

APPENDIX

EXAMPLES FOR CALCULATION

Chapter: 2.3 Flat Heads

The significance of the individual letters can be seen from Fig. 2.1.

$$\begin{array}{lll} R = 300 \text{ mm} & E = 2 \cdot 10^5 \text{ N/mm}^2 & T_m = T_0 \\ t_s = 20 \text{ mm} & \mu = 0.3 & \\ t = 60 \text{ mm} & p_i = 150 \text{ bar} & \end{array}$$

$$w = \frac{2F_3}{3E(t/R)} \cdot Q + \frac{F_3}{E \cdot R(t/R)^2} \cdot M - p_i \frac{t}{2} \frac{F_1}{E(t/R)^3} \quad (2.1)$$

$$\Theta = \frac{F_3}{ER(t/R)^3} \cdot Q + \frac{2F_3}{E \cdot R^2(t/R)^3} \cdot M - p_i \frac{F_1}{E(t/R)^3} \quad (2.1)$$

$$\frac{t}{R} = \frac{60}{300} = 0.2$$

$$R_m = R - \frac{t_s}{s} = 300 - \frac{20}{2} = 290 \text{ mm}$$

$$f = \frac{t_s}{R} = - \frac{20}{300} = 0.066 \text{ mm}$$

$$F_i = \frac{3(1-\mu)(2-f^2)(1-f^2) \cdot [8-f(4-f)(1-\mu)]}{16 \cdot (2-f)} = 1.054 \quad (2.2)$$

$$F_2 = \frac{3}{8}(1-f^2) \cdot \left[(1-\mu)(2-f^2) + 4(1+\mu) \left(1 + 2 \cdot \ln \frac{2-f}{2-2f} \right) \right] = 2.17 \quad (2.2)$$

$$F_3 = \frac{3}{8}(1-\mu)(2-f) \cdot [8-f(4-f)(1-\mu)] = 3.969 \quad (2.2)$$

$$F_4 = \frac{1}{8}[8-f(4-f)(1-\mu)] = 0.977 \quad (2.2)$$

$$w = \frac{2 \cdot 3.969}{3 \cdot 2 \cdot 10^5 \cdot 0.2} \cdot Q + \frac{3.969}{2 \cdot 10^5 \cdot 300 \cdot 0.2^2} \cdot M - 15 \cdot \frac{60}{2} \frac{1.054}{2 \cdot 10^5 \cdot 0.2^3}$$

$$w = 6.615 \cdot 10^{-5} \cdot Q + 0.1653 \cdot 10^{-5} \cdot M - 0.296$$

$$\Theta = \frac{3.969}{2 \cdot 10^5 \cdot 300 \cdot 0.2^2} \cdot Q + \frac{2 \cdot 3.969}{2 \cdot 10^5 \cdot 300^2 \cdot 0.2^3} \cdot M - 15 \cdot \frac{1.054}{2 \cdot 10^5 \cdot 0.2^3}$$

$$\Theta = 0.165 \cdot 10^{-5} \cdot Q + 0.0055 \cdot 10^{-5} \cdot M - 0.00988$$

For $x = \frac{t}{2}$ and $r = 0$:

$$\sigma_r = \frac{F_4}{t} \left(1 - \frac{6x}{t} \right) \cdot Q - \frac{12 \cdot F_4 \cdot x}{t^3} \cdot M + \frac{x \cdot p_i}{t(t/R)^2} \cdot F_2 \quad (2.3)$$

$$\sigma_r = \frac{0.977}{60} (1 - 3) \cdot Q - \frac{6 \cdot 0.977}{60^2} \cdot M + \frac{15}{2 \cdot 0.2^2} \cdot 2.17$$

$$\sigma_r = -0.0325 \cdot Q - 0.0016 \cdot M + 406.8$$

$$\sigma_t = \frac{F_4}{t} \left(1 - \frac{6x}{t} \right) \cdot Q - \frac{12 \cdot F_4 \cdot x}{t^3} \cdot M + \frac{x \cdot p_i}{t(t/R)^2} \cdot F_2 \quad (2.3)$$

$$\sigma_t = -0.0325 \cdot Q - 0.0016 \cdot M + 406.8$$

$$\sigma_a = \left(x - \frac{t}{2} \right) \cdot \frac{p_i}{t} \quad (2.3)$$

$$\sigma_a = 0$$

Chapter: 2.5 Spherical Shells

The significance of the individual letters can be seen from Fig. 2.1.

