

## Chapter 8

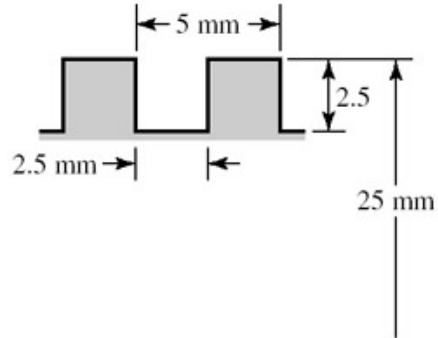
**8-1 (a)** Thread depth = 2.5 mm *Ans.*

Width = 2.5 mm *Ans.*

$$d_m = 25 - 1.25 - 1.25 = 22.5 \text{ mm}$$

$$d_r = 25 - 5 = 20 \text{ mm}$$

$$l = p = 5 \text{ mm} \quad \text{Ans.}$$



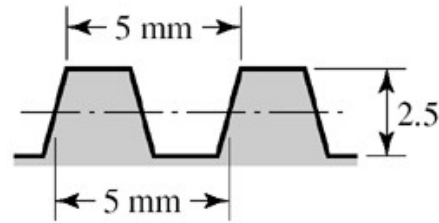
**(b)** Thread depth = 2.5 mm *Ans.*

Width at pitch line = 2.5 mm *Ans.*

$$d_m = 22.5 \text{ mm}$$

$$d_r = 20 \text{ mm}$$

$$l = p = 5 \text{ mm} \quad \text{Ans.}$$



**8-2** From Table 8-1,

$$d_r = d - 1.226\,869p$$

$$d_m = d - 0.649\,519p$$

$$\bar{d} = \frac{d - 1.226\,869p + d - 0.649\,519p}{2} = d - 0.938\,194p$$

$$A_t = \frac{\pi \bar{d}^2}{4} = \frac{\pi}{4} (d - 0.938\,194p)^2 \quad \text{Ans.}$$

**8-3** From Eq. (c) of Sec. 8-2,

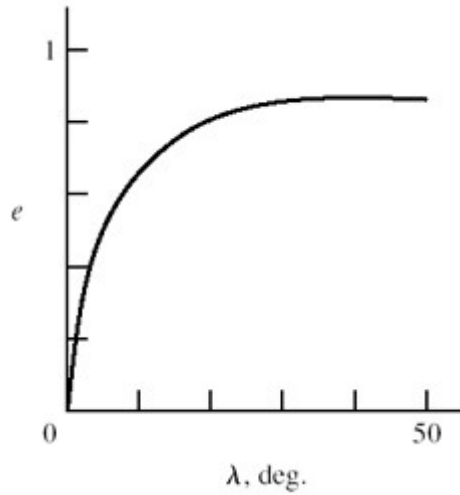
$$P_R = F \frac{\tan \lambda + f}{1 - f \tan \lambda}$$

$$T_R = \frac{P_R d_m}{2} = \frac{F d_m}{2} \frac{\tan \lambda + f}{1 - f \tan \lambda}$$

$$e = \frac{T_0}{T_R} = \frac{Fl / (2\pi)}{F d_m / 2} \frac{1 - f \tan \lambda}{\tan \lambda + f} = \tan \lambda \frac{1 - f \tan \lambda}{\tan \lambda + f} \quad \text{Ans.}$$

Using  $f = 0.08$ , form a table and plot the efficiency curve.

$\lambda$ , deg.	$e$
0	0
0	0.678
20	0.796
30	0.838
40	0.8517
45	0.8519



- 8-4** Given  $F = 5$  kN,  $l = 5$  mm, and  $d_m = d - p/2 = 25 - 5/2 = 22.5$  mm, the torque required to raise the load is found using Eqs. (8-1) and (8-6)

$$T_R = \frac{5(22.5)}{2} \left[ \frac{5 + \pi(0.09)22.5}{\pi(22.5) - 0.09(5)} \right] + \frac{5(0.06)45}{2} = 15.85 \text{ N} \cdot \text{m} \quad \text{Ans.}$$

The torque required to lower the load, from Eqs. (8-2) and (8-6) is

$$T_L = \frac{5(22.5)}{2} \left[ \frac{\pi(0.09)22.5 - 5}{\pi(22.5) + 0.09(5)} \right] + \frac{5(0.06)45}{2} = 7.83 \text{ N} \cdot \text{m} \quad \text{Ans.}$$

Since  $T_L$  is positive, the thread is self-locking. From Eq.(8-4) the efficiency is

$$e = \frac{5(5)}{2\pi(15.85)} = 0.251 \quad \text{Ans.}$$

- 8-5** Collar (thrust) bearings, at the bottom of the screws, must bear on the collars. The bottom segment of the screws must be in compression. Whereas, tension specimens and their grips must be in tension. Both screws must be of the same-hand threads.

- 8-6** Screws rotate at an angular rate of

$$n = \frac{1720}{60} = 28.67 \text{ rev/min}$$

(a) The lead is 0.25 in, so the linear speed of the press head is

$$V = 28.67(0.25) = 7.17 \text{ in/min} \quad \text{Ans.}$$

(b)  $F = 2500 \text{ lbf/screw}$

$$d_m = 2 - 0.25 / 2 = 1.875 \text{ in}$$

$$\sec \alpha = 1 / \cos(29^\circ / 2) = 1.033$$

Eq. (8-5):

$$T_R = \frac{2500(1.875)}{2} \left( \frac{0.25 + \pi(0.05)(1.875)(1.033)}{\pi(1.875) - 0.05(0.25)(1.033)} \right) = 221.0 \text{ lbf} \cdot \text{in}$$

Eq. (8-6):

$$T_c = 2500(0.08)(3.5 / 2) = 350 \text{ lbf} \cdot \text{in}$$

$$T_{\text{total}} = 350 + 221.0 = 571 \text{ lbf} \cdot \text{in/screw}$$

$$T_{\text{motor}} = \frac{571(2)}{60(0.95)} = 20.04 \text{ lbf} \cdot \text{in}$$

$$H = \frac{Tn}{63\,025} = \frac{20.04(1720)}{63\,025} = 0.547 \text{ hp} \quad \text{Ans.}$$

**8-7** AISI 1006 CD steel. Table A-20:  $S_y = 41 \text{ kpsi}$ .

(a) The handle has maximum bending moment where it enters the screw body.

$$M = (3.5 - 0.375) F = 3.125 F$$

$$S_y = \sigma = \frac{32M}{\pi d^3} = \frac{32(3.125)F}{\pi(0.375)^3} = 41\,000$$

$$F = 67.9 \text{ lbf} \quad \text{Ans.}$$

(b) Using Fig. 8-3 for the Acme thread,  $p = l = 1/6 = 0.1667 \text{ in}$

$$d_m = d - p / 2 = 0.75 - 1/12 = 0.6667 \text{ in}, d_r = d - p = 0.75 - 1/6 = 0.5833 \text{ in}$$

$$\alpha = 29^\circ / 2 = 14.5^\circ, \quad \sec 14.5^\circ = 1.033$$

From Eqs. (8-5) and (8-6),

$$T_{\text{total}} = \frac{Fd_m}{2} \left( \frac{l + \pi f d_m \sec \alpha}{\pi d_m - fl \sec \alpha} \right) + \frac{Ff_c d_c}{2}$$

$$= \frac{F(0.6667)}{2} \left[ \frac{0.1667 + \pi(0.15)(0.6667)(1.033)}{\pi(0.6667) - 0.15(0.1667)(1.033)} \right] + \frac{F(0.15)(1)}{2} = 0.1542F$$

From part (a),  $T_{\text{total}} = 3.5 F = 3.5(67.9) = 237.7 \text{ lbf} \cdot \text{in}$

$$F = \frac{237.7}{0.1542} = 1542 \text{ lbf} \quad \text{Ans.}$$

(c) Using Eqs. (8-11), (8-8), (8-7), and (8-12):

Bending stress in first thread, with the force on the first thread being  $0.38F$  and  $n_t = 1$ ,

$$\sigma_x = \frac{6(0.38F)}{\pi d_r n_t p} = \frac{6(0.38)(1542)}{\pi(0.5833)(1)(0.1667)} = 11\,510 \text{ psi} = 11.5 \text{ kpsi}$$

Axial stress in body of screw,

$$\sigma_y = -\frac{4F}{\pi d_r^2} = -\frac{4(1542)}{\pi(0.5833)^2} = -5770 \text{ psi} = -5.77 \text{ kpsi}$$

Torsion in body of screw:

$$\tau_{yz} = \frac{16T}{\pi d_r^3} = \frac{16(237.7)}{\pi(0.5833)^3} = 6100 \text{ psi} = 6.10 \text{ kpsi}$$

The tangential shear stress given by Eq. (8-12) with one thread carrying 0.38  $T$ :

$$\tau_{zx} = -\frac{4(0.38T)}{\pi d_r^2 (1)p} = -\frac{4(0.38)237.7}{\pi(0.5833)^2 (1)0.1667} = -2030 \text{ psi} = -2.03 \text{ kpsi}$$

From Eq. (5-14),

$$\sigma' = \frac{1}{\sqrt{2}} \left\{ [11.5 - (-5.77)]^2 + (-5.77 - 0)^2 + (0 - 11.5)^2 + 6(6.10)^2 + 6(-2.03)^2 \right\}^{1/2}$$

$$= 18.9 \text{ kpsi}$$

$$n_y = \frac{S_y}{\sigma'} = \frac{41}{18.9} = 2.2 \text{ Ans.}$$

**(d)** The column has one end fixed and the other end pivoted in the swivel joint of the anvil striker, so from Table 4-2,  $C = 1.2$ . We will use the root diameter of the screw body to check buckling, neglecting the effect of the threads.

$$A = \pi(0.5833^2)/4 = 0.267 \text{ in}^2, S_y = 41 \text{ kpsi}, E = 30(10^6) \text{ psi}, L = 8 \text{ in},$$

$$k = \sqrt{I/A} = \sqrt{\frac{\pi d^4 / 64}{\pi d^2 / 4}} = d / 4 = 0.5833 / 4 = 0.1458 \text{ in}, L/k = 8/0.1458 = 54.9$$

From Eq. (4-45),

$$\left(\frac{l}{k}\right)_1 = \left(\frac{2\pi^2 CE}{S_y}\right)^{1/2} = \left[\frac{2\pi^2 (1.2)30(10^6)}{41\,000}\right]^{1/2} = 131.7$$

Since  $54.9 < 131.7$ , the J.B. Johnson formula is applicable. From Eq. (4-48), the critical clamping force for buckling is

$$P_{cr} = A \left[ S_y - \left( \frac{S_y l}{2\pi k} \right)^2 \frac{1}{CE} \right]$$

$$= 0.267 \left\{ 41(10^3) - \left[ \frac{41(10^3)}{2\pi} (54.9) \right]^2 \frac{1}{1.2(30)10^6} \right\} = 9995 \text{ lbf} \quad \text{Ans}$$

$$n = \frac{P_{cr}}{F} = \frac{9995}{1542} = 6.5 \text{ Ans.}$$

It is confirmed that the weak link is the yielding of the handle.

**8-8**  $T = 8(3.5) = 28 \text{ lbf} \cdot \text{in}$

$$d_m = \frac{3}{4} - \frac{1}{12} = 0.6667 \text{ in}$$

$$l = \frac{1}{6} = 0.1667 \text{ in}, \quad \alpha = \frac{29^0}{2} = 14.5^0, \quad \sec 14.5^0 = 1.033$$

From Eqs. (8-5) and (8-6)

$$T_{\text{total}} = \frac{0.6667F}{2} \left[ \frac{0.1667 + \pi(0.15)(0.6667)(1.033)}{\pi(0.6667) - 0.15(0.1667)(1.033)} \right] + \frac{0.15(1)F}{2} = 0.1542F$$

$$F = \frac{28}{0.1542} = 182 \text{ lbf} \quad \text{Ans.}$$

**8-9**  $d_m = 1.5 - 0.25/2 = 1.375 \text{ in}, l = 2(0.25) = 0.5 \text{ in}$

From Eq. (8-1) and Eq. (8-6),

$$\begin{aligned} T_R &= \frac{2.2(10^3)(1.375)}{2} \left[ \frac{0.5 + \pi(0.10)(1.375)}{\pi(1.375) - 0.10(0.5)} \right] + \frac{2.2(10^3)(0.15)(2.25)}{2} \\ &= 330 + 371 = 701 \text{ lbf} \cdot \text{in} \end{aligned}$$

Since  $n = V/l = 2/0.5 = 4 \text{ rev/s} = 240 \text{ rev/min}$

so the power is

$$H = \frac{Tn}{63\,025} = \frac{701(240)}{63\,025} = 2.67 \text{ hp} \quad \text{Ans.}$$

**8-10**  $d_m = 40 - 4 = 36 \text{ mm}, l = p = 8 \text{ mm}$

From Eqs. (8-1) and (8-6)

$$\begin{aligned} T &= \frac{36F}{2} \left[ \frac{8 + \pi(0.14)(36)}{\pi(36) - 0.14(8)} \right] + \frac{0.09(100)F}{2} \\ &= (3.831 + 4.5)F = 8.33F \text{ N} \cdot \text{m} \quad (F \text{ in kN}) \\ \omega &= 2\pi n = 2\pi(1) = 2\pi \text{ rad/s} \\ H &= T\omega \\ T &= \frac{H}{\omega} = \frac{3000}{2\pi} = 477 \text{ N} \cdot \text{m} \\ F &= \frac{477}{8.33} = 57.3 \text{ kN} \quad \text{Ans.} \end{aligned}$$

$$e = \frac{Fl}{2\pi T} = \frac{57.3(8)}{2\pi(477)} = 0.153 \quad \text{Ans.}$$

**8-11 (a)** Table A-31, nut height  $H = 12.8$  mm.  $L \geq l + H = 2(15) + 12.8 = 42.8$  mm. Rounding up,

$$L = 45 \text{ mm} \quad \text{Ans.}$$

**(b)** From Eq. (8-14),  $L_T = 2d + 6 = 2(14) + 6 = 34$  mm  
 From Table 8-7,  $l_d = L - L_T = 45 - 34 = 11$  mm,  $l_t = l - l_d = 2(15) - 11 = 19$  mm,

$$A_d = \pi(14^2)/4 = 153.9 \text{ mm}^2. \text{ From Table 8-1, } A_t = 115 \text{ mm}^2. \text{ From Eq. (8-17)}$$

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{153.9(115)207}{153.9(19) + 115(11)} = 874.6 \text{ MN/m} \quad \text{Ans.}$$

**(c)** From Eq. (8-22), with  $l = 2(15) = 30$  mm

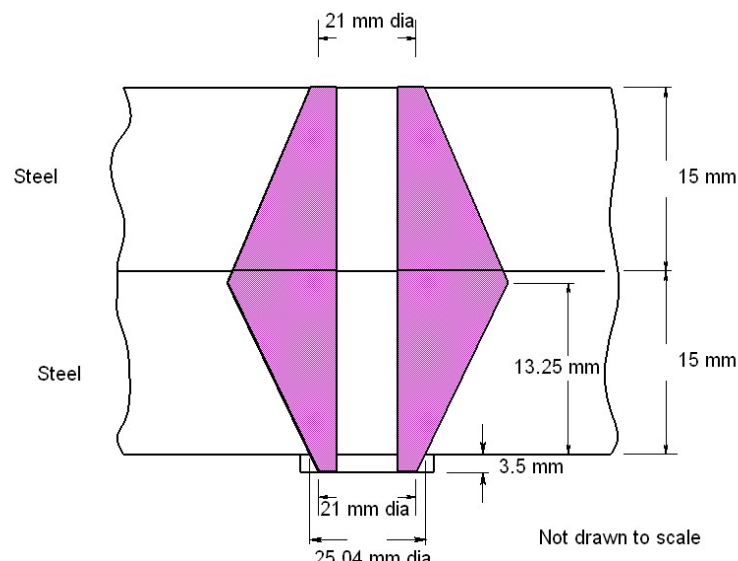
$$k_m = \frac{0.5774\pi Ed}{2 \ln \left( 5 \frac{0.5774l + 0.5d}{0.5774l + 2.5d} \right)} = \frac{0.5774\pi(207)14}{2 \ln \left[ 5 \frac{0.5774(30) + 0.5(14)}{0.5774(30) + 2.5(14)} \right]} = 3\,116.5 \text{ MN/m} \quad \text{Ans.}$$

**8-12 (a)** Table A-31, nut height  $H = 12.8$  mm. Table A-33, washer thickness  $t = 3.5$  mm. Thus, the grip is  $l = 2(15) + 3.5 = 33.5$  mm.  $L \geq l + H = 33.5 + 12.8 = 46.3$  mm. Rounding up  
 $L = 50$  mm *Ans.*

**(b)** From Eq. (8-14),  $L_T = 2d + 6 = 2(14) + 6 = 34$  mm  
 From Table 8-7,  $l_d = L - L_T = 50 - 34 = 16$  mm,  $l_t = l - l_d = 33.5 - 16 = 17.5$  mm,  
 $A_d = \pi(14^2)/4 = 153.9 \text{ mm}^2$ . From Table 8-1,  $A_t = 115 \text{ mm}^2$ . From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{153.9(115)207}{153.9(17.5) + 115(16)} = 808.2 \text{ MN/m} \quad \text{Ans.}$$

**(c)**



From Eq. (8-22)

$$k_m = \frac{0.5774\pi Ed}{2 \ln \left( 5 \frac{0.5774l + 0.5d}{0.5774l + 2.5d} \right)} = \frac{0.5774\pi(207)14}{2 \ln \left[ 5 \frac{0.5774(33.5) + 0.5(14)}{0.5774(33.5) + 2.5(14)} \right]} = 2\,969 \text{ MN/m} \quad \text{Ans.}$$


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**8-13 (a)** Table 8-7,  $l = h + d/2 = 15 + 14/2 = 22 \text{ mm}$ .  $L \geq h + 1.5d = 36 \text{ mm}$ . Rounding up  
 $L = 40 \text{ mm}$       *Ans.*

**(b)** From Eq. (8-14),  $L_T = 2d + 6 = 2(14) + 6 = 34 \text{ mm}$   
 From Table 8-7,  $l_d = L - L_T = 40 - 34 = 6 \text{ mm}$ ,  $l_t = l - l_d = 22 - 6 = 16 \text{ mm}$

$A_d = \pi(14^2)/4 = 153.9 \text{ mm}^2$ . From Table 8-1,  $A_t = 115 \text{ mm}^2$ . From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{153.9(115)207}{153.9(16) + 115(6)} = 1\,162.2 \text{ MN/m} \quad \text{Ans.}$$

**(c)** From Eq. (8-22), with  $l = 22 \text{ mm}$

$$k_m = \frac{0.5774\pi Ed}{2 \ln \left( 5 \frac{0.5774l + 0.5d}{0.5774l + 2.5d} \right)} = \frac{0.5774\pi(207)14}{2 \ln \left[ 5 \frac{0.5774(22) + 0.5(14)}{0.5774(22) + 2.5(14)} \right]} = 3\,624.4 \text{ MN/m} \quad \text{Ans.}$$


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**8-14 (a)** From Table A-31, the nut height is  $H = 7/16 \text{ in}$ .  $L \geq l + H = 2 + 1 + 7/16 = 3\,7/16 \text{ in}$ .  
 Rounding up,  $L = 3.5 \text{ in}$       *Ans.*

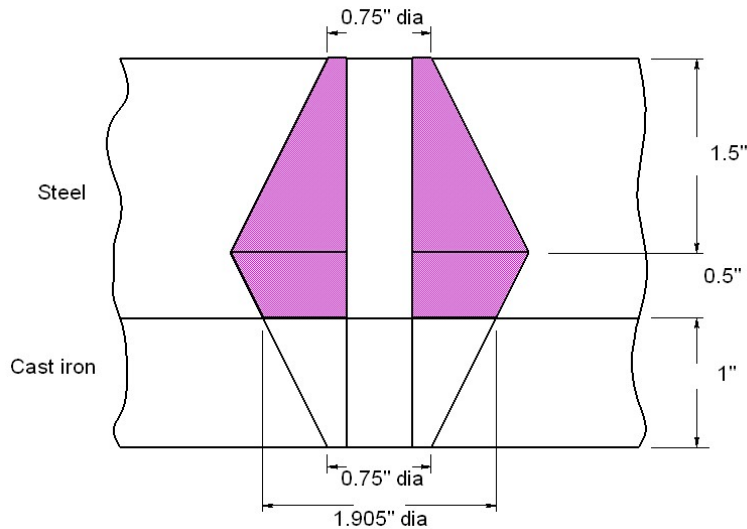
**(b)** From Eq. (8-13),  $L_T = 2d + 1/4 = 2(0.5) + 0.25 = 1.25 \text{ in}$

From Table 8-7,  $l_d = L - L_T = 3.5 - 1.25 = 2.25 \text{ in}$ ,  $l_t = l - l_d = 3 - 2.25 = 0.75 \text{ in}$

$A_d = \pi(0.5^2)/4 = 0.1963 \text{ in}^2$ . From Table 8-2,  $A_t = 0.1419 \text{ in}^2$ . From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1963(0.1419)30}{0.1963(0.75) + 0.1419(2.25)} = 1.79 \text{ Mlbf/in} \quad \text{Ans.}$$

**(c)**



Top steel frustum:  $t = 1.5$  in,  $d = 0.5$  in,  $D = 0.75$  in,  $E = 30$  Mpsi. From Eq. (8-20)

$$k_1 = \frac{0.5774\pi(30)0.5}{\ln \left[ \frac{[1.155(1.5) + 0.75 - 0.5](0.75 + 0.5)}{[1.155(1.5) + 0.75 + 0.5](0.75 - 0.5)} \right]} = 22.65 \text{ Mlbf/in}$$

Lower steel frustum:  $t = 0.5$  in,  $d = 0.5$  in,  $D = 0.75 + 2(1) \tan 30^\circ = 1.905$  in,  $E = 30$  Mpsi. Eq. (8-20)  $\Rightarrow k_2 = 210.7$  Mlbf/in

Cast iron:  $t = 1$  in,  $d = 0.5$  in,  $D = 0.75$  in,  $E = 14.5$  Mpsi (Table 8-8). Eq. (8-20)  $\Rightarrow k_3 = 12.27$  Mlbf/in

From Eq. (8-18),

$$k_m = (1/k_1 + 1/k_2 + 1/k_3)^{-1} = (1/22.65 + 1/210.7 + 1/12.27)^{-1} = 7.67 \text{ Mlbf/in} \quad \text{Ans.}$$

**8-15 (a)** From Table A-32, the washer thickness is 0.095 in. Thus,  $l = 2 + 1 + 2(0.095) = 3.19$  in. From Table A-31, the nut height is  $H = 7/16$  in.  $L \geq l + H = 3.19 + 7/16 = 3.63$  in. Rounding up,  $L = 3.75$  in *Ans.*

**(b)** From Eq. (8-13),  $L_T = 2d + 1/4 = 2(0.5) + 0.25 = 1.25$  in

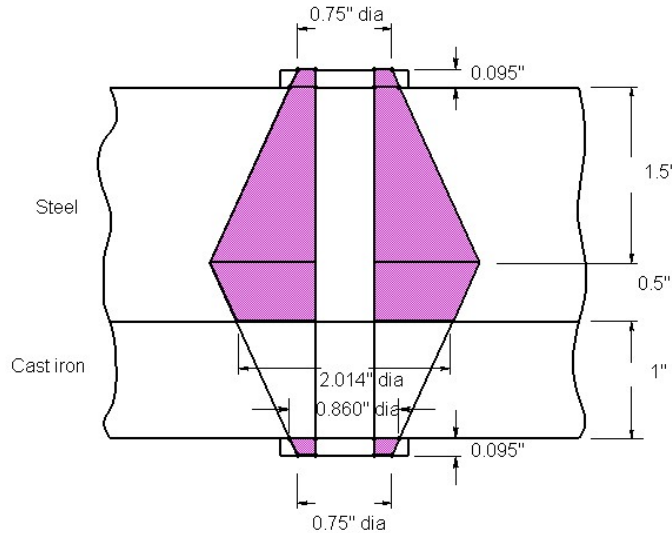
From Table 8-7,  $l_d = L - L_T = 3.75 - 1.25 = 2.5$  in,  $l_t = l - l_d = 3.19 - 2.5 = 0.69$  in

