y is the least minimum yield strength of shell and stiffening ring material at maximum operating temperature in MPa or 210 MPa, whichever is less;
- P_{wd} is design wind pressure including inward drag = P_{wv}+0.24 in kPa;
- P_{wv} is wind pressure at 10 m above ground per applicable building code considering all applicable factors, such as gust factor, exposure factor, height factor, importance factor, in (kPa), or
- P_{wv} is design wind pressure = $1.48\left(\frac{v}{190}\right)^2$ in kPa where design wind speed (V) is used;
- V is the design wind speed (3-sec gust), in km/h [see 5.2.1k)].

In USC units:

$$Z = \frac{1.5}{0.5F_y}H_2D^2\left(\frac{P_{wd}}{36}\right)$$

where

- Z is the required minimum section modulus, in inches^3;
- D is the nominal diameter of the tank (for tanks in excess of 200 ft diameter, the diameter shall be considered to be 200 ft when determining the section modulus), in feet (ft);
- H_2 is the height of the tank shell, in feet, including any freeboard provided above the maximum filling height as a guide for a floating roof;
- V is the design wind speed (3-sec gust), in mph [see 5.2.1k)];
- F_y is the least minimum yield strength of the shell and stiffening ring at maximum operating temperature or 30,000, in psi, whichever is less;
- P_{wd} is design wind pressure including inward drag = P_{wv} + 5 in (lbf/ft^2);
- P_{wv} is wind pressure at 33 ft above ground per applicable building code considering all applicable factors, such as gust factor, exposure factor, height factor, importance factor, in (lbf/ft^2); or
- P_{wv} is wind pressure = 31 (V/120)^2 in (lbf/ft^2) where design wind speed (V) is used.

5.9.5.4 For tanks larger than 61 m (200 ft) in diameter, an additional check for the minimum required moment of inertia for the top-stiffening ring shall be performed. The required minimum moment of inertia of the stiffening ring shall be determined by the following equations:

In SI units:

$$I = [(3583 \times H_2)/E] \times D^3 \times (P_{wd}/1.72)$$

where

I is the required minimum moment of inertia (cm^4);

D is the nominal diameter of the tank, in meters (m);

H_2 is the height of the tank shell (m), including any freeboard provided above the maximum filling height as a guide for a floating roof;

E is the modulus of elasticity (MPa) at maximum design temperature;

P_{wd} is design wind pressure including inward drag = $P_{wv} + 0.24$ in (kPa);

P_{wv} is wind pressure at 10 m above ground per applicable building code considering all applicable factors, such as gust factor, exposure factor, height factor, importance factor, in (kPa), or

P_{wv} is wind pressure = $1.48\left(\frac{V}{190}\right)^2$ in kPa where design wind speed (V) is used;

V is the design wind speed (3-sec gust) (km/h) (see 5.2.1[k]).

In USC units:

$$I = \frac{108H_2}{E}D^3\left(\frac{P_{wd}}{36}\right)$$

where

I is the required minimum moment of inertia ($in.^4$);

D is the nominal diameter of the tank, in feet (ft);

H_2 is the height of the tank shell (ft), including any freeboard provided above the maximum filling height as a guide for a floating roof;

E is the modulus of elasticity (psi) at maximum design temperature;

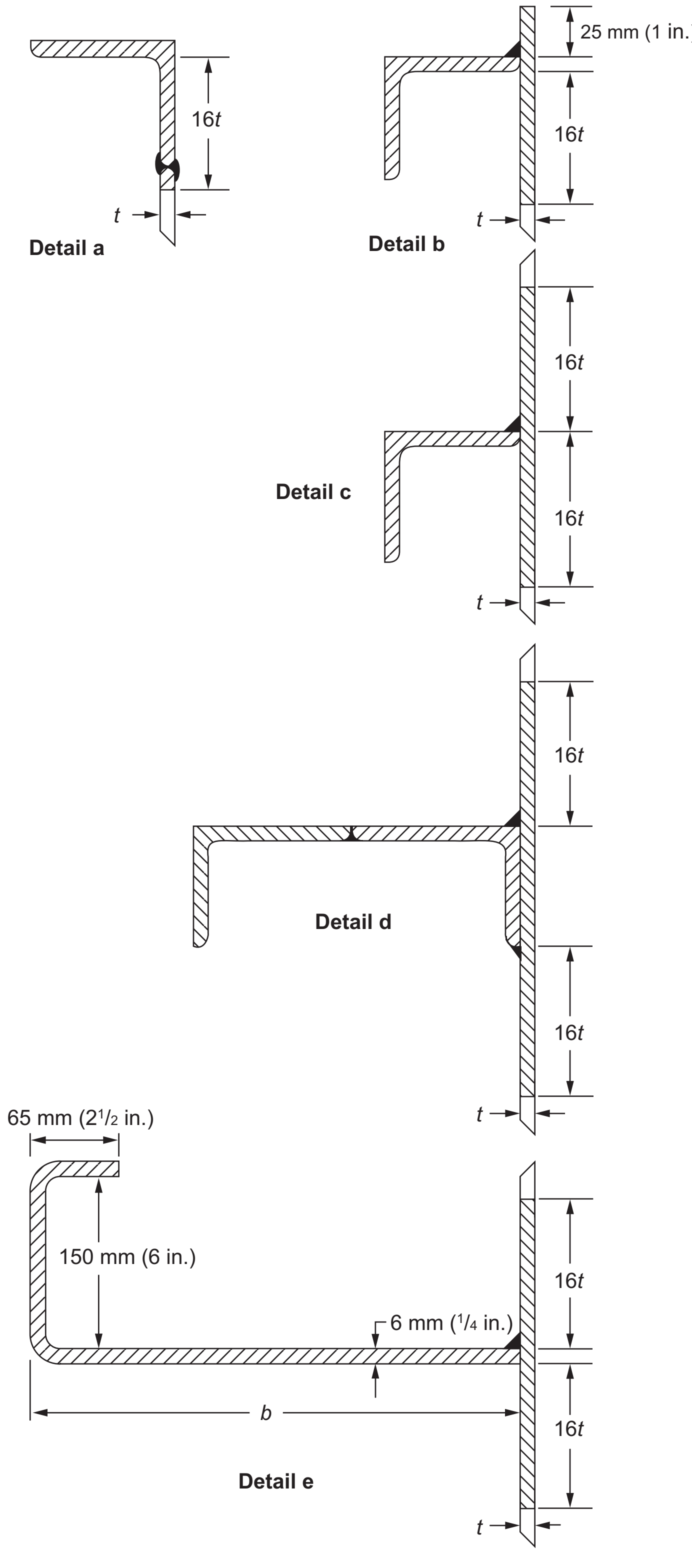
P_{wd} is design wind pressure including inward drag = $P_{wv} + 5$ in (lbf/ft^2);

P_{wv} is wind pressure at 33 ft above ground per applicable building code considering all applicable factors, such as gust factor, exposure factor, height factor, importance factor, in (lbf/ft^2), or

P_{wv} is wind pressure = $31\left(\frac{V}{120}\right)^2$ in (lbf/ft^2) where design wind speed (V) is used;

V is the design wind speed (3-sec gust) (mph) [see 5.2.1(k)].

5.9.5.5 The section modulus of the stiffening ring shall be based on the properties of the applied members and may include a portion of the tank shell for a distance of 16*t* below and, if applicable, above the shell-ring attachment where *t* is the as-built shell thickness, unless otherwise specified. When top angles are attached to the top edge of the shell ring by butt-welding, this distance shall be reduced by the width of the vertical leg of the angle (see Figure 5.24 and Table 5.19a and Table 5.19b).



Note: The section moduli given in Tables 5.19a and 5.19b for Details c and d are based on the longer leg being located horizontally (perpendicular to the shell) when angles with uneven legs are used.

Figure 5.24—Typical Stiffening-ring Sections for Tank Shells (see Table 5.19a and Table 5.19b)

Table 5.19a—Section Moduli (cm^3) of Stiffening-Ring Sections on Tank Shells (SI)

Dimensions in millimeters

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Member Size	As-Built Shell Thickness				
	5	6	8	10	11
Top Angle: Figure 5.24, Detail a					
65 × 65 × 6	6.58	6.77	—	—	—
65 × 65 × 8	8.46	8.63	—	—	—
75 × 75 × 10	13.82	13.97	—	—	—
Curb Angle: Figure 5.24, Detail b					
65 × 65 × 6	27.03	28.16	—	—	—
65 × 65 × 8	33.05	34.67	—	—	—
75 × 75 × 6	35.98	37.49	—	—	—
75 × 75 × 10	47.24	53.84	—	—	—
100 × 100 × 7	63.80	74.68	—	—	—
100 × 100 × 10	71.09	87.69	—	—	—
One Angle: Figure 5.24, Detail c (See Note)					
65 × 65 × 6	28.09	29.15	30.73	32.04	32.69
65 × 65 × 8	34.63	36.20	38.51	40.32	41.17
100 × 75 × 7	60.59	63.21	66.88	69.48	70.59
102 × 75 × 8	66.97	70.08	74.49	77.60	78.90
125 × 75 × 8	89.41	93.71	99.86	104.08	105.78
125 × 75 × 10	105.20	110.77	118.97	124.68	126.97
150 × 75 × 10	134.14	141.38	152.24	159.79	162.78
150 × 100 × 10	155.91	171.17	184.11	193.08	196.62
Two Angles: Figure 5.24, Detail d (See Note)					
100 × 75 × 8	181.22	186.49	195.15	201.83	204.62
100 × 75 × 10	216.81	223.37	234.55	243.41	247.16
125 × 75 × 8	249.17	256.84	269.59	279.39	283.45
125 × 75 × 10	298.77	308.17	324.40	337.32	342.77
150 × 75 × 8	324.97	335.45	353.12	366.82	372.48
150 × 75 × 10	390.24	402.92	425.14	443.06	450.61
150 × 100 × 10	461.11	473.57	495.62	513.69	521.41
Formed Plate: Figure 5.24, Detail e					
b = 250	—	341	375	392	399
b = 300	—	427	473	496	505
b = 350	—	519	577	606	618
b = 400	—	615	687	723	737
b = 450	—	717	802	846	864
b = 500	—	824	923	976	996
b = 550	—	937	1049	1111	1135
b = 600	—	1054	1181	1252	1280
b = 650	—	1176	1317	1399	1432
b = 700	—	1304	1459	1551	1589
b = 750	—	1436	1607	1709	1752
b = 800	—	1573	1759	1873	1921
b = 850	—	1716	1917	2043	2096
b = 900	—	1864	2080	2218	2276
b = 950	—	2016	2248	2398	2463
b = 1000	—	2174	2421	2584	2654

NOTE The section moduli for Details c and d are based on the longer leg being located horizontally (perpendicular to the shell) when angles with uneven legs are used.

