1. The tank height is 9 m (30 ft) or greater.
2. The tank shall meet the requirements of 5.10.2.6.a.2-5
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.1-5
2. 08 An elastic analysis[20] 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 anchored tanks of any diameter, the tank shall meet the requirements of 5.10.2.6.a and the anchorage and counterweight shall be designed for 3 times the failure pressure calculated by F.6 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
11 design methodology (ASD).

5.10.3.2 DELETED

5.10.3.3 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.

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[20]A frangible roof satisfies the emergency venting requirement for tanks exposed to fire outside the tank. See API 2000. Frangible roofs are not
08 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.

where

L = unbraced length, mm (in.),

r_c = least radius of gyration of column, mm (in.),

r = governing radius of gyration, mm (in.).

5.10.3.4 DELETED 11

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. 07

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 joints 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:

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

where

b = maximum allowable roof plate span, measured circumferentially from center-to-center of rafters. 08

Fy = specified minimum yield strength of roof plate,

t = corroded roof thickness, 11

p = uniform pressure as determined from load combinations described in Appendix R.

• **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. Where an unstiffened horizontal plate is designed to distribute the load, it shall have a nominal thickness of not less 11 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. 07

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. 11 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.

07 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 Appendix 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.

09 **5.10.4.10** Center columns shall be designed for both the balanced snow load and unbalanced snow load. Intermediate columns need only be designed for the balanced snow load.

• 5.10.5 Self-Supporting Cone Roofs

11 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:

11 Nominal thickness shall not be less than the greatest of $\frac{D}{4.8\sin\theta}\sqrt{\frac{T}{2.2}} + CA$, $\frac{D}{5.5\sin\theta}\sqrt{\frac{U}{2.2}} + CA$, and 5 mm

Corroded thickness shall not be more than 13 mm

where

D = nominal diameter of the tank (m),

T = greater of Appendix R load combinations (e)(1) and (e)(2) with balanced snow load S_b (kPa),

U = greater of Appendix R load combinations (e)(1) and (e)(2) with unbalanced snow load S_u (kPa),

θ = angle of cone elements to the horizontal (deg),

CA = corrosion allowance.

In US Customary units:

Nominal thickness shall not be less than the greatest of $\frac{D}{400\sin\theta}\sqrt{\frac{T}{45}} + CA$, $\frac{D}{460\sin\theta}\sqrt{\frac{U}{45}} + CA$, and $^3/_{16}$ in.

11 Corroded thickness shall not be more than $^1/_2$ in.

where

D = nominal diameter of the tank shell (ft),

T = greater of Appendix R load combinations (e)(1) and (e)(2) with balanced snow load S_b (lbf/ft^2),

U = greater of Appendix R load combinations (e)(1) and (e)(2) with unbalanced snow load S_u (lbf/ft^2),

θ = angle of cone elements to the horizontal (deg),

CA = corrosion allowance.

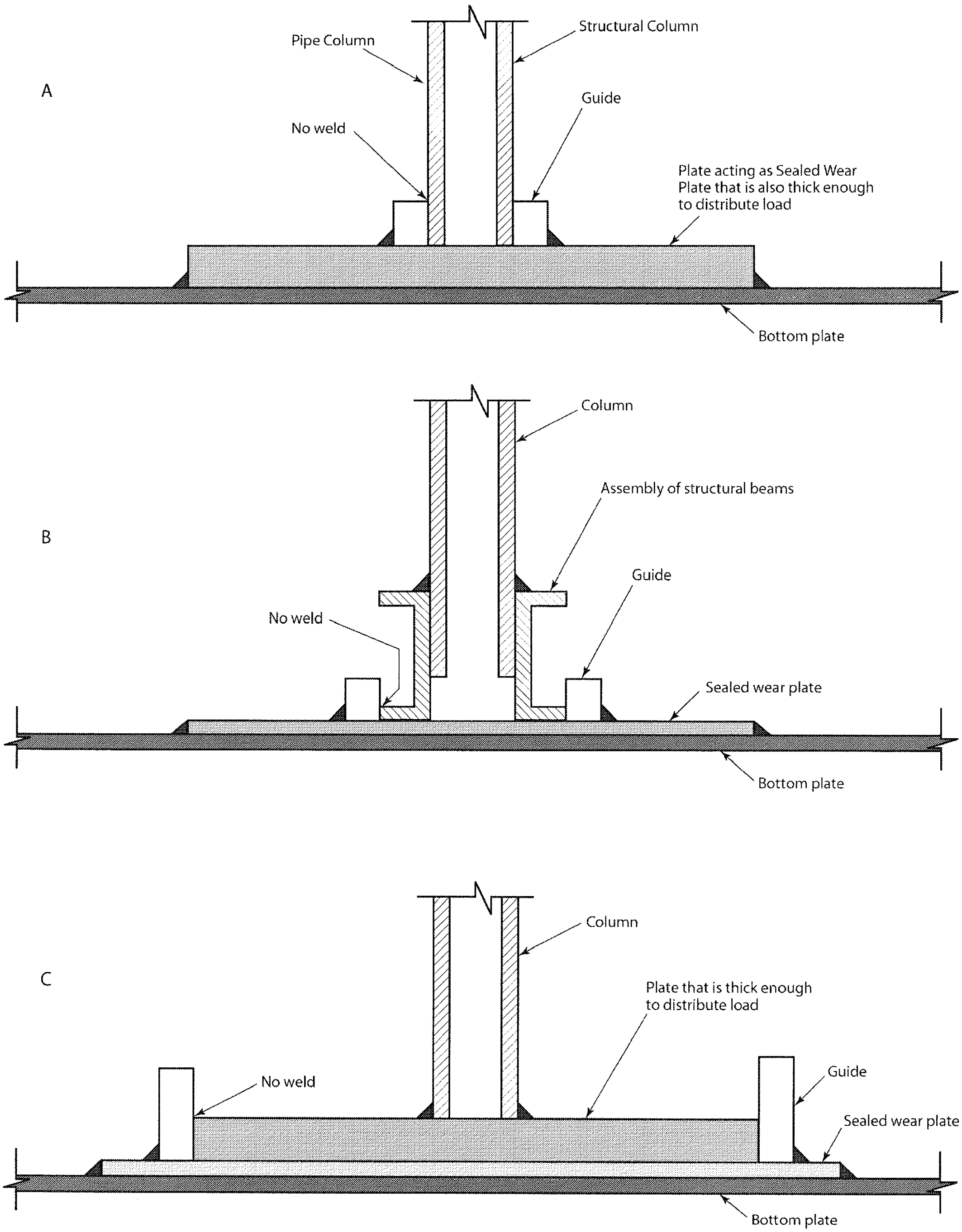

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Figure 5-26—Some Acceptable Column Base Details

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 = greater of load combinations (e)(1) and (e)(2) of Appendix R,

D = nominal diameter of the tank shell,

θ = angle of cone elements to the horizontal,

F_a = the least allowable tensile stress for the materials in the roof-to-shell joint determined in accordance with 5.10.3.1.

• 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.
08

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 $\frac{r_r}{2.4}\sqrt{\frac{T}{2.2}} + CA$, $\frac{r_r}{2.7}\sqrt{\frac{U}{2.2}} + CA$, and 5 mm

11

Corroded thickness shall not be more than 13 mm

where

D = nominal diameter of the tank shell (m),

T = greater of Appendix R load combinations (e)(1) and (e)(2) with balanced snow load S_b (kPa),

U = greater of Appendix R load combinations (e)(1) and (e)(2) with unbalanced snow load S_u (kPa),

r_r = roof radius (m).

09

In US Customary units:

Nominal thickness shall not be less than the greatest of $\frac{r_r}{200}\sqrt{\frac{T}{45}} + CA$, $\frac{r_r}{230}\sqrt{\frac{U}{45}} + CA$, $^3/_{16}$ in.

11

Corroded thickness shall not be more than $^1/_2$ in.

where

D = nominal diameter of the tank shell (ft),

T = greater of Appendix R load combinations (e)(1) and (e)(2) with balanced snow load S_b (lbf/ft^2),

U = greater of Appendix R load combinations (e)(1) and (e)(2) with unbalanced snow load S_u (lbf/ft^2),

r_r = roof radius (ft).

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 09

p = greater of load combinations (e)(1) and (e)(2) of Appendix R,

D = nominal diameter of the tank shell,

θ = angle of cone elements to the horizontal,

F_a = the least allowable tensile stress for the materials in the roof-to-shell joint determined in accordance with 5.10.3.1.

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 Unanchored Tanks 08

Unanchored tanks shall satisfy both of the following uplift criteria:

1. $0.6M_w + M_{Pi} < M_{DL}/1.5 + M_{DLR}$
2. $M_w + F_p(M_{Pi}) < (M_{DL} + M_F)/2 + M_{DLR}$ 11

where

F_P = pressure combination factor, see R.2, 10

M_{Pi} = moment about the shell-to-bottom joint from design internal pressure, 08

M_w = overturning moment about the shell-to-bottom joint from horizontal plus vertical wind pressure,

M_{DL} = moment about the shell-to-bottom joint from the nominal weight of the shell and roof structural supported by the shell that is not attached to roof plate, 11

M_F = moment about the shell-to-bottom joint from liquid weight,

M_{DLR} = moment about the shell-to-bottom joint from the nominal weight of the roof plate plus any attached structural. 11

The liquid weight (w_L) is the weight of a band of liquid at the shell using a specific gravity of 0.7 and a height of one-half the design liquid height H. w_L shall be the lesser of 140.8 HD for SI Units (0.90 HD for USC units) or the following:. 11

In SI units:

$$w_L = 59t_b\sqrt{FbyH} \text{ (N/m)}$$

In US Customary units

$$w_L = 4.67t_b\sqrt{FbyH} \text{ (lbf/ft)}$$

where

Fby = minimum specified yield stress of the bottom plate under the shell MPa (lbf/in.^{2}),

09 H = design liquid height, m (ft),

D = tank diameter, m (ft),

t_b = required corroded thickness of the bottom plate under the shell mm (in.) that is used to resist wind overturning. The
11 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.

09 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:

$$L_b = 0.0291 t_b \sqrt{F_{by}/H} \leq 0.035D \text{ (m)}$$

In US Customary units

$$L_b = 0.365 t_b \sqrt{F_{by}/H} \leq 0.035D \text{ (ft)}$$

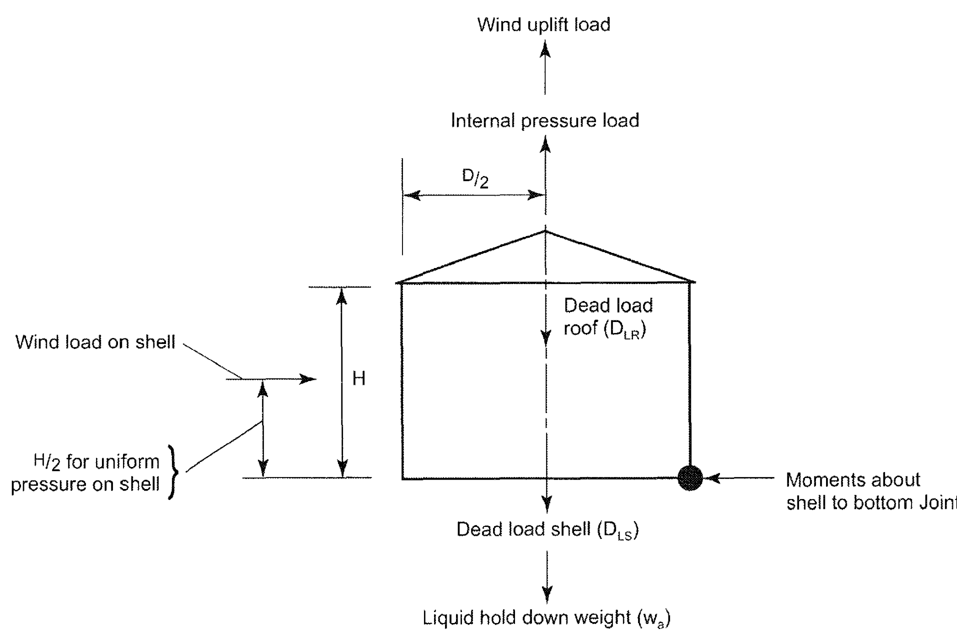
11 

Figure 5-27—Overturning Check for Unanchored Tanks

5.11.3 Anchored Tanks

09 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 anchored per 5.11, Appendix E, Appendix F, or when a tank is anchored for any other reason, the following minimum requirements shall be met.

5.12.2 Anchorage shall be provided to resist each of the uplift load cases listed in Tables 5-21a and 5-21b. The load per anchor shall be: 08

$$t_b = U/N$$

where

t_b = load per anchor,

U = net uplift load per Tables 5-21a and 5-21b, 08

N = number of anchors (a minimum of 4 is required), 07

Table 5-21a—(SI) Uplift Loads

Uplift Load Case	Net Uplift Formula, U (N)	Allowable Anchor Bolt Stress (MPa)	Allowable Shell Stress at Anchor Attachment (MPa)
Design Pressure	$[(P - 0.08t_h) \times D^2 \times 785] - W_1$	105	140
Test Pressure	$[(P_t - 0.08t_h) \times D^2 \times 785] - W_1$	140	170
Failure Pressure[a]	$[(1.5 \times P_f - 0.08t_h) \times D^2 \times 785] - W_3$	F_y	F_{ty}
Wind Load	$P_{WR} \times D^2 \times 785 + [4 \times M_{WH}/D] - W_2$	$0.8 \times F_y$	170
Seismic Load	$[4 \times M_{rw}/D] - W_2 (1 - 0.4A_V)$	$0.8 \times F_y$	170
Design Pressure[b] + Wind	$[(0.4P + P_{WR} - 0.08t_h) \times D^2 \times 785] + [4\ M_{WH}/D] - W_1$	140	170
Design Pressure[b] + Seismic	$[(0.4P - 0.08t_h) \times D^2 \times 785] + [4\ M_{rw}/D] - W_1 (1 - 0.4A_V)$	$0.8 \times F_y$	170
Frangibility Pressure[c]	$[(3 \times P_f - 0.08t_h) \times D^2 \times 785] - W_3$	F_y	F_{ty}

09

11

where

A_v = vertical earthquake acceleration coefficient, % g
D = tank diameter in (m)
F_{ty} = minimum yield strength of the bottom shell course (MPa)
F_y = minimum yield strength of the anchor bolt (MPa)
H = tank height in (m)
M_{WH} = $P_{WS} \times D \times H^2/2$ (N-m)
M_{rw} = seismic moment in (N-m) (see Appendix E)
P = design pressure in (kPa) (see Appendix F)
P_f = failure pressure in (kPa) (see Appendix F)
P_t = test pressure in (kPa) (see Appendix F)
P_{WR} = wind uplift pressure on roof in (kPa)
P_{WS} = wind pressure on shell in (N/m²)
t_h = roof plate thickness (the corroded thickness when used with W_1 and nominal thickness when used with W_3) in (mm)

W_1 = dead load of shell minus any corrosion allowance and any dead load other than roof plate acting on the shell minus any corrosion allowance (N)
W_2 = dead load of shell minus any corrosion allowance and any dead load including roof plate acting on the shell minus any corrosion allowance (N)
W_3 = dead load of the shell using nominal thicknesses and any dead load other than roof plate acting on the shell using nominal thicknesses (N) 11

[a]Failure pressure applies to tanks falling under F.1.3 only. The failure pressure shall be calculated using nominal thicknesses.
[b]Refer to note R.2 in Appendix R for Purchaser guidance when specifying the factor applied to the design pressure.
[c]Frangibility pressure applies only to tanks designed to 5.10.2.6.d. The frangibility pressure shall be calculated using nominal thicknesses.

5.12.3 The spacing between anchors shall not exceed 3 m (10 ft).

5.12.4 Allowable stresses for anchor bolts shall be in accordance with Tables 5-21a and 5-21b for each load case. The allowable stress shall apply to the net (root) area of the anchor bolt. 08

• **5.12.5** 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. The minimum anchor bolt diameter is 1 in. plus any specified corrosion allowance.

08 **Table 5-21b—(USC) Uplift Loads**

Uplift Load Case	Net Uplift Formula, U (lbf)	Allowable Anchor Bolt Stress (lbf/in.²)	Allowable Shell Stress at Anchor Attachment (lbf/in.²)
Design Pressure	$[(P - 8t_h) \times D^2 \times 4.08] - W_1$	15,000	20,000
Test Pressure	$[(P_t - 8t_h) \times D^2 \times 4.08] - W_1$	20,000	25,000
09 Failure Pressure[a]	$[(1.5 \times P_f - 8t_h) \times D^2 \times 4.08] - W_3$	F_y	F_{ty}
Wind Load	$P_{WR} \times D^2 \times 4.08 + [4 \times M_{WH}/D] - W_2$	$0.8 \times F_y$	25,000
Seismic Load	$[4 \times M_{rw}/D] - W_2 (1 - 0.4A_V)$	$0.8 \times F_y$	25,000
Design Pressure[b] + Wind	$[(0.4P + P_{WR} - 8t_h) \times D^2 \times 4.08] + [4 M_{WH}/D] - W_1$	20,000	25,000
Design Pressure[b] + Seismic	$[(0.4P - 8t_h) \times D^2 \times 4.08] + [4 M_{rw}/D] - W_1 (1 - 0.4A_V)$	$0.8 \times F_y$	25,000
Frangibility Pressure[c]	$[(3 \times P_f - 8t_h) \times D^2 \times 4.08] - W_3$	F_y	F_{ty}

where

A_v = vertical earthquake acceleration coefficient, % g

D = tank diameter in (ft)

F_{ty} = minimum yield strength of the bottom shell course (psi)

F_y = minimum yield strength of the anchor bolt (psi)

H = tank height in (ft)

11 M_{WH} = $P_{WS} \times D \times H^2/2$ (ft-lbs)

M_{rw} = seismic moment in (ft-lbs) (see Appendix E)

P = design pressure in inches of water column (see Appendix F)

P_f = failure pressure in inches of water column (see Appendix F)

P_t = test pressure in inches of water column (see Appendix F)

P_{WR} = wind uplift pressure on roof in inches of water column

P_{WS} = wind pressure on shell in (lbs/ft²)

t_h = roof plate thickness (the corroded thickness when used with W_1 and nominal thickness when used with W_3) in (in.)

W_1 = dead load of shell minus any corrosion allowance and any dead load other than roof plate acting on the shell minus any corrosion allowance (lbf)

W_2 = dead load of shell minus any corrosion allowance and any dead load including roof plate acting on the shell minus any corrosion allowance (lbf)

W_3 = dead load of the shell using nominal thicknesses and any dead load other than roof plate acting on the shell using nominal thicknesses (lbf)

[a]Failure pressure applies to tanks falling under F.1.3 only. The failure pressure shall be calculated using nominal thicknesses.

[b]Refer to note R.2 in Appendix R for Purchaser guidance when specifying the factor applied to the design pressure.

[c]Frangibility pressure applies only to tanks designed to 5.10.2.6.d. The frangibility pressure shall be calculated using nominal thicknesses.

● **5.12.6** 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 E-1, Volume II, Part VII "Anchor Bolt Chairs." When acceptable to the Purchaser, anchor straps may be used if the shell attachment is via chair-type assemblies or anchor rings of sufficient size and height.

5.12.7 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, Appendix 4, 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.

5.12.8 Allowable stresses for anchorage parts shall be in accordance with 5.10.3. A 33% increase of the allowable stress may be used for wind or seismic loading conditions.

08 **5.12.9** The maximum allowable local stress in the shell at the anchor attachment shall be in accordance with Tables 5-21a and 5-21b unless an alternate evaluation is made in accordance with 5.12.7.

● **5.12.10** When specified by the Purchaser, the anchors shall be designed to allow for thermal expansion of the tank resulting from a temperature greater than 93°C (200°F).

5.12.11 Any anchor bolts shall be uniformly tightened to a snug fit, 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, shall be taken to prevent the nuts from backing off the threads.

5.12.12 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.

5.12.13 The foundation shall provide adequate counterbalancing weight to resist the design uplift loads in accordance with the following:

5.12.13.1 The counterbalancing weight, such as a concrete ringwall, shall be designed so that the resistance to net uplift is in accordance with Tables 5-21a and 5-21b. When considering uplift due to a wind or seismic moment, an evaluation shall be made 08 to insure overturning stability of the foundation and to insure soil-bearing pressures are within allowable stress levels as determined using the recommendations of Appendix B.

5.12.13.2 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.

SECTION 6—FABRICATION

6.1 GENERAL

6.1.1 Workmanship

● **6.1.1.1** All work of fabricating API Std 650 tanks shall be done in accordance with this Standard and with the permissible alternatives specified in the Purchaser's inquiry or order. The workmanship and finish shall be first class in every respect and subject to the closest inspection by the Manufacturer's inspector even if the Purchaser has waived any part of the inspection.

6.1.1.2 When material requires straightening, the work shall be done by pressing or another noninjurious method prior to any layout or shaping. Heating or hammering is not permissible unless the material is maintained at forging temperature during straightening.

6.1.1.3 Materials used to aid in the fabrication of tanks shall not have a detrimental effect on the structural integrity of the tank. Lubricants, crayons, adhesives, and anti-weld spatter compounds shall not contain materials that will be detrimental to the tank, e.g., sulfur and chloride compounds for stainless steel materials. Attachments that will be welded to the pressure boundary shall not have a zinc or cadmium coating in the weld area within 12 mm (0.5 in.) of the weld. 07

6.1.2 Finish of Plate Edges

The edges of plates may be sheared, machined, chipped, or machine gas cut. Shearing shall be limited to plates less than or equal to 10 mm ($^{3}/_{8}$ in.) thick used for butt-welded joints and to plates less than or equal to 16 mm ($^{5}/_{8}$ in.) thick used for lap-welded joints.

● Note: With the Purchaser's approval, the shearing limitation on plates used for butt-welded joints may be increased to a thickness less than or equal to 16 mm ($^{5}/_{8}$ in.).

When edges of plates are gas cut, the resulting surfaces shall be uniform and smooth and shall be freed from scale and slag accumulations before welding. After cut or sheared edges are wire brushed, the fine film of rust adhering to the edges need not be removed before welding. Circumferential edges of roof and bottom plates may be manually gas cut.

● 6.1.3 Shaping of Shell Plates

Figure 6-1 provides criteria for shaping of plates to the curvature of the tank prior to installation in the tank. Shaping of plates concurrently with installation in the tank shell is permitted if the tank diameter exceeds the limit in Figure 6-1 or if the Manufacturer's alternate procedure for any diameter has been accepted by the Purchaser.

6.1.4 Marking

All special plates that are cut to shape before shipment as well as roof-supporting structural members shall be marked as shown on the Manufacturer's drawings.

6.1.5 Shipping

Plates and tank material shall be loaded in a manner that ensures delivery without damage. Bolts, nuts, nipples, and other small parts shall be boxed or put in kegs or bags for shipment. All flange faces and other machined surfaces shall be protected against corrosion and from physical damage. 07

6.2 SHOP INSPECTION

● **6.2.1** The Purchaser's inspector shall be permitted free entry to all parts of the Manufacturer's plant that are concerned with the contract whenever any work under the contract is being performed. The Manufacturer shall afford the Purchaser's inspector all reasonable facilities to assure the inspector that the material is being furnished in accordance with this Standard. Also, the Manufacturer shall furnish samples or specimens of materials for the purpose of qualifying welders in accordance with 9.3.

Unless otherwise specified, inspection shall be made at the place of manufacture prior to shipment. The Manufacturer shall give the Purchaser ample notice of when the mill will roll the plates and when fabrication will begin so that the Purchaser's inspector may be present when required. The usual mill test of plates shall be deemed sufficient to prove the quality of the steel furnished (except as noted in 6.2.2). Mill test reports or certificates of compliance, as provided for in the material specification, shall be furnished to the Purchaser only when the option is specified in the original contract that they be provided.

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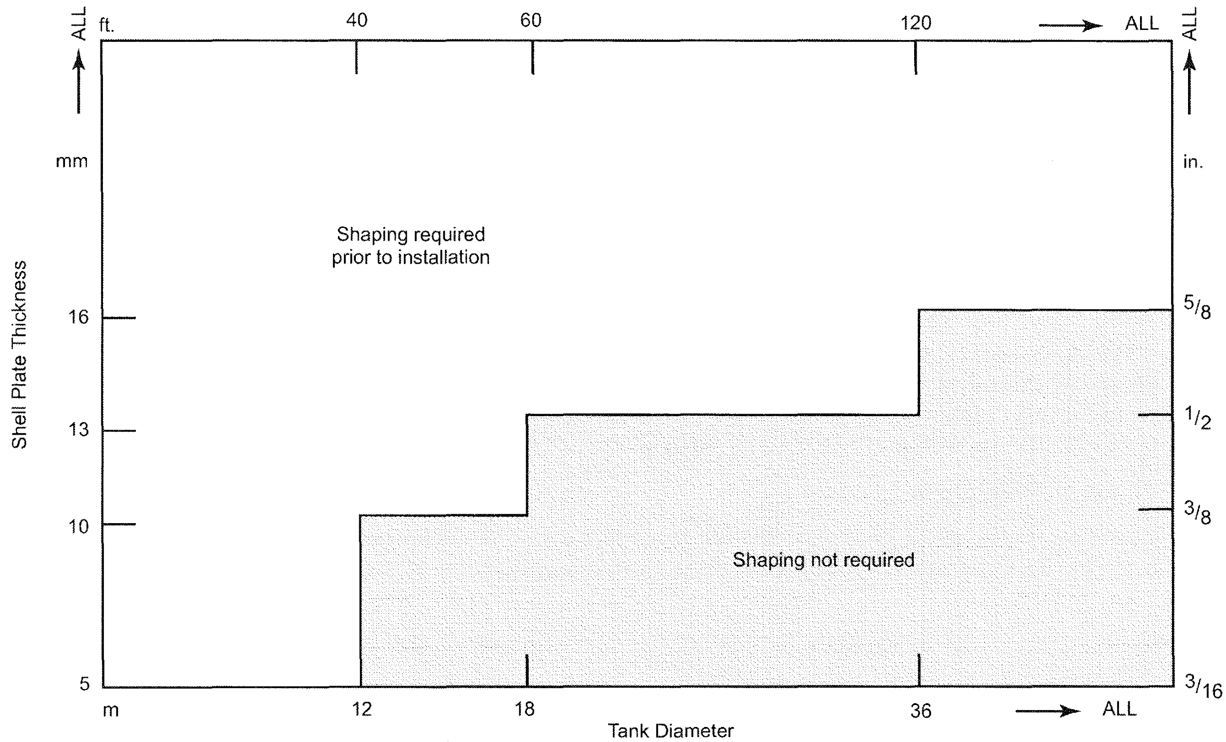


Note: Any combination of diameter and thickness falling on or above the solid line requires shaping prior to installation.

Figure 6-1—Shaping of Plates

6.2.2 Mill and shop inspection shall not release the Manufacturer from responsibility for replacing any defective material and for repairing any defective workmanship that may be discovered in the field.

• **6.2.3** Any material or workmanship that in any way fails to meet the requirements of this Standard may be rejected by the Purchaser's inspector, and the material involved shall not be used under the contract. Material that shows injurious defects subsequent to its acceptance at the mill, subsequent to its acceptance at the Manufacturer's works, or during erection and testing of the tank will be rejected. The Manufacturer will be notified of this in writing and will be required to furnish new material promptly and make the necessary replacements or suitable repairs.

• **6.2.4** a. The Manufacturer shall visually inspect all edges of shell and roof plates before installing the plates in the tank or before inserting a nozzle into the plate to determine if laminations are present. If a lamination is visually detected, the Manufacturer shall ultrasonically test the area to determine the extent of the laminations and shall reject the plate or make repairs in accordance with 6.2.4b.

07 b. For laminations found not exceeding 75 mm (3 in.) in length or 25 mm (1 in.) in depth, repairs may be made by edge gouging and rewelding to seal the lamination. The Manufacturer shall submit the edge repair procedure for Purchaser acceptance prior to the start of fabrication. For laminations exceeding these limits, the Manufacturer shall either reject the plate or repair the plate by entirely removing the lamination. Before making such repairs the Manufacturer shall document the extent of the lamination and submit a case-specific repair procedure for Purchaser approval.

SECTION 7—ERECTION

7.1 GENERAL

• **7.1.1** Required foundation and grade work shall be supplied by the Purchaser, unless otherwise specified in the Contract. The Manufacturer shall check level tolerances and contour before starting work, and shall notify the Purchaser of any deficiency discovered that might affect the quality of the finished work. Deficiencies noted shall be rectified by the Purchaser unless otherwise agreed by the Manufacturer.

7.1.2 After the Purchaser has turned the tank foundation over to the Manufacturer, the Manufacturer shall maintain the grade under the tank in true profile and free of foreign materials such as clay, coal, cinders, metal scraps, or animal or vegetable matter of any sort. The Manufacturer shall repair any damage to either the foundation or grade surface caused by the Manufacturer's operations.

7.1.3 Coating or foreign material shall not be used between surfaces in contact in the construction of the tank, except as permitted by 7.2.1.9.

• **7.1.4** Coating or other protection for structural work inside and outside of the tank shall be as specified in the contract and shall 07
be applied by competent workers.

7.1.5 All temporary attachments welded to the exterior of the tank shall be removed and any noticeable projections of weld metal shall be ground smooth with the surface of the plate. In the event of inadvertent tearing of the plate when attachments are removed, the damaged area shall be repaired by welding and subsequent grinding of the surface to a smooth condition.

7.1.6 All temporary attachments welded to the interior of the tank, including the shell, roof, tank bottom, roof columns and other internal structures shall be removed and any noticeable projections of weld metal shall be ground smooth. In the event of inadvertent tearing of the plate when attachments are removed, the damaged area shall be repaired by welding and subsequent grinding of the surface to a smooth condition. This work must be completed before the application of internal linings, the air rais- 11
ing of a fixed roof, the initial floating of a floating roof, and any other circumstance whereby projections may cause damage.

7.2 DETAILS OF WELDING

7.2.1 General

• **7.2.1.1** Tanks and their structural attachments shall be welded by the shielded metal-arc, gas metal-arc, gas tungsten-arc, oxyfuel, flux-cored arc, submerged-arc, electroslag, or electrogas process using suitable equipment. Use of the oxyfuel, electroslag, or electrogas process shall be by agreement between the Manufacturer and the Purchaser. Use of the oxyfuel process is not permitted when impact testing of the material is required. All tank welding shall be performed by manual, semiautomatic arc, machine, or automatic welding in accordance with the requirements of Section 9 of this Standard and welding procedure specifi- 11
cations as described in Section IX of the ASME *Code*. Welding shall be performed in a manner that ensures complete fusion with the base metal. At the Purchaser's request, the Purchaser may designate applicable sections of API RP 582 for supplementary
welding guidelines and practices. 08

7.2.1.2 No welding of any kind shall be performed when the surfaces to be welded are wet from rain, snow, or ice; when rain or snow is falling on such surfaces; or during periods of high winds unless the welder and the work are properly shielded. Also, preheat shall be applied when metal temperature is below the temperature required by Tables 7-1a and 7-1b. In that case the base metal shall be heated to at least the temperature indicated in Tables 7-1a and 7-1b within 75 mm (3 in.) of the place where welding is to be started and maintained 75 mm (3 in.) ahead of the arc.

