4.15 DESIGN RULES FOR SUPPORTS AND ATTACHMENTS

4.15.1 SCOPE

The rules in 4.15 cover requirements for the design of structural support system(s) for vessels. The structural support system may be, but not limited to, saddles for a horizontal vessel, a skirt for a vertical vessel, or lug and leg type supports for either of these vessel configurations.

4.15.2 DESIGN OF SUPPORTS

4.15.2.1 Vessels shall be supported for all specified design conditions. The design conditions including load and load case combinations defined in 4.15.3 shall be considered in the design of all vessel supports.

4.15.2.2 Unless otherwise defined in this paragraph, if a stress analysis of the vessel and support attachment configuration is performed, the stress results in the vessel and in the support within the scope of this Division shall satisfy the acceptance criteria in Part 5.

4.15.2.3 The vessel support attachment shall be subject to the fatigue screening criteria of 5.5.2. In this evaluation, supports welded to the vessel may be considered as integral attachments.

4.15.2.4 All supports shall be designed to prevent excessive localized stresses due to deformations produced by the internal pressure or to thermal gradients in the vessel and support system.

4.15.2.5 Vessel support systems composed of structural steel shapes shall be designed in accordance with a recognized code or standard that cover structural design (e.g., Specification for Structural Steel Buildings published by the American Institute of Steel Construction). If the support is at a temperature above ambient due to vessel operation and the recognized code or standard does not provide allowable stresses at temperatures above ambient conditions, then the allowable stress, yield strength, and ultimate tensile strength, as applicable, shall be determined from Annex 3-A and Annex 3-D using a material with a similar minimum specified yield strength and ultimate tensile strength.

4.15.2.6 Attachment welds for structural supports shall be in accordance with 4.2.

4.15.2.7 Reinforcing plates and saddles attached to the outside of a vessel shall be provided with at least one vent hole that may be tapped for a preliminary compressed air and soap solution (or equivalent) test for tightness of welds that seal the edge of the reinforcing plates and saddles. These vent 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. Vent holes shall not be plugged during heat treatment.

4.15.2.8 If nonpressure parts such as support lugs, brackets, leg supports and saddles extend over pressure-retaining welds, then these welds shall be ground flush for the portion of weld that is covered, or the nonpressure parts shall be notched or coped to clear these welds.

4.15.3 SADDLE SUPPORTS FOR HORIZONTAL VESSELS

4.15.3.1 Application of Rules.

(a) Design Method - The design method in this paragraph is based on an analysis of the longitudinal stresses exerted within the cylindrical shell by the overall bending of the vessel, considered as a beam on two single supports, the shear stresses generated by the transmission of the loads on the supports, and the circumferential stresses within the cylindrical shell, the head shear and additional tensile stress in the head, and the possible stiffening rings of this shell, by this transmission of the loads on the supports. The stress modes of failure by excessive deformation and elastic instability, see 4.15.5.c.

(b) Geometry - A typical horizontal vessel geometry is shown in Figure 4.15.1. Saddle supports for horizontal vessels shall be configured to provide continuous support for at least one-third of the shell circumference, or \( \theta \geq 120 \, \text{deg.} \)

(c) Reinforcing Plates - If a reinforcing plate is included in the design to reduce the stresses in the cylindrical shell at the saddle support, then the width of the reinforcing plate, \( b_1 \), shall satisfy eq. (4.15.1) and provide a supporting arc length that satisfies eq. (4.15.2). A typical reinforcing plate arrangement is shown in Figure 4.15.2.

\[
b_1 = \min \left\{ 2a, \sqrt{2av} \right\} \quad (4.15.1)
\]

\[
\theta_1 = \frac{\theta}{12} \quad (4.15.2)
\]
(d) Stiffening Rings - Stiffening rings may be used at the saddle support location, on either the inside or outside of the cylindrical shell. The stiffening rings may be mounted in the plane of the saddle (see Figure 4.15.3) or two stiffening rings may be mounted on each side of the saddle support equidistant from the saddle support (see Figure 4.15.4). In the later case, the spacing between the two stiffening rings, \( h \), as shown in Figure 4.15.4 shall not be greater than \( R_m \). If \( h \leq 1.56\sqrt{R_mL} \) as shown in Figure 4.15.3, sketch (c), then both of the stiffening rings shall be considered as a single stiffening ring situated in the plane of the saddle in the stress calculations.