Table 5.19b—Section Moduli (in.^{3}) of Stiffening-Ring Sections on Tank Shells (USC)

Dimensions in inches

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Member Size	As-Built Shell Thickness				
	$^3/_{16}$	$^1/_4$	$^5/_{16}$	$^3/_8$	$^7/_{16}$
Top Angle: Figure 5.24, Detail a					
$2^1/_2 \times 2^1/_2 \times {}^1/_4$	0.41	0.42	—	—	—
$2^1/_2 \times 2^1/_2 \times {}^5/_{16}$	0.51	0.52	—	—	—
$3 \times 3 \times {}^3/_8$	0.89	0.91	—	—	—
Curb Angle: Figure 5.24, Detail b					
$2^1/_2 \times 2^1/_2 \times {}^1/_4$	1.61	1.72	—	—	—
$2^1/_2 \times 2^1/_2 \times {}^5/_{16}$	1.89	2.04	—	—	—
$3 \times 3 \times {}^1/_4$	2.32	2.48	—	—	—
$3 \times 3 \times {}^3/_8$	2.78	3.35	—	—	—
$4 \times 4 \times {}^1/_4$	3.64	4.41	—	—	—
$4 \times 4 \times {}^3/_8$	4.17	5.82	—	—	—
One Angle: Figure 5.24, Detail c (See Note)					
$2^1/_2 \times 2^1/_2 \times {}^1/_4$	1.68	1.79	1.87	1.93	2.00
$2^1/_2 \times 2^1/_2 \times {}^5/_{16}$	1.98	2.13	2.23	2.32	2.40
$4 \times 3 \times {}^1/_4$	3.50	3.73	3.89	4.00	4.10
$4 \times 3 \times {}^5/_{16}$	4.14	4.45	4.66	4.82	4.95
$5 \times 3 \times {}^5/_{16}$	5.53	5.96	6.25	6.47	6.64
$5 \times 3^1/_2 \times {}^5/_{16}$	6.13	6.60	6.92	7.16	7.35
$5 \times 3^1/_2 \times {}^3/_8$	7.02	7.61	8.03	8.33	8.58
$6 \times 4 \times {}^3/_8$	9.02	10.56	11.15	11.59	11.93
Two Angles: Figure 5.24, Detail d (See Note)					
$4 \times 3 \times {}^5/_{16}$	11.27	11.78	12.20	12.53	12.81
$4 \times 3 \times {}^3/_8$	13.06	13.67	14.18	14.60	14.95
$5 \times 3 \times {}^5/_{16}$	15.48	16.23	16.84	17.34	17.74
$5 \times 3 \times {}^3/_8$	18.00	18.89	19.64	20.26	20.77
$5 \times 3^1/_2 \times {}^5/_{16}$	16.95	17.70	18.31	18.82	19.23
$5 \times 3^1/_2 \times {}^3/_8$	19.75	20.63	21.39	22.01	22.54
$6 \times 4 \times {}^3/_8$	27.74	28.92	29.95	30.82	31.55
Formed Plate: Figure 5.24, Detail e					
b = 10	—	23.29	24.63	25.61	26.34
b = 12	—	29.27	31.07	32.36	33.33
b = 14	—	35.49	37.88	39.53	40.78
b = 16	—	42.06	45.07	47.10	48.67
b = 18	—	48.97	52.62	55.07	56.99
b = 20	—	56.21	60.52	63.43	65.73
b = 22	—	63.80	68.78	72.18	74.89
b = 24	—	71.72	77.39	81.30	84.45
b = 26	—	79.99	86.35	90.79	94.41
b = 28	—	88.58	95.66	100.65	104.77
b = 30	—	97.52	105.31	110.88	115.52
b = 32	—	106.78	115.30	121.47	126.66
b = 34	—	116.39	125.64	132.42	138.17
b = 36	—	126.33	136.32	143.73	150.07
b = 38	—	136.60	147.35	155.40	162.34
b = 40	—	147.21	158.71	167.42	174.99

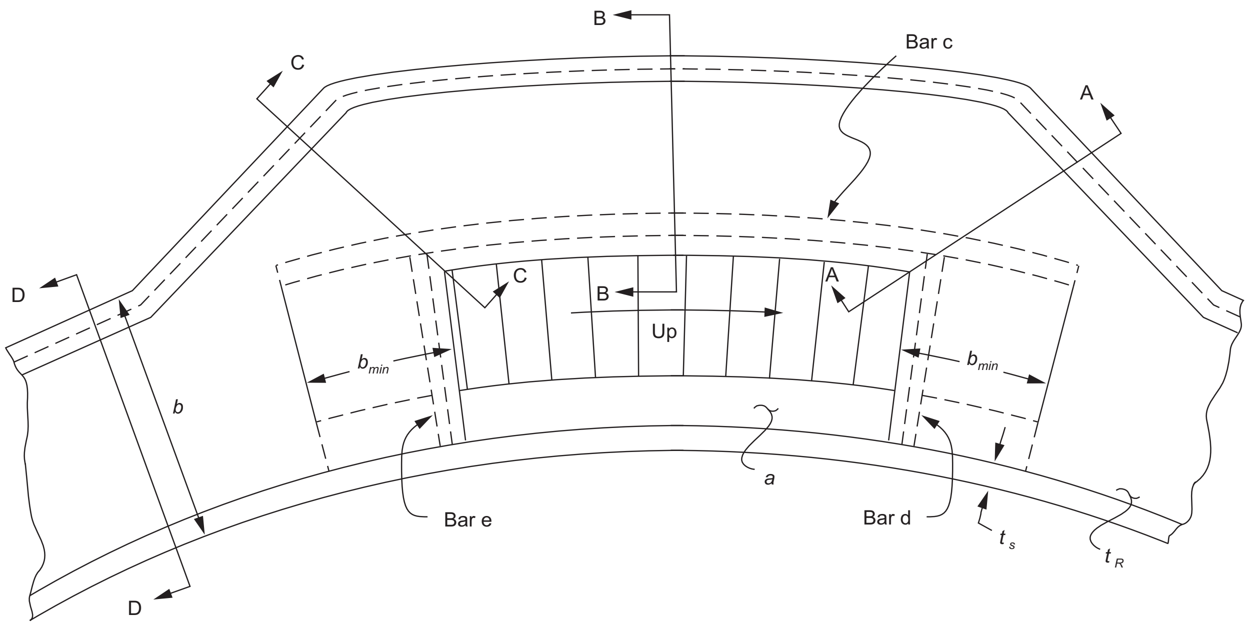
NOTE The section moduli for Details c and d are based on the longer leg being located horizontally (perpendicular to the shell) when angles with uneven legs are used.

5.9.5.6 Top Wind Girders as Walkways

A top wind girder or any portion of it that is specified as a walkway shall have a width not less than 710 mm (28 in.) clear of projections, including the angle on the top of the tank shell. The clearance around local projections shall not be less than 610 mm (24 in.). Unless the tank is covered with a fixed roof, the top wind girder (used as a walkway) shall be located between 1100 mm (42 in.) and 1225 mm (48 in.) below the top of the top angle or top of shell, whichever is higher, and shall be provided with a standard railing on the unprotected side and at the ends of the section used as a walkway.

5.9.5.7 When a stair opening is installed through a wind girder, the section modulus of the portion of the wind girder outside the opening, including the transition section, shall conform to the requirements of 5.9.5.2. The shell adjacent to the opening shall be stiffened with an angle or a bar, the wide side of which is placed in a horizontal plane. The other sides of the opening shall also be stiffened with an angle or a bar, the wide side of which is placed in a vertical plane. The cross-sectional area of these rim stiffeners shall be greater than or equal to the cross-sectional area of the portion of shell included in the section-modulus calculations for the wind girder. These rim stiffeners or additional members shall provide a suitable toe board around the opening.

The stiffening members shall extend beyond the end of the opening for a distance greater than or equal to the minimum depth of the regular ring sections. The end stiffening members shall frame into the side stiffening members, and the end and side stiffening members shall be connected to ensure that their full strength is developed. Figure 5.25 shows the opening described in this section. Alternative details that provide a load-carrying capacity equal to that of the girder cross-section away from the opening may be provided.



Notes:

1. The cross-sectional area of a, c, d, and e must equal $32t^2$. The section of the figure designated "a" may be a bar or an angle whose wide leg is horizontal. The other sections may be bars or angles whose wide legs are vertical.
2. Bars c, d, and e may be placed on the top of the girder web, provided they do not create a tripping hazard.
3. The section modulus of Sections A-A, B-B, C-C, and D-D shall conform to 5.9.6.1.
4. The stairway may be continuous through the wind girder or may be offset to provide a landing.
5. See 5.9.6.4 for toeboard requirements.

Figure 5.25—Stairway Opening through Stiffening Ring

5.9.6 Intermediate Wind Girders

5.9.6.1 The maximum height of the unstiffened shell shall be calculated as follows:

In SI units:

$$H_1 = 9.47t\sqrt{\left(\frac{t}{D}\right)^3}\left(\frac{1.72}{P_{wd}}\right)$$

where

H_1 is the maximum height of the unstiffened shell, in meters;

• t is the nominal thickness, unless otherwise specified, of the thinnest shell course, in millimeters (see Note 1);

D is the nominal tank diameter, in meters;

P_{wd} is design wind pressure including inward drag = $P_{wv} + 0.24$ in (kPa);

P_{wv} is wind pressure at 10 m above ground per applicable building code considering all applicable factors, such as gust factor, exposure factor, height factor, importance factor, in (kPa), or

P_{wv} is wind pressure = $1.48\left(\frac{V}{190}\right)^2$ in (kPa) where design wind speed (V) is used;

V is the design wind speed (3-sec gust), in km/h [see 5.2.1k)].

