Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure NC-3351-1 illustrates typical joint locations included in each category.

**NC-3351.1 Category A.** Category A comprises longitudinal welded joints within the main shell, communicating chambers, transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates of a flat-sided vessel; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

**NC-3351.2 Category B.** Category B comprises circumferential welded joints within the main shell, communicating chambers, nozzles, or transitions in diameter including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

**NC-3351.3 Category C.** Category C comprises welded joints connecting flanges, Van Stone laps, tubesheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers and any welded joint connecting one side plate to another side plate of a flat-sided vessel.

**NC-3351.4 Category D.** Category D comprises welded joints connecting communicating chambers or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat-sided vessels and those joints connecting nozzles to communicating chambers. For nozzles at the small end of a transition in diameter, see Category B.

---

Errata: Should be endnote 24, not endnote 22.
(b) For through-thickness temperature differences, adjacent points are defined as any two points on a line normal to any surface.

13 *Normal service* is defined as any set of service conditions other than startup and shutdown that are specified for the vessel to perform its intended function.

14 *Adjacent points* are defined as points that are spaced less than the distance $2\sqrt{Rt}$ from each other, where $R$ and $t$ are the mean radius and thickness, respectively, of the vessel, nozzle, flange, or other part in which the points are located.

15 The head design curves have been developed considering membrane stress requirements, plastic collapse, cyclic load conditions, and the effects of maximum allowable tolerances in accordance with NC-4222. See Section III Appendices, Nonmandatory Appendix A, Article A-4000 for the design equations for the curves of Figure NC-3224.6-1.

16 Heads having $D/2h = 2$ have equivalent torispherical properties of a torisphere of $L/D = 0.90$ and $r/D = 0.17$.

17 The minimum thickness for all pipe materials is the nominal thickness listed in Table 2 of ASME B36.10M less $12\frac{1}{2}\%$. For diameters other than those listed in the table, the minimum thickness shall be that of the next larger pipe size.

18 The equations provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

19 When axial compressive loadings occur in addition to the external pressure, the combined axial loading shall meet the requirements of NC-3245.

20 *Stress* means the maximum normal stress.

21 Since $H_r h_r$ in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for the flange design.

22 The rules in NC-3329(f) apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups that extend a distance greater than the inside diameter of the shell as covered in NC-3329(c). When this occurs, the efficiencies computed by the rules under NC-3329(b) shall govern.

23 *Communicating chambers* are defined as appurtenances to the vessel that intersect the shell or heads of a vessel and form an integral part of the pressure-retaining enclosure, such as sumps.

24 *Side plates of a flat-sided vessel* are defined as any of the flat plates forming an integral part of the pressure-retaining enclosure.

Correct endnote
(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than \( \frac{3}{16} \) in. (5 mm).

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in.\(^2\) (mm\(^2\)), plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed:

\[
\begin{align*}
\text{(U.S. Customary Units)} & \quad \frac{D^2}{3,000 \sin \theta} \\
\text{(SI Units)} & \quad \frac{D^2}{0.43 \sin \theta}
\end{align*}
\]

**NC-3856 Self-Supporting Dome and Umbrella Roofs**

**NC-3856.1 Nomenclature.** See NC-3855.1 for nomenclature.

**NC-3856.2 Design Requirements.** Self-supporting dome and umbrella roofs shall conform to the requirements of (a) through (c) below.

(a) Radius of Curvature

\[ R = D \text{ unless otherwise specified} \]

Minimum \( R = 0.80D \)

Maximum \( R = 1.2D \)

(b) Plate Thickness

(1) Minimum/Maximum

\[
\begin{align*}
\text{(U.S. Customary Units)} & \quad \text{Minimum } t = \frac{R}{200}, \text{ but not less than } \frac{3}{16} \text{ in.} \\
& \quad \text{Maximum } t = \frac{1}{2} \text{ in.}
\end{align*}
\]

\[
\begin{align*}
\text{(SI Units)} & \quad \text{Minimum } t = \frac{R}{2.4}, \text{ but not less than } 5 \text{ mm} \\
& \quad \text{Maximum } t = 13 \text{ mm}
\end{align*}
\]

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than \( \frac{3}{16} \) in. (5 mm).

