Notes to Editor:

1. This content is taken from the current NC-3200 in the 2019 Edition.

2. Replace all occurrences of "NC-" with "NCD-". This applies for the entire Subarticle, including all text, figures, and tables.

3. Cross check all references to Articles 1000, 2000, 3000, 4000, 5000, 6000, and 7000 to confirm that the paragraph number was not changed in another record.

(f) The rules of this Subarticle do not apply to Class 3 vessels except under the provisions of NCA-2134(b).
(c) For configurations where compressive stresses occur, the critical buckling stress shall be taken into account. For the special case of external pressure, the rules of NC-3133 shall be met.

NC-3211.3 Materials in Combination.

(a) A vessel may be designed for and constructed of any combination of materials permitted in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

(b) A stress analysis of a vessel region shall be made in accordance with Section III Appendices, Mandatory Appendix XIII unless all of the provisions of (c) or (d) below apply. This does not obviate the need for such analysis where required by other provisions of this subarticle.

(c) See below.

(1) The junction is a girth seam between pressure parts.

(2) Any taper required because of different thickness shall be in the material having the higher design stress intensity, or in weld deposit appropriate for the stronger material.

(3) No discontinuity is involved except that due to thickness and modulus of elasticity difference.

(4) \( S_{m2} \leq 1.2 \ S_{m1} \ \left( \frac{E_2}{E_1} \right) \) where subscripts 1 and 2 denote the material having the lower and higher design stress intensity value, respectively, and \( S_m \) and \( E \) are as defined in NC-3216 and NC-3219, respectively.

(d) See below.

(1) The junction is at a seam between pressure parts other than a girth seam covered by (c) above.

(2) Any taper required because of different thickness is in material having the higher design stress intensity or in weld deposit appropriate for the stronger material.

(3) \( S_{m2} \leq 1.1 \ S_{m1} \ \left( \frac{E_2}{E_1} \right) \) where subscripts and symbols are as given in (c)(4) above.

NC-3211.4 Combination Units. When a vessel unit consists of more than one independent chamber, operating at the same or different pressures and temperatures, each chamber or vessel shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected. Chambers which come within the scope of this subarticle may be connected to chambers constructed to the rules of NC-3300, provided the connection between such chambers meets all of the requirements of this subarticle.

NC-3211.5 Minimum Thickness of Shell or Head. The thickness after forming and without allowance for corrosion of any shell or head subject to pressure shall be not less than \( \frac{1}{8} \) in. (6 mm) for carbon and low alloy steels or \( \frac{1}{8} \) in. (3 mm) for stainless steel.

NC-3211.6 Selection of Material Thickness. The selected thickness of material shall be such that the forming, heat treatment, and other fabrication processes will not reduce the thickness of the material at any point below the minimum value required by these rules.

NC-3212 Loadings

The requirements of NC-3111 shall apply.

NC-3214 Cladding

The design calculations shall be based on a thickness equal to the nominal thickness of the base plate plus \( S_c/S_b \) times the nominal thickness of the cladding, less any allowance provided for corrosion, provided the conditions of (a), (b), and (c) below are met.

(a) The clad product conforms to one of the clad plate products referenced in NC-2121 or is overlay weld clad.

(b) The joints are completed by depositing corrosion resisting weld metal over the weld in the base material to restore the cladding.

(c) The \( S_m \) value of the weaker material is at least 70% of the \( S_m \) value of the stronger. Where

\[
S_b = \text{design stress intensity value for the base material at the Design Temperature, psi}
\]

\[
S_c = \text{design stress intensity value for the cladding or, for the weld overlay, that of the wrought material whose chemistry most closely approximates that of the cladding, at the Design Temperature, psi}
\]

the design stress intensity value shall be that given for base material in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. When \( S_c \) is greater than \( S_b \), the multiplier \( S_c/S_b \) shall be taken equal to unity.

NC-3215 Design Basis

NC-3215.1 Pressure and Temperature Relationships.

(a) Table NC-3215.1(a)-1 sets forth the pressure, temperature, and static head relationships which shall be considered by the designer.

(b) The design for a vessel part is usually controlled by coincident pressure and temperature at a point. The design shall take into account the maximum difference in fluid pressure, which exists under the specified service conditions, between the inside and outside of the vessel at any point or between two chambers of a combination unit. The design thickness for pressure shall not include any metal added as corrosion or erosion allowance or any metal required for any combination of loadings listed in NC-3218 which are likely to occur coincident with the service pressure and temperature.

NC-3215.2 Definitions.

(a) Design Pressure. The provisions of NC-3112.1 shall apply.

(b) Design Temperature. The provisions of NC-3112.2 shall apply.
Table NC-3215.1(a)-1
Pressure and Temperature Relationships

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pressure at Top of Vessel</th>
<th>Pressure Due to Static Head [Note (1)]</th>
<th>Temperature</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For vessel as a whole</td>
<td>Design Pressure</td>
<td>None</td>
<td>Coincident metal</td>
<td>Pressure and temperature to be stamped on nameplate</td>
</tr>
<tr>
<td>At any point</td>
<td>Coincident pressure</td>
<td>Pressure to point under consideration due to static head of vessel contents</td>
<td>Design coincident temperature</td>
<td>Temperature at various points may vary, in which case the maximum for these conditions shall be used for the vessel as a whole or coincident conditions for specific locations shall be listed on the Certificate Holder's Data Report and Stamping</td>
</tr>
<tr>
<td>Condition 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At any point</td>
<td>Coincident pressure</td>
<td>Coincident pressure to point under consideration due to static head</td>
<td>Design Temperature</td>
<td>Higher temperature and lower pressure combinations (than Condition 1) shall be checked or a part may be designed for the Maximum Design Pressure and the Design Temperature</td>
</tr>
<tr>
<td>Condition 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For vessel as a whole</td>
<td>Test pressure</td>
<td>None</td>
<td>Test temperature</td>
<td>...</td>
</tr>
<tr>
<td>At any point</td>
<td>Test pressure</td>
<td>Pressure at point under consideration due to static head</td>
<td>Test Temperature</td>
<td>...</td>
</tr>
<tr>
<td>Condition 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For vessel as a whole or any part</td>
<td>Coincident pressure</td>
<td>...</td>
<td>Minimum permissible temperature</td>
<td>Minimum permissible temperature is used together with impact testing to determine suitability of material at service temperature</td>
</tr>
<tr>
<td>Safety value setting</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>Usually set above the service pressure but not over the limits set in Article NC-7000</td>
</tr>
</tbody>
</table>

NOTE: (1) Similar applications shall be made for other sources of pressure variation such as that resulting from flow.

(c) Service Conditions. The provisions of NC-3113 shall apply.

(d) Test Pressure. The test pressure is the pressure to be applied at the top of the vessel during the test. This pressure plus any pressure due to static head at any point under consideration is used in the applicable equation to check the vessel under test conditions.

(e) Safety Valve Setting. The pressure for which the safety or safety relief valves are set to open is established by Article NC-7000.

NC-3216 Design Stress Intensity Values

NC-3216.1 Stress Tables. The design stress intensity values $S_m$ are given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. Values for intermediate temperatures may be found by interpolation. These $S_m$ values form the basis for the various stress limits which are described in Section III Appendices, Mandatory Appendix XIII and are used in determining the membrane stress intensity limits for the various load combinations given in Table NC-3217-1.

NC-3216.2 Coefficients of Thermal Expansion and Moduli of Elasticity. Values of the coefficients of thermal expansion are in Section II, Part D, Subpart 2, Tables TE, and values of the moduli of elasticity are in Section II, Part D, Subpart 2, Tables TM.

NC-3216.3 Special Stress Limits. The deviations given in (a), (b), and (c) below from the basic stress limits are provided to cover special conditions or configurations.

(a) Bearing Loads

(1) The average bearing stress for resistance to crushing under the maximum design load shall be limited to the yield strength $S_y$ at temperature except that, when the distance to a free edge is greater than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.
(2) When bearing loads are applied on parts having free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. The average shear stress shall be limited to $0.6S_m$ in the case of design load stress [Section III Appendices, Mandatory Appendix XIII, XIII-1300(m)] and to $0.5S_y$ in the case of design load stress plus secondary stress [Section III Appendices, Mandatory Appendix XIII, XIII-1300(ab)]. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(3) When considering bearing stresses in pins and similar members, the $S_y$ value at temperature is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

(b) Pure Shear. The average primary shear stress across a section under Design Loadings in pure shear, for example, keys, shear rings, and screw threads, shall be limited to $0.6S_m$. The maximum primary shear under Design Loadings, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$.

(c) Progressive Distortion of Nonintegral Connections. Screwed-on caps, screwed-in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell moulding or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (Section III Appendices, Mandatory Appendix XIII, XIII-3420), which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value $S_y$ given in Section II, Part D, Subpart 1, Table Y-1.

### NC-3217 Design Criteria

These design requirements provide specific design rules for certain commonly used pressure vessel shapes under pressure loading and, within prescribed limits, rules for the treatment of other loadings. Simplified criteria are included for determining whether an analysis for cyclic operation shall be made. The thickness of the vessel parts and attached supports covered by these rules shall be determined by the applicable equation using the most severe combination of loadings and design stress intensities $kS_m$ expected to occur simultaneously during design and service conditions. The basis for these equations is given in (a) through (d) below. Table NC-3217-1 lists values of $k$ that are appropriate for various load combinations.

(a) The theory of failure used in this subarticle is the maximum shear stress theory, except in the case of some specifically designated configurations, shapes, or design rules included as a part of this subarticle. Stress intensity is defined as two times the maximum shear stress.

