(4) It is recognized that it is impractical to write requirements to cover the multiplicity of devices used for quick access, or to prevent negligent operation or the circumventing of safety devices. Any device or devices that will provide the safeguards broadly described in (1)(-a), (1)(-b), and (1)(-c) above will meet the intent of this Division.

(4) Alternative Designs for Manually Operated Closures

1. Quick-actuating closures that are held in position by a locking mechanism designed for manual operation shall be designed such that if an attempt is made to open the closure when the vessel is under pressure, the closure will leak prior to full disengagement of the locking components and release of the closure. The design of the closure and vessel shall be such that any leakage shall be directed away from the normal position of the operator.

2. Manually operated closures need not satisfy (c)(1)(-a), (c)(1)(-b), or (c)(1)(-c) above, but such closures shall be equipped with an audible or visible warning device that will warn the operator if pressure is applied to the vessel before the holding elements and locking components are fully engaged in their intended position or if an attempt is made to disengage the locking mechanism before the pressure within the vessel is released.

3. Supplementary Requirements for Quick-Actuation (Quick-Opening) Closures

Nonmandatory Appendix FF provides additional design information for the Manufacturer and provides installation, operational, and maintenance requirements for the Owner and the user.

OPENINGS AND REINFORCEMENTS

UG-36 OPENINGS IN PRESSURE VESSELS

(a) Shape of Opening

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

2. Openings may be of other shapes than those given in (1) above, and all corners shall be provided with a suitable radius. When the openings are of such proportions that their strength cannot be computed with assurance of accuracy, or when doubt exists as to the safety of a vessel with such openings, the part of the vessel affected shall be subjected to a proof hydrostatic test as prescribed in UG-101.

(b) Size of Openings

1. Properly reinforced openings in cylindrical and conical shells are not limited as to size except with the following provisions for design. The rules in UG-36 through UG-43 apply to openings not exceeding the following: for vessels 60 in. (1 500 mm) inside diameter and less, one-half the vessel diameter, but not to exceed 20 in. (500 mm) for vessels over 60 in. (1 500 mm) inside diameter, one-third the vessel diameter, but not to exceed 40 in. (1 000 mm). (For conical shells, the inside shell diameter as used above is the cone diameter at the center of the opening.) For openings exceeding these limits, supplemental rules of 1-7 shall be satisfied in addition to the rules of this paragraph. Alternatively, openings in cylindrical or conical shells exceeding these limits may be designed for internal pressure using the rules of (c)(2)(-d).

2. Properly reinforced openings in formed heads and spherical shells are not limited in size. For an opening in an end closure, which is larger than one-half the inside diameter of the shell, one of the following alternatives to reinforcement may also be used:

(a) a conical section as shown in Figure UG-36 sketch (a);

(b) a cone with a knuckle radius at the large end as shown in Figure UG-36 sketch (b);

(c) a reverse curve section as shown in Figure UG-36 sketches (c) and (d); or

(d) using a flare radius at the small end as shown in Figure UG-33.1 sketch (d).

The design shall comply with all the requirements of the rules for reducer sections (see (e) below) insofar as these rules are applicable.

(c) Strength and Design of Finished Openings

1. All references to dimensions in this and succeeding paragraphs apply to the finished construction after deduction has been made for material added as corrosion allowance. For design purposes, no metal added as corrosion allowance may be considered as reinforcement. The finished opening diameter is the diameter \( d \) as defined in UG-37 and in Figure UG-40.

2. See below:

(a) Openings in cylindrical or conical shells, or formed heads shall be reinforced to satisfy the requirements in UG-37 except as given in (-c), (-d), and (3) below.

(b) Openings in flat heads shall be reinforced as required by UG-39.

(c) Openings in cylindrical and conical shells subjected to internal pressure may be designed to satisfy the requirements in Mandatory Appendix 1, 1-9 in lieu of the internal pressure requirements in UG-37.

(d) Openings in cylindrical and conical shells subjected to internal pressure may be designed to satisfy the requirements in Mandatory Appendix 1, 1-10 in lieu of the internal pressure requirements in UG-37.

3. Openings in vessels not subject to rapid fluctuations in pressure do not require reinforcement other than that inherent in the construction under the following conditions:
representing the value of \( p'/d \). Then project this point horizontally to the left, and read the equivalent longitudinal efficiency of the diagonal ligament. This equivalent longitudinal efficiency is used to determine the minimum required thickness and the maximum allowable working pressure.

\( (g) \) 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 working pressure is based.

\( (h) \) 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. For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable working pressure is based. When the inside 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 which gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable working pressure is based. When the inside radius of the shell exceeds 30 in., the length shall be taken as 30 in. (760 mm) in applying this rule.