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in.\(^2\) (mm\(^2\)), plus the cross-sectional areas of the shell and roof plates within a distance of 16
35 The limitation of the Design Pressure to *atmospheric* is not intended to preclude the use of these tanks at vapor pressure slightly above or below atmospheric within the range normally required to operate vent valves. If these pressures or vacuums exceed 0.03 psi (0.2 kPa), especially in combination with large diameter tanks, the forces involved may require special consideration in the design.

36 Any specified corrosion allowance for the shell plates shall be added to the calculated thickness.

37 The nominal thickness of shell plates refers to the tank shell as constructed. The thicknesses specified are based on erection requirements.


39 The decrease in yield stress at Design Temperature shall be taken into account.

40 The equations applying to self-supporting roofs provided for a uniform live load of 25 lb/ft² (1.2 kPa).

Correct endnote
\( t_h \) = thickness, in. (mm), of the roof or bottom plate at and near the juncture of the roof or bottom and sidewalls, including corrosion allowance

\( W_c \) = corresponding width, in. (mm), of the participating sidewall plate

\( W_h \) = width, in. (mm), of the roof or bottom plate considered to participate in resisting the circumferential force acting on the compression ring region

\( \alpha \) = angle between the direction of \( T_1 \) and a vertical line. In a conical surface it is also one-half of the total vertex angle of the cone.

**NC-3933.2 General Requirements.** When the roof or bottom of a tank is a cone or partial sphere and is attached to cylindrical sidewalls, the membrane stresses in the roof or bottom act inward on the periphery of the sidewalls. This results in circumferential compressive forces at the juncture, which shall be resisted either by a knuckle curvature in the roof or bottom or by a limited zone at the juncture of the intersecting roof or bottom plates and sidewall plates, supplemented in some cases by an angle, a rectangular bar, or a ring girder.

**NC-3933.3 Requirements for Knuckle Regions.**

(a) If a curved knuckle is provided, a ring girder or other form of compression ring shall not be used and there shall be no sudden changes in the direction of a meridional line at any point. In addition, the radius of curvature of the knuckle in a meridional plane shall not be less than 6%, and preferably not less than 12%, of the diameter of the sidewalls. Subject to the provisions of (b) below, the thickness of the knuckle at all points shall satisfy the requirements of NC-3932.

(b) Application of the equations in NC-3932.2 to levels immediately above and below a point where two surfaces of differing meridional curvature have a common meridional tangent, as at the juncture between the knuckle region and the spherically dished portion of a torispherical roof, will result in the calculation of two latitudinal unit forces, differing in magnitude and possibly in sign, at the same point. The latitudinal unit force at such a point will be between the two calculated values, depending on the geometry of the tank wall in that area.

**NC-3933.4 Requirements for Compression Rings.**

(a) If a curved knuckle is not provided, forces shall be resisted by other means in the compression ring region of the tank walls. The zone of the tank walls at the juncture between the roof or bottom and the sidewalls includes that width of plate on each side of the juncture which is considered to participate in resisting these forces [Figure NC-3933.4(a)-1]. The thickness of the wall plate on either side of the juncture shall not be less than the thickness needed to satisfy the requirements of NC-3932, and the widths of plate making up the compression ring region shall be computed from the following equations:

\[
W_h = 0.6\sqrt{R_2(t_h - c)} \tag{22}
\]

\[
W_c = 0.6\sqrt{R_c(t_c - c)} \tag{23}
\]

(b) The magnitude of the total circumferential force acting on any vertical cross section through the compression ring region shall be computed as follows:

\[
Q = T_2W_h + T_2W_c - T_1R_c\sin \alpha \tag{24}
\]

and the net cross-sectional area provided in the compression ring region shall not be less than that found to be required by the following equation:

(U.S. Customary Units)

\[
A_c = \frac{Q}{15,000} \quad \text{or} \quad \frac{Q}{S_{2S}} \tag{25}
\]

(SI Units)

\[
A_c = \frac{Q}{103}
\]

depending on whether the value of \( Q \) as determined by eq. (24) is negative or positive.