(b) The average value of the general primary membrane stress intensity across the thickness of the section under consideration $P_m$, due to any combination of pressure and mechanical loadings expected to occur simultaneously, is limited to $1.5kS_m$. The distance over which the stress intensity exceeds $1.1kS_m$ shall not extend in the meridional direction more than $1.0\sqrt{Rt}$, where $R$ is the mean radius at the middle surface of the shell or head and $t$ is the nominal thickness of the shell or head at the point under consideration. Examples of local primary membrane stress include

1. membrane stress in a shell produced locally by an external load
2. membrane stress in a shell at a permanent support or nozzle connection
3. circumferential membrane stress at the intersection of a cylindrical shell with a conical shell due to internal pressure, as illustrated in Figure NC-3217-1

<table>
<thead>
<tr>
<th>Service Limits [Note (1)]</th>
<th>$k$ [Note (2)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>1.0</td>
</tr>
<tr>
<td>Level A [Note (3)]</td>
<td>1.0</td>
</tr>
<tr>
<td>Level B [Note (3)]</td>
<td>1.1</td>
</tr>
<tr>
<td>Level C</td>
<td>1.2</td>
</tr>
<tr>
<td>Level D [Note (4)]</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**NOTES:**
1. For Design Limits, use Design Pressure at design metal temperature; for Service Limits, use service pressure at service metal temperature.
2. The condition of structural instability or buckling must be considered.
3. See NC-3219 and Section III Appendices, Mandatory Appendix XIII.
4. When a complete analysis is performed in accordance with NC-3211.1(c), Section III Appendices, Mandatory Appendix XXVII may be applied.
(d) The general or local primary membrane plus bending stress intensity \((P_m + P_b)\) due to any combination of pressure and mechanical loadings expected to occur simultaneously shall not exceed 1.5 \( kS_m \). When the design of vessels involves combinations of calculated stresses, the provisions of Section III Appendices, Mandatory Appendix XIII apply.

**NC-3217.1 Secondary Stresses.** Secondary stresses may exist in vessels designed and fabricated in accordance with the rules of this subarticle, but limitations are provided to restrict such stresses to levels consistent with the rules in Section III Appendices, Mandatory Appendix XIII. Where details are not covered or where design conditions exceed the equation limitations, a detailed stress analysis in accordance with the rules of Section III Appendices, Mandatory Appendix XIII shall be made. Secondary stresses need be evaluated only for Level A and Level B Limits.

**NC-3217.2 Definitions.**

\[ P_b = \text{primary bending stress intensity, psi (MPa). This stress intensity is the component of primary stress proportional to the distance from the centroid of the solid section. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.} \]

\[ P_L = \text{local primary membrane stress intensity, psi (MPa). This stress intensity is derived from the average value across the solid section under consideration. It considers discontinuities but not concentrations.} \]

\[ P_m = \text{general primary membrane stress intensity, psi (MPa). This stress intensity is derived from the average value across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.} \]

\[ S_m = \text{design stress intensity values given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, psi (MPa)} \]

\[ S_y = \text{yield strength values given in Section II, Part D, Subpart 1, Table Y-1, psi (MPa)} \]

**NC-3218 Upper Limits of Test Pressure**

The evaluation of pressure test loadings shall be in accordance with (a) through (d) below.

(a) **Test Pressure Limit.** If the calculated pressure at any point in a vessel, including static head, exceeds the required test pressure defined in NC-6221 or NC-6321 by more than 6%, the resulting stresses shall be calculated using all the loadings that may exist during the test. The stress allowables for this situation are given in (b) and (c) below.

(b) **Hydrostatically Tested Vessels.** The hydrostatic test pressure of a completed vessel shall not exceed that value which results in the following stress intensity limits:

1. A calculated primary membrane stress intensity \( P_m \) of 90% of the tabulated yield strength \( S_y \) at test temperature as given in Section II, Part D, Subpart 1, Table Y-1.

2. A calculated primary membrane plus primary bending stress intensity \( P_m + P_b \) shall not exceed the applicable limits given in (a) or (b) below:

   \[ P_m + P_b \leq 1.35S_y \text{ for } P_m \leq 0.67S_y \]

   \[ P_m + P_b \leq (2.15S_y - 1.2P_m) \text{ for } 0.67S_y < P_m \leq 0.90S_y \]

where \( S_y \) is the tabulated yield strength at test temperature. For other than rectangular sections, \( P_m + P_b \) shall not exceed a value of \( \alpha \) times 0.9\( S_y \), where the factor \( \alpha \) is defined as the ratio of the load set producing a fully plastic section divided by the load set producing initial yielding in the extreme fibers of the section.

(c) **Pneumatically Tested Vessels.** The limits given in (b) above shall apply to pneumatically tested vessels, except that if the calculated membrane stress intensity shall be limited to 80% of the yield strength at the test temperature. For other than rectangular sections, \( P_m + P_b \) shall not exceed a value of \( \alpha \) times 0.8\( S_y \), where the factor \( \alpha \) is defined in (b)(2) above.

(d) **Multichamber Vessels.** In the case of multichamber vessels, pressure may be applied simultaneously to the appropriate adjacent chamber to maintain the stress intensity limits given in (b) and (c) above (NC-6600).

**NC-3219 Fatigue Evaluation**

When determining whether or not a fatigue analysis shall be specified, the Owner may consider experience with comparable vessels under similar conditions in accordance with the provisions of NC-3219.1. When not based upon significant applicable service experience, the need for a fatigue analysis shall be determined in accordance with the provisions of NC-3219.2 and NC-3219.3.

**NC-3219.1 Service Experience.** When the Owner is considering experience with comparable vessels under similar service conditions as related to the design and service contemplated, particular attention shall be given to the possible deleterious effects of the design features of (a) through (e) below:

(a) nonintegral construction, such as the use of pad type reinforcements or of fillet welded attachments, as opposed to integral construction;

(b) use of pipe threaded connections, particularly for diameters in excess of 2\( \frac{3}{4} \) in. (70 mm);

(c) stud bolted attachments;

(d) partial penetration welds;

(e) major thickness changes between adjacent members.

\[ \]
Figure NC-3217-1
Example of Acceptable Local Primary Membrane Stress Due to Pressure

Legend:

- $P$ = pressure
- $R$ = minimum midsurface radius curvature
- $t$ = minimum thickness in stressed region considered
- $P_L$ = primary local membrane stress intensity limit
  applies within local region
- $P_m$ = primary general membrane stress intensity limit
  applies outside the local region

$SI_{max}$ = maximum stress intensity
$kS_m$ = allowable stress intensity for the material at service temperature, see NC-3216.1; for values of stress intensity $k$ factor, see Table NC-3217-1

$V_1$ and $V_2$ = meridional forces

NOTE:
(1) See NC-3217(c) for limits.
NC-3219.2 Rules to Determine Need for Fatigue Analysis of Integral Parts of Vessels. A fatigue analysis need not be made, provided all of Condition A or all of Condition B is met. If neither Condition A nor B is met, a detailed fatigue analysis shall be made in accordance with the rules of Section III Appendices, Mandatory Appendices XIII for those parts which do not satisfy the conditions. The rules of Condition A or Condition B are applicable to all integral parts of the vessel, including integrally reinforced type nozzles. For vessels having pad-type nozzles or nonintegral attachments, the requirements of NC-3219.3 apply.

NC-3219.2.1 Condition A. Fatigue analysis is not mandatory for materials having a specified minimum tensile strength not exceeding 80.0 ksi (550 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 1,000 cycles:

(a) is the expected design number of full range pressure cycles including startup and shutdown;

(b) is the expected number of service pressure cycles in which the range of pressure variation exceeds 20% of the Design Pressure. Cycles in which the pressure variation does not exceed 20% of the Design Pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered;

(c) is the effective number of changes in metal temperature between any two adjacent points in the pressure vessel, including nozzles. The effective number of such changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor given in the following table, and by adding the resulting numbers. The factors are as follows:

<table>
<thead>
<tr>
<th>Metal Temperature Differential, °F (°C)</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 (28) or less</td>
<td>0</td>
</tr>
<tr>
<td>51 to 100 (29 to 56)</td>
<td>1</td>
</tr>
<tr>
<td>101 to 150 (57 to 83)</td>
<td>2</td>
</tr>
<tr>
<td>151 to 250 (84 to 139)</td>
<td>4</td>
</tr>
<tr>
<td>251 to 350 (140 to 194)</td>
<td>8</td>
</tr>
<tr>
<td>351 to 450 (195 to 250)</td>
<td>12</td>
</tr>
<tr>
<td>Excess of 450 (250)</td>
<td>20</td>
</tr>
</tbody>
</table>

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

\[ \Delta T, ^{\circ}F \ (^{\circ}C) \quad \text{Cycles} \]

<table>
<thead>
<tr>
<th>\Delta T, °F (°C)</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 (22)</td>
<td>1,000</td>
</tr>
<tr>
<td>90 (50)</td>
<td>250</td>
</tr>
<tr>
<td>400 (220)</td>
<td>5</td>
</tr>
</tbody>
</table>

the effective number of changes in metal temperature is

\[ 1,000[0] + 250[1] + 5[12] = 31\]
effective number of changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor, given in the following table, and by adding the resulting numbers. The factors are as follows:

<table>
<thead>
<tr>
<th>Metal Temperature Differential, °F (°C)</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 (28) or less</td>
<td>0</td>
</tr>
<tr>
<td>51 to 100 (29 to 56)</td>
<td>1</td>
</tr>
<tr>
<td>101 to 150 (57 to 83)</td>
<td>2</td>
</tr>
<tr>
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</tr>
<tr>
<td>Excess of 450 (250)</td>
<td>20</td>
</tr>
</tbody>
</table>

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

<table>
<thead>
<tr>
<th>ΔT, °F (°C)</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 (28)</td>
<td>1,000</td>
</tr>
<tr>
<td>90 (50)</td>
<td>250</td>
</tr>
<tr>
<td>400 (220)</td>
<td>5</td>
</tr>
</tbody>
</table>

the effective number of changes in metal temperature is

\[1,000 \times 0 + 250 \times 1 + 5 \times 12 = 310\]

The number used as type (c) in performing the comparison with 1,000 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.