(19) 4.15.3.2 Moment and Shear Force.

(a) If the vessel is composed of a cylindrical shell with a formed head (i.e., torispherical, elliptical, or hemispherical) at each end that is supported by two saddle supports equally spaced and with \( a \leq 0.25L \), then the moment at the saddle, \( M_1 \), the moment at the center of the vessel, \( M_2 \), and the shear force at the saddle, \( T \), may be computed using the following equations.

\[
M_1 = -Qa \left( 1 - \frac{a}{L} + \frac{R_m^2 - a^2}{2L} \right) \quad (4.15.3)
\]

\[
M_2 = QL \left( 1 + \frac{2(R_h^2 - a^2)}{L} \right) \quad (4.15.4)
\]

\[
T = \frac{Q(L - 2a)}{L + \frac{4a}{3}} \quad (4.15.5)
\]

(b) If the vessel supports are not symmetric, or more than two supports are provided, then the highest moment in the vessel, and the moment and shear force at each saddle location shall be evaluated. The moments and shear force may be determined using strength of materials (i.e., beam analysis with a shear and moment diagram). If the vessel is supported by more than two supports, then differential settlement should be considered in the design.

4.15.3.3 Longitudinal Stress.

(a) The longitudinal membrane plus bending stresses in the cylindrical shell between the supports are given by the following equations.

\[
\sigma_1 = \frac{PR_m}{2t} - \frac{M_1}{\pi R_m t} \quad \text{(top of shell)} \quad (4.15.6)
\]

\[
\sigma_2 = \frac{PR_m}{2t} + \frac{M_2}{\pi R_m t} \quad \text{(bottom of shell)} \quad (4.15.7)
\]

(b) The longitudinal stresses in the cylindrical shell at the support location are given by the following equations. The values of these stresses depend on the rigidity of the shell at the saddle support. The cylindrical shell may be considered as suitably stiffened if it incorporates stiffening rings at, or on both sides of the saddle support, or if the support is sufficiently close defined as \( a \leq 0.5R_m \), to a torispherical or elliptical head (a hemispherical head is not considered a stiffening element), a flat cover, or tubesheet.

(1) Stiffened Shell - The maximum values of longitudinal membrane plus bending stresses at the saddle support are given by the following equations.

\[
\sigma_3 = \frac{PR_m}{2t} - \frac{M_1}{\pi R_m t} \quad \text{(top of shell)} \quad (4.15.8)
\]

\[
\sigma_4 = \frac{PR_m}{2t} + \frac{M_1}{\pi R_m t} \quad \text{(bottom of shell)} \quad (4.15.9)
\]

(2) Unstiffened Shell - The maximum values of longitudinal membrane plus bending stresses at the saddle support are given by the following equations. The coefficients \( K_1 \) and \( K_{-1} \) are given in Table 4.15.1.
Acceptance Criteria

(1) The absolute value of $\sigma_1$, $\sigma_2$, and $\sigma_3$, $\sigma_4$ or $\sigma^*_3, \sigma^*_4$, as applicable shall not exceed $SE$.

(2) If the any of the stresses in (a) or (b) above are negative, the absolute value of the stress shall not exceed $S_c$ that is given by eq. (4.15.12) where $K = 1.0$ for normal operating conditions and $K = 1.35$ for exceptional operating or hydrotest condition.

$$S_c = \frac{k R E_y}{16 R_m}$$  \hspace{1cm} (4.15.12)

4.15.3.4 Shear Stresses.

(a) The shear stress in the cylindrical shell with a stiffening ring in the plane of the saddle support is a maximum at Points C and D of Figure 4.15.5, sketch (b) and shall be computed using eq. (4.15.13).