In USC units:

$$H_1 = 600{,}000\ t\sqrt{\left(\frac{t}{D}\right)^3}\left(\frac{36}{P_{wd}}\right)$$

where

H_1 is the maximum height of the unstiffened shell, in feet;

• t is the nominal thickness, unless otherwise specified, of the thinnest shell course, in inches (see Note 1);

D is the nominal tank diameter, in feet;

P_{wd} is design wind pressure including inward drag = $P_{wv} + 5$ in (lbf/ft^2);

P_{wv} is wind pressure at 33 ft above ground per applicable building code considering all applicable factors, such as gust factor, exposure factor, height factor, importance factor, in (lbf/ft^2), or

P_{wv} is wind pressure = $31\left(\frac{V}{120}\right)^2$ in (lbf/ft^2) where design wind speed (V) is used;

V is the design wind speed (3-sec gust), in mph [see 5.2.1k)].

NOTE 1 The structural stability check of wind girder stiffened shells in accordance with 5.9.5 and 5.9.6, shall be based upon nominal dimensions of the shell course and the wind girders irrespective of specified corrosion allowances whenever the “No” option is selected for “Check Buckling in Corroded Cond.?” on the Data Sheet, Line 9. Whenever the “Yes” option is selected, the check must be based upon the nominal dimensions minus the specified corrosion allowance.

NOTE 2 This formula is intended to cover tanks with either open tops or closed tops and is based on the following factors (for the background for the factors given in this note, see ASCE 7 and R. V. McGrath's "Stability of API Standard 650 Tank Shells"): [16]

a) The velocity pressure is:

$$p = 0.00256 K_z K_{zt} K_d V^2 I G = 1.48 \text{ kPa } (31 \text{ lbf/ft}^2)$$

where

K_z equals the velocity pressure exposure coefficient = 1.04 for exposure C at a height of 40 ft;

K_{zt} is 1.0 for all structures except those on isolated hills or escarpments;

K_d is the directionality factor = 0.95 for round tanks;

V equals the 3-second gust design wind speed = 190 km/h (120 mph) at 10 m (33 ft) above ground [see 5.2.1k)];

I equals the importance factor = 1.0 for Category II structures;

G equals the gust factor = 0.85 for exposure C.

A 0.24 kPa (5 lbf/ft^2) internal vacuum is added for inward drag on open-top tanks or for external pressure on closed top tanks for a total of 1.72 kPa (36 lbf/ft^2).

b) The wind pressure is uniform over the theoretical buckling mode of the tank shell, which eliminates the need for a shape factor for the wind loading.

c) The modified U.S. Model Basin formula for the critical uniform external pressure on thin-wall tubes free from end loadings, subject to the total pressure specified in Item a.

5.9.6.2 After the maximum height of the unstiffened shell, H_1, has been determined, the height of the transformed shell shall be calculated as follows:

a) With the following equation, change the actual width of each shell course into a transposed width of each shell course having the top shell thickness:

$$W_{tr} = W\sqrt{\left(\frac{t_{\text{uniform}}}{t_{\text{actual}}}\right)^5}$$

where

W_{tr} is the transposed width of each shell course, in millimeters (inches);

W is the actual width of each shell course, in millimeters (inches);

• $t_{uniform}$ is the nominal thickness, unless otherwise specified, of the thinnest shell course, in millimeters (inches);

• t_{actual} is the nominal thickness, unless otherwise specified, of the shell course for which the transposed width is being calculated, in millimeters (inches).

b) Add the transposed widths of the courses. The sum of the transposed widths of the courses will give the height of the transformed shell.

5.9.6.3 If the height of the transformed shell is greater than the maximum height H_1, an intermediate wind girder is required.

[16] R.V. McGrath, "Stability of API Standard 650 Tank Shells," *Proceedings of the American Petroleum Institute, Section III—Refining,* American Petroleum Institute, New York, 1963, Vol. 43, pp. 458 – 469.

5.9.6.3.1 For equal stability above and below the intermediate wind girder, the girder should be located at the mid-height of the transformed shell. The location of the girder on the actual shell should be at the same course and same relative position as the location of the girder on the transformed shell, using the thickness relationship in 5.9.6.2.

5.9.6.3.2 Other locations for the girder may be used, provided the height of unstiffened shell on the transformed shell does not exceed H_1 (see 5.9.6.5).

5.9.6.4 If half the height of the transformed shell exceeds the maximum height H_1, a second intermediate girder shall be used to reduce the height of unstiffened shell to a height less than the maximum.

5.9.6.5 Intermediate wind girders shall not be attached to the shell within 150 mm (6 in.) of a horizontal joint of the shell. When the preliminary location of a girder is within 150 mm (6 in.) of a horizontal joint, the girder shall preferably be located 150 mm (6 in.) below the joint; however, the maximum unstiffened shell height shall not be exceeded.

5.9.6.6 The required minimum section modulus of an intermediate wind girder shall be determined by the following equation:

In SI units:

$$Z = \frac{6h_1D^2}{0.5F_y}\left(\frac{P_{Wd}}{1.72}\right)$$

where

Z is the required minimum section modulus, in cm^3;

D is the nominal tank diameter, in meters;

h_1 is the vertical distance, in meters, between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank;

V is the design wind speed (3-sec gust), in km/h [see 5.2.1k)].

F_y is the least minimum yield strength of the shell and intermediate wind girder at maximum operating temperature or 210, in MPa, whichever is less.

P_{wd} is design wind pressure including inward drag = P_{wv} + 0.24 in kPa;

P_{wv} is wind pressure at 10 m above ground per applicable building code considering all applicable factors, such as gust factor, exposure factor, height factor, importance factor, in (kPa); or

P_{wv} is design wind pressure = 1.48 (V/190)^2 in kPa where design wind speed (V) is used.

In USC units:

$$Z = \frac{1.5}{0.5F_y}h_1D^2\left(\frac{P_{wd}}{36}\right)$$

where

Z is the required minimum section modulus, in inches^3;

D is the nominal tank diameter, in feet;

h_1 is the vertical distance, in feet, between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank;

V is the design wind speed (3-sec gust), in mph [see 5.2.1k)].

F_y is the least minimum yield strength of the shell and intermediate wind girder at maximum operating temperature or 30,000 in psi, whichever is less.

P_{wd} is design wind pressure including inward drag = P_{wv} + 5 in (lbf/ft^2);

P_{wv} is wind pressure at 33 ft above ground per applicable building code considering all applicable factors, such as gust factor, exposure factor, height factor, importance factor, in (lbf/ft^2); or

P_{wv} is design wind pressure = 31 (V/120)^2 in (lbf/ft^2) where design wind speed (V) is used.

NOTE A description of the loads on the tank shell that are included in the design wind speed can be found in Item a of the note to 5.9.6.1.

5.9.6.6.1 Where the use of a transformed shell permits the intermediate wind girder to be located at a height that is less than H_1 calculated by the formula in 5.9.6.1, the spacing to the mid-height of the transformed shell, transposed to the height of the actual shell, may be substituted for h_1 in the calculation for the minimum section modulus if the girder is attached at the transposed location.

5.9.6.6.2 The section modulus of the intermediate wind girder shall be based on the properties of the attached members and may include a portion of the tank shell for a distance above and below the attachment to the shell, in mm (in.), of:

In SI units:

$$13.4\ (Dt)^{0.5}$$

where

D is the nominal tank diameter, in meters;

t is the nominal shell thickness, unless otherwise specified, at the attachment, in millimeters.

In USC units:

$$1.47\ (Dt)^{0.5}$$

where

D is the nominal tank diameter, in feet;

t is the nominal shell thickness, unless otherwise specified, at the attachment, in inches.

• **5.9.6.7** An opening for a stairway in an intermediate wind girder is unnecessary when the intermediate wind girder extends no more than 150 mm (6 in.) from the outside of the shell and the nominal stairway width is at least 710 mm (28 in.). For greater outward extensions of a wind girder, the stairway shall be increased in width to provide a minimum clearance of 450 mm (18 in.) between the outside of the wind girder and the handrail of the stairway, subject to the Purchaser’s approval. If an opening is necessary, it may be designed in a manner similar to that specified in

5.9.5.5 for a top wind girder with the exception that only a 560 mm (22 in.) width through the wind girder need be provided.

5.10 Roofs

5.10.1 Definitions

The following definitions apply to roof designs, but shall not be considered as limiting the type of roof permitted by 5.10.2.8.

a) A **supported cone roof** is a roof formed to approximately the surface of a right cone that is supported principally either by rafters on girders and columns or by rafters on trusses with or without columns.

b) A **self-supporting cone roof** is a roof formed to approximately the surface of a right cone that is supported only at its periphery.

c) A **self-supporting dome roof** is a roof formed to approximately a spherical surface that is supported only at its periphery.

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 identified in 5.2.2 (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, regardless of the type of steel (stainless, duplex, or other) or annex of this standard used, 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 nominal thickness of the lowest shell course shall not be less than 6 mm ($^1/_4$ in.).

3) The roof support members shall not be attached to the roof plate.

4) 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.

5) The roof-to-top angle compression ring is limited to details a through e in Figure F.2.

6) 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; area (A) shall be based on nominal thickness of participating elements:

$$A = \frac{D_{LS}}{2\pi F_y \tan\theta} \text{ mm}^2 \text{ (in.}^2\text{)}$$

where

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

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

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

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

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.

b) For self-anchored tanks with a diameter greater than or equal to 9 m (30 ft) but less than 15 m (50 ft), the tank shall meet all of the following.

1) The tank height is 9 m (30 ft) or greater.

2) The tank shall meet the requirements of 5.10.2.6.a.2 through 5.10.2.6.a.6.

3) The slope of the roof at the top angle attachment does not exceed $^3/_4$:12.

4) Attachments (including nozzles and manholes) to the tank shall be designed to accommodate at least 100 mm (4 in.) of vertical shell movement without rupture.

5) The bottom is butt-welded.

c) Alternately, for self-anchored tanks less than 15 m (50 ft) diameter, the tank shall meet all of the following.

1) The tank shall meet the requirements of 5.10.2.6.a.1 through 5.10.2.6.a.6.

2) An elastic analysis[17] shall be performed to confirm the shell to bottom joint strength is at least 1.5 times the top joint strength with the tank empty and 2.5 times the top joint strength with the tank full.