$A_d = \pi(0.5^2)/4 = 0.1963 \text{ in}^2$ . From Table 8-2,  $A_t = 0.1419 \text{ in}^2$ . From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1963(0.1419)30}{0.1963(0.69) + 0.1419(2.5)} = 1.705 \text{ Mlbf/in} \quad \text{Ans.}$$



(c)



Each steel washer frustum:  $t = 0.095$  in,  $d = 0.531$  in (Table A-32),  $D = 0.75$  in,  $E = 30$  Mpsi. From Eq. (8-20)

$$k_1 = \frac{0.5774\pi(30)(0.531)}{\ln \left[ \frac{1.155(0.095) + 0.75 - 0.531}{1.155(0.095) + 0.75 + 0.531} \right] (0.75 + 0.531)} = 89.20 \text{ Mlbf/in}$$

Top plate, top steel frustum:  $t = 1.5$  in,  $d = 0.5$  in,  $D = 0.75 + 2(0.095) \tan 30^\circ = 0.860$  in,  $E = 30$  Mpsi. Eq. (8-20)  $\Rightarrow k_2 = 28.99$  Mlbf/in

Top plate, lower steel frustum:  $t = 0.5$  in,  $d = 0.5$  in,  $D = 0.860 + 2(1) \tan 30^\circ = 2.015$  in,  $E = 30$  Mpsi. Eq. (8-20)  $\Rightarrow k_3 = 234.08$  Mlbf/in

Cast iron:  $t = 1$  in,  $d = 0.5$  in,  $D = 0.75 + 2(0.095) \tan 30^\circ = 0.860$  in,  $E = 14.5$  Mpsi (Table 8-8). Eq. (8-20)  $\Rightarrow k_4 = 15.99$  Mlbf/in

From Eq. (8-18)

$$k_m = (2/k_1 + 1/k_2 + 1/k_3 + 1/k_4)^{-1} = (2/89.20 + 1/28.99 + 1/234.08 + 1/15.99)^{-1} = 8.08 \text{ Mlbf/in} \quad \text{Ans.}$$

**8-16 (a)** From Table 8-7,  $l = h + d/2 = 2 + 0.5/2 = 2.25$  in.

$$L \geq h + 1.5d = 2 + 1.5(0.5) = 2.75 \text{ in} \quad \text{Ans.}$$

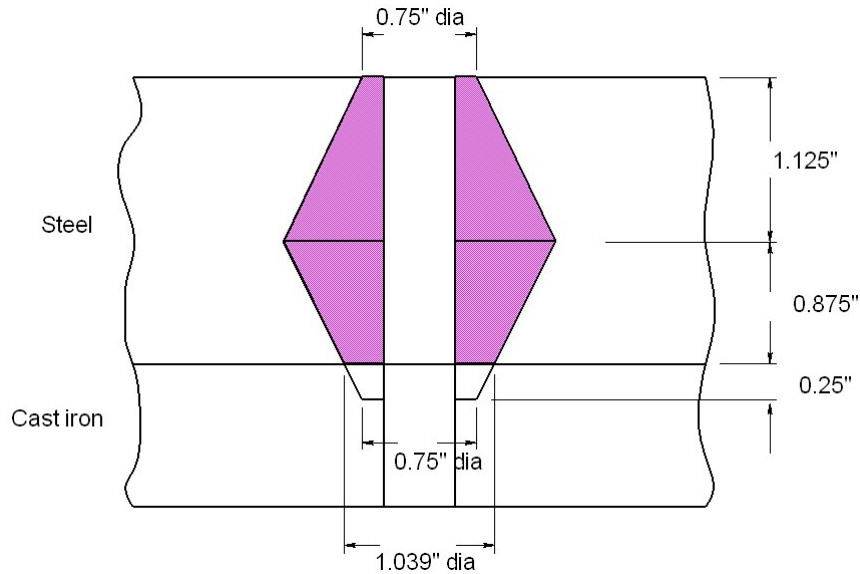
**(b)** From Table 8-7,  $L_T = 2d + 1/4 = 2(0.5) + 0.25 = 1.25$  in

$$l_d = L - L_T = 2.75 - 1.25 = 1.5 \text{ in}, \quad l_t = l - l_d = 2.25 - 1.5 = 0.75 \text{ in}$$

$$A_d = \pi(0.5^2)/4 = 0.1963 \text{ in}^2. \text{ From Table 8-2, } A_t = 0.1419 \text{ in}^2. \text{ From Eq. (8-17)}$$

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1963(0.1419)30}{0.1963(0.75) + 0.1419(1.5)} = 2.321 \text{ Mlbf/in} \quad \text{Ans.}$$

(c)



Top steel frustum:  $t = 1.125$  in,  $d = 0.5$  in,  $D = 0.75$  in,  $E = 30$  Mpsi. From Eq. (8-20)

$$k_1 = \frac{0.5774\pi(30)0.5}{\ln \left[ \frac{1.155(1.125) + 0.75 - 0.5}{1.155(1.125) + 0.75 + 0.5} \right] (0.75 + 0.5)} = 24.48 \text{ Mlbf/in}$$

Lower steel frustum:  $t = 0.875$  in,  $d = 0.5$  in,  $D = 0.75 + 2(0.25) \tan 30^\circ = 1.039$  in,  $E = 30$  Mpsi. Eq. (8-20)  $\Rightarrow k_2 = 49.36$  Mlbf/in

Cast iron:  $t = 0.25$  in,  $d = 0.5$  in,  $D = 0.75$  in,  $E = 14.5$  Mpsi (Table 8-8). Eq. (8-20)  $\Rightarrow k_3 = 23.49$  Mlbf/in

From Eq. (8-18)

$$k_m = (1/k_1 + 1/k_2 + 1/k_3)^{-1} = (1/24.48 + 1/49.36 + 1/23.49)^{-1} = 9.645 \text{ Mlbf/in} \quad \text{Ans.}$$

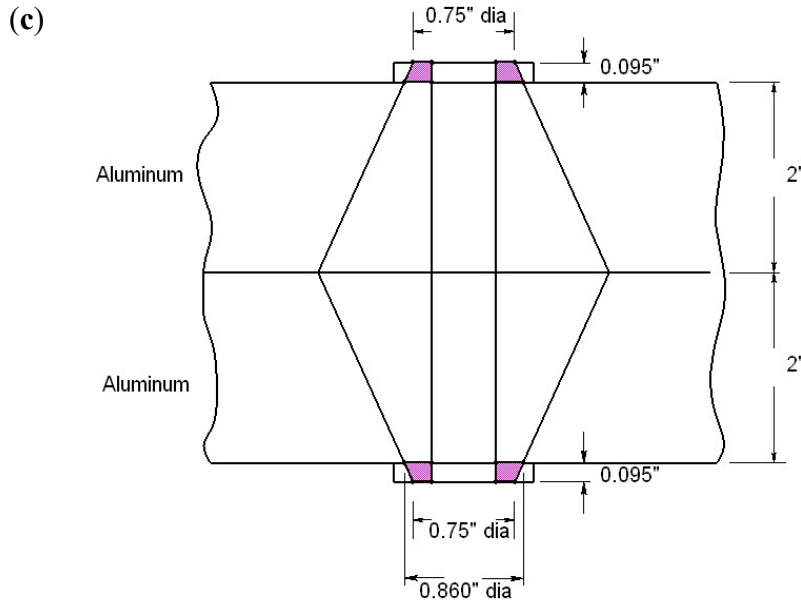
**8-17 a)** Grip,  $l = 2(2 + 0.095) = 4.19$  in.  $L \geq 4.19 + 7/16 = 4.628$  in.  
Rounding up,  $L = 4.75$  in *Ans.*

**(b)** From Eq. (8-13),  $L_T = 2d + 1/4 = 2(0.5) + 0.25 = 1.25$  in

From Table 8-7,  $l_d = L - L_T = 4.75 - 1.25 = 3.5$  in,  $l_t = l - l_d = 4.19 - 3.5 = 0.69$  in

$A_d = \pi(0.5^2)/4 = 0.1963 \text{ in}^2$ . From Table 8-2,  $A_t = 0.1419 \text{ in}^2$ . From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1963(0.1419)30}{0.1963(0.69) + 0.1419(3.5)} = 1.322 \text{ Mlbf/in} \quad \text{Ans.}$$



Upper and lower halves are the same. For the upper half,  
Steel frustum:  $t = 0.095 \text{ in}$ ,  $d = 0.531 \text{ in}$ ,  $D = 0.75 \text{ in}$ , and  $E = 30 \text{ Mpsi}$ . From Eq. (8-20)

$$k_1 = \frac{0.5774\pi(30)0.531}{\ln \left[ \frac{1.155(0.095) + 0.75 - 0.531}{1.155(0.095) + 0.75 + 0.531} \right] (0.75 + 0.531)} = 89.20 \text{ Mlbf/in}$$

Aluminum:  $t = 2 \text{ in}$ ,  $d = 0.5 \text{ in}$ ,  $D = 0.75 + 2(0.095) \tan 30^\circ = 0.860 \text{ in}$ , and  $E = 10.3 \text{ Mpsi}$ . Eq. (8-20)  $\Rightarrow k_2 = 9.24 \text{ Mlbf/in}$

For the top half,  $k'_m = (1/k_1 + 1/k_2)^{-1} = (1/89.20 + 1/9.24)^{-1} = 8.373 \text{ Mlbf/in}$

Since the bottom half is the same, the overall stiffness is given by

$$k_m = (1/k'_m + 1/k'_m)^{-1} = k'_m/2 = 8.373/2 = 4.19 \text{ Mlbf/in} \quad \text{Ans}$$

**8-18 (a)** Grip,  $l = 2(2 + 0.095) = 4.19 \text{ in}$ .  $L \geq 4.19 + 7/16 = 4.628 \text{ in}$ .  
Rounding up,  $L = 4.75 \text{ in}$       *Ans.*

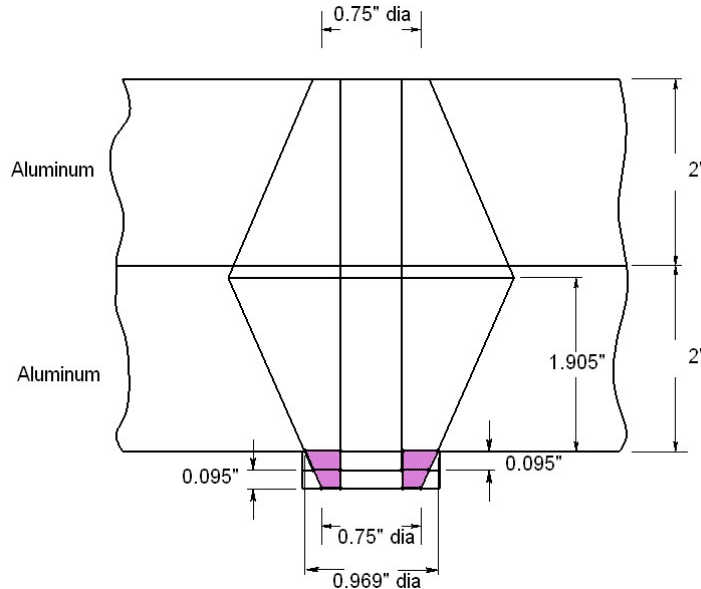
**(b)** From Eq. (8-13),  $L_T = 2d + 1/4 = 2(0.5) + 0.25 = 1.25 \text{ in}$

From Table 8-7,  $l_d = L - L_T = 4.75 - 1.25 = 3.5 \text{ in}$ ,  $l_t = l - l_d = 4.19 - 3.5 = 0.69 \text{ in}$

$A_d = \pi(0.5^2)/4 = 0.1963 \text{ in}^2$ . From Table 8-2,  $A_t = 0.1419 \text{ in}^2$ . From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1963(0.1419)30}{0.1963(0.69) + 0.1419(3.5)} = 1.322 \text{ Mlbf/in} \quad \text{Ans.}$$

(c)



Upper aluminum frustum:  $t = [4 + 2(0.095)]/2 = 2.095 \text{ in}$ ,  $d = 0.5 \text{ in}$ ,  $D = 0.75 \text{ in}$ , and  $E = 10.3 \text{ Mpsi}$ . From Eq. (8-20)

$$k_1 = \frac{0.5774\pi(10.3)0.5}{\ln \left[ \frac{1.155(2.095) + 0.75 - 0.5}{1.155(2.095) + 0.75 + 0.5} \right] (0.75 + 0.5)} = 7.23 \text{ Mlbf/in}$$

Lower aluminum frustum:  $t = 4 - 2.095 = 1.905 \text{ in}$ ,  $d = 0.5 \text{ in}$ ,  $D = 0.75 + 4(0.095) \tan 30^\circ = 0.969 \text{ in}$ , and  $E = 10.3 \text{ Mpsi}$ . Eq. (8-20)  $\Rightarrow k_2 = 11.34 \text{ Mlbf/in}$

Steel washers frustum:  $t = 2(0.095) = 0.190 \text{ in}$ ,  $d = 0.531 \text{ in}$ ,  $D = 0.75 \text{ in}$ , and  $E = 30 \text{ Mpsi}$ . Eq. (8-20)  $\Rightarrow k_3 = 53.91 \text{ Mlbf/in}$

From Eq. (8-18)

$$k_m = (1/k_1 + 1/k_2 + 1/k_3)^{-1} = (1/7.23 + 1/11.34 + 1/53.91)^{-1} = 4.08 \text{ Mlbf/in} \quad \text{Ans.}$$

**8-19 (a)** From Table A-31, the nut height is  $H = 8.4 \text{ mm}$ .  $L > l + H = 50 + 8.4 = 58.4 \text{ mm}$ .

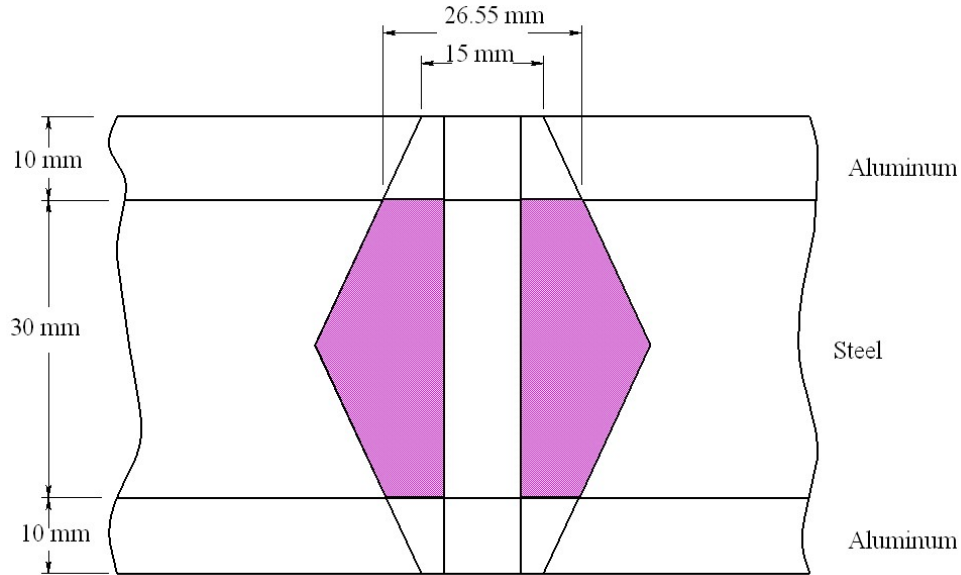
Rounding up,  $L = 60 \text{ mm}$  *Ans.*

**(b)** From Eq. (8-14),  $L_T = 2d + 6 = 2(10) + 6 = 26 \text{ mm}$ ,  $l_d = L - L_T = 60 - 26 = 34 \text{ mm}$ ,  $l_t = l - l_d = 50 - 34 = 16 \text{ mm}$ .  $A_d = \pi(10^2)/4 = 78.54 \text{ mm}^2$ . From Table 8-1,

$A_t = 58 \text{ mm}^2$ . From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{78.54(58.0)207}{78.54(16) + 58.0(34)} = 292.1 \text{ MN/m} \quad \text{Ans.}$$

(c)



Upper and lower frustums are the same. For the upper half,

Aluminum:  $t = 10 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 \text{ mm}$ , and from Table 8-8,  $E = 71 \text{ GPa}$ .

From Eq. (8-20)

$$k_1 = \frac{0.5774\pi(71)10}{\ln \left[ \frac{1.155(10) + 15 - 10}{1.155(10) + 15 + 10} \right] (15 + 10)} = 1576 \text{ MN/m}$$

Steel:  $t = 15 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 + 2(10) \tan 30^\circ = 26.55 \text{ mm}$ , and  $E = 207 \text{ GPa}$ . From Eq. (8-20)

$$k_2 = \frac{0.5774\pi(207)10}{\ln \left[ \frac{1.155(15) + 26.55 - 10}{1.155(15) + 26.55 + 10} \right] (26.55 + 10)} = 11\,440 \text{ MN/m}$$

For the top half,  $k'_m = (1/k_1 + 1/k_2)^{-1} = (1/1576 + 1/11\,440)^{-1} = 1385 \text{ MN/m}$

Since the bottom half is the same, the overall stiffness is given by

$$k_m = (1/k'_m + 1/k'_m)^{-1} = k'_m/2 = 1385/2 = 692.5 \text{ MN/m} \quad \text{Ans.}$$

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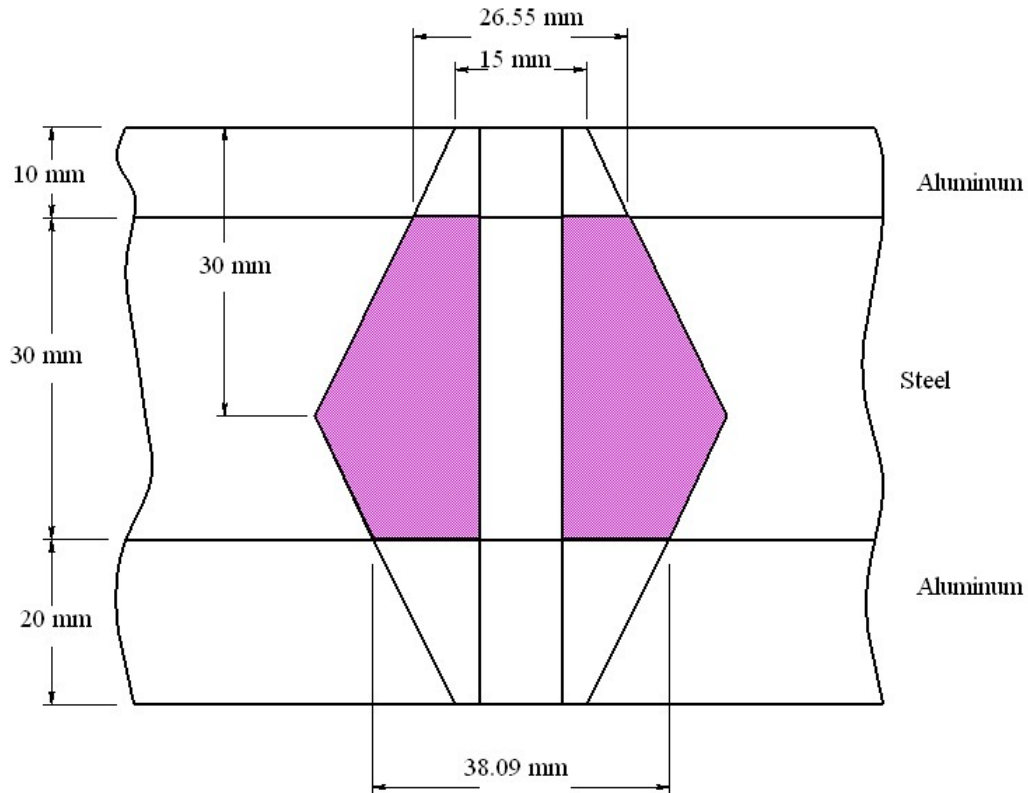
**8-20** (a) From Table A-31, the nut height is  $H = 8.4 \text{ mm}$ .  $L > l + H = 60 + 8.4 = 68.4 \text{ mm}$ .

