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**NCD-3300 Vessel Design**

**NCD-3310 General Requirements**

Class 2 and Class 3 vessel requirements as stipulated in the Design Specifications (NCA-3250) shall conform to the design requirements of this Article.

**NCD-3320 Design Considerations**

**NCD-3321 Stress Limits for Design and Service Loadings**

Stress limits for Design and Service Loadings are specified in Table NCD-3321-1. The symbols used in Table NCD-3321-1 are defined as follows:

- $S$: allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B and 3. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the condition under consideration.
- $\sigma_b$: bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.
- $\sigma_L$: local membrane stress. This stress is the same as $\sigma_m$, except that it includes the effect of discontinuities.
- $\sigma_m$: general membrane stress. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations, and is produced only by pressure and other mechanical loads.

Typical examples of locations for which $\sigma_b$, $\sigma_L$, and $\sigma_m$ are applicable are shown in Table NCD-3321-2.

<table>
<thead>
<tr>
<th>Service Limit</th>
<th>Stress Limits [Note (1)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and Level A</td>
<td>$\sigma_m \leq 1.0S$</td>
</tr>
<tr>
<td></td>
<td>$(\sigma_n + \sigma_t) + \sigma_b \leq 1.5S$</td>
</tr>
<tr>
<td>Level B</td>
<td>$\sigma_m \leq 1.10S$</td>
</tr>
<tr>
<td></td>
<td>$(\sigma_n + \sigma_t) + \sigma_b \leq 1.65S$</td>
</tr>
<tr>
<td>Level C</td>
<td>$\sigma_m \leq 1.5S$</td>
</tr>
<tr>
<td></td>
<td>$(\sigma_n + \sigma_t) + \sigma_b \leq 1.8S$</td>
</tr>
<tr>
<td>Level D</td>
<td>$\sigma_m \leq 2.0S$</td>
</tr>
<tr>
<td></td>
<td>$(\sigma_n + \sigma_t) + \sigma_b \leq 2.4S$</td>
</tr>
</tbody>
</table>
Note to Editors: Markups are based on 2019 Edition of Subsection ND. Changes are shown in red. Cross references to paragraphs within this sub-article shall be updated based on this proposal’s markups

GENERAL NOTE:
See NCD-3321.1 for definitions of symbols.

NOTE:
(1) These limits do not take into account either local or general buckling which might occur in thin wall vessels.

<table>
<thead>
<tr>
<th>Vessel Part</th>
<th>Location</th>
<th>Origin of Stress</th>
<th>Type of Stress</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical or spherical shell</td>
<td>Shell plate remote from discontinuities</td>
<td>Internal pressure</td>
<td>General membrane</td>
<td>( \sigma_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gradient through plate thickness</td>
<td>( Q )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Axial thermal gradient</td>
<td>Membrane</td>
<td>( Q )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>( Q )</td>
</tr>
<tr>
<td></td>
<td>Junction with head or flange</td>
<td>Internal pressure</td>
<td>Membrane</td>
<td>( \sigma_L )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>( Q ) [Note (1)]</td>
</tr>
<tr>
<td>Any shell or head</td>
<td>Any section across entire vessel</td>
<td>External load or moment, or internal pressure</td>
<td>General membrane averaged across full section. Stress component perpendicular to cross section.</td>
<td>( \sigma_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>External load or moment</td>
<td>Bending across full section. Stress component perpendicular to cross section.</td>
<td>( \sigma_m )</td>
</tr>
<tr>
<td></td>
<td>Near nozzle or other opening</td>
<td>External load or moment, or internal pressure</td>
<td>Local membrane</td>
<td>( \sigma_L )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>( Q )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak (fillet or corner)</td>
<td>( F )</td>
</tr>
<tr>
<td></td>
<td>Any location</td>
<td>Temperature difference between shell and head</td>
<td>Membrane</td>
<td>( Q )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>( Q )</td>
</tr>
<tr>
<td></td>
<td>Crown</td>
<td>Internal pressure</td>
<td>Membrane</td>
<td>( \sigma_m )</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Vessel Part</th>
<th>Location</th>
<th>Origin of Stress</th>
<th>Type of Stress</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dished head or conical head</td>
<td>Knuckle or junction to shell</td>
<td>Internal pressure</td>
<td>Bending</td>
<td>$\sigma_b$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Membrane</td>
<td>$\sigma_l$ [Note (2)]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$Q$</td>
</tr>
<tr>
<td>Flat head</td>
<td>Center region</td>
<td>Internal pressure</td>
<td>Membrane</td>
<td>$\sigma_m$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$\sigma_b$</td>
</tr>
<tr>
<td></td>
<td>Junction to shell</td>
<td>Internal pressure</td>
<td>Membrane</td>
<td>$\sigma_l$ [Note (1)]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$Q$</td>
</tr>
<tr>
<td>Perforated head or shell</td>
<td>Typical ligament in a uniform pattern</td>
<td>Pressure</td>
<td>Membrane (averaged through cross section)</td>
<td>$\sigma_m$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending (averaged through width of ligament, but gradient through plate)</td>
<td>$\sigma_b$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak</td>
<td>$F$</td>
</tr>
<tr>
<td></td>
<td>Isolated or atypical ligament</td>
<td>Pressure</td>
<td>Membrane</td>
<td>$Q$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$F$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak</td>
<td>$F$</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Within the limits of reinforcement defined by NCD-3334</td>
<td>Pressure and external loads and moments, including those attributable to restrained free end displacements of attached piping</td>
<td>General membrane</td>
<td>$\sigma_m$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness</td>
<td>$\sigma_m$</td>
</tr>
<tr>
<td></td>
<td>Outside the limits of reinforcement defined by NCD-3334</td>
<td>Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping</td>
<td>General membrane stresses</td>
<td>$\sigma_m$</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Vessel Part</th>
<th>Location</th>
<th>Origin of Stress</th>
<th>Type of Stress</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pressure and external loads and moments other than those attributable to restrained free end displacements of the attached piping</td>
<td>Membrane</td>
<td>$\sigma_{L}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$\sigma_{B}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure and all external loads and moments</td>
<td>Membrane</td>
<td>$\sigma_{L}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$Q$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak</td>
<td>$F$</td>
</tr>
<tr>
<td>Nozzle wall</td>
<td></td>
<td>Gross structural discontinuities</td>
<td>Local membrane</td>
<td>$\sigma_{L}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$Q$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak</td>
<td>$F$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Differential expansion</td>
<td>Membrane</td>
<td>$Q$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$Q$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak</td>
<td>$F$</td>
</tr>
<tr>
<td>Cladding</td>
<td>Any</td>
<td>Differential expansion</td>
<td>Membrane</td>
<td>$F$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bending</td>
<td>$F$</td>
</tr>
<tr>
<td>Any</td>
<td>Any</td>
<td>Radial temp. distribution [Note (3)]</td>
<td>Equivalent linear stress [Note (4)]</td>
<td>$Q$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nonlinear portion of stress distribution</td>
<td>$F$</td>
</tr>
<tr>
<td>Any</td>
<td>Any</td>
<td>Any</td>
<td>Stress concentration (notch effect)</td>
<td>$F$</td>
</tr>
</tbody>
</table>

GENERAL NOTE:
$Q$ and $F$ classifications of stresses refer to other than Design Condition.

NOTES:
1. If the bending moment at the edge is required to maintain the bending stress in the middle within acceptable limits, the edge bending is classified as $\sigma_{B}$. Otherwise, it is classified as $Q$.
2. Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with a large diameter–thickness ratio.
3. Consider possibility of thermal stress ratchet.
4. Equivalent linear stress is defined as the linear distribution that has the same net bending moment as the actual stress distribution.
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NCD-3322 Special Considerations

The provisions of NCD-3120 apply.

NCD-3323 General Design Rules

The provisions of NCD-3130 apply except as modified by the rules of this subarticle. In case of conflict, this subarticle governs the design of vessels.

NCD-3324 Vessels Under Internal Pressure

NCD-3324.1 General Requirements.

Equations are given for determining the minimum thicknesses under internal pressure loading in cylindrical and spherical shells and ellipsoidal, torispherical, conical, toriconical, and hemispherical heads. Provision shall be made for any of the other loadings listed in NCD-3111 when such loadings are specified.

NCD-3324.2 Nomenclature.

The symbols used in this paragraph and Figure NCD-3324.2-1 are defined as follows:

- \( D \) = head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis
- \( D_1 \) = inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone
- \( D_2 \) = head; or outside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis
- \( D/2h \) = ratio of the major to the minor axis of ellipsoidal heads, which equals the inside diameter of the skirt of the head divided by twice the inside height of the head and is used in Table NCD-3324.2-1
- \( E \) = joint efficiency for, or the efficiency of, appropriate joint in the shell or head; for hemispherical heads this includes head-to-shell joints. For welded construction use the value of \( E \) specified in NCD-3352. For seamless heads use \( E = 1 \), except for hemispherical heads furnished without a skirt, in which case the head-to-shell joint must be considered. \( E = 1 \) for Class 2 vessels.
- \( h \) = one-half of the length of the minor axis of the ellipsoidal head or the inside depth of the ellipsoidal head measured from the tangent line (head-bend line)
- \( K \) = a factor in the equations for ellipsoidal heads depending on the head proportion \( D/2h \) (Table NCD-3324.2-1)
- \( L \) = inside spherical or crown radius for torispherical and hemispherical heads
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$L = K_1 D$ for ellipsoidal heads in which $K_1$ is obtained from Table NCD-3332.2-1

$L_o$ = outside spherical or crown radius

$P$ = Design Pressure

$R$ = inside radius of the shell course under consideration before corrosion allowance is added

$r$ = inside knuckle radius

$R_o$ = outside radius of the shell course under consideration

$S$ = maximum allowable stress value (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

$t$ = minimum required thickness of shell or head after forming, exclusive of corrosion allowance

$\alpha$ = one-half of the included apex angle of the cone at the center line of the head, deg

Figure NCD-3324.2-1 — Principal Dimensions of Typical Heads
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<table>
<thead>
<tr>
<th>$D/2h$</th>
<th>3.0</th>
<th>2.9</th>
<th>2.8</th>
<th>2.7</th>
<th>2.6</th>
<th>2.5</th>
<th>2.4</th>
<th>2.3</th>
<th>2.2</th>
<th>2.1</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>1.83</td>
<td>1.73</td>
<td>1.64</td>
<td>1.55</td>
<td>1.46</td>
<td>1.37</td>
<td>1.29</td>
<td>1.21</td>
<td>1.14</td>
<td>1.07</td>
<td>1.00</td>
</tr>
<tr>
<td>$D/2h$</td>
<td>1.9</td>
<td>1.8</td>
<td>1.7</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>$K$</td>
<td>0.93</td>
<td>0.87</td>
<td>0.81</td>
<td>0.76</td>
<td>0.71</td>
<td>0.66</td>
<td>0.61</td>
<td>0.57</td>
<td>0.53</td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>

GENERAL NOTE: Use nearest value of $D/2h$; interpolation unnecessary.

NCD-3324.3 Cylindrical Shells.
The minimum thickness of cylindrical shells shall be the greater thickness as given by (a) through (d) below.

(a) Circumferential Stress (Longitudinal Joints). When the thickness does not exceed one-half of the inside radius, or $P$ does not exceed $0.385SE$, the following equations shall apply:

$$ t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SE}{R + 0.6t} $$

(b) Longitudinal Stress (Circumferential Joints). When the thickness does not exceed one-half of the inside radius, or $P$ does not exceed $1.25SE$, the following equations shall apply:

$$ t = \frac{PR}{2SE + 0.4P} \quad \text{or} \quad P = \frac{2SE}{R + 0.4t} $$

(c) Thickness of Cylindrical Shells. The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above:

$$ t = \frac{PR_o}{SE + 0.4P} \quad \text{or} \quad P = \frac{SEt}{R_o - 0.4t} $$

(d) Thick Cylindrical Shells

(1) Circumferential Stress (Longitudinal Joints). When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius or when $P$ exceeds $0.385SE$, the following equations shall apply. When $P$ is known and $t$ is desired:

$$ t = \bar{R} \left( z^{1/2} - 1 \right) = \bar{R} \left( \frac{z^{1/2} - 1}{z^{1/2}} \right) $$
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where

\[ Z = \frac{SE + P}{SE - P} \]

When \( t \) is known and \( P \) is desired

\[ P = SE\left(\frac{Z - 1}{Z + 1}\right) \]

where

\[ Z = \left(\frac{R + t}{R}\right)^2 = \left(\frac{R_o}{R}\right)^2 = \left(\frac{R_o}{R_o - t}\right)^2 \]

(2) Longitudinal Stress (Circumferential Joints). When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius or when \( P \) exceeds \( 1.25SE \), the following equations shall apply. When \( P \) is known and \( t \) is desired

\[ t = R\left(\frac{Z^2/2 - 1}{Z^2/2}\right) \]

where

\[ Z = \frac{P}{SE} + 1 \]

When \( t \) is known and \( P \) is desired

\[ P = SE[Z - 1] \]

where

\[ Z = \left(\frac{R + t}{R}\right)^2 = \left(\frac{R_o}{R}\right)^2 = \left(\frac{R_o}{R_o - t}\right)^2 \]
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NCD-3324.4 Spherical Shells.