\( (i) \) When ligaments occur in cylindrical shells made from welded pipe or tubes, and their calculated efficiency is less than 85% (longitudinal) or 50% (circumferential), the efficiency to be used in the equations of UG-27 is the calculated ligament efficiency. In this case, the appropriate stress value in tension (see UG-23) may be multiplied by the factor 1.18.

### UG-54 SUPPORTS

\( (a) \) All vessels shall be so supported and the supporting members shall be arranged and/or attached to the vessel wall in such a way as to provide for the maximum imposed loadings (see UG-22 and UG-82).

\( (b) \) Nonmandatory Appendix G contains suggested rules for the design of supports.
1-7 LARGE OPENINGS IN CYLINDRICAL AND CONICAL SHELLS

(a) Openings exceeding the dimensional limits given in UG-36(b)(1) shall be provided with reinforcement that complies with the following rules. Two-thirds of the required reinforcement shall be within the following limits:

(1) parallel to vessel wall: the larger of three-quarters times the limit in UG-40(b)(1), or equal to the limit in UG-40(b)(2);

(2) normal to vessel wall: the smaller of the limit in UG-40(c)(1), or in UG-40(c)(2).

(b) In addition to meeting the requirements of (a),

(1) openings for radial nozzles that exceed the limits in UG-36(b)(1) and that also are within the range defined by the following limits shall meet the requirements in (2), (3), and (4) below:

(-a) vessel diameters greater than 60 in. (1 520 mm) I.D.;

(-b) nozzle diameters that exceed 40 in. (1 020 mm) I.D. and also exceed \( \frac{3}{4} \sqrt{R} \); the terms \( R \) and \( t \) are defined in Figures 1-7-1 and 1-7-2;

(-c) the ratio \( \frac{R_n}{R} \) does not exceed 0.7; for nozzle openings with \( \frac{R_n}{R} \) exceeding 0.7, refer to U-2(g).

The rules are limited to radial nozzles in cylindrical and conical shells (with the half-apex angle equal to or less than 30 deg) that do not have internal projections, and do not include any analysis for stresses resulting from externally applied mechanical loads. For such cases, U-2(g) shall apply.

(2) The membrane stress \( S_m \) as calculated by eq. (4)(1) or (4)(2) below shall not exceed \( S \), as defined in UG-37 for the applicable materials at design conditions. The maximum combined membrane stress \( S_m \) and bending stress \( S_b \) shall not exceed 1.5\( S \) at design conditions. \( S_b \) shall be calculated by eq. (4)(5) below.

(3) Evaluation of combined stresses from pressure and external loads shall be made in accordance with U-2(g).

(4) For membrane stress calculations, use the limits defined in Figure 1-7-1, and comply with the strength of reinforcement requirements of UG-41. For bending stress calculation, the greater of the limits defined in Figure 1-7-1 or Figure 1-7-2 may be used. The strength reduction ratio requirements of UG-41 need not be applied, provided that the allowable stress ratio of the material in the nozzle neck, nozzle forging, reinforcing plate, and/or nozzle flange divided by the shell material allowable stress is at least 0.80.

NOTE: The bending stress \( S_b \) calculated by eq. (5) is valid and applicable only at the nozzle neck-shell junction. It is a primary bending stress because it is a measure of the stiffness required to maintain equilibrium at the longitudinal axis junction of the nozzle-shell intersection due to the bending moment calculated by eq. (3).

\[ S_m = P \left( \frac{R(R_n + t_n + \sqrt{R_{nm} t_n}) + R_n (t + \sqrt{R_{nm} t_n})}{A_s} \right) \]

Case B (see Figure 1-7-1)

\[ S_m = P \left( \frac{R(R_n + t_n + \sqrt{R_{nm} t_n}) + R_n (t + \sqrt{R_{nm} t_n})}{A_s} \right) \]

Cases A and B (See Figure 1-7-1 or Figure 1-7-2)

\[ M = \left( \frac{R_n^3}{6} + RR_n^2 \right) \]

\[ a = e + t/2 \]

\[ S_b = \frac{Ma}{I} \]

(5) Nomenclature. Symbols used in Figures 1-7-1 and 1-7-2 are as defined in UG-37(a) and as follows:

- \( A_s \) = shaded (cross-hatched) area in Figure 1-7-1, Case A or Case B
- \( a \) = distance between neutral axis of the shaded area and the inside of vessel wall
- \( e \) = distance between neutral axis of the shaded area and midwall of the shell
- \( I \) = moment of inertia of the larger of the shaded areas in Figure 1-7-1 or Figure 1-7-2 about neutral axis
- \( P \) = internal or external pressure
- \( R_m \) = mean radius of shell
- \( R_{nm} \) = mean radius of nozzle neck
- \( S_b \) = bending stress at the intersection of inside of the nozzle neck and inside of the vessel shell along the vessel shell longitudinal axis
- \( S_m \) = membrane stress calculated by eq. (4)(1) or eq. (4)(2)
- \( S_y \) = yield strength of the material at test temperature, see Table Y-1 in Subpart 1 of Section II, Part D