Rounding up,  $L = 70$  mm *Ans.*

(b) From Eq. (8-14),  $L_T = 2d + 6 = 2(10) + 6 = 26$  mm,  $l_d = L - L_T = 70 - 26 = 44$  mm,  $l_t = l - l_d = 60 - 44 = 16$  mm.  $A_d = \pi(10^2) / 4 = 78.54$  mm<sup>2</sup>. From Table 8-1,  $A_t = 58$  mm<sup>2</sup>. From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{78.54(58.0)207}{78.54(16) + 58.0(44)} = 247.6 \text{ MN/m} \quad \text{Ans.}$$

(c)



Upper aluminum frustum:  $t = 10$  mm,  $d = 10$  mm,  $D = 15$  mm, and  $E = 71$  GPa. From Eq. (8-20)

$$k_1 = \frac{0.5774\pi(10.3)71}{\ln \left[ \frac{1.155(2.095) + 15 - 10}{1.155(2.095) + 15 + 10} \right] (15 + 10)} = 1576 \text{ MN/m}$$

Lower aluminum frustum:  $t = 20$  mm,  $d = 10$  mm,  $D = 15$  mm, and  $E = 71$  GPa. Eq. (8-20)  $\Rightarrow k_2 = 1\,201$  MN/m

Top steel frustum:  $t = 20$  mm,  $d = 10$  mm,  $D = 15 + 2(10) \tan 30^\circ = 26.55$  mm, and  $E = 207$  GPa. Eq. (8-20)  $\Rightarrow k_3 = 9\,781$  MN/m

Lower steel frustum:  $t = 10$  mm,  $d = 10$  mm,  $D = 15 + 2(20) \tan 30^\circ = 38.09$  mm, and  $E = 207$  GPa. Eq. (8-20)  $\Rightarrow k_4 = 29\,070$  MN/m

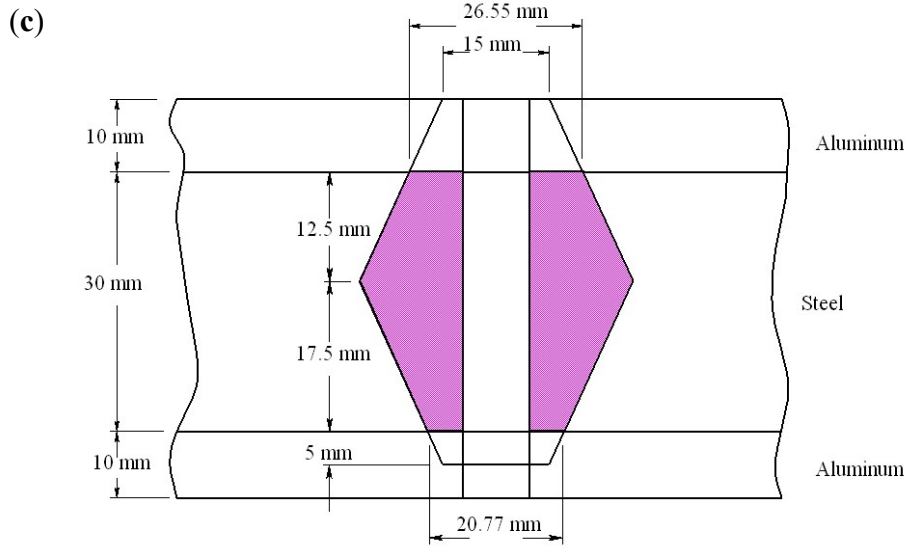
From Eq. (8-18)

$$k_m = (1/k_1 + 1/k_2 + 1/k_3 + 1/k_4)^{-1} = (1/1576 + 1/201 + 1/9781 + 1/29070)^{-1} = 623.5 \text{ MN/m} \quad \text{Ans.}$$

**8-21 (a)** From Table 8-7,  $l = h + d/2 = 10 + 30 + 10/2 = 45 \text{ mm}$ .  $L \geq h + 1.5d = 10 + 30 + 1.5(10) = 55 \text{ mm}$  *Ans.*

**(b)** From Eq. (8-14),  $L_T = 2d + 6 = 2(10) + 6 = 26 \text{ mm}$ ,  $l_d = L - L_T = 55 - 26 = 29 \text{ mm}$ ,  $l_t = l - l_d = 45 - 29 = 16 \text{ mm}$ .  $A_d = \pi(10^2)/4 = 78.54 \text{ mm}^2$ . From Table 8-1,  $A_t = 58 \text{ mm}^2$ . From Eq. (8-17)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{78.54(58.0)207}{78.54(16) + 58.0(29)} = 320.9 \text{ MN/m} \quad \text{Ans.}$$



Upper aluminum frustum:  $t = 10 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 \text{ mm}$ , and  $E = 71 \text{ GPa}$ . From Eq. (8-20)

$$k_1 = \frac{0.5774\pi(10.3)71}{\ln \left[ \frac{1.155(2.095) + 15 - 10}{1.155(2.095) + 15 + 10} \right] \left( \frac{15 + 10}{15 - 10} \right)} = 1576 \text{ MN/m}$$

Lower aluminum frustum:  $t = 5 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 \text{ mm}$ , and  $E = 71 \text{ GPa}$ . Eq. (8-20)  $\Rightarrow k_2 = 2300 \text{ MN/m}$

Top steel frustum:  $t = 12.5 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 + 2(10) \tan 30^\circ = 26.55 \text{ mm}$ , and  $E = 207 \text{ GPa}$ . Eq. (8-20)  $\Rightarrow k_3 = 12759 \text{ MN/m}$

Lower steel frustum:  $t = 17.5 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 + 2(5) \tan 30^\circ = 20.77 \text{ mm}$ , and  $E = 207 \text{ GPa}$ . Eq. (8-20)  $\Rightarrow k_4 = 6806 \text{ MN/m}$

From Eq. (8-18)

$$k_m = (1/k_1 + 1/k_2 + 1/k_3 + 1/k_4)^{-1} = (1/1\,576 + 1/2\,300 + 1/12\,759 + 1/6\,806)^{-1} \\ = 772.4 \text{ MN/m} \quad \text{Ans.}$$

**8-22** Equation (f), Sec. 8-7:  $C = \frac{k_b}{k_b + k_m}$

Eq. (8-17):  $k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$

Eq. (8-22):  $k_m = \frac{0.5774\pi(207)d}{2 \ln \left[ 5 \frac{0.5774(40) + 0.5d}{0.5774(40) + 2.5d} \right]}$

See Table 8-7 for other terms used.

Using a spreadsheet, with coarse-pitch bolts (units are mm, mm<sup>2</sup>, MN/m):

$d$	$A_t$	$A_d$	$H$	$L >$	$L$	$L_T$
10	58	78.53982	8.4	48.4	50	26
12	84.3	113.0973	10.8	50.8	55	30
14	115	153.938	12.8	52.8	55	34
16	157	201.0619	14.8	54.8	55	38
20	245	314.1593	18	58	60	46
24	353	452.3893	21.5	61.5	65	54
30	561	706.8583	25.6	65.6	70	66

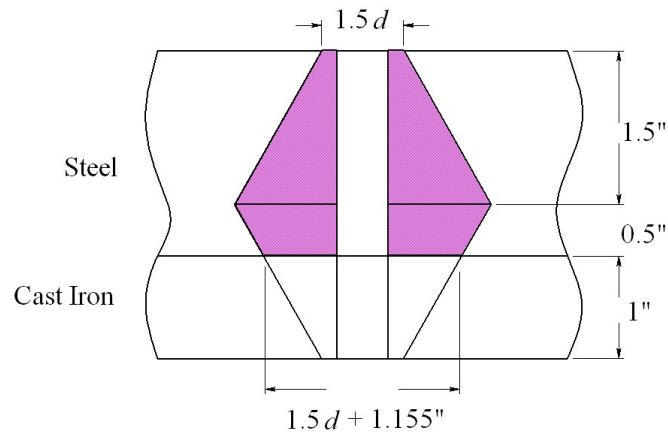
$d$	$l$	$l_d$	$l_t$	$k_b$	$k_m$	$C$
10	40	24	16	356.0129	1751.566	0.16892
12	40	25	15	518.8172	2235.192	0.188386
14	40	21	19	686.2578	2761.721	<b>0.199032</b>
16	40	17	23	895.9182	3330.796	0.211966
20	40	14	26	1373.719	4595.515	0.230133
24	40	11	29	1944.24	6027.684	0.243886
30	40	4	36	2964.343	8487.533	0.258852

Use a M14 × 2 bolt, with length 55 mm. *Ans.*

**8-23** Equation (f), Sec. 8-7:  $C = \frac{k_b}{k_b + k_m}$

Eq. (8-17):  $k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$





For upper frustum, Eq. (8-20), with  $D = 1.5d$  and  $t = 1.5$  in:

$$k_1 = \frac{0.5774\pi(30)d}{\ln \left[ \frac{\left[ \frac{1.155(1.5) + 0.5d}{1.155(1.5) + 2.5d} \right] (2.5d)}{(0.5d)} \right]} = \frac{0.5774\pi(30)d}{\ln \left[ 5 \frac{(1.733 + 0.5d)}{(1.733 + 2.5d)} \right]}$$

Lower steel frustum, with  $D = 1.5d + 2(1) \tan 30^\circ = 1.5d + 1.155$ , and  $t = 0.5$  in:

$$k_2 = \frac{0.5774\pi(30)d}{\ln \left[ \frac{(1.733 + 0.5d)(2.5d + 1.155)}{(1.733 + 2.5d)(0.5d + 1.155)} \right]}$$

For cast iron frustum, let  $E = 14.5$  Mpsi, and  $D = 1.5d$ , and  $t = 1$  in:

$$k_3 = \frac{0.5774\pi(14.5)d}{\ln \left[ 5 \frac{(1.155 + 0.5d)}{(1.155 + 2.5d)} \right]}$$

Overall,  $k_m = (1/k_1 + 1/k_2 + 1/k_3)^{-1}$

See Table 8-7 for other terms used.

Using a spreadsheet, with coarse-pitch bolts (units are in, in<sup>2</sup>, Mlbf/in):

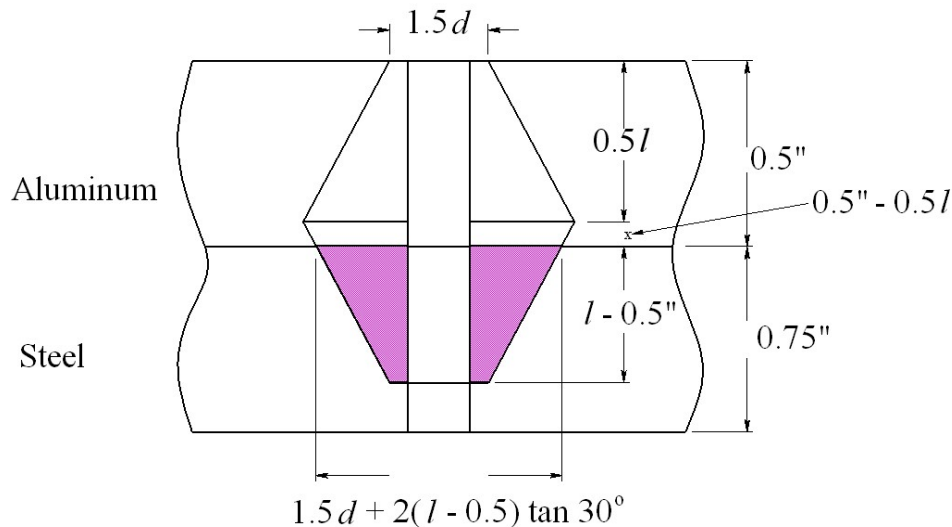
$d$	$A_t$	$A_d$	$H$	$L >$	$L$	$L_T$	$l$
0.375	0.0775	0.110447	0.328125	3.328125	3.5	1	3
0.4375	0.1063	0.15033	0.375	3.375	3.5	1.125	3
0.5	0.1419	0.19635	0.4375	3.4375	3.5	1.25	3
0.5625	0.182	0.248505	0.484375	3.484375	3.5	1.375	3
0.625	0.226	0.306796	0.546875	3.546875	3.75	1.5	3
0.75	0.334	0.441786	0.640625	3.640625	3.75	1.75	3
0.875	0.462	0.60132	0.75	3.75	3.75	2	3

$d$	$l_d$	$l_t$	$k_b$	$k_1$	$k_2$	$k_3$	$k_m$	$C$
0.375	2.5	0.5	1.031389	15.94599	178.7801	8.461979	5.362481	0.161309
0.4375	2.375	0.625	1.383882	19.21506	194.465	10.30557	6.484256	0.175884
0.5	2.25	0.75	1.791626	22.65332	210.6084	12.26874	7.668728	0.189383
0.5625	2.125	0.875	2.245705	26.25931	227.2109	14.35052	8.915294	<b>0.20121</b>
0.625	2.25	0.75	2.816255	30.03179	244.2728	16.55009	10.22344	0.215976
0.75	2	1	3.988786	38.07191	279.7762	21.29991	13.02271	0.234476
0.875	1.75	1.25	5.341985	46.7663	317.1203	26.51374	16.06359	0.24956

Use a  $\frac{9}{16}$ -12 UNC  $\times$  3.5 in long bolt *Ans.*

**8-24** Equation (f), Sec. 8-7:  $C = \frac{k_b}{k_b + k_m}$

Eq. (8-17):  $k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$



Top frustum, Eq. (8-20), with  $E = 10.3\text{Mpsi}$ ,  $D = 1.5 d$ , and  $t = l/2$ :

$$k_1 = \frac{0.5774\pi(10.3)d}{\ln \left[ 5 \frac{1.155 l/2 + 0.5d}{1.155 l/2 + 2.5d} \right]}$$

Middle frustum, with  $E = 10.3\text{ Mpsi}$ ,  $D = 1.5d + 2(l - 0.5) \tan 30^\circ$ , and  $t = 0.5 - l/2$

$$k_2 = \frac{0.5774\pi(10.3)d}{\ln \left\{ \frac{\left[ 1.155(0.5 - 0.5l) + 0.5d + 2(l - 0.5) \tan 30^\circ \right] \left[ 2.5d + 2(l - 0.5) \tan 30^\circ \right]}{\left[ 1.155(0.5 - 0.5l) + 2.5d + 2(l - 0.5) \tan 30^\circ \right] \left[ 0.5d + 2(l - 0.5) \tan 30^\circ \right]} \right\}}$$

Lower frustum, with  $E = 30\text{Mpsi}$ ,  $D = 1.5 d$ ,  $t = l - 0.5$

$$k_3 = \frac{0.5774\pi(30)d}{\ln 5 \left\{ \frac{\left[ 1.155(l - 0.5) + 0.5d \right]}{\left[ 1.155(l - 0.5) + 2.5d \right]} \right\}}$$

See Table 8-7 for other terms used.

Using a spreadsheet, with coarse-pitch bolts (units are in, in<sup>2</sup>, Mlbf/in)

Size	$d$	$A_t$	$A_d$	$L >$	$L$	$L_T$	$l$	$l_d$
1	0.073	0.00263	0.004185	0.6095	0.75	0.396	0.5365	0.354
2	0.086	0.0037	0.005809	0.629	0.75	0.422	0.543	0.328
3	0.099	0.00487	0.007698	0.6485	0.75	0.448	0.5495	0.302
4	0.112	0.00604	0.009852	0.668	0.75	0.474	0.556	0.276
5	0.125	0.00796	0.012272	0.6875	0.75	0.5	0.5625	0.25
6	0.138	0.00909	0.014957	0.707	0.75	0.526	0.569	0.224
8	0.164	0.014	0.021124	0.746	0.75	0.578	0.582	0.172
10	0.19	0.0175	0.028353	0.785	1	0.63	0.595	0.37
Size	$d$	$l_t$	$k_b$	$k_1$	$k_2$	$k_3$	$k_m$	$C$
1	0.073	0.1825	0.194841	1.084468	1.954599	7.09432	0.635049	0.23478
2	0.086	0.215	0.261839	1.321595	2.449694	8.357692	0.778497	<b>0.251687</b>
3	0.099	0.2475	0.333134	1.570439	2.993366	9.621064	0.930427	0.263647
4	0.112	0.28	0.403377	1.830494	3.587564	10.88444	1.090613	0.27
5	0.125	0.3125	0.503097	2.101297	4.234381	12.14781	1.258846	0.285535
6	0.138	0.345	0.566787	2.382414	4.936066	13.41118	1.434931	0.28315
8	0.164	0.41	0.801537	2.974009	6.513824	15.93792	1.809923	0.306931
10	0.19	0.225	1.15799	3.602349	8.342138	18.46467	2.214214	0.343393

Use a 2–56 UNC  $\times$  0.75 in long bolt.

*Ans.*

**8-25** For half of joint, Eq. (8-20):  $t = 20$  mm,  $d = 14$  mm,  $D = 21$  mm, and  $E = 207$  GPa

$$k_1 = \frac{0.5774\pi(207)14}{\ln \left[ \frac{[1.155(20) + 21 - 14](21 + 14)}{[1.155(20) + 21 + 14](21 - 14)} \right]} = 5523 \text{ MN/m}$$

$$k_m = (1/k_1 + 1/k_1)^{-1} = k_1/2 = 5523/2 = 2762 \text{ MN/m} \quad \text{Ans.}$$

From Eq. (8-22) with  $l = 40$  mm

$$k_m = \frac{0.5774\pi(207)14}{2 \ln \left[ 5 \frac{0.5774(40) + 0.5(14)}{0.5774(40) + 2.5(14)} \right]} = 2762 \text{ MN/m} \quad \text{Ans.}$$

which agrees with the earlier calculation.

For Eq. (8-23), from Table 8-8,  $A = 0.787$  15,  $B = 0.628$  73

$$k_m = 207(14)(0.78715) \exp [0.62873(14)/40] = 2843 \text{ MN/m} \quad \text{Ans.}$$

This is 2.9% higher than the earlier calculations.

**8-26 (a)** Grip,  $l = 10$  in. Nut height,  $H = 41/64$  in (Table A-31).

$L \geq l + H = 10 + 41/64 = 10.641$  in. Let  $L = 10.75$  in.

Table 8-7,  $L_T = 2d + 0.5 = 2(0.75) + 0.5 = 2$  in,  $l_d = L - L_T = 10.75 - 2 = 8.75$  in,

$l_t = l - l_d = 10 - 8.75 = 1.25$  in

$A_d = \pi(0.75^2)/4 = 0.4418$  in<sup>2</sup>,  $A_t = 0.373$  in<sup>2</sup> (Table 8-2)

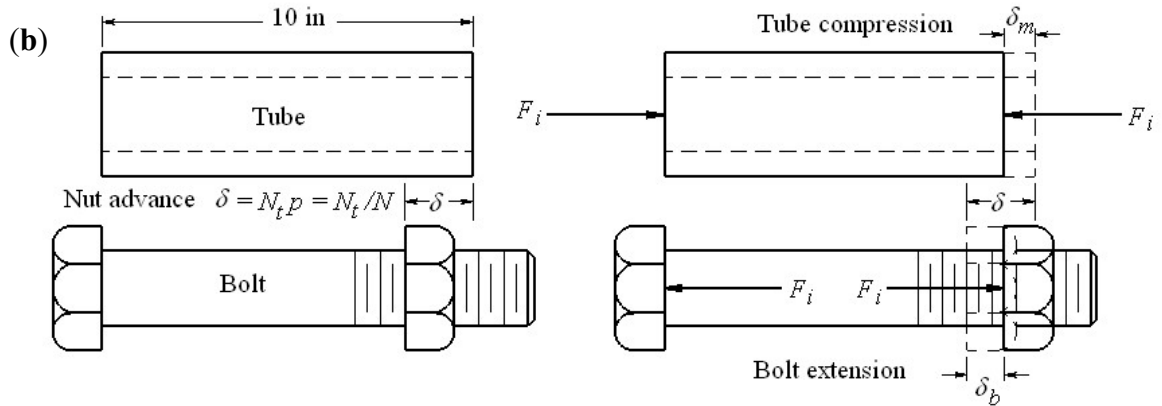
Eq. (8-17),

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.4418(0.373)30}{0.4418(1.25) + 0.373(8.75)} = 1.296 \text{ Mlbf/in} \quad \text{Ans.}$$

Eq. (4-4),

$$k_m = \frac{A_m E_m}{l} = \frac{(\pi/4)(1.125^2 - 0.75^2)30}{10} = 1.657 \text{ Mlbf/in} \quad \text{Ans.}$$

$$\text{Eq. (f), Sec. 8-7,} \quad C = k_b/(k_b + k_m) = 1.296/(1.296 + 1.657) = 0.439 \quad \text{Ans.}$$



Let:  $N_t$  = no. of turns,  $p$  = pitch of thread (in),  $N$  = no. of threads per in =  $1/p$ . Then,

$$\delta = \delta_b + \delta_m = N_t p = N_t / N \quad (1)$$

But,  $\delta_b = F_i / k_b$ , and,  $\delta_m = F_i / k_m$ . Substituting these into Eq. (1) and solving for  $F_i$  gives

$$\begin{aligned} F_i &= \frac{k_b k_m}{k_b + k_m} \frac{N_t}{N} \quad (2) \\ &= \frac{1.296(1.657)10^6}{1.296 + 1.657} \frac{1/3}{16} = 15\,150 \text{ lbf} \quad \text{Ans.} \end{aligned}$$

**8-27** Proof for the turn-of-nut equation is given in the solution of Prob. 8-26, Eq. (2), where  $N_t = \theta / 360^\circ$ .

The relationship between the turn-of-nut method and the torque-wrench method is as follows.

$$\begin{aligned} N_t &= \left( \frac{k_b + k_m}{k_b k_m} \right) F_i N \quad (\text{turn-of-nut}) \\ T &= K F_i d \quad (\text{torque-wrench}) \end{aligned}$$

Eliminate  $F_i$

$$N_t = \left( \frac{k_b + k_m}{k_b k_m} \right) \frac{NT}{Kd} = \frac{\theta}{360^\circ} \quad \text{Ans.}$$

**8-28 (a)** From Ex. 8-4,  $F_i = 14.4$  kip,  $k_b = 5.21(10^6)$  lbf/in,  $k_m = 8.95(10^6)$  lbf/in  
 Eq. (8-27):  $T = k F_i d = 0.2(14.4)(10^3)(5/8) = 1800$  lbf · in *Ans.*  
 From Prob. 8-27,

$$N_t = \left( \frac{k_b + k_m}{k_b k_m} \right) F_i N = \left[ \frac{5.21 + 8.95}{5.21(8.95)10^6} \right] (14.4)(10^3)11$$

$$= 0.0481 \text{ turns} = 17.3^\circ \quad \text{Ans.}$$

Bolt group is  $(1.5) / (5/8) = 2.4$  diameters. Answer is much lower than RB&W recommendations.

- 8-29**  $C = k_b / (k_b + k_m) = 3/(3+12) = 0.2$ ,  $P = P_{\text{total}} / N = 80/6 = 13.33$  kips/bolt  
 Table 8-2,  $A_t = 0.1419 \text{ in}^2$ ; Table 8-9,  $S_p = 120$  kpsi; Eqs. (8-31) and (8-32),  
 $F_i = 0.75 A_t S_p = 0.75(0.1419)(120) = 12.77$  kips  
 (a) From Eq. (8-28), the factor of safety for yielding is

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{120(0.1419)}{0.2(13.33) + 12.77} = 1.10 \quad \text{Ans.}$$

- (b) From Eq. (8-29), the overload factor is

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{120(0.1419) - 12.77}{0.2(13.33)} = 1.60 \quad \text{Ans.}$$

- (c) From Eq. (8-30), the joint separation factor of safety is

$$n_0 = \frac{F_i}{P(1-C)} = \frac{12.77}{13.33(1-0.2)} = 1.20 \quad \text{Ans.}$$

- 8-30**  $1/2 - 13$  UNC Grade 8 bolt,  $K = 0.20$

- (a) Proof strength, Table 8-9,  $S_p = 120$  kpsi  
 Table 8-2,  $A_t = 0.1419 \text{ in}^2$   
 Maximum,  $F_i = S_p A_t = 120(0.1419) = 17.0$  kips *Ans.*  
 (b) From Prob. 8-29,  $C = 0.2$ ,  $P = 13.33$  kips  
 Joint separation, Eq. (8-30) with  $n_0 = 1$   
 Minimum  $F_i = P(1-C) = 13.33(1-0.2) = 10.66$  kips *Ans.*  
 (c)  $\bar{F}_i = (17.0 + 10.66)/2 = 13.8$  kips  
 Eq. (8-27),  $T = K F_i d = 0.2(13.8)10^3(0.5)/12 = 115 \text{ lbf} \cdot \text{ft}$  *Ans.*

- 8-31** (a) Table 8-1,  $A_t = 20.1 \text{ mm}^2$ . Table 8-11,  $S_p = 380 \text{ MPa}$ .

$$\text{Eq. (8-31), } F_i = 0.75 F_p = 0.75 A_t S_p = 0.75(20.1)380(10^{-3}) = 5.73 \text{ kN}$$

$$\text{Eq. (f), Sec. 8-7, } C = \frac{k_b}{k_b + k_m} = \frac{1}{1 + 2.6} = 0.278$$

$$\text{Eq. (8-28) with } n_p = 1,$$

$$P = \frac{S_p A_t - F_i}{C} = \frac{0.25 S_p A_t}{C} = \frac{0.25(20.1)380(10^{-3})}{0.278} = 6.869 \text{ kN}$$

$$P_{\text{total}} = NP = 8(6.869) = 55.0 \text{ kN} \quad \text{Ans.}$$

(b) Eq. (8-30) with  $n_0 = 1$ ,

$$P = \frac{F_i}{1-C} = \frac{5.73}{1-0.278} = 7.94 \text{ kN}$$

$$P_{\text{total}} = NP = 8(7.94) = 63.5 \text{ kN} \quad \text{Ans.} \quad \text{Bolt stress would exceed proof strength}$$

**8-32** (a) Table 8-2,  $A_t = 0.1419 \text{ in}^2$ . Table 8-9,  $S_p = 120 \text{ kpsi}$ .

$$\text{Eq. (8-31), } F_i = 0.75 F_p = 0.75 A_t S_p = 0.75(0.1419)120 = 12.77 \text{ kips}$$

$$\text{Eq. (f), Sec. 8-7, } C = \frac{k_b}{k_b + k_m} = \frac{4}{4 + 12} = 0.25$$

Eq. (8-28) with  $n_p = 1$ ,

$$P_{\text{total}} = N \left( \frac{S_p A_t - F_i}{C} \right) = \frac{0.25 N S_p A_t}{C}$$

$$N = \frac{P_{\text{total}} C}{0.25 S_p A_t} = \frac{80(0.25)}{0.25(120)0.1419} = 4.70$$

Round to  $N = 5$  bolts *Ans.*

(b) Eq. (8-30) with  $n_0 = 1$ ,

$$P_{\text{total}} = N \left( \frac{F_i}{1-C} \right)$$

$$N = \frac{P_{\text{total}}(1-C)}{F_i} = \frac{80(1-0.25)}{12.77} = 4.70$$

Round to  $N = 5$  bolts *Ans.*

**8-33** Bolts: From Table A-31, the nut height is  $H = 10.8 \text{ mm}$ .  $L \geq l + H = 40 + 10.8 = 50.8 \text{ mm}$ .