$$\tau_1 = \frac{T}{\pi R_m t}$$  \hspace{1cm} (4.15.13)

(b) The shear stress in the cylindrical shell with stiffening rings on both sides of the saddle support is a maximum at Points E and F of Figure 4.15.5, sketch (c) and shall be computed using eq. (4.15.14). The coefficient $K_2$ is given in Table 4.15.1.

$$\tau_2 = \frac{K_2 T}{R_m t}$$  \hspace{1cm} (4.15.14)

(c) The shear stress in a cylindrical shell without stiffening ring(s) that is not stiffened by a formed head, flat cover, or tubesheet, ($a > 0.5 R_m$) is also at Points E and F of Figure 4.15.5, sketch (c) and shall be computed using eq. (4.15.14).

(d) The shear stress in the cylindrical shell without stiffening ring(s) and stiffened by a torispherical or elliptical head, flat cover, or tubesheet, ($a \leq 0.5 R_m$) is a maximum at Points E and F of Figure 4.15.5, sketch (c) and shall be computed using the equations shown below. In addition to the shear stress, the membrane stress in the formed head, if applicable, shall also be computed using the equations shown below.

(1) Shear stress, the coefficient $K_3$ is given in Table 4.15.1.

$$\tau_3 = \frac{K_3 Q}{R_m t}$$  \hspace{1cm} (4.15.15)

(2) Membrane stress in a torispherical or elliptical head acting as a stiffener, the coefficient $K_4$ is given in Table 4.15.1.

$$\sigma_5 = \frac{K_4 Q}{R_m h} + \frac{P h}{2 t}$$  \hspace{1cm} (torispherical head)  \hspace{1cm} (4.15.16)

$$\sigma_5 = \frac{K_4 Q}{R_m h} + \frac{P h}{2 t h}$$  \hspace{1cm} (elliptical head)  \hspace{1cm} (4.15.17)

(e) Acceptance Criteria

(1) The absolute value of $\tau_1$, $\tau_2$, and $\tau_3$, as applicable, shall not exceed min$(0.8 S, 0.533 S_y)$.

(2) The absolute value of $\tau^*_3$ shall not exceed min$(0.8 S_h, 0.533 S_{hy})$.

(3) The absolute value of $\sigma_5$ shall not exceed $1.25 S_h$. 

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4.15.3.5 Circumferential Stress.

(a) Maximum circumferential bending moment - the distribution of the circumferential bending moment at the saddle support is dependent on the use of stiffeners at the saddle location.

(1) Cylindrical shell without a stiffening ring or with a stiffening ring in the plane of the saddle - the maximum circumferential bending moment is shown in Figure 4.15.6, sketch (a) and shall be computed using eq. (4.15.20). The coefficient $K_7$ is given in Table 4.15.1.

$$M_\theta = K_7 Q R_m$$ \hspace{1cm} (4.15.20)

(2) Cylindrical shell with stiffening rings on both side of the saddle - the maximum circumferential bending moment is shown in Figure 4.15.6, sketch (b) and shall be computed using eq. (4.15.21). The coefficient $K_{10}$ is given in Table 4.15.1.

$$M_\theta = K_{10} Q R_m$$ \hspace{1cm} (4.15.21)

(b) Width of cylindrical shell - the width of the cylindrical shell that contributes to the strength of the cylindrical shell at the saddle location shall be determined using eq. (4.15.22). If the width $x_1$ extends beyond the limits in Figures 4.15.2, 4.15.3 or 4.15.4, as applicable, then the width $x_1$ shall be reduced such as not to exceed this limit.

$$x_1, x_2 \leq 0.78 \sqrt{R_m t}$$ \hspace{1cm} (4.15.22)

(c) Circumferential stresses in the cylindrical shell without stiffening ring(s)

(1) The maximum compressive circumferential membrane stress in the cylindrical shell at the base of the saddle support shall be computed using eq. (4.15.23). The coefficient $K_5$ is given in Table 4.15.1.

$$\sigma_6 = \frac{-K_5 Q k}{b (b + x_1 + x_2)}$$ \hspace{1cm} (4.15.23)

(2) The circumferential compressive membrane plus bending stress at Points G and H of Figure 4.15.6, sketch (a) is determined as follows. The coefficient $K_7$ is given in Table 4.15.1.