3) Attachments (including nozzles and manholes) to the tank shall be designed to accommodate at least 100 mm (4 in.) of vertical shell movement without rupture.

4) The bottom is butt-welded.

d) For mechanically-anchored tanks of any diameter, the tank shall meet the requirements of 5.10.2.6.a.1 through 5.10.2.6.a.6 and the anchorage and counterweight shall be designed for 3 times the failure pressure calculated by F.7 as specified in 5.12.

• **5.10.2.7** ***Stiffeners:*** For all types of roofs, the plates may be stiffened by sections welded to the plates. Refer to 5.10.2.3 for requirements for supported cone roofs.

• **5.10.2.8** ***Alternate Designs:*** These rules cannot cover all details of tank roof design and construction. With the approval of the Purchaser, the roof need not comply with 5.10.4, 5.10.5, 5.10.6, and 5.10.7. The Manufacturer shall provide a roof designed and constructed to be as safe as otherwise provided for in this standard. In the roof design, particular attention should be given to preventing failure through instability.

5.10.2.9 ***Lateral Loads on Columns:*** When the Purchaser specifies lateral loads that will be imposed on the roof-supporting columns, the columns must be proportioned to meet the requirements for combined axial compression and bending as specified in 5.10.3.

5.10.3 Allowable Stresses

• 5.10.3.1 General

The allowable strength of roof components shall be determined in accordance with the ANSI/AISC 360 using allowable strength design methodology (ASD).

5.10.3.2 Maximum Slenderness Ratios

For columns, the value L / r_c shall not exceed 180. For other compression members, the value L / r shall not exceed 200. For all other members, except tie rods whose design is based on tensile force, the value L / r shall not exceed 300.

where

L is the unbraced length, in millimeters (inches);

r_c is the least radius of gyration of column, in millimeters (inches);

r is the governing radius of gyration, in millimeters (inches).

[17] A frangible roof satisfies the emergency venting requirement for tanks exposed to fire outside the tank. See API 2000. Frangible roofs are not intended to provide emergency venting for other circumstances such as a fire inside the tank, utility failures, chemical reactions, or overfill. See API Publication 937 and API Publication 937-A.

5.10.4 Supported Cone Roofs

• **5.10.4.1** The slope of the roof shall be 1:16 or greater if specified by the Purchaser. If the rafters are set directly on chord girders, producing slightly varying rafter slopes, the slope of the flattest rafter shall conform to the specified or ordered roof slope.

5.10.4.2 Main supporting members, including those supporting the rafters, may be rolled or fabricated sections or trusses. Although these members may be in contact with the roof plates, the compression flange of a member or the top chord of a truss shall be considered as receiving no lateral support from the roof plates and shall be laterally braced, if necessary, by other acceptable methods. The allowable stresses in these members shall be governed by 5.10.3.

5.10.4.3 Structural members serving as rafters may be rolled or fabricated sections but in all cases shall conform to the rules of 5.10.2, 5.10.3, and 5.10.4. Rafters shall be designed for the dead load of the rafters and roof plates with the compression flange of the rafter considered as receiving no lateral support from the roof plates and shall be laterally braced if necessary (see 5.10.4.2). When considering additional dead loads or live loads, the rafters in direct contact with the roof plates applying the loading to the rafters may be considered as receiving adequate lateral support from the friction between the roof plates and the compression flanges of the rafters, with the following exceptions:

a) trusses and open-web joists used as rafters;

b) rafters with a nominal depth greater than 375 mm (15 in.);

c) rafters with a slope greater than 1:6.

• **5.10.4.4** Rafters shall be spaced to satisfy:

$$b = t(1.5F_y/p)^{\frac{1}{2}} \leq 2100 \text{ mm (84 in.)}$$

where

- b is the maximum allowable roof plate span, measured circumferentially from center-to-center of rafters;
- F_y is the specified minimum yield strength of roof plate;
- t is the corroded roof thickness;
- p is the uniform pressure as determined from load combinations given in 5.2.2.

• **5.10.4.5** Roof columns shall be made from either pipe or structural shapes as selected on the Data Sheet, Line 11. Pipe columns shall either be sealed or have openings on both the top and bottom of the column.

5.10.4.6 Rafter clips for the outer row of rafters shall be welded to the tank shell.

5.10.4.7 Roof support columns shall be provided at their bases with details that provide for the following.

a) ***Load Distribution***: Column loads shall be distributed over a bearing area based on the specified soil bearing capacity or foundation design. The pressure applied by the tank liquid height need not be considered when sizing column bases to distribute loads. If an unstiffened horizontal plate is designed to distribute the load, it shall have a nominal thickness of not less than 12 mm (1/2 in.). Alternatively, the column load may be distributed by an assembly of structural beams. The plate or members shall be designed to distribute the load without exceeding allowable stresses prescribed in 5.10.3.1.

b) ***Corrosion and Abrasion Protection***: At each column a wear plate with a nominal thickness of not less than 6 mm (1/4 in.) shall be welded to the tank bottom with a 6 mm (1/4 in.) minimum fillet weld. A single adequate thickness plate may be designed for the dual functions of load distribution and corrosion/abrasion protection.

c) ***Vertical Movement***: The design shall allow the columns to move vertically relative to the tank bottom without restraint in the event of tank overpressure or bottom settlement.

d) ***Lateral Movement***: The columns shall be effectively guided at their bases to prevent lateral movement. The guides shall remain effective in the event of vertical movement of columns relative to tank bottom of up to 75 mm (3 in.). The guides shall be located such that they are not welded directly to the tank bottom plates.

5.10.4.8 Three acceptable arrangements to provide the functions required by 5.10.4.7 are illustrated in Figure 5.26.

5.10.4.9 For Annex F tanks, when supporting members are attached to the roof plate, consideration shall be given to the design of the supporting members and their attachment details when considering internal pressure.

5.10.4.10 Center columns shall be designed for both the balanced snow load (S_b) and unbalanced snow load (S_u). Intermediate columns need only be designed for the balanced snow load (S_b).

• 5.10.5 Self-Supporting Cone Roofs

NOTE Self-supporting roofs whose roof plates are stiffened by sections welded to the plates need not conform to the minimum thickness requirements, but the nominal thickness of the roof plates shall not be less than 4.8 mm (3/16 in.) when so designed by the Manufacturer, subject to the approval of the Purchaser.

5.10.5.1 Self-supporting cone roofs shall conform to the following requirements:

$\theta \leq 37$ degrees (slope = 9:12)

$\theta \geq 9.5$ degrees (slope = 2:12)

In SI units:

Nominal thickness shall not be less than the greatest of:

$$\frac{2x1000D}{\sin\theta}\sqrt{\frac{B}{1000xE}} + \text{CA, or } \frac{2x1000D}{\sin\theta}\sqrt{\frac{U}{1.33x1000E}} + \text{CA, or 5 mm}$$

Corroded thickness shall not be more than 13 mm.

where

D is the nominal diameter of the tank, in meters;

E is the modulus of elasticity (MPa) at maximum temperature;

B is the greater of load combinations 5.2.2 (e)(1) and (e)(2) with balanced snow load S_b, in kPa;

U is the greater of load combinations 5.2.2 (e)(1) and (e)(2) with unbalanced snow load S_u, in kPa;

θ is the angle of cone elements to the horizontal, in degrees;

CA is the corrosion allowance.

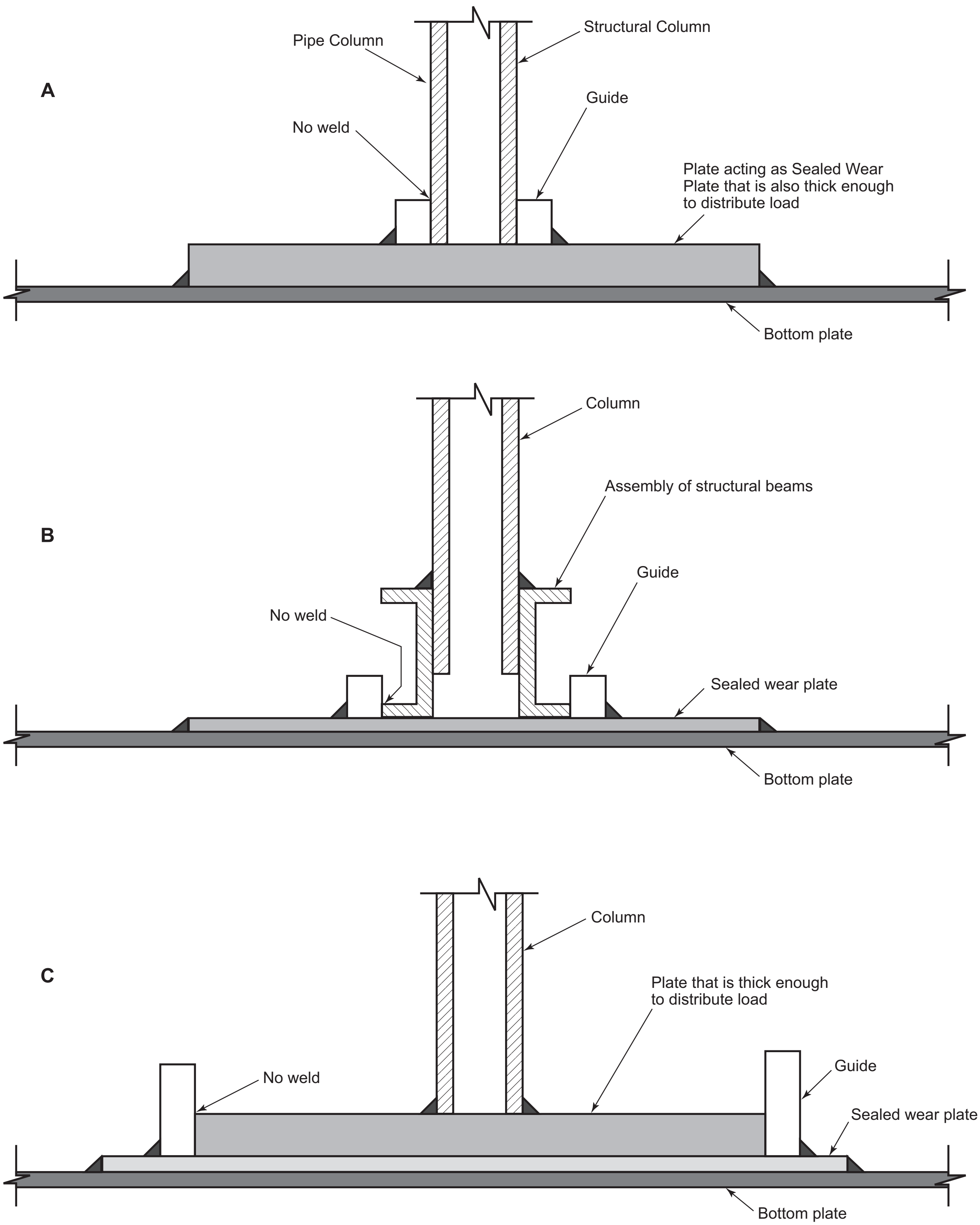


Figure 5.26—Some Acceptable Column Base Details

In USC units:

Nominal thickness shall not be less than the greatest of:

$$\frac{2x12D}{\sin\theta}\sqrt{\frac{B}{144xE}} + \text{CA, or } \frac{2x12D}{\sin\theta}\sqrt{\frac{U}{1.33x144E}} + \text{CA, and } 3/16 \text{ in.}$$

Corroded thickness shall not be more than 1/2 in.

where

D is the nominal diameter of the tank shell, in feet;

E is the modulus of elasticity (psi) at maximum design temperature;

B is the greater of load combinations 5.2.2 (e)(1) and (e)(2) with balanced snow load S_b (lbf/ft^2);

U is the greater of load combinations 5.2.2 (e)(1) and (e)(2) with unbalanced snow load S_u (lbf/ft^2);

θ is the angle of cone elements to the horizontal, in degrees;

CA is the corrosion allowance.

5.10.5.2 The participating area at the roof-to-shell joint shall be determined using Figure F.2 and the nominal material thickness less any corrosion allowance shall equal or exceed the following:

$$\frac{pD^2}{8F_a \tan\theta}$$

where

p is the greater of load combinations 5.2.2 (e)(1) and (e)(2);

D is the nominal diameter of the tank shell;

θ is the angle of cone elements to the horizontal;

F_a equals (0.6 F_y), the least allowable tensile stress for the materials in the roof-to-shell joint;

F_y is the Least Yield Strength of roof-to-shell joint material at maximum design temperature.

• 5.10.6 Self-supporting Dome and Umbrella Roofs

NOTE Self-supporting roofs whose roof plates are stiffened by sections welded to the plates need not conform to the minimum thickness requirements, but the thickness of the roof plates shall not be less than 4.8 mm (3/16 in.) when so designed by the Manufacturer, subject to the approval of the Purchaser.

5.10.6.1 Self-supporting dome and umbrella roofs shall conform to the following requirements:

Minimum radius = 0.8D (unless otherwise specified by the Purchaser)

Maximum radius = 1.2D

In SI units:

Nominal thickness shall not be less than the greatest of:

$$4x1000\ r_r\sqrt{\frac{B}{1000xE}} + \text{CA},\ 4x1000\ r_r\sqrt{\frac{U}{1.33x1000E}} + \text{CA, or 5 mm}$$

Corroded thickness shall not be more than 13 mm.

where

D is the nominal diameter of the tank shell, in meters;

E is the modulus of elasticity (MPa) at maximum design temperature;

B is the greater of load combinations 5.2.2 (e)(1) and (e)(2) with balanced snow load S_b (kPa);

U is the greater of load combinations 5.2.2 (e)(1) and (e)(2) with unbalanced snow load S_u (kPa);

r_r is the roof radius, in meters.

In USC units:

Nominal thickness shall not be less than the greatest of:

$$4x12\ r_r\sqrt{\frac{B}{144xE}} + \text{CA},\ 4x12\ r_r\sqrt{\frac{U}{1.33x144E}} + \text{CA, and } {}^3\!/_{16}\text{ in.}$$

Corroded thickness shall not be more than 1/2 in.

where

D is the nominal diameter of the tank shell, in feet;

E is the modulus of elasticity (psi) at maximum design temperature;

B is the greater of load combinations 5.2.2 (e)(1) and (e)(2) with balanced snow load S_b (lbf/ft^2);

U is the greater of load combinations 5.2.2 (e)(1) and (e)(2) with unbalanced snow load S_u (lbf/ft^2);

r_r is the roof radius, in feet.

5.10.6.2 The participating area at the roof-to-shell joint determined using Figure F.2 and the nominal material thickness less any corrosion allowance shall equal or exceed:

$$\frac{pD^2}{8F_a\tan\theta}$$

where

p is the greater of load combinations 5.2.2 (e)(1) and (e)(2);

D is the nominal diameter of the tank shell;

θ is the roof angle to horizontal at the shell, in degrees;

F_a equals (0.6 F_y), the least allowable tensile stress for the materials in the roof-to-shell joint;

F_y is the Least Yield Strength of roof-to-shell joint material at maximum design temperature.

5.10.7 Top-angle Attachment for Self-Supporting Roofs

Information and certain restrictions on types of top-angle joints are provided in Item c of 5.1.5.9. Details of welding are provided in 7.2.

5.11 Wind Load on Tanks (Overturning Stability)

5.11.1 Wind Pressure

Overturning stability shall be calculated using the wind pressures given in 5.2.1(k).

5.11.2 Self-anchored Tanks

Self-anchored tanks shall meet the requirements of 5.11.2.1 or 5.11.2.2. See Figure 5.27.

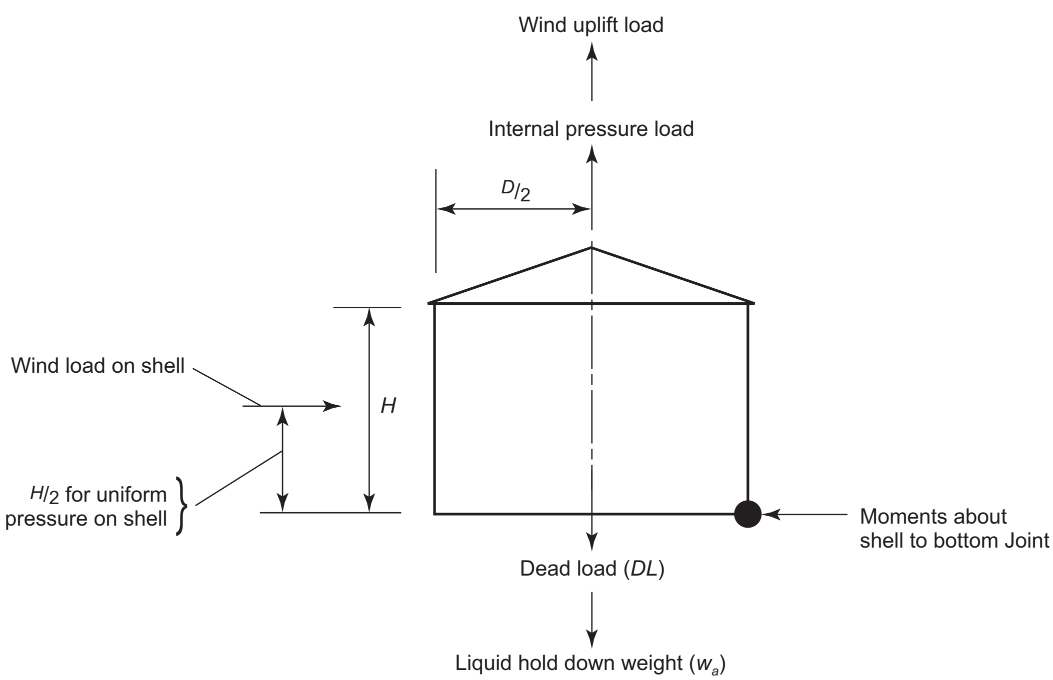


Figure 5.27—Overturning Check for Self-anchored Tanks

5.11.2.1 Self-anchored tanks, except supported cone roof tanks meeting the requirements of 5.10.4, shall satisfy all of the following uplift criteria:

1) $0.6M_w + M_{Pi} < M_{DL}/1.5 + M_{DLR}$

2) $M_w + F_p(M_{Pi}) < (M_{DL} + M_F)/2 + M_{DLR}$

3) $M_{ws} + F_p\ (M_{Pi}) < M_{DL}/1.5 + M_{DLR}$

where

F_P is the pressure combination factor, see 5.2.2;

M_{Pi} is the moment about the shell-to-bottom joint from design internal pressure;

M_w is the overturning moment about the shell-to-bottom joint from horizontal plus vertical wind pressure;

M_{DL} is the moment about the shell-to-bottom joint from the nominal weight of the shell and roof structure supported by the shell that is not attached to the roof plate;

M_F is the moment about the shell-to-bottom joint from liquid weight;

M_{DLR} is the moment about the shell-to-bottom joint from the nominal weight of the roof plate plus any attached structural;

M_{WS} is the overturning moment about the shell-to-bottom joint from horizontal wind pressure.

5.11.2.2 Self-anchored tanks with supported cone roofs meeting the requirements of 5.10.4 shall satisfy the following criteria:

$$M_{ws} + F_p\,(M_{Pi}) < M_{DL}/1.5 + M_{DLR}$$

5.11.2.3 w_L is the resisting weight of the tank contents per unit length of shell circumference based on a specific gravity (G) of 0.7 or the actual product specific gravity, whichever is less, and a height of one-half the design liquid height H. w_L shall be the lesser of 70.4 HD for SI Units (0.45 HD for USC units) or the following:

In SI units:

$$w_L = 59(t_b - CA)\sqrt{(F_{by}H)} \text{ (N/m)}$$

In USC units:

$$w_L = 4.67(t_b - CA)\sqrt{(F_{by}H)} \text{ (lbf/ft)}$$

where

F_{by} is the minimum specified yield stress of the bottom plate under the shell, in MPa (lbf/in.^{2});

G is the actual specific gravity of the stored liquid or 0.7, whichever is less;

H is the design liquid height, in meters (ft);

D is the tank diameter, in meters (ft);

t_b is the required corroded thickness of the bottom plate under the shell, in mm (inches), that is used to resist wind overturning. The bottom plate shall have the following restrictions:

1) The corroded thickness, t_b, used to calculate w_L shall not exceed the first shell course corroded thickness less any shell corrosion allowance.