(a) When the thickness of the shell of a spherical vessel does not exceed 0.356\(R\) or \(P\) does not exceed 0.665\(SE\), the following equations shall apply. Any reduction in thickness within a shell course of a spherical shell shall be in accordance with NCD-3361.

\[
t = \frac{PR}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{R + 0.2t}
\]

(b) The following equations, in terms of the outside radius, are equivalent and may be used instead of those given in (a) above:

\[
t = \frac{PR_p}{2SE + 0.8P}
\]

\[
P = \frac{2SEt}{R_p - 0.8R}
\]

(c) When the thickness of the shell of a spherical vessel under internal pressure exceeds 0.356\(R\) or when \(P\) exceeds 0.665\(SE\), the following equations shall apply. When \(P\) is known and \(t\) is desired

\[
t = R\left(\frac{y^{4/3}}{3} - 1\right) = R\left(\frac{y^{4/3} - 1}{y^{4/3}}\right)
\]

where

\[
Y = \frac{2(Se + P)}{2SE - P}
\]

When \(t\) is known and \(P\) is desired

\[
P = 2SE\left(\frac{Y - 1}{Y + 2}\right)
\]

where

\[
Y = \left(\frac{R + t}{R}\right)^3 = \left(\frac{R_p}{R_p - t}\right)^3
\]
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**NCD-3324.5 Formed Heads, General Requirements.**

Formed heads shall meet the requirements of (a) through (i) below.

(a) All formed heads, thicker than the shell and concave to pressure, for butt-welded attachment, shall have a skirt length sufficient to meet the requirements of Figure NCD-3358.1(a)-1 when a tapered transition is required.

(b) Any taper at a welded joint within a formed head shall be in accordance with NCD-3361. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of NCD-3358 for the respective type of joint shown therein.

(c) All formed heads concave to pressure and for butt-welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same diameter.

(d) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than three times the head thickness.

(e) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by eq. NCD-3325.2(b)(4) or eq. NCD-3325.2(b)(5) using $C = 0.25$.

(f) Openings in formed heads under internal pressure shall comply with the requirements of NCD-3330.

(g) For Class 3 only, when an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of NCD-3324.5, it shall be stayed as a flat surface according to the rules of NCD-3329.

(h) For Class 3 only, a dished head with a reversed skirt may be used in a component, provided the maximum allowable pressure for the head is established in accordance with the requirements of NCD-6900.

(i) For Class 3 only, heads concave to pressure, intended for attachment by brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints (NCD-4500).
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NCD-3324.6 Ellipsoidal Heads.

(a) 2:1 Ellipsoidal Heads. The required thickness of a dished head of semiellipsoidal form, in which one-half the minor axis (inside depth of the head minus the skirt) equals one-fourth the inside diameter of the head skirt, shall be determined by

\[ t = \frac{PD}{2SE - 0.2P} \text{ or } P = \frac{2SEt}{D + 0.2} \]

(b) Ellipsoidal Heads of Other Ratios. The minimum required thickness of an ellipsoidal head of other than a 2:1 ratio shall be determined by

\[ t = \frac{PDK}{2SE - 0.2P} \text{ or } P = \frac{2SEt}{KD + 0.2} \]

\[ t = \frac{P(K - 0.1)}{2SE + 2P(K - 0.1)} \]

or

\[ P = \frac{25Et}{KD_0 - 2t(K - 0.1)} \]

where

\[ K = \frac{1}{6} \left[ 2 + \left( \frac{D}{2h} \right)^2 \right] \]

Numerical values of the factor \( K \) are given in Table NCD-3324.2-1.

NCD-3324.7 Hemispherical Heads.

(a) When the thickness of a hemispherical head does not exceed 0.356L or \( P \) does not exceed 0.665SE, the following equations shall apply:

\[ t = \frac{PL}{2SE - 0.2P} \text{ or } P = \frac{25Et}{L + 0.2t} \]

(b) When the thickness of the hemispherical head under internal pressure exceeds 0.356L or when \( P \) exceeds 0.665SE, the following equations shall apply:
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\[ t = L \left( \frac{\gamma^4}{3} - 1 \right) = L \left( \frac{\gamma^4}{3} - 1 \right) \]

where

\[ \tilde{Y} = \frac{2(LE + P)}{2SE - P} \]

or

\[ P = 2S \left( \frac{Y - 1}{Y + 2} \right) \]

where

\[ Y = \left( \frac{L + t}{L} \right)^3 = \left( \frac{L}{t} \right)^3 \]

**NCD-3324.8 Torispherical Heads.**

(a) **Torispherical Heads With 6% Knuckle Radius.** The required thickness of a torispherical head in which the knuckle radius is 6% of the inside crown radius shall be determined by

\[ t = \frac{0.885PL}{SE - 0.1P} \quad \text{or} \quad P = \frac{SEt}{0.885L + 0.1t} \]

(b) **Torispherical Heads of Other Proportions.** The required thickness of a torispherical head in which the knuckle radius is other than 6% of the crown radius shall be determined by

\[ t = \frac{PLM}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{LM + 0.2t} \quad (1) \]

\[ t = \frac{Pt_M}{2SE + P(M - 0.2)} \quad (2) \]

or

\[ P = \frac{2SE}{L \eta - t(M - 0.2)} \quad (3) \]
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where

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

Numerical values of the factor $M$ are given in Table NCD-3324.8(b)-1.

(c) Torispherical heads made of material having a specified minimum tensile strength exceeding 80 ksi (550 MPa) shall be designed using a value of $S$ equal to 20 ksi (140 MPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material as shown in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

### Table NCD-3324.8(b)-1 — Values of Factor $M$

<table>
<thead>
<tr>
<th>$L/r$</th>
<th>1.00</th>
<th>1.03</th>
<th>1.06</th>
<th>1.10</th>
<th>1.13</th>
<th>1.15</th>
<th>1.17</th>
<th>1.20</th>
<th>1.22</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M$</td>
<td>1.00</td>
<td>1.03</td>
<td>1.06</td>
<td>1.10</td>
<td>1.13</td>
<td>1.15</td>
<td>1.17</td>
<td>1.20</td>
<td>1.22</td>
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<table>
<thead>
<tr>
<th>$L/r$</th>
<th>4.00</th>
<th>4.50</th>
<th>5.00</th>
<th>5.50</th>
<th>6.00</th>
<th>6.50</th>
<th>7.00</th>
<th>7.50</th>
<th>8.00</th>
<th>8.50</th>
<th>9.00</th>
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<tr>
<td>$M$</td>
<td>1.25</td>
<td>1.28</td>
<td>1.31</td>
<td>1.34</td>
<td>1.36</td>
<td>1.39</td>
<td>1.41</td>
<td>1.44</td>
<td>1.46</td>
<td>1.48</td>
<td>1.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$L/r$</th>
<th>9.50</th>
<th>10.00</th>
<th>10.50</th>
<th>11.00</th>
<th>11.50</th>
<th>12.00</th>
<th>13.00</th>
<th>14.00</th>
<th>15.00</th>
<th>16.00</th>
<th>16.67 [Note (1)]</th>
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</thead>
<tbody>
<tr>
<td>$M$</td>
<td>1.52</td>
<td>1.54</td>
<td>1.56</td>
<td>1.58</td>
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<td>1.62</td>
<td>1.65</td>
<td>1.69</td>
<td>1.72</td>
<td>1.75</td>
<td>1.77</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Use nearest value of $L/r$; interpolation unnecessary.

**NOTE:**

(1) Maximum ratio allowed by NCD-3324.5(d) when $L$ equals the outside diameter of the skirt of the head.

### NCD-3324.9 Conical Heads Without Transition Knuckle.

The required thickness of conical heads or conical shell sections that have a half-apex angle $\alpha$ not greater than 30 deg shall be determined by

$$t = \frac{PD}{2 \cos \alpha (5E - 0.6F)} \quad \text{or} \quad P = \frac{2SE \cos \alpha}{D + 1.2t \cos \alpha}

For $\alpha > 30$ deg, see NCD-3324.11(b)(5). A compression ring shall be provided when required by the rule in NCD-3324.11(b).
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NCD-3324.10 Toriconical Heads.
Toriconical heads in which the inside knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than 3 times the knuckle thickness shall be used when the angle $\alpha$ exceeds 30 deg except when the design complies with NCD-3324.11. The required thickness of the knuckle shall be determined by the equation (1) of NCD-3324.8(b) in which

$$L = \frac{D_1}{2\cos \alpha}$$

The required thickness of the conical portion shall be determined by the equation in NCD-3324.9, using $D_1$ in place of $D$.

NCD-3324.11 Reducer Sections.

(a) General Requirements

(1) The rules of (a) apply to concentric reducer sections.

(2) The symbols used are defined as follows:

- $A$ = required area of reinforcement
- $A_e$ = effective area of reinforcement, due to excess metal thickness
- $D_1$ = inside diameter of reducer section at point of tangency to the knuckle or reverse curve
- $m$ = the lesser of $\frac{t_c \cos \alpha}{t} (a - \delta)$ or $\frac{t_c \cos \alpha \cos (a - \delta)}{t}$
- $R_L$ = inside radius of larger cylinder
- $r_L$ = inside radius of knuckle at larger cylinder
- $R_s$ = inside radius of smaller cylinder
- $r_s$ = radius to the inside surface of flare at the small end
- $t_c$ = nominal thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance
- $t_e$ = the smaller of $(t_c - t)$ or $[t_c - (t/cos \alpha)]$
- $t_s$ = nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance
- $\Delta$ = value to indicate need for reinforcement at cone-to-cylinder intersection having a half-apex angle $\alpha \leq 30$ deg. When $\delta \geq \alpha$, no reinforcement at the junction is required [Tables NCD-3324.11(b)(2)-1 and NCD-3324.11(b)(3)-1]
(3) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable equation. In addition, provisions shall be made for any of the other loadings listed in NCD-3111 when such loadings are expected.

(4) A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of (-a) and (-b) below are met.

(-a) Conical Shell Section. The required thickness of a conical shell section or the allowable pressure for such a section of given thickness shall be determined by the equations given in NCD-3324.9.

(-b) Knuckle Tangent to the Larger Cylinder. Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of NCD-3324.

(5) When elements of (4) above having different thicknesses are combined to form a reducer, the joints, including the plate taper required by NCD-3361, shall lie entirely within the limits of the thinner element being joined.

(6) A reducer may be a simple conical shell section [Figure NCD-3324.11(a)(6)-1, sketch (a)] without knuckle, provided the half-apex angle, \( \alpha \), is not greater than 30 deg, except as provided for in (b) below. A reinforcement ring shall be provided at either or both ends of the reducer when required by (b) below.

(7) A toriconical reducer [Figure NCD-3324.11(a)(6)-1, sketch (b)] may be shaped as a portion of a toriconical shell, a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half-apex angle, \( \alpha \), is not greater than 30 deg, except as provided for in (b) below. A reinforcement ring shall be provided at the small end of a conical reducer element when required by (b) below.

(8) Reverse curve reducers [Figure NCD-3324.11(a)(6)-1, sketches (c) and (d)] may be shaped of elements other than those as illustrated.

(b) Supplementary Requirements for Reducer Sections and Conical Heads Under Internal Pressure

(1) The equations of (2) and (3) below provide for the design of reinforcement, if needed, at the cone-to-cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half-apex angle \( \alpha \leq 30 \) deg. In (5)
Note to Editors: Markups are based on 2019 Edition of Subsection ND. Changes are shown in red. Cross references to paragraphs within this sub-article shall be updated based on this proposal’s markups below, provision is made for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where $\alpha > 30$ deg.

(2) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of $\Delta$, obtained from Table NCD-3324.11(b)(2)-1, using the appropriate ratio $P/SE$, is less than $\alpha$. Interpolation may be made in the Table.

**Figure NCD-3324.11(a)(6)-1 — Large Head Openings, Reverse Curve, and Conical Shell Reducer Sections**

**GENERAL NOTES:**
(a) $r_L$ shall not be less than the smaller of $0.12 \left( R_L + t \right)$ or $3t$
(b) $r_s$ has no dimensional requirement

(-a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{P(R_L)^2}{2SE} \left( 1 - \frac{\Delta}{\alpha} \right) \sin \alpha$$

(-b) When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that required by the applicable design equations, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:
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\[ A_e = 4 \sqrt{R_0 t_1} \]

(-c) Any additional area of reinforcement that is required shall be situated within a distance of \( \sqrt{R_0 t_1} \) from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of \( 0.5 \sqrt{R_0 t_1} \) from the junction.

(3) Reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder when the value of \( \Delta \) obtained from Table NCD-3324.11(b)(3)-1, using the appropriate ratio \( P/SE \), is less than \( \alpha \).

(-a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

\[ A = \frac{PR_e^2}{2SE} \left( 1 - \frac{\Delta}{\alpha} \right) \tan \alpha \]

(-b) When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design equation, the excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

\[ A_e = m \sqrt{R_0 t} (t - (t / \cos \alpha) + (t_1 - t)) \]

(-c) Any additional area of reinforcement that is required shall be situated within a distance of \( \sqrt{R_0 t_1} \) from the junction, and the centroid of the added area shall be within a distance of \( 0.5 \sqrt{R_0 t_1} \) from the junction.

(4) Reducers not described in (a)(3), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (5) below.

(5) When the half apex angle \( \alpha \) is greater than 30 deg, cone-to-cylinder junctions without a knuckle may be used, with or without reinforcing rings, if the design is based on stress analysis. When such an analysis is made, the calculated localized stresses at the discontinuity shall not exceed the following values.