Table 7-1a—(SI) Minimum Preheat Temperatures

Material Group per Table 4-4a	Thickness (t) of Thicker Plate (mm)	Minimum Preheat Temperature	11
Groups I, II, III & IIIA	$t \le 32$	0°C	08
	$32 < t \le 40$	10°C	
	$t > 40$	93°C	
Groups IV, IVA, V & VI	$t \le 32$	10°C	
	$32 < t \le 40$	40°C	
	$t > 40$	93°C	

Table 7-1b—(USC) Minimum Preheat Temperatures

	Material Group per Table 4-4b	Thickness (t) of Thicker Plate (in.)	Minimum Preheat Temperature
11	Groups I, II, III & IIIA	$t \leq 1.25$	32°F
08		$1.25 < t \leq 1.50$	50°F
		$t > 1.50$	200°F
	Groups IV, IVA, V & VI	$t \leq 1.25$	50°F
		$1.25 < t \leq 1.50$	100°F
		$t > 1.50$	200°F

7.2.1.3 Each layer of weld metal or multilayer welding shall be cleaned of slag and other deposits before the next layer is applied.

7.2.1.4 The edges of all welds shall merge smoothly with the surface of the plate without a sharp angle.

07 **7.2.1.5** All welding shall be free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys that interfere with interpretation of NDE results.

7.2.1.6 During the welding operation, plates shall be held in close contact at all lap joints.

• **7.2.1.7** The method proposed by the Manufacturer for holding the plates in position for welding shall be submitted to the Purchaser's inspector for approval if approval has not already been given in writing by the Purchaser.

7.2.1.8 Tack welds used during the assembly of vertical joints of tank shells shall be removed and shall not remain in the finished joints when the joints are welded manually. When such joints are welded by the submerged-arc process, the tack welds shall be thoroughly cleaned of all welding slag but need not be removed if they are sound and are thoroughly fused into the subsequently applied weld beads.

Whether tack welds are removed or left in place, they shall be made using a fillet-weld or butt-weld procedure qualified in accordance with Section IX of the ASME *Code*. Tack welds to be left in place shall be made by welders qualified in accordance with Section IX of the ASME *Code* and shall be visually examined for defects, which shall be removed if found (see 8.5 for criteria for visual examination).

7.2.1.9 If protective coatings are to be used on surfaces to be welded, the coatings shall be included in welding-procedure qualification tests for the brand formulation and maximum thickness of coating to be applied.

7.2.1.10 Low-hydrogen electrodes shall be used for all manual metal-arc welds in annular rings and shell courses, including the attachment of the first shell course to bottom or annular plates, as follows:

a. Where the plates are thicker than 12.5 mm ($^1/_2$ in.) (based on the thickness of the thicker member being joined) and made of material from Groups I–III.

b. For all thicknesses when the plates are made of material from Groups IV, IVA, V and VI.

7.2.1.11 Non-structural small attachments such as insulation clips, studs and pins but not insulation support rings or bars may be welded by the arc stud, capacitor discharge or shielded metal arc process to the exterior of the shell including reinforcing plates or PWHT assemblies and roof either before or after hydrostatic testing is performed, but before the tank will be filled with product provided:

a. The attachment locations meet the spacing requirements of 5.8.1.2a.

b. The arc stud welding process is limited to 10 mm ($^3/_8$ in.) maximum diameter studs or equivalent cross-section.

c. The maximum shielded metal arc electrode is limited to 3 mm ($^1/_8$ in.) diameter and shall be a low-hydrogen type.

d. The attachment welds, except for those made by the capacitor discharge method, shall be inspected per 7.2.3.5. The attachment welds made by the capacitor discharge method shall be visually examined for all types and groups of shell materials.

e. All stud welding and capacitor discharge procedures have been qualified in accordance with ASME Section IX. Capacitor discharge procedures do not require procedure qualification provided the power output is 125 watt-sec or less.

The shielded metal arc weld procedures shall meet the requirements of Section 9 for qualification for use.

7.2.2 Bottoms

7.2.2.1 After the bottom plates are laid out and tacked, they shall be joined by welding the joints in a sequence that the Manufacturer has found to result in the least distortion from shrinkage and thus to provide as nearly as possible a plane surface.

7.2.2.2 The welding of the shell to the bottom shall be practically completed before the welding of bottom joints that may have been left open to compensate for shrinkage of any welds previously made is completed.

7.2.2.3 Shell plates may be aligned by metal clips attached to the bottom plates, and the shell may be tack welded to the bottom before continuous welding is started between the bottom edge of the shell plate and the bottom plates.

7.2.3 Shells

7.2.3.1 Plates to be joined by butt welding shall be matched accurately and retained in position during the welding operation. Misalignment in completed vertical joints for plates greater than 16 mm ($^5/_8$ in.) thick shall not exceed 10% of the plate thickness or 3 mm ($^1/_8$ in.), whichever is less; misalignment for plates less than or equal to 16 mm ($^5/_8$ in.) thick shall not exceed 1.5 mm ($^1/_{16}$ in.).

7.2.3.2 In completed horizontal butt joints, the upper plate shall not project beyond the face of the lower plate at any point by more than 20% of the thickness of the upper plate, with a maximum projection of 3 mm ($^1/_8$ in.); however, for upper plates less than 8 mm ($^5/_{16}$ in.) thick, the maximum projection shall be limited to 1.5 mm ($^1/_{16}$ in.). The upper plate at a horizontal butt joint shall have a 4:1 taper when its thickness is more than 3 mm ($^1/_8$ in.) greater than the lower plate. 08

• **7.2.3.3** The reverse side of double-welded butt joints shall be thoroughly cleaned in a manner that will leave the exposed surface satisfactory for fusion of the weld metal to be added, prior to the application of the first bead to the second side. This cleaning may be done by chipping; grinding; melting out; or where the back of the initial bead is smooth and free from crevices that might entrap slag, another method that, upon field inspection, is acceptable to the Purchaser.

7.2.3.4 For circumferential and vertical joints in tank shell courses constructed of material more than 40 mm ($1^1/_2$ in.) thick (based on the thickness of the thicker plate at the joint), multipass weld procedures are required, with no pass over 19 mm ($^3/_4$ in.) thick permitted. 08

7.2.3.5 The requirements of this section shall be followed when welding to Group IV, IVA, V, and VI materials. Permanent and temporary attachments (see 7.2.1.10 for information on shell-to-bottom welds) shall be welded with low-hydrogen electrodes. Both permanent and temporary attachments shall be welded in accordance with a procedure that minimizes the potential for underbead cracking. The welds of permanent attachments (not including shell-to-bottom welds) and areas where temporary attachments are removed, shall be examined visually and by either the magnetic particle method or by the liquid penetrant method (see 8.2, 8.4, or 8.5 for the appropriate inspection criteria).

7.2.3.6 Completed welds of stress-relieved assemblies shall be examined by visual, as well as by magnetic particle or penetrant methods, after stress relief, but before hydrostatic test.

7.2.3.7 Flush-type connections shall be inspected according to 5.7.8.11.

7.2.4 Shell-to-Bottom Welds

• **7.2.4.1** The initial weld pass inside the shell shall have all slag and non-metals removed from the surface of the weld and then examined for its entire circumference prior to welding the first weld pass outside the shell (temporary weld fit-up tacks excepted), both visually and by one of the following methods to be agreed to by Purchaser and the Manufacturer:

a. Magnetic particle.

b. Applying a solvent liquid penetrant to the weld and then applying a developer to the gap between the shell and the bottom and examining for leaks after a minimum dwell time of one hour.

c. Applying a water-soluble liquid penetrant to either side of the joint and then applying a developer to the other side of the joint and examining for leaks after a minimum dwell time of one hour.

d. Applying a high flash-point penetrating oil such as light diesel to the gap between the shell and the bottom, letting stand for at least four hours, and examining the weld for evidence of wicking.

Note: Residual oil may remain on the surfaces yet to be welded even after the cleaning required below and contamination of the subsequent weld is possible.

e. Applying a bubble-forming solution to the weld, using a right angle vacuum box, and examining for bubbles.

Thoroughly clean all residual examination materials from the as yet to be welded surfaces and from the unwelded gap between the shell and bottom. Remove defective weld segments and reweld as required. Reexamine the repaired welds and a minimum of 150 mm (6 in.) to either side in the manner described above. Repeat this clean-remove-repair-examine-and-clean process until there is no evidence of leaking. Complete all welding passes of the joint both inside and outside the shell. Visually examine the finished weld surfaces of the joint both inside and outside the shell for their entire circumference.

7.2.4.2 As an alternative to 7.2.4.1, the initial weld passes, inside and outside of the shell, shall have all slag and non-metals removed from the surface of the welds and the welds shall be examined visually. Additionally, after the completion of the inside and outside fillet or partial penetration welds, the welds may be tested by pressurizing the volume between the inside and outside
08 welds with air pressure to 100 kPa (15 lbf/in.^{2} gauge) and applying a solution film to both welds. To assure that the air pressure reaches all parts of the welds, a sealed blockage in the annular passage between the inside and outside welds must be provided by welding at one or more points. Additionally, a small pipe coupling communicating with the volume between the welds must be connected at one end and a pressure gauge connected to a coupling on the other end of the segment under test.

• **7.2.4.3** By agreement between the Purchaser and the Manufacturer, the examinations of 7.2.4.1 may be waived if the following examinations are performed on the entire circumference of the weld(s):

a. Visually examine the initial weld pass (inside or outside).

b. Visually examine the finished joint welded surfaces, both inside and outside the shell.

c. Examine either side of the finished joint weld surfaces by magnetic particle, or liquid penetrant, or right angle vacuum box.

7.2.5 Roofs

Except for the stipulation that the structural framing (such as the rafters and girders) of the roof must be reasonably true to line and surface, this Standard does not include special stipulations for erection of the roof.

7.3 INSPECTION, TESTING, AND REPAIRS

7.3.1 General

7.3.1.1 The Purchaser's inspector shall at all times have free entry to all parts of the job while work under the contract is being performed. The Manufacturer shall afford the Purchaser's inspector reasonable facilities to assure the inspector that the work is being performed in accordance with this Standard.

7.3.1.2 Any material or workmanship shall be subject to the replacement requirements of 6.2.3.

• **7.3.1.3** Material that is damaged by defective workmanship or that is otherwise defective will be rejected. The Manufacturer will be notified of this in writing and will be required to furnish new material promptly or to correct defective workmanship.

7.3.1.4 Before acceptance, all work shall be completed to the satisfaction of the Purchaser's inspector, and the entire tank, when filled with oil, shall be tight and free from leaks.

7.3.2 Inspection of Welds

• 7.3.2.1 Butt-Welds

Complete penetration and complete fusion are required for welds joining shell plates to shell plates. Inspection for the quality of the welds shall be made using either the radiographic method specified in 8.1 or alternatively, by agreement between the Purchaser and the Manufacturer, using the ultrasonic method specified in 8.3.1 (see Appendix U). In addition to the radiographic or
07 ultrasonic examination, these welds shall also be visually examined. Furthermore, the Purchaser's inspector may visually inspect all butt-welds for cracks, arc strikes, excessive undercut, surface porosity, incomplete fusion, and other defects. Acceptance and repair criteria for the visual method are specified in 8.5.

7.3.2.2 Fillet Welds

Fillet welds shall be inspected by the visual method. The final weld shall be cleaned of slag and other deposits prior to inspection. Visual examination acceptance and repair criteria are specified in 8.5.

• 7.3.2.3 Responsibility

The Manufacturer shall be responsible for making radiographs and any necessary repairs; however, if the Purchaser's inspector requires radiographs in excess of the number specified in Section 6, or requires chip-outs of fillet welds in excess of one per 30 m (100 ft) of weld and no defect is disclosed the additional inspections and associated work shall be the responsibility of the Purchaser.

7.3.3 Examination and Testing of the Tank Bottom

Upon completion of welding of the tank bottom, the bottom welds and plates shall be examined visually for any potential defects and leaks. Particular attention shall apply to areas such as sumps, dents, gouges, three-plate laps, bottom plate breakdowns, arc strikes, temporary attachment removal areas, and welding lead arc burns. Visual examination acceptance and repair criteria are specified in 8.5. In addition, all welds shall be tested by one of the following methods: 11

a. A vacuum-box test in accordance with 8.6.

b. A tracer gas test in accordance with 8.6.11.

c. After at least the lowest shell course has been attached to the bottom, water (to be supplied by the Purchaser) shall be pumped underneath the bottom. A head of 150 mm (6 in.) of liquid shall be maintained using a temporary dam to hold that depth around the edge of the bottom. The line containing water for testing may be installed temporarily by running it through a manhole to one or more temporary flange connections in the bottom of the tank, or the line may be installed permanently in the subgrade beneath the tank. The method of installation should be governed by the nature of the subgrade. Reasonable care shall be taken to preserve the prepared subgrade under the tank.

7.3.4 Inspection of Reinforcing-Plate Welds

After fabrication is completed but before the tank is filled with test water, the reinforcing plates shall be tested by the Manufacturer by applying up to 100 kPa (15 lbf/in.^{2}) gauge pneumatic pressure between the tank shell and the reinforcement plate on each opening using the telltale hole specified in 5.7.5.1. While each space is subjected to such pressure, a soap film, linseed oil, or another material suitable for the detection of leaks shall be applied to all attachment welding around the reinforcement, both inside and outside the tank.

• 7.3.5 Testing of the Shell

After the entire tank and roof structure is completed, the shell (except for the shell of tanks designed in accordance with Appendix F) shall be tested by one of the following methods, as specified on the Data Sheet, Line 14: 07

• 1. If water is available for testing the shell, the tank shall be filled with water as follows: (1) to the maximum design liquid level, H; (2) for a tank with a tight roof, to 50 mm (2 in.) above the weld connecting the roof plate or compression bar to the top angle or shell; (3) to a level lower than that specified in Subitem 1 or 2 when restricted by overflows, an internal floating roof, or other freeboard by agreement between the Purchaser and the Manufacturer, or 4) to a level of seawater producing a bottom of shell hoop stress equal to that produced by a full-height fresh water test. The tank shall be inspected frequently during the filling operation, and any welded joints above the test-water level shall be examined in accordance with Item 2 below. This test shall be conducted before permanent external piping is connected to the tank. Attachments to 08 the shell defined in 5.8.1.1, located at least 1 m (3 ft) above the water level, and roof appurtenances may be welded during the filling of the tank. After completion of the hydro-test, only non-structural small attachments may be welded to the tank in accordance with 7.2.1.11.

2. If sufficient water to fill the tank is not available, the tank may be tested by (1) painting all of the joints on the inside with a highly penetrating oil, such as automobile spring oil, and carefully examining the outside of the joints for leakage; (2) applying vacuum to either side of the joints or applying internal air pressure as specified for the roof test in 7.3.7 and carefully examining the joints for leakage; or (3) using any combination of the methods stipulated in 7.3.5, Subitems 1 and 2.

7.3.6 Hydrostatic Testing Requirements 07

7.3.6.1 This hydrostatic test of the tank shall be conducted before permanent external piping is connected to the tank. Attachments to the shell defined in 5.8.1.1, located at least 1 m (3 ft) above the water level, and roof appurtenances may be welded during the filling of the tank. After completion of the hydro-test, only non-structural small attachments may be welded to the tank in accordance with 7.2.1.11. Any welded joints above the test-water level shall be examined for leakage by one of the following methods:

11 1. applying a highly penetrating oil on all interior weld joints, e.g., automobile spring oil, and carefully examining the outside of the joints for leakage;

2. applying vacuum to either side of the joints or applying internal air pressure as specified for the roof test in 7.3.7 and carefully examining the joints for leakage; or

3. using any combination of the methods stipulated in Subitems 1 and 2.

7.3.6.2 The Manufacturer shall be responsible for:

1. Preparing the tank for testing. This shall include removal of all trash, debris, grease, oil, weld scale, weld spatter, and any other foreign matter from the interior and the roof(s) of the tank.

• 2. Furnishing, laying, and removing all lines from the water source tie-in location and to the water disposal point as prescribed on the Data Sheet, Line 14.

• 3. Filling and emptying the tank. (See 1.3 for Purchaser responsibility to obtain any required permits for disposal of water.)

• 4. Cleaning, rinsing, drying, or other prescribed activity, if specified on Data Sheet, Line 14, following the hydro-test to make the tank ready for operation.

• 5. Taking settlement measurements (unless explicitly waived by the Purchaser on the Data Sheet, Line 14).

6. Furnishing all other test materials and facilities, including blinds, bolting, and gaskets (see 4.9).

• 7. Checking the wind girders for proper drainage during or following the hydro-test. If water is retained, additional drainage shall be provided subject to the Purchaser's approval.

• **7.3.6.3** The Purchaser shall be responsible for:

07 1. Furnishing and disposing of the water for hydro-testing the tank from the water source tie-in location as designated on the Data Sheet, Line 14. If biocide or caustic additions are specified to the Manufacturer, the Purchaser is responsible for determining or identifying disposal restrictions on the treated water.

2. Specifying the test water quality. Potable water is preferred for hydro-testing. This does not preclude the use of condensate, reverse osmosis water, well water, river water, or sea water. The Purchaser shall consider issues such as-low temperature brittle fracture, freeze damage, amount of suspended solids, sanitation issues, animal/plant incubation and/or growth, acidity, general corrosion, pitting, protecting against cathodic cells, microbiologically-induced corrosion, material dependent sensitivity to trace chemical attack, disposal, rinsing, and residuals left in the tank after emptying. If the Purchaser-supplied test water causes corrosion, the Purchaser is responsible for the required repairs.

3. For the following metallurgies, describe on the Data Sheet, Line 14, (using a Supplemental Specification) any additional restrictions on the water quality:

   a. Carbon Steel—For carbon steel equipment where water contact exceeds 14 days, including filling and draining (e.g., consider adding an oxygen scavenger and a biocide, and raise the pH by the addition of caustic).

   b. Stainless Steel—See Appendix S.

   c. Aluminum Components—See Appendix H.

7.3.6.4 For carbon and low-alloy steel tanks, the tank metal temperature during hydrostatic testing shall not be colder than the design metal temperature per Figure 4-1, as long as the water is prevented from freezing. The Manufacturer is responsible for heating the test water, if heating is required, unless stated otherwise on the Data Sheet, Line 14.

• **7.3.6.5** The minimum fill and discharge rate, if any, shall be specified by the Purchaser on the Data Sheet, Line 23. When settlement measurements are specified by the Purchaser, the maximum filling rates shall be as follows, unless otherwise restricted by the requirements in 5.8.5:

Water Filling Rate

Bottom Course Thickness	Tank Portion	Maximum Filling Rate
Less than 22 mm ($^7/_8$ in.)	– Top course – Below top course	300 mm (12 in.)/hr 460 mm (18 in.)/hr
22 mm ($^7/_8$ in.) and thicker	– Top third of tank – Middle third of tank – Bottom third of tank	230 mm (9 in.)/hr 300 (12 in.)/hr 460 (18 in.)/hr

Filling may continue while elevation measurements are being made as long as the change in water elevation for a set of readings does not exceed 300 mm (12 in.). Unless waived on the Data Sheet, the Manufacturer shall make shell elevation measurements in accordance with the following: 07

1. Shell elevation measurements shall be made at equally-spaced intervals around the tank circumference not exceeding 10 m (32 ft). The minimum number of shell measurement points shall be eight. 08
2. Observed elevations shall be referred to a permanent benchmark. The level instrument shall be set up at least $1\frac{1}{2}$ times tank diameter away from the tank when tank elevation readings are taken. Six sets of settlement readings are required:
   a. Before start of the hydrostatic test
   b. With tank filled to $\frac{1}{4}$ test height (±600 mm [2 ft])
   c. With tank filled to $\frac{1}{2}$ test height (±600 mm [2 ft])
   d. With tank filled to $\frac{3}{4}$ test height (±600 mm [2 ft])
   e. At least 24 hours after the tank has been filled to the maximum test height. This 24-hour period may be increased to duration specified on the data sheet if the Purchaser so requires for conditions such as:
      i. The tank is the first one in the area.
      ii. The tank has a larger capacity than any other existing tank in the area.
      iii. The tank has a higher unit bearing load than any other existing tank in the area. 07
      iv. There is a question regarding the rate or magnitude of settlement that will take place.
   f. After tank has been emptied of test water

• Note: The three sets of settlement readings described in paragraphs b, c, and d above may be omitted if specified by the Purchaser.

7.3.6.6 If settlement measurements are specified by the Purchaser, any differential settlement greater than 13 mm per 10 m ($\frac{1}{2}$ in. per 32 ft) of circumference or a uniform settlement over 50 mm (2 in.) shall be reported to the Purchaser for evaluation. Filling of the tank shall be stopped until cleared by the Purchaser.

7.3.6.7 For floating-roof tanks, the maximum and minimum annular space between the shell and the roof rim plate prior to initial flotation and at the maximum test fill height shall be measured and recorded.

7.3.6.8 Internal bottom elevation measurements shall be made before and after hydrostatic testing. Measurements shall be made at maximum intervals of 3 m (10 ft) measured on diametrical lines across the tank. The diametrical lines shall be spaced at equal angles, with a maximum separation measured at the tank circumference of 10 m (32 ft). A minimum of four diametrical lines shall be used.

7.3.6.9 All elevation measurements shall be included in the Manufacturer's Post-Construction Document Package (see W.1.5).

7.3.7 Testing of the Roof

7.3.7.1 Upon completion, the roof of a tank designed to be gas-tight (except for roofs designed under 7.3.7.2, F.4.4, and F.7.6) shall be tested by one of the following methods:

a. Applying internal air pressure not exceeding the weight of the roof plates and applying to the weld joints a bubble solution or other material suitable for the detection of leaks. 07

b. Vacuum testing the weld joints in accordance with 8.6 to detect any leaks.

• **7.3.7.2** Upon completion, the roof of a tank not designed to be gas-tight, such as a tank with peripheral circulation vents or a tank with free or open vents, shall receive only visual inspection of its weld joints, unless otherwise specified by the Purchaser.

7.4 REPAIRS TO WELDS

• **7.4.1** All defects found in welds shall be called to the attention of the Purchaser's inspector, and the inspector's approval shall be obtained before the defects are repaired. All completed repairs shall be subject to the approval of the Purchaser's inspector. Acceptance criteria are specified in 8.2, 8.4, and 8.5, as applicable.

7.4.2 Pinhole leaks or porosity in a tank bottom joint may be repaired by applying an additional weld bead over the defective area. Other defects or cracks in tank bottom or tank roof (including floating roofs in Appendix C) joints shall be repaired as required by 8.1.7. Mechanical caulking is not permitted.

7.4.3 All defects, cracks, or leaks in shell joints or the shell-to-bottom joint shall be repaired in accordance with 8.1.7.

• **7.4.4** Repairs of defects discovered after the tank has been filled with water for testing shall be made with the water level at least 0.3 m (1 ft) below any point being repaired or, if repairs have to be made on or near the tank bottom, with the tank empty. Welding shall not be done on any tank unless all connecting lines have been completely blinded. Repairs shall not be attempted on a tank that is filled with oil or that has contained oil until the tank has been emptied, cleaned, and gas freed. Repairs on a tank that has contained oil shall not be attempted by the Manufacturer unless the manner of repair has been approved in writing by the Purchaser and the repairs are made in the presence of the Purchaser's inspector.

7.5 DIMENSIONAL TOLERANCES

• 7.5.1 General

07 The purpose of the tolerances given in 7.5.2 through 7.5.7 is to produce a tank of acceptable appearance and to permit proper functioning of floating roofs. Measurements shall be taken prior to the hydrostatic water test. Unless waived or modified by the Purchaser on Data Sheet, Line 15, or established separately by agreement between the Purchaser and the Manufacturer, the following tolerances apply:

7.5.2 Plumbness

a. The maximum out-of-plumbness of the top of the shell relative to the bottom of the shell shall not exceed 1/200 of the total tank height. The out-of-plumbness in one shell course shall not exceed the permissible variations for flatness and waviness as specified in ASTM A 6M/A 6, ASTM A 20M/A 20, or ASTM A 480M/A 480, whichever is applicable.

b. The maximum out-of-plumbness of roof columns, guide poles, or other vertical internal components shall not exceed 1/200 of the total height. The 1/200 criteria shall also apply to fixed roof columns. For tanks with internal floating roofs, apply the criteria of this section or Appendix H, whichever is more stringent.

7.5.3 Roundness

Radii measured at 0.3 m (1 ft) above the bottom corner weld shall not exceed the following tolerances:

Tank Diameter m (ft)	Radius Tolerance mm (in.)
< 12 (40)	± 13 ($^1/_2$)
From 12 (40) to < 45 (150)	± 19 ($^3/_4$)
From 45 (150) to < 75 (250)	± 25 (1)
≥ 75 (250)	± 32 (1$^1/_4$)

7.5.4 Local Deviations

Local deviations from the theoretical shape (for example, weld discontinuities and flat spots) shall be limited as follows:

a. Deviations (peaking) at vertical weld joints shall not exceed 13 mm ($^1/_2$ in.). Peaking at vertical weld joints shall be determined using a horizontal sweep board 900 mm (36 in.) long. The sweep board shall be made to the nominal radius of the tank.

b. Deviations (banding) at horizontal weld joints shall not exceed 13 mm ($^1/_2$ in.). Banding at horizontal weld joints shall be determined using a straight edge vertical sweep board 900 mm (36 in.) long.

c. Flat spots measured in the vertical plane shall not exceed the appropriate plate flatness and waviness requirements given in 7.5.2.

7.5.5 Foundations

7.5.5.1 To achieve the tolerances specified in 7.5.2 through 7.5.4, it is essential that a foundation true to the plane be provided for the tank erection. The foundation should have adequate bearing to maintain the trueness of the foundation (see Appendix B).

7.5.5.2 Where foundations true to a horizontal plane are specified, tolerances shall be as follows:

a. Where a concrete ringwall is provided under the shell, the top of the ringwall shall be level within ±3 mm ($^{1}/_{8}$ in.) in any 9 m (30 ft) of the circumference and within ±6 mm ($^{1}/_{4}$ in.) in the total circumference measured from the average elevation.

b. Where a concrete ringwall is not provided, the foundation under the shell shall be level within ±3 mm ($^{1}/_{8}$ in.) in any 3 m (10 ft) of the circumference and within ±13 mm ($^{1}/_{2}$ in.) in the total circumference measured from the average elevation.

c. Where a concrete slab foundation is provided, the first 0.3 m (1 ft) of the foundation (or width of the annular ring), measured from the outside of the tank radially towards the center, shall comply with the concrete ringwall requirement. The remainder of the foundation shall be within ±13 mm ($^{1}/_{2}$ in.) of the design shape.

7.5.5.3 Where a sloping foundation is specified, elevation differences about the circumference shall be calculated from the specified high point. Actual elevation differences about the circumference shall be determined from the actual elevation of the specified high point. The actual elevation differences shall not deviate from the calculated differences by more than the following tolerances:

a. Where a concrete ringwall is provided, ±3 mm ($^{1}/_{8}$ in.) in any 9 m (30 ft) of circumference and ±6 mm ($^{1}/_{4}$ in.) in the total circumference.

b. Where a concrete ringwall is not provided, ±3 mm ($^{1}/_{8}$ in.) in any 3 m (10 ft) of circumference and ±13 mm ($^{1}/_{2}$ in.) in the total circumference.

7.5.6 Nozzles

Nozzles (excluding manholes) shall be installed within the following tolerances:

a. Specified projection from outside of tank shell to extreme face of flange: ±5 mm ($^{3}/_{16}$ in.)

b. Elevation of shell nozzle or radial location of a roof nozzle: ±6 mm ($^{1}/_{4}$ in.)

c. Flange tilt in any plane, measured on the flange face:

±$^{1}/_{2}$ degree for nozzles greater than NPS 12 in nominal diameter

±3 mm ($^{1}/_{8}$ in.) at the outside flange diameter for nozzles NPS 12 and smaller 07

d. Flange bolt hole orientation: ±3 mm ($^{1}/_{8}$ in.)

7.5.7 Shell Manholes

Manholes shall be installed within the following tolerances:

a. Specified projection from outside of shell to extreme face of flange, ±13 mm ($^{1}/_{2}$ in.) 08

b. Elevation and angular location, ±13 mm ($^{1}/_{2}$ in.)

c. Flange tilt in any plane, measured across the flange diameter, ±13 mm ($^{1}/_{2}$ in.) 07

SECTION 8—METHODS OF INSPECTING JOINTS

Note: In this Standard, the term inspector, as used in Sections V and VIII of the ASME *Code*, shall be interpreted to mean the Purchaser's inspector.

8.1 RADIOGRAPHIC METHOD

For the purposes of this paragraph, plates shall be considered of the same thickness when the difference in their specified or design thickness does not exceed 3 mm ($^1/_8$ in.).

8.1.1 Application

Radiographic inspection is required for shell butt-welds (see 8.1.2.2, 8.1.2.3, and 8.1.2.4), annular-plate butt-welds (see 8.1.2.9), and flush-type connections with butt-welds (see 5.7.8.11). Radiographic inspection is not required for the following: roof-plate welds, bottom-plate welds, welds joining the top angle to either the roof or shell, welds joining the shell plate to the bottom plate, welds in nozzle and manway necks made from plate, or appurtenance welds to the tank.

8.1.2 Number and Location of Radiographs

8.1.2.1 Except when omitted under the provisions of A.3.4, radiographs shall be taken as specified in 8.1.2 through 8.1.9.

8.1.2.2 The following requirements apply to vertical joints:

a. For butt-welded joints in which the thinner shell plate is less than or equal to 10 mm ($^3/_8$ in.) thick, one spot radiograph shall be taken in the first 3 m (10 ft) of completed vertical joint of each type and thickness welded by each welder or welding operator. The spot radiographs taken in the vertical joints of the lowest course may be used to meet the requirements of Note 3 in Figure 8-1 for individual joints. Thereafter, without regard to the number of welders or welding operators, one additional spot radiograph shall be taken in each additional 30 m (100 ft) (approximately) and any remaining major fraction of vertical joint of the same type and thickness. At least 25% of the selected spots shall be at junctions of vertical and horizontal joints, with a minimum of two such intersections per tank. In addition to the foregoing requirements, one random spot radiograph shall be taken in each vertical joint in the lowest course (see the top panel of Figure 8-1).

b. For butt-welded joints in which the thinner shell plate is greater than 10 mm ($^3/_8$ in.) but less than or equal to 25 mm (1 in.) in thickness, spot radiographs shall be taken according to Item a. In addition, all junctions of vertical and horizontal joints in plates in this thickness range shall be radiographed; each film shall clearly show not less than 75 mm (3 in.) of vertical weld and 50 mm (2 in.) of weld length on each side of the vertical intersection. In the lowest course, two spot radiographs shall be taken in each vertical joint: one of the radiographs shall be as close to the bottom as is practicable, and the other shall be taken at random (see the center panel of Figure 8-1).

