Step 4. Calculate the shell coefficients.

(a) Configurations a, b, and c:

$$\beta_s = \frac{\left[12\left(1 - \nu_s^2\right)\right]^{0.25}}{\left[\left(D_s + t_s\right)t_s\right]^{0.5}} \tag{4.18.18}$$

$$k_s = \frac{\beta_s E_s t_s^3}{6\left(1 - \nu_s^2\right)} \tag{4.18.19}$$

$$\lambda_s = \frac{6k_s\left(D_s + t_s\right)}{h^3}\left(1 + h\beta_s + \frac{h^2\beta_s^2}{2}\right) \tag{4.18.20}$$

$$\delta_s = \frac{D_s^2}{4E_s t_s}\left[1 - \frac{D_s \nu_s}{2\left(Ds + t_s\right)}\right] \tag{4.18.21}$$

$$\omega_s = \rho_s k_s \beta_s \delta_s\left(1 + h\beta_s\right) \tag{4.18.22}$$

(b) Configurations a, e, and f:

$$\beta_c = \frac{\sqrt[4]{12\left(1 - \nu_c^2\right)}}{\sqrt{\left(D_c + t_c\right)t_c}} \quad \text{for a cylindrical or hemispherical channel} \tag{4.18.23}$$

$$\beta_c = \frac{\sqrt[4]{12\left(1 - \nu_c^2\right)}}{\sqrt{\left(D_c + t_c\right)t_c \cos\left(\theta_{cc}\right)}} \quad \text{for a concentric conical channel} \tag{4.18.24}$$

$$k_c = \beta_c \frac{E_c t_c^3}{6\left(1 - \nu_c^2\right)} \tag{4.18.25}$$

$$\lambda_c = \frac{6k_c\left[D_c + \dfrac{t_c}{\cos\left(\theta_{cc}\right)}\right]}{h^3}\left(C_{m\theta} + h\beta_c\frac{C_{m\delta} + C_{q\theta}}{2} + \frac{h^2\beta_c^{\,2}}{2}C_{q\delta}\right) \tag{4.18.26}$$

$$\delta_c = \frac{D_c^2}{4E_c t_c}\left[1 \frac{D_c \nu_c}{2\left(D_c + t_c\right)}\right] \quad \text{for a cylinder} \tag{4.18.27}$$

$1 - \dfrac{D_c \nu_c}{2\left(D_c + t_c\right)}$

$$\delta_c = \frac{D_c^2}{4E_c t_c}\left[\frac{1}{2} - \frac{D_c \nu_c}{2\left(D_c + t_c\right)}\right] \quad \text{for a hemispherical head} \tag{4.18.28}$$

$$\delta_c = \left\{1 - \frac{\nu_c D_c}{2\left[D_c + \dfrac{t_c}{\cos\left(\theta_{cc}\right)}\right]}\right\}\frac{D_c^2}{4E_c t_c \cos\left(\theta_{cc}\right)} - \frac{\left[D_c + \dfrac{t_c}{\cos\left(\theta_{cc}\right)}\right]\tan\left(\theta_{cc}\right)}{4k_c\beta_c^{\,2}\cos\left(\theta_{cc}\right)} \quad \text{for concentric conical channel} \tag{4.18.29}$$

$$\zeta_c = 0 \text{ for a cylinder or a hemisphere}$$

$$k_s = \frac{\beta_s E_s t_s^3}{6\left(1 - \nu_s^2\right)} \tag{4.18.72}$$

$$\lambda_s = \frac{6k_s\left(D_s t_s\right)}{h^3}\left(1 + h\beta_s + \frac{h^2\beta_s^2}{2}\right) \tag{4.18.73}$$

$$\delta_s = \frac{D_s^2}{4E_s\, t_s}\left[1 - \frac{D_s \nu_s}{2\left(D_s + t_s\right)}\right] \tag{4.18.74}$$

For Configuration d, $\beta_s = k_s = \lambda_s = \delta_s = 0$.