2) When the bottom plate under the shell is thicker due to wind overturning than the remainder of the tank bottom, the minimum projection of the supplied thicker annular ring inside the tank wall, L, shall be the greater of 450 mm (18 in.) or L_b, however, need not be more than 0.035D.

In SI units:

$$L_b = 0.0291\ (t_b - CA)\sqrt{F_{by}/H} \leq 0.035\ D \text{ (in meters)}$$

In USC units:

$$L_b = 0.365\ (t_b - CA)\sqrt{F_{by}/H} \leq 0.035\ D \text{ (in feet)}$$

5.11.3 Mechanically-anchored Tanks

When the requirements of 5.11.2 cannot be satisfied, anchor the tank per the requirements of 5.12.

5.11.4 Sliding Friction

Unless otherwise required, tanks that may be subject to sliding due to wind shall use a maximum allowable sliding friction of 0.40 multiplied by the force against the tank bottom.

5.12 Tank Anchorage

5.12.1 When a tank is required to be mechanically anchored per 5.11 (wind), Annex E (seismic), Annex F (internal pressure), or when a tank is mechanically anchored for any other reason, the following minimum requirements shall be met.

5.12.2 Anchorage shall be provided to resist each of the applicable uplift load cases listed in Table 5.20a and Table 5.20b. The load per anchor shall be:

$$T_b = U/N$$

where

- T_b is the load per anchor;
- U is the net uplift load per Table 5.20a and Table 5.20b;
- N is the number of equally spaced anchors. If not equally spaced, then t_b shall be increased to account for unequal spacing (a minimum of 4 anchors are required).

5.12.3 The anchor center-to-center spacing measured along the tank circumference at the shell outer diameter shall not exceed 3 m (10 ft).

5.12.4 The minimum anchor bolt eccentricity from the shell outside surface shall be set to the bottom plate projection specified in 5.4.2 plus 3 mm ($^1/_8$ in.) plus one half of anchor bolt diameter plus any required thermal growth clearance according to the following equations (see Figure 5.28):

$$e \geq e_m$$

and

In SI units:

$$e_m = 54 + d/2 + 500E_tDT$$

Table 5.20a—Uplift Loads (SI)

Uplift Load Case	Net Uplift Formula, U (N)	Allowable Anchor Bolt or Anchor Strap Stress (MPa)	Allowable Shell Stress at Anchor Attachment (MPa)
Design Pressure	$[P_i \times D^2 \times 785] - W_1$	$^5/_{12} \times F_y$	$^2/_3\ F_{ty}$
Test Pressure	$[P_t \times D^2 \times 785] - W_3$	$^5/_9 \times F_y$	$^5/_6\ F_{ty}$
Wind Load	$P_{WR} \times D^2 \times 785 + [4 \times M_{WS}/D] - W_2$	$0.8 \times F_y$	$^5/_6\ F_{ty}$
Seismic Load	$[4 \times M_{rw}/D] - W_2\ (1 - 0.4A_V)$	$0.8 \times F_y$	$^5/_6\ F_{ty}$
Design Pressure[a] + Wind	$[(F_p\ P_i + P_{WR}) \times D^2 \times 785] + [4\ M_{WS}/D] - W_1$	$^5/_9 \times F_y$	$^5/_6\ F_{ty}$
Design Pressure[a] + Seismic	$[F_p\ P_i \times D^2 \times 785] + [4\ M_{rw}/D] - W_1\ (1 - 0.4A_V)$	$0.8 \times F_y$	$^5/_6\ F_{ty}$
Frangibility Pressure[b]	$[3 \times P_f \times D^2 \times 785] - W_3$	F_y	F_{ty}

where

A_v is the vertical earthquake acceleration coefficient, in % g;

D is the tank diameter, in meters;

F_p is the pressure combination factor;

F_{ty} is the minimum yield strength of the bottom shell course, in MPa;

F_y is the minimum yield strength of the anchor bolt or strap; bolts are limited to specified material minimum yield strength or 380 MPa, whichever is less, in MPa; anchor strap material minimum yield strength shall not exceed the minimum yield strength of the shell;

H is the tank height, in meters;

M_{WS} equals $P_{WS} \times D \times H^2/2$, in N-m;

M_{rw} is the seismic moment, in N-m (see Annex E);

P_i is the design internal pressure, in kPa (see Annex F);

P_f is the failure pressure, in kPa (see Annex F);

P_t is the test pressure, in kPa (see Annex F);

P_{WR} is the wind uplift pressure on roof, in kPa; for supported cone roofs meeting the requirements of 5.10.4, P_{WR} shall be taken as zero;

P_{WS} is the wind pressure on shell, in N/m^2;

W_1 is the corroded weight of the roof plates plus the corroded weight of the shell and any other corroded permanent attachments acting on the shell, in N;

W_2 is the corroded weight of the shell and any corroded permanent attachments acting on the shell including the portion of the roof plates and framing acting on the shell, in N;

W_3 is the nominal weight of the roof plates plus the nominal weight of the shell and any other permanent attachments acting on the shell, in N.

[a] Refer to 5.2.2 concerning the pressure combination factor applied to the design pressure.

[b] Frangibility pressure applies only to tanks designed to 5.10.2.6 d.

Table 5.20b—Uplift Loads (USC)

Uplift Load Case	Net Uplift Formula, U (lbf)	Allowable Anchor Bolt or Anchor Strap Stress (lbf/in.^{2})	Allowable Shell Stress at Anchor Attachment (lbf/in.^{2})
Design Pressure	$[P_i \times D^2 \times 4.08] - W_1$	$5/12 \times F_y$	$2/3\ F_{ty}$
Test Pressure	$[P_t \times D^2 \times 4.08] - W_3$	$5/9 \times F_y$	$5/6\ F_{ty}$
Wind Load	$P_{WR} \times D^2 \times 4.08 + [4 \times M_{WS}/D] - W_2$	$0.8 \times F_y$	$5/6\ F_{ty}$
Seismic Load	$[4 \times M_{rw}/D] - W_2\ (1 - 0.4A_V)$	$0.8 \times F_y$	$5/6\ F_{ty}$
Design Pressure[a] + Wind	$[(F_p\,P_i + P_{WR}) \times D^2 \times 4.08] + [4\ M_{WS}/D] - W_1$	$5/9 \times F_y$	$5/6\ F_{ty}$
Design Pressure[a] + Seismic	$[F_p\,P_i \times D^2 \times 4.08] + [4\ M_{rw}/D] - W_1\ (1 - 0.4A_V)$	$0.8 \times F_y$	$5/6\ F_{ty}$
Frangibility Pressure[b]	$[3 \times P_f \times D^2 \times 4.08] - W_3$	F_y	F_{ty}

where

- A_v is the vertical earthquake acceleration coefficient, in % g;
- D is the tank diameter, in feet;
- F_p is the pressure combination factor;
- F_{ty} is the minimum yield strength of the bottom shell course, in psi;
- F_y is the minimum yield strength of the anchor bolt or strap; bolts are limited to specified material minimum yield strength or 55,000 psi, whichever is less, in psi; anchor strap material minimum yield strength shall not exceed the minimum yield strength of the shell;
- H is the tank height, in feet;
- M_{WS} equals $P_{WS} \times D \times H^2/2$, in ft-lbs;
- M_{rw} is the seismic moment, in ft-lbs (see Annex E);
- P_i is the design internal pressure, in inches of water column (see Annex F);
- P_f is the failure pressure, in inches of water column (see Annex F);
- P_t is the test pressure, in inches of water column (see Annex F);
- P_{WR} is the wind uplift pressure on roof, in inches of water column; for supported cone roofs meeting the requirements of 5.10.4, P_{WR} shall be taken as zero;
- P_{WS} is the wind pressure on shell, in lbs/ft^2;
- W_1 is the corroded weight of the roof plates plus the corroded weight of the shell and any other corroded permanent attachments acting on the shell, in lbf;
- W_2 is the corroded weight of the shell and any corroded permanent attachments acting on the shell including the portion of the roof plates and framing acting on the shell, in lbf;
- W_3 is the nominal weight of the roof plates plus the nominal weight of the shell and any other permanent attachments acting on the shell, in lbf.

[a] Refer to 5.2.2 concerning the pressure combination factor applied to the design pressure.

[b] Frangibility pressure applies only to tanks designed to 5.10.2.6 d.

In USC units:

$$e_m = 2.125 + d/2 + 6E_tDT$$

where:

d is the anchor bolt diameter in mm (inches);

D is the tank nominal diameter in meters (feet);

e is the design anchor bolt eccentricity in mm (inches);

e_m is the minimum anchor bolt eccentricity in mm (inches);

E_t is the coefficient of thermal expansion of tank floor material in mm/mm °C (in./in. °F);

T is the difference between the ambient temperature and the maximum design temperature in °C (°F).

5.12.5 Allowable stresses for anchor bolts shall be in accordance with Table 5.20a and Table 5.20b for each load case. The allowable stress shall apply to the net root area or area based on nominal corroded shank diameter of the anchor bolt, whichever is less. In the case of hold down straps, the allowable stress shall apply to the corroded or reduced area of the anchor strap, whichever is less. F_y shall be taken at maximum design temperature for uninsulated straps welded directly to the shell and insulated anchors, and at ambient temperature for exposed anchors. Anchor straps shall be evaluated at the cross sectional area where connected to the tank shell and at any reduced cross sectional area, each with the appropriate F_y for the evaluation location.

• **5.12.6** The Purchaser shall specify any corrosion allowance that is to be added to the anchor dimensions. Unless otherwise specified, corrosion allowance for anchor bolts shall be applied to the nominal diameter and not to the threaded part of anchor bolt. When anchor bolts are used, they shall have a corroded shank diameter of no less than 25 mm (1 in.). Carbon steel anchor straps shall have a nominal thickness of not less than 6 mm (1/4 in.) and shall have a minimum corrosion allowance of 1.5 mm (1/16 in.) on each surface for a distance at least 75 mm (3 in.), but not more than 300 mm (12 in.) above the surface of the concrete.

• **5.12.7** Attachment of the anchor bolts to the shell shall be through stiffened chair-type assemblies or anchor rings of sufficient size and height. An acceptable procedure for anchor chair design is given in AISI Steel Plate Engineering Data, Volume 2, Part 5, “Anchor Bolt Chairs.” See Figure 5.28 for typical chair detail. When acceptable to the Purchaser, hold down straps may be used. See 5.12.15 for strap design requirements and Figure 5.29 and Figure 5.30 for typical hold down strap configurations.