(-a) Membrane hoop stress plus average discontinuity hoop stress shall not be greater than \( 1.5SE \), where the “average discontinuity hoop stress” is the average hoop stress across the wall thickness due to the discontinuity at the junction, disregarding the effect of Poisson’s ratio times the longitudinal stress at the surfaces.
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(-b) Membrane longitudinal stress plus discontinuity longitudinal stress due to bending shall not be greater than 3SE.

(-c) The angle joint between the cone and cylinder shall be designed equivalent to a double butt-welded joint, and, because of the high bending stress, there shall be no weak zones around the angle joint. The thickness of the cylinder may have to be increased to limit the difference in thickness so that the angle joint has a smooth contour.

| Table NCD-3324.11(b)(2)-1 — Values of Δ for Junctions at the Large Cylinder for α ≤ 30 deg |
|:---|---|---|---|---|---|---|---|---|---|
| $P/SE$ | 0.001 | 0.002 | 0.003 | 0.004 | 0.005 | 0.006 | 0.007 | 0.008 | 0.009 [Note (1)] |
| $\Delta, \text{ deg}$ | 11 | 15 | 18 | 21 | 23 | 25 | 27 | 28.5 | 30 |

NOTE:
(1) $\Delta = 30 \text{ deg for greater values of } P/SE$.

| Table NCD-3324.11(b)(3)-1 — Values of Δ for Junctions at the Small Cylinder for α ≤ 30 deg |
|:---|---|---|---|---|---|---|---|---|---|
| $P/SE$ | 0.002 | 0.005 | 0.010 | 0.02 | 0.04 | 0.08 | 0.10 | 0.125 [Note (1)] |
| $\Delta, \text{ deg}$ | 4 | 6 | 9 | 12.5 | 17.5 | 24 | 27 | 30 |

NOTE:
(1) $\Delta = 30 \text{ deg for greater values of } P/SE$.

NCD-3324.12 Nozzles.

(a) The wall thickness of a nozzle or other connection shall not be less than the nominal thickness of the connecting piping. In addition, the wall thickness shall not be less than the thickness computed for the applicable loadings in NCD-3111 plus the thickness added for corrosion allowance. Except for access openings and openings for inspection only, the wall thickness shall not be less than the smaller of (1) and (2) below:

(1) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;
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(2) the nominal wall thickness of standard wall pipe listed in ASME B36.10M less 12.5% plus the corrosion allowance on the connection. For diameters other than those listed in ASME B36.10M, nominal wall shall be based on the next larger pipe size; for nozzles larger than the largest pipe size included in ASME B36.10M, the nominal wall shall be based on largest size listed.

(b) The allowable stress value for shear in a nozzle neck shall be 70% of the allowable tensile stress for the vessel material.

NCD-3324.13 Nozzle Piping Transitions.

The stress limits of Table NCD-3321-1 shall apply to all portions of nozzles that lie within the limits of reinforcement given in NCD-3334, except as provided for in NCD-3324.14. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NCD-3600.

NCD-3324.14 Consideration of Standard Reinforcement.

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NCD-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NCD-3321-1. Under these conditions no analysis is required to demonstrate compliance for pressure-induced stresses in the nozzle region.

(b) Where external piping loads are specified, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure-induced stresses, shall meet the limits of Table NCD-3321-1 for \((\sigma_m + \sigma_b)\). In this case the pressure-induced stresses in the \((\sigma_m + \sigma_b)\) category may be assumed to be no greater than the limit for \(\sigma_m\) in Table NCD-3321-1 for a given condition.

NCD-3324.15 Other Loadings.

When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in NCD-3111 other than pressure and temperature.

NCD-3325 Flat Heads and Covers

The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular heads and covers. Some acceptable types of flat heads and covers are shown in Figure NCD-3325-1. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.
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Special consideration shall be given to the design of shells, nozzle necks, or flanges to which noncircular heads or covers are attached.

Figure NCD-3325-1 — Some Acceptable Types of Unstayed Flat Heads and Covers

See Fig. NCD-4240-1 for details of outside welded joint, $f_p$ not less than 1.25$f_y$.

See Fig. NCD-3325-2 for details of outside welded joint.

GENERAL NOTE:
The illustrations above are diagrammatic only. Other designs that meet the requirements of NCD-3325 are acceptable.

Commented [WSM2]: Add “For Class 3 vessels only” to figures (c), (e), (f), (g), (h), (i), (q), (r), (s).
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NOTES:
1 Circular covers, \( C = 0.33 \), \( C_{\min} = 0.20 \).
2 Noncircular covers, \( C = 0.33 \).
3 When pipe threads are used, see Table NCD-3361.2(a)-1.

NCD-3325.1 Nomenclature.
The symbols used are defined as follows:
- \( C \) = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in NCD-3325.3, dimensionless
- \( D \) = long span of noncircular heads or covers measured perpendicular to short span
- \( d \) = diameter, or short span, measured as indicated in Figure NCD-3325-1
- \( h_{g} \) = line of the gasket reaction, as shown in Section III Appendices, Mandatory Appendix XI, Table XI-3221.1-2
- \( L \) = perimeter of noncircular bolted head measured along the centers of the bolt holes
- \( l \) = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Figure NCD-3325-1 sketches (a) and (c)
- \( m \) = the ratio \( t_{f}/t_{s} \); dimensionless
- \( P \) = Design Pressure
- \( r \) = inside corner radius on a head formed by flanging or forging
- \( S \) = maximum allowable stress value, from Section II, Part D, Subpart 1, Tables 1A, 1B, and 3
- \( t \) = minimum required thickness of flat head or cover, exclusive of corrosion allowance
- \( t_{f} \) = throat dimension of the closure weld, as indicated in Figure NCD-3325-1 sketch (r)
- \( t_{f} \) = actual thickness of the flange on a forged head, at the large end, exclusive of corrosion allowance, as indicated in Figure NCD-3325-1 sketches (b-1) and (b-2)
- \( t_{b} \) = actual thickness of flat head or cover, exclusive of corrosion allowance
- \( t_{r} \) = required thickness of seamless shell, for pressure
- \( t_{s} \) = actual thickness of shell, exclusive of corrosion allowance
- \( t_{w} \) = thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Figure NCD-3325-1 sketch (g)
- \( W \) = total bolt load, given for circular heads for Section III Appendices, Mandatory Appendix XI, XI-3223, eqs. (3) and (4)
- \( Z \) = a factor of noncircular heads and covers that depends on the ratio of short span to long span (NCD-3325.2), dimensionless
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NCD-3325.2 Thickness.

The thickness of unstayed flat heads, covers, and blind flanges shall conform to one of the following four requirements.

Note: The equations provide structural integrity as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

(a) Circular blind flanges of ferrous materials conforming to ASME B16.5 shall be acceptable for the diameters and pressure-temperature ratings in Tables 2 through 8 of that Standard, when of the types shown in Figure NCD-3325-1 sketches (j) and (k).

(b) The minimum required thickness of flat unstayed circular heads, covers, and blind flanges shall be calculated by eq. (4)

\[ t = \frac{d}{\sqrt{CP/S}} \]  

except when the head, cover, or blind flange is attached by bolts causing an edge moment [Figure NCD-3325-1 sketches (j) and (k)], in which case the thickness shall be calculated by eq. (5)

\[ t = \frac{d}{\sqrt{CP/S}} + 1.27W_{ig}/Sd^2 \]  

When using eq. (5), the thickness \( t \) shall be calculated for both Service Loadings and gasket seating and the greater of the two values shall be used. For Service Loadings, the value of \( P \) shall be the Design Pressure and the values of \( S \) at the Design Temperature and \( W \) from Section III Appendices, Mandatory Appendix XI, XI-3223, eq. (3) shall be used. For gasket seating, \( P \) equals zero and the values of \( S \) at atmospheric temperature and \( W \) from Section III Appendices, Mandatory Appendix XI, XI-3223, eq. (4) shall be used.

(c) For Class 3 vessels only, flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by eqs. (6) and (7)

\[ t = \frac{d}{\sqrt{ZCP/S}} \]  

where

\[ Z = \frac{2A}{D} \]
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with the limitation that $Z$ need not be greater than 2.5.

(d) For Class 3 vessels only, Equation (c)(6) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [Figure NCD-3325-1 sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following equation:

$$t = 4 \sqrt{ZCF / S + 4W_{IC} / SL_d^2} \quad (8)$$

When using eq. (8), the thickness $t$ shall be calculated in the same way as specified above for eq. (b)(5).

NCD-3325.3 Values of $C$

For the types of construction shown in Figure NCD-3325-1, the minimum values of $C$ to be used in eqs. NCD-3325.2(b)(4), NCD-3325.2(b)(5), NCD-3325.2(c)(6), and NCD-3325.2(d)(8) are given in (a) through (o) below.

(a) In sketch (a), $C = 0.17$ for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange.

1. $C = 0.17$ for circular heads, when the flange length for heads of the above design is not less than

$$l = \left(1.1 - 0.8 \frac{L^2}{t_h^2}\right) \sqrt{\frac{t_h}{l}}$$

(2) $C = 0.10$ for circular heads, when the flange length $l$ is less than the requirement in (1) above but the shell thickness is not less than

$$t_s = 1.12l_{\gamma}L - 1/ \sqrt{4b_h}$$

for a length of at least $2 \sqrt{\frac{t_h}{l}}$.

(3) When $C = 0.10$ is used, the taper shall be 1:4.

(b) In sketch (b-1), $C = 0.17$ for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements for circumferential joints given in Article NCD-4000.
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(c) In sketch (b-2), $C = 0.33m$ but not less than 0.20 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than 1.5 times the flange thickness, and the welding meets all the requirements for circumferential joints given in Article NCD-4000. [See Figure NCD-4243.3-1 sketches (a) and (b) for the special case where $t_f$ equals $t_s$.]

(d) In sketch (c), $C = 0.13$ for circular heads lap welded or brazed to the shell with corner radius not less than $3t$ and $l$ not less than required by (a)(1) above and the requirements of NCD-3358 are met. This sketch is for Class 3 vessels only.

(1) $C = 0.20$ for circular and noncircular lap-welded or brazed construction as above but with no special requirement with regard to $l$.

(2) $C = 0.20$ for circular flanged plates screwed over the end of the vessel with inside corner radius not less than $3t$, in which the design of the threaded joint against failure by shear, tension, or compression, resulting from the end force due to pressure, is based on a factor of safety of at least 4 and the threaded parts are at least as strong as the threads for standard piping of the same diameter. Seal welding may be used, if desired.

(e) In sketch (d), $C = 0.13$ for integral flat circular heads when the dimension $d$ does not exceed 24 in. (600 mm), the ratio of thickness of the head to the dimension $d$ is not less than 0.05 nor greater than 0.25, the head thickness $t_h$ is not less than the shell thickness $t_s$, the inside corner radius is not less than 0.25 $t$, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(f) In sketches (e), (f), and (g), $C = 0.33m$ but not less than 0.20 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of $m$ less than 1 is used in calculating $t$, the shell thickness $t_s$ shall be maintained along a distance inwardly from the inside face of the head equal to at least $\sqrt[2]{2}\bar{a}t$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld $t_w$ in sketch (g) shall be not less than two times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness, but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the figure.

For noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels, $C = 0.33$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld $t_w$ in sketch (g) shall be not less than two times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness, but need not be greater than the head
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thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the figure. These sketches are for Class 3 vessels only.

(g) In sketch (h), \( C = 0.33 \) for circular plates welded to the end of the shell when \( t_e \) is at least 1.25\( t_e \) and the weld details conform to the requirements of NCD-3358.3(e) and Figure NCD-4243.2-1 sketches (a) through (g). This sketch is for Class 3 vessels only.

(h) In sketch (i), \( C = 0.33m \) but not less than 0.20 for circular plates if an inside fillet weld with minimum throat thickness of 0.7\( t_e \) is used and the details of the outside weld conform to the requirements of NCD-3358.3(e) and Figure NCD-4243.2-1 sketches (a) through (g), in which the inside weld can be considered to contribute an amount equal to \( t_e \) to the sum of the dimensions \( a \) and \( b \). This sketch is for Class 3 vessels only.

(i) In sketches (j) and (k), \( C = 0.20 \) for Class 2 circular heads and Class 3 circular heads, noncircular heads, and covers bolted to the vessel as indicated in the figures. Noncircular heads and covers bolted to the vessel are not permitted for Class 2 vessels. Note that eq. NCD-3325.2(b)(5) or eq. NCD-3325.2(d)(8) shall be used because of the extra moment applied to the cover by bolting. When the cover plate is grooved for a peripheral gasket, as shown in sketch (k), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than

\[
d \sqrt{\frac{1.27 WH_c}{SD^{3}}}
\]

for circular heads and covers, nor less than

\[
d \sqrt{\frac{4 WH_c}{SLd^{2}}}
\]

for noncircular heads and covers.

(j) In sketches (m), (n), and (o), \( C = 0.20 \) for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement and when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are resisted using stresses consistent with this Article. Seal welding may be used, if desired.

(k) In sketch (p), \( C = 0.17 \) for circular and noncircular covers bolted with a full face gasket to shells, flanges, or side plates.

(l) In sketch (q), \( C = 0.50 \) for circular plates screwed into the end of a vessel having an inside diameter \( d \) not exceeding 12 in. (300 mm) or for heads having an integral flange screwed over the end of a vessel having an inside diameter \( d \) not exceeding 12 in. (300 mm) and when the design of the threaded joint against failure by shear, tension, compression, or radial
deformation, including flaring, resulting from pressure and differential thermal expansion, is based on stresses consistent with this Subsection. If a tapered pipe thread is used, the requirements of NCD-3361.2 shall also be met. Seal welding may be used, if desired. This sketch is for Class 3 vessels only.