(-a) If $L \geq 8 R_m$, then the circumferential compressive membrane plus bending stress shall be computed using eq. (4.15.24).

$$\sigma_7 = \frac{-Q}{4t (b + x_1 + x_2)} - \frac{3K_7 Q}{2t^2}$$ \hspace{1cm} (4.15.24)

(-b) If $L < 8 R_m$, then the circumferential compressive membrane plus bending stress shall be computed using eq. (4.15.25).

$$\sigma_7 = \frac{-Q}{4t (b + x_1 + x_2)} - \frac{12K_7 Q R_m}{L t^2}$$ \hspace{1cm} (4.15.25)

(3) The stresses $\sigma_6$, $\sigma_7$, and $\sigma_7^*$ may be reduced by adding a reinforcement or wear plate at the saddle location that is welded to the cylindrical shell that satisfies the requirements of 4.15.3.1(c). The stress can be computed using the equations shown below.

$$\sigma_{6, r} = \frac{-K_5 Q k}{b_1 (t + \eta t_r)}$$ \hspace{1cm} (4.15.26)

$$\sigma_{7, r} = \frac{-Q}{4(t + \eta t_r)} b_1 - \frac{3K_7 Q}{2 (t + \eta t_r)^2}$$ \hspace{1cm} (4.15.27)

$$\sigma_{7, r}^* = \frac{-Q}{4(t + \eta t_r)} b_1 - \frac{12K_7 Q R_m}{L (t + \eta t_r)}$$ \hspace{1cm} (4.15.28)

where

INSERT ANNEX A
ANNEX A

(-a) If the width of the reinforcement plate, \( b_1 \), satisfies eq. (4.15.24), the stress \( \sigma_6 \) can be computed as shown in eq. (4.15.25).

\[
\begin{align*}
    b_1 &= \min \left[ (b + 1.56 \sqrt{R \eta t}), \ 2a \right] \quad \text{(4.15.24)} \\
    \sigma_{6,r} &= \frac{-K_5 Q \kappa}{b_1(t + \eta t_r)} \\
    \eta &= \min \left[ \frac{S_r}{S}, 1.0 \right] \quad \text{(4.15.26)}
\end{align*}
\]

Where

(-b) If the reinforcement plate provides a supporting arc length, \( \theta_1 \), that satisfies eq. (4.15.27), the stresses \( \sigma_7 \) and \( \sigma^* \) can be computed as shown in eq. (4.15.28) and eq. (4.15.29), respectively.

\[
\begin{align*}
    \theta_1 &= \theta + \frac{\theta}{12} \quad \text{(4.15.27)} \\
    \sigma_{7,r} &= \frac{-Q}{4(t + \eta t_r)b_1} - \frac{3K_7 Q}{2(t + \eta t_r)^2} \\
    \sigma^* &= \frac{-Q}{4(t + \eta t_r)b_1} - \frac{12K_7 Q \tau m}{L(t + \eta t_r)^2} \quad \text{(4.15.28)} \quad \text{(4.15.29)}
\end{align*}
\]
(4) If $t_r > 2t$, then the compressive membrane plus bending stress at the ends of the reinforcing plate [points G1 and H1 in Figure 4.15.2, sketch (b)] shall be computed using the equations shown below. In these equations, coefficient $K_{7,1}$ is computed using the equation for $K_7$ in Table 4.15.1 evaluated at the angle $\theta_1$, see eq. (4.15.2).