5.12.8 Other evaluations of anchor attachments to the shell may be made to ensure that localized stresses in the shell will be adequately handled. An acceptable evaluation technique is given in ASME Section VIII Division 2, Part 5, using the allowable stresses given in this section for S_m. The method of attachment shall take into consideration the effect of deflection and rotation of the shell.

5.12.9 Allowable stresses for anchorage parts shall be in accordance with the ANSI/AISC 360 using allowable strength design methodology (ASD). A 33 % increase of the allowable stress may be used for wind or seismic loading conditions. Wind loading need not be considered in combination with seismic loading.

5.12.10 The maximum allowable local stress in the shell at the anchor attachment shall be in accordance with Table 5.20a and Table 5.20b unless an alternate evaluation is made in accordance with 5.12.8.

5.12.11 The anchors and their attachments shall be designed to allow for radial expansion and contraction of the tank shell resulting from temperature change and product loading. P.2.5.1 shall be used for Radial Growth of Shell calculation methodology. (For variable L, use the vertical distance from the anchor chair top plate to the tank bottom. Temperature change shall be taken from ambient to specified maximum design temperature and from ambient to specified minimum design metal temperature.) See Figure 5.28 for a depiction of the anchor chair top plate bolt-hole slot option.

5.12.12 Any anchor bolts shall be uniformly tightened to a snug fit (nuts hand tight in contact with anchor chair top plate plus maximum of $^1/_8$ turn with wrench) and any anchor straps shall be welded while the tank is filled with test water but before any pressure is applied on top of the water. Measures such as peening the threads, or adding locking nuts, or tack welding nuts to chairs, shall be taken to prevent the nuts from backing off the threads.

5.12.13 The embedment strength of the anchor in the foundation shall be sufficient to develop the specified minimum yield strength of the anchor. Hooked anchors or end plates may be used to resist pullout. See E.6.2.1.2 restrictions for hooked anchors for Annex E tanks. When mechanical anchorage is required for seismic, the anchor embedment or attachment to the foundation, the anchor attachment assembly and the attachment to the shell shall be designed for anchor attachment design load. The anchor attachment design load shall be the lesser of the load equal to the minimum specified yield strength multiplied by the nominal root area of the anchor or three times seismic design uplift load per anchor, T_b, defined in 5.12.2.

5.12.14 The foundation shall provide adequate counterbalancing weight to resist the design uplift loads in accordance with the following.

5.12.14.1 The counterbalancing weight, such as a concrete ringwall, shall be designed so that the resistance to net uplift is in accordance with Table 5.20a and Table 5.20b. When considering uplift due to a wind or seismic moment, an evaluation shall be made to insure overturning stability of the foundation and to insure soil-bearing pressures are within allowable stress levels as determined using the recommendations of Annex B.

5.12.14.2 When a footing is included in the ringwall design, the effective weight of the soil above the footing may be included in the counterbalancing weight.

5.12.15 Anchor strap design provisions include the following.

5.12.15.1 When anchor straps are utilized, the anchorage into the foundation shall be mechanical, and not rely on bond strength. The ability of the detail selected to yield the anchor strap prior to over-stressing the shell shall be demonstrated. Anchor strap embedment shall terminate in an anchor plate welded to the bottom of the strap. The minimum thickness of the anchor plate shall match the thickness of the embedded anchor strap. The minimum width and length of the anchor plate shall match the embedded anchor strap width. Additionally, shear studs may be added to the embedded anchor strap to help develop the anchorage design load.

5.12.15.2 The design and detailing of the strap shall account for corrosion of the strap near the foundation, while not providing excessive steel area that reduces the desirable ductile stretching of the strap under overload. One solution is to contour the strap to produce reduced area over a portion of the strap length. See Figure 5.29 and Figure 5.30. Another solution is to specify stainless steel for the hold down strap portion cast in the foundation as shown in item 2.1 of Figure 5.29 and Figure 5.30. The cross-sectional area of any strap portion cast in the foundation shall be large enough to intentionally yield the upper portion of the strap under overload condition, irrespective of strap materials of construction.

5.12.15.3 Straps may contain a splice weld located above the embedded portion. The splice shall be a double-welded butt joint or single-welded butt joint with back-up bar in accordance with Figure 5.31. Butt welds with or without a back-up bar shall be 100 % radiographic examined, and fillet welds attaching the back-up bar shall be 100 % magnetic particle examined.

5.12.15.4 The details of the anchor strap connection to the tank shell are critical. Attaching the strap with a single horizontal fillet weld is not recommended. Attaching the strap to a thicker reinforcing plate may be necessary to avoid over-stressing the shell. One method of detailing a strap is shown is Figure 5.29. Caulking shall be provided at crevices for carbon steel field attachments inaccessible for welding and those where welding is not part of the prescribed detail; see top of strap detail in Figure 5.30.

5.12.15.5 The design slope of the anchor strap from vertical shall not exceed 5 degrees.

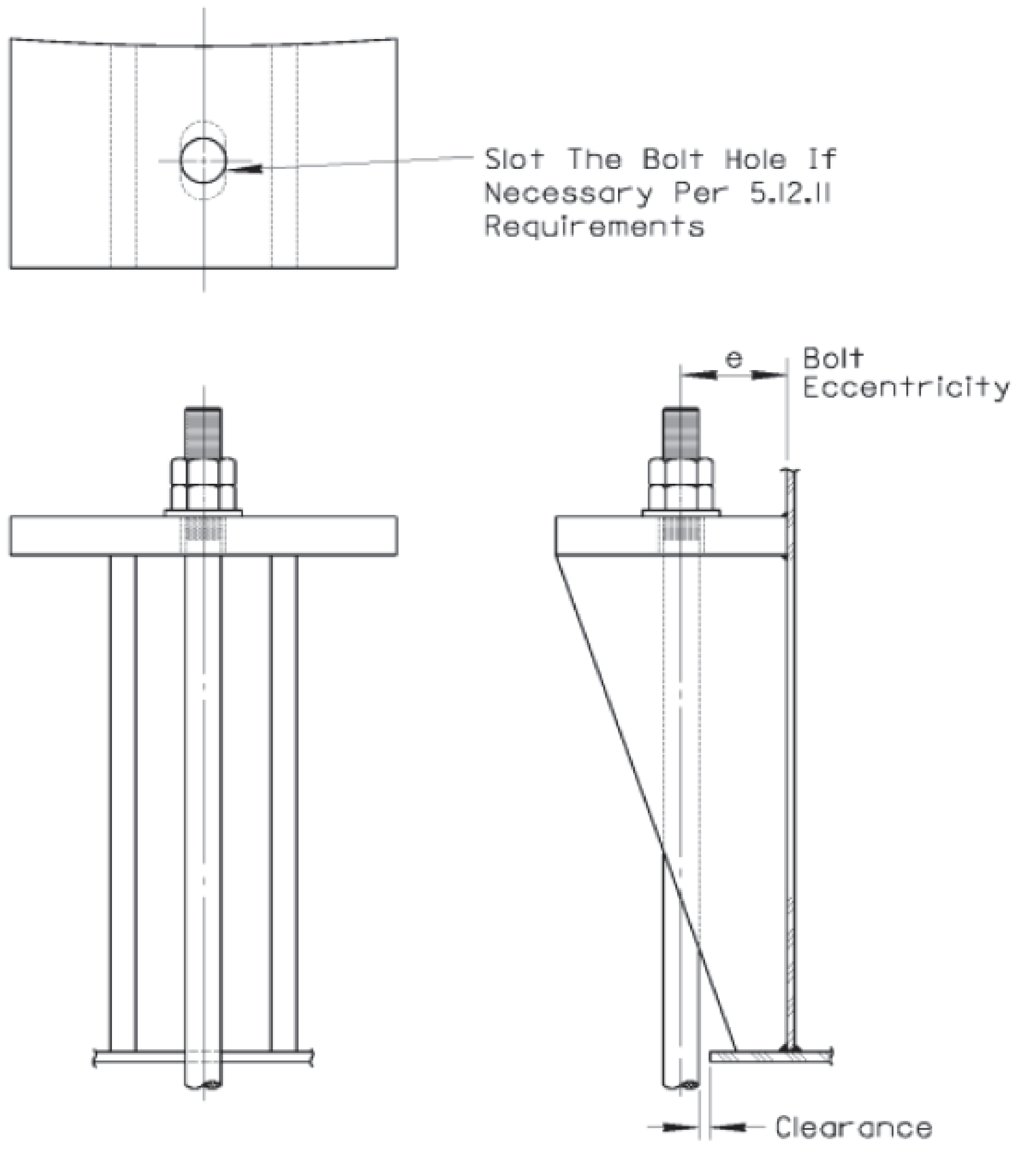
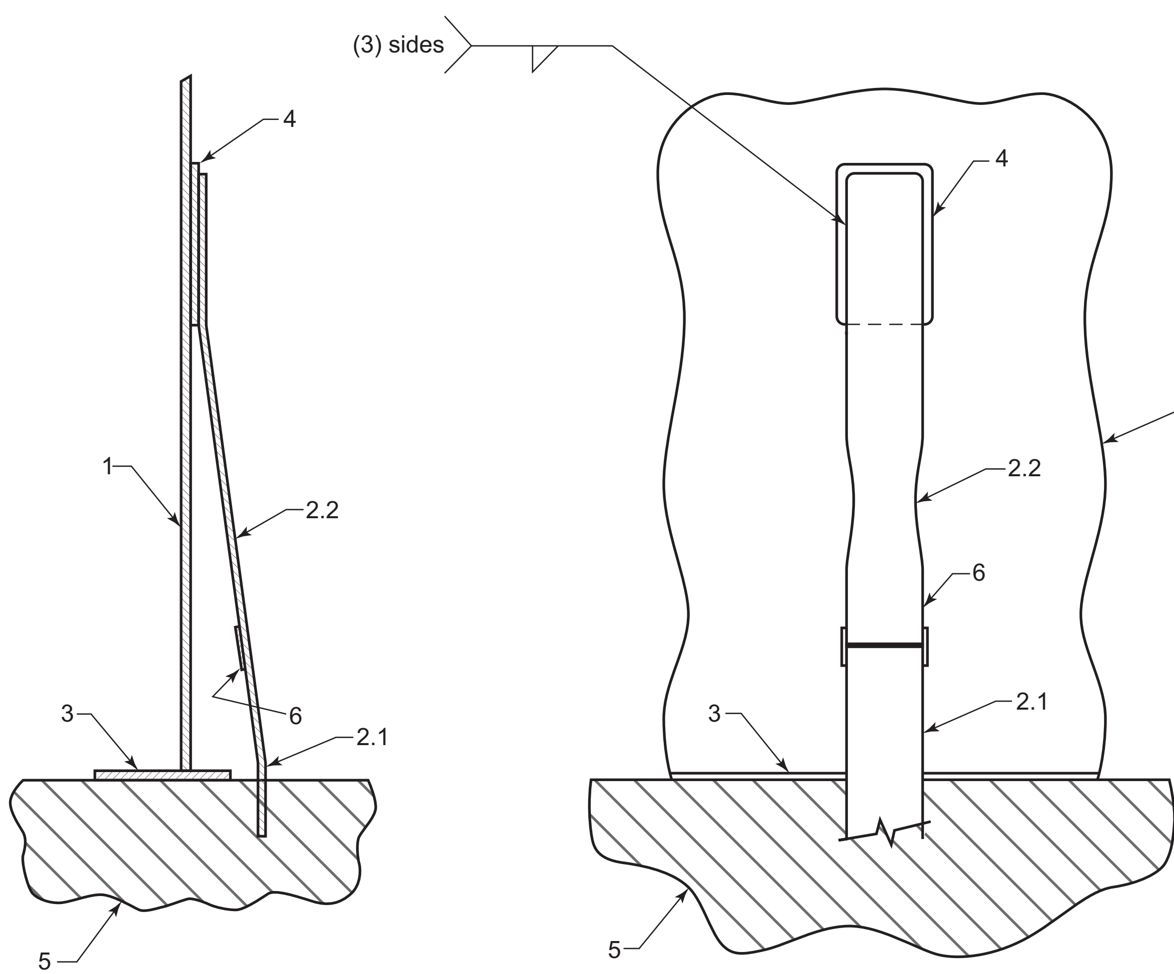