(c) In the design and fabrication of large openings, the Manufacturer should consider details that may be appropriate to minimize distortion and localized stresses around the opening. For example, reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening; weld may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations. The user and the Manufacturer should agree on the extent and type of non-destructive examination of welds that may be appropriate.
(d) Caution to the Designer. The design methods of 1-7(b) are particularly applicable to large bolted flanged nozzles in relatively thin \(D_i / t > 100\) vessels when the vessel nozzle flange is located close to the nozzle/shell intersection. The nozzle/shell intersection in these cases is more flexible and the usual assumption of axial-only strain may not be valid. This flexing results in strain redistribution around the nozzle circumference. Strain redistribution may cause distortion (ovaling) of the nozzle neck and flange such that a proper seal at the bolted flange connection cannot be obtained or maintained. Flanged connections with a minimum projection from flange face to outside surface of shell less than \(3.0 \sqrt{R_n t_n}\) may be affected by ovaling distortion and should be considered by the designer as permitted by U-2(g) or by the rules in 1-7(b).

For radial openings in shell having \(D_i/t\) greater than 200 and the nozzle I.D. \(d_n\) greater than 40 in. \((1000 \text{ mm})\), consideration should be given in design of reinforcement using the method in 1-7(b) or the rules of U-2(g).
4.10 DESIGN RULES FOR LIGAMENTS

4.10.1 SCOPE

4.10.1.1 Rules for determining the ligament efficiency for hole patterns in cylindrical shells are covered in this paragraph. The ligament efficiency or weld joint factor (see 4.10.3) is used in conjunction with the design equations for shells in 4.3.

4.10.2 LIGAMENT EFFICIENCY

4.10.2.1 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 4.10.1 through 4.10.3, the efficiency of the ligaments between the tube holes shall be determined as follows.

(a) When the pitch of the tube holes on every row is equal (see Figure 4.10.1), the ligament efficiency is:

\[
E = \frac{b - d}{p}
\]  

\(4.10.1\)

(b) When the pitch of tube holes on any one row is unequal (as in Figures 4.10.2 and 4.10.3), the ligament efficiency is:

\[
E = \frac{p_1 - nd}{p_1}
\]  

\(4.10.2\)

(c) When the adjacent longitudinal rows are drilled as described in (b), diagonal and circumferential ligaments shall also be examined. The least equivalent longitudinal efficiency shall be used to determine the minimum required thickness and the maximum allowable working pressure.

(d) When a cylindrical shell is drilled for holes so as to form diagonal ligaments, as shown in Figure 4.10.4, the efficiency of these ligaments shall be determined by Figures 4.10.5 and 4.10.6. Figure 4.10.5 is used to determine the efficiency of longitudinal and diagonal ligaments with limiting boundaries where the condition of equal efficiency of diagonal and longitudinal ligaments form one boundary and the condition of equal efficiency of diagonal and circumferential ligaments form the other boundary. Figure 4.10.6 is used for determining the equivalent longitudinal efficiency of diagonal ligaments. This efficiency is used in the equations for setting the minimum required thickness.

(1) Figure 4.10.5 is used when either or both longitudinal and circumferential ligaments exist with diagonal ligaments. To use Figure 4.10.5, 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 minimum shell thickness and the maximum allowable working pressure shall be based on the ligament that has the lower efficiency.

(2) Figure 4.10.6 is used for holes that are not in-line, or holes that are placed longitudinally along a cylindrical shell. The diagram may be used for pairs of holes for all planes between the longitudinal plane and the circumferential plane. To use Figure 4.10.6, determine the angle \(\theta\) between the longitudinal shell axis and the line between the centers of the openings and compute the value of \(p^*/d\). Find in the diagram, the vertical line corresponding to the value of \(\theta\) and follow this line vertically to the line representing the value of \(p^*/d\). Then project this point horizontally to the left, and read the equivalent longitudinal efficiency of the diagonal ligament. This equivalent longitudinal efficiency is used to determine the minimum required thickness and the maximum allowable working pressure.

(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 working 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 non-uniform spacing, shall be computed by the following rules and shall satisfy the requirements of both. These rules only apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups which extend a distance greater than the inside diameter of the shell as covered in (e). When this occurs, the efficiencies computed by the rules under (b) shall govern.

(1) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable working pressure is based. When the inside diameter of the shell exceeds 1520 mm (60 in.), the length shall be taken as 1520 mm (60 in.), 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 working pressure is based. When the inside radius of the shell exceeds 762 mm (30 in.), the length shall be taken as 762 mm (30 in.), in applying this rule.