(a) If $L \geq 8R_m$, then the circumferential compressive membrane plus bending stress shall be computed using eq. (4.15.30).

$$\sigma_{7,1} = \frac{-Q}{4t(b + x_1 + x_2)} - \frac{3K_{7,1}Q}{2t^2}$$

(b) If $L < 8R_m$, then the circumferential compressive membrane plus bending stress shall be computed using eq. (4.15.31).

$$\sigma_{7,1}^* = \frac{-Q}{4t(b + x_1 + x_2)} - \frac{12K_{7,1}QR_m}{Lt^2}$$

(d) Circumferential stresses in the cylindrical shell with a stiffening ring along the plane of the saddle support.

(1) The maximum compressive circumferential membrane stress in the cylindrical shell shall be computed using eq. (4.15.32). The coefficient $K_5$ is given in Table 4.15.1.

$$\sigma_5 = \frac{-K_5Qk}{A}$$

(2) The circumferential compressive membrane plus bending stress at Points G and H of Figure 4.15.6, sketch (a) for stiffening rings located on the inside of the shell are determined as follows. The coefficients $K_6$ and $K_8$ are given in Table 4.15.1.

$$\sigma_6 = \frac{-K_6Q}{A} + \frac{K_6QR_mC_1}{l}$$ (stress in the shell)  

$$\sigma_8 = \frac{-K_8Q}{A} + \frac{K_8QR_mC_2}{l}$$ (stress in the stiffening ring)

(3) The circumferential compressive membrane plus bending stress at Points G and H of Figure 4.15.6, sketch (a) for stiffening rings located on the outside of the shell are determined as follows. The coefficients $K_6$ and $K_8$ are given in Table 4.15.1.

$$\sigma_6^* = \frac{-K_6Q}{A} + \frac{K_6QR_mC_1}{l}$$ (stress in the shell)  

$$\sigma_8^* = \frac{-K_8Q}{A} - \frac{K_8QR_mC_2}{l}$$ (stress in the stiffening ring)

(e) Circumferential stresses in the cylindrical shell with stiffening rings on both sides of the saddle support

(1) The maximum compressive circumferential membrane stress in the cylindrical shell shall be computed using eq. (4.15.37). The coefficient $K_5$ is given in Table 4.15.1.

$$\sigma_6 = \frac{-K_5Qk}{l(b + 2x_2)}$$

(2) The circumferential compressive membrane plus bending stress at Points I and J of Figure 4.15.6, sketch (b) for stiffening rings located on the inside of the shell are determined as follows. The coefficients $K_9$ and $K_{10}$ are given in Table 4.15.1.

$$\sigma_{10} = \frac{-K_9Q}{A} + \frac{K_9QR_mC_1}{l}$$ (stress in the shell)  

$$\sigma_{11} = \frac{-K_9Q}{A} - \frac{K_9QR_mC_2}{l}$$ (stress in the stiffening ring)
(3) The circumferential compressive membrane plus bending stress at Points I and J of Figure 4.15.6, sketch (b) for stiffening rings located on the outside of the shell are determined as follows. The coefficients $K_9$ and $K_10$ are given in Table 4.15.1.

\[
\sigma_{10} = -\frac{K_9Q}{A} - \frac{K_{10}Q\rho_m c_1}{l} \quad \text{(stress in the shell)} \tag{4.15.40}
\]

\[
\sigma_{11} = -\frac{K_9Q}{A} + \frac{K_{10}Q\rho_m c_2}{l} \quad \text{(stress in the stiffening ring)} \tag{4.15.41}
\]

(f) Acceptance Criteria

(1) The absolute value of $\sigma_6$ or $\sigma_{6,r}$, as applicable, shall not exceed $S$.

(2) The absolute value of $\sigma^*_{6,r}$, as applicable, shall not exceed $\min[S, S_r]$.

(3) The absolute value of $\sigma_7, \sigma^*_7, \sigma_{7,r}, \sigma_{7,1}, \sigma^*_7, \sigma_{7,1}, \sigma_8, \sigma^*_8, \sigma_{10}$, and $\sigma^*_10$, as applicable, shall not exceed $1.25S$.

(4) The absolute value of $\sigma_9, \sigma^*_9, \sigma_{11}$, and $\sigma^*_11$, as applicable, shall not exceed $1.25S_r$.