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

(d) for vessels with welds between materials having different coefficients of expansion, is the number of temperature cycles which causes the value of \((\alpha_1 - \alpha_2) \Delta T\) to exceed 0.00034, where \(\alpha_1\) and \(\alpha_2\) are the mean coefficients of thermal expansion, 1/°F (1/°C) (Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 in the various equations).

NC-3224.2 Nomenclature. The symbols used are defined below. Except for test conditions, dimensions used or calculated shall be in the corroded condition.

\(D\) = inside diameter of a head skirt or inside length of the major axis of an ellipsoidal head or inside diameter of a conical head at the point under consideration measured perpendicular to the axis of revolution.

\(F\) = meridional membrane force in the shell wall at the point under consideration resulting from primary loadings other than internal pressure, lb/in. (N/mm) length of circumference. If this force is not uniform, as when resulting from wind or earthquake moment loading, the loading requiring the greatest shell thickness shall be used where the tensile load is positive.

\(h\) = one-half the length of the minor axis of an ellipsoidal head or the inside depth of an ellipsoidal head, measured from the tangent line.

\(k\) = stress intensity factor for design, service, and test load combination from Table NC-3217-1

\(L\) = inside spherical or crown radius of torispherical and hemispherical heads.

\(P\) = internal pressure at the top of vessel plus any pressure due to the static head of the fluid, at any point under consideration, psi (MPa)

\(Q\) = a factor in the equations for cone to cylinder junctions depending on \(P/S\) and \(\alpha\)
\( R \) = inside radius of the shell under consideration. This radius is measured normal to the surface from the point of revolution

\( R_L \) = radius of a cylinder at the large end of a cone to cylinder junction

\( R_s \) = radius of a cylinder at the small end of a cone to cylinder junction

\( r \) = inside knuckle radius of torispherical and toriconical heads

\( S \) = membrane stress intensity limit from Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 multiplied by the stress intensity factor in Table NC-3217-1

\( t \) = minimum required thickness of shell

\( t_r \) = \( Q \) times the required thickness of a cylinder calculated in accordance with NC-3224.13(b)(6)(b)

\( \alpha \) = one-half of the apex angle of a cone to cylinder junction

**NC-3224.3 Minimum Thickness of Cylindrical Shells.** The minimum thickness of cylindrical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a) 

\[ t = \frac{PR}{S - 0.5P} \]

If \( P > 0.4S \), the following equation must be used:

\[ \ln \left( \frac{R + t}{R} \right) = \frac{P}{S} \]

where \( \ln \) is the natural log.

(b) If \( F \) is positive and exceeds \( 0.5PR \),

\[ t = \frac{0.5PR + F}{S - 0.5P} \]

(c) If \( F \) is negative, the condition of instability shall be considered. NC-3245 for cylinders may be used for spheres, provided biaxial compression does not exist.

**NC-3224.5 Minimum Thickness of Formed Heads.** The minimum thickness at the thinnest point after forming of ellipsoidal, torispherical, and hemispherical heads under pressure acting against the concave surface shall be determined by the appropriate rule or equation in the following subparagraphs.

**NC-3224.6 Minimum Thickness of Ellipsoidal Heads.** (a) The minimum thickness of a 2:1 ellipsoidal head shall be established using the procedures given in NC-3224.8 and the curve of Figure NC-3224.6-1 which is labeled “2:1 ellipsoidal head.” Ellipsoidal head designs which have \( D/2h \) values different from 2 shall be analyzed as equivalent torispherical heads or according to Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII.

**NC-3224.7 Minimum Thickness of Hemispherical Heads.** For hemispherical heads, the thickness shall be as required for spherical shells, NC-3224.4. The requirements for the transition to cylindrical shells of different thickness, given in NC-3361 and Figure NC-3358.1(a)-1, shall be met.

**NC-3224.8 Minimum Thickness of Torispherical Heads.** The minimum thickness of a torispherical head having \( t/L \geq 0.002 \) up to a \( t/L \) where \( P/S \leq 0.08 \) (approximately \( t/L = 0.04 \) to 0.05) shall be established by using the curves in Figure NC-3224.6-1. Interpolation may be used for \( r/D \) values which fall within the range of the curves; however, no extrapolation of the curves is permitted. For designs where \( P/S > 0.08 \), which is above the upper limit of Figure NC-3224.6-1, the thickness shall be set by the following equation:

\[ t = \frac{D}{2} \left( e^{P/S} - 1 \right) \]

Where \( t/L < 0.002 \), which is below the lower limit of Figure NC-3224.6-1, the head design must be analyzed according to Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder,
Design Curves for Torispherical Heads and 2:1 Ellipsoidal Heads for Use With NC-3224.8 and NC-3224.6

For 2:1 ellipsoidal heads, use $L = 0.9D$ to calculate $t/L$
of not less than \( \sqrt{Rt} \). Transition joints to shells of thickness less than the required head thickness shall not be located within this minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with NC-3361 and Figure NC-3358.1(a)-1. Heads having \( D/2h = 2 \) have equivalent torispherical properties of a torisphere of \( L/D = 0.90 \) and \( r/D = 0.17 \).

**NC-3224.8.1 Crown and Knuckle Radii.** In connection with the design procedures of NC-3224.8 and Figure NC-3224.6-1, the inside crown radius to which an unstayed head is formed shall not be greater than the inside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall not be less than 6% of the outside diameter of the skirt nor less than three times the head thickness.

**NC-3224.9 Minimum Thickness of Integral Head Skirts.** In addition to the requirements of NC-3224.8 or NC-3224.6, when an integral head skirt is provided, the skirt thickness shall not be less than the required thickness of a seamless shell of the same diameter. All transition joints shall be in accordance with NC-3361 and Figure NC-3358.1(a)-1.

**NC-3224.10 Composite Head Shapes.** A head for a cylindrical shell may be built up of several head shapes, the thicknesses of which satisfy the requirements of the appropriate equations above. The adjoining shapes must be so formed that they have a common tangent transverse to the joint. Any taper at a joint shall be within the boundary of the shape having the thinner wall (Figure NC-3361.1-1).

**NC-3224.11 Loadings on Heads Other Than Pressure.** Provision shall be made for other loadings given in NC-3212. For torispherical and ellipsoidal heads, the effect of other loadings must be determined in accordance with Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII. For conical or spherical portions of heads, the effect of composite loading may be treated as in NC-3224.3, NC-3224.4, and NC-3224.13(a)(4).

**NC-3224.12 Toriconical Heads.** (In preparation.)

**NC-3224.13 Reducer Sections.**

1. **General Requirements**
   1. **Applicable Equations and Rules.** These rules apply to concentric reducer sections when all the longitudinal loads are transmitted wholly through the shell of the reducer. When loads are transmitted in part or as a whole by other elements, such as inner shells, stays, or tubes, these rules do not apply.
   2. **Minimum Thickness of Reducer Elements.** The thickness of each element of a reducer 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 NC-3212.

3. **Transition Section Reducers Joining Two Cylindrical Shells.** 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 these requirements are met.
   4. **Minimum Thickness of Conical Shells.** The minimum thickness of conical shells shall be determined by the same equations as for cylindrical shells in which \( R \) is the radius measured normal to the wall surface at the point under consideration. Subparagraphs (b) and (c) give rules for cone to cylinder junctions of the large and small end, respectively.

   (a) \[ t = \frac{PR}{S - 0.5P} \]

   If \( P > 0.4S \),

   \[ \ln \left( \frac{R + t}{R} \right) = \frac{P}{S} \]

   (b) If \( F \) is positive and exceeds 0.5 \( PR \),

   \[ t = \frac{0.5PR + F}{S - 0.5P} \]

   (c) If \( F \) is negative, the condition of axial structural instability or buckling must be considered separately. NC-3245 for cylinders may be used for conical sections.

5. **Knuckle Tangent to the Larger Cylinder.** When a knuckle is used at the large end of a reducer section, it shall have a shape that is a portion of an ellipsoidal, hemispherical, toriconical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of NC-3224.5.

6. **Combination of Elements to Form a Reducer.** When elements having different thicknesses are combined to form a reducer, the joints including the plate taper shall lie entirely within the limits of the thinner element being joined.

7. **Combination of Shapes to Form a Toriconical Reducer.** A toriconical reducer may be shaped as a portion of a toriconical head or a portion of an ellipsoidal head plus a conical section, provided the design of the small end of the reducer element satisfies the requirements of (c).

   (b) **Supplementary Requirements for Reducer Sections and Conical Heads, Large End.** These rules apply, provided the requirements of (1) through (6) below are met:

   1. The two parts to be joined have the same rotational axis
   2. The load is internal pressure (see NC-3224.11)
   3. The joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness
   4. The weld at the junction is radiographed and meets the requirements of NC-5250
(5) the junction is not closer than \(4\sqrt{RL} \times t_r\) to another junction or major discontinuity.

(6) Reinforcement Requirements

(-a) When Inherent Reinforcement Is Adequate. The thickness of the cone and cylinder forming a junction at the large end for half apex angles up to 30 deg need not be thicker than required by NC-3224.3 or (a)(4)(-a), if the point representing the junction lies in the Adequate region of Figure NC-3224.13(b)(6)(-a)-1.

(-b) Requirements for Integral Reinforcement. When the half-apex angle exceeds the maximum permitted by Figure NC-3224.13(b)(6)(-a)-1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure NC-3224.13(b)(6)(-b)-1 gives \(Q\) values for ratios of Design Pressure \(P\) to \(S\) and values of \(\alpha\) up to 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to \(t_r\) and provided that the requirements of (-1) through (-3) below are met.

(-1) The increased cylinder thickness extends a minimum distance of \(2.0\sqrt{RL} t_r\) from the junction, where \(RL\) is the radius of the cylinder at the large end of the cone.

(-2) The increased cone thickness extends a minimum distance of \(2.0\sqrt{RL} t_r\) from the junction.