(d) The channel coefficients for Configuration a.

$$\beta_c = \frac{\sqrt[4]{12\left(1 - \nu_c^2\right)}}{\sqrt{\left(D_c + t_c\right)t_c}} \quad \text{for a cylindrical or hemispherical channel} \tag{4.18.75}$$

$$\beta_c = \frac{\sqrt[4]{12\left(1 - \nu_c^2\right)}}{\sqrt{\left(D_c + t_c\right)t_c\cos\left(\theta_{cc}\right)}} \quad \text{for a concentric conical channel} \tag{4.18.76}$$

$$k_c = \frac{\beta_c E_c t_c^3}{6\left(1 - \nu_c^2\right)} \tag{4.18.77}$$

$$\lambda_c = \frac{6k_c\left[D_c + \dfrac{t_c}{\cos\left(\theta_{cc}\right)}\right]}{h^3}\left(C_{m\theta} + h\beta_c\frac{C_{m\delta} + C_{q\theta}}{2} + \frac{h^2{\beta_c}^2}{2}C_{q\delta}\right) \tag{4.18.78}$$

$$\delta_c = \frac{D_c^2}{4E_c\;\, t_c}\left[1 - \frac{D_c \nu_c}{2\left(D_c + t_c\right)}\right] \quad \text{for a cylinder} \tag{4.18.79}$$

Should be:
"δ_c"

$$\delta_c = \frac{D_c^2}{4E_c\;\, t_c}\left[\frac{1}{2} - \frac{D_c \nu_c}{2\left(D_c + t_c\right)}\right] \quad \text{for a hemispherical channel} \tag{4.18.80}$$

$$\delta = \left\{1 - \frac{\nu_c D_c}{2\left[D_c + \dfrac{t_c}{\cos\left(\theta_{cc}\right)}\right]}\right\}\frac{D_c^2}{4E_c t_c \cos\left(\theta_{cc}\right)} - \frac{\left[D_c + \dfrac{t_c}{\cos\left(\theta_{cc}\right)}\right]}{4k_c{\beta_c}^2\cos\left(\theta_{cc}\right)} \quad \text{for a concentric conical channel} \tag{4.18.81}$$

$$\zeta_c = 0 \quad \text{for a cylindrical or hemispherical channel}$$

$$\zeta_c = \left(\frac{3}{4E_c t_c} - \frac{1}{4k_c\beta_c}\right)\left[D_c + \frac{t_c}{\cos\left(\theta_{cc}\right)}\right]\left[\frac{\tan\left(\theta_{cc}\right)}{\cos\left(\theta_{cc}\right)}\right] \quad \text{for a concentric conical channel} \tag{4.18.82}$$

$$\mathrm{CC} = C_{m\delta} = C_{m\theta} = C_{q\delta} = C_{q\theta} = 1 \quad \text{for a cylindrical or hemispherical channel}$$

$$\mathrm{CC} = 1 + \frac{2\tan\left(\theta_{cc}\right)}{\beta_c D_c} \quad \text{for a concentric conical channel} \tag{4.18.83}$$

Errata

$$\sigma = \left(\frac{1.5F_m}{\mu^*}\right)\left(\frac{2a_o}{h - h'_g}\right)^2 P_e \tag{4.18.111}$$

(2) If $P_e = 0$, calculate the tubesheet maximum bending stress

$$\sigma = \frac{6Q_2}{\mu^*\left(h - h'_g\right)^2} \tag{4.18.112}$$

(c) Acceptance Criteria. For the design loading cases, if $|\sigma| \le 1.5S$, and for the operating loading cases, if $|\sigma| \le S_{PS}$, the assumed tubesheet thickness is acceptable for bending. Otherwise, increase the assumed tubesheet thickness h and return to Step 1.

Step 8. For each loading case, check the average shear stress in the tubesheet at the outer edge of the perforated region, if required.

(a) Calculate the average shear stress.

If $\left| P_e \right| \le \frac{2\mu h}{a_o} \min\left[0.8S,\ 0.533S_y\right]$, the shear stress is not required to be calculated; proceed to Step 9. Otherwise:

$$\tau = \frac{A_p P_e}{\mu h C_p} \tag{4.18.113}$$

(b) Acceptance Criteria. If $|\tau| \le \min(0.8S,\ 0.533S_y)$, the assumed tubesheet thickness is acceptable for shear. Otherwise, increase the assumed tubesheet thickness h and return to Step 1.