$$\begin{array}{lll} R = 1000 \text{ mm} & E = 2 \cdot 10^5 \text{ N/mm}^2 & p_i = 50 \text{ bar} \\ t = 20 \text{ mm} & \mu = 0.3 & T_m = T_0 \end{array}$$

$$w = \frac{2R\lambda}{Et} \cdot Q + \frac{2\lambda^2}{Et} \cdot M + p_i \frac{2R^3(1-2\mu) + (R+t/2)^3(1+\mu)}{2ER^2(u^3 - 1)} \quad (2.13)$$

$$\Theta = \frac{2\lambda^2}{Et} \cdot Q + \frac{4\lambda^3}{ERt} \cdot M \quad (2.13)$$

$$\lambda = \beta \cdot R = 0.009 \cdot 1000 = 9 \quad (2.14)$$

$$\beta = [3(1 - \mu^2)]^{1/4} \frac{1}{\sqrt{Rt}} = (3 \cdot 0.91)^{1/4} \frac{1}{\sqrt{1000 \cdot 20}} = 0.009 \quad (2.14)$$

$$u = \frac{R + t/2}{R - t/2} = \frac{1000 + 10}{1000 - 10} = 1.02 \quad (2.14)$$

$$w = \frac{2 \cdot 1000 \cdot 9}{2 \cdot 10^5 \cdot 20} \cdot Q + \frac{2 \cdot 9^2}{2 \cdot 10^5 \cdot 20} \cdot M + 5 \frac{2 \cdot 1000^3 \cdot 0.4 + 1010^3 \cdot 1.3}{2 \cdot 2 \cdot 10^5 \cdot 1000^2 (1.02^3 - 1)} \\ = 4.5 \cdot 10^{-3} \cdot Q + 4.05 \cdot 10^{-5} \cdot M + 0.0873$$

$$\Theta = \frac{2 \cdot 9^2}{2 \cdot 10^5 \cdot 20} \cdot Q + \frac{2 \cdot 9^3}{2 \cdot 10^5 \cdot 1000 \cdot 20} \cdot M = 4.05 \cdot 10^{-5} \cdot Q \\ + 7.29 \cdot 10^{-7} \cdot M$$

Chapter: 2.6 Cylindrical Shells

The significance of the individual letters can be seen from Fig. 2.3. For the long cylindrical shell is

$$B_{11} = B_{12} = B_{22} = 1 \quad R = 1000 \text{ mm} \quad E = 2 \cdot 10^5 \text{ N/mm}^2 \\ G_{11} = G_{12} = G_{22} = 1 \quad t = 20 \text{ mm} \quad \mu = 0.3 \\ p_i = 20 \text{ bar} \quad T_m = T_0$$

$$w_L = -\frac{1}{2\beta^3 D} \cdot Q_L + \frac{1}{2\beta^2 D} \cdot M_L + p_i \frac{(1 - \mu/2)R(R - t/2)}{Et} \quad (2.18)$$

$$\Theta_L = -\frac{1}{2\beta^2 D} \cdot Q_L + \frac{1}{2\beta D} \cdot M_L \quad (2.18)$$

$$D = \frac{Et^3}{12(1 - \mu^2)} = \frac{2 \cdot 10^5 \cdot 20^3}{12 \cdot 0.91} = 1.465 \cdot 10^8 \text{ [Nmm]} \quad (2.24)$$