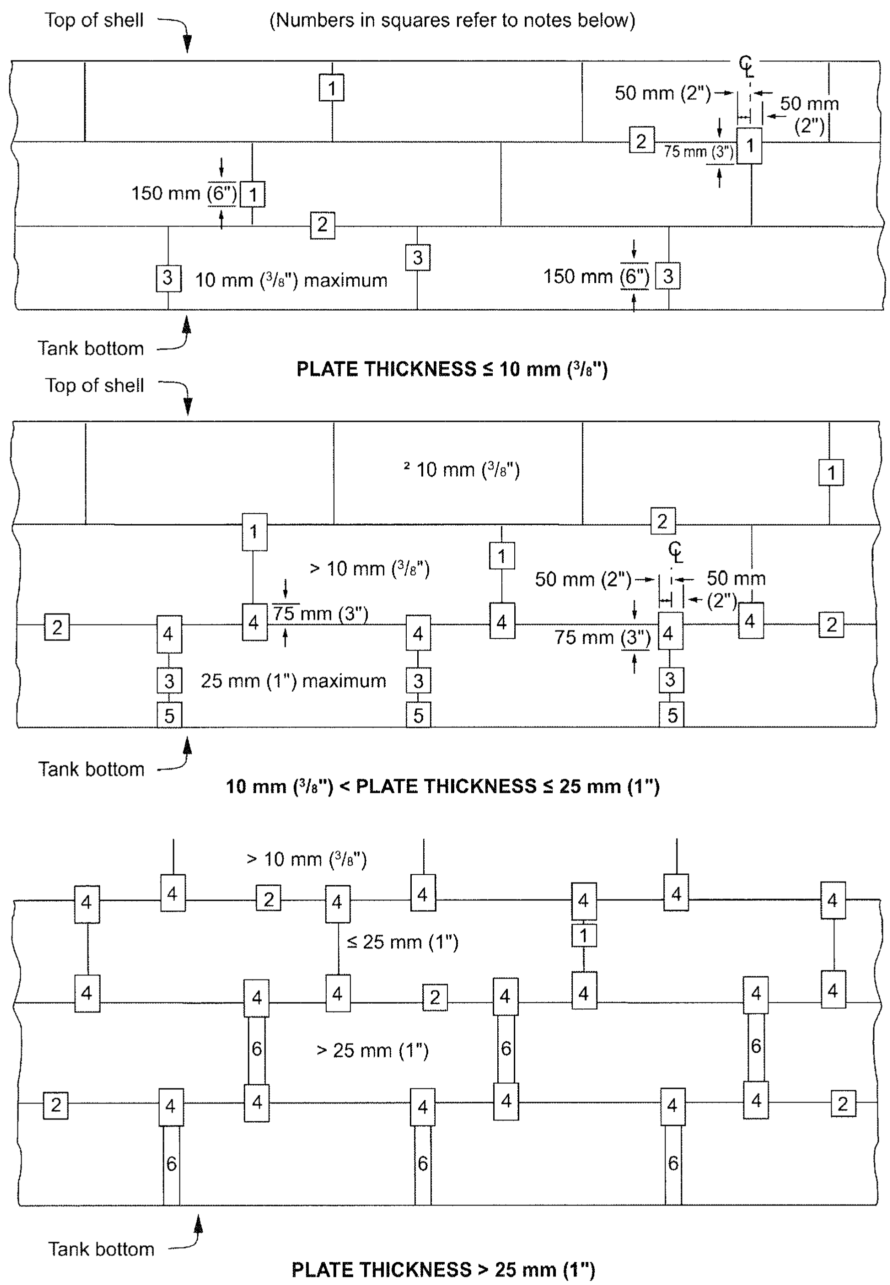
c. Vertical joints in which the shell plates are greater than 25 mm (1 in.) thick shall be fully radiographed. All junctions of vertical and horizontal joints in this thickness range shall be radiographed; each film shall clearly show not less than 75 mm (3 in.) of vertical weld and 50 mm (2 in.) of weld length on each side of the vertical intersection (see the bottom panel of Figure 8-1).

d. The butt-weld around the periphery of an insert plate that extends less than the adjacent shell course height and that contains shell openings (i.e. nozzle, manway, flush-type cleanout, flush type shell-connection) and their reinforcing elements shall be completely radiographed. 08

e. The butt-weld around the periphery of an insert plate which extends to match the adjacent shell course height shall have the vertical and the horizontal butt joints and the intersections of vertical and horizontal weld joints radiographed using the same rules that apply to the weld joints in adjacent shell plates in the same shell course.

8.1.2.3 One spot radiograph shall be taken in the first 3 m (10 ft) of completed horizontal butt joint of the same type and thickness (based on the thickness of the thinner plate at the joint) without regard to the number of welders or welding operators. Thereafter, one radiograph shall be taken in each additional 60 m (200 ft) (approximately) and any remaining major fraction of horizontal joint of the same type and thickness. These radiographs are in addition to the radiographs of junctions of vertical joints required by Item c of 8.1.2.2 (see Figure 8-1).

8.1.2.4 The number of spot radiographs required herein shall be applicable on a per tank basis, irrespective of the number of tanks being erected concurrently or continuously at any location. 07



Notes:

1. Vertical spot radiograph in accordance with 8.1.2.2, Item a: one in the first 3 m (10 ft) and one in each 30 m (100 ft)thereafter, 25% of which shall be at intersections.
2. Horizontal spot radiograph in accordance with 8.1.2.3: one in the first 3 m (10 ft) and one in each 60 m (200 ft) thereafter.
3. Vertical spot radiograph in each vertical seam in the lowest course (see 8.1.2.2, Item b). Spot radiographs that satisfy the requirements of Note 1 for the lowest course may be used to satisfy this requirement.
4. Spot radiographs of all intersections over 10 mm (3/8 in.) (see 8.1.2.2, Item b).
5. Spot radiograph of bottom of each vertical seam in lowest shell course over 10 mm (3/8 in.) (see 8.1.2.2, Item b).
6. Complete radiograph of each vertical seam over 25 mm (1 in.). The complete radiograph may include the spot radiographs of the intersections if the film has a minimum width of 100 mm (4 in.) (see 8.1.2.2, Item c).

Figure 8-1—Radiographic Requirements for Tank Shells

8.1.2.5 It is recognized that in many cases the same welder or welding operator does not weld both sides of a butt joint. If two welders or welding operators weld opposite sides of a butt joint it is permissible to inspect their work with one spot radiograph. If the radiograph is rejected, additional spot radiographs shall be taken to determine whether one or both of the welders or welding operators are at fault.

8.1.2.6 An equal number of spot radiographs shall be taken from the work of each welder or welding operator in proportion to the length of joints welded.

● **8.1.2.7** As welding progresses, radiographs shall be taken as soon as it is practicable. The locations where spot radiographs are to be taken may be determined by the Purchaser's inspector.

8.1.2.8 Each radiograph shall clearly show a minimum of 150 mm (6 in.) of weld length. The film shall be centered on the weld and shall be of sufficient width to permit adequate space for the location of identification marks and an image quality indicator (IQI) penetrameter. 07

8.1.2.9 When bottom annular plates are required by 5.5.1, or by M.4.1, the radial joints shall be radiographed as follows: (a) For double-welded butt joints, one spot radiograph shall be taken on 10% of the radial joints; (b) For single-welded butt joints with permanent or removable back-up bar, one spot radiograph shall be taken on 50% of the radial joints. Extra care must be exercised in the interpretation of radiographs of single-welded joints that have a permanent back-up bar. In some cases, additional exposures taken at an angle may determine whether questionable indications are acceptable. The minimum radiographic length of each radial joint shall be 150 mm (6 in.). Locations of radiographs shall preferably be at the outer edge of the joint where the shell plate and annular plate join.

8.1.3 Technique

8.1.3.1 Except as modified in this section, the radiographic examination method employed shall be in accordance with Section V, Article 2, of the ASME *Code*.

8.1.3.2 Personnel who perform and evaluate radiographic examinations according to this section shall be qualified and certified by the Manufacturer as meeting the requirements of certification as generally outlined in Level II or Level III of ASNT SNT-TC-1A (including applicable supplements). Level-I personnel may be used if they are given written acceptance/rejection procedures prepared by Level-II or Level-III personnel. These written procedures shall contain the applicable requirements of Section V, Article 2, of the ASME *Code*. In addition, all Level-I personnel shall be under the direct supervision of Level-II or Level-III personnel.

8.1.3.3 The requirements of T-285 in Section V, Article 2, of the ASME *Code* are to be used only as a guide. Final acceptance of radiographs shall be based on whether the prescribed penetrameter image and the specified hole can be seen.

8.1.3.4 The finished surface of the weld reinforcement at the location of the radiograph shall either be flush with the plate or have a reasonably uniform crown not to exceed the following values:

Plate Thickness mm (in.)	Maximum Thickness of Reinforcement mm (in.)
≤ 13 (1/2)	1.5 (1/16)
> 13 (1/2) to 25 (1)	2.5 (3/32)
> 25 (1)	3 (1/8)

● 8.1.4 Submission of Radiographs

Before any welds are repaired, the radiographs shall be submitted to the inspector with any information requested by the inspector regarding the radiographic technique used.

8.1.5 Radiographic Standards

Welds examined by radiography shall be judged as acceptable or unacceptable by the standards of Paragraph UW-51(b) in Section VIII of the ASME *Code*.

● 8.1.6 Determination of Limits of Defective Welding

When a section of weld is shown by a radiograph to be unacceptable under the provisions of 8.1.5 or the limits of the deficient welding are not defined by the radiograph, two spots adjacent to the section shall be examined by radiography; however, if the original radiograph shows at least 75 mm (3 in.) of acceptable weld between the defect and any one edge of the film, an additional radiograph need not be taken of the weld on that side of the defect. If the weld at either of the adjacent sections fails to comply with the requirements of 8.1.5, additional spots shall be examined until the limits of unacceptable welding are determined, or the erector may replace all of the welding performed by the welder or welding operator on that joint. If the welding is replaced, the inspector shall have the option of requiring that one radiograph be taken at any selected location on any other joint on which the same welder or welding operator has welded. If any of these additional spots fail to comply with the requirements of 8.1.5, the limits of unacceptable welding shall be determined as specified for the initial section.

8.1.7 Repair of Defective Welds

8.1.7.1 Defects in welds shall be repaired by chipping or melting out the defects from one side or both sides of the joint, as required, and rewelding. Only the cutting out of defective joints that is necessary to correct the defects is required.

• **8.1.7.2** All repaired welds in joints shall be checked by repeating the original inspection procedure and by repeating one of the testing methods of 7.3, subject to the approval of the Purchaser.

8.1.8 Record of Radiographic Examination

11 **8.1.8.1** The Manufacturer shall prepare a radiograph map showing the final location of all radiographs taken along with the film identification marks.

• **8.1.8.2** After the structure is completed, the films shall be the property of the Purchaser unless otherwise agreed upon by the Purchaser and the Manufacturer.

8.2 MAGNETIC PARTICLE EXAMINATION

8.2.1 When magnetic particle examination is specified, the method of examination shall be in accordance with Section V, Article 7, of the ASME *Code*.

8.2.2 Magnetic particle examination shall be performed in accordance with a written procedure that is certified by the Manufacturer to be in compliance with the applicable requirements of Section V of the ASME *Code*.

8.2.3 The Manufacturer shall determine that each magnetic particle examiner meets the following requirements:

a. Has vision (with correction, if necessary) to be able to read a Jaeger Type 2 standard chart at a distance of not less than 300 mm (12 in.) and is capable of distinguishing and differentiating contrast between the colors used. Examiners shall be checked annually to ensure that they meet these requirements.

b. Is competent in the technique of the magnetic particle examination method, including performing the examination and interpreting and evaluating the results; however, where the examination method consists of more than one operation, the examiner need only be qualified for one or more of the operations.

8.2.4 Acceptance standards and the removal and repair of defects shall be in accordance with Section VIII, Appendix 6, Paragraphs 6-3, 6-4, and 6-5, of the ASME *Code*.

8.3 ULTRASONIC EXAMINATION

8.3.1 Ultrasonic Examination in Lieu of Radiography

When ultrasonic examination is applied in order to fulfill the requirement of 7.3.2.1, the provisions of Appendix U shall apply.

8.3.2 Ultrasonic Examination NOT in Lieu of Radiography

8.3.2.1 When the radiographic method is applied in order to fulfill the requirement of 7.3.2.1, then any ultrasonic examination specified shall be in accordance with this section.

08 **8.3.2.2** The method of examination shall be in accordance with Section V, Article 4, of the ASME *Code*.

8.3.2.3 Ultrasonic examination shall be performed in accordance with a written procedure that is certified by the Manufacturer to be in compliance with the applicable requirements of Section V of the ASME *Code*.

8.3.2.4 Examiners who perform ultrasonic examinations under this section shall be qualified and certified by the Manufacturers as meeting the requirements of certification as generally outlined in Level II or Level III of ASNT SNT-TC-1A (including applicable supplements). Level-I personnel may be used if they are given written acceptance/rejection criteria prepared by Level-II or Level-III personnel. In addition, all Level-I personnel shall be under the direct supervision of Level-II or Level-III personnel.

● **8.3.2.5** Acceptance standards shall be agreed upon by the Purchaser and the Manufacturer.

8.4 LIQUID PENETRANT EXAMINATION

8.4.1 When liquid penetrant examination is specified, the method of examination shall be in accordance with Section V, Article 6, of the ASME *Code*.

8.4.2 Liquid penetrant examination shall be performed in accordance with a written procedure that is certified by the Manufacturer to be in compliance with the applicable requirements of Section V of the ASME *Code*.

8.4.3 The Manufacturer shall determine and certify that each liquid penetrant examiner meets the following requirements:

a. Has vision (with correction, if necessary) to enable him to read a Jaeger Type 2 standard chart at a distance of not less than 300 mm (12 in.) and is capable of distinguishing and differentiating contrast between the colors used. Examiners shall be checked annually to ensure that they meet these requirements.

b. Is competent in the technique of the liquid penetrant examination method for which he is certified, including making the examination and interpreting and evaluating the results; however, where the examination method consists of more than one operation, the examiner may be certified as being qualified for one or more of the operations.

8.4.4 Acceptance standards and the removal and repair of defects shall be in accordance with Section VIII, Appendix 8, Paragraphs 8-3, 8-4, and 8-5, of the ASME *Code*.

8.5 VISUAL EXAMINATION

8.5.1 The Manufacturer shall determine and certify that each visual examiner meets the following requirements:

a. Has vision (with correction, if necessary) to be able to read a Jaeger Type 2 standard chart at a distance of not less than 300 mm (12 in.) and is capable of passing a color contrast test. Examiners shall be checked annually to ensure that they meet this requirement; and

b. Is competent in the technique of the visual examination, including performing the examination and interpreting and evaluating the results; however, where the examination method consists of more than one operation, the examiner performing only a portion of the test need only be qualified for the portion that the examiner performs. 11

8.5.2 A weld shall be acceptable by visual inspection if the inspection shows the following:

a. There are no crater cracks, other surface cracks or arc strikes in or adjacent to the welded joints.

b. Maximum permissible undercut is 0.4 mm (1/64 in.) in depth for vertical butt joints, vertically oriented permanent attachments, attachment welds for nozzles, manholes, flush-type openings, and the inside shell-to-bottom welds. For horizontal butt joints, horizontally oriented permanent attachments, and annular-ring butt joints, the maximum permissible undercut is 0.8 mm (1/32 in.) in depth. 07

c. The frequency of surface porosity in the weld does not exceed one cluster (one or more pores) in any 100 mm (4 in.) of length, and the diameter of each cluster does not exceed 2.5 mm (3/32 in.).

d. The reinforcement of the welds on all butt joints on each side of the plate shall not exceed the following thicknesses:

Plate Thickness mm (in.)	Maximum Reinforcement Thickness mm (in.)		
	Vertical Joints	Horizontal Joints	
≤ 13 (1/2)	2.5 (3/32)	3 (1/8)	07
> 13 (1/2) to 25 (1)	3 (1/8)	5 (3/16)	
> 25 (1)	5 (3/16)	6 (1/4)	

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

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

a. Any defects shall be removed by mechanical means or thermal gouging processes. Arc strikes discovered in or adjacent to welded joints shall be repaired by grinding and rewelding as required. Arc strikes repaired by welding shall be ground flush with the plate.

b. Rewelding is required if the resulting thickness is less than the minimum required for design or hydrostatic test conditions. All defects in areas thicker than the minimum shall be feathered to at least a 4:1 taper.

c. The repair weld shall be visually examined for defects.

Notes:

1. Vertical spot radiograph in accordance with 8.1.2.2, Item a: one in the first 3 m (10 ft) and one in each 30 m (100 ft) thereafter, 25% of which shall be at intersections.
2. Horizontal spot radiograph in accordance with 8.1.2.3: one in the first 3 m (10 ft) and one in each 60 m (200 ft) thereafter.
3. Vertical spot radiograph in each vertical seam in the lowest course (see 8.1.2.2, Item b). Spot radiographs that satisfy the requirements of Note 1 for the lowest course may be used to satisfy this requirement.
4. Spot radiographs of all intersections over 10 mm ($^3/_8$ in.) (see 8.1.2.2, Item b).
5. Spot radiograph of bottom of each vertical seam in lowest shell course over 10 mm ($^3/_8$ in.) (see 8.1.2.2, Item b).
6. Complete radiograph of each vertical seam over 25 mm (1 in.). The complete radiograph may include the spot radiographs of the intersections if the film has a minimum width of 100 mm (4 in.) (see 8.1.2.2, Item c).

8.6 VACUUM TESTING

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

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

a. Performing a visual examination of the bottom and welds prior to performing the vacuum-box test;

b. Verifying the condition of the vacuum box and its gasket seals;

c. Verifying that there is no quick bubble or spitting response to large leaks; and

d. Applying the film solution to a dry area, such that the area is thoroughly wetted and a minimum generation of application bubbles occurs.

11 ● **8.6.3** A partial vacuum of 21 kPa (3 lbf/in.^{2}, 6 in. Hg) to 35 kPa (5 lbf/in.^{2}, 10 in Hg) gauge shall be used for the test. If specified by the Purchaser, a second partial vacuum test of 56 kPa (8 lbf/in.^{2}, 16 in. Hg) to 70 kPa (10 lbf/in.^{2}, 20 in. Hg) shall be performed for the detection of very small leaks.

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

a. Has vision (with correction, if necessary) to be able to read a Jaeger Type 2 standard chart at a distance of not less than 300 mm (12 in.). Operators shall be checked annually to ensure that they meet this requirement; and

b. Is competent in the technique of the vacuum-box testing, including performing the examination and interpreting and evaluating the results; however, where the examination method consists of more than one operation, the operator performing only a portion of the test need only be qualified for that portion the operator performs.

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

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

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

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

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

● **8.6.10** A record or report of the test including a statement addressing temperature and light intensity shall be completed and furnished to the Purchaser upon request. 07

● **8.6.11** As an alternate to vacuum-box testing, a suitable tracer gas and compatible detector can be used to test the integrity of welded bottom joints for their entire length. Where tracer gas testing is employed as an alternate to vacuum-box testing, it shall meet the following requirements:

a. Tracer gas testing shall be performed in accordance with a written procedure which has been reviewed and approved by the Purchaser and which shall address as a minimum: the type of equipment used, surface cleanliness, type of tracer gas, test pressure, soil permeability, soil moisture content, satisfactory verification of the extent of tracer gas permeation, and the method or technique to be used including scanning rate and probe standoff distance.

b. The technique shall be capable of detecting leakage of 1×10^{-4} Pa $m^3/_s$ (1×10^{-3} std $cm^3/_s$) or smaller

c. The test system parameters (detector, gas, and system pressure, i.e., level of pressure under bottom) shall be calibrated by placing the appropriate calibrated capillary leak, which will leak at a rate consistent with (b) above, in a temporary or permanent fitting in the tank bottom away from the tracer gas pressurizing point. Alternatively, by agreement between the Purchaser and the Manufacturer, the calibrated leak may be placed in a separate fitting pressurized in accordance with the system parameters.

d. While testing for leaks in the welded bottom joints, system parameters shall be unchanged from those used during calibration.

SECTION 9—WELDING PROCEDURE AND WELDER QUALIFICATIONS

9.1 DEFINITIONS

In this Standard, terms relating to welding shall be interpreted as defined in Section IX of the ASME *Code*. Additional terms are defined in 9.1.1 and 9.1.2.

9.1.1 An angle joint is a joint between two members that intersect at an angle between 0 degrees (a butt joint) and 90 degrees (a corner joint).

9.1.2 Porosity refers to gas pockets or voids in metal.

9.2 QUALIFICATION OF WELDING PROCEDURES

9.2.1 General Requirements

9.2.1.1 The erection Manufacturer and the fabrication Manufacturer if other than the erection Manufacturer, shall prepare welding procedure specifications and shall perform tests documented by procedure qualification records to support the specifications, as required by Section IX of the ASME *Code* and any additional provisions of this Standard. If the Manufacturer is part of an organization that has, to the Purchaser's satisfaction, established effective operational control of the qualification of welding procedures and of welder performance for two or more companies of different names, then separate welding procedure qualifications are not required, provided all other requirements of 9.2, 9.3, and Section IX of the ASME *Code* are met. Welding procedures for ladder and platform assemblies, handrails, stairways, and other miscellaneous assemblies, but not their attachments to the tank, shall comply with either AWS D1.1, AWS D1.6, or Section IX of the ASME *Code*, including the use of standard WPSs.

9.2.1.2 The welding procedures used shall produce weldments with the mechanical properties required by the design.

9.2.1.3 Material specifications listed in Section 4 of this Standard but not included in Table QW-422 of Section IX of the ASME *Code* shall be considered as P1 material with group numbers assigned as follows according to the minimum tensile strength specified:

a. Less than 485 MPa (70 ksi)—Group 1.
b. Equal to or greater than 485 MPa (70 ksi) but less than 550 MPa (80 ksi)—Group 2. 11
c. Equal to or greater than 550 MPa (80 ksi)—Group 3.

Separate welding procedures and performance qualifications shall be conducted for A 841M/A 841 material.

9.2.1.4 Welding variables (including supplementary essential variables when impact tests are required by 9.2.2), as defined by QW-250 of Section IX of the ASME *Code*, shall be used to determine the welding procedure specifications and the procedure qualification records to be instituted. In addition, when impact tests of the heat-affected zone are required, the heat-treated condition of the base material shall be a supplementary essential variable. Plates produced by the controlled-rolled process are not to be considered as having received any heat treatment. If a protective coating has been applied to weld edge preparations, the coating 11
shall be included as an essential variable of the welding procedure specification, as required by 7.2.1.9.

9.2.2 Impact Tests

9.2.2.1 Impact tests for the qualification of welding procedures shall comply with the applicable provisions of 4.2.8 and shall be made at or below the design metal temperature.

9.2.2.2 When impact testing of a material is required by 4.2.8, 4.2.9, or 4.5.5, impact tests of the heat-affected zone shall be made for all machine, automatic, and semiautomatic welding procedures.

9.2.2.3 For all materials to be used at a design metal temperature below 10°C (50°F), the qualification of the welding procedure 11
for vertical joints shall include impact tests of the weld metal. If vertical joints are to be made by a machine, automatic, or semiautomatic process, impact tests of the heat-affected zone shall also be made.

9.2.2.4 When the design metal temperature is below –7°C (20°F), impact tests of the weld metal shall be made for all procedures used for welding the components listed in 4.2.9.1, for welding attachments to these components, and for fabricating shell nozzles and manholes from pipe and forgings listed in 4.5.

9.2.2.5 Impact tests shall show minimum values for acceptance in accordance with 4.2.8.3 and the following:

a. For P1, Group 1, materials—20 J (15 ft-lbf), average of three specimens.
b. For P1, Group 2, materials—27 J (20 ft-lbf), average of three specimens.
c. For P1, Group 3, materials—34 J (25 ft-lbf), average of three specimens.

08 For shell plates thicker than 40 mm ($1^1/_2$ in.), these values shall be increased by 7 J (5 ft-lbf) for each 13 mm ($^1/_2$ in.) over 40 mm ($1^1/_2$ in.). Interpolation is permitted.

9.2.2.6 Weld-metal impact specimens shall be taken across the weld with one face substantially parallel to and within 1.5 mm ($^1/_{16}$ in.) of the surface of the material. The notch shall be cut normal to the original material surface and with the weld metal entirely within the fracture zone.

9.2.2.7 Heat-affected-zone impact specimens shall be taken across the weld and as near the surface of the material as is practicable. Each specimen shall be etched to locate the heat-affected zone, and the notch shall be cut approximately normal to the original material surface and with as much heat-affected-zone material as possible included in the fracture zone.

9.2.2.8 Production welding shall conform to the qualified welding procedure, but production-weld test plates need not be made.

9.3 QUALIFICATION OF WELDERS

9.3.1 The erection Manufacturer and the fabrication Manufacturer, if other than the erection Manufacturer, shall conduct tests
11 for all welders assigned to manual and semiautomatic welding and all welding operators assigned to machine and automatic welding to demonstrate the welders' and welding operators' ability to make acceptable welds. Tests conducted by one Manufacturer shall not qualify a welder or welding operator to do work for another Manufacturer.

9.3.2 The welders and welding operators who weld pressure parts and join nonpressure parts, such as all permanent and temporary clips and lugs, to pressure parts shall be qualified in accordance with Section IX of the ASME *Code*.

9.3.3 The records of the tests for qualifying welders and welding operators shall include the following:

a. Each welder or welding operator shall be assigned an identifying number, letter, or symbol by the fabrication or erection Manufacturer.
b. The fabrication or erection Manufacturer shall maintain a record of the welders or welding operators employed that shows the date and results of the tests for each welder or operator and the identifying mark assigned to each welder or operator. This record shall be certified by the fabrication or erection Manufacturer and shall be accessible to the inspector.

9.4 IDENTIFICATION OF WELDED JOINTS

The welder or welding operator's identification mark shall be hand- or machine-stamped adjacent to and at intervals not exceeding 1 m (3 ft) along the completed welds. In lieu of stamping, a record may be kept that identifies the welder or welding operator employed for each welded joint; these records shall be accessible to the inspector. Roof plate welds and flange-to-nozzle-neck welds do not require welder identification.

SECTION 10—MARKING

10.1 NAMEPLATES

10.1.1 A tank made in accordance with this Standard shall be identified by a nameplate similar to that shown in Figure 10-1. The nameplate shall indicate, by means of letters and numerals not less than 4 mm ($^5/_{32}$ in.) high, the following information:

a. API Standard 650.

b. The applicable appendix to API Standard 650.

c. The year the tank was completed.

d. The edition and the addendum number of API Standard 650.

● e. The nominal diameter and nominal height, in meters (ft and in.). 09

● f. The maximum capacity (see 5.2.6.2), in m^3 (42-gallon barrels).

● g. The design liquid level (see 5.6.3.2), in meters (ft and in.).

h. The design specific gravity of the liquid.

i. The design pressure, which shall be shown as "atmospheric" unless Appendix F or Appendix V applies. If Appendix V 09
applies, design pressure shall be shown as a negative number. If both Appendices F and V apply, the positive and negative pressures shall be separated by a forward slash and shall be followed by consistent units of measurement. 07

● j. The design metal temperature as described in 3.4 in °C (°F).

● k. The maximum design temperature, in °C (°F), which shall not exceed 93°C (200°F) except in cases where Appendix M, S, X, or AL applies. 08

l. The name of the fabrication Manufacturer if other than the erection Manufacturer. The Manufacturer's serial number or contract number shall be from the erection Manufacturer.

m. The material specification number for each shell course.

API STANDARD 650

APPENDIX		YEAR COMPLETED	
EDITION		ADDENDUM NO.	
NOMINAL DIAMETER		NOMINAL HEIGHT	
MAXIMUM CAPACITY		DESIGN LIQUID LEVEL	
DESIGN SPECIFIC GRAVITY		DESIGN METAL TEMP.	
DESIGN PRESSURE		MAXIMUM DESIGN TEMP.	09
MANUFACTURER'S SERIAL NO.		STRESS RELIEF	
PRESS. COMBINATION FACTOR		PURCHASER'S TANK NO.	11
FABRICATED BY			
ERECTED BY			

SHELL COURSE	MATERIAL

● Note: At the Purchaser's request or at the erection Manufacturer's discretion, additional pertinent information may be shown on the nameplate, and the size of the nameplate may be increased proportionately.

Figure 10-1—Manufacturer's Nameplate

n. When thermal stress-relief is performed to shell openings (nozzles, manholes, flush-type connections, and flush-type cleanout fittings) in accordance with the requirements of 5.7.4, or when applied to an entire tank, the following markings shall be used.

1. Use "SR1" when only flush-type cleanout fittings and flush-type shell connections have been thermally stress-relieved.

2. Use "SR2" when thermal stress-relief has been performed on flush-type cleanout fittings, flush-type shell connections and all shell openings NPS 12 and greater in size in shell plates (or insert plates) of Groups I through IIIA.

09 3. Use "SR3" when thermal stress-relief has been performed on flush-type cleanout fittings, flush-type shell connections and all shell openings greater than NPS 2 in size in shell plates (or insert plates) of Groups IV through VI.

4. Use "SR4" when thermal stress-relief has been performed on all flush-type cleanout fittings, flush-type shell connections and all shell openings.

5. Use "SR5" when the completed tank, including all shell openings and attachments, has been thermally stress-relieved as a special requirement by the Purchaser.

6. Use "NONE" when thermal stress-relief has not been performed on any tank appurtenances.

o. The Purchaser's tank number.

10.1.2 The nameplate shall be attached to the tank shell adjacent to a manhole or to a manhole reinforcing plate immediately above a manhole. A nameplate that is placed directly on the shell plate or reinforcing plate shall be attached by continuous welding or brazing all around the nameplate. A nameplate that is riveted or otherwise permanently attached to an auxiliary plate of ferrous material shall be attached to the tank shell plate or reinforcing plate by continuous welding. The nameplate shall be of corrosion-resistant metal.

10.1.3 When a tank is fabricated and erected by a single organization, that organization's name shall appear on the nameplate as both fabricator and erector.

10.1.4 When a tank is fabricated by one organization and erected by another, the names of both organizations shall appear on the nameplate, or separate nameplates shall be applied by each.

10.2 DIVISION OF RESPONSIBILITY

Unless otherwise agreed upon, when a tank is fabricated by one Manufacturer and erected by another, the erection Manufacturer shall be considered as having the primary responsibility. The erection Manufacturer shall make certain that the materials used in the fabrication of the components and in the construction of the tank are in accordance with all applicable requirements.

10.3 CERTIFICATION

The Manufacturer shall certify to the Purchaser, by a letter such as that shown in Figure 10-2, that the tank has been constructed in accordance with the applicable requirements of this Standard. An as-built data sheet in accordance with Appendix L shall be attached to the certification letter.

● Note: At the Purchaser's request or at the erection Manufacturer's discretion, additional pertinent information may be shown on the nameplate, and the size of the nameplate may be increased proportionately.

MANUFACTURER'S CERTIFICATION FOR A TANK BUILT TO API STANDARD 650

To ____
(name and address of Purchaser)
____
____

We hereby certify that the tank constructed for you at ______________________________
(location)
____
____

and described as follows: ____
(serial or contract number, diameter, height, capacity, floating or fixed roof)
____

meets all applicable requirements of API Standard 650, ____________ Edition, ____________Addendum, Appendix 09

__________, dated ________________, including the requirements for design, materials, fabrication, and erection.

The tank is further described on the attached as-built data sheet dated ____________________.

____
Manufacturer

____
Authorized Representative

____
Date

Figure 10-2—Manufacturer's Certification Letter

APPENDIX A—OPTIONAL DESIGN BASIS FOR SMALL TANKS

A.1 Scope

• **A.1.1** This appendix provides requirements for field-erected tanks of relatively small capacity in which the stressed components have a nominal thickness of no more than 13 mm ($^{1}/_{2}$ in.). The stressed components include the shell and reinforcing plates, shell reinforcing plates for flush-type cleanout fittings and flush-type shell connections, and bottom plates that are welded to the shell. The nominal thickness limit of 13 mm ($^{1}/_{2}$ in.) does not apply to: 07 11

1. bottom plates not welded to the shell,
2. the bottom reinforcing plate of flush-type cleanouts and flush-type shell connections, 07
3. flanges and cover plates of flush-type cleanouts,
4. flush-type shell connection necks attached to shell and flanges and cover plates of flush-type shell connections,
5. nozzle and manhole necks, their flanges and cover plates,
6. anchor bolt chair components and shell compression ring.

• **A.1.2** This appendix is applicable only when specified by the Purchaser and is limited to design metal temperatures above –30°C (–20°F) (above –40°C [–40°F] when killed, fine-grain material is used).

A.1.3 This appendix is applicable to any of the Section 4 materials, although the single allowable stress does not provide any advantage to higher strength steels.