(-3) In no case shall \(t\) be less than the thickness required for the cone in accordance with NC-3224.3.

(c) Supplementary Requirements for Reducer Section’s Small End. These rules apply, provided the requirements of (1) through (6) below are met:

(1) the two parts to be joined have the same rotational axis

(2) the load is internal pressure (NC-3224.11)

(3) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness

(4) the weld at the junction is radiographed and meets the requirements of NC-5250

(5) the junction is not closer than \(2.8\sqrt{R_{s}} t_r\) to another junction or discontinuity, where \(R_{s}\) is the radius of the cylinder at the small end of the cone

(6) Reinforcement Requirements:

(-a) When Inherent Reinforcement Is Adequate. The thickness of the cone and cylinder forming a junction at the small end of half apex angles up to 30 deg need not
be thicker than required by NC-3224.3 if the point representing the junction lies in the Adequate region of Figure NC-3224.13(c)(6)(-a)-1.

(b) Requirements for Integral Reinforcement. When the half apex angle exceeds the maximum permitted by Figure NC-3224.13(c)(6)(-a)-1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure NC-3224.13(c)(6)(-b)-1 gives values for ratios of Design Pressure \( P \) to \( S \) and values of \( \alpha \) up to 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to \( t_r \) and provided that the requirements of (-1) through (-3) below are met.

(-1) The increased cylinder thickness \( t_r \) extends a minimum distance \( 1.4 \sqrt{R_s t_r} \) from the junction.

(-2) The increased cone thickness \( t_r \) extends a minimum distance \( 1.4 \sqrt{R_s t_r / \cos \alpha} \) from the junction.

(-3) In no case shall \( t_r \) be less than the thickness required for the cone in accordance with NC-3224.3 at a distance \( 1.4 \sqrt{R_s t_r / \cos \alpha} \) from the junction.

(d) Supplementary Requirements for Reducer Sections, Small End, Treated As Openings. Cone to cylinder junctions at the small ends of reducers as shown in Figure NC-3224.13(d)-1 may be treated as openings in conical heads provided the requirements of (1) through (4) below are met.

(1) The diameter \( d \) of the small end is not more than one-half the diameter of the large end.

(2) The half apex angle \( \alpha \) is greater than 30 deg but not greater than 60 deg.

(3) The reinforcement meets the requirements of NC-3232 and NC-3234.1, except that the total cross-sectional area of reinforcement \( A \) required at the junction in any plane for a vessel under internal pressure shall not be less than \( A = d t \tan \alpha / 2 \) and two-thirds of this area shall be provided within a limit of \( 0.5 \sqrt{d t / 2} \) measured along the cylinder and \( 0.5 \sqrt{d t / 2 \cos^2 \alpha} \) measured along the cone.
Reinforcement shall be integral with cone or cylinder and all other applicable requirements of NC-3230 are met.

**NC-3224.14 Minimum Thickness of Nozzle Necks and Other Connections.** The wall thickness of a nozzle neck or other connection shall not be less than the thickness computed for the applicable loadings plus the thickness added for corrosion and erosion allowance and, except for access openings and openings for inspection only, not less than the smaller of (a) and (b) below:

(a) 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;

(b) the minimum thickness of standard wall pipe plus the corrosion allowance on the connections. The minimum thickness for all pipe materials is the nominal thickness listed in Table 2 of ASME B36.10M less 12 1/2%. For diameters other than those listed in the table, the minimum thickness shall be that of the next larger pipe size.

**NC-3224.15 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 NC-3111 other than pressure and temperature.
GENERAL NOTE: Curves governed by membrane stress intensity due to average circumferential tension stress and average radial compression stress limited by $1.15\sigma_m$ at $0.25\sqrt{\text{rad} \times \text{thk}}$ either side of junction.
Figure NC-3224.13(d)-1
Cone–Cylinder Junction at Small End Treated as Opening

(a) \[ \alpha = 30 \text{ deg} < \alpha < 60 \text{ deg} \]

(b) \[ A \leq A_1 + A_2 + A_3 \]

where

- \( A_1 \) = reinforcement area integral with cone
- \( A_2 \) = reinforcement area integral with cylinder
- \( A_3 \) = area of fillet weld

See Fig. NC-3259.3-1 for attachment weld requirements

\( \frac{d}{2} \)
NC-3225 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. Some acceptable types of flat heads and covers are shown in Figure NC-3225-2. The dimensions are exclusive of extra metal added for corrosion allowance.

NC-3225.1 Nomenclature. The notations used are defined as follows:

- \( C \) = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in NC-3225.2, dimensionless (Figures NC-3225-1 through NC-3225-3)
- \( D \) = bolt circle diameter
- \( d \) = diameter
- \( h_G \) = gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction (Figure NC-3225-2)
- \( L \) = distance from center line of head to shell weld to tangent line on formed heads, as indicated in Figure NC-3225-2 sketch (a)
- \( m \) = the ratio \( t_r/t_s \), dimensionless
- \( P \) = Design Pressure, psi (MPa)
- \( r \) = inside corner radius on a head formed by flanging or forging
- \( S \) = design stress intensity \( S_m \) from Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 multiplied by tabulated stress intensities, psi (MPa)
- \( T \) = minimum required thickness of flat head, cover, or flange, exclusive of corrosion allowance
- \( t_f \) = actual thickness of the flange on a formed head, at the large end, exclusive of corrosion allowance
- \( t_p \) = the smallest dimension from the face of the head to the edge of the weld preparation
- \( t_r \) = required thickness of shell or nozzle for pressure
- \( t_s \) = actual thickness of shell or nozzle
- \( W \) = total bolt load

NC-3225.2 Equations for Minimum Thickness.13

(a) The thickness of flat heads, as shown in Figures NC-3225-1 through NC-3225-3, shall be not less than that calculated by the following equation:

\[
T = d\sqrt{CP/S}
\]

(b) The thickness of cover plates and blind flanges attached by bolts causing an edge moment as shown in Figure NC-3225-2 shall be not less than that calculated by the following equation:

\[
T = d\sqrt{CP/S} + 1.27W h_G/Sd^3
\]

NOTE: In some cases, the initial bolt load required to seat the gasket is larger than the service bolt load. The thickness should be checked for both the service condition and the initial bolt load required to seat the gasket.

NC-3227 Quick Actuating Closures

The requirements for quick actuating closures are given in NC-3327.
Figure NC-3225-1
Typical Flat Heads and Supported and Unsupported Tubesheets With Hubs

For unstayed flat heads:
\[ C = 0.33m \]
but not less than 0.20, when \( r \) is not less than 1.5\( t_s \).

Thickness of flat head or tubesheet

(a)

(b)

(c)

(d)

(e)

For unstayed flat heads:
\[ C = 0.17 \]
when \( t_f \) is not less than 2\( t_s \), and \( r \) is not less than 3\( t_f \).

Thickness of flat head or tubesheet
GENERAL NOTE: All these illustrations are diagrammatic only. Other designs that meet the requirements of NC-3225.2 are acceptable.
Figure NC-3225-3
Attachment of Pressure Parts to Plates to Form a Corner Joint

(a) \( a + b \) not less than \( 2t_s \)
\( b + c \) not less than \( t_s \)
\( C = 0.33m \) but not less than 0.20

(b) \( a + b \) not less than \( 2t_s \)
\( C = 0.33m \) but not less than 0.20

(c) \( a + b \) not less than \( 3t_s \)
\( b + c \) not less than \( t_s \)

(d) \( t_s \)
\( C = 0.33m \) but not less than 0.20

(e) \( t_s \)
\( C = 0.33m \) but not less than 0.20

(f) \( t_s \)
\( C = 0.33m \) but not less than 0.20

(g) \( t_s \)
\( C = 0.33m \) but not less than 0.20

\( C_{\text{min.}} = 0.7t_s \) or \( \frac{1}{4} \) in. (6 mm), whichever is less
\( b = \) the lesser of \( t_s \) or \( T/2 \)
NC-3230 OPENINGS AND THEIR REINFORCEMENT

NC-3231 General Requirements

The rules contained in this subarticle provide for a satisfactory design in the vicinity of openings in the pressure shell, under pressure loading only, on the basis of its opening shape, area replacement, and distribution, provided a fatigue analysis is not required. These rules do not include design requirements for piping loads that may be imposed on the nozzle or shell portion or both and that may be added to the pressure loadings. Such additional loadings shall be considered by the designer.

NC-3231.1 Dimensions and Shape of Openings.

(a) Openings, except as permitted under (b), shall be circular, elliptical, or of any other shape which results from the intersection of a circular or elliptical cylinder with vessels of the shapes for which equations are given in NC-3220, provided the requirements of (1) through (4) below are met.

(1) The ratio of the diameter along the major axis to the diameter along the minor axis of the finished opening is 1.5 or less.

(2) The ratio \( d/D \leq 0.50 \) where \( d \) is the largest inside diameter of the intersecting nozzle and \( D \) is the inside diameter of the vessel.

(3) The arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or for openings along the longitudinal axis of a shell and is not less than two times the sum of their inside radii for openings along the circumference of a cylindrical shell. When two nozzles in a cylindrical shell are neither in a longitudinal line nor in a circumferential arc, their center line distance along the inside surface of the shell shall be such that \( \left( \frac{L_c}{2} \right)^2 + \left( \frac{L_f}{3} \right)^2 \) is not less than the sum of their inside radii, where \( L_c \) is the component of the center line distance in the circumferential direction and \( L_f \) is the component of the center line distance in the longitudinal direction.

(4) Reinforcement is provided around the edge of the opening in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface as stipulated in NC-3232.2.

(b) Openings of other shapes or dimensions may be used subject to the requirements of Section III Appendices, Mandatory Appendix XIII or Mandatory Appendix XIII.

(c) Any type of opening permitted by these rules may be located in a butt welded joint.