Round up to  $L = 55 \text{ mm}$  *Ans.*

$$\text{Eq. (8-14): } L_T = 2d + 6 = 2(12) + 6 = 30 \text{ mm}$$

$$\text{Table 8-7: } l_d = L - L_T = 55 - 30 = 25 \text{ mm, } l_t = l - l_d = 40 - 25 = 15 \text{ mm}$$

$$A_d = \pi(12^2)/4 = 113.1 \text{ mm}^2, \text{ Table 8-1: } A_t = 84.3 \text{ mm}^2$$

Eq. (8-17):

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{113.1(84.3)207}{113.1(15) + 84.3(25)} = 518.8 \text{ MN/m}$$

Members: Steel cyl. head:  $t = 20 \text{ mm}$ ,  $d = 12 \text{ mm}$ ,  $D = 18 \text{ mm}$ ,  $E = 207 \text{ GPa}$ . Eq. (8-20),

$$k_1 = \frac{0.5774\pi(207)12}{\ln \frac{[1.155(20) + 18 - 12](18 + 12)}{[1.155(20) + 18 + 12](18 - 12)}} = 4470 \text{ MN/m}$$

Cast iron:  $t = 20 \text{ mm}$ ,  $d = 12 \text{ mm}$ ,  $D = 18 \text{ mm}$ ,  $E = 100 \text{ GPa}$  (from Table 8-8). The only difference from  $k_1$  is the material

$$k_2 = (100/207)(4470) = 2159 \text{ MN/m}$$

$$\text{Eq. (8-18): } k_m = (1/4470 + 1/2159)^{-1} = 1456 \text{ MN/m}$$

$$C = k_b / (k_b + k_m) = 518.8 / (518.8 + 1456) = 0.263$$

Table 8-11:  $S_p = 650 \text{ MPa}$

For a non-permanent connection, using Eqs. (8-31) and (8-32)

$$F_i = 0.75 A_t S_p = 0.75(84.3)(650)10^{-3} = 41.1 \text{ kN}$$

The total external load is  $P_{\text{total}} = p_g A_g$ , where  $A_g$  is the effective area of the cylinder, based on the effective sealing diameter of 100 mm. The external load per bolt is  $P = P_{\text{total}} / N$ . Thus

$$P = [6\pi(100^2)/4](10^{-3})/10 = 4.712 \text{ kN/bolt}$$

Yielding factor of safety, Eq. (8-28):

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{650(84.3)10^{-3}}{0.263(4.712) + 41.10} = 1.29 \quad \text{Ans.}$$

Overload factor of safety, Eq. (8-29):

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{650(84.3)10^{-3} - 41.10}{0.263(4.712)} = 11.1 \quad \text{Ans.}$$

Separation factor of safety, Eq. (8-30):



$$n_0 = \frac{F_i}{P(1-C)} = \frac{41.10}{4.712(1-0.263)} = 11.8 \quad \text{Ans.}$$

**8-34** Bolts: Grip,  $l = 1/2 + 5/8 = 1.125$  in. From Table A-31, the nut height is  $H = 7/16$  in.  
 $L \geq l + H = 1.125 + 7/16 = 1.563$  in.

Round up to  $L = 1.75$  in *Ans.*

Eq. (8-13):  $L_T = 2d + 0.25 = 2(0.5) + 0.25 = 1.25$  in

Table 8-7:  $l_d = L - L_T = 1.75 - 1.25 = 0.5$  in,  $l_t = l - l_d = 1.125 - 0.5 = 0.625$  in

$A_d = \pi(0.5^2)/4 = 0.1963$  in<sup>2</sup>, Table 8-2:  $A_t = 0.1419$  in<sup>2</sup>

Eq. (8-17):

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1963(0.1419)30}{0.1963(0.625) + 0.1419(0.5)} = 4.316 \text{ Mlbf/in}$$

Members: Steel cyl. head:  $t = 0.5$  in,  $d = 0.5$  in,  $D = 0.75$  in,  $E = 30$  Mpsi. Eq. (8-20),

$$k_1 = \frac{0.5774\pi(30)0.5}{\ln \left[ \frac{1.155(0.5) + 0.75 - 0.5}{1.155(0.5) + 0.75 + 0.5} \right] \frac{(0.75 + 0.5)}{(0.75 - 0.5)}} = 33.30 \text{ Mlbf/in}$$

Cast iron: Has two frusta. Midpoint of complete joint is at  $(1/2 + 5/8)/2 = 0.5625$  in.

Upper frustum,  $t = 0.5625 - 0.5 = 0.0625$  in,  $d = 0.5$  in,

$D = 0.75 + 2(0.5) \tan 30^\circ = 1.327$  in,  $E = 14.5$  Mpsi (from Table 8-8)

Eq. (8-20)  $\Rightarrow k_2 = 292.7$  Mlbf/in

Lower frustum,  $t = 0.5625$  in,  $d = 0.5$  in,  $D = 0.75$  in,  $E = 14.5$  Mpsi

Eq. (8-20)  $\Rightarrow k_3 = 15.26$  Mlbf/in

Eq. (8-18):  $k_m = (1/33.30 + 1/292.7 + 1/15.26)^{-1} = 10.10$  Mlbf/in

$C = k_b / (k_b + k_m) = 4.316 / (4.316 + 10.10) = 0.299$

Table 8-9:  $S_p = 85$  kpsi

For a non-permanent connection, using Eqs. (8-31) and (8-32)

$$F_i = 0.75 A_t S_p = 0.75(0.1419)(85) = 9.05 \text{ kips}$$

The total external load is  $P_{\text{total}} = p_g A_g$ , where  $A_g$  is the effective area of the cylinder, based on the effective sealing diameter of 3.5 in. The external load per bolt is  $P = P_{\text{total}}/N$ . Thus,

$$P = [1500\pi(3.5^2)/4](10^{-3})/10 = 1.443 \text{ kips/bolt}$$

Yielding factor of safety, Eq. (8-28):

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{85(0.1419)}{0.299(1.443) + 9.05} = 1.27 \quad \text{Ans.}$$

Overload factor of safety, Eq. (8-29):

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{85(0.1419) - 9.05}{0.299(1.443)} = 6.98 \quad \text{Ans.}$$

Separation factor of safety, Eq. (8-30):

$$n_0 = \frac{F_i}{P(1-C)} = \frac{9.05}{1.443(1-0.299)} = 8.95 \quad \text{Ans.}$$

**8-35** Bolts: Grip:  $l = 20 + 25 = 45$  mm. From Table A-31, the nut height is  $H = 8.4$  mm.

$$L \geq l + H = 45 + 8.4 = 53.4 \text{ mm.}$$

Round up to  $L = 55$  mm *Ans.*

$$\text{Eq. (8-14): } L_T = 2d + 6 = 2(10) + 6 = 26 \text{ mm}$$

$$\text{Table 8-7: } l_d = L - L_T = 55 - 26 = 29 \text{ mm, } l_t = l - l_d = 45 - 29 = 16 \text{ mm}$$

$$A_d = \pi(10^2)/4 = 78.5 \text{ mm}^2, \text{ Table 8-1: } A_t = 58.0 \text{ mm}^2$$

Eq. (8-17):

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{78.5(58.0)207}{78.5(16) + 58.0(29)} = 320.8 \text{ MN/m}$$

Members: Steel cyl. head:  $t = 20$  mm,  $d = 10$  mm,  $D = 15$  mm,  $E = 207$  GPa. Eq. (8-20),

$$k_1 = \frac{0.5774\pi(207)10}{\ln \frac{[1.155(20) + 15 - 10](15 + 10)}{[1.155(20) + 15 + 10](15 - 10)}} = 3503 \text{ MN/m}$$

Cast iron: Has two frusta. Midpoint of complete joint is at  $(20 + 25)/2 = 22.5$  mm

Upper frustum,  $t = 22.5 - 20 = 2.5$  mm,  $d = 10$  mm,

$$D = 15 + 2(20) \tan 30^\circ = 38.09 \text{ mm, } E = 100 \text{ GPa (from Table 8-8),}$$

$$\text{Eq. (8-20)} \Rightarrow k_2 = 45\,880 \text{ MN/m}$$

Lower frustum,  $t = 22.5$  mm,  $d = 10$  mm,  $D = 15$  mm,  $E = 100$  GPa

$$\text{Eq. (8-20)} \Rightarrow k_3 = 1632 \text{ MN/m}$$

$$\text{Eq. (8-18): } k_m = (1/3503 + 1/45\,880 + 1/1632)^{-1} = 1087 \text{ MN/m}$$

$$C = k_b / (k_b + k_m) = 320.8 / (320.8 + 1087) = 0.228$$

Table 8-11:  $S_p = 830$  MPa

For a non-permanent connection, using Eqs. (8-31) and (8-32)

$$F_i = 0.75 A_t S_p = 0.75(58.0)(830)10^{-3} = 36.1 \text{ kN}$$

The total external load is  $P_{\text{total}} = p_g A_g$ , where  $A_g$  is the effective area of the cylinder, based on the effective sealing diameter of 0.8 m. The external load per bolt is  $P = P_{\text{total}} / N$ . Thus,

$$P = [550\pi(0.8^2)/4]/36 = 7.679 \text{ kN/bolt}$$

Yielding factor of safety, Eq. (8-28):

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{830(58.0)10^{-3}}{0.228(7.679) + 36.1} = 1.27 \quad \text{Ans.}$$

Overload factor of safety, Eq. (8-29):

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{830(58.0)10^{-3} - 36.1}{0.228(7.679)} = 6.88 \quad \text{Ans.}$$

Separation factor of safety, Eq. (8-30):

$$n_0 = \frac{F_i}{P(1-C)} = \frac{36.1}{7.679(1-0.228)} = 6.09 \quad \text{Ans.}$$

### 8-36

Bolts: Grip,  $l = 3/8 + 1/2 = 0.875$  in. From Table A-31, the nut height is  $H = 3/8$  in.

$L \geq l + H = 0.875 + 3/8 = 1.25$  in.

Let  $L = 1.25$  in *Ans.*

Eq. (8-13):  $L_T = 2d + 0.25 = 2(7/16) + 0.25 = 1.125$  in

Table 8-7:  $l_d = L - L_T = 1.25 - 1.125 = 0.125$  in,  $l_t = l - l_d = 0.875 - 0.125 = 0.75$  in

$A_d = \pi(7/16)^2/4 = 0.1503$  in<sup>2</sup>, Table 8-2:  $A_t = 0.1063$  in<sup>2</sup>

Eq. (8-17),

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1503(0.1063)30}{0.1503(0.75) + 0.1063(0.125)} = 3.804 \text{ Mlbf/in}$$

Members: Steel cyl. head:  $t = 0.375$  in,  $d = 0.4375$  in,  $D = 0.65625$  in,  $E = 30$  Mpsi. Eq. (8-20),

$$k_1 = \frac{0.5774\pi(30)0.4375}{\ln \left[ \frac{[1.155(0.375) + 0.65625 - 0.4375](0.65625 + 0.4375)}{[1.155(0.375) + 0.65625 + 0.4375](0.65625 - 0.4375)} \right]} = 31.40 \text{ Mlbf/in}$$

Cast iron: Has two frusta. Midpoint of complete joint is at  $(3/8 + 1/2)/2 = 0.4375$  in.

Upper frustum,  $t = 0.4375 - 0.375 = 0.0625$  in,  $d = 0.4375$  in,

$D = 0.65625 + 2(0.375) \tan 30^\circ = 1.089$  in,  $E = 14.5$  Mpsi (from Table 8-8)

Eq. (8-20)  $\Rightarrow k_2 = 195.5$  Mlbf/in

Lower frustum,  $t = 0.4375$  in,  $d = 0.4375$  in,  $D = 0.65625$  in,  $E = 14.5$  Mpsi

Eq. (8-20)  $\Rightarrow k_3 = 14.08$  Mlbf/in

Eq. (8-18):  $k_m = (1/31.40 + 1/195.5 + 1/14.08)^{-1} = 9.261$  Mlbf/in

$C = k_b / (k_b + k_m) = 3.804 / (3.804 + 9.261) = 0.291$

Table 8-9:  $S_p = 120$  kpsi

For a non-permanent connection, using Eqs. (8-31) and (8-32)

$$F_i = 0.75 A_t S_p = 0.75(0.1063)(120) = 9.57 \text{ kips}$$

The total external load is  $P_{\text{total}} = p_g A_g$ , where  $A_g$  is the effective area of the cylinder, based on the effective sealing diameter of 3.25 in. The external load per bolt is  $P = P_{\text{total}} / N$ .

Thus,

$$P = [1200\pi(3.25^2)/4](10^{-3})/8 = 1.244 \text{ kips/bolt}$$

Yielding factor of safety, Eq. (8-28):

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{120(0.1063)}{0.291(1.244) + 9.57} = 1.28 \quad \text{Ans.}$$

Overload factor of safety, Eq. (8-29):

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{120(0.1063) - 9.57}{0.291(1.244)} = 8.80 \quad \text{Ans.}$$

Separation factor of safety, Eq. (8-30):

$$n_0 = \frac{F_i}{P(1 - C)} = \frac{9.57}{1.244(1 - 0.291)} = 10.9 \quad \text{Ans.}$$

### 8-37

From Table 8-7,  $h = t_1 = 20 \text{ mm}$

For  $t_2 > d$ ,  $l = h + d/2 = 20 + 12/2 = 26 \text{ mm}$

$L \geq h + 1.5d = 20 + 1.5(12) = 38 \text{ mm}$ . Round up to  $L = 40 \text{ mm}$

$L_T = 2d + 6 = 2(12) + 6 = 30 \text{ mm}$

$l_d = L - L_T = 40 - 30 = 10 \text{ mm}$

$l_t = l - l_d = 26 - 10 = 16 \text{ mm}$

From Table 8-1,  $A_t = 84.3 \text{ mm}^2$ .  $A_d = \pi(12^2)/4 = 113.1 \text{ mm}^2$

Eq. (8-17),

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{113.1(84.3)207}{113.1(16) + 84.3(10)} = 744.0 \text{ MN/m}$$

Similar to Fig. 8-23, we have three frusta.

Top frusta, steel:  $t = l/2 = 13 \text{ mm}$ ,  $d = 12 \text{ mm}$ ,  $D = 18 \text{ mm}$ ,  $E = 207 \text{ GPa}$ . Eq. (8-20)

$$k_1 = \frac{0.5774\pi(207)12}{\ln \frac{[1.155(13) + 18 - 12](18 + 12)}{[1.155(13) + 18 + 12](18 - 12)}} = 5316 \text{ MN/m}$$

Middle frusta, steel:  $t = 20 - 13 = 7 \text{ mm}$ ,  $d = 12 \text{ mm}$ ,  $D = 18 + 2(13 - 7) \tan 30^\circ = 24.93 \text{ mm}$ ,  $E = 207 \text{ GPa}$ . Eq. (8-20)  $\Rightarrow k_2 = 15660 \text{ MN/m}$

Lower frusta, cast iron:  $t = 26 - 20 = 6 \text{ mm}$ ,  $d = 12 \text{ mm}$ ,  $D = 18 \text{ mm}$ ,  $E = 100 \text{ GPa}$  (see Table 8-8). Eq. (8-20)  $\Rightarrow k_3 = 3887 \text{ MN/m}$

Eq. (8-18),  $k_m = (1/5316 + 1/15660 + 1/3887)^{-1} = 1964 \text{ MN/m}$

$$C = k_b / (k_b + k_m) = 744.0 / (744.0 + 1\,964) = 0.275$$

Table 8-11:  $S_p = 650$  MPa. For a non-permanent connection, using Eqs. (8-31) and (8-32)

$$F_i = 0.75 A_t S_p = 0.75(84.3)(650)10^{-3} = 41.1 \text{ kN}$$

The total external load is  $P_{\text{total}} = p_g A_g$ , where  $A_g$  is the effective area of the cylinder, based on the effective sealing diameter of 100 mm. The external load per bolt is  $P = P_{\text{total}} / N$ .

Thus

$$P = [6\pi(100^2)/4](10^{-3})/10 = 4.712 \text{ kN/bolt}$$

Yielding factor of safety, Eq. (8-28)

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{650(84.3)10^{-3}}{0.275(4.712) + 41.1} = 1.29 \quad \text{Ans.}$$

Overload factor of safety, Eq. (8-29)

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{650(84.3)10^{-3} - 41.1}{0.275(4.712)} = 10.7 \quad \text{Ans.}$$

Separation factor of safety, Eq. (8-30)

$$n_0 = \frac{F_i}{P(1-C)} = \frac{41.1}{4.712(1-0.275)} = 12.0 \quad \text{Ans.}$$

### 8-38

From Table 8-7,  $h = t_1 = 0.5$  in

For  $t_2 > d$ ,  $l = h + d/2 = 0.5 + 0.5/2 = 0.75$  in

$L \geq h + 1.5d = 0.5 + 1.5(0.5) = 1.25$  in. Let  $L = 1.25$  in

$L_T = 2d + 0.25 = 2(0.5) + 0.25 = 1.25$  in. All threaded.

From Table 8-1,  $A_t = 0.1419 \text{ in}^2$ . The bolt stiffness is  $k_b = A_t E / l = 0.1419(30)/0.75 = 5.676 \text{ Mlbf/in}$

Similar to Fig. 8-23, we have three frusta.

Top frusta, steel:  $t = l/2 = 0.375$  in,  $d = 0.5$  in,  $D = 0.75$  in,  $E = 30 \text{ Mpsi}$

$$k_1 = \frac{0.5774\pi(30)0.5}{\ln \frac{[1.155(0.375) + 0.75 - 0.5](0.75 + 0.5)}{[1.155(0.375) + 0.75 + 0.5](0.75 - 0.5)}} = 38.45 \text{ Mlbf/in}$$

Middle frusta, steel:  $t = 0.5 - 0.375 = 0.125$  in,  $d = 0.5$  in,

$D = 0.75 + 2(0.75 - 0.5) \tan 30^\circ = 1.039$  in,  $E = 30 \text{ Mpsi}$ .

Eq. (8-20)  $\Rightarrow k_2 = 184.3 \text{ Mlbf/in}$

Lower frusta, cast iron:  $t = 0.75 - 0.5 = 0.25$  in,  $d = 0.5$  in,  $D = 0.75$  in,  $E = 14.5 \text{ Mpsi}$ .

Eq. (8-20)  $\Rightarrow k_3 = 23.49 \text{ Mlbf/in}$

Eq. (8-18),  $k_m = (1/38.45 + 1/184.3 + 1/23.49)^{-1} = 13.51 \text{ Mlbf/in}$

$$C = k_b / (k_b + k_m) = 5.676 / (5.676 + 13.51) = 0.296$$

Table 8-9,  $S_p = 85 \text{ kpsi}$ . For a non-permanent connection, using Eqs. (8-31) and (8-32)

$$F_i = 0.75 A_t S_p = 0.75(0.1419)(85) = 9.05 \text{ kips}$$

The total external load is  $P_{\text{total}} = p_g A_g$ , where  $A_g$  is the effective area of the cylinder, based on the effective sealing diameter of 3.5 in. The external load per bolt is  $P = P_{\text{total}} / N$ . Thus

$$P = [1\,500\pi(3.5^2)/4](10^{-3})/10 = 1.443 \text{ kips/bolt}$$

Yielding factor of safety, Eq. (8-28)

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{85(0.141\,9)}{0.296(1.443) + 9.05} = 1.27 \quad \text{Ans.}$$

Overload factor of safety, Eq. (8-29)

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{85(0.141\,9) - 9.05}{0.296(1.443)} = 7.05 \quad \text{Ans.}$$

Separation factor of safety, Eq. (8-30)

$$n_0 = \frac{F_i}{P(1 - C)} = \frac{9.05}{1.443(1 - 0.296)} = 8.91 \quad \text{Ans.}$$

### 8-39

From Table 8-7,  $h = t_1 = 20 \text{ mm}$

For  $t_2 > d$ ,  $l = h + d/2 = 20 + 10/2 = 25 \text{ mm}$

$L \geq h + 1.5d = 20 + 1.5(10) = 35 \text{ mm}$ . Let  $L = 35 \text{ mm}$

$L_T = 2d + 6 = 2(10) + 6 = 26 \text{ mm}$

$l_d = L - L_T = 35 - 26 = 9 \text{ mm}$

$l_t = l - l_d = 25 - 9 = 16 \text{ mm}$

From Table 8-1,  $A_t = 58.0 \text{ mm}^2$ .  $A_d = \pi(10^2)/4 = 78.5 \text{ mm}^2$

Eq. (8-17),

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{78.5(58.0)207}{78.5(16) + 58.0(9)} = 530.1 \text{ MN/m}$$

Similar to Fig. 8-23, we have three frusta.

Top frusta, steel:  $t = l/2 = 12.5 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 \text{ mm}$ ,  $E = 207 \text{ GPa}$ . Eq. (8-20)

$$k_1 = \frac{0.5774\pi(207)10}{\ln \left[ \frac{[1.155(12.5) + 15 - 10](15 + 10)}{[1.155(12.5) + 15 + 10](15 - 10)} \right]} = 4\,163 \text{ MN/m}$$

Middle frusta, steel:  $t = 20 - 12.5 = 7.5 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 + 2(12.5 - 7.5) \tan 30^\circ = 20.77 \text{ mm}$ ,  $E = 207 \text{ GPa}$ . Eq. (8-20)  $\Rightarrow k_2 = 10\,975 \text{ MN/m}$

Lower frusta, cast iron:  $t = 25 - 20 = 5 \text{ mm}$ ,  $d = 10 \text{ mm}$ ,  $D = 15 \text{ mm}$ ,  $E = 100 \text{ GPa}$  (see Table 8-8). Eq. (8-20)  $\Rightarrow k_3 = 3\,239 \text{ MN/m}$

Eq. (8-18),  $k_m = (1/4\,163 + 1/10\,975 + 1/3\,239)^{-1} = 1\,562 \text{ MN/m}$

$$C = k_b / (k_b + k_m) = 530.1 / (530.1 + 1\,562) = 0.253$$

Table 8-11:  $S_p = 830 \text{ MPa}$ . For a non-permanent connection, using Eqs. (8-31) and (8-32)

$$F_i = 0.75 A_t S_p = 0.75(58.0)(830)10^{-3} = 36.1 \text{ kN}$$

The total external load is  $P_{\text{total}} = p_g A_g$ , where  $A_g$  is the effective area of the cylinder, based on the effective sealing diameter of 0.8 m. The external load per bolt is  $P = P_{\text{total}} / N$ . Thus

$$P = [550 \pi (0.8^2)/4]/36 = 7.679 \text{ kN/bolt}$$

Yielding factor of safety, Eq. (8-28)

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{830(58.0)10^{-3}}{0.253(7.679) + 36.1} = 1.27 \quad \text{Ans.}$$

Overload factor of safety, Eq. (8-29)

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{830(58.0)10^{-3} - 36.1}{0.253(7.679)} = 6.20 \quad \text{Ans.}$$

Separation factor of safety, Eq. (8-30)

$$n_0 = \frac{F_i}{P(1-C)} = \frac{36.1}{7.679(1-0.253)} = 6.29 \quad \text{Ans.}$$

#### 8-40

From Table 8-7,  $h = t_1 = 0.375$  in

For  $t_2 > d$ ,  $l = h + d/2 = 0.375 + 0.4375/2 = 0.59375$  in

$L \geq h + 1.5d = 0.375 + 1.5(0.4375) = 1.031$  in. Round up to  $L = 1.25$  in

$L_T = 2d + 0.25 = 2(0.4375) + 0.25 = 1.125$  in

$l_d = L - L_T = 1.25 - 1.125 = 0.125$

$l_t = l - l_d = 0.59375 - 0.125 = 0.46875$  in

$A_d = \pi(7/16)^2/4 = 0.1503 \text{ in}^2$ , Table 8-2:  $A_t = 0.1063 \text{ in}^2$

Eq. (8-17),

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1503(0.1063)30}{0.1503(0.46875) + 0.1063(0.125)} = 5.724 \text{ Mlbf/in}$$

Similar to Fig. 8-23, we have three frusta.