A.1.4 This appendix states only the requirements that differ from the basic rules in this Standard. When differing requirements are not stated, the basic rules must be followed; however, the overturning effect of a wind load should be considered.

A.1.5 Typical sizes, capacities, and shell-plate thicknesses are listed in Tables A-1a through A-4b for a design in accordance with A.4 (joint efficiency = 0.85; specific gravity = 1.0; and corrosion allowance = 0). 08

A.2 Materials

A.2.1 Shell-plate materials shall not be more than 13 mm ($^{1}/_{2}$ in.) thick, as stated in A.1.1. 08

A.2.2 For stressed components, the Group-I and Group-II materials listed in Tables 4-3a and 4-3b may be used at a design metal temperature of –30°C (–20°F) or warmer but need not conform to the toughness requirements of 4.2.9, Figure 4-1, and 9.2.2. Group-III and Group-IIIA materials may be used at a design metal temperature of –40°C (–40°F) or warmer and shall conform to impact requirements of 9.2.2. 11

A.2.3 Material used for shell nozzle and manhole necks and flanges shall conform to 4.5, 4.6, and Tables 4-3a and 4-3b but need not conform to the toughness requirements of 4.2.9, 4.5.5, and Figure 4-1. 08

A.2.4 Bottom reinforcing plates in flush-type cleanouts and flush-type shell connections, and flush-type fitting necks attached to shell shall conform to toughness requirements of 4.2.9 and Figure 4-1 at design metal temperature. 07

A.3 Design

A.3.1 The maximum tensile stress before the joint efficiency factor is applied shall be 145 MPa (21,000 lbf/in.^{2}).

A.3.2 Stresses shall be computed on the assumption that the tank is filled with water (specific gravity = 1.0) or with the liquid to be stored if it is heavier than water.

A.3.3 The tension in each ring shall be computed 300 mm (12 in.) above the centerline of the lower horizontal joint of the course in question. When these stresses are computed, the tank diameter shall be taken as the nominal diameter of the bottom course.

• **A.3.4** The joint efficiency factor shall be 0.85 with the spot radiography required by A.5.3. By agreement between the Purchaser and the Manufacturer, the spot radiography may be omitted, and a joint efficiency factor of 0.70 shall be used.

08 **Table A-1a—(SI) Typical Sizes and Corresponding Nominal Capacities (m^3) for Tanks with 1800-mm Courses**

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Tank Diameter m	Capacity per m of Height m^3	Tank Height (m) / Number of Courses in Completed Tank								
		3.6 / 2	5.4 / 3	7.2 / 4	9 / 5	10.8 / 6	12.6 / 7	14.4 / 8	16.2 / 9	18 / 10
3	7.07	25	38	51	64	76	—	—	—	—
4.5	15.9	57	86	115	143	172	—	—	—	—
6	28.3	102	153	204	254	305	356	407	—	—
7.5	44.2	159	239	318	398	477	557	636	716	795
9	63.6	229	344	458	573	687	802	916	1,031	1,145
10.5	86.6	312	468	623	779	935	1,091	1,247	1,403	1,559
12	113	407	611	814	1,018	1,221	1,425	1,629	1,832	2,036
13.5	143	515	773	1,031	1,288	1,546	1,804	2,061	2,319	2,576
15	177	636	954	1,272	1,590	1,909	2,227	2,545	2,863	3,181
18	254	916	1,374	1,832	2,290	2,748	3,206	3,664	4,122	4,580
										D = 18
21	346	1,247	1,870	2,494	3,117	3,741	4,364	4,988	5,089	—
24	452	1,629	2,443	3,257	4,072	4,886	5,700	5,474	*D = 20*	—
27	573	2,061	3,092	4,122	5,153	6,184	6,690	*D = 22*	—	—
30	707	2,545	3,817	5,089	6,362	7,634	*D = 26*	—	—	—
36	1,018	3,664	5,497	7,329	9,161	*D = 30*	—	—	—	—
					D = 36					
42	1,385	4,988	7,481	9,975	—	—	—	—	—	—
48	1,810	6,514	9,772	11,966	—	—	—	—	—	—
54	2,290	8,245	12,367	*D = 46*	—	—	—	—	—	—
60	2,827	10,179	15,268	—	—	—	—	—	—	—
66	3,421	12,316	16,303	—	—	—	—	—	—	—
			D = 62							

Note: The nominal capacities given in this table were calculated using the following formula:

07 In SI units:

$$C = 0.785D^2H$$

where

C = capacity of tank, in m^3,
D = diameter of tank, in m (see A.4.1),
H = height of tank, in m (see A.4.1).

The capacities and diameters in italics (Columns 4 – 11) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of 13 mm, a 08 maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-1b—(USC) Typical Sizes and Corresponding Nominal Capacities (barrels) for Tanks with 72-in. Courses 08

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
Tank Diameter ft	Capacity per ft of Height barrels	Tank Height (ft) / Number of Courses in Completed Tank								
		12 / 2	18 / 3	24 / 4	30 / 5	36 / 6	42 / 7	48 / 8	54 / 9	60 / 10
10	14.0	170	250	335	420	505	—	—	—	—
15	31.5	380	565	755	945	1,130	—	—	—	—
20	56.0	670	1,010	1,340	1,680	2,010	2,350	2,690	—	—
25	87.4	1,050	1,570	2,100	2,620	3,150	3,670	4,200	4,720	5,250
30	126	1,510	2,270	3,020	3,780	4,530	5,290	6,040	6,800	7,550
35	171	2,060	3,080	4,110	5,140	6,170	7,200	8,230	9,250	10,280
40	224	2,690	4,030	5,370	6,710	8,060	9,400	10,740	12,100	13,430
45	283	3,400	5,100	6,800	8,500	10,200	11,900	13,600	15,300	17,000
50	350	4,200	6,300	8,400	10,500	12,600	14,700	16,800	18,900	21,000
60	504	6,040	9,060	12,100	15,110	18,130	21,150	24,190	37,220	28,260
										D = 58
70	685	8,230	12,340	16,450	20,580	24,700	28,800	32,930	30,970	—
80	895	10,740	16,120	21,500	26,880	32,260	37,600	35,810	*D = 64*	—
90	1,133	13,600	20,400	27,220	34,030	40,820	40,510	*D = 73*	—	—
100	1,399	16,800	25,200	33,600	42,000	48,400	*D = 83*	—	—	—
120	2,014	24,190	36,290	48,380	58,480	*D = 98*	—	—	—	—
					D = 118					
140	2,742	32,930	49,350	65,860	—	—	—	—	—	—
160	3,581	43,000	64,510	74,600	—	—	—	—	—	—
180	4,532	54,430	81,650	*D = 149*	—	—	—	—	—	—
200	5,595	67,200	100,800	—	—	—	—	—	—	—
220	6,770	81,310	102,830	—	—	—	—	—	—	—
			D = 202							

Note: The nominal capacities given in this table were calculated using the following formula:

In US Customary units:

$$C = 0.14D^2H,$$

where

C = capacity of tank, in 42-gal barrels,
D = diameter of tank, in ft (see A.4.1),
H = height of tank, in ft (see A.4.1).

The capacities and diameters in italics (Columns 4 – 11) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of $^1/_2$ in., a maximum allowable design stress of 21,000 lbf/in.^{2}, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

08 Table A-2a—(SI) Shell-Plate Thicknesses (mm) for Typical Sizes of Tanks with 1800-mm Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
Tank Diameter m	Tank Height (m) / Number of Courses in Completed Tank										Maximum Allowable Height for Diameter[a] m
	1.8 / 1	3.6 / 2	5.4 / 3	7.2 / 4	9 / 5	10.8 / 6	12.6 / 7	14.4 / 8	16.2 / 9	18 / 10	
3	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—	—	—
4.5	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—	—	—
6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—
7.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.3	—
9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.7	6.3	—
10.5	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.9	6.6	7.4	—
12	5.0	5.0	5.0	5.0	5.0	5.0	5.9	6.7	7.6	8.4	—
13.5	5.0	5.0	5.0	5.0	5.0	5.6	6.6	7.6	8.5	9.5	—
15	6.0	6.0	6.0	6.0	6.0	6.3	7.3	8.4	9.5	10.6	—
18	6.0	6.0	6.0	6.0	6.2	7.5	8.8	10.1	11.4	—	17.8
21	6.0	6.0	6.0	6.0	7.3	8.8	10.3	11.8	—	—	15.3
24	6.0	6.0	6.0	6.6	8.3	10.0	11.7	—	—	—	13.4
27	6.0	6.0	6.0	7.4	9.3	11.3	—	—	—	—	11.9
30	6.0	6.0	6.0	8.2	10.4	12.5	—	—	—	—	10.8
36	8.0	8.0	8.0	9.9	12.5	—	—	—	—	—	9.0
42	8.0	8.0	8.5	11.5	—	—	—	—	—	—	7.8
48	8.0	8.0	9.7	—	—	—	—	—	—	—	6.9
54	8.0	8.0	10.9	—	—	—	—	—	—	—	6.1
60	8.0	8.0	12.2	—	—	—	—	—	—	—	5.5
66	10.0	10.0	—	—	—	—	—	—	—	—	5.1

08 [a]Based on a maximum permissible shell-plate thickness of 13 mm, a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance.

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-2b—(USC) Shell-Plate Thicknesses (in.) for Typical Sizes of Tanks with 72-in. Courses 08

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
Tank Diameter ft	Tank Height (ft) / Number of Courses in Completed Tank										Maximum Allowable Height for Diameter[a] ft
	6 / 1	12 / 2	18 / 3	24 / 4	30 / 5	36 / 6	42 / 7	48 / 8	54 / 9	60 / 10	
10	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—	—	—
15	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—	—	—
20	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—
25	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	0.20	0.22	—
30	3/16	3/16	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.26	—
35	3/16	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.27	0.30	—
40	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.28	0.31	0.35	—
45	3/16	3/16	3/16	3/16	3/16	0.23	0.27	0.31	0.35	0.38	—
50	1/4	1/4	1/4	1/4	1/4	0.26	0.30	0.35	0.39	0.43	—
60	1/4	1/4	1/4	1/4	0.26	0.31	0.36	0.41	0.47	—	58.2
70	1/4	1/4	1/4	1/4	0.30	0.36	0.42	0.48	—	—	50.0
80	1/4	1/4	1/4	0.27	0.34	0.41	0.48	—	—	—	43.9
90	1/4	1/4	1/4	0.31	0.38	0.46	—	—	—	—	39.1
100	1/4	1/4	1/4	0.34	0.43	—	—	—	—	—	35.3
120	5/16	5/16	5/16	0.41	—	—	—	—	—	—	29.6
140	5/16	5/16	0.35	0.47	—	—	—	—	—	—	25.5
160	5/16	5/16	0.40	—	—	—	—	—	—	—	22.5
180	5/16	5/16	0.45	—	—	—	—	—	—	—	20.1
200	5/16	0.32	0.50	—	—	—	—	—	—	—	18.2
220	3/8	3/8	—	—	—	—	—	—	—	—	16.6

[a]Based on a maximum permissible shell-plate thickness of 1/2 in., a maximum allowable design stress of 21,000 lbf/in.^{2}, a joint efficiency of 0.85, and no corrosion allowance. 07

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 21,000 lbf/in.^{2}, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

08 **Table A-3a—(SI) Typical Sizes and Corresponding Nominal Capacities (m^3) for Tanks with 2400-mm Courses.**

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Tank Diameter m	Capacity per m of Height m^3	Tank Height (m) / Number of Courses in Completed Tank						
		4.8 / 2	7.2 / 3	9.6 / 4	12 / 5	14.4 / 6	16.8 / 7	19.2 / 8
3	7.07	34	51	68	—	—	—	—
4.5	15.9	76	115	153	191	—	—	—
6	28.3	136	204	272	339	407	—	—
7.5	44.2	212	318	424	530	636	742	848
9	63.6	305	458	610	763	916	1,069	1,221
10.5	86.6	416	623	831	1,039	1,247	1,455	1,663
12	113	543	814	1085	1,357	1,629	1,900	2,171
13.5	143	687	1,031	1373	1,718	2,061	2,405	2,748
15	177	848	1,272	1696	2,121	2,545	2,969	3,393
18	254	1,221	1,832	2442	3,054	3,664	4,275	*4,358*
								D = 17
21	346	1,663	2,494	3323	4,156	4,988	*4,763*	—
24	452	2,171	3,257	4341	5,429	*5,474*	*D = 19*	—
27	573	2,748	4,122	5494	*6,871*	*D = 22*	—	—
30	707	3,393	5,089	6782	*D = 27*	—	—	—
36	1,018	4,886	7,329	*8712*	—	—	—	—
				D = 34				
42	1,385	6,650	9,975	—	—	—	—	—
48	1,810	8,686	*11,966*	—	—	—	—	—
54	2,290	10,993	*D = 46*	—	—	—	—	—
60	2,827	13,572	—	—	—	—	—	—
66	3,421	16,422	—	—	—	—	—	—

Note: The nominal capacities given in this table were calculated using the following formula:

In SI units:

$$C = 0.785 D^2 H$$

where

C = capacity of tank, in m^3,
D = diameter of tank, in m (see A.4.1),
H = height of tank, in m (see A.4.1).

The capacities and diameters in italics (Columns 4 – 9) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of 13 mm, a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1). 08

Table A-3b—(USC) Typical Sizes and Corresponding Nominal Capacities (barrels) for Tanks with 96-in. Courses 08

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Tank Diameter ft	Capacity per ft of Height barrels	Tank Height (ft) / Number of Courses in Completed Tank						
		16 / 2	24 / 3	32 / 4	40 / 5	48 / 6	56 / 7	64 / 8
10	14.0	225	335	450	—	—	—	—
15	31.5	505	755	1,010	1,260	—	—	—
20	56.0	900	1,340	1,790	2,240	2,690	—	—
25	87.4	1,400	2,100	2,800	3,500	4,200	4,900	5,600
30	126	2,020	3,020	4,030	5,040	6,040	7,050	8,060
35	171	2,740	4,110	5,480	6,850	8,230	9,600	10,980
40	224	3,580	5,370	7,160	8,950	10,740	12,540	14,340
45	283	4,530	6,800	9,060	11,340	13,600	15,880	18,140
50	350	5,600	8,400	11,200	14,000	16,800	19,600	22,400
60	504	8,060	12,100	16,130	20,160	24,190	28,220	*26,130*
								D = 54
70	685	10,960	16,450	21,950	27,440	32,930	*30,140*	—
80	895	14,320	21,500	28,670	35,840	*35,810*	*D = 62*	—
90	1,133	18,130	27,220	36,290	*45,360*	*D = 73*	—	—
100	1,399	22,380	33,600	44,800	*D = 88*	—	—	—
120	2,014	32,250	48,380	*54,200*	—	—	—	—
				D = 110				
140	2,742	43,900	65,860	—	—	—	—	—
160	3,581	57,340	*74,600*	—	—	—	—	—
180	4,532	72,570	*D = 149*	—	—	—	—	—
200	5,595	89,600	—	—	—	—	—	—
220	6,770	108,410	—	—	—	—	—	—

Note: The nominal capacities given in this table were calculated using the following formula:

In US Customary units:

$$C = 0.14D^2H,$$

where

C = capacity of tank, in 42-gal barrels,
D = diameter of tank, in ft (see A.4.1),
H = height of tank, in ft (see A.4.1).

The capacities and diameters in italics (Columns 4 – 9) are the maximums for the tank heights given in the column heads, based on a maximum permissible shell-plate thickness of $^1/_2$ in., a maximum allowable design stress of 21,000 lbf/in.^{2}, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

08 Table A-4a—(SI) Shell-Plate Thicknesses (mm) for Typical Sizes of Tanks with 2400-mm Courses

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
	Tank Height (m) / Number of Courses in Completed Tank								Maximum Allowable Height for Diameter[a] m
Tank Height Diameter m	2.4 / 1	4.8 / 2	7.2 / 3	9.6 / 4	12 / 5	14.4 / 6	16.8 / 7	19.2 / 8	
3	5.0	5.0	5.0	5.0	—	—	—	—	—
4.5	5.0	5.0	5.0	5.0	5.0	—	—	—	—
6	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—
7.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	—
9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	—
10.5	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.9	—
12	5.0	5.0	5.0	5.0	5.0	5.0	5.9	6.7	—
13.5	5.0	5.0	5.0	5.0	5.0	5.6	6.6	7.6	—
15	6.0	6.0	6.0	6.0	6.0	6.3	7.3	8.4	—
18	6.0	6.0	6.0	6.0	6.2	7.5	8.8	10.1	17.8
21	6.0	6.0	6.0	6.0	7.3	8.8	10.3	11.8	15.3
24	6.0	6.0	6.0	6.6	8.3	10.0	11.7	—	13.4
27	6.0	6.0	6.0	7.4	9.3	11.3	—	—	11.9
30	6.0	6.0	6.1	8.2	10.4	12.5	—	—	10.8
36	8.0	8.0	8.0	9.9	12.5	—	—	—	9.0
42	8.0	8.0	8.5	11.5	—	—	—	—	7.8
48	8.0	8.0	9.7	—	—	—	—	—	6.9
54	8.0	8.0	10.9	—	—	—	—	—	6.1
60	8.0	8.0	12.2	—	—	—	—	—	5.5
66	10.0	10.0	—	—	—	—	—	—	5.1

08 [a]Based on a maximum permissible shell-plate thickness of 13 mm, a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance.
Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 145 MPa, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

Table A-4b—(USC) Shell-Plate Thicknesses (in.) for Typical Sizes of Tanks with 96-in. Courses 08

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
	Tank Height (ft) / Number of Courses in Completed Tank								Maximum Allowable Height for Diameter[a] ft
Tank Height Diameter ft	8 / 1	16 / 2	24 / 3	32 / 4	40 / 5	48 / 6	56 / 7	64 / 8	
10	3/16	3/16	3/16	3/16	—	—	—	—	—
15	3/16	3/16	3/16	3/16	3/16	—	—	—	—
20	3/16	3/16	3/16	3/16	3/16	3/16	—	—	—
25	3/16	3/16	3/16	3/16	3/16	3/16	0.20	0.23	—
30	3/16	3/16	3/16	3/16	3/16	0.21	0.24	0.28	—
35	3/16	3/16	3/16	3/16	0.20	0.24	0.28	0.33	—
40	3/16	3/16	3/16	3/16	0.23	0.28	0.32	0.37	—
45	3/16	3/16	3/16	0.21	0.26	0.31	0.36	0.42	—
50	1/4	1/4	1/4	0.25	0.29	0.35	0.40	0.46	—
60	1/4	1/4	1/4	0.27	0.34	0.41	0.48	—	58.2
70	1/4	1/4	1/4	0.32	0.40	0.48	—	—	50.0
80	1/4	1/4	0.27	0.37	0.46	—	—	—	43.9
90	1/4	1/4	0.31	0.41	—	—	—	—	39.1
100	1/4	1/4	0.34	0.46	—	—	—	—	35.3
120	5/16	5/16	0.41	—	—	—	—	—	29.6
140	5/16	5/16	0.47	—	—	—	—	—	25.5
160	5/16	0.35	—	—	—	—	—	—	22.5
180	5/16	0.40	—	—	—	—	—	—	20.1
200	5/16	0.44	—	—	—	—	—	—	18.2
220	3/8	0.48	—	—	—	—	—	—	16.6

[a]Based on a maximum permissible shell-plate thickness of 1/2 in., a maximum allowable design stress of 21,000 lbf/in.^{2}, a joint efficiency of 0.85, and no corrosion allowance.

Note: The plate thicknesses shown in this table are based on a maximum allowable design stress of 21,000 lbf/in.^{2}, a joint efficiency of 0.85, and no corrosion allowance (see A.4.1).

A.4 Thickness of Shell Plates

11 **A.4.1** The nominal thicknesses of shell plates shall not be less than that computed from the stress on the vertical joints, using the following formula:

In SI units:

$$t = \frac{4.9D(H-0.3)G}{(E)(145)} + CA$$

where

11 t = nominal thickness, in mm (see 5.6.1.1),

D = nominal diameter of the tank, in m (see 5.6.1.1, Note 1),

H = design liquid level, in m (see 5.6.3.2),

• G = specific gravity of the liquid to be stored, as specified by the Purchaser. The specific gravity shall not be less than 1.0,

E = joint efficiency, which is either 0.85 or 0.70 (see A.3.4),

• CA = corrosion allowance, in mm, as specified by the Purchaser (see 5.3.2).

In US Customary units:

$$t = \frac{2.6D(H-1)G}{(E)(21,000)} + CA$$

where

11 t = nominal thickness (in.) (see 5.6.1.1),

D = nominal diameter of the tank (ft) (see 5.6.1.1, Note 1),

H = design liquid level (ft) (see 5.6.3.2),

• G = specific gravity of the liquid to be stored, as specified by the Purchaser. The specific gravity shall not be less than 1.0,

E = joint efficiency, which is either 0.85 or 0.70 (see A.3.4),

• CA = corrosion allowance (in.), as specified by the Purchaser (see 5.3.2).

A.4.2 The nominal thickness of shell plates (including shell extensions for floating roofs) shall not be less than that listed in
11 5.6.1.1. The nominal thickness of shell plates refers to the tank shell as constructed. The nominal thicknesses given in 5.6.1.1 are based on erection requirements.

A.5 Tank Joints

A.5.1 Vertical and horizontal joints in the shell, bottom joints, shell-to-bottom joints, wind-girder joints, and roof and top-angle joints shall conform to 5.1.5.

A.5.2 The requirements of 5.7.3 for the spacing of welds do not apply except for the requirement that the spacing between the toes of welds around a connection shall not be less than $2^1/_2$ times the shell thickness at the connection (i.e., dimension A, B, C, or
09 E in Figure 5-6 shall not be less than $2^1/_2$ times the shell thickness).

A.5.3 When radiographic inspection is required (joint efficiency = 0.85), the spot radiographs of vertical joints shall conform to 8.1.2.2, Item a only, excluding the 10 mm ($^3/_8$ in.) shell-thickness limitation in Item a and excluding the additional random spot radiograph required by Item a. The spot radiographs of horizontal joints shall conform to 8.1.2.3.

● A.6 Intermediate Wind Girders

Calculations for and installation of intermediate wind girders are not required unless specified by the Purchaser.

A.7 Shell Manholes and Nozzles

A.7.1 Except for other designs and shapes permitted by 5.7.1.2, shell manholes shall conform to 5.7.5, Figures 5-7A and 5-7B, and Tables 5-3a through 5-5b. 08

A.7.2 Shell nozzles and flanges shall conform to 5.7.6; Figures 5-7B, 5-8, and 5-10; and Tables 5-6a through 5-8b. For regular type reinforced nozzles, minimum elevation dimension H_N shown in column 8 of Table 5-6 may be reduced when specified by the Purchaser provided the minimum weld spacing of A.5.2 is maintained. 09

A.7.3 The radiographic requirements of 5.7.3.4 do not apply.

A.8 Flush-Type Cleanout Fittings

A.8.1 The details and dimensions of flush-type cleanout fittings shall conform to 5.7.7, Figures 5-12 and 5-13, and Tables 5-9a through 5-11b. 08

● **A.8.2** The provisions for stress relief specified in 5.7.4 and 5.7.7.3 are not required unless they are specified by the Purchaser or unless any plate in the unit has a thickness greater than 16 mm ($^5/_8$ in.).

A.9 Flush-Type Shell Connections

A.9.1 The details and dimensions of flush-type shell connections shall conform to 5.7.8, Figure 5-14, and Tables 5-12a and 5-12b. 08

● **A.9.2** The provisions for stress relief specified in 5.7.4 and 5.7.8.3 are not required unless they are specified by the Purchaser or unless any plate in the assembly has a thickness greater than 16 mm ($^5/_8$ in.). 07

APPENDIX AL—ALUMINUM STORAGE TANKS

AL.1 Scope

AL.1.1 CONSTRUCTION

This appendix provides material, design, fabrication, erection, and testing requirements for vertical, cylindrical, aboveground, closed- and open top, welded aluminum storage tanks constructed of the alloys specified in AL.4.

AL.1.2 REQUIREMENTS

This appendix states only the requirements that differ from the rules in this standard. For requirements not stated, follow the rules of this standard.

AL.1.3 TEMPERATURE

This appendix applies for maximum design temperatures up to 200°C (400°F). Alloys 5083, 5086, 5154, 5183, 5254, 5356, 5456, 5556, and 5654 shall not be used if the maximum design temperature exceeds 65°C (150°F). Ambient temperature tanks shall have a maximum design temperature of 40°C (100°F).

For maximum design temperatures above 93°C (200°F) designers shall consider thermal stresses and fatigue.

AL.1.4 UNITS

Use consistent units in this appendix's equations. For example, in an equation, use inches for all lengths (stress in $lb/in.^2$ and tank diameter in inches) or use mm for all lengths (stress in N/mm^2 and tank diameter in mm). 08

AL.1.5 NOMENCLATURE

Variables used in this appendix have the following meanings:

A = area of the roof-to-shell joint determined using Figure F-2

A_1 = 0.3 m (1 ft)

CA = corrosion allowance, as specified by the Purchaser (see 5.3.2)

D = nominal diameter of the tank (see 5.6.1.1)

E = compressive modulus of elasticity (see Table AL-8a and Table AL-8b)

E_j = joint efficiency, 1.0, 0.85, or 0.70 (see Table AL-2)

F_{ty} = minimum tensile yield strength

G = design specific gravity of the stored liquid

H = design liquid level (see 5.6.3.2)

p_h = greater of Appendix R load combinations (e)(1) and (e)(2)

S_d = allowable stress for the design condition (see Table AL-6a and Table AL-6b)

S_t = allowable stress for hydrostatic test condition (see Table AL-6a and Table Al-6b)

t_b = nominal thickness of the annular bottom plate

t_h = nominal roof thickness

t_s = nominal shell thickness

W = weight of the shell and any framing (but not roof plates) supported by the shell

γ_w = density of water

θ = roof slope to horizontal at the shell

ρ_h = density of the roof plate

AL.2 References

The following references are cited in this appendix. The latest edition shall be used.

AAI [21]

Aluminum Design Manual (ADM)

ASTM [22]

A 193 *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications*

A 194 *Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*

B 209 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*

B 209M *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate [Metric]*

B 210 *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes*

B 210M *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes [Metric]*

B 211 *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire*

B 211M *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire [Metric]*

B 221 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*

B 221M *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes [Metric]*

B 241/B 241M *Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube*

08 B 247 *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings*

B 247M *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings [Metric]*

B 308/B 308M *Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles*

B 345/B 345M *Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube for Gas and Oil Transmission and Distribution Piping Systems*

B 928 *Standard Specification for High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service and Similar Environments*

F 467 *Standard Specification for Nonferrous Nuts for General Use*

F 467M *Standard Specification for Nonferrous Nuts for General Use [Metric]*

F 468 *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use*

F 468M *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric]*

F 593 *Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs*

F 594 *Standard Specification for Stainless Steel Nuts*

AWS [23]

A5.10/A5.10M *Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods*

D1.2 *Structural Welding Code—Aluminum*

AL.3 Definitions

For the purposes of this appendix, the following definition applies:

AL3.1 aluminum: Aluminum and aluminum alloys.

AL.4 Materials

AL.4.1 GENERAL

Alloys shall be selected from Table AL-1. Dimensional tolerances shall meet the material specifications given in AL.4. Impact testing and toughness verification are not required.

[21]Aluminum Association Inc., 1525 Wilson Blvd, Suite 600, Arlington, Virginia 22209, www.aluminum.org.
[22]ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
[23]American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, www.aws.org.

Table AL-1—Material Specifications

Sheet and Plate		Rod, Bar, and Shapes		Pipe and Tube		Forgings	
Alloy	Temper	Alloy	Temper	Alloy	Temper	Alloy	Temper
1060	all	1060	all	1060	all		
1100	all	1100	all	1100	all	1100	H112
3003	all	2024	T4	3003	all	3003	H112
Alclad 3003				Alclad 3003	all		
3004	all	3004	all				
Alclad 3004	all						
5050	all			5050	all		
5052	all	5052	all	5052	all		
5083	all	5083	all	5083	all	5083	H111, H112
5086	all	5086	all	5086	all		
5154	all	5154	all	5154	all		
5254	all			5254	all		
5454	all	5454	all	5454	all		
5456	all	5456	all	5456	all		
5652	all			5652	all		
6061	(1)	6061	T6	6061	T4, T6	6061	T6
Alclad 6061	(1)	6063	T5, T6	6063	T5, T6		

(1) Includes T4, T42, T451, T6, T62, T651 tempers.

08

Table AL-2—Joint Efficiency

Joint Efficiency (E_j)	Shell Radiography Requirements
1.00	Full radiography required for all vertical joints. Horizontal joints per 0.85 joint efficiency requirements.
0.85	Radiography per 8.1.2 except additional random spot radiography in first course vertical seams is not required.
0.70	No shell radiography required.

Table AL-3a—(SI) Minimum Mechanical Properties

Minimum Tensile Yield Strengths F_{ty} (MPa) at Temperatures (°C)

Alloy	Temper	40	65	90	120	150	175	200
1060	all	17	17	17	15	13	12	11
1100	all	24	24	24	23	22	19	17
3003	all	34	34	34	34	32	30	26
Alclad 3003	all	31	31	31	30	28	27	23
3004	all	59	59	59	59	59	55	51
Alclad 3004	all	55	55	55	55	55	50	46
5050	all	41	41	41	41	41	40	39
5052, 5652	all	66	66	66	66	66	66	58
5083 (1)	all	124	123			do not use above 65°C		
5083 (2)	all	117	117			do not use above 65°C		
5086	all	97	96			do not use above 65°C		
5154, 5254	all	76	76			do not use above 65°C		
5454	all	93	83	83	83	82	80	77
5456 (1)	all	131	130			do not use above 65°C		
5456 (2)	all	124	123			do not use above 65°C		
6061, Alclad 6061	T4, T6 welded	103	103	103	103	101	91	72
08 6061	T6 extrusions	240	240	232	201	163	103	54
6063	T5, T6 welded	55	55	55	55	52	31	23
6063	T6	172	172	159	137	111	61	36
1060	all	55	55					
1100	all	76	76					
3003	all	95	95					
Alclad 3003	all	90	90					
3004	all	150	150					
Alclad 3004	all	145	145					
5050	all	125	125					
5052, 5652	all	175	175					
5083 (1)	all	275	275			do not use above 65°C		
5083 (2)	all	270	270			do not use above 65°C		
5086	all	240	240			do not use above 65°C		
5154, 5254	all	205	205			do not use above 65°C		
5454	all	215	215					
5456 (1)	all	290	290			do not use above 65°C		
5456 (2)	all	285	285			do not use above 65°C		
6061, Alclad 6061	T4, T6 welded	165	165					
6061	T6 extrusions	260	260	243	208	169	117	76
6063	T5, T6 welded	115	115					
6063	T6	205	205	188	160	130	83	53

Notes:
(1) up to 40 mm thick.
(2) > 40 mm and ≤ 75mm thick.
(3) strengths are for the –O temper for all alloys except 6061, Alclad 6061, and 6063 which are as noted.