$$\beta = [3(1 - \mu)]^{1/4} \frac{1}{\sqrt{Rt}} = (3 \cdot 0.7)^{1/4} \cdot \frac{1}{\sqrt{1000 \cdot 20}} = 0.0085 \quad (2.24)$$

$$w_L = \frac{1}{2 \cdot 0.0085^3 \cdot 1.465 \cdot 10^8} Q_L + \frac{1}{2 \cdot 0.0085^2 \cdot 1.465 \cdot 10^8} M_L$$

$$+ 2 \cdot \frac{0.85 \cdot 1000 \cdot 990}{2 \cdot 10^5 \cdot 20}$$

$$w_L = -1.11 \cdot 10^{-2} Q_L + 9.4 \cdot 10^{-5} \cdot M_L + 0.42$$

$$\Theta_L = -\frac{1}{2 \cdot 0.0085^2 \cdot 1.465 \cdot 10^8} Q_L + \frac{1}{2 \cdot 0.0085 \cdot 1.465 \cdot 10^8} M_L$$

$$\Theta_L = -9.4 \cdot 10^{-5} Q_L + 2.36 \cdot 10^{-6} \cdot M_L$$

Chapter: 2.9 Rings

The significance of the individual letters can be seen in Fig. 2.6.

$$\begin{array}{lll} r_a = 1200 \text{ mm} & S_L = S_R = 20 \text{ mm} & p_i = 20 \text{ bar} \\ r_i = 20 \text{ mm} & E = 2 \cdot 10^5 \text{ N/mm}^2 & T_m = T_0 \\ h = 300 \text{ mm} & \mu = 0.3 & r_L = r_R = r_i \end{array}$$

$$w_L = (A + B) \cdot Q_L + C \cdot M_L + (-A + B) \cdot Q_R - C \cdot M_R$$

$$+ p_i \left[\frac{h \cdot r_i^2 (a_L - a_r)}{4ED_R} + \frac{r_i(r_a + r_i)}{2E(r_a - r_i)} \right] \quad (2.40)$$

$$\Theta_L = C \cdot Q_L + \frac{2C}{h} \cdot M_L - C \cdot Q_R - \frac{2C}{h} \cdot M_R + p_i \frac{r_i^2 (a_L - a_r)}{2ED_R} \quad (2.40)$$

$$w_R = (-A + B) \cdot Q_L - C \cdot M_L + (A + B) \cdot Q_R + C \cdot M_R$$

$$+ p_i \left[\frac{-h \cdot r_i^2 (a_L - a_r)}{4ED_R} + \frac{r_i(r_a - r_i)}{2E(r_a - r_i)} \right] \quad (2.40)$$

$$\Theta_R = \Theta_L \quad (2.40)$$

$$D_R = \frac{h^3}{12} \cdot \ln \frac{r_a}{r_i} = \frac{300^3}{12} \cdot \ln \frac{1200}{1000} = 4.1 \cdot 10^5 [\text{mm}^3] \quad (2.41)$$

$$a_L = \frac{(r_a + r_i)}{2} - \left(r_L + \frac{s_L}{2} \right) = \frac{(1200 + 1000)}{2} - \left(1000 + \frac{20}{2} \right) = 90 \text{ [mm]} \quad (2.41)$$

$$a_R = a_L \quad (2.41)$$

$$A = \frac{h^2}{8 \cdot \pi \cdot E \cdot D_R} = \frac{300^2}{8 \cdot \pi \cdot 2 \cdot 10^5 \cdot 4.1 \cdot 10^5} = 4.36 \cdot 10^{-8} \left[\frac{\text{mm}}{\text{N}} \right] \quad (2.41)$$