(m) In sketch (r), \( C = 0.33 \) for circular plates having a dimension \( d \) not exceeding 18 in. (450 mm) inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg, but not more than 45 deg. The crimping may be done cold only when this operation will not injure the metal. The throat of the weld shall be not less than the thickness of the flat head or shell, whichever is greater. This sketch is for Class 3 vessels only.

(n) In sketch (s), \( C = 0.33 \) for circular beveled plates having a diameter \( d \) not exceeding 18 in. (450 mm), inserted into a vessel, the end of which is crimped over at least 30 deg but not more than 45 deg and when the undercutting for seating leaves at least 80% of the shell thickness. The beveling shall be not less than 75% of the head thickness. The crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material used. For this construction, the ratio \( t/d \) shall be not less than the ratio \( P/S \) nor less than 0.05. The maximum allowable pressure for this construction shall not exceed \( P = S/5d \). This sketch is for Class 3 vessels only. (o) In Figure NCD-4243.3-1, \( C = 0.33m \), but not less than 0.20 when the dimensional requirements of NCD-3358.4 are met.

(p) In Figure NCD-4243.1-1 sketches (b), (c), (e), and (f), \( C = 0.33m \) but not less than 0.20 when the dimensional requirements of NCD-3358.3 are met. This sketch is for Class 2 vessels only.

(q) In Figure NCD-4243.1-2 sketches (a) and (b), \( C = 0.33m \) but not less than 0.20 when the dimensional requirements of NCD-3358.3 are met. This sketch is for Class 2 vessels only.

**NCD-3326 Spherically Dished Covers With Bolting Flanges**

**NCD-3326.1 Nomenclature.**
The symbols used are defined as follows:

\[
\begin{align*}
A & = \text{outside diameter of flange} \\
B & = \text{inside diameter of flange} \\
C & = \text{bolt circle diameter} \\
H_D & = \text{axial component of the membrane load in the spherical segment, acting at the inside of the flange ring} \\
& = 0.785B^2P \\
h_D & = \text{radial distance from the bolt circle to the inside of the flange ring}
\end{align*}
\]
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radial component of the membrane load in the spherical segment = \( H_D \ cot\ \beta_1 \), acting at
\( H_r \)
the intersection of the inside of the flange ring with the center line of the dished cover thickness

\( h_r \)
lever arm of \( H_r \) about centroid of flange ring

\( L \)
inside spherical or crown radius

the total moment, determined as in XI-3230 for heads concave to pressure, and XI-3260 for heads convex to pressure; except that, for heads of the type shown in Figure NCD-3326.1-1 sketch (d), \( H_D \) and \( h_D \) shall be as defined below, and an additional moment \( H_r \) shall be included

\( M_t \)

Note: 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.

\( P \)
Design Pressure

\( r \)
inside knuckle radius

\( S \)
maximum allowable stress value

\( T \)
flange thickness

\( t \)
minimum required thickness of head plate after forming

\( \beta_1 \)
where

\[ \beta_1 = \arcsin \left( \frac{B}{2L + t} \right) \]
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**Figure NCD-3326.1-1 — Spherically Dished Covers With Bolting Flanges**

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**NCD-3326.2 Spherically Dished Heads With Bolting Flanges.**

Circular spherically dished heads with bolting flanges, both concave and convex to the pressure, and conforming to the several types illustrated in Figure NCD-3326.1-1, shall be designed in accordance with the requirements of (a) through (d) below. For heads convex to pressure, the spherical segments shall be thickened, if necessary, to meet the requirements of NCD-3133. The actual value of the total moment $M_o$ may calculate to be either plus or minus for both the heads concave to pressure and the heads convex to pressure. However, for use in all of the equations that follow, the absolute values for both $P$ and $M_o$ shall be used.

(a) *Heads of the Type Shown in Figure NCD-3326.1-1 Sketch (a)* This sketch is for Class 3 vessels only.

1. The thickness of the head $t$ shall be determined by the appropriate equation in NCD-3324.

2. The head radius $L$ or the knuckle radius $r$ shall not exceed the limitations given in NCD-3324.

3. The flange shall comply at least with the requirements of Section III Appendices, Mandatory Appendix XI, Figure XI-3120-1 and shall be designed in accordance with the applicable provisions of Section III Appendices, Mandatory Appendix XI. Within
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the range of ASME B16.5, the flange facings and drillings should conform to those Standards and the thickness specified therein shall be considered as a minimum requirement.

(b) Heads of the Type Shown in Figure NCD-3326.1-1 Sketch (b) This sketch is for Class 3 vessels only.

(1) Head thickness

\[ t = \frac{5PL}{6S} \]

(2) Flange thickness \( T \)

(-a) For ring gasket

\[ T = \sqrt[3]{\frac{\sigma_f}{\sigma_b}} \left( \frac{A + B}{A - B} \right) \]

(-b) For full-face gasket

\[ T = 0.6 \sqrt{\frac{p}{S}} \left( \frac{B(A + B)(C - B)}{(A - B)^2} \right)^{\frac{3}{2}} \]

Note: The radial components of the membrane load in the spherical segment are assumed to be resisted by its flange.

Within the range of ASME B16.5, the flange facings and drillings should conform to those Standards, and the thickness specified therein shall be considered as a minimum requirement.

(c) Heads of the Type Shown in Figure NCD-3326.1-1 Sketch (c)

(1) Head thickness

\[ t = \frac{5PL}{6S} \quad (9) \]

(2) Flange thickness for ring gaskets shall be calculated as follows:

(-a) for heads with round bolting holes
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\[ T = Q + \sqrt{\frac{1.875 M_e (C + B)}{5L (7C - 5B)}} \]  \hspace{1cm} (10)

where

\[ Q = \frac{PL}{45} \left( \frac{C + B}{7C - 5B} \right) \]  \hspace{1cm} (11)

(-b) for heads with bolting holes slotted through the edge of the head

\[ T = Q + \sqrt{\frac{1.875 M_e (C + B)}{5L (3C - B)}} \]  \hspace{1cm} (12)

where

\[ Q = \frac{PL}{45} \left( \frac{C + B}{3C - B} \right) \]  \hspace{1cm} (13)

(3) Flange thickness for full face gaskets shall be calculated by the following equation:

\[ T = Q + \sqrt{Q^2 + \frac{3RL(C - B)}{L}} \]  \hspace{1cm} (14)

The value of \( Q \) in eq. (14) is calculated by eq. (2)(-a)(11) for round bolting holes or by eq. (2)(-b)(13) for bolting holes slotted through the edge of the head [see (2) above].

(4) The required flange thickness shall be \( T \) as calculated in (2) or (3) above, but in no case less than the value of \( t \) calculated in (1) above.

(d) Heads of the Type Shown in Figure NCD-3236.1-1 Sketch (d)

(1) Head thickness

\[ t = \frac{50L}{65} \]  \hspace{1cm} (15)

(2) Flange thickness
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\[ T = \phi + \sqrt{F^2 + J} \quad (16) \]

where

\[ F = \frac{PB\sqrt{4L^2 - \theta^2}}{8\pi(A - \theta)} \quad (17) \]

\[ J = \left( \frac{M_p}{S_B} \right) \left( \frac{A + \theta}{A - \theta} \right) \quad (18) \]

Note: These equations are approximate in that they do not take into account continuity between the flange ring and the dished head. A more exact method of analysis that takes this into account may be used. Such a method may parallel the method of analysis and allowable stresses for flange design in Section III Appendices, Mandatory Appendix XI. The dished portion of a cover designed under this rule may, if welded, require evaluation of any welded joint.

**NCD-3327 Quick Actuating Closures**

Closures other than the multibolted type designed to provide access to the contents space of a component shall have the locking mechanism or locking device so designed that failure of any one locking element or component in the locking mechanism cannot result in the failure of all other locking elements and the release of the closure. Quick actuating closures shall be so designed and installed that it may be determined by visual external observation that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

**NCD-3327.1 Positive Locking Devices.**

Quick actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limiting movement of the closure itself or the locking mechanism and any closure that is other than manually operated shall be so designated that when the vessel is installed the conditions of (a) through (c) below are met.

(a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(b) Pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.
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(c) In the event that compliance with (a) and (b) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

NCD-3327.2 Manual Operation.
Quick actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy NCD-3327.1, but such closures shall be equipped with an audible or visible warning device that will serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and further will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

NCD-3327.3 Pressure Indicating Device.
When installed, all vessels having quick actuating closures shall be provided with a pressure indicating device visible from the operating area.

NCD-3328 Combination Units
When a vessel consists of more than one independent chamber, operating at the same or different pressures and temperatures, each such chamber shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected in normal service.

NCD-3329 Ligaments, Braced and Stayed Surfaces, Staybolts

NCD-3329.1 Ligaments.

(a) The symbols used in the equations and chart of this paragraph are defined as follows:

\[ d \] = diameter of tube holes  
\[ n \] = number of tube holes in length \( p_1 \)  
\[ p \] = longitudinal pitch of tube holes  
\[ p' \] = diagonal pitch of tube holes  
\[ p_1 \] = unit length of ligament

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figures NCD-3329.1(b)-1 through NCD-3329.1(b)-3, the efficiency of the ligaments between the tube holes shall be determined by (1) or (2) below:
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(1) when the pitch of the tube holes on every row is equal [Figure NCD-3329.1(b)-1], the equation is \((p - d)/p = \text{efficiency of ligament}\);

(2) when the pitch of tube holes on any one row is unequal [Figures NCD-3329.1(b)-2 and NCD-3329.1(b)-3], the equation is \((p_1 - nd)/p_1 = \text{efficiency of ligament}\).

(c) The strength of ligaments between tube holes measured circumferentially shall be at least 50% of the strength of ligaments of similar dimensions taken in a line parallel to the axis of the cylindrical shell.

(d) When a cylindrical shell is drilled for tube holes so as to form diagonal ligaments, as shown in Figure NCD-3329.1(d)-1, the efficiency of these ligaments shall be that given by the diagram in Figure NCD-3329.1(d)-2. The pitch of tube holes shall be measured either on the flat plate before rolling or on the middle line of the plate after rolling. To use the diagram in Figure NCD-3329.1(d)-2, compute the value of \(p'/p_1\) and also the efficiency of the longitudinal ligament. Next find in the diagram the vertical line corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of \(p'/p_1\). Then project this point horizontally to the left and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The shell thickness and the maximum allowable pressure shall be based on the ligament that has the lower efficiency.

Figure NCD-3329.1(b)-1 — Example of Tube Spacing With Pitch of Holes Equal in Every Row

GENERAL NOTE:

\(\frac{5}{8} \text{ in.} = 133 \text{ mm}\)
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**Figure NCD-3329.1(b)-2** — Example of Tube Spacing With Pitch of Holes Unequal in Every Second Row

GENERAL NOTES:
(a) \( 5\frac{1}{2} \text{ in.} = 133 \text{ mm} \)
(b) \( 6\frac{1}{4} \text{ in.} = 171 \text{ mm} \)
(c) 12 in. = 300 mm

**Commented (WSM5):** Replace with Figure NC-3329.1(b)-2.

**Figure NCD-3329.1(b)-3** — Example of Tube Spacing With Pitch of Holes Varying in Every Second and Third Row

GENERAL NOTES:
(a) \( 5\frac{1}{2} \text{ in.} = 133 \text{ mm} \)
(b) \( 6\frac{1}{4} \text{ in.} = 171 \text{ mm} \)
(c) \( 29\frac{1}{4} \text{ in.} = 743 \text{ mm} \)

**Commented (WSM6):** Replace with Figure NC-3329.1(b)-3.
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Figure NCD-3329.1(d)-1 — Example of Tube Spacing With Tube Holes on Diagonal Lines

$p = 11\frac{1}{2}$ in. (292 mm)

Figure NCD-3329.1(d)-2 — Diagram for Determining the Efficiency of Longitudinal and Diagonal Ligaments Between Openings in Cylindrical Shells
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(e) When tube holes in a cylindrical shell are arranged in symmetrical groups that extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable pressure is based.

(f) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both (1) and (2) below.

Note: These rules 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 (e). When this occurs, the efficiencies computed by the rules under (b) shall govern.

(1) For a length equal to the inside diameter of the shell for the position that gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable pressure is based. When the diameter of the shell exceeds 60 in. (1 500 mm), the length shall be taken as 60 in. (1 500 mm) in applying this rule.

(2) For a length equal to the inside radius of the shell for the position that gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable pressure is based. When the radius of the shell exceeds 30 in. (750 mm), the length shall be taken as 30 in. (750 mm) in applying this rule.

(g) For holes that are not in line, placed longitudinally along a cylindrical shell, the rules in (f) above for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width, the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Figure NCD-3329.1(g)-1.
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Figure NCD-3329.1(g)-1 — Diagram for Determining Equivalent Longitudinal Efficiency of Diagonal Ligaments

NCD-3329.2 Braced and Stayed Surfaces for Class 3 Vessels Only.