4.15.3.6 Saddle Support. The horizontal force at the minimum section at the low point of the saddle is given by eq. (4.15.42). The saddle shall be designed to resist this force.

\[
F_h = Q \left( \frac{1 + \cos \beta - 0.5 \sin^2 \gamma}{\pi - \beta + \sin \beta \cos \beta} \right) \tag{4.15.42}
\]

4.15.4 SKIRT SUPPORTS FOR VERTICAL VESSELS

4.15.4.1 The following shall be considered in the design of vertical vessels supported on skirts.

(a) The skirt reaction

(1) The weight of vessel and contents transmitted in compression to the skirt by the shell above the level of the skirt attachment;

(2) The weight of vessel and contents transmitted to the skirt by the weight in the shell below the level of skirt attachment;

(3) The load due to externally applied moments and forces when these are a factor, e.g., wind, earthquake, or piping loads.

(b) Localized Stresses at The Skirt Attachment Location - High localized stresses may exist in the shell and skirt in the vicinity of the skirt attachment if the skirt reaction is not in line with the vessel wall. When the skirt is attached below the head tangent line, localized stresses are introduced in proportion to the component of the skirt reaction which is normal to the head surface at the point of attachment. When the mean diameter of the skirt and shell approximately coincide (see Figure 4.15.7) and a minimum knuckle radius in accordance with 4.3 is used, the localized stresses are minimized. In other cases an investigation of local effects may be warranted depending on the magnitude of the loading, location of skirt attachment, etc., and an additional thickness of vessel wall or compression rings may be necessary. Localized stresses at the skirt attachment location may be evaluated by the design by analysis methods in Part 5.

(c) Thermal Gradients - Thermal gradients may produce high localized stresses in the vicinity of the vessel to skirt attachment. A "hot-box" detail (see Figure 4.15.8) shall be considered to minimize thermal gradients and localized stresses at the skirt attachment to the vessel wall. If a hot-box is used, the thermal analysis shall consider convection and thermal radiation in the hot-box cavity.

4.15.4.2 The rules of 4.3.10 shall be used to determine the thickness requirements for the skirt support. Alternatively, skirt supports may be designed using the design by analysis methods in Part 5.

4.15.5 LUG AND LEG SUPPORTS

4.15.5.1 Lug supports may be used on horizontal or vertical vessels.
4.15.5.2 The localized stresses at the lug support locations on the shell may be evaluated using one of the following methods. If an acceptance criterion is not provided, the results from this analysis shall be evaluated in accordance with Part 5.

(a) Part 5 of this Division.

(b) Welding Research Council Bulletin Number 107, Local Stresses in Spherical and Cylindrical Shells Due to External Loadings.


(f) Other analytical methods contained in recognized codes and standards for pressure vessel construction (i.e., British Standard PD-5500, Specification for Fusion Welded Pressure Vessels (Advanced Design and Construction) for Use in the Chemical, Petroleum, and Allied Industries).

4.15.5.3 If vessels are supported by lugs, legs, or brackets attached to the shell, then the supporting members under these bearing attachments should be as close to the shell as possible to minimize local bending stresses in the shell.

4.15.5.4 Supports, lugs, brackets, stiffeners, and other attachments may be attached with stud bolts to the outside or inside of a vessel wall.

4.15.5.5 Lug and column supports should be located away from structural discontinuities (i.e., cone-to-cylinder junctions) and Category A or B weld seams. If these supports are located within \(1.8\sqrt{D_L}\) of these locations, then a stress analysis shall be performed and the results from this analysis shall be evaluated in accordance with 4.15.5.2.