NC-3232 Reinforcement Requirements for Openings in Shells and Formed Heads

NC-3232.1 Circular Openings Not Requiring Reinforcement. Circular openings need not be provided with reinforcement if all the requirements in (a), (b), and (c) below are satisfied.

(a) A single opening has a diameter not exceeding \( 0.2 \sqrt{R_t} \) or if there are two or more openings within any circle of diameter, \( 2.5 \sqrt{R_t} \) then the sum of the diameters of such unreinforced openings shall not exceed \( 0.25 \sqrt{R_t} \).

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than \( 2.5 \sqrt{R_t} \) to the edge of a locally stressed area in the shell where \( R \) is the mean radius and \( t \) is the nominal thickness of the vessel shell or head at the location of the openings and where locally stressed area means any area in the shell where the primary local membrane stress exceeds 1.1 \( k_s m \), but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

NC-3232.2 Required Area of Reinforcement.

(a) The total cross-sectional area of reinforcement \( A \) required in any given plane for a vessel under internal pressure shall be not less than

\[ A = dt_F \]

where

\[ d = \text{finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition} \]

\[ F = 1.00 \text{ when the plane under consideration is in the spherical portion of a head or when the given plane contains the longitudinal axis of a cylindrical shell. For other planes through a shell, use the value of } F \text{ determined from Figure } \text{NC-3332.2-1} \text{ except that, for reinforcing pads, } F = 1. \]

\[ t_F = \text{the thickness which meets the requirements of NC-3220 in the absence of the opening} \]

(b) Not less than one-half the required material shall be on each side of the center line of the opening [NC-3234.1(b)].

NC-3233 Required Reinforcement 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 \( A \), not less than that given by the equation

\[ A = 0.5dt_F \]
where
\[ d = \text{the diameter of the finished opening in its corroded condition} \]
\[ t_r = \text{the thickness that meets the requirements of NC-3225.2 in the absence of the opening} \]

(b) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter shall be designed according to Section III Appendices, Mandatory Appendix XIX.

**NC-3234 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 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 as described in the following subparagraphs.

**NC-3234.1 Limit of Reinforcement Along the Vessel Wall.** The limits of reinforcement, measured along the midsurface of the nominal wall thickness of the vessel, shall meet the following:

(a) 100% 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:

\[ (1) \, \text{the diameter of the finished opening in the corroded condition} \]
\[ (2) \, \text{the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall} \]

(b) two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the sum of the thicknesses of the vessel wall and the nozzle wall;

\[ (1) \, (2) \, \text{the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall} \]

\[ \theta = \text{slope offset distance} \]
\[ \theta = \text{angle between vertical and slope} \]

Other terms are defined in (a) above.

(c) For Figure NC-3234.2(a)-1 sketch (c), when reinforcing pads or insert plates are used, the limit is the larger of \[ 0.5\sqrt{r_m t_n} + t_e \] or \[ 2.5t_n + 2.5t_p \], but not to exceed 2.5t. In no case can the thickness \( t_e \), used to establish the limit normal to the shell, exceed 1.5t or 1.73W, where

\[ t_e = \text{thickness of added reinforcing element} \]
\[ W = \text{width of added reinforcing element} \]

Other terms are defined in (a) above.

**NC-3234.3 Nozzle Piping Transitions.** The stress limits of NC-3200 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NC-3234, except as noted in NC-3234.4. Stresses in the extension of any nozzle beyond the limits of reinforcement shall meet the stress limits of NC-3600.

**NC-3234.4 Consideration of Standard Reinforcement.** Where a nozzle-to-shell juncture is reinforced in accordance with the rules of NC-3234, the stresses in this region due to internal pressure may be considered to satisfy the limits of NC-3217. Under these conditions, no analysis is required to demonstrate compliance for pressure-induced stresses in the nozzle region. Where external piping loads are to be designed for, membrane plus bending stresses 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 NC-3217 for \( (P_m + P_L) + P_b \). In this case, the pressure-induced stresses in the \( (P_m + P_L) + P_b \) category may be assumed to be no greater than the limit specified for \( P_m \) in NC-3217 for a given condition.
Figure NC-3234.2(a)-1
Nozzle Nomenclature and Dimensions
Depicts Configuration Only

(a)

(b)

(c)

(d)

Alternative with fillet transition

Alternative with pad plate and fillet

Shell thickness

\[ t_n' = t_p + 0.667x \]

\[ r_m = r + 0.5t_n' \]

\[ \theta = 45 \text{ deg} \]

\[ \theta = 90 \text{ deg} \]

Changes are as described on Page 1
No other changes on this page
NC-3235 Metal Available for Reinforcement

Metal may be counted as contributing to the area of reinforcement called for in NC-3232.2 and NC-3233, provided it lies within the area of reinforcement specified in NC-3234 and shall be limited to material which meets the requirements of (a) through (e) below:

(a) metal forming a part of the vessel wall which is in excess of that required on the basis of primary stress intensity (NC-3221 through NC-3224 and NC-3225.2) and is exclusive of corrosion allowance;

(b) similar excess metal in the nozzle wall, provided the nozzle is integral with the vessel wall or is joined to it by a full penetration weld;

(c) weld metal which is fully continuous with the vessel wall;

(d) metal not fully continuous with the shell, such as a pad continuously welded around its periphery, may be counted as reinforcement, provided the requirements of NC-3237 are met;

(e) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b), (c), and (d) above shall be within 15% of the value for the metal in the vessel wall.

NC-3235.1 Metal Not Available for Reinforcement.

Metal not fully continuous with the shell, as that in nozzles attached by partial penetration welds, shall not be counted as reinforcement.

NC-3235.2 Reinforcement Metal Limited to One Opening. Metal available for reinforcement shall not be considered as applying to more than one opening.

NC-3236 Strength of Reinforcement Material

Material used for reinforcement shall preferably have the same design stress intensity value as that of the vessel wall. In no case shall material with an allowable design stress intensity value less than 80% of the value of the vessel wall material at the Design Temperature be used in determining area available for reinforcement. If the material of the nozzle wall or reinforcement has a lower design stress intensity value $S_m$ than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NC-3232 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement design stress intensity value to the vessel material design stress intensity value. No reduction in the reinforcement requirement may be made if the reinforcing material or weld metal has a design stress intensity value higher than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

NC-3237 Requirements for Nozzles With Separate Reinforcing Plates

Except for nozzles at small ends of cones reinforced in accordance with the requirements of NC-3224.13(d), added reinforcement in the form of separate reinforcing plates may be used, provided the vessel and the nozzles meet all the conditions of (a) through (d) below:

(a) The specified minimum tensile strengths of the materials do not exceed 80 ksi (550 MPa).

(b) The minimum elongation of materials is 12% in 2 in. (50 mm).

(c) The thickness of the added reinforcement does not exceed 1 1/2 times the shell thickness.

(d) The requirements of NC-3219 for pads in cyclic service are met.

NC-3239 Alternative Rules for Opening Reinforcement

The requirements of this paragraph constitute an acceptable alternative to the rules of NC-3231 through NC-3237.

NC-3239.1 Limitations. These rules are applicable only to openings utilizing nozzles in vessels within the limitations of (a) through (f) below.

(a) The nozzle is circular in cross section and its axis is perpendicular to the vessel or head.

(b) The nozzle and required reinforcing are welded integrally into the vessel with full penetration welds between all parts. Details such as those shown in Figures NC-4266(a)-1, NC-4266(b)-1 sketches (a), (b), and (c), and NC-4266(c)-1 are acceptable. However, fillet welds must be ground to a radius in accordance with Figure NC-3239.1(b)-1.

(c) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(d) The spacing between the edge of the opening and the nearest edge of any other opening is not less than the smaller of 1.25 $(d_1 + d_2)$ and $2.5\sqrt{R_{cr}}$, but in any case, not less than 1.0 $(d_1 + d_2)$, where $d_1$ and $d_2$ are the inside diameters of the openings.

(e) The materials used in the nozzle reinforcement and vessel wall adjacent to the nozzle shall have a ratio of $UTS/YS$ of not less than 1.5, where

$UTS = $ specified minimum ultimate tensile strength

$YS = $ specified minimum yield strength
The following dimensional limitations are met:

\[
\frac{D}{t} = 10 \text{ to } 100 \\
\frac{d}{D} = 0.5 \text{ max.} \\
\frac{d}{\sqrt{D}t} = ... \text{ max.} \\
\frac{d}{\sqrt{Dt}r_2/t} = 1.5 \text{ max.} 
\]

\[
r_1 = 0.1 \frac{t_n}{2} \text{ to } 0.5 \frac{t_n}{2}; \quad r_2 = \text{larger of } \frac{\sqrt{d}}{90} \text{ or } \frac{T_s}{2}; \quad \text{lager of } \frac{\sqrt{d}}{90} (dt) \text{ or } \frac{t_n}{90} t_n \]

\[
r_3 \geq \text{larger of } 1 - \frac{\sqrt{d}}{90} \text{ or } 1 - \frac{\sqrt{d}}{90} (T_s/2); \quad r_5 = \frac{\theta_2}{90} T_s; \quad \theta \text{ and } \theta_1 \text{ in degrees} \]

\[t_r = \text{wall thickness of vessel or head, computed by the} \]

\[\text{equation given in NC-3224.3 for cylindrical vessels;} \]

\[\text{by NC-3224.4 for spherical vessels or spherical heads} \]

\[t_{rn} = \text{wall thickness of nozzle, computed by the equation} \]

\[\text{given in NC-3224.3} \]

See Figure NC-3239.1(b)-1 for \(r_1, r_2, \theta, r_3, \text{ and } \theta_1\). See Figure NC-3239.4-1 for \(L_c\) and \(L_n\). See NC-3239.7 for \(S, \sigma_t, \sigma_n, \sigma_r, \text{ and } \sigma\).