$$\begin{aligned} B &= \frac{r_a + r_i}{4 \cdot \pi \cdot h \cdot E \cdot (r_a - r_i)} = \frac{1200 + 1000}{4 \cdot \pi \cdot 300 \cdot 2 \cdot 10^5 (1200 - 1000)} \\ &= 1.46 \cdot 10^{-8} \left[\frac{\text{mm}}{\text{N}} \right] \end{aligned} \quad (2.41)$$

$$C = \frac{h}{4 \cdot \pi \cdot E \cdot D_R} = \frac{300}{4 \cdot \pi \cdot 2 \cdot 10^5 \cdot 4.1 \cdot 10^5} = 2.912 \cdot 10^{-10} \left[\frac{\text{mm}}{\text{N}} \right] \quad (2.41)$$

$$\begin{aligned} w_L &= (4.36 \cdot 10^{-8} + 1.46 \cdot 10^{-8}) Q_L + 2.912 \cdot 10^{-10} \cdot M_L + (-4.36 \cdot 10^{-8} \\ &\quad + 1.46 \cdot 10^{-8}) Q_R - 2.912 \cdot 10^{-10} \cdot M_R + 2 \cdot \frac{1000 \cdot (1200 + 1000)}{2 \cdot 2 \cdot 10^5 (1200 - 1000)} \end{aligned}$$

$$\begin{aligned} w_L &= 5.82 \cdot 10^{-8} \cdot Q_L + 2.912 \cdot 10^{-10} \cdot M_L - 2.9 \cdot 10^{-8} \cdot Q_R - 2.912 \\ &\quad \cdot 10^{-10} \cdot M_R + 0.055 \end{aligned}$$

$$\Theta_L = 2.912 \cdot 10^{-10} \cdot Q_L + \frac{2.912 \cdot 10^{-10}}{300} \cdot M_L - 2.912 \cdot 10^{-10} \cdot Q_R - \frac{2 \cdot 2.912 \cdot 10^{-10}}{300} \cdot M_R$$

$$\Theta_L = 2.912 \cdot 10^{-10} \cdot Q_L + 1.94 \cdot 10^{-12} \cdot M_L - 2.912 \cdot 10^{-10} \cdot Q_R - 1.94 \cdot 10^{-12} \cdot M_R$$

$$\begin{aligned} w_R &= -2.9 \cdot 10^{-8} \cdot Q_L - 2.912 \cdot 10^{-10} \cdot M_L + 5.82 \cdot 10^{-8} \cdot Q_R \\ &\quad + 2.912 \cdot 10^{-10} \cdot M_R + 0.055 \end{aligned}$$

$$\Theta_R = \Theta_L$$

Chapter: 4.5. Dimensioning of Flanges Using the Deformation Calculation

The significance of the individual letters can be seen in Fig. 4.14.

$$\begin{array}{lll}
 d_i = 1000 \text{ mm} & S_R = 20 \text{ mm} & E = 2 \cdot 10^5 \text{ N/mm}^2 \\
 d_D = 1040 \text{ mm} & h_F = 80 \text{ mm} & \mu = 0.3 \\
 d_t = 1100 \text{ mm} & F_S = F_D & d_L = 22 \text{ mm} \\
 d_F = 1160 \text{ mm} & F_R = F_F = 0 & t = 66 \text{ mm}
 \end{array}$$

$$a_{11} \cdot T_1 + a_{12} \cdot M_1 = b_1 \quad (4.35)$$

$$a_{21} \cdot T_1 + a_{22} \cdot M_1 = b_2 \quad (4.35)$$

$$D_F = \frac{h_F^3}{12} \cdot \ln \frac{d_F}{d_i} = \frac{80^3}{12} \cdot \ln \frac{1160}{1000} = 6.33 \cdot 10^3 [\text{mm}^3] \quad (4.14)$$

$$\beta_z = \frac{\sqrt[4]{3(1 - \mu^2)}}{\sqrt{\frac{(d_i + s_R)}{2} \cdot s_R}} = \frac{\sqrt[4]{3 \cdot 0.91}}{\sqrt{\frac{1020}{2} \cdot 20}} = 0.0127 \left[\frac{1}{\text{mm}} \right] \quad (4.32)$$