(a) The minimum thickness and maximum allowable pressure for braced and stayed flat plates and those parts which, by these rules, require staying as flat plates with braces or staybolts of uniform diameter symmetrically spaced shall be calculated by the following equations:
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\[
t = p \sqrt{\frac{p}{Sc}}
\]  
\[
p = \frac{r^2Sc}{p^2}
\]

where

- \( C = 2.1 \) for welded stays or stays screwed through plates not over \( \frac{7}{16} \) in. (11 mm) in thickness with ends riveted over
- \( C = 2.2 \) for welded stays or stays screwed through plates over \( \frac{7}{16} \) in. (11 mm) in thickness with ends riveted over
- \( C = 2.5 \) for stays screwed through plates and fitted with single nuts outside of plate or with inside and outside nuts, omitting washers
- \( C = 2.8 \) for stays with heads not less than 1.3 times the diameter of the stays screwed through plates, or made a taper fit and having the heads formed on the stays before installing them and not riveted over
- \( C = 3.2 \) for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than 0.4\( p \) and thickness not less than \( t \)

- \( P = \) Design Pressure
- \( p = \) maximum pitch measured between straight lines passing through the centers of the staybolts in the different rows, which lines may be horizontal, vertical, or inclined
- \( S = \) maximum allowable stress value, given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3
- \( t = \) minimum thickness of plate, exclusive of corrosion allowance

\( b \) The minimum thickness of plates to which stays may be applied, in other than cylindrical or spherical outer shell plates, shall be \( \frac{7}{16} \) in. (8 mm) except for welded construction (NCD-3329.4).

\( c \) If a stayed jacket extends completely around a cylindrical or spherical vessel, or completely covers a formed head, it shall meet the requirements given in (a) above and shall also meet the applicable requirements for shells or heads (NCD-3324).

\( d \) When two plates are connected by stays and but one of these plates requires staying, the value of \( C \) shall be governed by the thickness of the plate requiring staying.

\( e \) The acceptable proportions for the ends of through stays with washers are indicated in Figure NCD-3329.2(e)-1.
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(f) The maximum pitch shall be 8 1/2 in. (215 mm), except that for welded-in staybolts the pitch may be greater, provided it does not exceed 15 times the diameter of the staybolt.

(g) When the staybolting of shells is unsymmetrical by reason of interference with butt straps or other construction, it is permissible to consider the load carried by each staybolt as the area calculated by taking the distance from the center of the spacing on one side of the bolt to the center of the spacing on the other side.

Figure NCD-3329.2(e)-1 — Acceptable Proportions for Ends or Through Stays

NCD-3329.3 Threaded Staybolts for Class 3 Vessels Only.

(a) The ends of staybolts or stays screwed through the plate shall extend beyond the plate not less than two threads when installed, after which they shall be riveted over or upset by an equivalent process without excessive scoring of the plates, or they shall be fitted with threaded nuts through which the bolt or stay shall extend.

(b) The ends of steel stays upset for threading shall be fully annealed.

NCD-3329.4 Welded Stayed Construction for Class 3 Vessels Only.

For welded stayed construction, the provisions of NCD-4470 and NCD-5260 shall be met in addition to the requirements of (a) through (d) below.

(a) Welded-in staybolts shall meet the requirements of (1) through (4) below.
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(1) The arrangement shall conform to one of those illustrated in Figure NCD-4470-1.

(2) The required thickness of the plate shall not exceed 1 1/2 in. (38 mm) but, if greater than 3/4 in. (19 mm), the staybolt pitch shall not exceed 20 in. (500 mm).

(3) The provisions of NCD-3329.2 and NCD-3329.5 shall be met.

(4) The required area of the staybolt shall be determined in accordance with NCD-3329.6.

(b) Welded stays, as shown in Figure NCD-4470-1, may be used to stay jacketed vessels provided the requirements of (1) through (8) below are met.

(1) The pressure does not exceed 300 psi (2 MPa).

(2) The required thickness of the plate does not exceed 1/2 in. (13 mm).

(3) The size of the fillet welds is not less than the plate thickness.

(4) The inside welds are properly inspected before the closing plates are attached.

(5) The allowable load on the fillet welds is computed in accordance with NCD-3356.1(c).

(6) The maximum diameter or width of the hole in the plate does not exceed 1 1/4 in. (32 mm).

(7) The welders are qualified under the rules of Section IX.

(8) The maximum spacing of stays is determined by the equation in NCD-3329.2(a), using

\[ C = \begin{cases} 2.1 & \text{if either plate is not over } \frac{3}{16} \text{ in. (11 mm) thick} \\ 2.2 & \text{if both plates are over } \frac{3}{16} \text{ in. (11 mm) thick} \end{cases} \]

(c) Welded stayed construction, consisting of a dimpled or embossed plate welded to another like plate or to a plain plate, may be used, provided the requirements of (1) through (4) below are met.

(1) The pressure does not exceed 300 psi (2 MPa).
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(2) The welded attachment is made by fillet welds around holes or slots as shown in Figure NCD-4470-1 and is calculated in accordance with NCD-4470.

(3) The maximum allowable pressure of the dimpled or embossed components is established in accordance with the requirements of NCD-6900.

(4) The plain plate, if used, shall meet the requirements for braced and stayed surfaces.

(d) The welds need not be radiographed, nor need they be postweld heat treated unless the vessel is required to be postweld heat treated.

NCD-3329.5 Location of Staybolts for Class 3 Vessels Only.

(a) The distance from the edge of a staybolt hole to the edge of a flat stayed plate shall not be greater than the pitch of the stays.

(b) When the edge of a flat stayed plate is flanged, the distance from the center of the outermost stays to the inside of the supporting flange shall not be greater than the pitch of the stays plus the inside radius of the flange.

NCD-3329.6 Dimensions of Staybolts for Class 3 Vessels Only.

(a) The required area of a staybolt at its minimum cross section and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt, computed in accordance with (b) below, by the allowable stress for the material used (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3) and multiplying the result by 1.10. Note: The minimum cross section is usually at the root of the thread.

(b) The area supported by a stay shall be computed on the basis of the full pitch dimensions, with a deduction for the area occupied by the stay. The load carried by a stay is the product of the area supported by the stay and the maximum allowable pressure.

(c) Stays made of parts joined by welding shall be designed using a joint efficiency of 0.60 for the weld.

Commented [WSM7]: This wording was changed in ND-3329.6(a) by Record 18-2635. This record adds reference to Section II, Part D, Subpart 1, Table 3 – which provides allowable stresses for bolting materials and is applicable in this context.
Note to Editors: Markups are based on 2019 Edition of Subsection ND. Changes are shown in red. Cross references to paragraphs within this sub-article shall be updated based on this proposal’s markups

NCD-3330 Openings and Reinforcement

NCD-3331 General Requirements for Openings

(a) Openings in cylindrical or conical portions of vessels or in formed heads shall preferably be circular, elliptical, or obround. When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(b) Openings may be of other shapes than those given in (a) above, and all corners shall be provided with a suitable radius. When the openings are of such proportions that their strength cannot be computed with assurance of accuracy or when doubt exists as to the safety of a vessel with such openings, the part of the vessel affected shall be subjected to a proof hydrostatic test as prescribed in NCD-6900.

(c) See below.

(1) The rules for reinforcement of openings given in NCD-3330 are intended to apply to openings not exceeding the following:

- (a) for vessels 60 in. (1 500 mm) diameter and less: one-half the vessel diameter but not to exceed 20 in. (500 mm);

- (b) for vessels over 60 in. (1 500 mm) diameter: one-third the vessel diameter but not to exceed 40 in. (1 000 mm).

(2) Larger openings shall be given special attention. Two-thirds of the required reinforcement shall be within \( \frac{1}{2} r \) parallel to the vessel surface and measured from the edge of the opening, where \( r \) is the radius of the finished opening. The limit normal to the vessel wall is the smaller of the limits specified in NCD-3334.2. Special consideration shall be given to the fabrication details used and examination employed. Reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening. Welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations.

(d) All references to dimensions in NCD-3330 apply to the finished dimensions, excluding material added as corrosion allowance.

(e) Any type of opening may be located in a welded joint.
NCD-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

NCD-3332.1 Openings Not Requiring Reinforcement.
Reinforcement shall be provided in amount and distribution such that the requirements for area of reinforcement are satisfied for all planes through the center of the opening and normal to the surface of the vessel, except that single circular openings need not be provided with reinforcement if the openings have diameters equal to or less than NPS 2 (DN 50).

NCD-3332.2 Required Area of Reinforcement.
The total cross-sectional area of reinforcement $A$ required in any given plane for a vessel under internal pressure shall not be less than

$$A = d_t F$$

where

- $d$ = finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition
- $F$ = a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Figure NCD-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.
- $t_r$ = the required thickness of a shell or head computed in accordance with the rules of this Article for the Design Pressure, except that:
  (a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, $t_r$ is the thickness required by NCD-3324.8(b), using $E = 1$ and $M = 1$;
  (b) when the opening is in a cone, $t_r$ is the thickness required for a seamless cone of diameter $D$ measured where the nozzle axis pierces the inside wall of the cone;
  (c) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, $t_r$ is the thickness required for a seamless sphere of radius $K_1 D$, where $D$ is the shell diameter and $K_1$ is given by Table NCD-3332.2-1.

At least one-half of the required reinforcing shall be on each side of the center line of the opening.
Figure NCD-3332.2-1 — Chart for Determining Value of F

Table NCD-3332.2-1 — Values of Spherical Radius Factor K1

<table>
<thead>
<tr>
<th>(D/2h)</th>
<th>3.0</th>
<th>2.8</th>
<th>2.6</th>
<th>2.4</th>
<th>2.2</th>
<th>2.0</th>
<th>1.8</th>
<th>1.6</th>
<th>1.4</th>
<th>1.2</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>(K_1)</td>
<td>1.36</td>
<td>1.27</td>
<td>1.18</td>
<td>1.08</td>
<td>0.99</td>
<td>0.90</td>
<td>0.81</td>
<td>0.73</td>
<td>0.65</td>
<td>0.57</td>
<td>0.50</td>
</tr>
</tbody>
</table>

GENERAL NOTE:
Equivalent spherical radius = \(K_1D; D/2h\) = axis ratio. Interpolation is permitted for intermediate values.

NCD-3332.3 Reinforcement for External Pressure.

(a) The reinforcement required for openings in vessels designed for external pressure need only be 50% of that required in the equation for area in NCD-3332.2 except \(t_0\) is the wall thickness required by the rules for components under external pressure.
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(b) The reinforcement required for openings in each shell of a multiple walled vessel shall comply with (a) above when the shell is subject to external pressure and with NCD-3332.2 when the shell is subject to internal pressure.

NCD-3332.4 Reinforcement for Internal and External Pressure.
Reinforcement of vessels subject to both internal and external pressures shall meet the requirements of NCD-3332.2 for internal pressure and of NCD-3332.3 for external pressure.

NCD-3333 Reinforcement Required for Openings in Flat Heads

(a) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the equation

\[ A = 0.5 \pi d t \]

where \( d \) is as defined in NCD-3332.2 and \( t \) is the thickness, which meets the requirements of NCD-3325 in the absence of the opening.

(b) As an alternative to (a) above, the thickness of flat heads may be increased to provide the necessary opening reinforcement as follows:

1. In eq. NCD-3325.2(b)(4), by using 2\( C \) or 0.75 in place of \( C \), whichever is less;
2. In eq. NCD-3325.2(b)(5), by doubling the quantity under the square root sign.

(c) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter or shortest span, as defined in NCD-3325.1, shall be designed as follows.

1. When the opening is a single, circular, centrally located opening and when the shell–head juncture is integrally formed or integrally attached by a full penetration weld similar to those shown in Figure NCD-3325-1 sketches (a), (b-1), (b-2), (d), or (g), the head shall be designed according to Section III Appendices, Mandatory Appendix XIX and related parts of Section III Appendices, Mandatory Appendix XI. The required head thickness does not have to be calculated according to NCD-3325 since the head thickness that satisfies all the requirements of Section III Appendices, Mandatory Appendix XIX also satisfies the intent of NCD-3325. The opening in the head may have a nozzle that is integrally formed or integrally attached by a full penetration weld or it may be an opening without an attached nozzle or hub.

2. When the opening is of any other type than that described in (1) above, no specific rules are given. Consequently, the requirements of NCD-1110(c) shall be met.
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NCD-3334 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening and within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.

NCD-3334.1 Limits of Reinforcement Along the Vessel Wall.

The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following.

(a) One hundred percent of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

1. the diameter of the finished opening in the corroded condition;
2. the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

1. \( r + 0.5\sqrt{Rt} \), where \( R \) is the mean radius of shell or head, \( t \) is the nominal vessel wall thickness, in., \( r \) is the radius of the finished opening in the corroded condition;
2. the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

NCD-3334.2 Limits of Reinforcement Normal to the Vessel Wall.

The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the lesser of (a) or (b) below:

(a) \( 2^{1/2} \) times the nominal shell thickness less corrosion allowance;

(b) \( 2^{1/2} \) times the nozzle wall thickness less corrosion allowance, plus the thickness of any added reinforcement exclusive of weld metal on the side of the shell under consideration.

NCD-3335 Metal Available for Reinforcement

NCD-3335.1 Openings.