Step 9. Check the tube stress and tube-to-tubesheet joint design for each loading case.

(a) Check the axial tube stress.

(1) For each loading case, determine coefficients $F_{t,min}$ and $F_{t,max}$ from Table 4.18.4 and calculate the two extreme values of tube stress, $\sigma_{t,1}$ and $\sigma_{t,2}$. $\sigma_{t,1}$ and $\sigma_{t,2}$ may be positive or negative.

When $P_e \ne 0$

$$\sigma_{t,1} = \frac{1}{x_t - x_s}\left[\left(P_s x_s - P_t x_t\right) - P_e F_{t,\min}\right] \tag{4.18.114}$$

$$\sigma_{t,2} = \frac{1}{x_t - x_s}\left[\left(P_s x_s - P_t x_t\right) - P_e F_{t,\max}\right] \tag{4.18.115}$$

When $P_e = 0$

$$\sigma_{t,1} = \frac{1}{x_t - x_s}\left[\left(P_s x_s - P_t x_t\right) - \frac{2Q_2}{a_o^2} F_{t,\min}\right] \tag{4.18.116}$$

$$\sigma_{t,2} = \frac{1}{x_t - x_s}\left[\left(P_s x_s - P_t x_t\right) - \frac{2Q_2}{a_o^2} F_{t,\max}\right] \tag{4.18.117}$$

(2) Determine $\sigma_{t,max}$

$$\sigma_{t,\max} = \max\left[\left|\sigma_{t,1}\right|, \left|\sigma_{t,2}\right|\right] \tag{4.18.118}$$

(b) Acceptance Criteria. For the design loading cases, if $\sigma_{,max} > S$, and for the operating loading cases, if $\sigma_{max} > 2S$, reconsider the tube design and return to Step 1. Otherwise, proceed to (c).

(c) Check the tube-to-tubesheet joint design.

(1) Calculate the largest tube-to-tubesheet joint load, W_t

$\sigma_{t,max} > S_t$ $\sigma_{t,max} > 2S_t$

$$W_t = \sigma_{t,\max}\pi\left(d_t - t_t\right)t_t \tag{4.18.119}$$

(b) Channel Stresses (Configurations a, e, f, and A) - A concentric conical channel shall have a uniform thickness of t_c for a minimum length of $L_{\min,c}$ adjacent to the tubesheet. A concentric conical channel shall have a uniform thickness of t_c for a minimum length of $L_{\min,c}$ adjacent to the tubesheet. Calculate the axial membrane stress, $\sigma_{c,m}$; the bending stress, $\sigma_{c,b}$; and total axial stress, σ_c, in the channel at its junction to the tubesheet.

$$\sigma_{c,m} = \frac{{a_c}^2}{t_c\left(D_c + t_c\right)\cos\left(\theta_{cc}\right)} \tag{4.18.224}$$

$$Q\sigma_{c,b} = \frac{6}{{t_c}^2}k_c\left\{\left(\delta_c C_{m\delta}\beta_c - \zeta_c C_{m\theta}\right)P_t - 6\frac{\left(1-\nu^{*2}\right)}{E^*}\left(\frac{a_o}{h}\right)^3\left(C_{m\theta} + \frac{\beta_c h}{2}C_{m\delta}\right)\left[P_e\left(Z_v + Q_1 Z_m\right) + \frac{2}{{a_o}^2}Q_2 Z_m\right]\right\} \tag{4.18.225}$$

Delete the "Q" from the equation.

$$\sigma_c = \left|\sigma_{c,m}\right| + \left|\sigma_{c,b}\right| \tag{4.18.226}$$

(c) Acceptance Criteria

(1) Configuration a - For the design loading cases, if $\sigma_s \le 1.5S_s$ and $\sigma_c \le 1.5S_c$, and for the operating loading cases, if $\sigma_s \le S_{PS,s}$ and $\sigma_c \le S_{PS,c}$, the shell and channel designs are acceptable and the calculation procedure is complete. Otherwise, proceed to Step 11.