**NC-3933.5 Details of Compression Ring Regions.**

(a) If the force \( Q \) is negative, indicating compression, the horizontal projection of the effective compression ring region shall have a width in a radial direction not less than 0.015 times the horizontal radius of the tank wall at the level of the juncture between the roof or bottom and...
the sidewalls. If such projected width does not meet this requirement, appropriate corrective measures shall be taken as specified in this subparagraph.

(b) Whenever the circumferential force $Q$ determined in accordance with NC-3933.4 is of such magnitude that the area required by eq. NC-3933.4(b)(25) is not provided in a compression ring region with plates of the minimum thicknesses established by the requirements of NC-3932, or when $Q$ is compressive and the horizontal projection of the width $w_h$ is less than specified in (a), the compression ring region shall be reinforced either by thickening the roof or bottom and sidewall plates as required to provide a compression ring region having the necessary cross-sectional area and width as determined on the basis of the thicker plates,\textsuperscript{54} or by adding an angle, a rectangular bar, or a ring girder at the juncture of the roof or bottom and sidewall plates, or by a combination of these alternatives.

(c) An angle, bar, or ring girder, if used, may be located either inside or outside of the tank\textsuperscript{55} and shall have a cross section of such dimensions that:

(1) its area makes up the deficiency between the area $A_c$, required by eq. NC-3933.4(b)(25), and the cross-sectional area provided by the compression ring region in the walls of the tank;

(2) the horizontal width of the angle, bar, or ring girder is not less than 0.015 times the horizontal radius $R_c$ of the tank wall at the level of the juncture of the roof or bottom and the sidewalls, except that, when the cross-sectional area to be added in an angle or bar is not more than one-half of the total area required by eq. NC-3933.4(b)(25), the width requirement for this member may be disregarded, provided the horizontal projection of the width $w_h$ of participating roof or bottom plates alone is equal to or greater than 0.015$R_c$, or, with an angle or bar located on the outside of a tank, the sum of the projection of the width $w_h$ and the horizontal width of the added angle or bar is equal to or greater than 0.015$R_c$.

(3) when bracing must be provided as specified in (h), the moment of inertia of the cross section about a horizontal axis shall be not less than that required by eq. (h)(26).

(d) When the vertical leg of an angle ring or a vertical flange of a ring girder is located on the sidewall of the tank, it may be built into the sidewall if its thickness is not less than that of the adjoining wall plates. However, if this construction is not used, the leg, edge, or flange of the compression ring next to the tank shall make contact with the wall of the tank around the entire circumference and, except as provided in (e) below, shall be attached along both the top and bottom edges by continuous fillet welds. These welds shall be of sufficient size to transmit the portion, $Q_p$, of the total circumferential force $Q$, to the compression ring angle, bar, or girder, assuming, in the case of welds separated by the width of a leg or flange of a structural member as shown in Figure NC-3933.5(d)-1 sketches (a) and (d), that only the weld nearest the roof or bottom is effective. The part thicknesses and weld sizes in Table NC-4247.6(d)-1 relate to dimensions in the as-welded condition before deduction of corrosion allowances, but all other part thicknesses and weld sizes referred to, in this subparagraph, relate to dimensions after deduction of corrosion allowance.

(e) If a continuous weld is not needed for strength or as a seal against corrosive elements, attachment welds along the lower edge of a compression ring on the outside of a tank may be intermittent, provided:

(1) the summation of their lengths is not less than one-half the circumference of the tank;

(2) the unattached width of tank wall between the ends of welds does not exceed eight times the tank wall thickness exclusive of corrosion allowance;

(3) the welds are of such size as needed for strength but in no case smaller than specified in Table NC-4247.6(d)-1.

