In the event that compliance with (a) and (b) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

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

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

NC-3329 Ligaments

(a) The symbols used are defined as follows:
- \(d\) = diameter of tube holes
- \(n\) = number of tube holes in length \(p_1\)
- \(p\) = longitudinal pitch of tube holes
- \(p_1\) = unit length of ligament
- \(p'\) = diagonal pitch of tube holes

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figures NC-3329(b)-1 through NC-3329(b)-3, the efficiency of the ligaments between the tube holes shall be determined by (1) or (2) below:

\[
\frac{d}{p} = \text{efficiency of ligament}
\]

(1) when the pitch of the tube holes on every row is equal [Figure NC-3329(b)-1], the equation is:

\[
\frac{p - d}{p} = \text{efficiency of ligament}
\]

(2) when the pitch of tube holes on any one row is unequal [Figures NC-3329(b)-2 and NC-3329(b)-3], the equation is:

\[
\frac{p_1 - nd}{p_1} = \text{efficiency of ligament}
\]

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

(d) When a cylindrical shell is drilled for tube holes so as to form diagonal ligaments, as shown in Figure NC-3329(d)-1, the efficiency of these ligaments shall be that given by the diagram in Figure NC-3329(d)-2. The pitch of tube holes shall be measured either on the flat plate before rolling or on the middle line of the plate after rolling. To use the diagram in Figure NC-3329(d)-2, compute the value of \(p'/p_1\), and also the efficiency of the longitudinal ligament. Next, find in the diagram the vertical line corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of \(p'/p_1\). Then project this point horizontally to the left and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The shell thickness and the maximum allowable pressure shall be based on the ligament that has the lower efficiency.

(e) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group,
the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable pressure is based.

(f) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both (1) and (2) below.\(^{22}\)

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

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

(g) For holes which are not in line, placed longitudinally along a cylindrical shell, the rules in (f) above for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width, the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Figure NC-3329(g)-1.

Paragraph that references NC endnote 22.
ENDNOTES

1 Because of the different thermal coefficients of expansion of dissimilar materials, caution shall be exercised in construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint such as may occur at points of stress concentration and also because of metallurgical changes occurring at high temperatures.

2 Any postweld heat treatment time that is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

3 $T_{NDT}$ — temperature at or above the nil-ductility transition temperature NDT (ASTM E208); $T_{NDT}$ is 10°F (5°C) below the temperature at which at least two specimens show no-break performance.

4 **Lowest Service Temperature** (LST) is the minimum temperature of the fluid retained by the component or, alternatively, the calculated minimum metal temperature whenever the pressure within the component exceeds 20% of the preoperational system hydrostatic test pressure.

5 The **Lowest Service Metal Temperature** shall be the lowest temperature that the metal may experience in service while the plant is in operation and shall be established by appropriate calculations based on atmospheric ambient conditions, the insulation or enclosure provided, and the minimum temperature that will be maintained inside the vessel during the plant operation.

6 The requirements for impact testing of the heat-affected zone (NC-4335.2) may result in reduced test temperatures or increased toughness requirements for the base material.

7 For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels, use the lesser of:
   (a) the maximum radial thickness of the item, exclusive of integral butt welded projections;
   (b) the vessel shell thickness to which the item is welded;
   (c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges.

8 The methods given in the Appendix of SFA-5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

9 The volumetric examinations required by this paragraph need only be conducted from one surface.

10 It is recognized that high localized and secondary stresses may exist in components designed and fabricated in accordance with the rules of this Subsection; however, insofar as practical, design rules for details have been written to hold such stresses at a safe level consistent with experience.

11 Thermal protection devices, such as thermal sleeves in nozzles, may be used to reduce temperature differences or thermal shock.

12 **Adjacent points** are defined in (a) and (b) below.
   (a) For surface temperature differences:
      (1) on surfaces of revolution, in the meridional direction, adjacent points are defined as points that are less than the distance $2\sqrt{Rt}$, where $R$ is the radius measured normal to the surface from the axis of rotation to the midjoint wall, and $t$ is the thickness of the part at the point under consideration; if the product of $Rt$ varies, the average value of the points shall be used;
      (2) on surfaces of revolution, in the circumferential direction and on flat parts (such as flanges and flat heads) adjacent points are defined as any two points on the same surface.
22 The rules in NC-3329(f) apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups that extend a distance greater than the inside diameter of the shell as covered in NC-3329(e). When this occurs, the efficiencies computed by the rules under NC-3329(b) shall govern.

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

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

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

26 All dimensions given are nominal.

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

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

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

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

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

32 Socket welds should not be used where the existence of crevices could accelerate corrosion.

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

34 These rules do not limit storage tanks from being installed below grade or below ground, provided the tanks are not subject to external pressure resulting from earth or fill.
ND-3329.5 Dimensions of Staybolts.