(2) Configurations b and c - For the design loading cases, if $\sigma_s \le 1.5S_s$, and for the operating loading cases, if $\sigma_s \le S_{PS,s}$, the shell design is acceptable and the calculation procedure is complete. Otherwise, proceed to Step 11.

(3) Configurations e, f, and A - For the design loading cases, if $\sigma_c \le 1.5S_c$, and for the operating loading cases, if $\sigma_c \le S_{PS,c}$, the channel design is acceptable and the calculation procedure is complete. Otherwise, proceed to Step 11.

Step 11. The design shall be reconsidered. One or a combination of the following three options may be used.

(a) Option 1 - Increase the assumed tubesheet thickness h and return to Step 1.

(b) Option 2 - Increase the integral shell and/or channel thickness and return to Step 1.

(1) Configurations a, b, and c - If $\sigma_s \le 1.5S_s$, increase the shell thickness t_s.

(2) Configurations a, e, f, and A - If $\sigma_c \le 1.5S_c$, increase the channel thickness t_c.

(c) Option 3 - Perform the elastic–plastic calculation procedure as defined in 4.18.9.5 only when the conditions of applicability stated in 4.18.9.5(b) are satisfied.

4.18.9.5 Calculation Procedure for Effect of Plasticity at Tubesheet/Channel or Shell Joint. (23)

(a) Scope - This procedure describes how to use the rules of 4.18.9.4 when the effect of plasticity at the shell-tubesheet and/or channel-tubesheet joint is to be considered.

(1) When the calculated tubesheet stresses are within the allowable stress limits, but either or both of the calculated shell or channel total stresses exceed their allowable stress limits, an additional "elastic–plastic solution" calculation may be performed.

(2) This calculation permits a reduction of the shell and/or channel modulus of elasticity, where it affects the rotation of the joint, to reflect the anticipated load shift resulting from plastic action at the joint. The reduced effective modulus has the effect of reducing the shell and/or channel stresses in the elastic–plastic calculation; however, due to load shifting this usually leads to an increase in the tubesheet stress. In most cases, an elastic–plastic calculation using the appropriate reduced shell or channel modulus of elasticity results in a design where the calculated tubesheet stresses are within the allowable stress limits.

(b) Conditions of Applicability

(1) This procedure shall not be used at temperatures where the time-dependent properties govern the allowable stress.

(2) This procedure applies only for the design loading cases.

(3) This procedure applies to Configuration a when $\sigma_s \le S_{PS,s}$ and $\sigma_c \le S_{PS,c}$.

(4) This procedure applies to Configurations b and c when $\sigma_s \le S_{PS,s}$.

(5) This procedure applies to Configurations e, f, and A when $\sigma_s \le S_{PS,c}$.

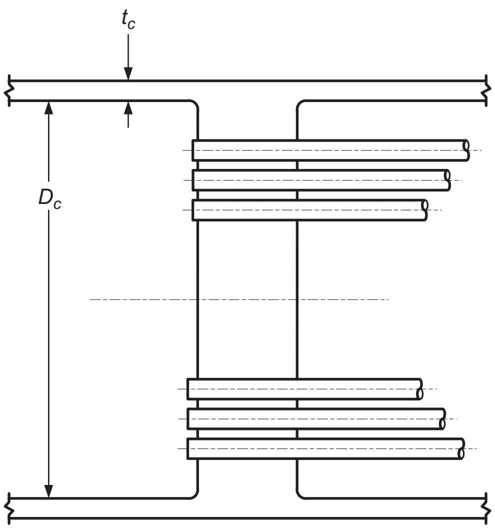
(6) This procedure may only be used once for each iteration of tubesheet, shell, and channel thickness and change of materials.

(c) Calculation Procedure - After the calculation procedure given in 4.18.9.4 (Steps 1 through 10) has been performed for the elastic solution, an elastic–plastic calculation using the referenced steps from 4.18.9.4 shall be performed in accordance with the following procedure for each applicable loading case. Except for those quantities modified below, the quantities to be used for the elastic–plastic calculation shall be the same as those calculated for the corresponding elastic loading case.