Top frusta, steel:  $t = l/2 = 0.296875$  in,  $d = 0.4375$  in,  $D = 0.65625$  in,  $E = 30$  Mpsi

$$k_1 = \frac{0.5774\pi(30)0.4375}{\ln \left[ \frac{1.155(0.296875) + 0.656255 - 0.4375}{1.155(0.296875) + 0.75 + 0.656255} \right] (0.75 + 0.656255)} = 35.52 \text{ Mlbf/in}$$

Middle frusta, steel:  $t = 0.375 - 0.296875 = 0.078125$  in,  $d = 0.4375$  in,

$D = 0.65625 + 2(0.59375 - 0.375) \tan 30^\circ = 0.9088$  in,  $E = 30$  Mpsi.

Eq. (8-20)  $\Rightarrow k_2 = 215.8 \text{ Mlbf/in}$

Lower frusta, cast iron:  $t = 0.59375 - 0.375 = 0.21875$  in,  $d = 0.4375$  in,  $D = 0.65625$  in,

$E = 14.5$  Mpsi. Eq. (8-20)  $\Rightarrow k_3 = 20.55 \text{ Mlbf/in}$

Eq. (8-18),  $k_m = (1/35.52 + 1/215.8 + 1/20.55)^{-1} = 12.28 \text{ Mlbf/in}$

$$C = k_b / (k_b + k_m) = 5.724 / (5.724 + 12.28) = 0.318$$

Table 8-9,  $S_p = 120$  kpsi. For a non-permanent connection, using Eqs. (8-31) and (8-32)

$$F_i = 0.75 A_t S_p = 0.75(0.1063)(120) = 9.57 \text{ kips}$$

The total external load is  $P_{\text{total}} = p_g A_g$ , where  $A_g$  is the effective area of the cylinder, based on the effective sealing diameter of 3.25 in. The external load per bolt is  $P = P_{\text{total}} / N$ . Thus

$$P = [1\ 200\pi(3.25^2)/4](10^{-3})/8 = 1.244 \text{ kips/bolt}$$

Yielding factor of safety, Eq. (8-28)

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{120(0.106\ 3)}{0.318(1.244) + 9.57} = 1.28 \quad \text{Ans.}$$

Overload factor of safety, Eq. (8-29)

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{120(0.106\ 3) - 9.57}{0.318(1.244)} = 8.05 \quad \text{Ans.}$$

Separation factor of safety, Eq. (8-30)

$$n_0 = \frac{F_i}{P(1-C)} = \frac{9.57}{1.244(1-0.318)} = 11.3 \quad \text{Ans.}$$

## 8-41

This is a design problem and there is no closed-form solution path or a unique solution. What is presented here is one possible iterative approach. We will demonstrate this with an example.

1. Select the diameter,  $d$ . For this example, let  $d = 10$  mm. Using Eq. (8-20) on members, and combining using Eq. (8-18), yields  $k_m = 1\ 141$  MN/m (see Prob. 8-33 for method of calculation).

2. Look up the nut height in Table A-31. For the example,  $H = 8.4$  mm. From this,  $L$  is rounded up from the calculation of  $l + H = 40 + 8.4 = 48.4$  mm to 50 mm. Next, calculations are made for  $L_T = 2(10) + 6 = 26$  mm,  $l_d = 50 - 26 = 24$  mm,  $l_t = 40 - 24 = 16$  mm. From step 1,  $A_d = \pi(10^2)/4 = 78.54$  mm<sup>2</sup>. Next, from Table 8-1,  $A_t = 78.54$  mm<sup>2</sup>. From Eq. (8-17),  $k_b = 356$  MN/m. Finally, from Eq. (f), Sec. 8-7,  $C = 0.238$ .

3. From Prob. 8-33, the bolt circle diameter is  $E = 200$  mm. Substituting this for  $D_b$  in Eq. (8-34), the number of bolts are

$$N = \frac{\pi D_b}{4d} = \frac{\pi(200)}{4(10)} = 15.7$$

Rounding this up gives  $N = 16$ .

4. Next, select a grade bolt. Based on the solution to Prob. 8-33, the strength of ISO 9.8 was so high to give very large factors of safety for overload and separation. Try ISO 4.6 with  $S_p = 225$  MPa. From Eqs. (8-31) and (8-32) for a non-permanent connection,  $F_i = 9.79$  kN.



5. The external load requirement per bolt is  $P = 1.15 p_g A_g/N$ , where from Prob 8-33,  $p_g = 6$  MPa, and  $A_g = \pi(100^2)/4$ . This gives  $P = 3.39$  kN/bolt.

6. Using Eqs. (8-28) to (8-30) yield  $n_p = 1.23$ ,  $n_L = 4.05$ , and  $n_0 = 3.79$ .

Steps 1 - 6 can be easily implemented on a spreadsheet with lookup tables for the tables used from the text. The results for four bolt sizes are shown below. The dimension of each term is consistent with the example given above.

$d$	$k_m$	$H$	$L$	$L_T$	$l_d$	$l_t$	$A_d$	$A_t$	$k_b$
8	854	6.8	50	22	28	12	50.26	36.6	233.9
10	1141	8.4	50	26	24	16	78.54	58	356
12	1456	10.8	55	30	25	15	113.1	84.3	518.8
14	1950	12.8	55	34	21	19	153.9	115	686.3

$d$	$C$	$N$	$S_p$	$F_i$	$P$	$n_p$	$n_L$	$n_0$
8	0.215	20	225	6.18	2.71	1.22	3.53	2.90
10	0.238	16	225	9.79	3.39	1.23	4.05	3.79
12	0.263	13*	225	14.23	4.17	1.24	4.33	4.63
14	0.276	12	225	19.41	4.52	1.25	5.19	5.94

\*Rounded down from 13.08997, so spacing is slightly greater than four diameters.

Any one of the solutions is acceptable. A decision-maker might be cost such as  $N \times \text{cost/bolt}$ , and/or  $N \times \text{cost per hole}$ , etc.

**8-42** This is a design problem and there is no closed-form solution path or a unique solution. What is presented here is one possible iterative approach. We will demonstrate this with an example.

1. Select the diameter,  $d$ . For this example, let  $d = 0.5$  in. Using Eq. (8-20) on three frusta (see Prob. 8-34 solution), and combining using Eq. (8-19), yields  $k_m = 10.10$  Mlbf/in.

2. Look up the nut height in Table A-31. For the example,  $H = 0.4375$  in. From this,  $L$  is rounded up from the calculation of  $l + H = 1.125 + 0.4375 = 1.5625$  in to 1.75 in. Next, calculations are made for  $L_T = 2(0.5) + 0.25 = 1.25$  in,  $l_d = 1.75 - 1.25 = 0.5$  in,  $l_t = 1.125 - 0.5 = 0.625$  in. From step 1,  $A_d = \pi(0.5^2)/4 = 0.1963$  in<sup>2</sup>. Next, from Table 8-1,  $A_t = 0.1419$  in<sup>2</sup>. From Eq. (8-17),  $k_b = 4.316$  Mlbf/in. Finally, from Eq. (f), Sec. 8-7,  $C = 0.299$ .

3. From Prob. 8-34, the bolt circle diameter is  $E = 6$  in. Substituting this for  $D_b$  in Eq. (8-34), for the number of bolts

$$N = \frac{\pi D_b}{4d} = \frac{\pi(6)}{4(0.5)} = 9.425$$

Rounding this up gives  $N = 10$ .

4. Next, select a grade bolt. Based on the solution to Prob. 8-34, the strength of SAE grade 5 was adequate. Use this with  $S_p = 85$  kpsi. From Eqs. (8-31) and (8-32) for a non-permanent connection,  $F_i = 9.046$  kips.

5. The external load requirement per bolt is  $P = 1.15 p_g A_g/N$ , where from Prob 8-34,  $p_g = 1500$  psi, and  $A_g = \pi(3.5^2)/4$ . This gives  $P = 1.660$  kips/bolt.

6. Using Eqs. (8-28) to (8-30) yield  $n_p = 1.26$ ,  $n_L = 6.07$ , and  $n_0 = 7.78$ .

$d$	$k_m$	$H$	$L$	$L_T$	$l_d$	$l_t$	$A_d$	$A_t$	$k_b$
0.375	6.75	0.3281	1.5	1	0.5	0.625	0.1104	0.0775	2.383
0.4375	9.17	0.375	1.5	1.125	0.375	0.75	0.1503	0.1063	3.141
0.5	10.10	0.4375	1.75	1.25	0.5	0.625	0.1963	0.1419	4.316
0.5625	11.98	0.4844	1.75	1.375	0.375	0.75	0.2485	0.182	5.329

$d$	$C$	$N$	$S_p$	$F_i$	$P$	$n_p$	$n_L$	$n_0$
0.375	0.261	13	85	4.941	1.277	1.25	4.95	5.24
0.4375	0.273	11	85	6.777	1.509	1.26	5.48	6.18
0.5	0.299	10	85	9.046	1.660	1.26	6.07	7.78
0.5625	0.308	9	85	11.6	1.844	1.27	6.81	9.09

Any one of the solutions is acceptable. A decision-maker might be cost such as  $N \times \text{cost/bolt}$ , and/or  $N \times \text{cost per hole}$ , etc.

**8-43** This is a design problem and there is no closed-form solution path or a unique solution. What is presented here is one possible iterative approach. We will demonstrate this with an example.

1. Select the diameter,  $d$ . For this example, let  $d = 10$  mm. Using Eq. (8-20) on three frusta (see Prob. 8-35 solution), and combining using Eq. (8-19), yields  $k_m = 1\,087$  MN/m.

2. Look up the nut height in Table A-31. For the example,  $H = 8.4$  mm. From this,  $L$  is rounded up from the calculation of  $l + H = 45 + 8.4 = 53.4$  mm to 55 mm. Next, calculations are made for  $L_T = 2(10) + 6 = 26$  mm,  $l_d = 55 - 26 = 29$  mm,  $l_t = 45 - 29 = 16$  mm. From step 1,  $A_d = \pi(10^2)/4 = 78.54$  mm<sup>2</sup>. Next, from Table 8-1,  $A_t = 58.0$  mm<sup>2</sup>. From Eq. (8-17),  $k_b = 320.9$  MN/m. Finally, from Eq. (f), Sec. 8-7,  $C = 0.228$ .

3. From Prob. 8-35, the bolt circle diameter is  $E = 1000$  mm. Substituting this for  $D_b$  in Eq. (8-34), for the number of bolts

$$N = \frac{\pi D_b}{4d} = \frac{\pi(1000)}{4(10)} = 78.5$$

Rounding this up gives  $N = 79$ . A rather large number, since the bolt circle diameter,  $E$  is so large. Try larger bolts.

4. Next, select a grade bolt. Based on the solution to Prob. 8-35, the strength of ISO 9.8 was so high to give very large factors of safety for overload and separation. Try ISO 5.8 with  $S_p = 380$  MPa. From Eqs. (8-31) and (8-32) for a non-permanent connection,  $F_i = 16.53$  kN.

5. The external load requirement per bolt is  $P = 1.15 p_g A_g/N$ , where from Prob 8-35,  $p_g = 0.550$  MPa, and  $A_g = \pi(800^2)/4$ . This gives  $P = 4.024$  kN/bolt.

6. Using Eqs. (8-28) to (8-30) yield  $n_p = 1.26$ ,  $n_L = 6.01$ , and  $n_0 = 5.32$ .

Steps 1 - 6 can be easily implemented on a spreadsheet with lookup tables for the tables used from the text. The results for three bolt sizes are shown below. The dimension of each term is consistent with the example given above.

$d$	$k_m$	$H$	$L$	$L_T$	$l_d$	$l_t$	$A_d$	$A_t$	$k_b$
10	1087	8.4	55	26	29	16	78.54	58	320.9
20	3055	18	65	46	19	26	314.2	245	1242
36	6725	31	80	78	2	43	1018	817	3791

$d$	$C$	$N$	$S_p$	$F_i$	$P$	$n_p$	$n_L$	$n_0$
10	0.228	79	380	16.53	4.024	1.26	6.01	5.32
20	0.308	40	380	69.83	7.948	1.29	9.5	12.7
36	0.361	22	380	232.8	14.45	1.3	14.9	25.2

A large range is presented here. Any one of the solutions is acceptable. A decision-maker might be cost such as  $N \times \text{cost/bolt}$ , and/or  $N \times \text{cost per hole}$ , etc.

**8-44** This is a design problem and there is no closed-form solution path or a unique solution. What is presented here is one possible iterative approach. We will demonstrate this with an example.

1. Select the diameter,  $d$ . For this example, let  $d = 0.375$  in. Using Eq. (8-20) on three frusta (see Prob. 8-36 solution), and combining using Eq. (8-19), yields  $k_m = 7.42$  Mlbf/in.

2. Look up the nut height in Table A-31. For the example,  $H = 0.3281$  in. From this,  $L \geq l + H = 0.875 + 0.3281 = 1.2031$  in. Rounding up,  $L = 1.25$ . Next, calculations are made for  $L_T = 2(0.375) + 0.25 = 1$  in,  $l_d = 1.25 - 1 = 0.25$  in,  $l_t = 0.875 - 0.25 = 0.625$  in. From step 1,  $A_d = \pi(0.375^2)/4 = 0.1104$  in<sup>2</sup>. Next, from Table 8-1,  $A_t = 0.0775$  in<sup>2</sup>. From Eq. (8-17),  $k_b = 2.905$  Mlbf/in. Finally, from Eq. (f), Sec. 8-7,  $C = 0.263$ .

3. From Prob. 8-36, the bolt circle diameter is  $E = 6$  in. Substituting this for  $D_b$  in Eq. (8-34), for the number of bolts

$$N = \frac{\pi D_b}{4d} = \frac{\pi(6)}{4(0.375)} = 12.6$$

Rounding this up gives  $N = 13$ .

4. Next, select a grade bolt. Based on the solution to Prob. 8-36, the strength of SAE grade 8 seemed high for overload and separation. Try SAE grade 5 with  $S_p = 85$  kpsi. From Eqs. (8-31) and (8-32) for a non-permanent connection,  $F_i = 4.941$  kips.

5. The external load requirement per bolt is  $P = 1.15 p_g A_g/N$ , where from Prob 8-36,  $p_g = 1\,200$  psi, and  $A_g = \pi(3.25^2)/4$ . This gives  $P = 0.881$  kips/bolt.

6. Using Eqs. (8-28) to (8-30) yield  $n_p = 1.27$ ,  $n_L = 6.65$ , and  $n_0 = 7.81$ .

Steps 1 - 6 can be easily implemented on a spreadsheet with lookup tables for the tables used from the text. For this solution we only looked at one bolt size,  $\frac{3}{8}$ -16, but evaluated changing the bolt grade. The results for four bolt grades are shown below. The dimension of each term is consistent with the example given above.

$d$	$k_m$	$H$	$L$	$L_T$	$l_d$	$l_t$	$A_d$	$A_t$	$k_b$
0.375	7.42	0.3281	1.25	1	0.25	0.625	0.1104	0.0775	2.905

$d$	$C$	$N$	SAE grade	$S_p$	$F_i$	$P$	$n_p$	$n_L$	$n_0$
0.375	0.281	13	1	33	1.918	0.881	1.18	2.58	3.03
0.375	0.281	13	2	55	3.197	0.881	1.24	4.30	5.05
0.375	0.281	13	4	65	3.778	0.881	1.25	5.08	5.97
0.375	0.281	13	5	85	4.941	0.881	1.27	6.65	7.81

Note that changing the bolt grade only affects  $S_p$ ,  $F_i$ ,  $n_p$ ,  $n_L$ , and  $n_0$ . Any one of the solutions is acceptable, especially the lowest grade bolt.

**8-45** (a)  $F'_b = RF'_{b,\max} \sin \theta$

Half of the external moment is contributed by the line load in the interval  $0 \leq \theta \leq \pi$

$$\frac{M}{2} = \int_0^\pi F'_b R^2 \sin \theta d\theta = \int_0^\pi F'_{b,\max} R^2 \sin^2 \theta d\theta$$

$$\frac{M}{2} = \frac{\pi}{2} F'_{b,\max} R^2$$

from which  $F'_{b,\max} = \frac{M}{\pi R^2}$

$$F_{\max} = \int_{\phi_1}^{\phi_2} F'_b R \sin \theta d\theta = \frac{M}{\pi R^2} \int_{\phi_1}^{\phi_2} R \sin \theta d\theta = \frac{M}{\pi R} (\cos \phi_1 - \cos \phi_2)$$

Noting  $\phi_1 = 75^\circ$ ,  $\phi_2 = 105^\circ$ ,

$$F_{\max} = \frac{12\,000}{\pi(8/2)} (\cos 75^\circ - \cos 105^\circ) = 494 \text{ lbf} \quad \text{Ans.}$$

(b) 
$$F_{\max} = F'_{b,\max} R \Delta\phi = \frac{M}{\pi R^2} (R) \left( \frac{2\pi}{N} \right) = \frac{2M}{RN}$$

$$F_{\max} = \frac{2(12\,000)}{(8/2)(12)} = 500 \text{ lbf} \quad \text{Ans.}$$

(c)  $F = F_{\max} \sin \theta$

$$M = 2 F_{\max} R [(1) \sin^2 90^\circ + 2 \sin^2 60^\circ + 2 \sin^2 30^\circ + (1) \sin^2 (0)] = 6 F_{\max} R$$

from which,

$$F_{\max} = \frac{M}{6R} = \frac{12\,000}{6(8/2)} = 500 \text{ lbf} \quad \text{Ans.}$$

The simple general equation resulted from part (b)

$$F_{\max} = \frac{2M}{RN}$$

**8-46**

(a) From Table 8-11,  $S_p = 600$  MPa. From Table 8-1,  $A_t = 353$  mm<sup>2</sup>.

$$\text{Eq. (8-31):} \quad F_i = 0.9 A_t S_p = 0.9(353)(600)(10^{-3}) = 190.6 \text{ kN}$$

$$\text{Table 8-15:} \quad K = 0.18$$

$$\text{Eq. (8-27):} \quad T = K F_i d = 0.18(190.6)(24) = 823 \text{ N}\cdot\text{m} \quad \text{Ans.}$$

(b) Washers:  $t = 4.6$  mm,  $d = 24$  mm,  $D = 1.5(24) = 36$  mm,  $E = 207$  GPa.

Eq. (8-20),

$$k_1 = \frac{0.5774\pi(207)24}{\ln \frac{[1.155(4.6) + 36 - 24](36 + 24)}{[1.155(4.6) + 36 + 24](36 - 24)}} = 31\,990 \text{ MN/m}$$

Cast iron:  $t = 20$  mm,  $d = 24$  mm,  $D = 36 + 2(4.6) \tan 30^\circ = 41.31$  mm,  $E = 135$  GPa.

$$\text{Eq. (8-20)} \Rightarrow k_2 = 10\,785 \text{ MN/m}$$

Steel joist:  $t = 20$  mm,  $d = 24$  mm,  $D = 41.31$  mm,  $E = 207$  GPa. Eq. (8-20)  $\Rightarrow k_3 = 16\,537$  MN/m

$$\text{Eq. (8-18):} \quad k_m = (2 / 31\,990 + 1 / 10\,785 + 1 / 16\,537)^{-1} = 4\,636 \text{ MN/m}$$

Bolt:  $l = 2(4.6) + 2(20) = 49.2$  mm. Nut, Table A-31,  $H = 21.5$  mm.  $L > 49.2 + 21.5 = 70.7$  mm. From Table A-17, use  $L = 80$  mm. From Eq. (8-14)

$$L_T = 2(24) + 6 = 54 \text{ mm}, l_d = 80 - 54 = 26 \text{ mm}, l_t = 49.2 - 26 = 23.2 \text{ mm}$$

$$\text{From Table (8-1), } A_t = 353 \text{ mm}^2, A_d = \pi(24^2) / 4 = 452.4 \text{ mm}^2$$

Eq. (8-17):

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{452.4(353)207}{452.4(23.2) + 353(26)} = 1680 \text{ MN/m}$$

$$C = k_b / (k_b + k_m) = 1680 / (1680 + 4636) = 0.266, S_p = 600 \text{ MPa}, F_i = 190.6 \text{ kN},$$

$$P = P_{\text{total}} / N = 18 / 4 = 4.5 \text{ kN}$$

Yield: From Eq. (8-28)

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{600(353)10^{-3}}{0.266(4.5) + 190.6} = 1.10 \quad \text{Ans.}$$

Load factor: From Eq. (8-29)

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{600(353)10^{-3} - 190.6}{0.266(4.5)} = 17.7 \quad \text{Ans.}$$

Separation: From Eq. (8-30)

$$n_0 = \frac{F_i}{P(1-C)} = \frac{190.6}{4.5(1-0.266)} = 57.7 \quad \text{Ans.}$$

As was stated in the text, bolts are typically preloaded such that the yielding factor of safety is not much greater than unity which is the case for this problem. However, the other load factors indicate that the bolts are oversized for the external load.

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**8-47 (a)** ISO M 20 × 2.5 grade 8.8 coarse pitch bolts, lubricated.