Table AL-3b—(USC) Minimum Mechanical Properties

		Minimum Tensile Yield Strengths F_{ty} (ksi) at Temperatures (°F)							
Alloy	Temper	100	150	200	250	300	350	400	
1060	all	2.5	2.5	2.4	2.2	1.9	1.8	1.6	
1100	all	3.5	3.5	3.5	3.4	3.2	2.8	2.4	
3003	all	5.0	5.0	5.0	4.9	4.6	4.3	3.7	
Alclad 3003	all	4.5	4.5	4.5	4.4	4.1	3.9	3.3	
3004	all	8.5	8.5	8.5	8.5	8.5	8.0	7.4	
Alclad 3004	all	8.0	8.0	8.0	8.0	8.0	7.2	6.7	
5050	all	6.0	6.0	6.0	6.0	6.0	5.8	5.6	
5052, 5652	all	9.5	9.5	9.5	9.5	9.5	9.5	8.4	
5083 (1)	all	18	17.9			do not use above 150°F			
5083 (2)	all	17	16.9			do not use above 150°F			
5086	all	14	13.9			do not use above 150°F			
5154, 5254	all	11	11			do not use above 150°F			
5454	all	12	12	12	12	11.9	11.6	11.1	
5456 (1)	all	19	18.8			do not use above 150°F			
5456 (2)	all	18	17.9			do not use above 150°F			
6061, Alclad 6061	T4, T6 welded	15	15	15	15	14.7	13.2	10.5	
6061	T6 extrusions	35	35	33.6	29.1	23.6	14.9	7.9	08
6063	T5, T6 welded	8	8	8	8	7.5	4.5	3.4	
6063	T6	25	25	23	19.8	16.1	8.9	5.2	
1060	all	8.0	8.0						
1100	all	11	11						
3003	all	14	14						
Alclad 3003	all	13	13						
3004	all	22	22						
Alclad 3004	all	21	21						
5050	all	18	18						
5052, 5652	all	25	25						
5083 (1)	all	40	40			do not use above 150°F			
5083 (2)	all	39	39			do not use above 150°F			
5086	all	35	35			do not use above 150°F			
5154, 5254	all	30	30			do not use above 150°F			
5454	all	31	31						
5456 (1)	all	42	42			do not use above 150°F			
5456 (2)	all	41	41			do not use above 150°F			
6061, Alclad 6061	T4, T6 welded	24	24						
6061	T6 extrusions	38	38	35.3	30.2	24.5	16.9	11.0	
6063	T5, T6 welded	17	17						
6063	T6	30	30	27.2	23.2	18.9	12.0	7.7	

Notes:
(1) up to 1.500 in. thick.
(2) > 1.500 in. thick, ≤ 3.000 in. thick.
(3) strengths are for the –O temper for all alloys except 6061, Alclad 6061, and 6063 which are as noted.

AL.4.2 SHEET AND PLATE

Sheet and plate shall meet ASTM B 209 or B 928. Tapered thickness plate may be used.

AL.4.3 ROD, BAR, AND STRUCTURAL SHAPES

Rod, bar, and shapes shall meet ASTM B 211, ASTM B 221, or ASTM B 308.

AL.4.4 PIPE AND TUBE

Pipe and tube shall meet ASTM B 210, ASTM B 241, or ASTM B 345.

AL.4.5 FORGINGS

Forgings shall meet ASTM B 247.

AL.4.6 FLANGES

AL4.6.1 Aluminum

Flanges shall meet ASTM B 247 and be 6061-T6. Flange dimensions shall meet ASME B16.5 or B16.47.

AL4.6.2 Composite Lap Joint Flanges

For composite lap joint flanges, the aluminum stub ends shall be one of the alloys listed in Table AL-1 for sheet and plate or pipe and tube, and the steel, stainless steel, or galvanized steel flanges shall meet ASME B16.5.

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AL.4.7 BOLTING

AL4.7.1 Aluminum

Aluminum bolts shall meet ASTM F 468. Aluminum nuts shall meet ASTM F 467. Bolts and nuts of 2024 alloy shall have an anodic coating at least 0.005 mm [0.0002 in.] thick. Bolts shall not be welded. Aluminum threads tend to gall, so aluminum threaded parts shall not be used where they must be reinstalled.

AL4.7.2 Stainless Steel

Stainless steel bolts shall meet ASTM F 593 alloy group 1 or 2, or ASTM A 193 B8. Stainless steel nuts shall meet ASTM F 594 alloy group 1 or 2 or ASTM A 194 Grade 8.

AL4.7.3 Carbon Steel

Carbon steel bolts shall be galvanized.

AL.4.8 WELDING ELECTRODES

Welding electrodes shall meet AWS A5.10/A5.10M and shall be chosen in accordance with AWS D1.2.

AL.5 Design

AL.5.1 JOINTS

Joints shall be as prescribed in 5.1.5 unless otherwise specified below.

AL5.1.1 Bottom Joints

a. Bottom plates under the shell thicker than 8 mm ($^5/_{16}$ in.) shall be butt welded.
b. *Butt-Welded Bottom Joints*. The butt welds may be made from both sides or from one side and shall have full penetration and full fusion. In the latter case, a backing strip 5 mm ($^3/_{16}$ in.) or thicker, of an aluminum alloy compatible with the bottom plate, shall be tacked to one of the plates, and the intersection joints of the strips shall be welded with full penetration and full fusion.

AL5.1.2 Roof and Top Angle Joints

The moment of inertia of the top angle and contributing portion of the shell (see AL.5.5) shall equal or exceed that provided by the sizes listed below:

Diameter (m)	Size (mm)
$D < 11$	65 × 65 × 6
$11 < D < 18$	65 × 65 × 8
$18 < D$	75 × 75 × 10

Diameter (ft)	Size (in.)
$D < 35$	2 1/2 × 2 1/2 × 1/4
$35 < D \leq 61$	2 1/2 × 2 1/2 × 5/16
$61 < D$	3 × 3 × 3/8

AL.5.2 BOTTOMS

AL5.2.1 Annular Bottom Plate Width

Annular bottom plates shall have a radial width that meets the requirements of 5.5.2 except that the width must equal or exceed:

$$2t_b\sqrt{\frac{F_{ty}}{2\gamma_w GH}}$$

AL5.2.2 Annular Bottom Plate Thickness 08

The nominal thickness of annular bottom plates shall equal or exceed the requirements given in Table AL-4a and Table AL-4b.

Table AL-4a—(SI) Annular Bottom Plate Thickness

Nominal Thickness of First Shell Course (mm)	Hydrostatic Test Stress in First Shell Course (MPa) 14	28	41	55	69	83	97	11
$t \leq 12.7$	6	6	6	6	6	6	7	
$12.7 < t \leq 19$	6	6	6	6	7	9	10	
$19 < t \leq 25$	6	6	6	7	10	12	15	
$25 < t \leq 32$	6	6	7	10	13	16	19	
$32 < t \leq 38$	6	6	10	12	16	19	27	
$38 < t \leq 51$	6	10	11	16	21	25	31	

Table AL-4b—(USC) Annular Bottom Plate Thickness

Nominal Thickness of First Shell Course (in.)	Hydrostatic Test Stress in First Shell Course (ksi) 2.0	4.0	6.0	8.0	10.0	12.0	14.0	11
$t \leq 0.50$	1/4	1/4	1/4	1/4	1/4	1/4	9/32	
$0.50 < t \leq 0.75$	1/4	1/4	1/4	1/4	9/32	11/32	13/32	
$0.75 < t \leq 1.00$	1/4	1/4	1/4	9/32	3/8	15/32	19/32	
$1.00 < t \leq 1.25$	1/4	1/4	9/32	3/8	1/2	5/8	3/4	
$1.25 < t \leq 1.50$	1/4	1/4	3/8	15/32	5/8	3/4	1 1/16	
$1.50 < t \leq 2.00$	1/4	3/8	7/16	5/8	13/16	1	1 7/32	

AL.5.3 SHELLS

11 The nominal thickness of the shell plates shall be no less than the greatest of the calculated design shell thickness t_d including any corrosion allowance, the hydrostatic test shell thickness t_t, and the thickness required by Table AL-5a and Table AL-5b:

$$t_d = \frac{\gamma_w G D (H - A_1)}{2 E_j S_d} + CA$$

$$t_t = \frac{\gamma_w D (H - A_1)}{2 E_j S_t}$$

Table AL-5a—(SI) Minimum Shell Thickness

Nominal Tank Diameter (m)	Nominal Plate Thickness (m)	
$D < 6$	5	
$6 \le D < 36$	6	
$36 \le D \le 60$	8	
$D > 60$	10	08

Table AL-5b—(USC) Minimum Shell Thickness

Nominal Tank Diameter (ft)	Nominal Plate Thickness (in.)
$D < 20$	3/16
$20 \le D < 120$	1/4
$120 \le D \le 200$	5/16
$D > 200$	3/8

AL.5.4 SHELL OPENINGS

AL5.4.1 Thermal Stress Relief

Thermal stress relief requirements of 5.7.4 do not apply.

AL5.4.2 Shell Manholes

Shell manholes shall meet 5.7.5 except the following.

a. *Cover Plate and Flange Thickness.* The cover plate and flange thickness shall comply with Figures AL-1 and AL-2. As an alternative to Figures AL-1 and AL-2, plate flanges may be designed in accordance with API 620 rules using the allowable stresses from Table AL-6a and Table AL-6b.

b. *Neck Thickness.* Where manhole neck thickness is controlled by thickness of the bolting flange (see note b of Table 5-4a and Table 5-4b), the flange thickness determined in item 1 above shall be used.

c. *Weld Sizes*: Fillet weld A shall comply with Table AL-9a and Table AL-9b.

AL5.4.3 Nozzles

Shell nozzles shall meet 5.7.6 except fillet weld A shall comply with AL-9a and Table AL-9b.

Table AL-6a—(SI) Allowable Tensile Stresses for Tank Shell (for Design and Test)

Alloy	Temper	Minimum Yield Strength MPa (4)	Minimum Tensile Strength MPa (4)	Allowable Stress (MPa) (5) S_d for Maximum Design Temperature Not Exceeding 40°C	65°C	90°	120°C	150°C	175°C	200°C	S_t Ambient (6)
1060	all	17	55	14	14	13	12	10	7	6	15
1100	all	24	76	19	19	19	19	12	9	7	21
3003	all	34	97	28	28	28	22	17	12	10	29
Alclad 3003	all	31	90	25	25	25	20	15	11	9	26
3004	all	59	152	47	47	47	47	40	26	16	50
Alclad 3004	all	55	145	44	44	44	44	40	26	16	47
5050	all	41	124	33	33	33	33	33	19	10	35
5052, 5652	all	66	172	52	52	52	52	39	28	16	56
5083 (1)	all	124	276	90	90	do not use above 65°C					91
5083 (2)	all	117	269	88	88	do not use above 65°C					89
5086	all	97	241	77	77	do not use above 65°C					80
5154, 5254	all	76	207	61	60	do not use above 65°C					64
5454	all	83	214	66	66	66	51	38	28	21	70
5456 (1)	all	131	290	96	96	do not use above 65°C					96
5456 (2)	all	124	283	93	93	do not use above 65°C					93
6061, Alclad 6061 (3)	T4, T6, T451, T651		165	55	55	55	54	51	42	30	55

Notes:
(1) up to 40 mm thick.
(2) > 40 mm and ≤ 80 mm thick
(3) Tempers T4 and T6 apply for thickness < 6 mm, T451 and T651 apply for thickness ≥ 6 mm.
(4) Strengths are for the –O temper for all alloys except 6061, Alclad 6061, and 6063.
(5) The design stress shall be the lesser of $^2/_3$ of the minimum tensile strength, 0.8 of the minimum yield strength, the stress producing a secondary creep rate of 0.1% in 1000 hr, or 67% of the average stress for rupture at the end of 100,000 hr.
(6) The allowable test stress shall be the lesser of $^2/_3$ of the minimum tensile strength or 0.85 of the minimum yield strength at ambient temperature.

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AL5.4.4 Flush Type Cleanouts

Flush-type cleanout fittings shall comply with Figures AL-1, AL-2, and AL-3.

AL.5.5 WIND GIRDERS

The length of the shell included in the area of wind girders shall be $0.424\sqrt{Dt_s}$ except for unstiffened shell above top wind girders, the length shall be $56t_s\sqrt{F_{ty}}$.

Table AL-6b—(USC) Allowable Tensile Stresses for Tank Shell (for Design and Test)

				Allowable Stress (psi) (5) S_d for Maximum Design Temperature Not Exceeding							
Alloy	Temper	Minimum Yield Strength (psi) (4)	Minimum Tensile Strength (psi) (4)	100°F	150°F	200°F	250°F	300°F	350°F	400°F	S_t Ambient (6)
1060	all	2,500	8,000	2,000	2,000	1,900	1,750	1,450	1,050	800	2,100
1100	all	3,500	11,000	2,800	2,800	2,800	2,700	1,750	1,350	1,000	3,000
3003	all	5,000	14,000	4,000	4,000	4,000	3,150	2,400	1,800	1,400	4,300
Alc 3003	all	4,500	13,000	3,600	3,600	3,600	2,850	2,150	1,600	1,250	3,800
3004	all	8,500	22,000	6,800	6,800	6,800	6,800	5,750	3,800	2,350	7,200
Alc 3004	all	8,000	21,000	6,400	6,400	6,400	6,400	5,750	3,800	2,350	6,800
5050	all	6,000	18,000	4,800	4,800	4,800	4,800	4,800	2,800	1,400	5,100
5052, 5652	all	9,500	25,000	7,600	7,600	7,600	7,500	5,600	4,100	2,350	8,100
5083 (1)	all	18,000	40,000	13,000	13,000		do not use above 150°F				13,200
5083 (2)	all	17,000	39,000	12,800	12,800		do not use above 150°F				12,900
5086	all	14,000	35,000	11,200	11,100		do not use above 150°F				11,600
5154, 5254	all	11,000	30,000	8,800	8,700		do not use above 150°F				9,400
08 5454	all	12,000	31,000	9,600	9,600	9,600	7,400	5,500	4,100	3,000	10,200
5456 (1)	all	19,000	42,000	13,900	13,900		do not use above 150°F				13,900
5456 (2)	all	18,000	41,000	13,500	13,500		do not use above 150°F				13,500
6061, Alc 6061 (3)	T4, T6, T451, T651		24,000	8,000	8,000	8,000	7,900	7,400	6,100	4,300	8,000

Notes:
(1) up to 1.500 in. thick.
(2) > 1.500 in. and ≤ 3.000 in. thick.
(3) Temper T4 and T6 apply for thickness < 6 mm (0.25 in.), T451 and T651 apply for thickness ≥ 0.25 in.
(4) Strengths are for the – O temper for all alloys except 6061, Alclad 6061, and 6063.
(5) The design stress shall be the lesser of $^2/_3$ of the minimum tensile strength, 0.8 of the minimum yield strength, the stress producing a secondary creep rate of 0.1% in 1000 hr, or 67% of the average stress for rupture at the end of 100,000 hr.
(6) The allowable test stress shall be the lesser of $^2/_3$ of the minimum tensile strength or 0.85 of the minimum yield strength at ambient temperature.

AL5.5.1 Wind Girders

The section modulus of wind girders shall equal or exceed

$$Z = \frac{pH_wD^3}{12Ec}$$

where

p = (1.48 kPa) $[V/(190 \text{ km/hr})]^2$;

p = (31 lb/ft^2) $[V/(120 \text{ mph})]^2$;

V = 3-sec gust design wind speed [see 5.2.1(k)];

H_W = for top wind girders on tanks with no intermediate wind girder, the tank height; for tanks with intermediate wind girders, the vertical distance between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank;

c = lesser of the distances from the neutral axis to the extreme fibers of the wind girder.

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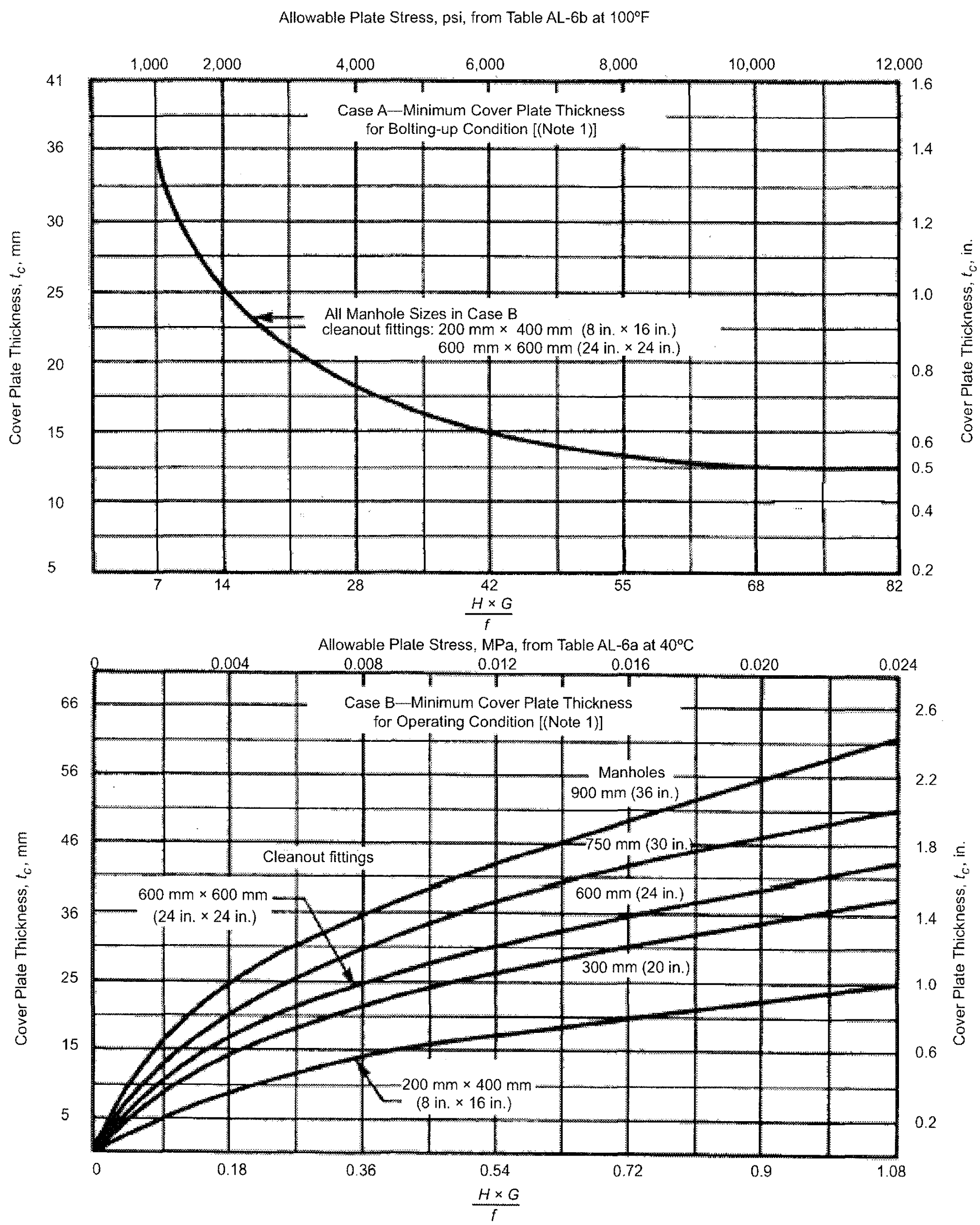

G = specific gravity of liquid that determines the shell thickness;
H = height of design liquid level above centerline of manhole m (ft);
f = allowable tensile stress (S_d or S_b) from Table AL-6a and Table AL-6b at the temperature coincident with G, MPa (psi).

Note:
(1) the minimum cover plate thickness shall be a maximum of Case A or B values.

Figure AL-1—Cover Plate Thickness for Shell Manholes and Cleanout Fittings

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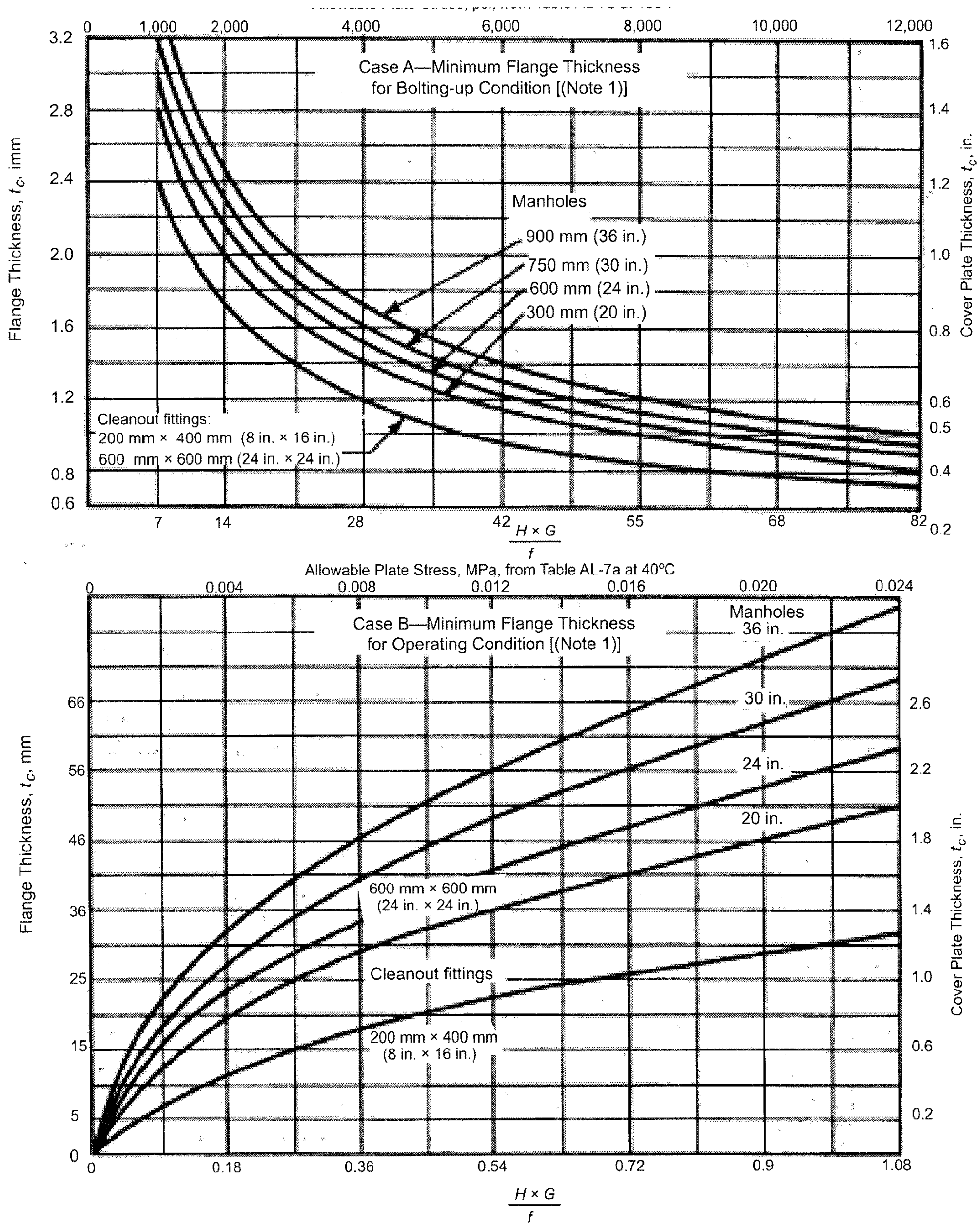
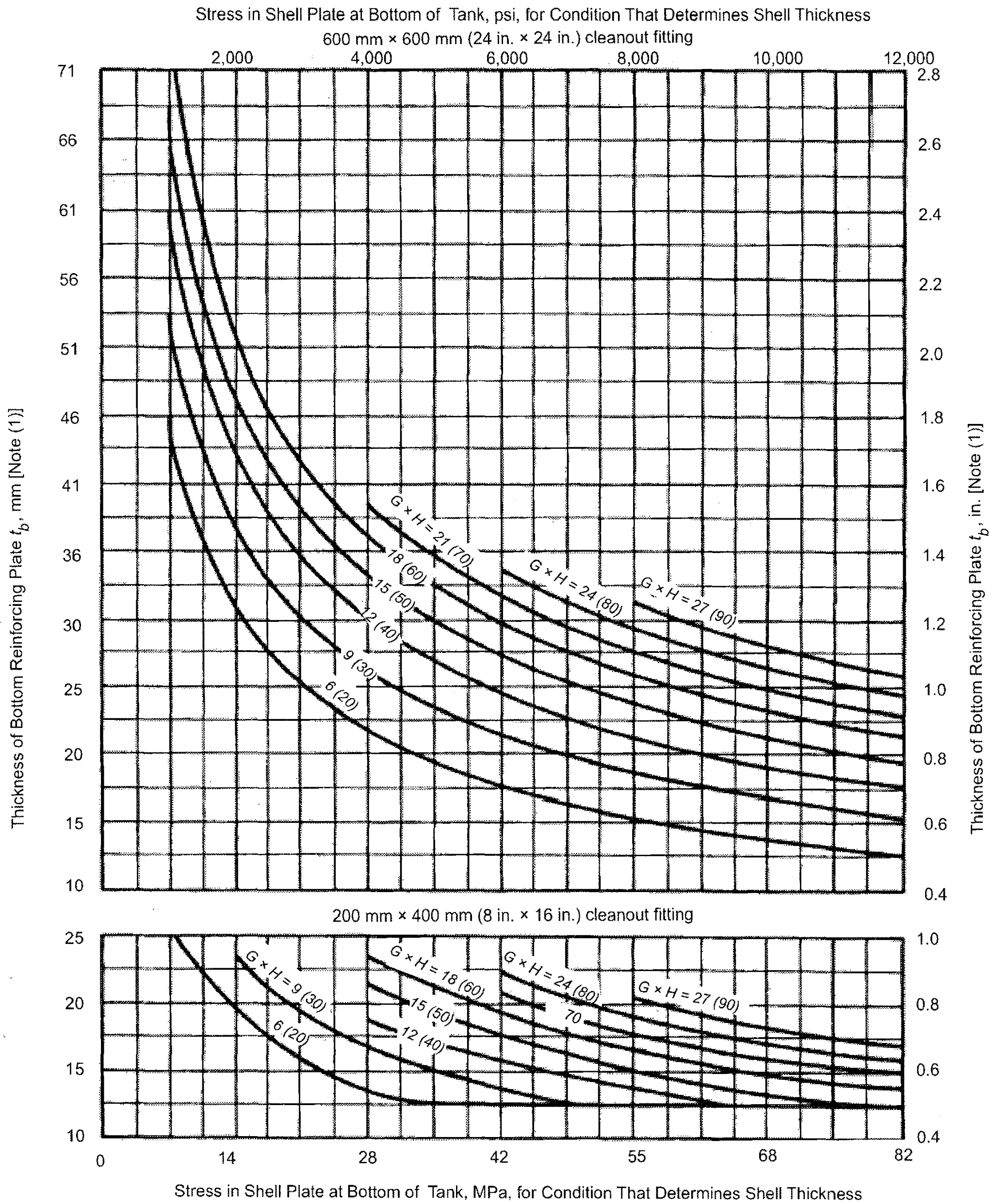


G = specific gravity of liquid that determines the shell thickness;
H = height of design liquid level above centerline of manhole, m (ft);
f = allowable tensile stress (S_d or S_b) from Table AL-6a and Table AL-6b at the temperature coincident with G, MPa (psi).

Note:
(1) the minimum cover plate thickness shall be a maximum of Case A or B values.

Figure AL-2—Flange Plate Thickness for Shell Manholes and Cleanout Fittings



G = specific gravity of liquid that determines the shell thickness;
H = design liquid level, m (ft);

Note:
(1) the bottom reinforcing plate shall be the same alloy and temper as the bottom shell plate.

Figure AL-3—Bottom Reinforcing Plate Thickness for Cleanout Fittings

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AL5.5.2 Intermediate Wind Girders

The height of the unstiffened shell shall not exceed:

08 $$H_1 = 2400t\sqrt{\left(\frac{1200t}{D}\right)^3}\left(\frac{E_{MDT}}{E_{40}}\right)$$

where

H_1 = vertical distance between the intermediate wind girder and the top angle of the shell or the top wind girder of an open-top tank;

11 ● t = nominal thickness, unless otherwise specified, of the top shell course;

E_{MDT} = modulus of elasticity at the maximum design temperature;

E_{40} = modulus of elasticity at 40°C (100°F).

AL.5.6 ROOFS

AL5.6.1 Structural Members

The minimum nominal thickness of structural members shall be 4 mm (0.15 in.).

AL5.6.2 Frangible Roofs

Roofs required to be frangible shall meet the requirements of 5.10.2.6 except that the cross sectional area A of the roof-to-shell joint shall not exceed $0.159\,W/(F_{ty}\tan\theta)$ where F_{ty} = the greatest tensile yield strength of the materials in the joint.

AL5.6.3 Allowable Stresses

08 Roofs shall be proportioned so that stresses from the load combinations specified in 5.10.2.1 do not exceed the allowable stresses given in the *Aluminum Design Manual (ADM) Specification for Aluminum Structures—Allowable Stress Design for building type structures.* Allowable stresses for ambient temperature service shall be calculated using the minimum mechanical properties given in the ADM. Allowable stresses for elevated temperature service shall be calculated using the minimum mechanical properties given in Table AL-8a and Table AL-8b. Section 5.10.3.4 does not apply.

AL5.6.4 Supported Cone Roofs

a. The stresses determined from Figure AL-4 for dead load and dead and live loads for the thickness and span of roof plates shall not exceed the allowable stresses given in Table AL-7a and Table AL-7b.
b. The roof supporting structure shall be of 6061-T6 or 6063-T6 and proportioned so stresses do not exceed allowable stresses. Dead load stresses for temperatures over 120°C (250°F) shall not exceed 25% of allowable stresses.
c. Low cycle fatigue failures may occur at the roof-to-top-angle weld and at roof lap welds for roofs designed to the minimum requirements of this standard when:

1. the internal pressure exceeds the weight of the roof plates; or
2. tanks larger than 15 m (50 ft) in diameter are subjected to steady wind speeds of 40 to 50 km/hr (25 to 30 mph) or greater.

Table AL-7a—(SI) Allowable Stresses for Roof Plates

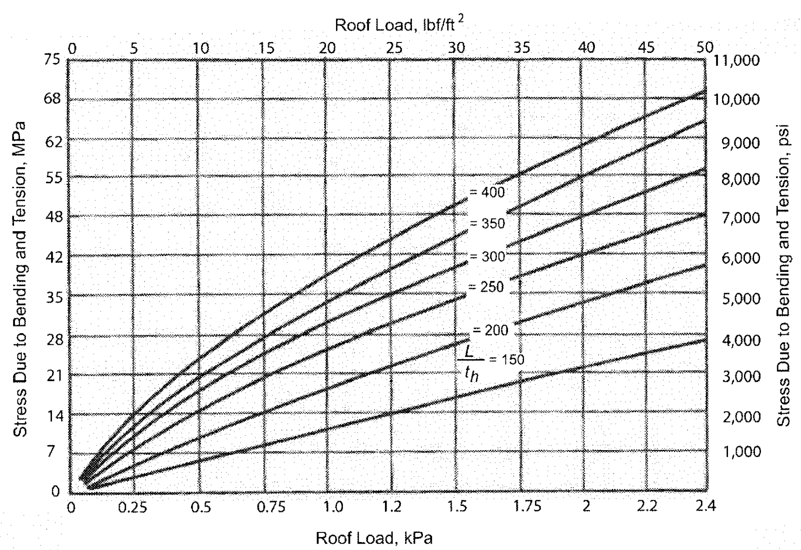
Alloy	Temper		Allowable Tensile Stresses (MPa) at Maximum Design Temperatures (°C) Not Exceeding						
			40	65	90	120	150	175	200
3003	all	(dead load)				22	16	12	9.6
		(dead + live load)	34	34	34	34	32	30	26
Alclad 3003	all	(dead load)				20	15	11	8.6
		(dead + live load)	31	31	31	30	29	27	23
3004	all	(dead load)					40	26	16
		(dead + live load)	59	59	59	59	59	55	51
Alclad 3004	all	(dead load)					36	23	17
		(dead + live load)	55	55	55	55	55	50	46
5050	all	(dead load)					37	19	9.6
		(dead + live load)	41	41	41	41	41	40	39
5052, 5652	all	(dead load)					43	28	16
		(dead + live load)	66	66	66	66	66	66	58
5083	all	(dead + live load)	124	123			do not use above 65°C		
5086	all	(dead + live load)	97	96			do not use above 65°C		
5154, 5254	all	(dead + live load)	76	76			do not use above 65°C		
5454	all	(dead load)			81	51	38	28	21
		(dead + live load)	83	83	83	83	82	80	77
5456	all	(dead + live load)	131	130			do not use above 65°C		
6061, Alclad 6061	T4, T6	(dead load)					57	42	30
		(dead + live load)	66	66	66	65	61	51	39

Note: For non-heat treatable alloys, allowable stresses for dead + live loads are the lesser of the yield strength, the stress producing a secondary creep rate of 0.1% in 10,000 hr, 67% of the average stress for rupture after 100,000 hr. For heat treatable alloys, allowable stresses are 40% of the minimum strength of groove welds.