**NC-3239.3 Required Reinforcement Area.**

(a) The required minimum reinforcing area is related to the value of \(d/\sqrt{Rt_f}\) shown in Table NC-3239.3(a)-1.

(b) The required minimum reinforcing area shall be provided in all planes containing the nozzle axis.

**NC-3239.4 Limits of Reinforcing Zone.** Reinforcing metal included in meeting the minimum reinforcing area specified in NC-3239.3 must be located within the reinforcing zone boundary shown in Figure NC-3239.4-1.

**NC-3239.5 Strength of Reinforcing Material Requirements.** Material in the nozzle wall used for reinforcing should preferably be the same as that of the vessel wall. If material with a lower design stress intensity value \(S_m\) is used, the area provided by such material shall be increased in proportion to the inverse ratio of the stress values of the nozzle and the vessel wall material. No reduction in the reinforcing area requirement may be taken.
for the increased strength of nozzle material or weld metal which has a higher design stress value than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses. The mean coefficient of thermal expansion of metal to be included as reinforcement shall be within 15% of the value for the metal of the vessel wall.

NC-3239.6 Transition Details. Examples of acceptable transition tapers and radii are shown in Figure NC-3239.1(b)-1. Other configurations which meet the reinforcing area requirements of NC-3239.3 and with equivalent or less severe transitions are also acceptable, such as larger radius–thickness ratios.

NC-3239.7 Stress Indices.

(a) The term stress index is defined as the numerical ratio of the stress components $\sigma_t$, $\sigma_n$, and $\sigma_r$ under consideration to the computed stress $S$. The symbols for the stress components are shown in Figure NB-3338.2(a)-1 and are defined as follows:

\[
P = \text{service pressure, psi (MPa)}
\]

\[
S = P(2R + t)/2t \text{ for nozzles in cylindrical vessels, psi (MPa)}
\]

\[
S = P(2R + t)/4t \text{ for nozzles in spherical vessels or heads, psi (MPa)}
\]

\[
\sigma = \text{the stress intensity, combined stress, at the point under consideration, psi (MPa)}
\]

\[
\sigma_n = \text{the stress component normal to the plane of the section, ordinarily the circumferential stress around the hole in the shell, psi (MPa)}
\]

\[
\sigma_r = \text{the stress component normal to the boundary of the section, psi (MPa)}
\]

\[
\sigma_t = \text{the stress component in the plane of the section under consideration and parallel to the boundary of the section, psi (MPa)}
\]

(b) When the conditions of NC-3239.1 through NC-3239.6 are satisfied, the stress indices given in Table NC-3239.7-1 may be used. These stress indices deal only

---

### Table NC-3239.3(a)-1

<table>
<thead>
<tr>
<th>Value of $d/\sqrt{Rt}$</th>
<th>Nozzles in Cylinders</th>
<th>Nozzles in Spherical Vessels or Heads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0.20</td>
<td>None [Note (1)]</td>
<td>None [Note (1)]</td>
</tr>
<tr>
<td>Greater than 0.20 and less than 0.40</td>
<td>$(4.05 - d/\sqrt{Rt})^{1/2}$</td>
<td>$(5.40 - d/\sqrt{Rt}^{1/2}$</td>
</tr>
<tr>
<td>Greater than 0.40</td>
<td>$0.75 , dt_r$</td>
<td>$dt_r \cos \phi$</td>
</tr>
</tbody>
</table>

**NOTE:**

(1) The transition radius $r_2$ shown in Figure NC-3239.1(b)-1, or equivalent, is required.

---

**Figure NC-3239.4-1**

Limits of Reinforcing Zone

- Plane of nozzle and vessel axes, nozzles in cylindrical shells
- Transverse plane, cylindrical shells
- All planes, heads

**GENERAL NOTES:**

(a) Reinforcing Zone Limit

1. $L_c = 0.75 (T/D)^{2/3}D$ for nozzles in cylindrical shells.
2. $L_n = (T/D)^{2/3}(d/D + 0.5)D$ for nozzles in heads.
3. The center of $L_c$ or $L_n$ is at the juncture of the outside surfaces of the shell and nozzles of thickness, $T$ and $t$.
4. In constructions where the zone boundary passes through a uniform thickness wall segment, the zone boundary may be considered as $L_c$ or $L_n$ through the thickness.

(b) Reinforcing Area

1. Hatched areas represent available reinforcement area, $A_a$.
2. Metal area within the zone boundary, in excess of the area formed by the intersection of the basic shells, shall be considered as contributing to the required area $A_r$. The basic shells are defined as having inside diameter $D$, thickness $T$, inside diameter of the nozzle $d$, and thickness $t$.
3. The available reinforcement area, $A_a$, shall be at least equal to $A_r/2$ on each side of the nozzle centerline and in every plane containing the nozzle axis.
with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses should be considered as acting at the same point and added algebraically. If the stresses are otherwise determined by more accurate analytical techniques or by the experimental stress analysis procedure of Section III Appendices, Mandatory Appendix II, the stresses are also to be added algebraically.

**NC-3240  VESSELS UNDER EXTERNAL PRESSURE**

**NC-3241  General Requirements**

These rules are applicable to spherical and cylindrical shells with or without stiffening rings and to formed heads and to tubular products (NC-4221.2). Charts for use in determining the thicknesses of these components are given in Section II, Part D, Subpart 3.

**NC-3241.1 Nomenclature.** The symbols used in this Article are defined below. Except for the test condition, dimensions used or calculated shall be in the corroded condition.

\[
A = \text{factor determined from the appropriate chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor} \ B \ \text{and the Design Temperature for the shell under consideration}
\]

\[
A_s = \text{cross-sectional area of the stiffening ring}
\]

\[
B = \text{factor from the charts in Section II, Part D, Subpart 3, psi (MPa)}
\]

\[
D_o = \text{outside diameter of the cylindrical shell course under consideration}
\]

\[
I_s = \text{required moment of inertia of the combined ring shell section about its neutral axis parallel to the axis of the shell. The width of shell that is taken as contributing to the combined moment of inertia shall not be greater than 1.10 \sqrt{D_o/T} \text{ and shall be taken as lying done-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.}
\]

\[
L = \text{design length of a vessel section, using the applicable definition as follows: the distance between head bend lines plus one-third of the depth of each head if there are no stiffening rings; the greatest center to center distance between any two adjacent stiffening rings; or the distance from the center of the first stiffening ring to the head bend line plus one-third of the depth of the head, all measured parallel to the axis of the vessel.}
\]

\[
L_s = \text{one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support, if any, on the other side of the stiffening ring, both measured parallel to the axis of the vessel. (A line of support is a stiffening ring that meets the requirements of this paragraph; a circumferential line on a head at one-third the depth of the head from the head bend line; a circumferential connection to a jacket.)}
\]

\[
P = \text{external Design Pressure, psi (MPa)}
\]

\[
R = \text{inside radius of spherical shells}
\]

\[
T = \text{minimum required thickness of the cylindrical or spherical shell or tubular product, exclusive of corrosion allowance}
\]

**NC-3242  Cylindrical Shells**

**NC-3242.1 For } D_o/T \geq 10.\text{ The minimum thickness of pipes or shell under external pressure having } D_o/T \text{ values equal to or greater than 10 shall be determined by the procedure given in NC-3133.3.}**

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

**NC-3242.2 For } D_o/T < 10.\text{ The minimum thickness of pipes or tubes under external pressure having } D_o/T \text{ values less than 10 shall be determined by the procedure given in Steps 1 through 4 below:}**

**Step 1.** Compute a value for factor \( A \) from the equation

\[
A = 1.1 / \left( D_o / T \right)^{0.15}
\]

**Step 2.** Enter the appropriate chart with the calculated value of \( A \) and move vertically to the material line for the Design Temperature or to the horizontal projection of the upper end of this material line where \( A \) falls to

---

**Table NC-3239.7-1**

**Stress Indices for Internal Pressure Loading**

<table>
<thead>
<tr>
<th>Nozzles in Spherical Shells and Spherical Heads</th>
<th>Stress Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside</td>
<td>Outside</td>
</tr>
<tr>
<td>( \sigma_a )</td>
<td>2.0 ( (r/R) )</td>
</tr>
<tr>
<td>( \sigma_t )</td>
<td>-0.2</td>
</tr>
<tr>
<td>( \sigma_r )</td>
<td>( -4T/r(2R + t_r) )</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>larger of: 2.2 ( (r/R) ) or ( 2.0 + [4T/r(2R + t_r)] / (r/R) )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nozzles in Cylindrical Shells</th>
<th>Longitudinal Plane</th>
<th>Transverse Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Indices</td>
<td>Inside</td>
<td>Outside</td>
</tr>
<tr>
<td>( \sigma_a )</td>
<td>3.1</td>
<td>1.2</td>
</tr>
<tr>
<td>( \sigma_t )</td>
<td>-0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>( \sigma_r )</td>
<td>( -2T/r(2R + t_r) )</td>
<td>0</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>3.3</td>
<td>1.2</td>
</tr>
</tbody>
</table>
the right of the end of the material line. From this intersection, move horizontally to the right and read the value of $B$.

**Step 3.** Using this value of $B$, calculate the maximum allowable pressure by the following equation:

$$P_a = \left[ \frac{2.167 L_s (T + A_s / L_s) A}{D_0 / T - 0.0833} \right]^{1.9}$$

**Step 4.** If $P_a$ is less than the external Design Pressure $P$, repeat the procedure using a larger value for $T$.

### NC-3243 Spherical Shells

The minimum thickness of a spherical shell under external pressure shall be determined by the procedure given in NC-3133.4.

### NC-3244 Stiffening Rings for Cylindrical Shells

**NC-3244.1 Required Moment of Inertia for Circumferential Stiffening Rings.** The required moment of inertia of the combined ring shell section is given by the equation:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

The moment of inertia for a stiffening ring shall be determined by the procedure given in **Step 1** through **Step 6** below.