Table 8-2,  $A_t = 245 \text{ mm}^2$

Table 8-11,  $S_p = 600 \text{ MPa}$

$$F_i = 0.90 A_t S_p = 0.90(245)600(10^{-3}) = 132.3 \text{ kN}$$

Table 8-15,  $K = 0.18$

$$\text{Eq. (8-27), } T = KF_i d = 0.18(132.3)20 = 476 \text{ N} \cdot \text{m} \quad \text{Ans.}$$

**(b)** Table A-31,  $H = 18 \text{ mm}$ ,  $L \geq L_G + H = 48 + 18 = 66 \text{ mm}$ . Round up to  $L = 80 \text{ mm}$  per Table A-17.

$$L_T = 2d + 6 = 2(20) + 6 = 46 \text{ mm}$$

$$l_d = L - L_T = 80 - 46 = 34 \text{ mm}$$

$$l_t = l - l_d = 48 - 34 = 14 \text{ mm}$$

$$A_d = \pi(20^2)/4 = 314.2 \text{ mm}^2,$$

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{314.2(245)(207)}{314.2(14) + 245(34)} = 1251.9 \text{ MN/m}$$

Members: Since all members are steel use Eq. (8-22) with  $E = 207 \text{ MPa}$ ,  $l = 48 \text{ mm}$ ,  $d = 20 \text{ mm}$

$$k_m = \frac{0.5774\pi Ed}{2 \ln \left( 5 \frac{0.5774l + 0.5d}{0.5774l + 2.5d} \right)} = \frac{0.5774\pi (207) 20}{2 \ln \left[ 5 \frac{0.5774(48) + 0.5(20)}{0.5774(48) + 2.5(20)} \right]} = 4236 \text{ MN/m}$$

$$C = \frac{k_b}{k_b + k_m} = \frac{1251.9}{1251.9 + 4236} = 0.228$$

$$P = P_{\text{total}} / N = 40/2 = 20 \text{ kN},$$

Yield: From Eq. (8-28)

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{600(245)10^{-3}}{0.228(20) + 132.3} = 1.07 \quad \text{Ans.}$$

Load factor: From Eq. (8-29)

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{600(245)10^{-3} - 132.3}{0.228(20)} = 3.22 \quad \text{Ans.}$$

Separation: From Eq. (8-30)

$$n_0 = \frac{F_i}{P(1-C)} = \frac{132.3}{20(1-0.228)} = 8.57 \quad \text{Ans.}$$

**8-48** From Prob. 8-29 solution,  $P_{\text{max}} = 13.33 \text{ kips}$ ,  $C = 0.2$ ,  $F_i = 12.77 \text{ kips}$ ,  $A_t = 0.1419 \text{ in}^2$

$$\sigma_i = \frac{F_i}{A_t} = \frac{12.77}{0.1419} = 90.0 \text{ kpsi}$$

$$\text{Eq. (8-39),} \quad \sigma_a = \frac{CP}{2A_t} = \frac{0.2(13.33)}{2(0.1419)} = 9.39 \text{ kpsi}$$

$$\text{Eq. (8-41),} \quad \sigma_m = \sigma_a + \sigma_i = 9.39 + 90.0 = 99.39 \text{ kpsi}$$

(a) Goodman Eq. (8-45) for grade 8 bolts,  $S_e = 23.2 \text{ kpsi}$  (Table 8-17),  $S_{ut} = 150 \text{ kpsi}$  (Table 8-9)

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{\sigma_a(S_{ut} + S_e)} = \frac{23.2(150 - 90.0)}{9.39(150 + 23.2)} = 0.856 \quad \text{Ans.}$$

(b) Gerber Eq. (8-46)

$$\begin{aligned} n_f &= \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e(S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right] \\ &= \frac{1}{2(9.39)23.2} \left[ 150 \sqrt{150^2 + 4(23.2)(23.2 + 90.0)} - 150^2 - 2(90.0)23.2 \right] = 1.32 \quad \text{Ans.} \end{aligned}$$

(c) ASME-elliptic Eq. (8-47) with  $S_p = 120 \text{ kpsi}$  (Table 8-9)



$$n_f = \frac{S_e}{\sigma_a (S_p^2 + S_e^2)} \left( S_p \sqrt{S_p^2 + S_e^2 - \sigma_i^2} - \sigma_i S_e \right)$$

$$= \frac{23.2}{9.39(120^2 + 23.2^2)} \left[ 120 \sqrt{120^2 + 23.2^2 - 90^2} - 90(23.2) \right] = 1.30 \quad \text{Ans.}$$

**8-49 Attention to the Instructor.** Part (d) requires the determination of the endurance strength,  $S_e$ , of a class 5.8 bolt. Table 8-17 does not provide this and the student will be required to estimate it by other means [see the solution of part (d)].

Per bolt,  $P_{b\max} = 60/8 = 7.5$  kN,  $P_{b\min} = 20/8 = 2.5$  kN

$$C = \frac{k_b}{k_b + k_m} = \frac{1}{1 + 2.6} = 0.278$$

(a) Table 8-1,  $A_t = 20.1$  mm<sup>2</sup>; Table 8-11,  $S_p = 380$  MPa

Eqs. (8-31) and (8-32),  $F_i = 0.75 A_t S_p = 0.75(20.1)380(10^{-3}) = 5.73$  kN

Yield, Eq. (8-28),  $n_p = \frac{S_p A_t}{CP + F_i} = \frac{380(20.1)10^{-3}}{0.278(7.5) + 5.73} = 0.98 \quad \text{Ans.}$

(b) Overload, Eq. (8-29),  $n_L = \frac{S_p A_t - F_i}{CP} = \frac{380(20.1)10^{-3} - 5.73}{0.278(7.5)} = 0.915 \quad \text{Ans.}$

(c) Separation, Eq. (8-30),  $n_0 = \frac{F_i}{P(1-C)} = \frac{5.73}{7.5(1-0.278)} = 1.06 \quad \text{Ans.}$

(d) Goodman, Eq. (8-35),  $\sigma_a = \frac{C(P_{b\max} - P_{b\min})}{2A_t} = \frac{0.278(7.5 - 2.5)10^3}{2(20.1)} = 34.6$  MPa

Eq. (8-36),  $\sigma_m = \frac{C(P_{b\max} + P_{b\min})}{2A_t} + \frac{F_i}{A_t} = \frac{0.278(7.5 + 2.5)10^3}{2(20.1)} + \frac{5.73(10^3)}{20.1} = 354.2$  MPa

Table 8-11,  $S_{ut} = 520$  MPa,  $\sigma_i = F_i / A_t = 5.73(10^3)/20.1 = 285$  MPa

We have a problem for  $S_e$ . Table 8-17 does not list  $S_e$  for class 5.8 bolts. Here, we will estimate  $S_e$  using the methods of Chapter 6. Estimate  $S'_e$  from the,

Eq. (6-10):  $S'_e = 0.5S_{ut} = 0.5(520) = 260$  MPa .

Table 6-2:  $a = 3.04$ ,  $b = -0.217$

Eq. (6-18):  $k_a = aS_{ut}^b = 3.04(520^{-0.217}) = 0.783$

Eq. (6-19):  $k_b = 1$

Eq. (6-25):  $k_c = 0.85$

The fatigue stress-concentration factor, from Table 8-16, is  $K_f = 2.2$ . For simple axial loading and infinite-life it is acceptable to reduce the endurance limit by  $K_f$  and use the nominal stresses in the stress/strength/design factor equations. Thus, from

Eq. (6-17),  $S_e = k_a k_b k_c S'_e / K_f = 0.783(1)0.85(260) / 2.2 = 78.7$  MPa

Eq. (8-38),

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{S_{ut}\sigma_a + S_e(\sigma_m - \sigma_i)} = \frac{78.7(520 - 285)}{520(34.6) + 78.7(354.2 - 285)} = 0.789 \quad \text{Ans.}$$

It is obvious from the various answers obtained, the bolted assembly is undersized. This can be rectified by a one or more of the following: more bolts, larger bolts, higher class bolts.

**8-50** Per bolt,  $P_{b\max} = P_{\max}/N = 80/10 = 8$  kips,  $P_{b\min} = P_{\min}/N = 20/10 = 2$  kips

$$C = k_b / (k_b + k_m) = 4/(4 + 12) = 0.25$$

(a) Table 8-2,  $A_t = 0.1419 \text{ in}^2$ , Table 8-9,  $S_p = 120$  kpsi and  $S_{ut} = 150$  kpsi

Table 8-17,  $S_e = 23.2$  kpsi

$$\text{Eqs. (8-31) and (8-32), } F_i = 0.75 A_t S_p \Rightarrow \sigma_i = F_i / A_t = 0.75 S_p = 0.75(120) = 90 \text{ kpsi}$$

$$\text{Eq. (8-35), } \sigma_a = \frac{C(P_{b\max} - P_{b\min})}{2A_t} = \frac{0.25(8 - 2)}{2(0.1419)} = 5.29 \text{ kpsi}$$

$$\text{Eq. (8-36), } \sigma_m = \frac{C(P_{b\max} + P_{b\min})}{2A_t} + \sigma_i = \frac{0.25(8 + 2)}{2(0.1419)} + 90 = 98.81 \text{ kpsi}$$

Eq. (8-38),

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{S_{ut}\sigma_a + S_e(\sigma_m - \sigma_i)} = \frac{23.2(150 - 90)}{150(5.29) + 23.2(98.81 - 90)} = 1.39 \quad \text{Ans.}$$

**8-51** Given: (8) M8  $\times$  1.5 class 9.8 bolts,  $k_b = 1.5 \text{ MN/mm}$ ,  $k_m = 3.9 \text{ MN/mm}$ , reversing load with  $P_{\max} = 50 \text{ kN}$ .

$$\text{Per bolt, } P = P_{\max}/N = 50/8 = 6.25 \text{ kN}$$

Table 8-1,  $A_t = 36.6 \text{ mm}^2$ , Table 8-11,  $S_{ut} = 900 \text{ MPa}$ ,  $S_p = 650 \text{ MPa}$ ,

Table 8-17,  $S_e = 140 \text{ MPa}$

$$\text{Eq. (f), Sec. 8-7: } C = k_b / (k_b + k_m) = 1.5/(1.5 + 3.9) = 0.278$$

$$\text{Eqs. (8-31) and (8-32): } F_i = 0.75 A_t S_p = 0.75(36.6)650(10^{-3}) = 17.84 \text{ kN}$$

$$\sigma_i = F_i / A_t = 17.84(10^3)/36.6 = 487.5 \text{ MPa}$$

$$\text{Eq. (8-39): } \sigma_a = CP / (2A_t) = 0.278(6.25)10^3/[2(36.6)] = 23.74 \text{ MPa}$$

(a) Goodman: Eq. (8-45):

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{\sigma_a(S_{ut} + S_e)} = \frac{140(900 - 487.5)}{23.74(900 + 140)} = 2.34 \quad \text{Ans.}$$

(b) Gerber: Eq. (8-46):

$$n_f = \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e(S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right]$$

$$= \frac{1}{2(23.74)(140)} \left[ 900 \sqrt{900^2 + 4(140)(140 + 487.5)} - 900^2 - 2(487.5) \right] = 3.52 \quad \text{Ans.}$$

(c) Morrow: Use Goodman Eq. (8-45) replacing  $S_{ut}$  with  $\sigma'_f$ . Equation (6-44) gives

$$\sigma'_f = S_{ut} + 345 = 900 + 345 = 1\,245 \text{ MPa}$$

$$n_f = \frac{S_e(\sigma'_f - \sigma_i)}{\sigma_a(\sigma'_f + S_e)} = \frac{140(1245 - 487.5)}{23.74(1245 + 140)} = 3.23 \quad \text{Ans.}$$

**8-52** From Prob. 8-33,  $C = 0.263$ ,  $P_{\max} = 4.712 \text{ kN / bolt}$ ,  $F_i = 41.1 \text{ kN}$ ,  $S_p = 650 \text{ MPa}$ , and

$$A_t = 84.3 \text{ mm}^2$$

$$\sigma_i = 0.75 S_p = 0.75(650) = 487.5 \text{ MPa}$$

$$\text{Eq. (8-39):} \quad \sigma_a = \frac{CP}{2A_t} = \frac{0.263(4.712)10^3}{2(84.3)} = 7.350 \text{ MPa}$$

$$\text{Eq. (8-40)} \quad \sigma_m = \frac{CP}{2A_t} + \frac{F_i}{A_t} = 7.350 + 487.5 = 494.9 \text{ MPa}$$

(a) Goodman: From Table 8-11,  $S_{ut} = 900 \text{ MPa}$ , and from Table 8-17,  $S_e = 140 \text{ MPa}$

$$\text{Eq. (8-45):} \quad n_f = \frac{S_e(S_{ut} - \sigma_i)}{\sigma_a(S_{ut} + S_e)} = \frac{140(900 - 487.5)}{7.350(900 + 140)} = 7.55 \quad \text{Ans.}$$

(b) Gerber:

Eq. (8-46):

$$\begin{aligned} n_f &= \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e(S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right] \\ &= \frac{1}{2(7.350)140} \left[ 900 \sqrt{900^2 + 4(140)(140 + 487.5)} - 900^2 - 2(487.5)(140) \right] \\ &= 11.4 \quad \text{Ans.} \end{aligned}$$

(c) ASME-elliptic:

Eq. (8-47):

$$\begin{aligned} n_f &= \frac{S_e}{\sigma_a(S_p^2 + S_e^2)} \left( S_p \sqrt{S_p^2 + S_e^2 - \sigma_i^2} - \sigma_i S_e \right) \\ &= \frac{140}{7.350(650^2 + 140^2)} \left[ 650 \sqrt{650^2 + 140^2 - 487.5^2} - 487.5(140) \right] = 9.73 \quad \text{Ans.} \end{aligned}$$

**8-53** From Prob. 8-34,  $C = 0.299$ ,  $P_{\max} = 1.443 \text{ kips/bolt}$ ,  $F_i = 9.05 \text{ kips}$ ,  $S_p = 85 \text{ kpsi}$ , and  $A_t = 0.141 \text{ in}^2$

$$\sigma_i = 0.75 S_p = 0.75(85) = 63.75 \text{ kpsi}$$

$$\text{Eq. (8-37):} \quad \sigma_a = \frac{CP}{2A_t} = \frac{0.299(1.443)}{2(0.1419)} = 1.520 \text{ kpsi}$$

$$\text{Eq. (8-38)} \quad \sigma_m = \frac{CP}{2A_t} + \sigma_i = 1.520 + 63.75 = 65.27 \text{ kpsi}$$

(a) Goodman: From Table 8-9,  $S_{ut} = 120$  kpsi, and from Table 8-17,  $S_e = 18.8$  kpsi

$$\text{Eq. (8-45):} \quad n_f = \frac{S_e(S_{ut} - \sigma_i)}{\sigma_a(S_{ut} + S_e)} = \frac{18.8(120 - 63.75)}{1.520(120 + 18.8)} = 5.01 \quad \text{Ans.}$$

(b) Gerber:

Eq. (8-46):

$$\begin{aligned} n_f &= \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e^2(S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right] \\ &= \frac{1}{2(1.520)18.6} \left[ 120 \sqrt{120^2 + 4(18.6)(18.6 + 63.75)} - 120^2 - 2(63.75)(18.6) \right] \\ &= 7.45 \quad \text{Ans.} \end{aligned}$$

(c) ASME-elliptic:

Eq. (8-47):

$$\begin{aligned} n_f &= \frac{S_e}{\sigma_a(S_p^2 + S_e^2)} \left( S_p \sqrt{S_p^2 + S_e^2 - \sigma_i^2} - \sigma_i S_e \right) \\ &= \frac{18.6}{1.520(85^2 + 18.6^2)} \left[ 85 \sqrt{85^2 + 18.6^2 - 63.75^2} - 63.75(18.6) \right] = 6.22 \quad \text{Ans.} \end{aligned}$$

**8-54** From Prob. 8-35,  $C = 0.228$ ,  $P_{\max} = 7.679$  kN/bolt,  $F_i = 36.1$  kN,  $S_p = 830$  MPa, and  $A_t = 58.0 \text{ mm}^2$

$$\sigma_i = 0.75 S_p = 0.75(830) = 622.5 \text{ MPa}$$

$$\text{Eq. (8-37):} \quad \sigma_a = \frac{CP}{2A_t} = \frac{0.228(7.679)10^3}{2(58.0)} = 15.09 \text{ MPa}$$

$$\text{Eq. (8-38)} \quad \sigma_m = \frac{CP}{2A_t} + \sigma_i = 15.09 + 622.5 = 637.6 \text{ MPa}$$

(a) Goodman: From Table 8-11,  $S_{ut} = 1040$  MPa, and from Table 8-17,  $S_e = 162$  MPa

$$\text{Eq. (8-45):} \quad n_f = \frac{S_e(S_{ut} - \sigma_i)}{\sigma_a(S_{ut} + S_e)} = \frac{162(1040 - 622.5)}{15.09(1040 + 162)} = 3.73 \quad \text{Ans.}$$

(b) Gerber:

Eq. (8-46):

$$\begin{aligned} n_f &= \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e(S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right] \\ &= \frac{1}{2(15.09)162} \left[ 1040 \sqrt{1040^2 + 4(162)(162 + 622.5)} - 1040^2 - 2(622.5)(162) \right] \\ &= 5.74 \quad \text{Ans.} \end{aligned}$$

(c) ASME-elliptic:

Eq. (8-47):

$$\begin{aligned} n_f &= \frac{S_e}{\sigma_a(S_p^2 + S_e^2)} \left( S_p \sqrt{S_p^2 + S_e^2 - \sigma_i^2} - \sigma_i S_e \right) \\ &= \frac{162}{15.09(830^2 + 162^2)} \left[ 830 \sqrt{830^2 + 162^2 - 622.5^2} - 622.5(162) \right] = 5.62 \quad \text{Ans.} \end{aligned}$$

**8-55** From Prob. 8-36,  $C = 0.291$ ,  $P_{\max} = 1.244$  kips/bolt,  $F_i = 9.57$  kips,  $S_p = 120$  kpsi, and  $A_t = 0.1063 \text{ in}^2$

$$\sigma_i = 0.75S_p = 0.75(120) = 90 \text{ kpsi}$$

$$\text{Eq. (8-37):} \quad \sigma_a = \frac{CP}{2A_t} = \frac{0.291(1.244)}{2(0.1063)} = 1.703 \text{ kpsi}$$

$$\text{Eq. (8-38)} \quad \sigma_m = \frac{CP}{2A_t} + \sigma_i = 1.703 + 90 = 91.70 \text{ kpsi}$$

(a) Goodman: From Table 8-9,  $S_{ut} = 150$  kpsi, and from Table 8-17,  $S_e = 23.2$  kpsi

$$\text{Eq. (8-45):} \quad n_f = \frac{S_e(S_{ut} - \sigma_i)}{\sigma_a(S_{ut} + S_e)} = \frac{23.2(150 - 90)}{1.703(150 + 23.2)} = 4.72 \quad \text{Ans.}$$

(b) Gerber:

Eq. (8-46):

$$\begin{aligned}
 n_f &= \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e(S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right] \\
 &= \frac{1}{2(1.703)23.2} \left[ 150 \sqrt{150^2 + 4(23.2)(23.2 + 90)} - 150^2 - 2(90)(23.2) \right] \\
 &= 7.28 \quad \text{Ans.}
 \end{aligned}$$

(c) ASME-elliptic:

Eq. (8-47):

$$\begin{aligned}
 n_f &= \frac{S_e}{\sigma_a (S_p^2 + S_e^2)} \left( S_p \sqrt{S_p^2 + S_e^2 - \sigma_i^2} - \sigma_i S_e \right) \\
 &= \frac{23.2}{1.703(120^2 + 18.6^2)} \left[ 120 \sqrt{120^2 + 23.2^2 - 90^2} - 90(23.2) \right] = 7.24 \quad \text{Ans.}
 \end{aligned}$$

**8-56** From Prob. 8-52,  $C = 0.263$ ,  $S_e = 140$  MPa,  $S_{ut} = 900$  MPa,  $A_t = 84.4$  mm<sup>2</sup>,  $\sigma_i = 487.5$  MPa, and  $P_{\max} = 4.712$  kN.

$$P_{\min} = P_{\max} / 2 = 4.712 / 2 = 2.356 \text{ kN}$$

$$\text{Eq. (8-35):} \quad \sigma_a = \frac{C(P_{\max} - P_{\min})}{2A_t} = \frac{0.263(4.712 - 2.356)10^3}{2(84.3)} = 3.675 \text{ MPa}$$

Eq. (8-36):

$$\begin{aligned}
 \sigma_m &= \frac{C(P_{\max} + P_{\min})}{2A_t} + \sigma_i \\
 &= \frac{0.263(4.712 + 2.356)10^3}{2(84.3)} + 487.5 = 498.5 \text{ MPa}
 \end{aligned}$$

Eq. (8-38):

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{S_{ut}\sigma_a + S_e(\sigma_m - \sigma_i)} = \frac{140(900 - 487.5)}{900(3.675) + 140(498.5 - 487.5)} = 11.9 \quad \text{Ans.}$$

**8-57** From Prob. 8-53,  $C = 0.299$ ,  $S_e = 18.8$  kpsi,  $S_{ut} = 120$  kpsi,  $A_t = 0.1419$  in<sup>2</sup>,  $\sigma_i = 63.75$  kpsi, and  $P_{\max} = 1.443$  kips

$$P_{\min} = P_{\max} / 2 = 1.443 / 2 = 0.722 \text{ kips}$$

$$\text{Eq. (8-35):} \quad \sigma_a = \frac{C(P_{\max} - P_{\min})}{2A_t} = \frac{0.299(1.443 - 0.722)}{2(0.1419)} = 0.760 \text{ kpsi}$$

Eq. (8-36):

$$\begin{aligned} \sigma_m &= \frac{C(P_{\max} + P_{\min})}{2A_t} + \sigma_i \\ &= \frac{0.299(1.443 + 0.722)}{2(0.1419)} + 63.75 = 66.03 \text{ kpsi} \end{aligned}$$

Eq. (8-38):

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{S_{ut}\sigma_a + S_e(\sigma_m - \sigma_i)} = \frac{18.8(120 - 63.75)}{120(0.760) + 18.8(66.03 - 63.75)} = 7.89 \quad \text{Ans.}$$

**8-58** From Prob. 8-54,  $C = 0.228$ ,  $S_e = 162$  MPa,  $S_{ut} = 1040$  MPa,  $A_t = 58.0$  mm<sup>2</sup>,  $\sigma_i = 622.5$  MPa, and  $P_{\max} = 7.679$  kN.

$$P_{\min} = P_{\max} / 2 = 7.679 / 2 = 3.840 \text{ kN}$$

$$\text{Eq. (8-35):} \quad \sigma_a = \frac{C(P_{\max} - P_{\min})}{2A_t} = \frac{0.228(7.679 - 3.840)10^3}{2(58.0)} = 7.546 \text{ MPa}$$

Eq. (8-36):

$$\begin{aligned} \sigma_m &= \frac{C(P_{\max} + P_{\min})}{2A_t} + \sigma_i \\ &= \frac{0.228(7.679 + 3.840)10^3}{2(58.0)} + 622.5 = 645.1 \text{ MPa} \end{aligned}$$

Eq. (8-38):

$$n_f = \frac{S_e (S_{ut} - \sigma_i)}{S_{ut} \sigma_a + S_e (\sigma_m - \sigma_i)} = \frac{162(1040 - 622.5)}{1040(7.546) + 162(645.1 - 622.5)} = 5.88 \quad \text{Ans.}$$


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**8-59** From Prob. 8-55,  $C = 0.291$ ,  $S_e = 23.2$  kpsi,  $S_{ut} = 150$  kpsi,  $A_t = 0.1063 \text{ in}^2$ ,  $\sigma_i = 90$  kpsi, and  $P_{\max} = 1.244$  kips

$$P_{\min} = P_{\max} / 2 = 1.244 / 2 = 0.622 \text{ kips}$$

$$\text{Eq. (8-35):} \quad \sigma_a = \frac{C(P_{\max} - P_{\min})}{2A_t} = \frac{0.291(1.244 - 0.622)}{2(0.1063)} = 0.851 \text{ kpsi}$$

Eq. (8-36):

$$\begin{aligned} \sigma_m &= \frac{C(P_{\max} + P_{\min})}{2A_t} + \sigma_i \\ &= \frac{0.291(1.244 + 0.622)}{2(0.1063)} + 90 = 92.55 \text{ kpsi} \end{aligned}$$

Eq. (8-38):

$$n_f = \frac{S_e (S_{ut} - \sigma_i)}{S_{ut} \sigma_a + S_e (\sigma_m - \sigma_i)} = \frac{23.2(150 - 90)}{150(0.851) + 23.2(92.55 - 90)} = 7.45 \quad \text{Ans.}$$


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**8-60** Let the repeatedly-applied load be designated as  $P$ . From Table A-22,  $S_{ut} = 93.7$  kpsi. Referring to the Figure of Prob. 3-136, the following notation will be used for the radii of Section AA.

$$r_i = 1.5 \text{ in}, \quad r_o = 2.5 \text{ in}, \quad r_c = 2.0 \text{ in}$$

From Table 3-4, with  $R = 0.5$  in,

$$r_n = \frac{R^2}{2(r_c - \sqrt{r_c^2 - R^2})} = \frac{0.5^2}{2(2 - \sqrt{2^2 - 0.5^2})} = 1.968246 \text{ in}$$

$$e = r_c - r_n = 2.0 - 1.968246 = 0.031754 \text{ in}$$

$$c_o = r_o - r_n = 2.5 - 1.968246 = 0.531754 \text{ in}$$

$$c_i = r_n - r_i = 1.968246 - 1.5 = 0.468246 \text{ in}$$

$$A = \pi(1^2) / 4 = 0.7854 \text{ in}^2$$

If  $P$  is the maximum load



$$M = Pr_c = 2P$$

$$\sigma_i = \frac{P}{A} \left( 1 + \frac{r_c c_i}{er_i} \right) = \frac{P}{0.7854} \left( 1 + \frac{2(0.468)}{0.031754(1.5)} \right) = 26.29P$$

$$\sigma_a = \sigma_m = \frac{\sigma_i}{2} = \frac{26.294P}{2} = 13.15P$$

(a) Eye: Section AA,

Table 6-2:  $a = 11.0$  kpsi,  $b = -0.650$

Eq. (6-18):  $k_a = 11.0(93.7)^{-0.650} = 0.575$

Eq. (6-23):  $d_e = 0.370 d$

Eq. (6-19):  $k_b = \left( \frac{0.37}{0.30} \right)^{-0.107} = 0.978$

Eq. (6-25):  $k_c = 0.85$

Eq. (6-10):  $S'_e = 0.5S_{ut} = 0.5(93.7) = 46.85$  kpsi

Eq. (6-18):  $S_e = 0.575(0.978)(0.85)(46.85) = 22.4$  kpsi

From Eq. 6-48, for Gerber,

$$n_f = \frac{1}{2} \left( \frac{S_{ut}}{\sigma_m} \right)^2 \frac{\sigma_a}{S_e} \left[ -1 + \sqrt{1 + \left( \frac{2\sigma_m S_e}{S_{ut} \sigma_a} \right)^2} \right]$$

With  $\sigma_m = \sigma_a$ ,

$$n_f = \frac{1}{2} \frac{S_{ut}^2}{\sigma_a S_e} \left[ -1 + \sqrt{1 + \left( \frac{2S_e}{S_{ut}} \right)^2} \right] = \frac{1}{2} \frac{93.7^2}{13.15P(22.4)} \left[ -1 + \sqrt{1 + \left( \frac{2(22.4)}{93.7} \right)^2} \right] = \frac{1.616}{P}$$

where  $P$  is in kips.