Table AL-7b—(USC) Allowable Stresses for Roof Plates

	Alloy	Temper		Allowable Tensile Stresses (ksi) at Maximum Design Temperatures (°F) Not Exceeding 100	150	200	250	300	350	400
	3003	all	(dead load)				3.15	2.4	1.8	1.4
			(dead + live load)	5.0	5.0	5.0	4.9	4.6	4.3	3.7
	Alclad 3003	all	(dead load)				2.85	2.15	1.6	1.25
			(dead + live load)	4.5	4.5	4.5	4.4	4.15	3.85	3.35
	3004	all	(dead load)					5.75	3.8	2.35
			(dead + live load)	8.5	8.5	8.5	8.5	8.5	8.0	7.4
	Alclad 3004	all	(dead load)					5.15	3.4	2.4
			(dead + live load)	8.0	8.0	8.0	8.0	8.0	7.2	6.65
	5050	all	(dead load)					5.35	2.8	1.4
			(dead + live load)	6.0	6.0	6.0	6.0	6.0	5.8	5.6
	5052, 5652	all	(dead load)					6.25	4.1	2.35
			(dead + live load)	9.5	9.5	9.5	9.5	9.5	9.5	8.4
	5083	all	(dead + live load)	18	17.9			do not use above 150°F		
	5086	all	(dead + live load)	14	13.9			do not use above 150°F		
	5154, 5254	all	(dead + live load)	11	11			do not use above 150°F		
08	5454	all	(dead load)			11.7	7.4	5.5	4.1	3.0
			(dead + live load)	12	12	12	12	11.9	11.6	11.1
	5456	all	(dead + live load)	19	18.8			do not use above 150°F		
	6061, Alclad 6061	T4, T6	(dead load)					8.2	6.1	4.3
			(dead + live load)	9.6	9.6	9.6	9.45	8.85	7.45	5.65

Note: For non-heat treatable alloys, allowable stresses for dead + live loads are the lesser of the yield strength, the stress producing a secondary creep rate of 0.1% in 10,000 hr, 67% of the average stress for rupture after 100,000 hr. For heat treatable alloys, allowable stresses are 40% of the minimum strength of groove welds.



L = maximum rafter spacing, mm (in.);
t_h = thickness of roof, mm (in.).

Figure AL-4—Stresses in Roof Plates

Table AL-8a—(SI) Compressive Moduli of Elasticity *E* (MPa) at Temperature (°C)

	40	65	90	120	150	175	200
1060	69,600	68,300	66,900	64,800	63,400	60,700	57,900
1100	69,600	68,300	66,900	64,800	63,400	60,700	57,900
3003, Alclad 3003	69,600	68,300	66,900	64,800	63,400	60,700	57,900
3004, Alclad 3004	69,600	68,300	66,900	64,800	63,400	60,700	57,900
5050	69,600						
5052, 5652	71,000	68,900	67,600	64,800	62,700	59,300	55,800
5083	71,700	70,300			do not use above 65°C		
5086	71,700	70,300			do not use above 65°C		
5154, 5254	71,000				do not use above 65°C		
5454	71,000	68,900	67,600	64,800	62,700	59,300	55,800
5456	71,700	70,300			do not use above 65°C		
6061	69,600	68,300	66,900	65,500	64,100	62,700	60,700
6063	69,600	68,300	66,900	65,500	64,100	62,700	60,700

Note: (1) Tensile moduli = (compressive moduli)/1.02.

Table AL-8b—(USC) Compressive Moduli of Elasticity *E* (ksi) at Temperature (°F) 08

Alloy	100	150	200	250	300	350	400
1060	10,100	9,900	9,700	9,400	9,200	8,800	8,400
1100	10,100	9,900	9,700	9,400	9,200	8,800	8,400
3003, Alclad 3003	10,100	9,900	9,700	9,400	9,200	8,800	8,400
3004, Alclad 3004	10,100	9,900	9,700	9,400	9,200	8,800	8,400
5050	10,100						
5052, 5652	10,300	10,000	9,800	9,400	9,100	8,600	8,100
5083	10,400	10,200			do not use above 150°F		
5086	10,400	10,200			do not use above 150°F		
5154, 5254	10,300				do not use above 150°F		
5454	10,300	10,000	9,800	9,400	9,100	8,600	8,100
5456	10,400	10,200			do not use above 150°F		
6061	10,100	9,900	9,700	9,500	9,300	9,100	8,800
6063	10,100	9,900	9,700	9,500	9,300	9,100	8,800

Note: (1) Tensile moduli = (compressive moduli)/1.02.

Table AL-9a and Table AL-9b are the same as Table 5-7a and Table 5-7b, respectively, with the following modifications:

Table AL-9a—(SI) Shell Nozzle Welding Schedule

	Column 1 Thickness of Shell and Reinforcing Plate *t* and *T*	Column 5 Size of Fillet Weld A Nozzles Larger Than NPS 2
	mm	mm
	5	6
	6	6
	8	6
	10	6
	11	6
	13	6
	14	6
	16	8
	17	8
	20	10
	21	11
	22	11
08	24	13
	25	13
	27	14
	28	14
	30	14
	32	16
	33	16
	35	17
	36	17
	38	20
	40	21
	41	21
	43	22
	45	22

Table AL-9b—(USC) Shell Nozzle Welding Schedule

Column 1 Thickness of Shell and Reinforcing Plate *t* and *T*	Column 5 Size of Fillet Weld A Nozzles Larger Than NPS 2
in.	in.
3/16	1/4
1/4	1/4
5/16	1/4
3/8	1/4
7/16	1/4
1/2	1/4
9/16	1/4
5/8	5/16
11/16	5/16
3/4	3/8
13/16	7/16
7/8	7/16
15/16	1/2
1	1/2
1 1/16	9/16
1 1/8	9/16
1 3/16	9/16
1 1/4	5/8
1 5/16	5/8
1 3/8	11/16
1 7/16	11/16
1 1/2	3/4
1 9/16	13/16
1 5/8	13/16
1 11/16	7/8
1 3/4	7/8

08

AL5.6.5 Self-Supporting Cone Roofs

a. The minimum nominal roof thickness is t_h.

$$t_h = \frac{2D}{\sin\theta}\sqrt{\frac{p_h}{E}}$$

b. The minimum area of the roof-to-shell joint is A.

$$A = p_h D^2 / (8 f \tan\theta)$$

where

f = least allowable tensile stress of the materials in the roof-to-shell joint.

AL5.6.6 Self-Supporting Dome and Umbrella Roofs

a. The minimum nominal roof thickness is t_h.

$$t_h = 4.0 r_h \sqrt{\frac{p_h}{E}}$$

where

08 r_h = roof radius

b. The minimum area of the roof-to-shell joint *is* A.

$$A = p_h D^2 / (8 f \tan\theta)$$

where

f = least allowable tensile stress of the materials in the roof-to-shell joint.

AL5.6.7 Structurally Supported Aluminum Dome Roofs

Structurally supported aluminum dome roofs shall meet Appendix G.

AL.6 Fabrication

AL.6.1 FINISH OF PLATE EDGES

At least 3 mm (1/8 in.) shall be mechanically removed from edges of heat treatable alloys that have been plasma arc cut. Oxygen cutting shall not be used.

AL.6.2 MARKING MATERIALS

Marking materials shall not contain carbon or heavy metal compounds.

AL.7 Erection

AL.7.1 WELDING METHODS

Welding shall be gas metal arc welding, gas tungsten arc welding, plasma arc welding without using flux, or friction stir welding.
11 The welding may be performed by the manual, machine, automatic, or semiautomatic welding processes according to procedures by welders or welding operators qualified in accordance with ASME Section IX or AWS D1.2.

AL.7.2 PREHEATING

Parts to be welded shall not be preheated except to the extent needed to drive off moisture or bring base metal temperature up to minimum welding temperature per 7.2.1.2.

AL.7.3 PLUMBNESS

The plumbness requirements shall be per 7.5.2 except the out-of-plumbness in any shell course shall not exceed the flatness tolerance in ASTM B 209M (B 209).

AL.7.4 STORAGE

Aluminum parts shall not be stored in contact with one another when moisture is present. Aluminum shall not be stored or erected in contact with carbon steel or the ground.

AL.8 Inspection of Welds

AL.8.1 LIQUID PENETRANT EXAMINATION

The following welds shall be examined by the liquid penetrant method before the hydrostatic test of the tank:

a. shell opening reinforcement and structural attachment plates, excluding lightly loaded attachments, that intersect a shell weld shall be examined for a distance of 150 mm (6 in.) on each side of the intersection and the butt weld for a distance of 50 mm (2 in.) beyond the pad weld;

b. all welds of openings in the shell that are not completely radiographed, including nozzle and manhole neck welds and neck-to-flange welds; 08

c. all butt-welded joints in tank shell and annular plate on which backing strips are to remain.

AL.8.2 MAGNETIC PARTICLE EXAMINATION

Section 8.2 does not apply.

AL.9 Welding Procedures and Welder Qualifications

Weld procedures and welder qualifications shall meet Section 9 except that impact tests are not required.

AL.10 Marking

AL.10.1 MATERIAL

In addition to the requirements of Section 10, the bottom and roof alloys shall be shown on the nameplate.

AL.11 Foundations

AL.11.1 CONCRETE

Aluminum shall not be placed in direct contact with concrete.

AL.12 Internal Pressure

AL.12.1 GENERAL

Appendix F shall be met with the following exceptions.

AL.12.2 DESIGN PRESSURE

The design internal pressure P in F.4.1:

$$P = \frac{8AF_{ty}\tan\theta}{(SF)D^2} + \rho_h t_h$$

where

F_{ty} = tensile yield strength of the materials in the roof-to-shell joint;

SF = safety factor = 1.6;

A = area resisting the compressive force as illustrated in Figure F-2 except that $16t$ shall be replaced by $56t_s\sqrt{F_{ty}}$.

AL.12.3 MAXIMUM DESIGN PRESSURE

The maximum design pressure in F.4.2 shall be:

$$P_{max} = \rho_h t_h + \frac{4W}{\pi D^2} - \frac{8(1.67)M}{\pi D^3}$$

where

P_{max} = maximum design pressure;

08 M = wind overturning moment.

AL.12.4 REQUIRED COMPRESSION AREA AT THE ROOF-TO-SHELL JUNCTION

The required area at the roof-to-shell joint in F.5.1 shall be:

$$A = \frac{(SF)D^2(P - \rho_h t_h)}{8F_{ty}\tan\theta}$$

AL.12.5 CALCULATED FAILURE PRESSURE

The calculated failure pressure in F.6 shall be:

$$P_f = 1.6P - 0.6\rho_h t_h$$

AL.12.6 ANCHORED TANKS

The allowable compressive stress in F.7.2 shall be $F_{ty}/1.6$.

AL.13 Seismic Design

AL.13.1 GENERAL

Appendix E shall be met with the following exceptions.

AL.13.2 ALLOWABLE LONGITUDINAL MEMBRANE COMPRESSION STRESS IN SHELL

The allowable compressive stress in E.6.2.2.3 shall be determined in accordance with the ASME *Boiler and Pressure Vessel Code,* Section VIII, Division 1.

AL.14 External Pressure

AL.14.1 GENERAL

Appendix V does not apply to aluminum tanks.

APPENDIX B—RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION OF FOUNDATIONS FOR ABOVEGROUND OIL STORAGE TANKS

B.1 Scope

B.1.1 This appendix provides important considerations for the design and construction of foundations for aboveground steel oil storage tanks with flat bottoms. Recommendations are offered to outline good practice and to point out some precautions that should be considered in the design and construction of storage tank foundations.

B.1.2 Since there is a wide variety of surface, subsurface, and climatic conditions, it is not practical to establish design data to cover all situations. The allowable soil loading and the exact type of subsurface construction to be used must be decided for each individual case after careful consideration. The same rules and precautions shall be used in selecting foundation sites as would be applicable in designing and constructing foundations for other structures of comparable magnitude.

B.2 Subsurface Investigation and Construction

B.2.1 At any tank site, the subsurface conditions must be known to estimate the soil bearing capacity and settlement that will be experienced. This information is generally obtained from soil borings, load tests, sampling, laboratory testing, and analysis by an experienced geotechnical engineer familiar with the history of similar structures in the vicinity. The subgrade must be capable of supporting the load of the tank and its contents. The total settlement must not strain connecting piping or produce gauging inaccuracies, and the settlement should not continue to a point at which the tank bottom is below the surrounding ground surface. The estimated settlement shall be within the acceptable tolerances for the tank shell and bottom.

B.2.2 When actual experience with similar tanks and foundations at a particular site is not available, the following ranges for factors of safety should be considered for use in the foundation design criteria for determining the allowable soil bearing pressures. (The owner or geotechnical engineer responsible for the project may use factors of safety outside these ranges.)

a. From 2.0 to 3.0 against ultimate bearing failure for normal operating conditions.

b. From 1.5 to 2.25 against ultimate bearing failure during hydrostatic testing.

c. From 1.5 to 2.25 against ultimate bearing failure for operating conditions plus the maximum effect of wind or seismic loads.

B.2.3 Some of the many conditions that require special engineering consideration are as follows:

a. Sites on hillsides, where part of a tank may be on undisturbed ground or rock and part may be on fill or another construction or where the depth of required fill is variable.

b. Sites on swampy or filled ground, where layers of muck or compressible vegetation are at or below the surface or where unstable or corrosive materials may have been deposited as fill.

c. Sites underlain by soils, such as layers of plastic clay or organic clays, that may support heavy loads temporarily but settle excessively over long periods of time.

d. Sites adjacent to water courses or deep excavations, where the lateral stability of the ground is questionable.

e. Sites immediately adjacent to heavy structures that distribute some of their load to the subsoil under the tank sites, thereby reducing the subsoil's capacity to carry additional loads without excessive settlement.

f. Sites where tanks may be exposed to flood waters, possibly resulting in uplift, displacement, or scour.

g. Sites in regions of high seismicity that may be susceptible to liquefaction.

h. Sites with thin layers of soft clay soils that are directly beneath the tank bottom and that can cause lateral ground stability problems.

B.2.4 If the subgrade is inadequate to carry the load of the filled tank without excessive settlement, shallow or superficial construction under the tank bottom will not improve the support conditions. One or more of the following general methods should be considered to improve the support conditions:

a. Removing the objectionable material and replacing it with suitable, compacted material.

b. Compacting the soft material with short piles.

c. Compacting the soft material by preloading the area with an overburden of soil. Strip or sand drains may be used in conjunction with this method.

d. Stabilizing the soft material by chemical methods or injection of cement grout.

e. Transferring the load to a more stable material underneath the subgrade by driving piles or constructing foundation piers. This involves constructing a reinforced concrete slab on the piles to distribute the load of the tank bottom.

f. Constructing a slab foundation that will distribute the load over a sufficiently large area of the soft material so that the load intensity will be within allowable limits and excessive settlement will not occur.

g. Improving soil properties by vibro-compaction, vibro-replacement, or deep dynamic-compaction.

h. Slow and controlled filling of the tank during hydrostatic testing. When this method is used, the integrity of the tank may be compromised by excessive settlements of the shell or bottom. For this reason, the settlements of the tank shall be closely monitored. In the event of settlements beyond established ranges, the test may have to be stopped and the tank releveled.

B.2.5 The fill material used to replace muck or other objectionable material or to build up the grade to a suitable height shall be adequate for the support of the tank and product after the material has been compacted. The fill material shall be free of vegetation, organic matter, cinders, and any material that will cause corrosion of the tank bottom. The grade and type of fill material shall be capable of being compacted with standard industry compaction techniques to a density sufficient to provide appropriate bearing capacity and acceptable settlements. The placement of the fill material shall be in accordance with the project specifications prepared by a qualified geotechnical engineer.

B.3 Tank Grades

B.3.1 The grade or surface on which a tank bottom will rest should be constructed at least 0.3 m (1 ft) above the surrounding ground surface. This will provide suitable drainage, help keep the tank bottom dry, and compensate for some small settlement that is likely to occur. If a large settlement is expected, the tank bottom elevation shall be raised so that the final elevation above grade will be a minimum of 150 mm (6 in.) after settlement.

B.3.2 There are several different materials that can be used for the grade or surface on which the tank bottom will rest. To minimize future corrosion problems and maximize the effect of corrosion prevention systems such as cathodic protection, the material in contact with the tank bottom should be fine and uniform. Gravel or large particles shall be avoided. Clean washed sand 75 mm – 100 mm (3 in. – 4 in.) deep is recommended as a final layer because it can be readily shaped to the bottom contour of the tank to provide maximum contact area and will protect the tank bottom from coming into contact with large particles and debris. Large foreign objects or point contact by gravel or rocks could cause corrosion cells that will cause pitting and premature tank bottom failure.

During construction, the movement of equipment and materials across the grade will mar the graded surface. These irregularities should be corrected before bottom plates are placed for welding.

Adequate provisions, such as making size gradients in sublayers progressively smaller from bottom to top, should be made to prevent the fine material from leaching down into the larger material, thus negating the effect of using the fine material as a final layer. This is particularly important for the top of a crushed rock ringwall.

Note: For more information on tank bottom corrosion and corrosion prevention that relates to the foundation of a tank, see API RP 651.

● **B.3.3** Unless otherwise specified by the Purchaser, the finished tank grade shall be crowned from its outer periphery to its center at a slope of 1 in. in 10 ft. The crown will partly compensate for slight settlement, which is likely to be greater at the center. It will also facilitate cleaning and the removal of water and sludge through openings in the shell or from sumps situated near the shell. Because crowning will affect the lengths of roof-supporting columns, it is essential that the tank Manufacturer be fully informed of this feature sufficiently in advance. (For an alternative to this paragraph, see B.3.4.)

● **B.3.4** As an alternative to B.3.3, the tank bottom may be sloped toward a sump. The tank Manufacturer must be advised as required in B.3.3.

B.4 Typical Foundation Types

B.4.1 EARTH FOUNDATIONS WITHOUT A RINGWALL

B.4.1.1 When an engineering evaluation of subsurface conditions that is based on experience and/or exploratory work has shown that the subgrade has adequate bearing capacity and that settlements will be acceptable, satisfactory foundations may be constructed from earth materials. The performance requirements for earth foundations are identical to those for more extensive foundations. Specifically, an earth foundation should accomplish the following:

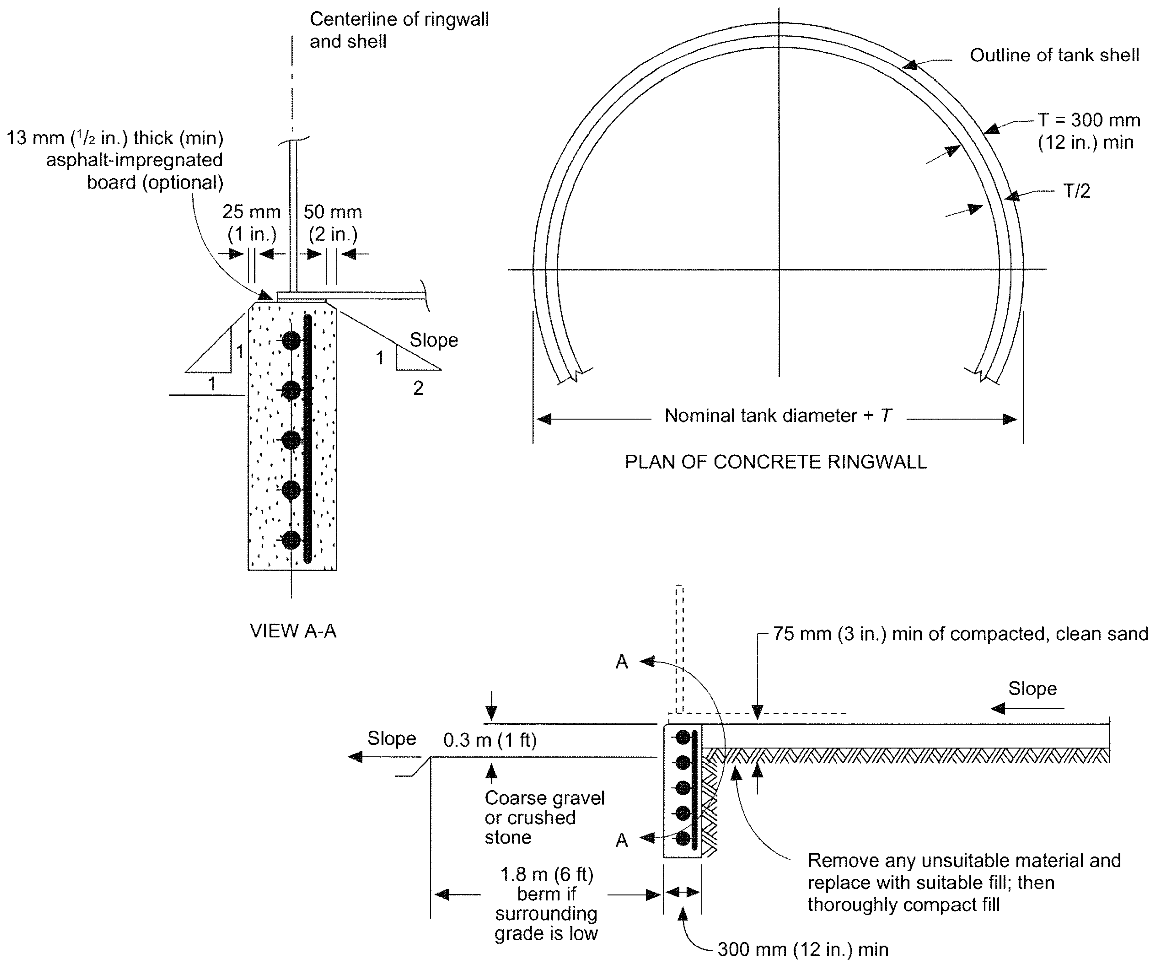
a. Provide a stable plane for the support of the tank.

b. Limit overall settlement of the tank grade to values compatible with the allowances used in the design of the connecting piping.

c. Provide adequate drainage.

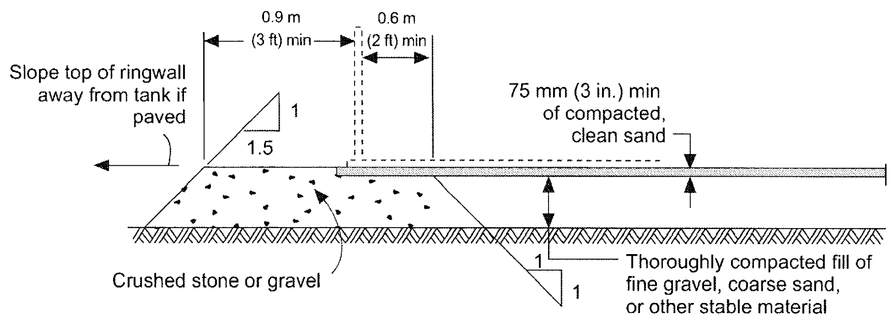
d. Not settle excessively at the perimeter due to the weight of the shell wall.

B.4.1.2 Many satisfactory designs are possible when sound engineering judgment is used in their development. Three designs are referred to in this appendix on the basis of their satisfactory long-term performance. For smaller tanks, foundations can consist of compacted crushed stone, screenings, fine gravel, clean sand, or similar material placed directly on virgin soil. Any unstable material must be removed, and any replacement material must be thoroughly compacted. Two recommended designs that include ringwalls are illustrated in Figures B-1 and B-2 and described in B.4.2 and B.4.3.



Notes:
1. See B.4.2.3 for requirements for reinforcement.
2. The top of the concrete ringwall shall be smooth and level. The concrete strength shall be at least 20 MPa (3000 lbf/in.^{2}) after 28 days. Reinforcement splices must be staggered and shall be lapped to develop full strength in the bond. If staggering of laps is not possible, see ACI 318 for additional development requirements.
3. Ringwalls that exceed 300 mm (12 in.) in width shall have rebars distributed on both faces.
4. See B.4.2.2 for the position of the tank shell on the ringwall.

Figure B-1—Example of Foundation with Concrete Ringwall



Note: Any unsuitable material shall be removed and replaced with suitable fill; the fill shall then be thoroughly compacted.

Figure B-2—Example of Foundation with Crushed Stone Ringwall

B.4.2 EARTH FOUNDATIONS WITH A CONCRETE RINGWALL

B.4.2.1 Large tanks and tanks with heavy or tall shells and/or self-supported roofs impose a substantial load on the foundation under the shell. This is particularly important with regard to shell distortion in floating-roof tanks. When there is some doubt whether a foundation will be able to carry the shell load directly, a concrete ringwall foundation should be used. As an alternative to the concrete ringwall noted in this section, a crushed stone ringwall (see B.4.3) may be used. A foundation with a concrete ringwall has the following advantages:

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

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

c. It provides a better means of leveling the tank grade, and it is capable of preserving its contour during construction.

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

e. It minimizes moisture under the tank.

A disadvantage of concrete ringwalls is that they may not smoothly conform to differential settlements. This disadvantage may lead to high bending stresses in the bottom plates adjacent to the ringwall.

B.4.2.2 When a concrete ringwall is designed, it shall be proportioned so that the allowable soil bearing is not exceeded. The ringwall shall not be less than 300 mm (12 in.) thick. The centerline diameter of the ringwall should equal the nominal diameter of the tank; however, the ringwall centerline may vary if required to facilitate the placement of anchor bolts or to satisfy soil bearing limits for seismic loads or excessive uplift forces. The depth of the wall will depend on local conditions, but the depth must be sufficient to place the bottom of the ringwall below the anticipated frost penetration and within the specified bearing strata. As a minimum, the bottom of the ringwall, if founded on soil, shall be located 0.6 m (2 ft) below the lowest adjacent finish grade. Tank foundations must be constructed within the tolerances specified in 7.5.5. Recesses shall be provided in the wall for flush-type cleanouts, drawoff sumps, and any other appurtenances that require recesses.

B.4.2.3 A ringwall should be reinforced against temperature changes and shrinkage and reinforced to resist the lateral pressure of the confined fill with its surcharge from product loads. ACI 318 is recommended for design stress values, material specifications, and rebar development and cover. The following items concerning a ringwall shall be considered:

a. The ringwall shall be reinforced to resist the direct hoop tension resulting from the lateral earth pressure on the ringwall's inside face. Unless substantiated by proper geotechnical analysis, the lateral earth pressure shall be assumed to be at least 50% of the vertical pressure due to fluid and soil weight. If a granular backfill is used, a lateral earth pressure coefficient of 30% may be used.

b. The ringwall shall be reinforced to resist the bending moment resulting from the uniform moment load. The uniform moment load shall account for the eccentricities of the applied shell and pressure loads relative to the centroid of the resulting soil pressure. The pressure load is due to the fluid pressure on the horizontal projection of the ringwall inside the shell.

c. The ringwall shall be reinforced to resist the bending and torsion moments resulting from lateral, wind, or seismic loads applied eccentrically to it. A rational analysis, which includes the effect of the foundation stiffness, shall be used to determine these moments and soil pressure distributions.

d. The total hoop steel area required to resist the loads noted above shall not be less than the area required for temperature changes and shrinkage. The hoop steel area required for temperature changes and shrinkage is 0.0025 times the vertical cross-sectional area of the ringwall or the minimum reinforcement for walls called for in ACI 318, Chapter 14.

e. For ringwalls, the vertical steel area required for temperature changes and shrinkage is 0.0015 times the horizontal cross-sectional area of the ringwall or the minimum reinforcement for walls called for in ACI 318, Chapter 14. Additional vertical steel may be required for uplift or torsional resistance. If the ring foundation is wider than its depth, the design shall consider its behavior as an annular slab with flexure in the radial direction. Temperature and shrinkage reinforcement shall meet the ACI 318 provisions for slabs. (See ACI 318, Chapter 7.)

f. When the ringwall width exceeds 460 mm (18 in.), using a footing beneath the wall should be considered. Footings may also be useful for resistance to uplift forces.

g. Structural backfill within and adjacent to concrete ringwalls and around items such as vaults, undertank piping, and sumps requires close field control to maintain settlement tolerances. Backfill should be granular material compacted to the density and compacting as specified in the foundation construction specifications. For other backfill materials, sufficient tests shall be conducted to verify that the material has adequate strength and will undergo minimal settlement.

h. If the tank is designed and constructed for elevated temperature service, see B.6. 08

B.4.3 EARTH FOUNDATIONS WITH A CRUSHED STONE AND GRAVEL RINGWALL

B.4.3.1 A crushed stone or gravel ringwall will provide adequate support for high loads imposed by a shell. A foundation with a crushed stone or gravel ringwall has the following advantages:

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

b. It provides a means of leveling the tank grade, and it is capable of preserving its contour during construction.

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

d. It can more smoothly accommodate differential settlement because of its flexibility.

A disadvantage of the crushed stone or gravel ringwall is that it is more difficult to construct it to close tolerances and achieve a flat, level plane for construction of the tank shell.

B.4.3.2 For crushed stone or gravel ringwalls, careful selection of design details is necessary to ensure satisfactory performance. The type of foundation suggested is shown in Figure B-2. Significant details include the following:

a. The 0.9 m (3 ft) shoulder and berm shall be protected from erosion by being constructed of crushed stone or covered with a permanent paving material.

b. Care shall be taken during construction to prepare and maintain a smooth, level surface for the tank bottom plates.

c. The tank grade shall be constructed to provide adequate drainage away from the tank foundation.

d. The tank foundation must be true to the specified plane within the tolerances specified in 7.5.5.

B.4.4 SLAB FOUNDATIONS

● **B.4.4.1** When the soil bearing loads must be distributed over an area larger than the tank area or when it is specified by the owner, a reinforced concrete slab shall be used. Piles beneath the slab may be required for proper tank support.

B.4.4.2 The structural design of the slab, whether on grade or on piles, shall properly account for all loads imposed upon the slab by the tank. The reinforcement requirements and the design details of construction shall be in accordance with ACI 318.

B.5 Tank Foundations for Leak Detection

Appendix I provides recommendations on the construction of tank and foundation systems for the detection of leaks through the bottoms of storage tanks.