**Step 1.** Assuming that the shell has been designed and $D_o$, $L_s$, and $T$ are known, select a member to be used for the stiffening ring and determine its area $A_s$ and the value of $I_s$. Calculate $B$ by the equation:

$$B = \left[ \frac{P D_o}{T + A_s / L_s} \right]^{3/4}$$

**Step 2.** Enter the right hand side of the chart in Section II, Part D, Subpart 3 for the material under consideration at the value of $B$ determined in **Step 1**.

**Step 3.** Move horizontally to the material line for the Design Temperature.

**Step 4.** From this intersection move vertically to the bottom of the chart and read the value of $A$.

**Step 5.** Compute the value of the required moment of inertia $I_s$ from the equation given above.

**Step 6.** If the required $I_s$ is greater than the computed moment of inertia for the combined ring shell section selected in **Step 1**, a new section with a larger moment of inertia must be selected and a new $I_s$ determined. If the required $I_s$ is less than the computed moment of inertia for the section selected in **Step 1**, that section should be satisfactory.

### NC-3244.2 Permissible Methods of Attaching Stiffening Rings.** Stiffening rings shall be attached to either the outside or the inside of the vessel in accordance with NC-4267.

### NC-3245 Cylinders Under Axial Compression

The maximum allowable compressive stress in cylindrical shells subjected to loadings that produce longitudinal compressive stresses shall be the smaller of the values determined by (a) and (b) below:

(a) the $S_m$ value for the applicable material at Design Temperature given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4;

(b) the value of the factor $B$ determined in accordance with NC-3133.6(b).

### NC-3250 WELDED JOINTS

### NC-3251 Welded Joint Categories

Welded joint categories are defined in NC-3351.

### NC-3252 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 NC-3352-1 shows typical butt welds for each category joint.

**NC-3252.1 Joints of Category A.** All welded joints of Category A shall meet the fabrication requirements of NC-4263 and shall be capable of being examined in accordance with NC-5251.

**NC-3252.2 Joints of Category B.** All welded joints of Category B shall meet the fabrication requirements of NC-4264 and shall be capable of being examined in accordance with NC-5252. When fatigue analysis of Type 2 joints is required and backing strips are not removed, stress concentration factors of 2.0 for membrane stresses and of 2.5 for bending stresses shall be applied in the design of the joints.

**NC-3252.3 Joints of Category C.** All welded joints of Category C shall meet the fabrication requirements of NC-4265 and shall be capable of being examined in accordance with NC-5253. Minimum dimensions shall be as specified in NC-3258.3 and NC-3258.4.

**NC-3252.4 Joints of Category D.** All welded joints of Category D shall be in accordance with the requirements of NC-3259 and one of (a) through (d) below.

(a) Butt Welded Nozzles. Nozzles shall meet the fabrication requirements of NC-4266(a) and shall be capable of being examined in accordance with NC-5254. The minimum dimensions and geometrical requirements of Figure NC-4266(a)-1 shall be met where:

$$r_1 = \frac{1}{4}t \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less}$$

$$r_2 = \frac{1}{4} \text{ in. (6 mm) min.}$$

$t = \text{nominal thickness of part penetrated}$

$t_n = \text{nominal thickness of penetrating part}$
(b) Full Penetration Corner Welded Nozzles. Nozzles shall meet the fabrication requirements of NC-4266(b) and shall be capable of being examined as required in NC-5254. The minimum dimensions of Figure NC-4266(b)-1 shall be met where:

\[
\begin{align*}
  r_1 &= \frac{1}{4} t_n \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less} \\
  r_2 &= \frac{1}{4} \text{ in. (6 mm) min.} \\
  r_3 &= \frac{1}{4} t_n \text{ or } \frac{1}{8} \text{ in. (10 mm), whichever is less, or chamfer} \\
  t &= \text{ thickness of part penetrated} \\
  t_c &= 0.7 t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \\
  t_n &= \text{ thickness of penetrating part}
\end{align*}
\]

(c) Pad and Screwed Fitting Types of Welded Nozzles. Nozzles and fittings shall meet the fabrication requirements of NC-4266(c) and shall be capable of being examined in accordance with NC-5254. The minimum dimensions and geometrical requirements of Figure NC-4266(c)-1 shall be met, where:

\[
\begin{align*}
  c &= \text{ smaller of } 0.7t_c \text{ or } 0.7t \\
  r_1 &= \frac{1}{4} t_n \text{ or } \frac{3}{8} \text{ in. (10 mm), whichever is less} \\
  r_3 &= \frac{1}{4} t_n \text{ or } \frac{1}{8} \text{ in. (10 mm), whichever is less, or chamfer} \\
  t &= \text{ thickness of shell} \\
  t_c &= 0.7 t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \\
  t_n &= \text{ thickness of reinforcement element}
\end{align*}
\]

(d) Attachment of Nozzles Using Partial Penetration Welds. Partial penetration welds shall meet the fabrication requirements of NC-4266(d) and shall be capable of being examined in accordance with NC-5254. They shall be used only for attachments such as instrumentation openings and inspection openings, which are subjected to essentially no external mechanical loadings and on which there will be no thermal stresses greater than in the vessel itself. Such attachments shall satisfy the rules for reinforcement of openings, except that no material in the neck shall be used for reinforcement in the attachment. The inside diameter of such openings shall not exceed 4 in. (100 mm). The minimum dimensions of Figure NC-4266(d)-1 shall be met where:

\[
\begin{align*}
  C &= \text{ maximum diametral clearance between nozzle and vessel penetration, in. (mm)} \\
  &= 0.010 \text{ in. for } d \leq 1 \text{ in. (0.25 mm for } d \leq 25 \text{ mm)} \\
  &= 0.020 \text{ in. for } 1 \text{ in. } < d \leq 4 \text{ in. (0.50 mm for } 25 \text{ mm } < d \leq 100 \text{ mm)} \\
  &= 0.030 \text{ in. for } d > 4 \text{ in. (0.75 mm for } d > 100 \text{ mm), except that the above limits on maximum clearance need not be met for the full length of the opening, provided there is a region at the weld preparation and a region near the end of the opening opposite the weld that does meet the above limit on maximum clearance and the latter region is extensive enough (not necessarily continuous) to provide a positive stop for nozzle deflection.}
\end{align*}
\]

\[
\begin{align*}
  d &= \text{ outside diameter of nozzle} \\
  r_1 &= \frac{1}{4} t_n \text{ or } \frac{1}{4} \text{ in. (19 mm), whichever is less} \\
  t &= \text{ nominal thickness of vessel} \\
  t_c &= 0.7t \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less} \\
  t_n &= \text{ nominal thickness of neck} \\
  t_w &= \text{ depth of weld penetration, not less than } \frac{1}{4} t_n, \text{ in. (mm)}
\end{align*}
\]

NC-3254 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NC-4267.

NC-3255 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 NC-3252.4.

NC-3257 Welded Joints Subject to Bending Stress

The requirements of NC-3357 shall be met.

NC-3258 Design Requirements for Head Attachments

NC-3258.1 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 NC-3358.1(a)-1.

(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 NC-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 \( \frac{1}{6} \) in., whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment [Figure NC-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

NC-3258.2 Unstayed Flat Head Welded to Shells.

The requirements of welded unstayed flat heads to shells are given in NC-3225, NC-3258.3, and NC-3258.4.

NC-3258.3 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, the welds shall meet the requirements given in (a) through (e) below.

(a) On the cross section through the welded joint, the line 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 supported and unsupported tubesheets with a projection for a bolted connection, the sum of \( a \) and \( b \) shall be not less than three times the nominal wall thickness of the abutting pressure parts.

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

(d) 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 permitted.

(e) The minimum dimensions in Figures NC-4265-1 and NC-4265-2 are as follows:

\begin{enumerate}
  \item \textbf{Figure NC-4265-1}
    \begin{enumerate}
      \item Sketch \( a \)
      \[
      a + b \text{ not less than } 2t_s
      \]
      \[
      b + c \text{ not less than } t_s
      \]
      \[
      t_p \text{ not less than } t_s
      \]
      \item Sketch \( b \)
      \[
      a + b \text{ not less than } 2t_s
      \]
      \item Sketch \( c \)
      \[
      a + b \text{ not less than } 3t_s
      \]
      \[
      b + c \text{ not less than } t_s
      \]
      \item Sketches \( d \) and \( e \)
    \end{enumerate}
  \item \textbf{Figure NC-4265-2}
    \begin{enumerate}
      \item Sketch \( a \)
      \[
      b \text{ = the lesser of } t_s/2 \text{ or } T/4
      \]
      \[
      c \text{ = } 0.7t_s \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less}
      \]
      \[
      T, t_s \text{ = nominal thickness of welded parts}
      \]
      \item Sketch \( b \)
      \[
      t \text{ and } t_n \text{ = nominal thickness of welded parts}
      \]
      \[
      h \text{ or } g \text{ = } 0.25t_n \text{ but not less than } \frac{1}{4} \text{ in. (6 mm)}
      \]
      \[
      t_n \text{ = nominal thickness of neck}
      \]
      \[
      a + b \text{ not less than } 3t_n
      \]
      \[
      c \text{ not less than } t_n
      \]
    \end{enumerate}
\end{enumerate}

\textbf{NC-3258.4 Head Attachments Using Butt Welds.}

When flat heads are attached using butt welds, as shown in Figure NC-4243.1-1, the minimum dimensions are as follows:

\begin{enumerate}
  \item Sketch \( a \)
  \[
  r \text{ not less than } 1.5t_s
  \]
  \item Sketch \( b \)
  \[
  r \text{ not less than } 1.5t_s
  \]
  \[
  e \text{ not less than } t_s
  \]
  \item Sketch \( c \)
  \[
  h \text{ not less than } 1.5t_s
  \]
  \item Sketch \( d \)
  \[
  t_f \text{ not less than } 2r
  \]
  \[
  r \text{ not less than } 3t_f
  \]
  \item Sketch \( e \)
  \[
  t_f \text{ not less than } 2r
  \]
  \[
  r \text{ not less than } 3t_f
  \]
  \[
  e \text{ not less than } t_f
  \]
\end{enumerate}

\textbf{NC-3259 Design Requirements for Nozzle Attachment Welds and Other Connections}

The minimum design requirements for nozzle attachment welds and other connections are set forth in (a) through (c) below.