4.15.6 NOMENCLATURE

\[A = \text{cross-sectional area of the stiffening ring(s) and the associated shell width width used in the stress calculation.}\]

\[a = \text{distance from the axis of the saddle support to the tangent line on the curve for a dished head or to the inner face of a flat cover or tubeshell.}\]

\[b = \text{width of contact surface of the cylindrical shell and saddle support.}\]

\[b_1 = \text{width of the reinforcing plate welded to the cylindrical shell at the saddle location.}\]

\[c_1, c_2 = \text{distance to the extreme axes of the cylinder-stiffener cross section to the neutral axis of the cylinder-stiffener cross-section.}\]

\[E_y = \text{modulus of elasticity.}\]

\[E = \text{weld joint efficiency (see 4.2.4) for the circumferential weld seam being evaluated.}\]

\[\eta = \text{shell to reinforcing plate strength reduction factor.}\]

\[F_h = \text{saddle horizontal force.}\]

\[h = \text{spacing between two mounted stiffening rings placed on each side of the saddle support.}\]

\[h_2 = \text{depth of the formed head.}\]

\[I = \text{moment of inertia of cross-sectional area } A \text{ in relation to its neutral axis that is parallel to the axis of the cylindrical shell.}\]

\[k = \text{factor to account for the vessel support condition; } k = 1 \text{ is the vessel is resting on the support and } k = 0.1 \text{ is the vessel is welded to the support.}\]

\[K = \text{factor to set the allowable compressive stress for the cylindrical shell material.}\]

\[L = \text{length of the cylindrical shell measured from tangent line to tangent line for a vessel with dished heads or from the inner face to inner face for vessels with flat covers or tubeshells.}\]

\[M_1 = \text{net-section maximum longitudinal bending moment at the saddle support; this moment is negative when it results in a tensile stress on the top of the shell.}\]

\[M_2 = \text{net-section maximum longitudinal bending moment between the saddle supports; this moment is positive it results in a compressive stress on the top of the shell.}\]

\[P = \text{design pressure, positive for internal pressure and negative for external pressure.}\]

\[Q = \text{maximum value of the reaction at the saddle support from weight and other loads as applicable.}\]

\[R_p = \text{inside radius of the spherical dome or a torispherical head.}\]

\[R_m = \text{mean radius of the cylindrical shell.}\]

\[S = \text{allowable stress from Annex 3-A for the cylindrical shell material at the design temperature.}\]

\[S_c = \text{allowable compressive stress for the cylindrical shell material at the design temperature.}\]

\[S_h = \text{allowable stress from Annex 3-A for the head material at the design temperature.}\]

\[S_{ty} = \text{yield strength from Annex 3-A for the reinforcing plate material at the design temperature.}\]

\[S_r = \text{allowable stress from Annex 3-A for the reinforcing plate material at the design temperature.}\]
$S_s$ = allowable stress from Annex 3-A for the stiffener material at the design temperature.
$S_y$ = yield strength from Annex 3-A for the cylindrical shell material at the design temperature.
$t$ = cylindrical shell or shell thickness, as applicable.
$t_h$ = head thickness.
$t_r$ = reinforcing plate thickness.
$T$ = maximum shear force at the saddle.
$\theta$ = opening of the supported cylindrical shell arc.
$\theta_1$ = opening of the cylindrical shell arc engaged by a welded reinforcing plate.
$x_1, x_2$ = width of cylindrical shell used in the circumferential normal stress strength calculation.
### Table 4.15.1
Stress Coefficients for Horizontal Vessels on Saddle Supports