Metal within the limits of reinforcement that may be considered to have reinforcing value shall be that given in (a) through (d) below.
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(a) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. The area in the vessel wall available as reinforcement is the larger of the values of $A_1$ given by

$$A_1 = (t_1 - t_2)\phi$$

or

$$A_1 = 2(t_1 - t_2)(t_1 + t_2)$$

(b) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the lesser of the values of $A_2$ given by

$$A_2 = (t_n - t_0)t$$

or

$$A_2 = (t_n - t_0)(t_n + 2\psi)$$

(c) all metal in the nozzle wall extending inside the vessel wall may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening where

$$A_1 = \text{area in excess thickness in the vessel wall available for reinforcement, (NCD-3334)}$$

$$A_2 = \text{area in excess thickness in the nozzle wall available for reinforcement, (NCD-3334)}$$

$$d = \text{diameter in the plane under consideration of the finished opening in its corroded condition (NCD-3332.2)}$$

$$E_1 = 1 \text{ when an opening is in the plate or when the opening passes through a circumferential joint in a shell or cone exclusive of head-to-shell joints; or}$$

$$\text{the joint efficiency obtained from NCD-3352 when any part of the opening passes through any other welded joint, this value is 1 for Class 2 vessels.}$$

$$F = \text{a correction factor that compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations, except that Figure NCD-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.}$$
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\[ t = \text{nominal thickness of the vessel wall, less corrosion allowance} \]
\[ t_r = \text{thickness of attached reinforcing pad or height of the largest 60 deg right triangle} \]
\[ t_n = \text{supported by the vessel and nozzle outside diameter projected surfaces and lying completely within the area of integral reinforcement, [Figure NCD-3335.1(b)-1]} \]
\[ t_o = \text{nominal thickness of nozzle wall, less corrosion allowance} \]
\[ t_r = \text{required thickness of a seamless shell or head as defined in NCD-3332.2} \]
\[ t_n = \text{required thickness of a seamless nozzle wall} \]

(d) metal added as reinforcement and metal in attachment welds.
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Figure NCD-3335.1(b)-1 — Some Representative Configurations Describing the t₀ Reinforcement Dimension

(a) When any two openings in a group of two or more openings are spaced at less than two times their average diameter so that their limits of reinforcement overlap, the two openings shall be reinforced in the plane connecting the centers (Figure NCD-3335.2-1), in accordance with NCD-3330 through NCD-3336, with a combined reinforcement that has an area equal to the combined area of the reinforcements required for separate openings. No portion of the
cross section is to be considered as applying to more than one opening, or to be evaluated more than once in a combined area. The following additional requirements shall also apply:

(1) When the distance between the centers of the openings is greater than $1\frac{1}{3}$ times their average diameter, the area of reinforcement between them shall be not less than 50% of the total required for these openings.

(2) When the distance between the centers of the openings is less than $1\frac{1}{3}$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings, and the openings shall be reinforced as described in (b) below.

Figure NCD-3335.2-1 — Arrangement of Multiple Openings

GENERAL NOTES:
(a) Hatched area represents overlapping of the reinforcement limits.
(b) Each cross-section indicated by a straight line a-a must be investigated for adequacy of reinforcement.
(c) Heavy circles represent openings, and light circles represent limits of reinforcement.

(b) Any number of adjacent openings, in any arrangement, may be reinforced for an assumed opening of a diameter enclosing all such openings. The diameter of the assumed opening shall not exceed the following:
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(1) for vessels 60 in. (1,500 mm) diameter and less, one-half the vessel diameter, but not to exceed 20 in. (500 mm);

(2) for vessels over 60 in. (1,500 mm) diameter, one-third the vessel diameter, but not to exceed 40 in. (1,000 mm).

(c) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in NCD-3361.

(d) When a series of two or more openings in a pressure vessel are arranged in a regular pattern, reinforcement of the openings may be provided in accordance with the requirements of NCD-3329.1.

**NCD-3335.3 Flued Openings in Formed Heads.**

(a) Flued openings in formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in NCD-3332.

(b) The minimum depth of flange of a flued opening exceeding 6 in. (150 mm) in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or $(t_r + 3\text{ in.}) (t_r + 75\text{ mm})$, whichever is less, where $t_r$ is the required head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straight edge to the edge of the flanged opening [Figure NCD-3335.3(b)-1].

(c) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with NCD-3363.7.

![Figure NCD-3335.3(b)-1 — Minimum Depth for Flange of Flued Openings](image-url)
Note to Editors: Markups are based on 2019 Edition of Subsection ND. Changes are shown in red. Cross references to paragraphs within this sub-article shall be updated based on this proposal’s markups.

NCD-3336 Strength of Reinforcement

Material used for reinforcement shall preferably be the same as that of the vessel wall. If the material of the nozzle wall or reinforcement has a lower design stress value \( S \) than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NCD-3332 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement material design stress value to the vessel material design stress value. No reduction in the reinforcing required may be taken for the increased strength of reinforcing material and weld metal having higher design stress values than that of the material of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

NCD-3336.1 Strength of Weld.

On each side of the plane defined in NCD-3334, the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the lesser of (a) or (b) below:

(a) the strength in tension of the cross section of the element of reinforcement being considered;

(b) the strength in tension of the area defined in NCD-3332 less the strength in tension of the reinforcing area that is integral in the vessel wall.

NCD-3336.2 Strength of Attachment.

The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in NCD-3334. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening that passes through the center of the semicircular end of the opening.

NCD-3350 Design of Welded Construction

NCD-3351 Welded Joint Categories

The term Category defines the location of a joint in a vessel but not the type of joint. The categories established are for use in specifying special requirements regarding joint type and degree of examination for certain welded joints. 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
Note to Editors: Markups are based on 2019 Edition of Subsection ND. Changes are shown in red. Cross references to paragraphs within this sub-article shall be updated based on this proposal’s markups 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 NCD-3351-1 illustrates typical joint locations included in each category.

Figure NCD-3351-1 — Welded Joint Locations Typical of Categories A, B, C, and D

NCD-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.

NCD-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.

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

**NCD-3352 Permissible Types of Welded Joints**
The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle $\alpha$ not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure NCD-3352-1 shows typical butt welds for each category joint.
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**NCD-3352.1 Joints of Category A.**

All welded joints of Category A as defined in NCD-3351 shall meet the fabrication requirements of NCD-4241 and shall be capable of being examined in accordance with NCD-5210. For Class 2 vessel design only, the value of $E$ is 1.00. For Class 3 vessel design only, the joint efficiency $E$ shall not exceed that given in (a) through (e) below.

(a) When the butt weld is fully radiographed in accordance with NCD-5211.2(a)(1), $E$ used in the design calculations for determining the thickness of the part shall not exceed 1.00 for Type 1 butt welds and 0.90 for Type 2 butt welds.

(b) When the vessel section or part is spot radiographed in accordance with NCD-5211.2(a)(2), the value of $E$ used in the design calculations for determining the thickness of the part shall not exceed 0.85 for Type 1 butt welds and 0.80 for Type 2 butt welds.

(c) When the vessel section or part is neither fully radiographed nor spot radiographically examined as allowed by NCD-5211.1(a)(3), the value of $E$ used in the design calculations for determining the thickness of the part shall not exceed 0.70 for Type 1; 0.65 for Type 2; 0.60 for Type 3; 0.55 for Type 4; 0.50 for Type 5; and 0.45 for Type 6 welds. In other cases, the allowable stresses used in the design calculations shall not exceed 80% of the listed values in the stress tables. This 80% factor does not apply to allowable stresses for $S_a$, $S_b$, $S_f$, and $S_n$ used in flange design and defined in Section III Appendices, Mandatory Appendix XI, Article XI-3000, XI-3130 or for calculating the thickness of braced and stayed surfaces for eqs. NCD-3329.2(a)(19) and NCD-3329.2(a)(20). The value of $E$ for vessels designed for external pressure only may be taken as 1.00.

(d) For vessels constructed of unalloyed titanium, all weld joints of Category A shall be Type 1 or Type 2.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category A shall be Type 1 or Type 2.

**NCD-3352.2 Joints of Category B.**

All welded joints of Category B as defined in NCD-3351 shall meet the fabrication requirements of NCD-4242 and shall be capable of being examined in accordance with NCD-5220. For Class 2 vessel design only, the value of $E$ is 1.00. For Class 3 vessel design only, the joint efficiency $E$ shall not exceed that given in (a) through (e) below.

(a) When the butt weld is fully radiographed, the design provisions of NCD-3352.1(a) shall apply.

(b) When the butt weld is partially radiographed as allowed by NCD-5221(b) or when the vessel section or part is spot radiographed in accordance with NCD-5221(c), the value of $E$ used in the longitudinal stress calculations shall be as stated in NCD-3352.1(b). When
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seamless vessel sections or heads with Category B butt weld joints are spot radiographed, the allowable stresses used in the design calculations for determining the thickness of the vessel section or part shall not exceed 85% of the values listed in the stress tables. This factor does not apply to allowable stresses for $S_a$, $S_b$, $S_f$, and $S_n$ used in flange design and defined in XI-3130 or for calculating the thickness of braced or stayed surfaces for eqs. NCD-3329.2(a)(19) and NCD-3329.2(a)(20).

(c) When the vessel section or part is neither fully radiographed, partially radiographed, nor spot radiographed, the design provisions of NCD-3352.1(c) apply.

(d) For vessels constructed of unalloyed titanium, all weld joints of Category B shall be Type 1 or Type 2.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category B shall be Type 1 or Type 2.

NCD-3352.3 Joints of Category C.
All welded joints of Category C as defined in NCD-3351 shall meet the fabrication requirements of NCD-4243 and shall be capable of being examined in accordance with NCD-5230. The design for attaching flanged heads shall meet the requirements of NCD-3358. For Class 2 vessel design only, the value of $E$ is 1.00. For Class 3 vessel design only, the design requirements of Category C butt welds are given in (a) through (e) below.

(a) When a Category C butt weld is fully radiographed, the design provisions of NCD-3352.1(a) shall apply.

(b) When a Category C butt weld is spot radiographed, the design provisions of NCD-3352.2(b) shall apply.

(c) When a Category C butt weld is not radiographed, the design provisions of NCD-3352.1(c) shall apply.

(d) When a Category C corner joint is used, the design requirements of NCD-3325 and the dimensional requirements of Figure NCD-4243.2-1, specified in NCD-3358.3, shall be met.

(e) For vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category C shall be Type 1 or Type 2 when the Design Temperature is 1,000°F (540°C) or higher.

NCD-3352.4 Joints of Category D.
For Class 2 vessels only, all welded joints of Category D as defined in NCD-3351 shall be in accordance with the requirements of NCD-3359 and one of (a) through (e) below. For Class 3
vessels only, all welded joints of Category D as defined in NCD-3351 shall be in accordance with the requirements of NCD-3359 and one of (a) through (h) below.

(a) Butt-Welded Attachments. Nozzles shall meet the fabrication requirements of NCD-4244.1(a) (Class 2 vessels) or NCD-4244.2(a) (Class 3 vessels), and shall be capable of being examined in accordance with NCD-5241. The minimum dimensions and geometrical requirements of Figure NCD-4244(a)-1 shall be met, where

\[ r_1 = \frac{1}{4}t \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less} \]
\[ r_2 = \frac{1}{4} \text{ in. (6 mm) minimum} \]
\[ t = \text{nominal thickness of part penetrated} \]
\[ t_o = \text{nominal thickness of penetrating part} \]

(b) Full Penetration Corner-Welded Attachments. Nozzles shall meet the fabrication requirements of NCD-4244.1(b) (Class 2 vessels) or NCD-4244.2(b) (Class 3 vessels), and shall be capable of being examined as required in NCD-5241. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of \( \frac{1}{2}t_{\text{min}} \). The minimum dimensions of Figure NCD-4244(b)-1 shall be met, where

\[ r_1 = \frac{1}{4}t \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less} \]
\[ r_2 = \frac{3}{4} \text{ in. (6 mm) minimum} \]
\[ t = \text{nominal thickness of part penetrated} \]
\[ t_r = 0.7t_o \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \]
\[ t_o = \text{thickness of reinforcing element} \]
\[ t_{\text{min}} = \text{the lesser of } \frac{3}{4} \text{ in. (19 mm) or the thickness of the thinner of the parts joined} \]
\[ t_u = \text{nominal thickness of penetrating part} \]

(c) Use of Deposited Weld Metal for Openings and Attachments

(1) Nozzles shall meet the requirements of NCD-4244.1(c) (Class 2 vessels) or NCD-4244.2(c) (Class 3 vessels), and shall be capable of being examined in accordance with NCD-5241.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Figure NCD-4244(c)-1 shall be met, where
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\[ r_1 = \frac{1}{4}t \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less} \]

\[ t = \text{nominal thickness of part penetrated} \]

\[ t_e = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \]

\[ t_n = \text{nominal thickness of penetrating part} \]

(4) The corners of the end of each nozzle extending less than \( \sqrt{\frac{2t}{c}} \) beyond the inner surface of the part penetrated shall be rounded to a radius of one-half the thickness \( t_n \) of the nozzle or \( \frac{3}{4} \text{ in. (19 mm), whichever is less.} \)

(d) Attachment of Nozzles Using Partial Penetration Welds

(1) Partial penetration welds shall meet the requirements of NCD-4244.1(d) (Class 2 vessels) or NCD-4244.2(d) (Class 3 vessels). Typical details are shown in Figure NCD-4244(d)-1. For inserted nozzles without reinforcing elements, two partial penetration welds or a combination of fillet, single bevel, and single J-welds may be used. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of \( \frac{1}{2}t_{min} \). The welds attaching the nozzles to the vessel wall and to the reinforcement shall consist of one of the combinations given in (-a) through (-c) below.

(-a) A single bevel or single J-weld in the shell plate and a single bevel or single J-weld in each reinforcement plate. The dimension \( t_n \) of each weld shall be not less than 0.7\( t_{min} \) [Figure NCD-4244(d)-1].

(-b) A full penetration groove weld in the shell plate and a fillet, single bevel, or single J-weld with a weld dimension \( t_n \) not less than 0.7\( t_{min} \) in each reinforcement plate [Figure NCD-4244(d)-1, sketch (f)].