(f) The projecting part of a compression ring shall be placed as close as possible to the juncture between the roof or bottom plates and the sidewall plates.

(g) If a compression ring on either the inside or outside of a tank is of such shape that liquid may be trapped, it shall be provided with adequate drain holes uniformly distributed along its length. Similarly, if the shape of a compression ring on the inside of a tank is such that gas would be trapped on the underside thereof when the tank is being filled with liquid, adequate vent holes shall be provided along its length. Where feasible, such drain or vent holes shall be not less than $\frac{3}{4}$ in. (19 mm) in diameter.

(h) The projecting part of a compression ring without an outer vertical flange need not be braced, provided the width of such projecting part in a radial vertical plane does not exceed 16 times its thickness. With this exception, the horizontal part of the compression ring shall be braced at intervals around the circumference of the tank with brackets or other suitable members securely attached to both the ring and the tank wall to prevent such part of the ring from buckling laterally. When such bracing is required, the moment of inertia of the cross section of the angle, bar, or ring girder about a horizontal axis shall be not less than that calculated to be required by the following equation:\textsuperscript{56}

(U.S. Customary Units)

$$I_1 = \frac{1.44Q_pR_c^2}{29,000,000k} = 5\frac{Q_pR_c^2}{k} \times 10^{-6}$$ (26)

(SI Units)

$$I_1 = \frac{1.44Q_pR_c^2}{200000k} = 7.2\frac{Q_pR_c^2}{k} \times 10^{-6}$$
where

\[ I_1 = \text{required moment of inertia, in.}^4 \text{ (mm}^4\text{), for the cross section of a steel compression ring with respect to a horizontal axis through the centroid of the section, not taking credit for any portion of the tank wall, except that, in the case of an angle ring whose vertical leg is attached to or forms a part of the tank wall, the moment of inertia of only the horizontal leg shall be considered, and it shall be figured with respect to a horizontal axis through the centroid of such leg.} \]

\[ k = \text{a constant whose value depends on the magnitude of the angle } \theta, \text{ subtended at the central axis of the tank by the space between adjacent brackets, or other supports, which value shall be determined from the following tabulation in which } n \text{ is the number of brackets or other supports evenly spaced around the circumference of the tank.} \]

<table>
<thead>
<tr>
<th>( n )</th>
<th>30</th>
<th>24</th>
<th>20</th>
<th>18</th>
<th>15</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \theta, \text{ deg} )</td>
<td>12</td>
<td>15</td>
<td>18</td>
<td>20</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>( k )</td>
<td>186.6</td>
<td>119.1</td>
<td>82.4</td>
<td>66.6</td>
<td>45.0</td>
<td>29.1</td>
</tr>
</tbody>
</table>

**Errata:** Should be end note 56, not end note 55.
51 These forces are computed by the applicable equations in NC-3932.

52 Use of a knuckle radius as small as 6% of the sidewall diameter will frequently require an excessively heavy thickness for the knuckle region. The thickness requirements for such region will be found more reasonable if a larger knuckle radius is used.

53 Because of the discontinuities and other conditions found in a compression ring region, biaxial stress design criteria are not considered applicable for a compressive force determined as eq. NC-3933.4(b)(24). Experience has shown that a compressive stress of the order of 15.0 ksi (103 MPa) as indicated in eq. NC-3933.4(b)(25), is permissible in this case, provided the requirements of NC-3933.5 are satisfied.

54 Note that, unless the effect of the unit forces $T_2$ and $T_{2r}$ on the resulting increments in width of participating plate may safely be neglected, the use of thicker plates involves recomputing not only $w_h$ and $w_e$ but also $Q$ and $A_e$ for the increased plate thicknesses; hence, the design of the compression ring region in this case resolves into a trial and error procedure.