B.6 Tank Foundations for Elevated Temperature Service

The design and construction of foundations for tanks operating at elevated temperatures [> 93°C (200°F)] should address the following considerations.

a. When subjected to elevated operating temperatures, an unanchored tank may tend to move in one or more directions over time. This movement must be accommodated in the design of the tank fittings and attachments.

b. Elevated temperature service may evaporate moisture in the soil supporting the tank and lead to increased, and possibly non-uniform, settlement. Such settlement may include differential settlement between the ringwall and soil under the tank bottom immediately adjacent to the ringwall resulting from non-uniform shrinkage of the soil with respect to the stone or concrete
08 ringwall.

c. In cases where there is high groundwater table, elevated temperatures may vaporize groundwater and generate undesirable steam.

d. Attachments between the tank and the foundation must accommodate the thermal expansion and contraction of the tank without resulting in unacceptable stress levels.

e. The elevated temperature must be accounted for in the design of concrete ringwall foundations. The ringwall is subject to a moment due to the higher temperature at the top of the ringwall with respect to the temperature at the bottom of the ringwall. If not adequately accounted for in the design of the ringwall, this moment can lead to cracking of the concrete foundation and loss of tank support.

APPENDIX C—EXTERNAL FLOATING ROOFS

• C.1 Scope

C.1.1 This appendix provides minimum requirements that, unless otherwise qualified in the text, apply to single-deck pontoon-type and double-deck-type floating roofs. See Section 3 for the definition of these roof types. This appendix is intended to limit only those factors that affect the safety and durability of the installation and that are considered to be consistent with the quality and safety requirements of this Standard. Numerous alternative details and proprietary appurtenances are available; however, agreement between the Purchaser and the Manufacturer is required before they are used. 11

C.1.2 The type of roof and seal to be provided shall be as specified on the Data Sheet, Line 30. If the type is not specified, the Manufacturer shall provide a roof and seal that is cost-effective and suitable for the specified service. Pan-type floating roofs shall not be used. 07

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

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

C.2 Material

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

a. ASTM A 27M, grade 405-205 (ASTM A 27, grade 60-30), fully annealed.

b. ASTM A 27M, grade 450-240 (ASTM A 27, grade 65-35), fully annealed or normalized and tempered, or quenched and tempered.

c. ASTM A 216M (ASTM A 216) WCA, WCB, or WCC grades annealed and normalized, or normalized and tempered.

C.3 Design

C.3.1 GENERAL

• **C.3.1.1** The roof and accessories shall be designed and constructed so that the roof is allowed to float to the maximum design liquid level and then return to a liquid level that floats the roof well below the top of the tank shell without damage to any part of the roof, tank, or appurtenances. During such an occurrence, no manual attention shall be required to protect the roof, tank, or appurtenances. If a windskirt or top-shell extension is used, it shall contain the roof seals at the highest point of travel. The Purchaser shall provide appropriate alarm devices to indicate a rise of the liquid in the tank to a level above the normal and overfill protection levels (see NFPA 30 and API RP 2350). Overflow slots shall not be used as a primary means of detecting an overfill incident. If specified by the Purchaser (Table 4 of the Data Sheet), emergency overflow openings may be provided to protect the tank and floating roof from damage. 07

• **C.3.1.2** The application of corrosion allowances shall be a matter of agreement between the Purchaser and the Manufacturer. Corrosion allowance shall be added to the required minimum thickness or, when no minimum thickness is required, added to the minimum thickness required for functionality. 11

C.3.1.3 Sleeves and fittings that penetrate the single deck or lower decks of annular pontoons or lower decks of double-deck roofs, except for automatic bleeder vents, rim space vents, and leg sleeves, shall have a minimum wall thickness of "Standard Wall" for pipe NPS 6 and larger and 6 mm ($^1/_4$ in.) for all other pipe and plate construction unless otherwise specified on the Data Sheet, Table 5. Such penetrations shall extend into the liquid.

C.3.1.4 The annular space between the roof outer rim of the floating roof and the product side of the tank shell shall be designed for proper clearance of the peripheral seal (see C.3.13). All appurtenances and internal components of the tank shall have adequate clearance for the proper operation of the completed roof assembly. 07

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

07 **C.3.1.6** All conductive parts of the external floating roof shall be electrically interconnected and bonded to the outer tank structure. Bonding (grounding) shunts shall be provided on the external floating roof and shall be located above the uppermost seal. Shunts shall be 50-mm (2-in.) wide by 28-gauge (0.4-mm [$^1/_{64}$-in.] thick) austenitic stainless steel as a minimum, or shall provide equivalent corrosion resistance and current carrying capacity as stated in NFPA 780 and API RP 2003. Shunt spacing shall be no more than 3 m (10 ft). All movable cover accessories (hatches, manholes, pressure relief devices, and other openings) on the external floating roof shall be electrically bonded to the external floating roof to prevent static electricity sparking when they are opened.

C.3.2 JOINTS

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

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

C.3.3 DECKS

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

08 • **C.3.3.2** Unless otherwise specified by the Purchaser, all deck plates shall have a minimum nominal thickness of 48 mm ($^3/_{16}$ in.) (permissible ordering basis—37.4 kg/m^2, 7.65 lbf/ft^2 of plate, 0.180-in. plate, or 7-gauge sheet).

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

C.3.3.4 Top decks of double-deck roofs and of pontoon sections, which are designed with a permanent slope shall be designed, fabricated, and erected (with a minimum slope of 1 in 64) to minimize accumulation of standing water (e.g., pooling adjacent to a rolling ladder's track) when primary roof drains are open. This requirement is not intended to completely eliminate isolated puddles. 07 When out of service, water shall flow freely to the primary roof drains. These decks shall preferably be lapped to provide the best drainage. Plate buckles shall be kept to a minimum.

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

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

C.3.4 PONTOON DESIGN

C.3.4.1 Floating roofs shall have sufficient buoyancy to remain afloat on liquid with a specific gravity of the lower of the product specific gravity or 0.7 and with primary drains inoperative for the following conditions:

a. 250 mm (10 in.) of rainfall in a 24-hour period over the full horizontal tank area with the roofs intact. This condition does not apply to double-deck roofs provided with emergency drains designed to keep water to a lesser volume that the roofs will safely 07 support. Such emergency drains shall not allow the product to flow onto the roof.

Note: The rainfall rate for sizing the roof drains in C.3.8 may result in a larger accumulated rainfall.

• b. Single-deck and any two adjacent pontoon compartments punctured and flooded in single-deck pontoon roofs and any two adjacent compartments punctured and flooded in double-deck roofs, both roof types with no water or live load.

With agreement by the Purchaser, Item b may be replaced by the following for floating roofs 6 m (20 ft) in diameter or less: Any one compartment punctured and flooded in single-deck pontoon roofs or double-deck roofs, both roof types with no water or live load.

• **C.3.4.2** The pontoon portions of single-deck pontoon-type roofs shall be designed to have adequate strength to prevent permanent distortion when the center deck is loaded by its design rainwater (C.3.4.1, Item a) or when the center deck and two adjacent pontoons are punctured (C.3.4.1, Item b). The allowable stress and stability criteria shall be jointly established by the Purchaser and the Manufacturer as part of the inquiry. Alternatively, a proof test simulating the conditions of C.3.4.1, with the roof floating on water, may be performed on the roof or on one of similar design that is of equal or greater diameter.

C.3.4.3 Any penetration of the floating roof shall not allow product to flow onto the roof under design conditions. The sag of the roof deck under design conditions and the minimum design specific gravity (0.7) of the stored liquid shall be considered in establishing the minimum elevations of all roof penetrations. 08

C.3.5 PONTOON OPENINGS

• Each compartment shall be provided with a liquid-tight manhole with a minimum nominal size of NPS 20. Manhole covers shall be provided with suitable hold-down fixtures (which may be of the quick-opening type) or with other means of preventing wind or fire-fighting hose streams from removing the covers. The top edge of the manhole necks shall be at an elevation that prevents liquid from entering the compartments under the conditions of C.3.4. With agreement by the Purchaser, floating roofs 6 m (20 ft) in diameter or less may be designed using a pontoon inspection port in place of a pontoon manhole. 07

Each compartment shall be vented to protect against internal or external pressure. Vents may be in the manhole cover, inspection port cover, or the top deck of the compartment. The vents shall be at an elevation that prevents liquid from entering the compartment under the conditions of C.3.4 and shall terminate in a manner that prevents entry of rain and fire-fighting liquids.

C.3.6 COMPARTMENTS

Compartment plates are radial or circumferential dividers forming compartments that provide flotation for the roof (see C.3.4). All internal compartment plates (or sheets) shall be single-fillet welded along all of their edges, and other welding shall be performed at junctions as required to make each compartment leak tight. Each compartment weld shall be tested for leak tightness using internal pressure or a vacuum box and a soap solution or penetrating oil. 07

C.3.7 LADDERS

• Unless otherwise specified by the Purchaser, the floating roof shall be supplied with a ladder that automatically adjusts to any roof position so that access to the roof is always provided. The ladder shall be designed for full-roof travel, regardless of the normal setting of the roof-leg supports. The ladder shall have full-length handrails on both sides and shall be designed for a 4450 N (1000 lbf) midpoint load with the ladder in any operating position. Step assemblies shall be of open type and have non-slip walking surfaces and self-leveling treads with a minimum width of 510 m (20 in.) and a 860 mm (34 in.) high handrail at the nose of the tread. When the roof is in its extreme low position, the slope of the rolling ladder shall not be less than 35 degrees to vertical, unless specified otherwise by the Purchaser. Wheels shall be provided at the lower end of the ladder, sized to prevent binding of the ladder, and provided with maintenance-free bearings. Ladders shall be grounded to both the roof and the gauger's platform with at least an AWG (American Wire Gage) 2/0 (67 sq. mm [0.104 sq. in.]), non-tangling cable. Cable shall be configured so that it will not freeze to adjacent surfaces in cold weather. Ladder and track design shall minimize ponding by using trussed runways or other details considering fatigue and stiffening effects resulting from supports. The Purchaser may elect to add requirements such as a wider stair width, lateral roof loading, and alternate runway designs that reduce ponding under the ladder. 07

C.3.8 ROOF DRAINS

C.3.8.1 Primary Roof Drains

• 1. Primary roof drains shall be sized and positioned to accommodate the rainfall rates specified on the Data Sheet, Line 33, while preventing the roof from accumulating a water level greater than design, without allowing the roof to tilt excessively or interfere with its operation. Roof drains shall be furnished attached to double-flanged, low-type nozzles on the tank shell with valves to be supplied by the Purchaser. A swing-type check valve shall be provided at the inlet of drains unless otherwise specified on the Data Sheet, Line 32. The drains shall be removable, if required by the Purchaser. Primary roof drains shall not be smaller than NPS 3 for roofs with a diameter less than or equal 36 m (120 ft) or smaller than NPS 4 for roofs with a diameter greater than 36 m (120 ft). 07

2. Primary roof drains shall be resistant to the tank's contents, or suitably coated, and shall be free from floating, kinking, or catching on any internal appurtenance or obstruction during operation, and from being crushed by landing legs on the bottom.

• 3. The Purchaser shall specify, on the Data Sheet, Line 32, the required primary roof drain. Acceptable types of primary roof drains are:

a. Manufacturer's standard drain,
b. Steel swing or pivot-jointed pipe drains, designed and packed for external pressure,
c. Stainless steel armored hose.

4. If supplied, rigid segments of drain piping attached to the bottom or the roof shall be guided, not rigidly attached, to allow for differential thermal expansion and plate flexing. The design shall avoid being damaged by the roof support legs or other obstructions.

5. Siphon-type and non-armored hose-type drains are not acceptable as primary roof drains.

6. Double-deck floating roofs up to 60 m (200 ft) in diameter shall have either a single center sump or a reversed-slope, top-center deck with multiple sumps connected to a single drain line, depending on the design rainfall quantity and the roof configuration. Double-deck floating roofs larger than 60 m (200 ft) in diameter shall have a reversed-slope, top-center deck with multiple roof sumps having individual drain lines.

7. Inlets to single-deck primary roof drains shall have guarded trash stops or screens to stop debris from entering and obstructing the drain system. The Manufacturer shall provide isolation valves to stop product flow onto the roof when the check valve fails, unless specified otherwise on the Data Sheet, Line 32. Cut-off valves for this purpose shall have extension handles to permit actuation when puddles obstruct access to the valve.

8. When specified on the Data Sheet, Line 32, drains, sumps, check valves, and cut-off valves shall be protected from freeze damage by using special equipment designs. Any mechanically actuated cut-off valve shall permit actuation when the drain
07 pipe is partially obstructed by chunk ice or slush (e.g., a ram valve or a metal-seated ball valve).

• C.3.8.2 Emergency Roof Drains

Double-deck roofs shall have a minimum of three open-ended emergency roof drains designed to provide drainage to prevent sinking the roof during severe rainfall events. Emergency drains are prohibited on single-deck floating roofs. Elevation of the emergency overflow drains shall be such that the outer rim cannot be completely submerged. These drains shall discharge at least 300 mm (1 ft) below the bottom of the roof and shall consist of open-ended pipes, braced as necessary to the roof structure. The drains shall be sized to handle the rainfall specified by the Purchaser, with a minimum diameter of NPS 4. The drains shall be sealed with a slit fabric seal or similar device that covers at least 90% of the opening that will reduce the product-exposed surfaces while permitting rainwater passage. The drains shall be fabricated from Schedule 80 pipe, or heavier, and fittings with 6 mm ($^1/_4$-in.) thick roof deck reinforcing plates.

C.3.8.3 Out-of-Service Supplementary Drains

• Threaded pipe couplings and plugs with a 600-mm (24-in.) extension "T-bar" handle shall be provided as supplementary drains when the roof is resting on its legs and when the primary drains are inoperative. The number of drains shall be based on the specified rainfall rate (see Line 33 of the Data Sheet) and tank size. Fittings shall be at least NPS 4. Plugs shall have threads coated with a non-stick coating or anti-seize paste such as tetrafluoroethylene. One supplementary drain shall be located adjacent to the ladder track.

C.3.9 VENTS

To prevent overstressing of the roof deck or seal membrane, automatic bleeder vents (vacuum breakers) shall be furnished for venting air to or from the underside of the deck when filling or emptying the tank. The Manufacturer shall determine and recommend the number and sizes of bleeder vents to be provided based on maximum filling and emptying rates specified. Each automatic bleeder vent (vacuum breaker vent) shall be closed at all times, except when required to be open to relieve excess pressure or vacuum, in accordance with the Manufacturer's design. Each automatic bleeder vent (vacuum breaker vent) shall be equipped with a gasketed lid, pallet, flapper, or other closure device.

07 C.3.10 SUPPORTING LEGS

• **C.3.10.1** Floating roofs shall be provided with either removable or non-removable legs. If removable legs are specified on the Data Sheet, Line 32, the legs shall be adjustable from the top side of the roof. and designed to be inserted through either fixed low legs or leg sleeves. Both low and high legs shall have cutouts (minimum of 19 mm [$^3/_4$ in.] wide) at the bottom to permit drainage of trapped product. Removable covers shall be provided for leg sleeves or fixed low legs when the adjustable legs are removed. Adjustable legs shall be capped on top. If specified on the Data Sheet, Line 32, removable legs shall be provided with storage rack(s) on the top of the pontoon or deck appropriate for leg storage during normal operation or during maintenance. Rack quantity and location shall be determined by the Manufacturer to balance the roof live load and shall take into account the weight of the rolling ladder. The materials of construction shall be tabulated on the Data Sheet, Table 5. Removable legs shall be no smaller than NPS 2. High legs shall have a stop to prevent their dropping through the low legs during installation. See C.1.3 regarding Purchaser specification of jurisdictional requirements.

C.3.10.2 The legs and attachments shall be designed to support the roof and a uniform live load of at least 1.2 kPa (25 lbf/ft^2). Where possible, the roof load shall be transmitted to the legs through bulkheads or diaphragms. Leg attachments to single decks shall be given particular attention to prevent failures at the points of attachment.

C.3.10.3 Legs shall have settings for at least two levels:

a. A minimum setting determined by the Manufacturer to support the roof in the low-roof position while clearing mixers, nozzles, shell manholes, seals, and other components inside the tank by at least 75 mm (3 in.), and

• b. The minimum clearance of the roof in the high-roof position specified on the Data Sheet, Line 32.

When specified on the Data Sheet, Line 33, the two settings shall be field-adaptable to allow for uneven tank bottom settlement (i.e., constructed to permit small variations from the required positions for each leg).

• **C.3.10.4** Legs shall be Schedule 80 minimum and sleeves shall be Schedule 40 minimum unless specified otherwise on the Data Sheet, Table 5. 07

C.3.10.5 Roof legs shall have matching steel landing pads continuous full-fillet welded to the tank bottom with minimum dimensions of 10-mm ($^3/_8$-in.) thickness by 350-mm (14-in.) diameter. The centerline of the legs shall coincide with the centerline of the landing pads.

C.3.10.6 Roof support legs sleeves shall be installed plumb. Fixed legs or leg sleeves through single decks shall be reinforced.

C.3.10.7 All fixed leg or leg sleeve penetrations through the deck plate (top and bottom for pontoon and double-deck roofs) shall be attached to the deck plate(s) with continuous fillet welds made from the top side, as a minimum.

• **C.3.10.8** If specified (see C.1.3 regarding Purchaser specification of jurisdictional requirements), covers and seals shall be provided at all openings.

• **C.3.10.9** When side entry mixers are specified and there is inadequate clearance between the roof and mixer components, rather than increasing the leg lengths, the pontoon (or double deck) shall be notched with a recessed pocket providing at least 75 mm (3 in.) mixer component clearance at the low-roof position.

C.3.11 ROOF MANHOLES

Roof manholes shall be provided for access to the tank interior and for ventilation when the tank is empty. Manholes shall be located around the roof to provide an effective pattern for access, lighting, and ventilation of the product storage interior. Each manhole shall have a minimum nominal diameter of 600 mm (24 in.) and shall have a liquid-tight gasketed, bolted cover equivalent to the cover shown in Figure 5-16. 07

The minimum number of manholes shall be as follows:

Nominal Tank Diameter *D*, m (ft)	Minimum Number
$D \le 61$ (200)	2
61 (200) < $D \le 91$ (300)	3
91 (300) < D	4

C.3.12 CENTERING AND ANTI-ROTATION DEVICES

C.3.12.1 A guide pole shall be provided as an anti-rotation device for the floating roof. Locate the guide pole near the gauger's platform. The guide pole shall be capable of resisting the lateral forces imposed by the roof ladder, unequal snow loads, and wind loads. 07

C.3.12.2 Guide pole sections shall be welded with full penetration butt welds. Backing strips are not permitted. Provision must be made for draining and venting of unslotted pipe. See 7.5.2 for guide pole erection tolerance requirements.

● **C.3.12.3** The guide pole shall have all required emission control devices around the well opening where it penetrates the roof, such as those described in C.3.14.1, Item (1) and specified on the Data Sheet, Line 32. (See C.1.3 regarding Purchaser specification of jurisdictional requirement.)

C.3.13 PERIPHERAL SEALS

C.3.13.1 See H.4.4 for descriptions of peripheral seal types, selection guidelines, and additional requirements. Peripheral seals are also referred to as rim seals.

● **C.3.13.2** The Purchaser shall specify the seal materials in the Data Sheet, Table 5.

● **C.3.13.3** See C.1.3 regarding Purchaser specification of jurisdictional requirements. All seals shall be installed such that gaps between the seal and the shell of the tank meet the gap requirements of the jurisdiction for new construction, if any, and the Purchaser's gap requirements.

C.3.13.4 Installation and removal of peripheral seals shall not require draining the tank.

C.3.13.5 The specific requirements for external floating roof peripheral seals are:

07 ● **Primary Seal**

The type of primary seal may be controlled by jurisdiction regulations. Types generally used are mechanical shoe seals and liquid-mounted (envelope) seals. Unless specified otherwise on the Data Sheet, Line 31, primary seals shall be the mechanical shoe type and shall be supplied and installed by the roof Manufacturer.

● **Secondary Seal**

The type of secondary seal may be controlled by jurisdiction regulations. If required by the Purchaser, a secondary seal shall be provided by the roof Manufacturer as specified on the Data Sheet, Line 31. Unless specified otherwise, secondary seals shall be the wiper type and shall be supplied and installed by the roof Manufacturer. The design of the secondary seal shall permit inspection of the primary seal without removal.

Mechanical Shoe Seals

The following additional requirements apply to mechanical shoe seals, if used, and which may be used as primary or secondary seals:

The metal band (shoe) is typically formed as a series of sheets that are overlapped or joined together to form a ring that is held against the shell by a series of mechanical devices. For external floating roofs only, the mechanical shoe seal shoes shall extend at least 610 mm (24 in.) above and at least 100 mm (4 in.) into the liquid at the design flotation level, except when this type of seal is the secondary seal, installed above a primary seal. The "design flotation level" is defined as the roof position (under dead load conditions) for the specific gravity range from 0.7 to the design specific gravity on the Data Sheet.

C.3.14 GAUGING DEVICE

● **C.3.14.1** Each roof shall be provided with gauging ports with caps (gauging wells or hatches) as indicated on the Data Sheet, Line 32 (see C.1.3 regarding Purchaser specification of jurisdictional requirement), with one port located adjacent to the gauger's platform and remote from regions of turbulent flow. These ports may be as follows:

● 1. Slotted guide pole gauge wells: These are vertical anti-rotation pipes that can be used for gauging. Unless specified otherwise by the Purchaser, the pipe shall have two rows of 25-mm by 300-mm (1-in. by 12-in.) vertical slots on staggered 280-mm (11-in.) centers located 180 degrees apart. Slots shall range from the maximum fill height to near the tank bottom. Holes may be provided in lieu of slots if holes are required by the Purchaser. Well and pole shall be equipped with all required emission
07 control devices, which may include items such as a gasketed sliding well cover, and a pole wiper, as well as either a pole sleeve or a pole float and float wiper (see API *MPMS* 19.2 for requirements and illustrations of some of these devices). If there are no slots or holes located so as to allow the stored liquid to flow into the pole at liquid levels above the lowest operating level, then the pole is not considered slotted for purposes of air regulation compliance (even if there are slots or holes located below the lowest operating level).

2. Non-guide pole gauge wells: These shall be NPS 8 pipes projecting at least 150 mm (6 in.) above the roof's outer rim. For sample hatches without gauging apparatus, see C.3.15.3.

● **C.3.14.2** Each gauge well shall have a B16.5 Class 150 bolt pattern, flat-face pipe flange with a full-face gasket at its top, and shall be attached to a non-sparking cap. See C.1.3 regarding Purchaser specification of jurisdictional requirements.

C.3.14.3 Each gauge well shall have a permanent gauge mark or tab just inside the cap on the pipe wall called a "reference point" or "knife edge."

• **C.3.14.4** When specified on the Data Sheet, Line 32, a datum plate shall be attached to the bottom of the slotted guide pole at the distance designated by the Purchaser.

• **C.3.14.5** If striking plates are specified on the Data Sheet, Line 32, they shall be provided on the tank bottom beneath the guide pole or under the gauge well if no guide pole is specified.

• **C.3.14.6** A gauger's platform shall be located at an elevation that remains above and clear of the roof, its sealing system, and foam dam even during an overflow event. The Purchaser shall specify the platform location on the Data Sheet Plan. The direction is typically upwind of the direction of the prevailing wind.

C.3.15 OTHER ROOF ACCESSORIES

C.3.15.1 Wax Scrapers

If wax scrapers are specified on the Data Sheet, Line 31, they shall be located such that the scraping action occurs below the liquid surface. Design of wax scrapers shall not interfere with bottom shell course accessories.

C.3.15.2 Foam Dams

• A foam dam, if specified on the Data Sheet, Line 32, shall be installed on top plates of pontoon or roof deck at least 300 mm (12 in.) but no more than 600 mm (24 in.) from the tank shell to contain foam fire-fighting solution. The foam dam shall be a minimum of 300 mm (12 in.) high and extend at least 50 mm (2 in.) above the lower of the secondary seal or any burnout panel, measured at its highest contact point with the shell. The dam shall be fabricated from 10 gauge (0.134 in.) or thicker steel plate with support braces installed on the side of the foam dam closest to the center of the tank at a circumferential spacing of approximately 1.5 m (5 ft) on center. Bottom of plate shall have 10-mm ($^3/_8$-in.) slotted weep holes. The dam shall be attached to the top deck plate by a continuous fillet weld on the foam side. See NFPA 11 for additional information regarding foam dams. 07

• C.3.15.3 Sample Hatches

If specified on the Data Sheet, Line 32, the Manufacturer shall install an NPS 8 sample hatch with funnel on the roof deck with remote access from the gauging platform. Manufacturer shall install a recoil reel on the gauging platform. The hatch shall be equipped with a self-closing liquid-tight cover that can be opened and closed from the gauger's platform.

C.3.15.4 Automatic Level Gauge

• a. Tanks shall have a ground-level reading, automatic float-level gauge, unless otherwise specified on the Data Sheet, Table 4.
b. Access for maintenance and repair shall be considered.
c. Level gauge shall be located such that the float well is away from any appurtenances that produce turbulence.
d. 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.
• e. Gauge float wells shall be equipped with a gasketed cover that is bolted closed. See C.1.3 regarding Purchaser specification of jurisdictional requirements.

C.3.15.5 Side Entry Mixers

a. Mixers shall conform to the Data Sheet, Line 26.
b. Each mixer shall be installed in cover plates in dedicated shell nozzles or manholes.

C.4 Fabrication, Erection, Welding, Inspection, and Testing

C.4.1 The applicable fabrication, erection, welding, inspection, and testing requirements of this Standard shall apply.

C.4.2 Deck seams and other joints that are required to be liquid- or vapor-tight shall be tested for leaks by means of penetrating oil or any other method consistent with the methods described in this Standard for testing cone-roof seams and tank-bottom seams.

C.4.3 The roof shall be given a flotation test while the tank is being filled with water and emptied. During this test, the upper side of the lower deck shall be examined for leaks. The appearance of a damp spot on the upper side of the lower deck shall be considered evidence of leakage.

C.4.4 The upper side of the upper decks of pontoon and double-deck roofs shall be visually inspected for pinholes and defective welding.

C.4.5 Drainpipe and hose systems of primary drains shall be tested with water at a pressure of 350 kPa (50 lbf/in.^{2}) gauge. During the flotation test, the roof drain valves shall be kept open and observed for leakage of the tank contents into the drain lines.

APPENDIX D—TECHNICAL INQUIRIES

D.1 Introduction

API will consider written requests for interpretations of API Std 650. API staff will make such interpretations in writing after consulting, if necessary, with the appropriate committee officers and committee members. The API committee responsible for maintaining API Std 650 meets regularly to consider written requests for interpretations and revisions and to develop new criteria dictated by technological development. The committee's activities in this regard are limited strictly to interpretations of the Std and to the consideration of revisions to the present standard on the basis of new data or technology. As a matter of policy, API does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity, and accordingly, inquiries that require such consideration will be returned. Moreover, API does not act as a consultant on specific engineering problems or on the general understanding or application of the Standard. If, based on the inquiry information submitted, it is the opinion of the committee that the inquirer should seek other assistance, the inquiry will be returned with the recommendation that such assistance be obtained. All inquiries that cannot be understood because they lack information will be returned.

D.2 Inquiry Format

D.2.1 Inquiries shall be limited strictly to requests for interpretation of the current standard or to the consideration of revisions to the standard on the basis of new data or technology. Inquiries shall be submitted in the format described in D.2.2 through D.2.5. 07

D.2.2 The scope of an inquiry shall be limited to a single subject or a group of closely related subjects. An inquiry concerning two or more unrelated subjects will be returned.

D.2.3 An inquiry shall start with a background section that states the purpose of the inquiry, which would be either to obtain an interpretation of the Standard or to propose a revision to the Standard. The background section shall concisely provide the information needed for the committee's understanding of the inquiry (with sketches as necessary) and shall cite the applicable edition, revision, paragraphs, figures, and tables.

D.2.4 After the background section, an inquiry's main section shall state the inquiry as a condensed, precise question, omitting superfluous background information and, where appropriate, posing the question so that the reply could take the form of "yes" or "no" (perhaps with provisos). This inquiry statement should be technically and editorially correct. The inquirer shall state what he or she believes the Standard requires. If the inquirer believes a revision to the Standard is needed, he or she shall provide recommended wording.

D.2.5 The inquirer shall include his or her name and mailing address. The inquiry should be typed; however, legible handwritten inquiries will be considered. Inquiries should be submitted to the general manager of the Downstream Segment, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Inquiries complying with the above format may be submitted by electronic mail to: standards@api.org. 07

D.3 Technical Inquiry Responses

Following are selected responses to requests for interpretation API Std 650 requirements. A more extensive listing of interpretations can be found on the API website at www.api.org in the "Committees/Standards" section. The current version of API Std 650 may differ from the following inquiries, which were developed against prior editions/addenda, making the following inquiries possibly invalid. The paragraph references in the following have not been revised to the reflect the new paragraph numbering issued in the 11th Edition of API Std 650. 07

SECTION 1.1 SCOPE

07 650-I-03/00 (Note: See 1.1.3 in the 11th Edition for revised rules pertaining to the use of SI units within the Standard.])

Question 1: Regarding the use of SI units, does API 650 allow either of the following?

(1) Use of SI units throughout the design process.

(2) Use the original U.S. Customary units with a hard conversion to SI units as a final step to the design process.

Reply 1: Yes, both are allowed.

Question 2: When SI units are used, does API 650 require different dimensional details compared to previous API 650 Editions or USC unit details now specified in the 10th Edition?

Reply 2: The committee currently has an agenda item to study this question. Any changes resulting from this agenda item will appear in a future addendum or edition to API 650.

Question 3: When SI units are used, does API 650 require material thickness, material properties, configurations, etc. based solely on the SI units for a particular tank?

Reply 3: The committee currently has an agenda item to study this question. Any changes resulting from this agenda item will appear in a future addendum or edition to API 650.

Question 4: Does the wording of the Foreword to API 650 require a separate check of the USC results when SI unit are specified and after making such a check using the USC results if more restrictive?

Reply 4: No.

SECTION 2.2 PLATES

650-I-09/01

Question: For plate material certified by the Manufacturer to meet more than one specification, such as A 516 Grade 60 and A 516 Grade 70, which specification should be used when applying the rules in Table 2-3, Figure 2-1, and Section 2.2.9 of API 650? 07

Reply: Dual certification of material is not addressed in API 650, except in 2.1.4 and Appendix S.

650-I-11/01

Question: Does API 650 require that the material in the bottom shell course and the annular plate be the same material specification?

Reply: API 650, Section 2.2.9.1, requires bottom plates welded to the shell to comply with Figure 2-1, but does not require the bottom shell course and annular plate to be the same material specification.

650-I-33/03

Question: Are roof materials required to meet the toughness requirements in 2.2.9?

Reply: No. Refer to 2.2.9.1.

650-I-06/04

Question 1: Does the 0.01 in. thickness tolerance specified for plate in API 650, 2.2.1.2.3 apply to carbon and stainless coil product?

Reply 1: Yes. All requirements of the base document apply to an Appendix S tank unless specifically changed or waived by a statement in Appendix S. Refer to S.1.5.

Question 2: When purchasing hot-rolled coil-processed steel for use as roof, shell, and/or bottom plate on a stainless tank, does the ASTM under-run tolerance apply?

Reply 2: The minimum of the ASTM tolerance or as specified in API 650, Sections 2.2.1.1, 2.2.1.2, or 2.2.1.3, shall apply.

SECTION 2.5 PIPING AND FORGINGS

650-I-15/00

Question: 1 For nozzles made from pipe materials, does API 650, Section 2.5.2 require that seamless pipe be used for nozzles in shells made from Group I, II, III, or IIIA materials?

Reply 1: Yes, unless ASTM A 671 pipe is used.

Question: 2: Does API 650, Section. 2.5.2 preclude the use of electric-resistance welded pipe meeting ASTM A 53, or electric-welded pipe meeting API 5L, for nozzles in shells made from Group IV, IVA, V, or VI materials, but allow use of electric-fusion-welded pipe nozzles made from ASTM A 671?