(a) \textbf{Permitted Types of Nozzles and Other Connections.} Nozzles and other connections may be any of the types for which rules are given in this subarticle, provided the requirements of (1) through (7) below are met.

(1) Nozzles shall meet requirements regarding location.

(2) The attachment weld shall meet the requirements of \textbf{NC-3252.4}.

(3) The requirements of \textbf{NC-3230} shall be met.

(4) Type No. 1 full penetration joints shall be used when the openings are in shells \( 2\frac{1}{2} \text{ in. (64 mm)} \) or more in thickness.

(5) The welded joints shall be examined by the methods stipulated in \textbf{NC-5250}.

(6) Studded connections shall meet the requirements of \textbf{NC-3262.4}.

(7) Threaded connections shall meet the requirements of \textbf{NC-3266}.
(b) Provision of Telltale Holes for Air Testing. Reinforcing plates and saddles attached to the outside of a vessel shall be provided with at least one telltale hole, of maximum size 1/4 in. (6 mm) pipe tap, that may be tapped for a preliminary compressed air and soap solution or equivalent test for tightness of welds that seal off the inside of the vessel. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall. Telltale holes shall not be plugged during heat treatment.

(c) Attachments. Typical attachments are shown in Figure NC-4267-1. The minimum dimensions in this figure are as follows:

\[ a \geq t/4; \quad b \geq t/2; \quad C \geq t \]

where

\[ c = \text{minimum thickness of weld metal from the root to the face of the weld} \]
\[ t = \text{thickness of attached member} \]

NC-3260 SPECIAL VESSEL REQUIREMENTS

NC-3261 Transition Joints Between Sections of Unequal Thickness

Unless the requirements of Section III Appendices, Mandatory Appendix XIII, or Mandatory Appendix II are shown to be satisfied, a tapered transition as shown in Figures NC-3358.1(a)-1 and NC-3361.1-1 shall be provided at joints of Categories A and B 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). The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section. When Section III Appendices, Mandatory Appendix XIII, or Mandatory Appendix II are not used, the following requirements of (a) through (e) below shall also apply.

(a) The length of taper shall be not less than three times the offset between adjacent surfaces.

(b) Figure NC-3361.1-1 shall apply to all joints of Categories A and B except joints connecting formed heads to main shells, for which case Figure NC-3358.1(a)-1 shall apply.

(c) When a taper is required on any formed head intended for butt welded attachment, the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

(d) An ellipsoidal or hemispherical head which has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder, provided the remaining thickness is at least as great as that required for a shell of the same diameter.

(e) The requirements of this paragraph are not applicable to flange hubs.

NC-3262 Bolted Flanged Connections

NC-3262.1 Flanges and Flanged Fittings Conforming to ASME B16.5. Except as provided in NC-3262.3, the dimensional requirements of flanges used in bolted flange connections to external piping shall conform to ASME B16.5, Steel Pipe Flanges and Flanged Fittings. Flanges and flanged fittings conforming to ASME B16.5 and listed in Tables 8 through 28 of that Standard, with the exception of threaded and socket welding types, may be used at the pressure-temperature ratings specified in that Standard.

NC-3262.2 Slip-On Flanges Conforming to ASME B16.5. Slip-on flanges conforming to ASME B16.5 may be used, provided all the conditions of (a) through (e) below are met.

(a) The specified minimum tensile strengths of materials do not exceed 80.0 ksi (550 MPa).

(b) The minimum elongation of materials is 12% in 2 in. (50 mm).

(c) The thickness of the materials to which the flange is welded does not exceed 1/4 in. (32 mm).

(d) The throat thickness, taken as the minimum thickness in any direction through the attaching fillet welds, is at least 0.7 times the thickness of the material to which the flange is welded.

(e) The fatigue analysis described for nozzles with separate reinforcement and nonintegral attachments, as set forth in NC-3219.3, is applied to the design.

NC-3262.3 Flanges Not Conforming to ASME B16.5. Flanges that do not conform to ASME B16.5 shall be designed in accordance with the Rules for Bolted Flange Connections, Section III Appendices, Mandatory Appendix XI, or by the rules of Section III Appendices, Mandatory Appendices II and XIII.

NC-3262.4 Studded Connections. 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 \( d \) or

\[
0.75d_s \times \frac{\text{Design stress intensity value of stud material at Design Temperature}}{\text{Design stress intensity value of tapped material at Design Temperature}}
\]

in which \( d \) is the root diameter of the stud, except that the thread engagement need not exceed \( 1/2d_s \).

NC-3263 Access and Inspection Openings

The requirements for access and inspection openings are given in NC-3363.

NC-3264 Attachments and Supports

NC-3264.1 General Requirements. Supports, lugs, brackets, stiffeners, and other attachments may be welded or stud bolted to the outside or inside of a vessel
wall. All stud bolted attachments require a detailed fatigue analysis in accordance with the requirements of Section III Appendices, Mandatory Appendix XIII unless the conditions of NC-3219 are met. Attachments shall conform reasonably to the curvature of the shell to which they are to be attached. The fabrication requirements of NC-4267 and the examination requirements of NC-5250 shall be met.

**NC-3264.2 Attachment Materials.** Materials welded directly to pressure parts shall meet the requirements of NC-2190.

**NC-3264.3 Design of Attachments.** The effects of attachments, including external and internal piping connections, shall be taken into account in the design. Attachments shall meet the requirements of NC-3135.

**NC-3264.4 Design of Supports.**

(a) All vessels shall be so supported and the supporting members so arranged and attached to the vessel as to provide for the maximum imposed loadings. Wind and earthquake loads need not be assumed to occur simultaneously.

(b) All supports should be designed to prevent excessive localized stresses due to temperature changes in the vessel or deformations produced by the internal pressure.

(c) Horizontal vessels supported by saddles shall provide bearing extending over at least one-third of the shell circumference.

(d) Additional requirements for the design of supports are given in NCA-3240 and Subsection NF.

**NC-3264.5 Types of Attachment Welds.** Welds attaching nonpressure parts or stiffeners to pressure parts shall meet the requirements of NC-4267.

**NC-3264.6 Stress Values for Weld Material.** Attachment weld strength shall be based on the nominal weld area and the design stress intensity values in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 and stress criteria in NC-3200 for the weaker of the two materials joined, or, where weaker weld metal is permitted, the design stress intensity values of the weld metal multiplied by the following reduction factors: 0.5 for fillet welds NC-3264.5; 0.75 for partial penetration groove or partial penetration groove plus fillet welds NC-3264.5; 1.0 for complete weld penetration. The nominal weld area for fillet welds is the throat area; for groove welds, the depth of penetration times the length of weld; and for groove welds with fillet welds, the combined throat and depth of penetration, exclusive of reinforcement, times the length of weld.

(a) Attachment Welds — Evaluation of Need for Fatigue Analysis. In applying Condition AP or BP of NC-3219.3, fillet welds and partial penetration welds are considered nonintegral attachments, except that the following welds need not be considered:

(1) welds for minor attachments

(2) welds for supports which may be considered integral as covered by Conditions A and B of NC-3219.2

### NC-3266 Threaded Connections

(a) Threads

(1) 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 NC-3266-1 after allowance has been made for curvature of the vessel wall. A built-up pad or a properly attached plate or fitting shall be used to provide the metal thickness and number of threads required in Table NC-3266-1 or to furnish reinforcement when required.

(2) Straight threaded connections may be employed as provided for in (b)(2).

(b) Restrictions on the Use of Threaded Connections

(1) Taper Threaded Connections. Internal taper pipe thread connections larger than NPS 2 (DN 50) shall not be used.

(2) Straight Threaded Connections

(a) Threaded connections employing straight threads shall provide for mechanical seating of the assembly by a shoulder or similar means. Straight thread center openings in vessel heads shall meet the requirements of NC-3230. The length of the thread shall be calculated for the opening design and they shall not exceed the smaller of one-half the vessel diameter or NPS 8 (DN 200). In addition, they shall be placed at a point where the calculated stress without a hole, due to any combination of design pressure and mechanical loadings expected to occur simultaneously, is not more than 0.5Sn.

(b) Threaded connections above 2\(\frac{3}{4}\) in. (70 mm) in diameter may be used only if they meet the requirements of NC-3219, or, if these requirements are not met, a detailed fatigue analysis shall be made in accordance with the rules of Section III Appendices, Mandatory Appendix XIII.

### Table NC-3266-1

<table>
<thead>
<tr>
<th>Size of Pipe Connection, NPS (DN)</th>
<th>Threads Engaged</th>
<th>Min. Plate Thickness Required, in. (mm)</th>
</tr>
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<tbody>
<tr>
<td>(\frac{3}{8}) (15)</td>
<td>6</td>
<td>0.43 (11)</td>
</tr>
<tr>
<td>(\frac{1}{4}) (20)</td>
<td>6</td>
<td>0.43 (11)</td>
</tr>
<tr>
<td>1 (25)</td>
<td>6</td>
<td>0.61 (16)</td>
</tr>
<tr>
<td>(1\frac{1}{4}) (32)</td>
<td>6</td>
<td>0.61 (16)</td>
</tr>
<tr>
<td>(1\frac{1}{2}) (40)</td>
<td>6</td>
<td>0.61 (16)</td>
</tr>
<tr>
<td>2 (50)</td>
<td>8</td>
<td>0.70 (18)</td>
</tr>
</tbody>
</table>

Changes are as described on Page 1
No other changes on this page

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