55 See Figure NC-3933.5(d)-1 for some acceptable details of construction of compression rings.

56 Note that the value required for $I_1$ as calculated from eq. NC-3933.5(h)(26) is not applicable for materials other than steel.
(b) Plate Thickness

(U.S. Customary Units)

\[ t_r = \frac{D}{1414 \sin \theta \sqrt{P}} \]

(SI Units)

\[ t_r = \frac{D}{539 \sin \theta \sqrt{P}} \]

but not less than \( \frac{3}{16} \) in. (5 mm) nominal.

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in square inches (mm²), plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed

(U.S. Customary Units)

\[ \text{Minimum} \ A_t = \frac{PD^2}{8f \sin \theta} \]

(SI Units)

\[ \text{Minimum} \ A_t = \frac{PD^2}{138f \sin \theta} \]

ND-3856 Self-Supporting Dome and Umbrella Roofs

ND-3856.1 Nomenclature. See ND-3855.1 for nomenclature.

ND-3856.2 Design Requirements for Ferrous Material. Self-supporting dome and umbrella roofs shall conform to the requirements of (a) through (c) below.

(a) Radius of Curvature

Minimum \( R = 0.80D \)

Maximum \( R = 1.2D \)

(b) Plate Thickness

(1) Minimum \( t = \frac{R}{200} \left( t = \frac{R}{2.39} \right) \) but not less than \( \frac{3}{16} \) in. (5 mm). Maximum \( t = \frac{1}{2} \) in. (13 mm)

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than \( \frac{3}{16} \) in. (5 mm).

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in square inches (mm²), plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed

Errata: Should be endnote 35, not endnote 33.
17 Communicating chambers are defined as appurtenances to the vessel that intersect the shell or heads of a vessel and form an integral part of the pressure-retaining closure, e.g., sumps.

18 Side plates of a flat sided vessel are defined as any of the flat plates forming an integral part of the pressure-retaining enclosure.

19 Written for fittings with internal threads but also applicable to externally threaded and socket or butt welded fittings.

20 $t_D$ is defined in Section III Appendices, Mandatory Appendix XI, XI-3130.

21 All dimensions given, for size of vessel on which inspection openings are required, are nominal.

22 It is recognized that other acceptable procedures may exist that also constitute adequate design methods, and it is not the intention to rule out these alternative methods provided they can be shown to have been satisfactory by actual service experience.

23 Expansion Joint Manufacturers Association, 25 North Broadway, Tarrytown, NY 10591.

24 See Section III Appendices, Mandatory Appendix II, II-1520(g).

25 The pressure term in eqs. ND-3652(8), ND-3653.1(a)(9a), ND-3653.1(b)(9b) and ND-3653.2(c)(11) may not apply for bellows and expansion joints.

26 Design Pressure may be used if the Design Specification states that peak pressure and earthquake need not be taken as acting concurrently.

27 Socket welded joints should not be used where the existence of crevices could result in accelerated corrosion.

28 Fillet and partial penetration welds should not be used where severe vibration is expected.

29 These rules do not limit storage tanks from being installed below grade or below ground, provided the tanks are not subject to external pressure resulting from earth or fill.

30 The limitation of the Design Pressure to atmospheric is not intended to preclude the use of these tanks at vapor pressure slightly above or below atmospheric within the range normally required to operate vent valves. If these pressures or vacuums exceed $\frac{1}{2}$ oz/in.$^2$, especially in combination with large diameter tanks, the forces involved may require special consideration in the design.

31 Any specified corrosion allowance for the shell plates shall be added to the calculated thickness.

32 The nominal thickness of shell plates refers to the tank shell as constructed. The thicknesses specified are based on erection requirements.


34 The decrease in yield stress at Design Temperature shall be taken into account.

35 The equations applying to self-supporting roofs provide for a uniform live load of 25 lb/ft$^2$ (1.2 kPa).