(-c) A full penetration groove weld in each reinforcement plate and a fillet, single bevel, or single J-weld with a weld dimension \( t_n \) not less than 0.7\( t_{min} \) in the shell plate [Figure NCD-4244(d)-1, sketch (e)]. These welds shall be capable of being examined in accordance with the requirements of NCD-5241.

(2) The minimum dimensions of Figure NCD-4244(d)-1 shall be met, where

\[ c = \frac{1}{2}t_{min} \]

\[ t = \text{nominal thickness of part penetrated} \]
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\[
t_1 \text{ or } t_2 = \text{ not less than the lesser of } \frac{1}{4} \text{ in. (6 mm)} \text{ or } 0.7t_{\text{min}}
\]

\[
t_1 + t_2 = 1\frac{1}{4}t_{\text{min}}
\]

\[
t_e = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm)}, \text{ whichever is less}
\]

\[
t_e = \text{ thickness of reinforcement element}
\]

\[
t_{\text{min}} = \text{ the lesser of } \frac{3}{8} \text{ in. (19 mm)} \text{ or the thickness of the thinner of the parts joined}
\]

\[
t_n = \text{ nominal thickness of penetrating part}
\]

\[
t_w = 0.7t_n, \text{ except } t_w = 0.7t_{\text{min}} \text{ for sketch (e)}
\]

(e) Attachment of Fittings With Internal Threads. (Written for fittings with internal threads but also applicable to externally threaded and socket-welded or butt-welded fittings.) The attachment of internally threaded fittings shall meet the requirements of (1) through (3) below.

(1) Except as provided for in (2) and (3) below, the provisions of NCD-4244.1(e) (Class 2 vessels) or NCD-4244.2(e) (Class 3 vessels) shall be met. The minimum weld dimensions shall be as shown in Figure NCD-4244(e)-1 where

\[
t_{\text{min}} = \text{ lesser of } \frac{3}{8} \text{ in. (19 mm)} \text{ or the thickness of the parts joined}
\]

\[
t_e = \frac{1}{4} \text{ in. (6 mm), minimum}
\]

<table>
<thead>
<tr>
<th>sketches (a) and (b)</th>
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<td>( t_1 + t_2 = 1\frac{1}{4}t_{\text{min}} )</td>
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<td>( t_w = \text{ thickness of Sch. 160 pipe (ASME-B36.10M)} )</td>
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<td>( t_1 + t_2 = \text{ not less than the lesser of } \frac{1}{4} \text{ in. (6 mm)} \text{ or } 0.7t_{\text{min}} )</td>
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<tbody>
<tr>
<td>( t_w = 0.7t_{\text{min}} )</td>
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</table>

(2) Fittings shown in Figure NCD-4244(e)-1 sketches (a-2), (b-2), (c-2), and (d) not exceeding NPS 3 may be attached by welds that are exempt from size requirements other than those specified in NCD-3359.

(3) See below.

(-a) When internally threaded fittings and bolting pads not exceeding NPS 3 (DN 80) are attached to vessels having a wall thickness not greater than \( \frac{3}{8} \text{ in. (10 mm)} \) by a fillet weld deposited from the outside only, the welds shall
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comply with the dimensions shown in Figure NCD-4244(e)-2. These openings do not require reinforcement other than that inherent in the construction as permitted in NCD-3332.1.

(-b) If the opening exceeds 5\(\frac{1}{8}\) in. (135 mm) in any direction or is greater than one-half the vessel diameter, the part of the vessel affected shall be subjected to a proof test as required in NCD-6900 or the opening shall be reinforced in accordance with NCD-3332 with the nozzle or other connections attached, using a suitable detail in Figure NCD-4244(e)-1.

(f) Attachment of Tubed Connections for Class 3 Vessels. Nozzles or tubes recessed into thick walled vessels or headers, welded from only one side, shall have a welding groove in the vessel wall not deeper than \(t_c\) on the longitudinal axis of the opening. A recess \(\frac{1}{16}\) in. (1.5 mm) deep shall be provided at the bottom of the groove in which to center the nozzle. The dimension \(t_w\) of the attachment weld shall not be less than \(t_n\) nor less than \(\frac{1}{4}\) in. (6 mm). The minimum dimension for \(t_c\) shall be \(\frac{1}{4}\) in. (6 mm) [Figure NCD-4244(f)-1, sketches (a) and (b)].

(g) Nozzles With Integral Reinforcing for Class 3 Vessels. Nozzles and other connections having integral reinforcement in the form of extended nozzles or saddle type pads shall have the throat dimension of the outer weld not less than \(\frac{1}{2}t_{min}\) [Figure NCD-4244(g)-1]. The dimension \(t_n\) of the inner weld shall be not less than \(0.7t_{min}\) where

\[
\begin{align*}
    c & = \frac{1}{2}t_{min} \\
    t & = \text{nominal thickness of shell} \\
    t_c & = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \\
    t_v & = \text{thickness of reinforcement element} \\
    t_{min} & = \text{lesser of } \frac{3}{4} \text{ in. (19 mm) or the thickness of the thinner of the parts joined} \\
    t_n & = \text{nominal thickness of neck} \\
    t_w & = 0.7t_{min}
\end{align*}
\]

(h) For Class 3 vessels constructed of SB-443, SB-444, and SB-446, all weld joints of Category D shall be Type 1 or Type 2 when the Design Temperature is 1,000°F (540°C) or higher.

**NCD-3354 Structural Attachment Welds**

Welds for structural attachments shall meet the requirements of NCD-4430.
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NCD-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in NCD-3352.4

NCD-3356 Fillet Welds, Lap Joints, and Plug Welds

NCD-3356.1 Fillet Welds.

(a) Fillet welds may be used as strength welds within the limitations given in NCD-3352 and Figure NCD-4427-1. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for lugs or clips.

(c) The allowable load on fillet welds shall equal the product of the weld area based on minimum leg dimensions, the allowable stress value in tension of the material being welded, and a joint efficiency of 0.55.

NCD-3356.2 Lap Joints for Class 3 Vessels.

For lap joints, the surface overlap shall be not less than four times the thickness of the inner plate except as otherwise provided for heads in NCD-3358 and for tanks in NCD-4246.

NCD-3356.3 Plug Welds for Class 3 Vessels.

(a) Plug welds may be used in lap joints, in reinforcements around openings, and in structural attachments. Plug welds shall be properly spaced to carry no more than 30% of the total load to be transmitted.

(b) Plug weld holes shall have a diameter not less than \( t + \frac{1}{4} \) in. (6 mm) and not more than \( 2t + \frac{1}{4} \) in. (6 mm), where \( t \) is the thickness in inches of the plate or attached part in which the hole is made.

(c) Plug weld holes shall be completely filled with weld metal when the thickness of the plate or attached part in which the weld is made is \( \frac{5}{16} \) in. (8 mm) or less; for thicker plates or attached parts, the holes shall be filled to a depth of at least half the plate thickness or \( \frac{5}{16} \) of the hole diameter, whichever is larger, but in no case less than \( \frac{5}{16} \) in. (8 mm).
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(d) The allowable load on a plug weld in either shear or tension shall be computed by the following equation:

(U.S. Customary Units)

\[ P = 0.63S(d - 1/4)^2 \]

(SI Units)

\[ P = 0.63S(d - 6)^2 \]

where

\( d \) = the bottom diameter of the hole in which the weld is made, in. (mm)

\( P \) = total allowable load on the plug weld

\( S \) = maximum allowable stress (Section II, Part D, Subpart 1, Tables 1A and 1B)

NCD-3357 Welded Joints Subject to Bending Stresses

Except where specific details are permitted in other paragraphs, fillet welds shall be added where necessary to reduce stress concentration. The requirements of NCD-3356(b) apply. For Class 3 vessels, corner joints, with fillet welds only, shall not be used unless the plates forming the corner are properly supported independently of such welds [NCD-3356.1(b)].

NCD-3358 Design Requirements for Head Attachments

NCD-3358.1 Skirt Length of Formed Heads.

(a) Ellipsoidal and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Figure NCD-3358.1(a)-1. Heads that are fitted inside or over a shell shall have a driving fit before welding.

(b) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Figure NCD-3358.1(a)-1 shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than \( \frac{1}{8} \) in. (3 mm), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt-welded attachment [Figure NCD-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.
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**Figure NCD-3358.1(a)-1 — Heads Attached to Shells**

**NOTES:**

1. Length of required taper \( \ell \) may include the width of the weld.
2. In all cases, the projected length of taper \( \ell \) shall be not less than \( 3y \).
3. The shell plate center line may be on either side of the head plate center line.
4. In all cases, \( \ell \) shall be not less than 3 times \( y \) when \( t_b \) exceeds 1.25 \( t_s \); minimum length of skirt is 3\( t_b \), but need not exceed 11/2 in. (38 mm) except when necessary to provide required length of taper.
5. When \( t_b \) is equal to or less than 1.25\( t_s \), length of skirt shall be sufficient for any required taper.
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**NCD-3358.2 Unstayed Flat Heads Welded to Shells.**
The requirements for the attachment of unstayed flat heads welded to shells are given in NCD-3325, NCD-3358.3, and NCD-3358.4.

**NCD-3358.3 Head Attachments Using Corner Joints.**
When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Figure NCD-4243-1, the joint shall meet the requirements of (a) through (i) below.

(a) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b, respectively.

(b) For flange rings of bolted flanged connections and for flat heads and unsupported tube sheets with a projection having holes for a bolted connection, the sum of a and b shall not be less than three times the nominal wall thickness of the abutting pressure part.

(c) For supported tube sheets with a projection having holes for a bolted connection, the sum of a and b shall not be less than two times the nominal wall thickness of the abutting pressure part. A supported tubesheet is defined as one in which not less than 80% of the pressure load on the tubesheet is carried by tubes, stays, or braces.

(d) For other components, the sum of a and b shall be not less than two times the nominal wall thickness of the abutting pressure part. Examples of such components are flat heads and supported and unsupported tubesheets without a projection having holes for a bolted connection and the side plates of a rectangular vessel.

(e) For Class 2 vessels, other dimensions of the joint shall be in accordance with details shown in Figures NCD-4243.1-1 and NCD-4243.1-2 where:

(1) *Figure NCD-4243.1-1*

    Sketches (a), (b), and (c)

    (a) for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

    \[ t, t_a = \text{nominal thickness of welded parts} \]
    \[ t_c = 0.7t_a \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \]
    \[ t_w = \text{the lesser of } t_a/2 \text{ or } t/4 \]
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(-b) for all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

\[ t_n = \text{nominal thicknesses of welded parts} \]
\[ t_c = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \]
\[ t_w = \text{the lesser of } t_n \text{ or } t'/2 \]

Sketch (d)

\[ t, t_n = \text{nominal thickness of welded parts, in., either leg of fillet weld = } 0.25 t_n \]

but not less than \( \frac{1}{4} \) in. (6 mm)

Sketches (e) and (f)

\[ t, t_n = \text{nominal thickness of welded parts} \]
\[ t_c = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \]

(2) Figure NCD-4243.1-2

Sketch (a)

\[ a + b \text{ not less than } 2t_s, t_w \text{ not less than } t_s \]

Sketch (b)

\[ a + b \text{ not less than } 2t_s \]

Sketch (c)

\[ t_s = \text{actual thickness of shell} \]
\[ t_r = \text{required thickness of shell} \]

for supported tubesheets:
\[ c \text{ not less than } 0.7t_r \text{ or } 1.4t_r, \text{ whichever is less } a + b \text{ not less than } 2t_s \]

for flange rings, flat heads, and unsupported tubesheets:
\[ c \text{ not less than } t_s \text{ or } 2t_s, \text{ whichever is less } a + b \text{ not less than } 3t_s \]

Sketch (d)

\[ t_s = \text{actual thickness of shell} \]
\[ t_r = \text{required thickness of shell} \]
\[ a + b \text{ not less than } 3t_s \]
\[ c \text{ not less than } t_s \]

(f) For Class 2 vessels, in Figure NCD-4243.1-1,
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\[ t_n, t_n = \text{nominal thicknesses} \]
\[ t_c = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \]
\[ t_w = \text{the lesser of } t_n \text{ or } t/2 \]

(g) For Class 3 vessels, other dimensions at the joint shall be in accordance with details as shown in Figure NCD-4243.2-1

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<td>( a + b ) not less than ( 2t_s ), ( b = 0 )</td>
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<tr>
<td>( t_r ) not less than ( t_s )</td>
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<tr>
<td>( t_s = \text{actual thickness of shell} )</td>
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<tr>
<td>( t_r ) not less than ( t_s )</td>
</tr>
<tr>
<td>( t_f ) not less than ( t_s )</td>
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<tr>
<td>( t_s = \text{actual thickness of shell} )</td>
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<td>( a + b ) not less than ( 2t_s )</td>
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<tr>
<td>( a ) not less than ( t_s )</td>
</tr>
<tr>
<td>( t_f ) not less than ( t_s )</td>
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<td>( t_s = \text{actual thickness of shell} )</td>
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<td>( t_f ) not less than ( t_s )</td>
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<tr>
<td>( a_1 + a_2 = a )</td>
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<td>( t_s = \text{actual thickness of shell} )</td>
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Note to Editors: Markups are based on 2019 Edition of Subsection ND. Changes are shown in red. Cross references to paragraphs within this sub-article shall be updated based on this proposal’s markups.