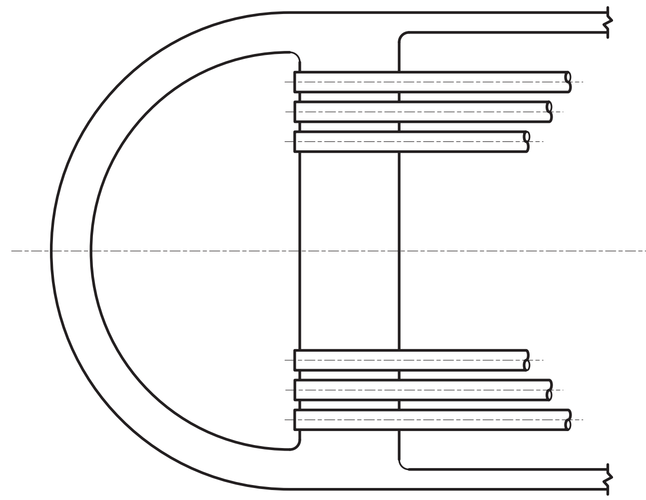
(1) Define the maximum permissible bending stress limit in the shell and channel.

(23)

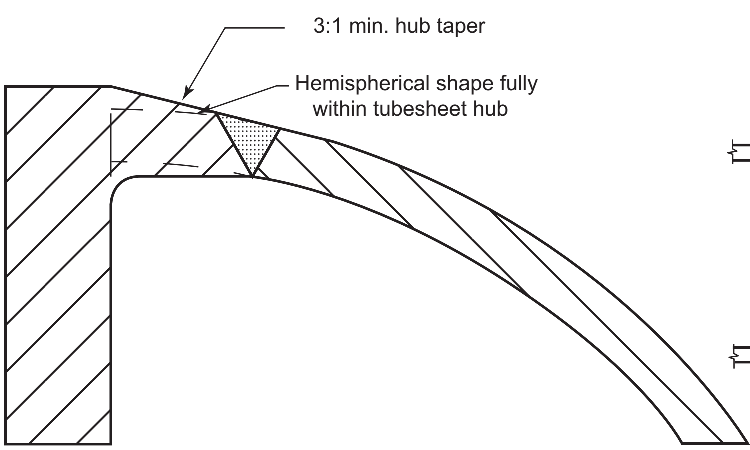
Figure 4.18.15
Integral Channels



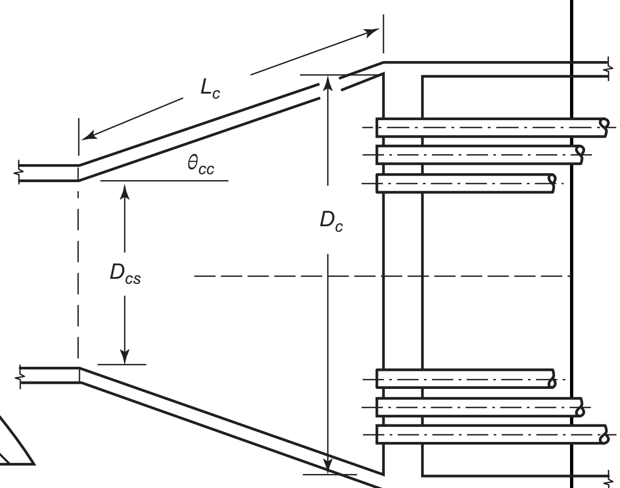
(a) Cylindrical Channel [Note (1)]



(b) Hemispherical Channel [Note (2)]



(c) Hemispherical Channel With Tubesheet Hub Thicker Than Channel



(d) Conical Channel [Note (4)]

NOTES:

(1) Length of the cylinder shall be $\geq 1.8\sqrt{D_c t_c}$.

(2) Head shall be 180 deg with no intervening cylinders. These rules also apply to channels integral with tubesheets having extensions.

(3) These rules also apply to channels with tubesheets having extensions.

(4) Length of cone, L_c, shall be $\geq L_{\min,c} = \sqrt{\frac{D_c T_c}{\cos(\theta_{cc})}} + \text{O.B.}\sqrt{\frac{D_{cs} T_c}{\cos(\theta_{cc})}}$

0.8