(a) The required area of a staybolt at its minimum cross section$^{12}$ and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt, computed in accordance with (b) below, and by increasing the allowable stress value by a factor of 1.10 for the material used (Section II, Part D, Subpart 1, Tables 1A and 1B).

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

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

ND-3329.6 Ligaments.

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

\[
\begin{align*}
  d & = \text{diameter of tube holes, in. (mm)} \\
  n & = \text{number of tube holes in length } p_1 \\
  p & = \text{longitudinal pitch of tube holes, in. (mm)} \\
  p' & = \text{diagonal pitch of tube holes, in. (mm)} \\
  p_1 & = \text{unit length of ligament, in. (mm)}
\end{align*}
\]

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figures ND-3329.6(b)-1 through ND-3329.6(b)-3, the efficiency of the ligaments between the tube holes shall be determined as follows:

(1) when the pitch of the tube holes on every row is equal [Figure ND-3329.6(b)-1], the equation is \((p - d)/p = \text{efficiency of ligament}\);

(2) when the pitch of tube holes on any one row is unequal [Figures ND-3329.6(b)-2 and ND-3329.6(b)-3], the equation is \((p_1 - nd)/p_1 = \text{efficiency of ligament}\).

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

Figure ND-3329.6(b)-1
Example of Tube Spacing With Pitch of Holes Equal in Every Row

\[
\begin{array}{cccccccc}
5\frac{1}{4} & 5\frac{1}{4} & 5\frac{1}{4} & 5\frac{1}{4} & 5\frac{1}{4} & 5\frac{1}{4} & 5\frac{1}{4} & 5\frac{1}{4} \\
\text{in.} & \text{in.} & \text{in.} & \text{in.} & \text{in.} & \text{in.} & \text{in.} & \text{in.}
\end{array}
\]

GENERAL NOTE: 5\(\frac{1}{4}\) in. = 133 mm
When a cylindrical shell is drilled for tube holes so as to form diagonal ligaments, as shown in Figure ND-3329.6(d)-1, the efficiency of these ligaments shall be that given by the diagram in Figure ND-3329.6(d)-2. The pitch of tube holes shall be measured either on the flat plate before rolling or on the middle line of the plate after rolling. To use the diagram in Figure ND-3329.6(d)-2, compute the value of \( p'/p \) and also the efficiency of the longitudinal ligament. Next find in the diagram the vertical line corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of \( p'/p \). Then project this point horizontally to the left and read the diagonal efficiency of the ligament at the scale on the diagram.

The shell thickness and the maximum allowable pressure shall be based on the ligament that has the lower efficiency.

(c) When tube holes in a cylindrical shell are arranged in symmetrical groups that extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable pressure is based.

(f) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both (1) and (2) below.\(^\text{13}\)

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

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

(g) For holes that are not in line, placed longitudinally along a cylindrical shell, the rules in (f) above for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width, the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Figure ND-3329.6(g)-1.
ENDNOTES

1 Because of the different thermal coefficients of expansion of dissimilar materials, caution shall be exercised in construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint such as may occur at points of stress concentration and also because of metallurgical changes occurring at high temperatures.

2 Any postweld heat treatment time that is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

3 **Lowest Service Temperature (LST)** is the minimum temperature of the fluid retained by the component, or, alternatively, the calculated minimum metal temperature whenever the pressure within the component exceeds 20% of the preoperational system hydrostatic test pressure.

4 The requirements for impact testing of the heat affected zone (ND-4335.2) may result in reduced test temperatures or increased toughness requirements for the base material.

5 The methods given in the Appendix of SFA 5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

6 It is recognized that high localized and secondary stresses may exist in components designed and fabricated in accordance with the rules of this Subsection; however, insofar as practical, design rules for details have been written to hold such stresses at a safe level consistent with experience.

7 **Stress** means the maximum normal stress.

8 The minimum thickness for all pipe materials is the nominal wall thickness listed in Table 2 of ASME B36.10M less 121/2%. For diameters other than those listed in the table, this shall be based on the next larger pipe size.

9 Special consideration shall be given to the design of shells, nozzle necks, or flanges to which noncircular heads or covers are attached.

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

11 Since \( Hr \) in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for the flange design.

12 The minimum cross section is usually at the root of the thread.

13 The rules in this paragraph apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups that extend a distance greater than the inside diameter of the shell as covered in ND-3329.6(c). When this occurs, the efficiencies computed by the rules under ND-3329.6(b) shall govern.

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

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

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

Errata. Should be ND-3329.6(e)