$$D_Z = \frac{s_R^3 \cdot E}{12(1 - \mu)} = \frac{20^3 \cdot 2 \cdot 10^5}{12 \cdot 0.7} = 1.9 \cdot 10^8 [\text{Nmm}] \quad (4.32)$$

$$a_{11} = \frac{ED_F}{\beta_z^2 \cdot D_Z(d_i + s_R)} - \frac{h_F}{2} = \frac{2 \cdot 10^5 \cdot 6.33 \cdot 10^3}{0.0127^2 \cdot 1.9 \cdot 10^8 \cdot (1000 + 20)} - \frac{80}{2} = 0.5 \quad (4.36)$$

$$a_{12} = -\frac{2ED_F}{\beta_z \cdot D_Z(d_i + s_R)} - 1 = -\frac{2 \cdot 10^5 \cdot 6.33 \cdot 10^3}{0.0127^2 \cdot 1.9 \cdot 10^8 \cdot (1000 + 20)} - 1 = -1.514 \quad (4.36)$$

$$a_{21} = -\frac{h_F}{2} - \frac{(d_i + s_R)D_F}{h_F \cdot A_F} - \frac{2ED_F}{h_F(d_i + s_R) \cdot \beta_z^3 Z \cdot D_Z} \quad (4.36)$$

$$A_F = A_1 \frac{1}{1 + e/t(A_1/A_2 - 1)} \quad (4.15)$$

$$A_1 = \frac{(d_F - d_i)h_F}{2} = \frac{(1160 - 1000) \cdot 80}{2} = 6400 [\text{mm}^2] \quad (4.15)$$

$$A_2 = e \cdot h_F = 22 \cdot 80 = 1760 [\text{mm}^2] \quad (4.15)$$

$$A_F = 6400 \frac{1}{1 + \frac{22}{66} \left(\frac{6400}{1760} - 1 \right)} = 3406 [\text{mm}^2]$$

$$a_{21} = -\frac{80}{2} - \frac{(1000 + 20) \cdot 6.33 \cdot 10^3}{80 \cdot 3406} - \frac{2 \cdot 2 \cdot 10^5 \cdot 6.33 \cdot 10^3}{80(1000 + 20) \cdot 0.0127^3 \cdot 1.9 \cdot 10^8}$$

$$= -40 - 23.69 - 79.72 = -143.41$$

$$a_{22} = -1 + \frac{2 \cdot E \cdot D_F}{(d_i + s_R) \beta_z^2 h_F D_Z} = -1 + \frac{2 \cdot 2 \cdot 10^5 \cdot 6.33 \cdot 10^3}{(1000 + 20) \cdot 0.0127^2 \cdot 1.9 \cdot 10^8 \cdot 80}$$

$$= -1 + 1.0125 = 0.0125$$

$$b_1 = F_s \left(\frac{d_t - d_0}{2} + F_D \frac{(d_0 - d_D)}{2} \right) \quad (4.36)$$

$$d_0 = 2 \cdot \frac{\frac{d_F}{2} - \frac{d_i}{2} - \frac{d_L^2}{t}}{\ln \frac{d_F}{d_i} - \frac{d_L}{t} \cdot \ln \frac{d_t + d_L}{d_t - d_L}} = 2 \cdot \frac{580 - 500 - \frac{22^2}{66}}{\ln \frac{1160}{1000} - \frac{22}{66} \cdot \ln \frac{1100 + 22}{1100 - 22}} = 1075.8 \text{ [mm]}$$

$$b_1 = F_s \cdot \left(\frac{1100 - 1075.8}{2} + \frac{1075.8 - 1040}{2} \right) = 30 \cdot F_s$$

$$b_2 = b_1 \quad (4.36)$$

$$M_1 = -19.88 \cdot F_s$$

$$T_1 = 0$$