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<tr>
<td>( c = 0.7t_s )</td>
<td></td>
</tr>
<tr>
<td>( t_w = 2t_s ) but not less than ( 1.25t_s )</td>
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<tr>
<td>( t_w ) need not be greater than ( t )</td>
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<tr>
<td>( t_s ) = actual thickness of shell</td>
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<tr>
<th>sketches (k) through (o)</th>
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</table>
| For supported tubesheets:
| \( a + b \) not less than \( 2t_s \) |
| \( c \) not less than \( 0.7t_s \) or \( 1.4t_s \), whichever is less |
| \( a_1 \) not less than \( 0.5a_2 \) |
| \( t_s \) = actual thickness of shell |
| For flange rings, flat heads, and unsupported tubesheets:
| \( a + b \) not less than \( 3t_s \) |
| \( c \) not less than \( t_s \) or \( 2t_s \), whichever is less |
| \( a_1 \) not less than \( 0.5a_2 \) |
| \( t_s \) = actual thickness of shell |

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<tr>
<td>( c ) not less than ( t_n ) or ( t_D ), whichever is less ( (t_n ) and ( t_D ) are defined in Section III Appendices, Mandatory Appendix XI, XI-3130)</td>
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<td>( c ) not less than ( t_n ) or ( t_D ), whichever is less ( (t_n ) and ( t_D ) are defined in Section III Appendices, Mandatory Appendix XI, XI-3130)</td>
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</table>

(h) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part, or that provide eccentric attachment, are not permissible [Figure NCD-4243-1 sketches (r), (s), and (t)].

NCD-3358.4 Flat Heads and Tubesheets With Hubs.

Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Figure NCD-4243.3-1, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize if necessary) taken in this direction and as close to the hub as is practical.

In Figure NCD-4243.3-1, the minimum dimensions are as follows:

| sketch (a) |  |
NCD-3358.5 Heads Concave to Pressure for Class 3 Vessels.

Heads concave to pressure may be attached to shells using a butt weld with one plate offset as shown in Figure NCD-4245-1 sketch (k). The offset shall be smooth and symmetrical, and shall not be machined or otherwise reduced in thickness. There shall be a uniform force fit with the mating section at the root of the weld.

NCD-3358.6 Intermediate Heads for Class 3 Vessels.

(a) Intermediate heads of the type shown in Figure NCD-4245-1 sketch (f), without limit to thickness, may be used for all types of vessels provided that the outside diameter of the head skirt is a close fit inside the overlapping ends of the adjacent length of cylinder.

(b) The butt weld and fillet weld shall be designed to take shear based on 1.5 times the maximum differential pressure that can exist. The allowable stress value for the butt weld shall be 70% of the stress value for the vessel material, and the allowable value for the fillet weld shall be 55% of the stress value for the vessel material. The area of the fillet weld is the minimum leg dimension times the length of the weld. The area of the butt weld in shear is the smaller of the width at the root of the weld or the thickness of the vessel shell to which it is attached times the length of the weld.

(c) This construction may also be used for end closures when the thickness of the shell section of the vessel does not exceed $\frac{5}{8}$ in. (16 mm).
NCD-3359 Design Requirements for Nozzle Attachment Welds

In addition to the requirements of NCD-3352.4, the minimum design requirements for nozzle attachment welds are given in (a) and (b) below.

(a) Required Weld Strength. Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as required in NCD-3336, through shear or tension in the weld, whichever is applicable. The strength of groove welds shall be based on the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear, computed on the minimum leg dimension. The inside diameter of a fillet weld shall be used in figuring its length. Calculations are not required when full penetration welds are used.

(b) Allowable Stress Values for Welds. The allowable stress values for groove and fillet welds and for shear in nozzles, in percentage of stress values for the vessel material, are as follows:

1. Nozzle wall shear, 70%
2. Groove weld tension, 74%
3. Groove weld shear, 60%
4. Fillet weld shear, 49%

NCD-3360 Special Vessel Requirements

NCD-3361 Tapered Transitions, Threaded Connections, and Staggered Welds

NCD-3361.1 Tapered Transitions.

A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections (Figure NCD-3361.1-1) shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than 1/8 in. (3 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be in the tapered section or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential butt-welded joints connecting formed heads to main shells are contained in NCD-3358.1(b).
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Figure NCD-3361.1-1 — Butt Welding of Plates of Unequal Thicknesses

GENERAL NOTES:
(a) In all cases $\ell$ shall be not less than $3y$.
(b) $\ell \geq 3y$, where $\ell$ is required length of taper and $y$ is the offset between the adjacent surfaces of abutting sections.
(c) Length of required taper $\ell$ may include the width of the weld.

NCD-3361.2 Threaded Connections for Class 2 Vessels
Threaded connections shall be in accordance with NCD-3266.

NCD-3361.3 Threaded Connections for Class 3 Vessels.

(a) Pipes, tubes, and other threaded connections that conform to ANSI/ASME B1.20.1, Pipe Threads, General Purpose, may be screwed into a threaded hole in a vessel wall provided the pipe engages the minimum number of threads specified in Table NCD-3361.2(a)-1 after allowance has been made for curvature of the vessel wall. A built-up pad or a properly attached plate or fitting may be used to provide the metal thickness and number of threads required in Table NCD-3361.2(a)-1, or to furnish reinforcement when required.

(b) Threaded connections larger than NPS 3 (DN 80) shall not be used when the maximum allowable pressure exceeds 125 psi (860 kPa), except that this NPS 3 (DN 80) restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes.
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<table>
<thead>
<tr>
<th>Size of Pipe Connections, in. (DN)</th>
<th>Threads Engaged</th>
<th>Min. Plate Thickness Required, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\frac{1}{2}, \frac{3}{4}(15, 20))</td>
<td>6</td>
<td>0.43 (11)</td>
</tr>
<tr>
<td>1, 1(\frac{1}{4}, 1\frac{1}{2}(25, 32, 40))</td>
<td>7</td>
<td>0.61 (16)</td>
</tr>
<tr>
<td>2 (50)</td>
<td>8</td>
<td>0.70 (18)</td>
</tr>
<tr>
<td>2(\frac{1}{2}, 3(65, 80))</td>
<td>8</td>
<td>1.0 (25)</td>
</tr>
<tr>
<td>4–6 (100–150)</td>
<td>10</td>
<td>1.25 (32)</td>
</tr>
<tr>
<td>8 (200)</td>
<td>12</td>
<td>1.5 (38)</td>
</tr>
<tr>
<td>10 (250)</td>
<td>13</td>
<td>1.62 (41)</td>
</tr>
<tr>
<td>12 (300)</td>
<td>14</td>
<td>1.75 (45)</td>
</tr>
</tbody>
</table>

NCD-3361.4 Staggered Welds for Class 3 Vessels.

Except when radiographed 4 in. (100 mm) each side of each welded intersection, vessels made up of two or more courses shall have the centers of the welded longitudinal joints of adjacent courses staggered or separated by a distance of at least five times the thickness of the thicker plate.

NCD-3362 Bolted Flange and Studded Connections

(a) It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ASME Standard B16.5, Pipe Flanges and Flanged Fittings; ANSI B16.24, Cast Copper Alloy Pipe Flanges and Flanged Fittings; or to ASME B16.47, Large Diameter Steel Flanges. Such flanges and flanged fittings may be used for the pressure–temperature ratings given in the appropriate standard. Flanges and flanged fittings to other standards are acceptable provided they have been designed in accordance with the rules of Section III Appendices, Mandatory Appendix XI for the vessel design loadings and are used within the pressure–temperature ratings so determined.

(b) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of \(d_t\) or

\[
0.75d_t \times \frac{\text{maximum allowable stress value of stud material at Design Temperature}}{\text{maximum allowable stress value of tapped material at Design Temperature}}
\]
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in which $d_s$ is the diameter of the stud. The thread engagement need not exceed $1\frac{1}{2}d_s$.

### NCD-3363 Access or Inspection Openings

All dimensions given are nominal.

#### NCD-3363.1 General Requirements.

(a) All vessels for use with compressed air, except as otherwise permitted, and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion (NCD-3121), shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

(b) Vessels over 12 in. (300 mm) inside diameter under air pressure which also contain other substances that will prevent corrosion need not have openings for inspection only, providing the vessel contains suitable openings through which inspection can be made conveniently and providing such openings are equivalent in size and number to the requirements for inspection openings in NCD-3363.3.

(c) Compressed air is not intended to include air which has had moisture removed to the degree that it has an atmospheric dew point of $-50^\circ F \ (-45^\circ C)$ or less. The Certificate Holder’s Data Report shall include a statement for “noncorrosive service” when inspection openings are not provided.

(d) When provided with telltale holes complying with the provisions of (e) below, inspection openings as required in NCD-3363 may be omitted in vessels subject only to corrosion. This provision does not apply to vessels for compressed air.

(e) Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. When telltale holes are provided they shall be at least $\frac{3}{16}$ in. (5 mm) in diameter and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the surface opposite to that where deterioration is expected.

#### NCD-3363.2 Requirements for Vessels 12 in. (300 mm) Inside Diameter and Smaller.

For vessels 12 in. (300 mm) or less inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS $\frac{3}{4}$ (DN 20).

#### NCD-3363.3 Requirements for Vessels Over 12 in. (300 mm), but Not Over 16 in. (400 mm) Inside Diameter.

Vessels over 12 in. (300 mm), but not over 16 in. (400 mm) inside diameter, that are to be installed so that they may be disconnected from an assembly to permit inspection, need not be
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provided with openings for inspection only, if there are at least two removable pipe connections not less than NPS $\frac{1}{4}$ (DN 40).

**NCD-3363.4 Equipment of Vessels Requiring Access or Inspection Openings.**

Vessels that require access or inspection openings shall be equipped as required in (a) through (f) below.

(a) All vessels less than 18 in. (450 mm) and over 12 in. (300 mm) inside diameter shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS $\frac{1}{4}$ (DN 40).

(b) All vessels 18 in. to 36 in. (450 mm to 900 mm), inclusive, inside diameter shall have a manhole or at least two handholes or two threaded pipe plug inspection openings of not less than NPS 2 (DN 50).

(c) All vessels over 36 in. (900 mm) inside diameter shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 4 in. × 6 in. (100 mm × 150 mm) or two equal openings of equivalent areas.

(d) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head.

(e) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings provided they are equal at least to the size of the required inspection openings.

(f) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings provided it is of such size and location as to afford at least an equal view of the interior.

**NCD-3363.5 Size and Type of Access and Inspection Openings.**

When inspection or access openings are required, they shall comply at least with the requirements of (a) and (b) below.

(a) An elliptical or obround manhole shall be not less than 11 in. × 15 in. (275 mm × 375 mm) or 10 in. × 16 in. (250 mm × 400 mm). A circular manhole shall be not less than 15 in. (375 mm) inside diameter.

(b) A handhole opening shall be not less than 2 in. × 3 in. (50 mm × 75 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.
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**NCD-3363.6 Design of Access and Inspection Openings in Shells and Heads.**
All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules for openings.

**NCD-3363.7 Minimum Gasket Bearing Width for Manhole Cover Plates.**
Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of $\frac{11}{16}$ in. (17 mm).

**NCD-3363.8 Threaded Openings.**
When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed for that material. The thread shall be a standard taper pipe thread, except that a straight thread of equal strength may be used if other sealing means to prevent leakage are provided.

**NCD-3364 Attachments**
Attachments used to transmit support loads shall meet the requirements of NCD-3135.

**NCD-3365 Supports**
All vessels shall be so supported and the supporting members shall be arranged or attached to the vessel wall in such a way as to withstand the maximum imposed loadings (NCD-3111 and Subsection NF).

**NCD-3366 Bellows Expansion Joints**
Expansion joints of the bellows type may be used to provide flexibility for vessels. Expansion joints in piping portions of vessels shall meet the requirements of NCD-3649. The design, material, fabrication, examination, and testing of expansion joints which are constructed as a part or appurtenance of a vessel shall conform with the requirements of (a) through (i) below.

(a) Bellows may be used to absorb axial movement, lateral deflection, angular rotation, or any combination of these movements. They are not normally designed for absorbing torsion. The layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by either or both pressure or the bellows spring force shall be resisted by rigid anchors, cross connections of the expansion joint ends, or other means.
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(c) The expansion joint shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length or offset to accommodate connecting parts that are not properly aligned unless such movements have been specified by the system designer or can be justified by the expansion joint manufacturer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Internal sleeves shall be provided for expansion joints over 6 in. (150 mm) in diameter when flow velocities exceed the following values:

   (1) air, steam, and other gases — 25 ft/sec (7.6 m/s);

   (2) water and other liquids — 10 ft/sec (3.0 m/s).

(g) Pressure-retaining material in the expansion joint shall comply with the requirements of Article NCD-2000.

(h) All welded joints shall comply with the requirements of NCD-4400.

(i) Design of bellows-type expansion joints shall comply with the requirements of NCD-3649.4.
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ENDNOTES

7 Stress means the maximum normal stress.

8 Class 3 vessels only. The rules governing openings as given in this Subsection are based on the stress intensification created by the existence of a hole in an otherwise symmetrical section. They are based on experience with vessels designed with design factors of 4 and 5 applied to the ultimate strength of the shell material. External loadings such as those due to the thermal expansion or unsupported weight of connecting piping have not been evaluated. These factors should be given attention in unusual designs or under conditions of cyclic loading.

9 The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.

10 An obround opening is one that is formed by two parallel sides and semicircular ends.

11 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.

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