Figure 5.28—Typical Anchor Chair

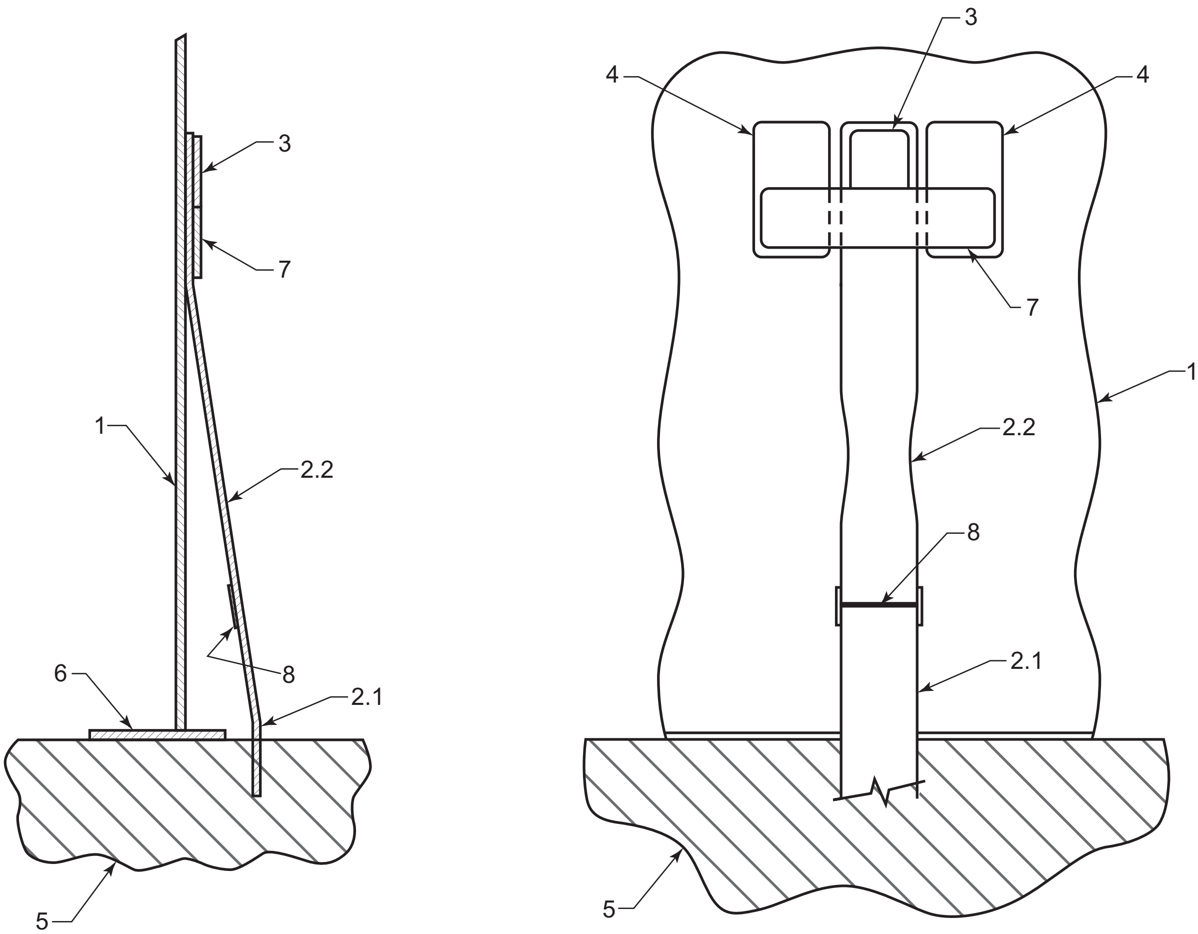


Key

1 tank shell
2.1 SS hold down strap
2.2 CS hold down strap
3 tank bottom
4 shell re-pad
5 base foundation
6 butt weld joint (w/ backing bar)

NOTE Part 2.2 tensile and yield properties of the strap material to be equal to or less than those of the shell plate material.

Figure 5.29—Typical Anchor Strap Welded Attachment (for Carbon Steel Tank)

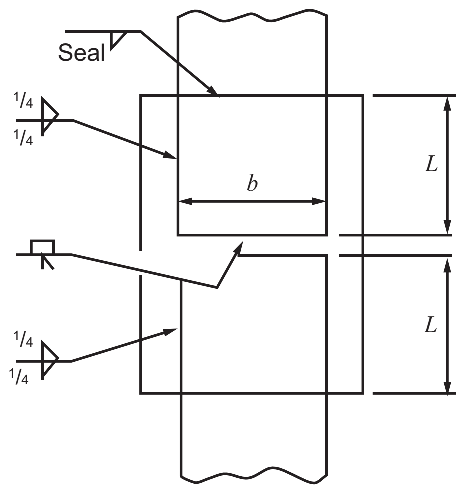


Key

1	tank shell	5	base foundation
2.1	SS hold down strap	6	tank bottom
2.2	CS hold down strap	7	cross plate
3	stopper plate	8	butt weld joint (w/ backing bar)
4	shell re-pads		

NOTE Part 2.2 tensile and yield properties of the strap material to be equal to or less than those of the shell plate material.

Figure 5.30—Typical Hold-down Strap Configuration (for Carbon Steel Tank)



Strap cross-sectional area = $b \times t$

where

b is the strap width

t is the strap thickness

$L_{min} = 1.1 \times b \times t$

where

L is the length of fillet weld

Figure 5.31—Butt Weld Joint with Back-up Bar

5.13 Downward Reactions on Foundations

The vertical reactions acting downward on the tank foundation are given in Table 5.21. Units for reactions are:

a) shell: force/length,

b) bottom: force/area,

c) roof columns: force.

Table 5.21—Unfactored (Working Stress) Downward Reactions on Foundations

Load Case	Location	Load Formula
Dead Load	Shell	$(W_s + W_{rss})/(\Pi D)$
	Column	$W_c + W_{rsc}$
	Bottom	$t_b \gamma_b$
	Column and shell (cable loads for supporting floating roof)	From floating roof design for cable-supported floating roofs
Floating Roof Live Load	Column and shell (cable loads for supporting floating roof)	From floating roof design for cable-supported floating roofs
Internal Pressure	Bottom	P_i
Vacuum	Shell	$(P_e A_{rss})/(\Pi D)$
	Column	$P_e A_{rsc}$
Hydrostatic Test	Bottom	$H\gamma_w$
Minimum Roof Live Load	Shell	$(L_r A_{rss})/(\Pi D)$
	Column	$L_r A_{rsc}$
Seismic	Shell	$[4M_{rw}/D + 0.4\ (W_s + W_{rss})A_v]/(\Pi D)$
	Bottom	Varies linearly from $32M_s/(\Pi D^3)$ at the tank shell to zero at the center of the tank
Snow	Shell	$(SA_{rss})/(\Pi D)$
	Column	SA_{rsc}
Stored Liquid	Bottom	$GH\gamma_w$
Pressure Test	Bottom	P_t
Wind (horizontal wind component)	Shell	$2H_s^2 P_{WS}/(\Pi D)$

where

A_v	is the vertical earthquake acceleration coefficient (Annex E);
D	is the nominal tank diameter;
G	is the design specific gravity of the liquid to be stored;
H	is the maximum design liquid level;
H_s	is the height of the tank shell;
M_{rw}	is the seismic ringwall moment (Annex E);
M_s	is the seismic slab moment (Annex E);
P_i	is the design internal pressure;
P_e	is the design external pressure;
P_t	is the test pressure;
P_{WS}	is the design wind pressure on shell;
t_b	is the thickness of the bottom plate;
A_{rss}	is the area of the tank roof supported by the tank shell;
W_{rss}	is the weight of the tank roof supported by the tank shell;
W_s	is the weight of the tank shell and shell appurtenances;
A_{rsc}	is the area of the tank roof supported by column;
W_{rsc}	is the weight of the tank roof supported by column;
W_c	is the weight of the column;
γ_b	is the density of the bottom plate;
γ_w	is the density of water;
L_r	is the minimum live load on the roof (force/area);
S	is the snow load on the roof (force/area).