*Thread:* Die cut. Table 8-17 gives  $S_e = 18.6$  kpsi for rolled threads. Use Table 8-16 to find  $S_e$  for die cut threads

$$S_e = 18.6(3.0/3.8) = 14.7 \text{ kpsi}$$

Table 8-2,  $A_t = 0.663 \text{ in}^2$ ,  $\sigma = P/A_t = P/0.663 = 1.51 P$ ,  $\sigma_a = \sigma_m = \sigma/2 = 0.755 P$

From Eq. 6-48, Gerber

$$n_f = \frac{1}{2} \frac{S_{ut}^2}{\sigma_a S_e} \left[ -1 + \sqrt{1 + \left( \frac{2S_e}{S_{ut}} \right)^2} \right] = \frac{1}{2} \frac{93.7^2}{0.755P(14.7)} \left[ -1 + \sqrt{1 + \left( \frac{2(14.7)}{93.7} \right)^2} \right] = \frac{19.01}{P}$$

Comparing  $19.01/P$  with  $1.616/P$ , we conclude that the eye is weaker in fatigue. *Ans.*

(b) Strengthening steps can include heat treatment, cold forming, cross section change (a round section is a poor cross section for a curved bar in bending because the bulk of the material is located where the stress is small). *Ans.*

(c) For  $n_f = 2$

$$P = \frac{1.616(10^3)}{2} = 808 \text{ lbf, max. load} \quad \text{Ans.}$$

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**8-61** Member, Eq. (8-22) with  $E = 16 \text{ Mpsi}$ ,  $d = 0.75 \text{ in}$ , and  $l = 1.5 \text{ in}$

$$k_m = \frac{0.5774\pi Ed}{2 \ln \left( 5 \frac{0.5774l + 0.5d}{0.5774l + 2.5d} \right)} = \frac{0.5774\pi(16)0.75}{2 \ln \left[ 5 \frac{0.5774(1.5) + 0.5(0.75)}{0.5774(1.5) + 2.5(0.75)} \right]} = 13.32 \text{ Mlbf/in}$$

Bolt, Eq. (8-13),

$$L_T = 2d + 0.25 = 2(0.75) + 0.25 = 1.75 \text{ in}$$

$$l = 1.5 \text{ in}$$

$$l_d = L - L_T = 2.5 - 1.75 = 0.75 \text{ in}$$

$$l_t = l - l_d = 1.5 - 0.75 = 0.75 \text{ in}$$

Table 8-2,

$$A_t = 0.373 \text{ in}^2$$

$$A_d = \pi(0.75^2)/4 = 0.442 \text{ in}^2$$

Eq. (8-17),

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.442(0.373)30}{0.442(0.75) + 0.373(0.75)} = 8.09 \text{ Mlbf/in}$$

$$C = \frac{k_b}{k_b + k_m} = \frac{8.09}{8.09 + 13.32} = 0.378$$

Eq. (8-35),

$$\sigma_a = \frac{C(P_{\max} - P_{\min})}{2A_t} = \frac{0.378(6 - 4)}{2(0.373)} = 1.013 \text{ kpsi}$$

Eq. (8-36),

$$\sigma_m = \frac{C(P_{\max} + P_{\min})}{2A_t} + \frac{F_i}{A_t} = \frac{0.378(6 + 4)}{2(0.373)} + \frac{25}{0.373} = 72.09 \text{ kpsi}$$

(a) From Table 8-9,  $S_p = 85 \text{ kpsi}$ , and Eq. (8-51), the yielding factor of safety is

$$n_p = \frac{S_p}{\sigma_m + \sigma_a} = \frac{85}{72.09 + 1.013} = 1.16 \quad \text{Ans.}$$

(b) From Eq. (8-29), the overload factor of safety is

$$n_L = \frac{S_p A_t - F_i}{CP_{\max}} = \frac{85(0.373) - 25}{0.378(6)} = 2.96 \quad \text{Ans.}$$

(c) From Eq. (8-30), the factor of safety based on joint separation is

$$n_0 = \frac{F_i}{P_{\max}(1-C)} = \frac{25}{6(1-0.378)} = 6.70 \quad \text{Ans.}$$

(d) From Table 8-17,  $S_e = 18.6$  kpsi; Table 8-9,  $S_{ut} = 120$  kpsi; the preload stress is  $\sigma_i = F_i / A_t = 25/0.373 = 67.0$  kpsi; and from Eq. (8-38)

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{S_{ut}\sigma_a + S_e(\sigma_m - \sigma_i)} = \frac{18.6(120 - 67.0)}{120(1.013) + 18.6(72.09 - 67.0)} = 4.56 \quad \text{Ans.}$$

**8-62** (a) Table 8-2,  $A_t = 0.1419 \text{ in}^2$   
 Table 8-9,  $S_p = 120$  kpsi,  $S_{ut} = 150$  kpsi  
 Table 8-17,  $S_e = 23.2$  kpsi  
 Eqs. (8-31) and (8-32),  $\sigma_i = 0.75 S_p = 0.75(120) = 90$  kpsi

$$C = \frac{k_b}{k_b + k_m} = \frac{4}{4 + 16} = 0.2$$

$$\sigma_a = \frac{CP}{2A_t} = \frac{0.2P}{2(0.1419)} = 0.705P \text{ kpsi}$$

Eq. (8-45) for the Goodman criterion,

$$n_f = \frac{S_e(S_{ut} - \sigma_i)}{\sigma_a(S_{ut} + S_e)} = \frac{23.2(150 - 90)}{0.705P(150 + 23.2)} = \frac{11.4}{P} = 2 \Rightarrow P = 5.70 \text{ kips} \quad \text{Ans.}$$

(b)  $F_i = 0.75 A_t S_p = 0.75(0.1419)120 = 12.77$  kips  
 Yield, Eq. (8-28),

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{120(0.1419)}{0.2(5.70) + 12.77} = 1.22 \quad \text{Ans.}$$

Load factor, Eq. (8-29),

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{120(0.1419) - 12.77}{0.2(5.70)} = 3.74 \quad \text{Ans.}$$

Separation load factor, Eq. (8-30)

$$n_0 = \frac{F_i}{P(1 - C)} = \frac{12.77}{5.70(1 - 0.2)} = 2.80 \quad \text{Ans.}$$


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**8-63** Table 8-2,  $A_t = 0.969 \text{ in}^2$  (coarse),  $A_t = 1.073 \text{ in}^2$  (fine)

Table 8-9,  $S_p = 74 \text{ kpsi}$ ,  $S_{ut} = 105 \text{ kpsi}$

Table 8-17,  $S_e = 16.3 \text{ kpsi}$

Coarse thread,

$$F_i = 0.75 A_t S_p = 0.75(0.969)74 = 53.78 \text{ kips}$$

$$\sigma_i = 0.75 S_p = 0.75(74) = 55.5 \text{ kpsi}$$

$$\sigma_a = \frac{CP}{2A_t} = \frac{0.30P}{2(0.969)} = 0.155P \text{ kpsi}$$

Gerber, Eq. (8-46),

$$\begin{aligned} n_f &= \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e(S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right] \\ &= \frac{1}{2(0.155P)16.3} \left[ 105 \sqrt{105^2 + 4(16.3)(16.3 + 55.5)} - 105^2 - 2(55.5)16.3 \right] = \frac{64.28}{P} \end{aligned}$$

With  $n_f = 2$ ,

$$P = \frac{64.28}{2} = 32.14 \text{ kip} \quad \text{Ans.}$$

Fine thread,

$$F_i = 0.75 A_t S_p = 0.75(1.073)74 = 59.55 \text{ kips}$$

$$\sigma_i = 0.75 S_p = 0.75(74) = 55.5 \text{ kpsi}$$

$$\sigma_a = \frac{CP}{2A_t} = \frac{0.32P}{2(1.073)} = 0.149P \text{ kpsi}$$

The only thing that changes in Eq. (8-46) is  $\sigma_a$ . Thus,

$$n_f = \frac{0.155}{0.149} \frac{64.28}{P} = \frac{66.87}{P} = 2 \Rightarrow P = 33.43 \text{ kips} \quad \text{Ans.}$$

Percent improvement,

$$\frac{33.43 - 32.14}{32.14}(100) \square 4\% \quad \text{Ans.}$$


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**8-64** For an M 30  $\times$  3.5 ISO 8.8 bolt with  $P = 65 \text{ kN/bolt}$  and  $C = 0.28$

Table 8-1,  $A_t = 561 \text{ mm}^2$

Table 8-11,  $S_p = 600 \text{ MPa}$ ,  $S_{ut} = 830 \text{ MPa}$

Table 8-17,  $S_e = 129 \text{ MPa}$

$$\begin{aligned}\text{Eq. (8-31), } F_i &= 0.75F_p = 0.75 A_t S_p \\ &= 0.75(5610600)(10^{-3}) = 252.45 \text{ kN}\end{aligned}$$

$$\sigma_i = 0.75 S_p = 0.75(600) = 450 \text{ MPa}$$

$$\text{Eq. (8-39), } \sigma_a = \frac{CP}{2A_t} = \frac{0.28(65)10^3}{2(561)} = 16.22 \text{ MPa}$$

Gerber, Eq. (8-46),

$$\begin{aligned}n_f &= \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e(S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right] \\ &= \frac{1}{2(16.22)129} \left[ 830 \sqrt{830^2 + 4(129)(129 + 450)} - 830^2 - 2(450)129 \right] \\ &= 4.75 \quad \text{Ans.}\end{aligned}$$

The yielding factor of safety, from Eq. (8-28) is

$$n_p = \frac{S_p A_t}{CP + F_i} = \frac{600(561)10^{-3}}{0.28(65) + 252.45} = 1.24 \quad \text{Ans.}$$

From Eq. (8-29), the load factor is

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{600(561)10^{-3} - 252.45}{0.28(65)} = 4.62 \quad \text{Ans.}$$

The separation factor, from Eq. (8-30) is

$$n_0 = \frac{F_i}{P(1-C)} = \frac{252.45}{65(1-0.28)} = 5.39 \quad \text{Ans.}$$

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**8-65** (a) Table 8-2,  $A_t = 0.0775 \text{ in}^2$   
 Table 8-9,  $S_p = 85 \text{ kpsi}$ ,  $S_{ut} = 120 \text{ kpsi}$   
 Table 8-17,  $S_e = 18.6 \text{ kpsi}$   
 Unthreaded grip,

$$k_b = \frac{A_d E}{l} = \frac{\pi(0.375)^2(30)}{4(13.5)} = 0.245 \text{ Mlbf/in per bolt} \quad \text{Ans.}$$

$$A_m = \frac{\pi}{4}[(D + 2t)^2 - D^2] = \frac{\pi}{4}(4.75^2 - 4^2) = 5.154 \text{ in}^2$$

$$k_m = \frac{A_m E}{l} = \frac{5.154(30)}{12} \left( \frac{1}{6} \right) = 2.148 \text{ Mlbf/in/bolt.} \quad \text{Ans.}$$

$$\begin{aligned}
\text{(b)} \quad F_i &= 0.75 A_t S_p = 0.75(0.0775) (85) = 4.94 \text{ kip} \\
\sigma_i &= 0.75 S_p = 0.75(85) = 63.75 \text{ kpsi} \\
P &= pA = \frac{2000}{6} \left[ \frac{\pi}{4} (4)^2 \right] = 4189 \text{ lbf/bolt} \\
C &= \frac{k_b}{k_b + k_m} = \frac{0.245}{0.245 + 2.148} = 0.102 \\
\sigma_a &= \frac{CP}{2A_t} = \frac{0.102(4189)}{2(0.0775)} = 2.77 \text{ kpsi}
\end{aligned}$$

From Eq. (8-46) for Gerber fatigue criterion,

$$\begin{aligned}
n_f &= \frac{1}{2\sigma_a S_e} \left[ S_{ut} \sqrt{S_{ut}^2 + 4S_e (S_e + \sigma_i)} - S_{ut}^2 - 2\sigma_i S_e \right] \\
&= \frac{1}{2(2.77)18.6} \left[ 120 \sqrt{120^2 + 4(18.6)(18.6 + 63.75)} - 120^2 - 2(63.75)18.6 \right] = 4.09 \quad \text{Ans.}
\end{aligned}$$

(c) Pressure causing joint separation from Eq. (8-30)

$$\begin{aligned}
n_0 &= \frac{F_i}{P(1 - C)} = 1 \\
P &= \frac{F_i}{1 - C} = \frac{4.94}{1 - 0.102} = 5.50 \text{ kip} \\
p &= \frac{P}{A} = \frac{5.50}{\pi(4^2)/4} = 2.63 \text{ kpsi} \quad \text{Ans.}
\end{aligned}$$

**8-66** From the solution of Prob. 8-64,  $A_t = 0.0775 \text{ in}^2$ ,  $S_{ut} = 120 \text{ kpsi}$ ,  $S_e = 18.6 \text{ kpsi}$ ,  $C = 0.102$ ,  $\sigma_i = 63.75 \text{ kpsi}$

$$P_{\max} = p_{\max} A = 2 \pi (4^2)/4 = 25.13 \text{ kpsi}, \quad P_{\min} = p_{\min} A = 1.2 \pi (4^2)/4 = 15.08 \text{ kpsi},$$

$$\text{Eq. (8-35),} \quad \sigma_a = \frac{C(P_{\max} - P_{\min})}{2A_t} = \frac{0.102(25.13 - 15.08)}{2(0.0775)} = 6.61 \text{ kpsi}$$

$$\text{Eq. (8-36),} \quad \sigma_m = \frac{C(P_{\max} + P_{\min})}{2A_t} + \sigma_i = \frac{0.102(25.13 + 15.08)}{2(0.0775)} + 63.75 = 90.21 \text{ kpsi}$$

$$\text{Eq. (8-38),} \quad n_f = \frac{S_e (S_{ut} - \sigma_i)}{S_{ut} \sigma_a + S_e (\sigma_m - \sigma_i)} = \frac{18.6(120 - 63.75)}{120(6.61) + 18.6(90.21 - 63.75)} = 0.814 \quad \text{Ans.}$$

This predicts a fatigue failure.

**8-67** Members:  $S_y = 57 \text{ kpsi}$ ,  $S_{sy} = 0.577(57) = 32.89 \text{ kpsi}$ .

Bolts: SAE grade 5,  $S_y = 92$  kpsi,  $S_{sy} = 0.577(92) = 53.08$  kpsi

Shear in bolts,

$$A_s = 2 \left[ \frac{\pi(0.25^2)}{4} \right] = 0.0982 \text{ in}^2$$
$$F_s = \frac{A_s S_{sy}}{n} = \frac{0.0982(53.08)}{2} = 2.61 \text{ kips}$$

Bearing on bolts,

$$A_b = 2(0.25)0.25 = 0.125 \text{ in}^2$$
$$F_b = \frac{A_b S_{yc}}{n} = \frac{0.125(92)}{2} = 5.75 \text{ kips}$$

Bearing on member,

$$F_b = \frac{0.125(57)}{2} = 3.56 \text{ kips}$$

Tension of members,

$$A_t = (1.25 - 0.25)(0.25) = 0.25 \text{ in}^2$$
$$F_t = \frac{0.25(57)}{2} = 7.13 \text{ kip}$$
$$F = \min(2.61, 5.75, 3.56, 7.13) = 2.61 \text{ kip} \quad \text{Ans.}$$

The shear in the bolts controls the design.

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**8-68** Members, Table A-20,  $S_y = 42$  kpsi

Bolts, Table 8-9,  $S_y = 130$  kpsi,  $S_{sy} = 0.577(130) = 75.01$  kpsi

Shear of bolts,

$$A_s = 2 \left[ \frac{\pi(5/16)^2}{4} \right] = 0.1534 \text{ in}^2$$

$$\tau = \frac{F_s}{A_s} = \frac{5}{0.1534} = 32.6 \text{ kpsi}$$

$$n = \frac{S_{sy}}{\tau} = \frac{75.01}{32.6} = 2.30 \quad \text{Ans.}$$

Bearing on bolts,

$$A_b = 2(0.25)(5/16) = 0.1563 \text{ in}^2$$
$$\sigma_b = -\frac{5}{0.1563} = -32.0 \text{ kpsi}$$

$$n = \frac{S_y}{|\sigma_b|} = \frac{130}{32.0} = 4.06 \quad \text{Ans.}$$

Bearing on members,

$$n = \frac{S_y}{|\sigma_b|} = \frac{42}{32} = 1.31 \quad \text{Ans.}$$

Tension of members,

$$A_t = [2.375 - 2(5/16)] (1/4) = 0.4375 \text{ in}^2$$

$$\sigma_t = \frac{5}{0.4375} = 11.4 \text{ kpsi}$$

$$n = \frac{S_y}{\sigma_t} = \frac{42}{11.4} = 3.68 \quad \text{Ans.}$$

- 8-69** Members: Table A-20,  $S_y = 490 \text{ MPa}$ ,  $S_{sy} = 0.577(490) = 282.7 \text{ MPa}$   
 Bolts: Table 8-11, ISO class 5.8,  $S_y = 420 \text{ MPa}$ ,  $S_{sy} = 0.577(420) = 242.3 \text{ MPa}$

Shear in bolts,

$$A_s = 2 \left[ \frac{\pi(20^2)}{4} \right] = 628.3 \text{ mm}^2$$

$$F_s = \frac{A_s S_{sy}}{n} = \frac{628.3(242.3)10^{-3}}{2.5} = 60.9 \text{ kN}$$

Bearing on bolts,

$$A_b = 2(20)20 = 800 \text{ mm}^2$$

$$F_b = \frac{A_b S_{yc}}{n} = \frac{800(420)10^{-3}}{2.5} = 134 \text{ kN}$$

Bearing on member,

$$F_b = \frac{800(490)10^{-3}}{2.5} = 157 \text{ kN}$$

Tension of members,

$$A_t = (80 - 20) (20) = 1\,200 \text{ mm}^2$$

$$F_t = \frac{1\,200(490)10^{-3}}{2.5} = 235 \text{ kN}$$

$$F = \min(60.9, 134, 157, 235) = 60.9 \text{ kN} \quad \text{Ans.}$$

The shear in the bolts controls the design.