<table>
<thead>
<tr>
<th>Stress Coefficient</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$</td>
<td>$\Delta + \sin \Delta \cdot \cos \Delta - \frac{2\sin^2 \Delta}{\sin \Delta - \cos \Delta}$</td>
</tr>
<tr>
<td>$K_2$</td>
<td>$\pi \sin \alpha$</td>
</tr>
<tr>
<td>$K_3$</td>
<td>$a - \sin \alpha - \cos \alpha$</td>
</tr>
<tr>
<td>$K_4$</td>
<td>$\alpha - \sin \alpha - \cos \alpha$</td>
</tr>
<tr>
<td>$K_5$</td>
<td>$1 + \cos \alpha$</td>
</tr>
<tr>
<td>$K_6$</td>
<td>$\frac{3\cos \beta}{4} \left( \frac{\sin \beta}{\beta} \right)^2 - \frac{5\sin \beta \cos \beta}{4\beta} + \frac{3\beta}{2} \left( \frac{\sin \beta}{\beta} \right)^2$</td>
</tr>
<tr>
<td>$K_7$</td>
<td>$\frac{K_6}{4}$ when $\frac{a}{R_m} \leq 0.5$</td>
</tr>
<tr>
<td>$K_8$</td>
<td>$\frac{3}{2} K_6 \left( \frac{a}{R_m} \right)^{-1} \frac{1}{2} K_6$ when $0.5 &lt; \frac{a}{R_m} &lt; 1$</td>
</tr>
<tr>
<td>$K_9$</td>
<td>$\frac{1}{2\pi} \left[ \frac{\pi - \beta}{\beta} \right] \cos \rho + \rho \sin \rho$</td>
</tr>
<tr>
<td>$K_{10}$</td>
<td>$\frac{1}{2\pi} \left[ \rho \sin \rho + \cos \rho \left( \frac{3}{2} + \left( \frac{\pi - \beta}{\beta} \right) \right) - \left( \frac{\pi - \beta}{\sin \rho} \right) \right]$</td>
</tr>
</tbody>
</table>

**NOTES:**

1. $\Delta = \frac{\pi}{6} + \frac{5\theta}{12}$
2. $\alpha = 0.95 \left( \pi - \frac{\theta}{2} \right)$
3. $\beta = \pi - \frac{\theta}{2}$
4. The relationship between $\rho$ and $\theta$ is given by $\rho = \tan \alpha \left[ 0.5 + \left( \pi - \beta \right) \cot \beta \right]$.

### Relationship Between $\rho$ and $\theta$

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>120°</th>
<th>130°</th>
<th>140°</th>
<th>150°</th>
<th>160°</th>
<th>170°</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>93.667°</td>
<td>91.133°</td>
<td>87.833°</td>
<td>84.167°</td>
<td>79.667°</td>
<td>74°</td>
<td>66.933°</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:**

$\rho = -158.58 + 7.8668\theta - 8.8037(10)^{-2}\theta^2 + 4.3011(10)^{-4}\theta^3 - 8.0644(10)^{-7}\theta^4$ for all values of $\theta$ that satisfy $120° \leq \theta \leq 180°$. This curve fit provides $\rho$ in degrees.

5. The angles $\Delta$, $\theta$, $\beta$, and $\rho$ are in radians in the calculations.
Figure 4.15.1
Horizontal Vessel on Saddle Supports
Figure 4.15.2
Cylindrical Shell Without Stiffening Rings

(a)

(b)

Replace "er" with "t r"
Figure 4.15.3
Cylindrical Shell With Stiffening Rings in the Plane of the Saddle

(a)  
(b)  
(c)

Replace "e" with "t"

Replace "e" with "t"

Replace "e" with "t"

h ≤ 1.56\sqrt{R_m t}
Figure 4.15.4
Cylindrical Shell With Stiffening Rings on Both Sides of the Saddle

$$1.56 \sqrt{R_m t} < h \leq R_m$$

(a)  
(b)
Figure 4.15.5
Locations of Maximum Longitudinal Normal Stress and Shear Stress in the Cylinder

\[ \Delta = \frac{\beta}{6} + \frac{\theta}{2} \]

(a) \hspace{1cm} (b)

\[ \alpha = 0.95\beta \]

(c)
Figure 4.15.6
Locations of Maximum Circumferential Normal Stresses in the Cylinder

(a) Maximum bending moment: shell without stiffeners or shell stiffeners in the plane of the saddle

(b) Maximum bending moment: shell stiffeners on both sides of the saddle
Figure 4.15.7
Skirt Attachment Location on Vertical Vessels

Minimize this offset

Vessel head

Vessel skirt
Figure 4.15.8
A Typical Hot-Box Arrangement for Skirt Supported Vertical Vessels

- Hot-box cavity — this space to be left free of insulation and vents
- Typical segmented ring
- Insulation
- Typical vent
- Optional fireproofing
- Dimension established based on thermal stress analysis