Reply 2: Yes.

SECTION 3.1 JOINTS

650-I-11/02

Question: Is there any allowance or provision to omit the top angle as required by API 650, 3.1.5.9e and 3.1.5.9f if we can show by calculation that the top compression area is sufficient.

Reply: No.

650-I-32/02

Question: Referring to API 650, Section 3.1.5.3b, does the phrase "...horizontal joints shall have a common vertical centerline" mean that the mid-thickness of the plates align vertically?

Reply: Yes. This is sometimes referred to as "centerline-stacked".

650-I-40/02

Question: Does the lap weld of two bottom plates on the butt-welded annular plates have to be 12 in. away from the annular plates butt welds?

Reply: No

650-I-37/03

Question: Is it the intent of 3.1.3.5 to limit the maximum lap of a double welded lap joint to 2 in. and a single welded lap joint to 1 in. If not, is there a maximum lap requirement for single welded lap joint bottoms and roofs? Would this constraint, if any, also apply to bottom or roof repair or replacements governed by API 653.

Reply: No

650-I-49/03

Question 1: Section 3.1.3.5 of API 650 specifies minimum lap joint dimensions. Is there any limit on the maximum width of a lap joint?

Reply 1: API Standard 650 does not address maximum lap.

Question 2: Can a lap joint consisting of two (2) 1/4 in. plates be lapped 3 in.?

Reply 2: Yes. Any lap that exceeds the minimum is acceptable. Refer to 3.1.3.5.

SECTION 3.5 ANNULAR BOTTOM PLATES

650-I-49/00

Question: If a tank bottom slopes downward toward the center of the tank, are the annular plates required to lap over the bottom plates?

07 Reply: This is not covered by API 650. (5.1.5.4 in the 11th Edition covers this issue.)

650-I-22/03

Question: Section 3.5.2 states the annular bottom plates shall have at least a 50 mm projection outside the shell. Is the reference point to calculate the projection located on the outside or inside diameter of the shell?

Reply: The reference point is on the outside diameter of the shell plate, as stated in 3.5.2.

SECTION 3.6 SHELL DESIGN

650-I-02/02

Background: On one recent contract, corrosion allowance of 0.25 in. was specified only on first shell course. The tank is 250 ft (diameter) by 53 ft high, with a liquid height of 48 ft 0 in. (external floater) and design specific gravity = 0.968. Detail design per the current edition shows that the second course thickness is controlled by hydrostatic test condition, which is incorrect. Investigation has proven that the current rules in API 650 for the variable design point method are not valid for variable corrosion allowance. The second course thickness calculated is more than the one-foot method will calculate, however, this is not stated in API 650. It is not unusual for a customer to specify variable corrosion allowance. The variable design point method is used only for large tanks and in some cases, as I have discovered, the second course will be calculated $^1/_{16}$ in. thicker than needs to be when corrosion allowance is a significant percentage of first course. This extra thickness amounts to good some of money.

Question: Is the variable design point method of shell design covered under API 650, Section 3.6.4 valid for tanks with variable corrosion allowance (i.e., different corrosion for each shell course)?

Reply: No.

SECTION 3.7 SHELL OPENINGS

650-I-33/99

Question: Referring to API 650, Section 3.7.4, must all flush-type cleanouts and flush-type shell connections be stress-relieved regardless of the material used, the nozzle diameter, or the thickness of the shell insert plate?

Reply: Yes, see Section 3.7.4.1.

650-I-53/99

Question 1: Per Section 3.7.4.2, for shell openings over NPS 12, if insert plates are not used to reinforce the shell opening, is the shell thickness a factor in determining if PWHT of the assembly is required?

Reply 1: Yes.

Question 2: Regarding Section 3.7.4.2, is stress-relieving mandatory for the prefabricated assembly when the thickness of the thickened insert plate exceeds 1 in., irrespective of the shell opening size?

Reply 2: No. The requirement applies only to NPS 12 or larger connections.

650-I-01/00

Question: Does API 650, Section 3.7.4.3, allow stress-relieving nozzles, as described therein, after installation in the shell, using locally applied heaters?

Reply: No. The heat treatment must be performed prior to installation in the tank.

650-I-18/00

Question 1: Referencing Figure 3-14, does API 650 cover flush shell connections to be installed non-radially?

Reply 1: No.

Question 2: Referencing Figure 3-15, are flush-type shell connections smaller than 8 in. covered in API 650?

Reply 2: No.

650-I-20/00

Question: Does API 650, Section 3.7.4, require that all flush-type cleanout fittings be stress-relieved?

Reply: Yes, except as permitted by A.8.2.

650-I-32/00

Question: Are square or rectangular manways allowed per API 650? If no, what specific section limits them?

Reply: Yes. See Figure 3-14 for roof manway requirements.

650-I-34/00

Question: Does API 650, Section 3.7.4.2 require stress-relieving for materials in opening connections coming under Group I, II, III or III A, when the thickness of the shell is less than 1 in., but the sum of the shell plate thickness and the reinforcement plate thickness exceeds 1 in. for NPS 12 and larger?

Reply: No.

650-I-43/00

Question: Referring to API 650, Section 3.7.4.2, must a prefabricated manhole assembly be stress relieved if the material is Group II (A 131, Grade B), the shell plate is 3/8 in. thick, and the opening is a 24-in. diameter manhole?

Reply: No, because the shell is less than 1 in. thick.

650-I-47/00

Question: Does API 650, Section 3.7.6.1, permit making a hot tapping connection on a blind flange on a nozzle in a tank?

Reply: No. Refer to API 650, Section 3.8.3, for rules on installing a nozzle in a cover plate in a new tank. Refer to API 653, Section 7.14, for rules and guidance on hot tapping in an in-service tank.

650-I-48/00

Question: Does API 650 define a "neck" as piping or nozzle passing through the shell of the tank to the first flange, regardless of the length and configuration (such as an upturned pipe connected by an elbow and another short piece pipe to the first flange) of this pipe?

Reply: No. API does not define this term. Also, refer to Section 1.2, which defines the limits of applicability on piping.

650-I-07/02

Question: Given a 2 in. nominal bore non-reinforced nozzle in a non stress-relieved shell greater than 0.5 in. thickness. Are the minimum distances for: (1) the outer edge of nozzle attachment weld to center line of a shell butt weld, either vertical or horizontal, and (2) the toe-to-toe distance of the fillet to the shell-to-bottom weld, required to be 10 in. (or 8x weld thickness) and 3 in., respectively?

Reply: Yes, for new tanks, see API 650, sections 3.7.3.1, 3.7.3.3, and Figure 3-22.

650-I-28/02

Question: When stress relieving the assembly defined in API 650 Sections 3.7.4.1, 3.7.4.2, and 3.7.4.3, is it permissible to perform a local heat treatment that includes part of a shell plate, instead of the whole shell plate, i.e., the portion around the connection at full width of shell plate?

Reply: No, however, there is no rule against shortening the plate length circumferentially, prior to installation of the fitting or connection.

650-I-56/02

Question: Do the minimum thicknesses listed in Table 3-10, and calculated by the equations in section 3.7.7.6 have a corrosion allowance?

Reply: No. See Section 3.3.2.

650-I-07/04

Question: Regarding Section 3.7.2 as it applies to Appendix F, when calculating the required shell thickness at the nozzle location is it necessary to use the joint efficiency factor that was used for calculating the required tank shell thickness?

Reply: No.

650-I-09/04

Question 1: Section 3.7.1.8 states "Reinforcement of shell openings that comply with API Standard 620 are acceptable alternatives." When using API 620 to calculate nozzle reinforcement does the entire API 620 standard apply?

Reply 1: No.

Question 2: API 620 limits the design temperature to 250°F. Can the rules for nozzle reinforcement be used for designing nozzle reinforcement for an API 650 Appendix M tank with a design temperature greater than 250°F?

Reply 2: Yes.

Question 3: Can the rules for nozzle reinforcement in API 620 be used for designing nozzle reinforcement for a stainless steel API 650 Appendix S tank?

Reply 3: Yes.

Question 4: When designing nozzle reinforcement for an API 650 tank using the rules of API 620, should the allowable stresses of API 650 be used?

Reply 4: Yes.

SECTION 3.8 SHELL ATTACHMENTS AND TANK APPURTENANCES

650-I-51/00

Question: API 650, Section 3.8.3.2, requires mixer manway bolting flanges to be 40% thicker than the values shown in Table 3-3. Footnote b under Table 3-4 requires the minimum manway neck thickness to be the lesser of the flange thickness or the shell plate. Is it therefore required that the minimum neck thickness on a mixer manway be the lesser of 140% of the flange thickness value in Table 3-3 or the shell thickness?

Reply: No.

650-I-53/00

Question: Referring to API 650, is magnetic particle testing applicable for inspecting permanent attachments to the shell and at temporary attachment removal areas, when the material group is of Group I (A 283, Grade C)?

Reply: No. See 3.8.1.2 and 5.2.3.5, in Addendum 1 to the 10th Edition of API 650.

650-I-14/02

Background: Section 3.8.3.2 states: "a cover plate with a nozzle attachment for product-mixing equipment shall have a thickness at least 1.4 times greater than the thickness required by Table 3-3." Section 3.8.3.3 also states that "when cover plates (or blind flanges) are required for shell nozzles, the minimum thickness shall be that given for flanges in Table 3-8." There seems to be a conflict between these two sections in that when the thickness specified by Table 3-3 (at max liquid level) is increased by 40%, it is still thinner than the thickness specified by Table 3-8.

Question 1: In determining the thickness of a cover plate and bolting flange in which product mixing equipment is installed, is there a conflict between 3.8.3.2 and 3.8.3.3.

Reply 1: No.

Question 2: If we are to adhere to 3.8.3.3, how are we to compute the new thickness of a cover plate whose integrity has been compromised by the addition of a hole into which a smaller adapter nozzle has been placed. Section 3.8.3.3 only directs the reader to Table 3-8 to find the thickness of unadulterated cover plates. No mention is made in 3.8.3.3 regarding how to compute the new thickness after a nozzle has been added.

Reply 2: API does not provide consulting on specific engineering problems or on the general understanding of its standards. We can only provide interpretations requirements that are stated in an API Standard or consider revisions based on new data or technology.

SECTION 3.9 TOP AND INTERMEDIATE WIND GIRDERS

650-I-39/99

Question 1: Is it acceptable for the primary (upper) bottom, of an API 650 Appendix I double-bottom tank to not project through the shell and to be attached only to the inside of the shell?

07 Reply 1: No. API 650, Section 3.4.2 requires the bottom plate project at least 25 mm (1 in.) outside the toe of the outer shell-to-bottom weld. Section 3.5.2 requires the annular plate project at least 50 mm (2 in.) outside the shell. Furthermore, Section 3.1.5.7 requires the bottom be welded to the shell on both sides of the shell. The only way this can be accomplished is with a shell projection. Figure I-4 illustrates an acceptable double-bottom installation. (See the 11th Edition for revised rules.)

Question 2: What is the function of asphalt-impregnated board written as "optional"?

Reply 2: The function of the asphalt-impregnated board is to minimize water infiltration underneath the tank bottom and corrosion of the portion of the tank bottom in direct contact with the concrete ringwall.

Question 3: What is the expected effect on tank annular plates if the asphalt-impregnated board is not installed?

Reply 3: See reply to Question 1.

SECTION 3.10 ROOFS

650-I-51/99

Question 1: In API 650, Section 3.10.5, is the calculated minimum thickness the actual required thickness that takes into account the span of unstiffened cone plates with a total load of 45 lbf/ft^2?

Reply 1: Yes, it is the minimum required thickness, exclusive of corrosion allowance, for the tank diameter and roof slope under consideration. It should be noted that the maximum allowable roof plate thickness limits the tank diameter as a function of the roof slope.

Question 2: How is the minimum thickness used?

Reply 2: API does not act as a consultant on specific engineering problems or on the general understanding or application of its standards. API's activities in regard to technical inquiries are limited strictly to interpretations of the standard and to the consideration of revisions to the present standard based on new data or technology.

650-I-52/99

Question: Is welding of the main roof support members to the roof plates allowed by the standard?

Reply: No, see API 650, Section 3.10.2.3 that states that roof plates of supported cone roofs shall not be attached to the supporting members.

SECTION 5.2 DETAILS OF WELDING

650-I-11/00

Question 1: Does API 650 Section 5.2.1.10 require the use of low hydrogen electrodes when making manual horizontal welds between two shell plates when both plates are in Groups I-III, one plate is greater than 12.5 mm (0.5 in.) thick and the other plate is 12.5 mm (0.5 in.) thick or less?

Reply 1: Yes.

Question 2: Does API 650 Section 5.2.1.10 require the use of low hydrogen electrodes when making manual welds between the shell and bottom plates when both plates are in Groups I-III, the shell plate is greater than 12.5 mm (0.5 in.) thick and the tank bottom plate is 12.5 mm (0.5 in.) thick or less?

07 Reply 2: Yes. (The 11th Edition modifies these rules.)

Question 3: Does API 650 Section 5.2.1.10 require low hydrogen electrodes when making welds between two annular plates that are 12.5 mm thick or less and are made of material in Groups I-III.

Reply 3: No. This question will be referred to the appropriate Subcommittee to confirm this is the desired requirement.

650-I-28/00

Question 1: Referring to API 650, Section 5.2.2.1, is the tank Manufacturer allowed to set the sequence of welding the floor plates, if the sequence has been found by the Manufacturer to yield the least distortion from shrinkage?

Reply 1: Yes, see Section 5.2.2.1.

Question 2: If bottom plate seams are left open for shrinkage, then must the shell-to-bottom corner weld be practically complete prior to making the welds left open for shrinkage compensation?

Reply 2: Yes, see Section 5.2.2.2.

650-I-39/02

Question: Can a tank be constructed when the ambient air temperature is less than 0°F?

Reply: Yes, providing that the base metal temperature meets the requirements of section 5.2.1.2.

650-I-04/04

Question 1: Can E-7024 electrodes be used to weld the shell-to-bottom weld when the thickness of the shell and bottom plates are both less than __" and both materials are from Groups I-III?

Reply 1: Yes. Refer to API 650, Section 5.2.1.10.

SECTION 5.3 INSPECTING, TESTING, AND REPAIRS

650-I-16/00

Question: Regarding the hydro-testing of a tank to be lined internally, does API 650 require the tank to be filled with water before and after the lining is installed, or only before the lining is installed, or only after the lining is installed?

Reply: API 650 does not cover this issue. API does not provide consulting advice on issues that are not addressed in API 650.

650-I-21/00

Question 1: Does API 650 require any additional testing beyond the hydrostatic (water) test specified in Section 5.3.5 for a tank designed for product with specific gravity greater than 1?

Reply 1: No. Section F.7.6 provides additional requirements for Appendix F tanks. The Purchaser may require more stringent testing as a supplemental requirement.

Question 2: Given the following conditions: nominal diameter of the tank–30 m, height of shell–18.4 m, roof–torospherical, specific gravity of content–1.32, top gauge pressure–0. Can the design calculation for test condition be executed on API 650 and Appendix F (design pressure on bottom level 233 CPA or more)?

Reply 2: API does not provide consulting on specific engineering problems or on the general understanding and application of its standards. We can only provide interpretations of API 650 requirements. Please refer to Appendix D and restate your inquiry so that it poses a question on the meaning of a requirement in API 650.

650-I-22/00

Question: Referring to 5.3.6 and 5.3.7, is it permissible to weld insulation clips or pins, using a stud welding procedure, on a tank shell and/or roof after the hydrostatic test?

Reply: No.

650-I-33/00

Question: Does API 650, Section 5.3.5, prohibit starting the water filling for hydrostatic testing while completing some welded attachments on the last shell ring above the water level?

Reply: No. (See 7.3.5(1) in the 11^{th} Edition which gives new rules.) 07

650-I-12/01

Question 1: Does API 650 require that tolerances (plumbness/peaking bending/roundness) be checked after the construction of each shell course, rather than after the completion of the entire shell?

Reply 1: These tolerances must be measured by the Purchaser's inspector at anytime prior to the hydrostatic test. See Sections 4.2.3, 5.3.1.2, and 5.5.6 (7.5.1 in the 11^{th} Edition). 07

Question 2: If repairs are required to meet the specified tolerances, when must the repairs be made?

Reply 2: API 650 does not address the timing of these repairs.

SECTION 5.4 REPAIRS TO WELDS

650-I-48/99

Question 1: If welds in a non-radiographed tank (e.g., per Appendix A) are examined by visual examination and determined to be defective, does API 650 permit the Purchaser to then require radiographic examination of the welds?

Reply 1: Section 5.4.1 requires that the Purchaser's inspector approve the plan to resolve the problem. The ramifications of any upgrade to the NDE procedure originally required, such as radiographing the welds in this case, become a contractual matter.

Question 2: For Purchaser-specified NDE, if required to resolve a visual finding, what acceptance criteria applies?

Reply 2: This is a contractual matter not covered by API 650.

SECTION 5.5 DIMENSIONAL TOLERANCES

650-I-24/00

Question: API 650 gives tolerances for plumbness and roundness, but these are related to the tank shell. Are there any defined tolerances on the tank roof, such as on the rim space dimension?

Reply: No.

650-I-29/00

Question: Does the phrase in Section 5.5.5.2.a of API 650, "the top of the ring wall shall be level within ±3mm ($^1/_8$ in.) in any 9 m (30 ft) of the circumference", mean that the ring wall upper plane position is to be between two horizontal planes 6 mm apart or 3 mm apart?

Reply: 6 mm apart.

650-I-40/00

Question: For tanks built to API 650 and complying with Section 5.5 dimensional tolerances and subsequently commissioned, do the minimum requirements of API 650 with respect to plumbness, banding, etc., still apply after a tank has been placed in service?

Reply: No. API 650 covers the design and construction of new tanks. Any tolerance rules that might apply after the tank has been placed in service, typically API 653 plus any supplemental owner requirements, are to be determined by the local jurisdiction and the tank owner. See API 653, 1.1.1, Section 8, and 10.5.2, for further information and for some examples.

650-I-07/01

Question 1: API 650, Section 5.5.1, states that the tolerances as specified may be waived by (agreement between the Purchaser and the Manufacturer). If a tank does not meet the specified tolerance with regards to one specific area such as the roundness but has met the tolerance in relation to plumbness and local deviation as well as all the testing requirements such as radiography and hydro-testing, can the Manufacturer insist that the Purchaser accept the tank?

Reply 1: No. Agreement by both parties is required. (The Purchaser's waiver is required in the 11th Edition.) 07

Question 2: Since Section 5.5.1 states that the purpose of the tolerances as specified is for appearance and to permit proper functioning of floating roofs, is it therefore correct to conclude that the Purchaser has no right to refuse to accept a tank which has passed all tests required by API 650 but may have some out-of-tolerance in one or more areas?

Reply 2: No.

Question 3: An inspection measurement shows a maximum out of roundness of 28 mm on the uppermost shell course at three locations in a tank. Is this detrimental to the structural integrity of the tank?

Reply 3: API can only provide interpretations of API 650 requirements or consider revisions to the standard based on new data or technology. API does not provide consulting on specific engineering problems or on the general understanding of its standards.

650-I-08/01

Question: Does the 10th Edition of API 650 specify tolerances for the elevation and orientation of shell nozzles?

Reply: No. (See the 11th Edition for elevation tolerances.) 07

SECTION 6 METHODS OF INSPECTING JOINTS

650-I-47/99

Question: Does API 650 allow the Purchaser to require radiographic examination as a requirement for acceptance after fabrication on a tank that is not required to be radiographed per API 650 rules?

Reply: API 650 does not prohibit the Purchaser from specifying additional requirements. These are contractual issues outside the scope of the document.

SECTION 6.1 RADIOGRAPHIC METHOD

650-I-10/02

Question: For repaired regions made after spot radiography detects defective welding, is it correct that according to 6.1.7.2 that only the original spot radiography requirements apply no matter the number of original spot and tracer radiographs taken?

Reply: Yes, because the post-repair inspection procedure is spot radiography as was the original inspection requirement.

Section 7.2 Qualification of Welding Procedures

650-I-23/00

Question: Referring to 7.2.2, 2.2.8, and 2.2.9, for the fabrication and welding of shell nozzles made from pipe and forgings meeting toughness requirements of 2.5.5, is it mandatory to have impact tests on weld procedure qualifications for welding these components?

Reply: Yes, if these materials are welded to any of the components listed in 2.2.9.1 and the design metal temperature is below 20°F. See 7.2.2.4.

650-I-27/03

Question: For the purposes of determining radiographic requirements for tanks can tank shell plate thickness of 0.5 inch thickness be considered to be 0.375 inch thick as outlined in 6.1?

Reply: No. Refer to Section 6.1.2.2b.

650-I-34/03

Question: Do the requirements of API 650 section 6.1.2.2 apply to welds that will be in the vertical position when the tank is in service, but are made in the flat or horizontal position?

Reply: Yes. The requirements of 6.1.2.2 apply to welds that will be in the vertical position when the tank is in service.

650-I-42/03

Question 1: When annular plates are joined with single-welded butt joints, is one radiograph required at each of 50% of the total count of radial joints?

Reply 1: Yes. See Section 6.1.2.9 (b).

Question 2: When annular plates are joined with single-welded butt joints, is a radiograph required at each radial joint with the radiograph length covering 50% of the total length of the weld?

Reply 2: No. The 50% factor is applied to the number of joints, not the length of joint. See Section 6.1.2.9 (b).

SECTION 8.1 NAMEPLATES

650-I-49/00

Question: For a tank built to the 10th Edition, 1st Addendum, of API 650, is it acceptable to mark "November 1998" in the Edition box and "X" in the "Revision No." box on the nameplate?

Reply: No. The marks should be the "month and year" of the Edition in the first box, and the number of the addendum revision in the second box (e.g., 0, 1, 2).

SECTION 8.3 CERTIFICATION

650-I-16/02

Background: Secondary containment rules for petroleum tanks are almost universally applied. Most often these rules are satisfied by constructing dike or berm walls around a tank farm. However, due to space or other regulatory limitations, the owner may wish to install double wall tanks where the outer tank would contain the volume of the inner tank should a catastrophic failure occur. In this case, the outer wall would have to be designed to contain the hydrostatic pressure of the liquid from the inner tank. In addition, consideration of detailed design for piping flexibility passing through the outer wall would need to be made.

Question: Is it permissible to construct a tank within a tank and certify both tanks to API 650 Section 8.3?

Reply: Yes.

APPENDIX C EXTERNAL FLOATING ROOFS

650-I-12/2

Question 1: Referring to Section C.3.9, Must the thermal in-breathing/out-breathing requirements as per API Std 2000 also need to be considered during design of bleeder vents? (i.e., during deciding size and quantity of bleeder vents, so that there will not be any overstressing of roof deck or seal membrane).

Reply 1: No, C.3.9 does not require venting per API Std 2000.

Question 2: If answer to Question 2 is yes, would it not be worthwhile to clarify the same appropriately in Section C.3.9 of API 650?

Reply 2: See Reply 1.

APPENDIX E SEISMIC DESIGN OF STORAGE TANKS

650-I-44/99 (See Appendix E in the 11th Edition for new rules pertaining to seismic design.]) 07

Question 1: Do the changes to Chapter 16, *Division IV Earthquake Design*, of the *1997 Uniform Building Code* affect API 650, Appendix E requirements?

Reply 1: The committee is currently considering changes to Appendix E as a result of the revisions to the *Uniform Building Code*. Approved changes will appear in future addenda of API 650.

Question 2: Why is the Seismic Zone Map of the United States shown in API 650, Appendix E slightly different for that shown on page 2-37 of the *1997 Uniform Building Code*, Figure 16-2?

Reply 2: The committee is currently considering changes to Appendix E as a result of the revisions to the *Uniform Building Code*. Approved changes will appear in a future addendum or edition of API 650. 07

650-I-45/99 (See Appendix E in the 11th Edition for new rules pertaining to seismic design.])

Question: Is the value obtained from the equation in E.4.2 equal to the dimension measured radially inward from the interior face of the shell to the end of the annular plate (the "end of the annular plate" is defined here as the inner edge/perimeter of the typical lap joint between the bottom and the annular plate)? (See E.6.2.1.2 in the 11th Edition.)

Reply: No, the dimension is measured radially inward from the interior face of the shell to the end of the annular plate, defined as the inner edge of the annular plate. The extent of the overlap of the bottom plate on the annular plate is not a significant consideration.

650-I-25/00 (See Appendix E in the 11th Edition for new rules pertaining to seismic design.) 07

Question 1: Should the metric formula for calculating the natural period of the first sloshing mode in Section E.3.3.2 read:

$$T = k(D^{0.5})\left(\frac{1}{0.5521}\right)$$

Reply 1: Yes. This correction will appear in Addendum 2 of API 650. (See E.4.5 in the 11th Edition.) 07

Question 2: Should the metric formula for calculating the width of the thicker plate under the shell in Section E.4.2 read:

$$0.1745 \times 10^{-3} w_L / GH(m)$$

Reply 2: Yes. This correction will appear in Addendum 2 of API 650.

Question 3: Is the following revision to Section E.5.1 appropriate?

"When $M/[D^2\,(w_f + w_L)]$ is greater than 1.57 or when $b/1000t$ ($b/12t$) is greater than F_a (see E.5.3), the tank is structurally unstable."

Reply 3: Yes. This correction will appear in Addendum 2 of API 650.

Question 4: Is the following revision to Section E.5.3 appropriate?

"The maximum longitudinal compressive stress in the shell $b/1000t$ ($b/12t$), shall not exceed the maximum allowable stress, F_a, determined by the following formulas for F_a, which take in to account..."

Reply 4: Yes. This correction was made in Addendum 1 of API 650, released in March 2000.

APPENDIX F DESIGN OF TANKS FOR SMALL INTERNAL PRESSURES

650-I-12/00

Question: Assume a tank is to be designed to API 650, Appendix F.1.2, (the internal pressure will be greater than the weight of the roof plates but less than the weight of the shell, roof and framing). In addition, assume anchors are to be added for some reason other than internal pressure, for example: seismic, wind, sliding, overturning or user mandated. Does the tank have to be designed to API 650 Section F.7?

07 Reply: No, only Sections F.2 through F.6 apply. Section 3.11 applies to anchors that resist wind overturning when specified by the Purchaser. Appendix E applies to anchors provided for seismic. API's Subcommittee on Pressure Vessels and Tanks is currently reviewing API 650 anchor requirements. (F.2 has been deleted.)

650-I-15/02

Question 1: Is the "*W*" in 3.10.2.5.3 referring to the same "*W*" in F.4.2?

07 Reply 1: Yes. (Paragraph 3.10.2.5.3 has been deleted.)

Question 2: Does "*W*" in F.4.2 include the weight of the bottom of the tank?

07 Reply 2: No. ("*W*" has been revised to "D_{LS}" in the 11^{th} Edition.)

Question 3: Is the "*A*" in 3.10.2.5.3 referring to the same "*A*" in F.4.1 and cross-hatched area shown in Figure F-2?

Reply 3: Yes.

650-I-25/03

Question 1: If internal pressure inside tank does not exceed the weight of the shell, roof, and attached framing, but exceeds the weight of the roof plates (Basic Design plus Appendix F.1 to F.6), must *H* be increased by the quantity $P/12G$?

Reply 1: No.

650-I-30/03

Question: For an anchored tank, can the P_{max} calculation in F.4.2 be exceeded by the design pressure of the tank?

Reply: Yes.

APPENDIX H INTERNAL FLOATING ROOFS

650-I-50/99

Question 1: Does API 650 require that floating roof seals be installed prior to hydro-testing the tank?

Reply 1: No. (See H.4.4.4 in the 11th Edition for revised rules.) 07

Question 2: Is a roof seal considered a major component of the tank?

Reply 2: API 650 does not use the term "major component."

650-I-10/00

Question: Does API 650 provide a way to obtain a frangible roof connection on a small tank describe as follows?

- Diameter: 8 ft
- Height: 10 ft
- Cross sectional area of the roof-to-shell junction "A": larger than that allowed by the equation in Section 3.10.

Reply: No. The API Subcommittee on Pressure Vessels and Tanks is currently reviewing the design criteria for frangible roof joints. You may wish to review API Publ 937 *Evaluation of Design Criteria for Storage Tanks with Frangible Roof Joints.*

650-I-38/02

Question 1: Is the reference to NFPA 11 found in footnote number 1 under item H.2.1 meant to establish that non-perforated honeycomb floating roofs are the exclusively permitted type to be used if an H.2.2.f type floating roof is being considered?

Reply 1: No. The reference to NFPA 11 is solely related to the design of a fire suppression system (if used).

Question 2: Per H.4.1.7 "Inspection openings shall be located above the liquid level and closed compartments shall be capable of being resealed in the field after periodic inspection (to prevent liquid or vapor entry)." In the case of floating roofs type H.2.2.f, does "inspection openings" refer to screwed couplings, test plug or similar devices, or is it implied by "inspection openings" the disassembling in the field of flotation modules?

Reply 2: Yes, "inspection openings" in Section H.4.1.7 refers to screwed couplings, test plugs or similar devices and not to the disassembling in the field of flotation modules.

Question 3: Does note c of API 650 Table 3-6 allow the customer to locate nozzles lower than allowed by the weld spacing requirements of 3.7.3?

Reply 3: No.

650-I-09/03

Question: Does H.4.2.2 require internal floating roofs be designed to support a uniform load of 500 lbf/in.^{2}?

Reply: The 500 lb force is to be applied as a moving concentrated load over one square foot located anywhere on the roof. Refer to H.4.2.5 for distributed uniform loading.

APPENDIX J SHOP-ASSEMBLED STORAGE TANKS

650-I-05/02

Question: Referencing Appendix J, does the roof plate material have to meet the same toughness requirements as the shell plate on tanks located in -40°F areas? (Assume F.7 is not applicable.)

Reply: This is not addressed in API 650.

650-I-18/02

Background: Many times small tanks with diameters less than 10 ft are specified for construction in accordance with API 650. A review of API 650, Section 3.6.1.1, shows the minimum thickness to be $^{3}/_{16}$ in. and 3.6.1.2 indicates that the minimum shell plate width is 72 in. Appendix J states that the maximum tank diameter of a tank constructed to API 650 is 20 ft.

Question: Is there a minimum diameter or height or volume for which new tanks constructed to API 650 apply?

Response: No.

650-I-36/02

Question: On an API 650 shop-fabricated tank (Appendix J), can a reinforcing plate cross a shell weld?

Reply: Yes. See J.3.6.1 and 3.7.

APPENDIX P ALLOWABLE EXTERNAL LOADS ON SHELL OPENINGS

650-I-12/04

Question 1: If the nozzle has a compensating pad to Table 3-6, does the code require a check to be made on stress levels at the edge of the pad and if so can WRC 297 be used with the stress reduction factor applied from P.3?

Reply 1: No.

Question 2: If the nozzle neck meets the requirements of Table 3-7, are any further checks required to find stress levels in the nozzle neck and if so can WRC 297 be used with the stress reduction factor applied from P.3?

Reply 2: No.

APPENDIX S AUSTENITIC STAINLESS STEEL STORAGE TANKS

650-I-19/00

Question: In my opinion, the formulas given for shell thickness calculation for stainless steel materials in Appendix S, Par. S.3.2 include the corrosion allowance (CA) at the wrong place. The formulas should consist of two parts, the second part should be the CA without the division by.

Reply: Yes, you are correct. This typographical error was corrected in Addendum 1 to API 650, 10th Edition.

650-I-28/03

Question: Should the bottom plates be for stainless tanks be $^1/_4$ in. thick?

Reply: No. The $^3/_{16}$ in. minimum bottom plate thickness for stainless steel is intentional and is not related to the joint efficiency.