**8-70** Members: Table A-20,  $S_y = 320$  MPa

Bolts: Table 8-11, ISO class 5.8,  $S_y = 420$  MPa,  $S_{sy} = 0.577(420) = 242.3$  MPa

Shear of bolts,

$$A_s = \pi (20^2)/4 = 314.2 \text{ mm}^2$$

$$\tau_s = \frac{90(10^3)}{3(314.2)} = 95.48 \text{ MPa}$$

$$n = \frac{S_{sy}}{\tau_s} = \frac{242.3}{95.48} = 2.54 \quad \text{Ans.}$$

Bearing on bolt,

$$A_b = 3(20)15 = 900 \text{ mm}^2$$

$$\sigma_b = -\frac{90(10^3)}{900} = -100 \text{ MPa}$$

$$n = \frac{S_y}{|\sigma_b|} = \frac{420}{100} = 4.2 \quad \text{Ans.}$$

Bearing on members,

$$n = \frac{S_y}{|\sigma_b|} = \frac{320}{100} = 3.2 \quad \text{Ans.}$$

Tension on members,

$$\sigma_t = \frac{F}{A} = \frac{90(10^3)}{15[190 - 3(20)]} = 46.15 \text{ MPa}$$

$$n = \frac{S_y}{\sigma_t} = \frac{320}{46.15} = 6.93 \quad \text{Ans.}$$

**8-71** Members:  $S_y = 57$  kpsi

Bolts:  $S_y = 100$  kpsi,  $S_{sy} = 0.577(100) = 57.7$  kpsi

Shear of bolts,

$$A = 3 \left[ \frac{\pi (1/4)^2}{4} \right] = 0.1473 \text{ in}^2$$

$$\tau_s = \frac{F}{A_s} = \frac{5}{0.1473} = 33.94 \text{ kpsi}$$

$$n = \frac{S_{sy}}{\tau_s} = \frac{57.7}{33.94} = 1.70 \quad \text{Ans.}$$

Bearing on bolts,

$$A_b = 3(1/4)(5/16) = 0.2344 \text{ in}^2$$

$$\sigma_b = -\frac{F}{A_b} = -\frac{5}{0.2344} = -21.3 \text{ kpsi}$$

$$n = \frac{S_y}{|\sigma_b|} = \frac{100}{21.3} = 4.69 \quad \text{Ans.}$$

Bearing on members,

$$A_b = 0.2344 \text{ in}^2 \quad (\text{From bearing on bolts calculation})$$

$$\sigma_b = -21.3 \text{ kpsi} \quad (\text{From bearing on bolts calculation})$$

$$n = \frac{S_y}{|\sigma_b|} = \frac{57}{21.3} = 2.68 \quad \text{Ans.}$$

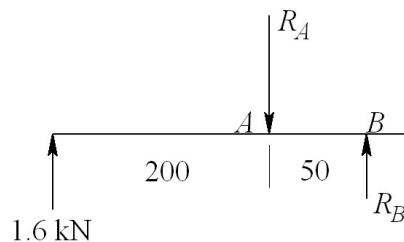
Tension in members, failure across two bolts,

$$A_t = \frac{5}{16} [2.375 - 2(1/4)] = 0.5859 \text{ in}^2$$

$$\sigma_t = \frac{F}{A_t} = \frac{5}{0.5859} = 8.534 \text{ kpsi}$$

$$n = \frac{S_y}{\sigma_t} = \frac{57}{8.534} = 6.68 \quad \text{Ans.}$$

**8-72** By symmetry, the reactions at each support is 1.6 kN. The free-body diagram for the left member is



$$\begin{aligned} \sum M_B = 0 \quad & 1.6(250) - 50R_A = 0 \quad \Rightarrow \quad R_A = 8 \text{ kN} \\ \sum M_A = 0 \quad & 200(1.6) - 50R_B = 0 \quad \Rightarrow \quad R_B = 6.4 \text{ kN} \end{aligned}$$

Members: Table A-20,  $S_y = 370 \text{ MPa}$

Bolts: Table 8-11,  $S_y = 420 \text{ MPa}$ ,  $S_{sy} = 0.577(420) = 242.3 \text{ MPa}$

$$\text{Bolt shear,} \quad A_s = \frac{\pi}{4}(12^2) = 113.1 \text{ mm}^2$$

$$\tau = \frac{F_{\max}}{A_s} = \frac{8(10^3)}{113.1} = 70.73 \text{ MPa}$$

$$n = \frac{S_{sy}}{\tau} = \frac{242.3}{70.73} = 3.43$$

Bearing on member,  $A_b = td = 10(12) = 120 \text{ mm}^2$

$$\sigma_b = -\frac{8(10^3)}{120} = -66.67 \text{ MPa}$$

$$n = \frac{S_y}{|\sigma_b|} = \frac{370}{66.67} = 5.55$$

Strength of member. The bending moments at the hole locations are:

In the left member at  $A$ ,  $M_A = 1.6(200) = 320 \text{ N} \cdot \text{m}$ . In the right member at  $B$ ,  $M_B = 8(50) = 400 \text{ N} \cdot \text{m}$ . The bending moment is greater at  $B$

$$I_B = \frac{1}{12}[10(50^3) - 10(12^3)] = 102.7(10^3) \text{ mm}^4$$

$$\sigma_B = \frac{M_A c}{I_A} = \frac{400(25)}{102.7(10^3)}(10^3) = 97.37 \text{ MPa}$$

$$n = \frac{S_y}{\sigma_A} = \frac{370}{97.37} = 3.80$$

At the center, call it point  $C$ ,

$$M_C = 1.6(350) = 560 \text{ N} \cdot \text{m}$$

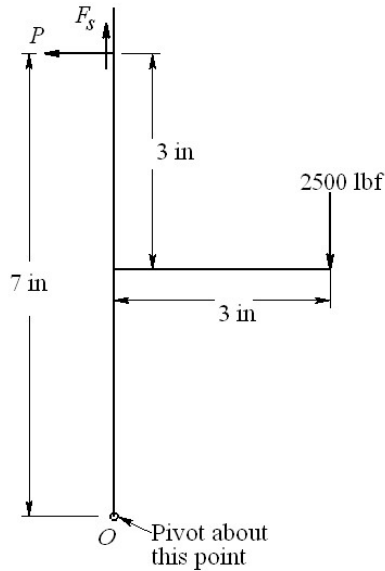
$$I_C = \frac{1}{12}(10)(50^3) = 104.2(10^3) \text{ mm}^4$$

$$\sigma_C = \frac{M_C c}{I_C} = \frac{560(25)}{104.2(10^3)}(10^3) = 134.4 \text{ MPa}$$

$$n = \frac{S_y}{\sigma_C} = \frac{370}{134.4} = 2.75 < 3.80 \quad \text{more critical at } C$$

$$n = \min(3.04, 3.80, 2.75) = 2.72 \quad \text{Ans.}$$

- 8-73** The free-body diagram of the bracket, assuming the upper bolt takes all the shear and tensile load is



$$F_s = 2500 \text{ lbf}$$

$$P = \frac{2500(3)}{7} = 1071 \text{ lbf}$$

Table A-31,  $H = 7/16 = 0.4375$  in. Grip,  $l = 2(1/2) = 1$  in.  $L \geq l + H = 1.4375$  in. Use 1.5 in bolts.

Eq. (8-13),  $L_T = 2d + 0.25 = 2(0.5) + 0.25 = 1.25$  in

Table 8-7,  $l_d = L - L_T = 1.5 - 1.25 = 0.25$  in

$$l_t = l - l_d = 1 - 0.25 = 0.75 \text{ in}$$

Table 8-2,  $A_t = 0.1419 \text{ in}^2$

$$A_d = \pi(0.5^2)/4 = 0.1963 \text{ in}^2$$

Eq. (8-17),  $k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.1963(0.1419)30}{0.1963(0.75) + 0.1419(0.25)} = 4.574 \text{ Mlbf/in}$

Eq. (8-22),

$$k_m = \frac{0.5774\pi E d}{2 \ln \left( 5 \frac{0.5774 l + 0.5 d}{0.5774 l + 2.5 d} \right)} = \frac{0.5774\pi(30)0.5}{2 \ln \left( 5 \frac{0.5774(1) + 0.5(0.5)}{0.5774(1) + 2.5(0.5)} \right)} = 16.65 \text{ Mlbf/in}$$

$$C = \frac{k_b}{k_b + k_m} = \frac{4.574}{4.574 + 16.65} = 0.216$$

Table 8-9,  $S_p = 65 \text{ kpsi}$

Eqs. (8-31) and (8-32),  $F_i = 0.75 A_t S_p = 0.75(0.1419)65 = 6.918 \text{ kips}$

$$\sigma_i = 0.75 S_p = 0.75(65) = 48.75 \text{ kips}$$

Eq. (a):  $\sigma_b = \frac{CP + F_i}{A_t} = \frac{0.216(1.071) + 6.918}{0.1419} = 50.38 \text{ kpsi}$

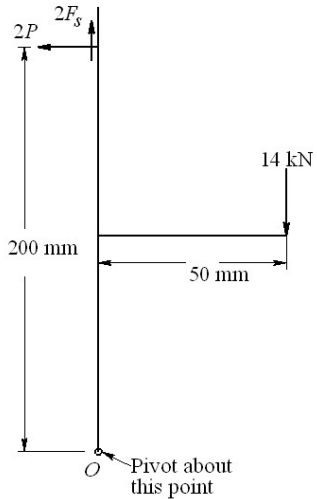
Direct shear,  $\tau_s \approx \frac{F_s}{A_t} = \frac{3}{0.1419} = 21.14 \text{ kpsi}$

von Mises stress, Eq. (5-15),

$$\sigma' = (\sigma_b^2 + 3\tau_s^2)^{1/2} = [50.38^2 + 3(21.14^2)]^{1/2} = 62.3 \text{ kpsi}$$

$$n = \frac{S_p}{\sigma'} = \frac{65}{62.3} = 1.04 \quad \text{Ans.}$$

**8-74**



$$2P(200) = 14(50)$$

$$P = \frac{14(50)}{2(200)} = 1.75 \text{ kN per bolt}$$

$$F_s = 7 \text{ kN/bolt}$$

$$S_p = 380 \text{ MPa}$$

$$A_t = 245 \text{ mm}^2, A_d = \frac{\pi}{4}(20^2) = 314.2 \text{ mm}^2$$

$$F_i = 0.75(245)(380)(10^{-3}) = 69.83 \text{ kN}$$

$$\sigma_i = 0.75(380) = 285 \text{ MPa}$$

$$\sigma_b = \frac{CP + F_i}{A_t} = \left( \frac{0.25(1.75) + 69.83}{245} \right) (10^3) = 287 \text{ MPa}$$

$$\tau = \frac{F_s}{A_d} = \frac{7(10^3)}{314.2} = 22.3 \text{ MPa}$$

$$\sigma' = [287^2 + 3(22.3^2)]^{1/2} = 290 \text{ MPa}$$

$$n = \frac{S_p}{\sigma'} = \frac{380}{290} = 1.31 \quad \text{Ans.}$$

**8-75** Using the result of Prob. 5-80 for lubricated assembly (replace 0.2 with 0.18 per Table 8-15)

$$F_x = \frac{2\pi f T}{0.18d}$$

With a design factor of  $n_d$  gives

$$T = \frac{0.18n_d F_x d}{2\pi f} = \frac{0.18(3)(1000)d}{2\pi(0.12)} = 716d$$

or  $T/d = 716$ . Also,

$$\begin{aligned}\frac{T}{d} &= K(0.75S_p A_t) \\ &= 0.18(0.75)(85\,000)A_t \\ &= 11\,475A_t\end{aligned}$$

Form a table

Size	$A_t$	$T/d = 11\,475A_t$	$n$
$\frac{1}{4}$ - 28	0.0364	417.70	1.75
$\frac{5}{16}$ - 24	0.058	665.55	2.8
$\frac{3}{8}$ - 24	0.0878	1007.50	4.23

where the factor of safety in the last column of the table comes from

$$n = \frac{2\pi f(T/d)}{0.18F_x} = \frac{2\pi(0.12)(T/d)}{0.18(1000)} = 0.0042(T/d)$$

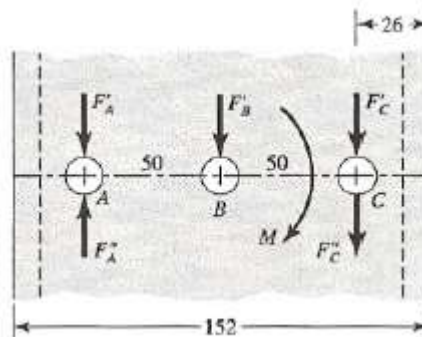
Select a  $\frac{3}{8}$  - 24 UNF cap screw. The setting is given by

$$T = (11\,475A_t)d = 1007.5(0.375) = 378 \text{ lbf} \cdot \text{in}$$

Given the coarse scale on a torque wrench, specify a torque wrench setting of 400 lbf · in.  
Check the factor of safety

$$n = \frac{2\pi f T}{0.18F_x d} = \frac{2\pi(0.12)(400)}{0.18(1000)(0.375)} = 4.47$$

## 8-76



Bolts, from Table 8-11,  $S_y = 420 \text{ MPa}$

Channel, From Table A-20,  $S_y = 170 \text{ MPa}$ . From Table A-7,  $t = 6.4 \text{ mm}$

Cantilever, from Table A-20,  $S_y = 190 \text{ MPa}$

$$F'_A = F'_B = F'_C = F/3$$

$$M = (50 + 26 + 125) F = 201 F$$

$$F_A'' = F_C'' = \frac{201F}{2(50)} = 2.01F$$

$$\text{Max. force, } F_C = F_C' + F_C'' = \left( \frac{1}{3} + 2.01 \right) F = 2.343F \quad (1)$$

Shear on Bolts: The shoulder bolt shear area,  $A_s = \pi(10^2) / 4 = 78.54 \text{ mm}^2$

$$S_{sy} = 0.577(420) = 242.3 \text{ KPa}$$

$$\tau_{\max} = \frac{F_C}{A_s} = \frac{S_{sy}}{n}$$

From Eq. (1),  $F_C = 2.343 F$ . Thus

$$F = \frac{S_{sy}}{n} \left( \frac{A_s}{2.343} \right) = \frac{242.3}{2.0} \left( \frac{78.54}{2.343} \right) 10^{-3} = 4.06 \text{ kN}$$

Bearing on bolt: The bearing area is  $A_b = td = 6.4(10) = 64 \text{ mm}^2$ . Similar to shear

$$F = \frac{S_y}{n} \left( \frac{A_b}{2.343} \right) = \frac{420}{2.0} \left( \frac{64}{2.343} \right) 10^{-3} = 5.74 \text{ kN}$$

Bearing on channel:  $A_b = 64 \text{ mm}^2$ ,  $S_y = 170 \text{ MPa}$ .

$$F = \frac{S_y}{n} \left( \frac{A_b}{2.343} \right) = \frac{170}{2.0} \left( \frac{64}{2.343} \right) 10^{-3} = 2.32 \text{ kN}$$

Bearing on cantilever:  $A_b = 12(10) = 120 \text{ mm}^2$ ,  $S_y = 190 \text{ MPa}$ .

$$F = \frac{S_y}{n} \left( \frac{A_b}{2.343} \right) = \frac{190}{2.0} \left( \frac{120}{2.343} \right) 10^{-3} = 4.87 \text{ kN}$$

Bending of cantilever: At C

$$I = \frac{1}{12} (12) (50^3 - 10^3) = 1.24 (10^5) \text{ mm}^4$$

$$\sigma_{\max} = \frac{S_y}{n} = \frac{Mc}{I} = \frac{151Fc}{I} \Rightarrow F = \frac{S_y}{n} \left( \frac{I}{151c} \right)$$

$$F = \frac{190}{2.0} \left[ \frac{1.24(10^5)}{151(25)} \right] 10^{-3} = 3.12 \text{ kN}$$

So  $F = 2.32 \text{ kN}$  based on bearing on channel. *Ans.*

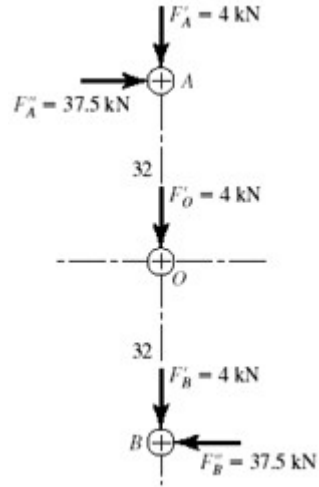
**8-77** Bolts, from Table 8-11,  $S_y = 420 \text{ MPa}$   
Bracket, from Table A-20,  $S_y = 210 \text{ MPa}$

$$F' = \frac{12}{3} = 4 \text{ kN}; M = 12(200) = 2400 \text{ N} \cdot \text{m}$$

$$F'_A = F'_B = \frac{2400}{64} = 37.5 \text{ kN}$$

$$F_A = F_B = \sqrt{(4)^2 + (37.5)^2} = 37.7 \text{ kN}$$

$$F_O = 4 \text{ kN}$$



Bolt shear:

The shoulder bolt shear area,  $A_s = \pi(12^2) / 4 = 113.1 \text{ mm}^2$

$$S_{sy} = 0.577(420) = 242.3 \text{ KPa}$$

$$\tau = \frac{37.7(10)^3}{113} = 333 \text{ MPa}$$

$$n = \frac{S_{sy}}{\tau} = \frac{242.3}{333} = 0.728 \quad \text{Ans.}$$

Bearing on bolts:

$$A_b = 12(8) = 96 \text{ mm}^2$$

$$\sigma_b = -\frac{37.7(10)^3}{96} = -393 \text{ MPa}$$

$$n = \frac{S_{yc}}{|\sigma_b|} = \frac{420}{393} = 1.07 \quad \text{Ans.}$$

Bearing on member:

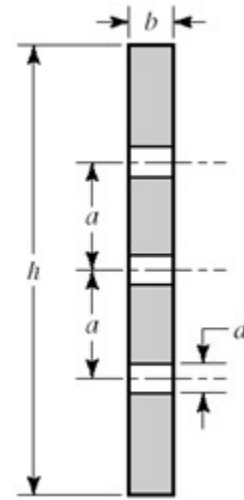
$$\sigma_b = -393 \text{ MPa}$$

$$n = \frac{S_{yc}}{|\sigma_b|} = \frac{210}{393} = 0.534 \quad \text{Ans.}$$



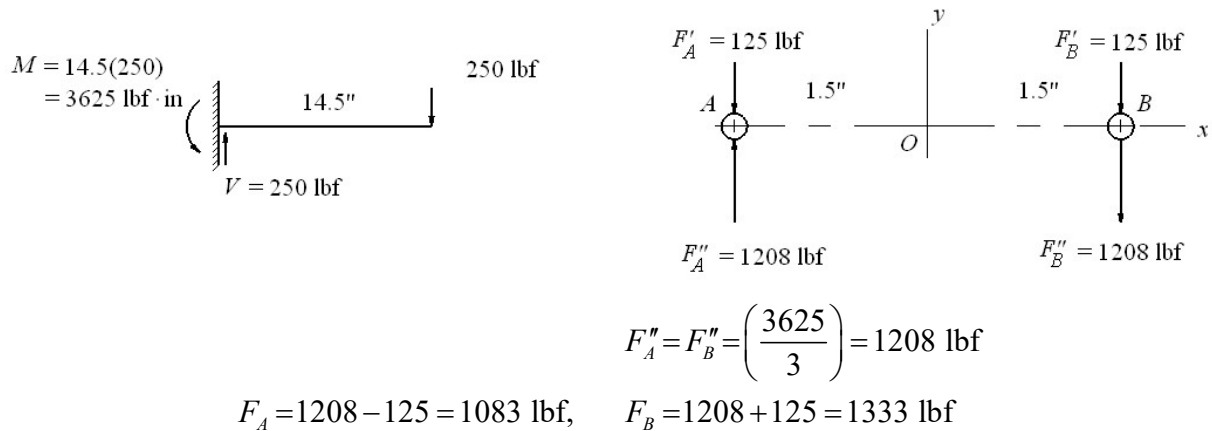
Bending stress in plate:

$$\begin{aligned}
 I &= \frac{bh^3}{12} - \frac{bd^3}{12} - 2\left(\frac{bd^3}{12} + a^2bd\right) \\
 &= \frac{8(136)^3}{12} - \frac{8(12)^3}{12} - 2\left[\frac{8(12)^3}{12} + (32)^2(8)(12)\right] \\
 &= 1.48(10)^6 \text{ mm}^4 \quad \text{Ans.} \\
 \sigma &= \frac{Mc}{I} = \frac{2400(68)}{1.48(10)^6}(10)^3 = 110 \text{ MPa} \\
 n &= \frac{S_y}{\sigma} = \frac{210}{110} = 1.91 \quad \text{Ans.}
 \end{aligned}$$



Failure is predicted for bolt shear and bearing on member.

8-78



Bolt shear:

$$A_s = (\pi/4)(0.375^2) = 0.1104 \text{ in}^2$$

$$\tau_{\max} = \frac{F_{\max}}{A_s} = \frac{1333}{0.1104} = 12\,070 \text{ psi}$$

From Table 8-10,  $S_y = 100 \text{ kpsi}$ ,  $S_{sy} = 0.577(100) = 57.7 \text{ kpsi}$

$$n = \frac{S_{sy}}{\tau_{\max}} = \frac{57.7}{12.07} = 4.78 \quad \text{Ans.}$$

Bearing on bolt: Bearing area is  $A_b = td = 0.375(0.375) = 0.1406 \text{ in}^2$ .

$$\sigma_b = -\frac{F}{A_b} = -\frac{1333}{0.1406} = -9\,481 \text{ psi}$$

$$n = \frac{S_y}{|\sigma_b|} = \frac{100}{9.481} = 10.55 \quad \text{Ans.}$$

Bearing on member: From Table A-20,  $S_y = 54$  kpsi. Bearing stress same as bolt

$$n = \frac{S_y}{|\sigma_b|} = \frac{54}{9.481} = 5.70 \quad \text{Ans.}$$

Bending of member: At  $B$ ,  $M = 250(13) = 3250$  lbf·in

$$I = \frac{1}{12} \left( \frac{3}{8} \right) \left[ 2^3 - \left( \frac{3}{8} \right)^3 \right] = 0.2484 \text{ in}^4$$

$$\sigma = \frac{Mc}{I} = \frac{3250(1)}{0.2484} = 13\,080 \text{ psi}$$

$$n = \frac{S_y}{\sigma} = \frac{54}{13.08} = 4.13 \quad \text{Ans.}$$

**8-79** The direct shear load per bolt is  $F' = 2000/6 = 333.3$  lbf. The moment is taken only by the four outside bolts. This moment is  $M = 2000(5) = 10\,000$  lbf·in.

Thus  $F'' = \frac{10\,000}{2(5)} = 1000$  lbf and the resultant bolt load is

$$F = \sqrt{(333.3)^2 + (1000)^2} = 1054 \text{ lbf}$$

Bolt strength, Table 8-9,  $S_y = 100$  kpsi; Channel and Plate strength,  $S_y = 42$  kpsi

Shear of bolt:  $A_s = \pi(0.5)^2/4 = 0.1963 \text{ in}^2$

$$n = \frac{S_{sy}}{\tau} = \frac{(0.577)(100)}{1.054 / 0.1963} = 10.7 \quad \text{Ans.}$$

Bearing on bolt: Channel thickness is  $t = 3/16$  in,  $A_b = 0.5(3/16) = 0.09375 \text{ in}^2$

$$n = \frac{100}{1.054 / 0.09375} = 8.89 \quad \text{Ans.}$$

Bearing on channel:  $n = \frac{42}{1.054 / 0.09375} = 3.74 \quad \text{Ans.}$

Bearing on plate:  $A_b = 0.5(0.25) = 0.125 \text{ in}^2$

$$n = \frac{42}{1.054 / 0.125} = 4.98 \quad \text{Ans.}$$

Strength of plate:

$$I = \frac{0.25(7.5)^3}{12} - \frac{0.25(0.5)^3}{12} - 2 \left[ \frac{0.25(0.5)^3}{12} + (0.25)(0.5)(2.5)^2 \right] = 7.219 \text{ in}^4$$

$$M = 5000 \text{ lbf} \cdot \text{in per plate}$$

$$\sigma = \frac{Mc}{I} = \frac{5000(3.75)}{7.219} = 2597 \text{ psi}$$

$$n = \frac{42}{2.597} = 16.2 \quad \text{Ans.}$$

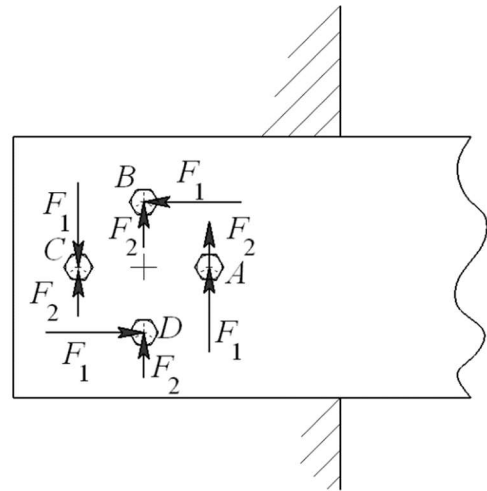
- 8-80**  $A = 58 \text{ mm}^2$ . From Table A-9, beam 14,  
 $R_1 = R_2 = F/2 = 10/2 = 5 \text{ kN}$ ,  
 $M_1 = M_2 = Fl/8 = 10(0.4)10^3/8 = 500 \text{ N} \cdot \text{m}$ .

$$M_1 = 500 = 4F_1 \left( \frac{0.050}{2} \right) \Rightarrow F_1 = 5000 \text{ N}$$

$$F_2 = \frac{R_1}{4} = \frac{5000}{4} = 1250 \text{ N}$$

Bolt  $A$  has the maximum force of  
 $F_A = F_1 + F_2 = 5000 + 1250 = 6250 \text{ N}$

$$\tau_{\max} = \tau_A = \frac{F_A}{A} = \frac{6250}{58} = 108 \text{ MPa} \quad \text{Ans.}$$



- 8-81** Given: 250 hp at 600 rev/min,  $r_1 = 2.5 \text{ in}$ ,  $r_2 = 5 \text{ in}$ .

$$\text{Eq. (3-42): } T = \frac{63\,025(250)}{600} = 26.26(10^3) \text{ lbf} \cdot \text{in}$$

$$\text{(a) } \frac{F_1}{r_1} = \frac{F_2}{r_2} \Rightarrow F_2 = \frac{r_2}{r_1} F_1 = \frac{5}{2.5} F_1 = 2F_1$$

$$4F_1 r_1 + 4F_2 r_2 = T \Rightarrow 4F_1(2.5) + 4(2F_1)5 = 26.26(10^3)$$

Yields  $F_1 = 525.2 \text{ lbf}$  and  $F_2 = 1050.4 \text{ lbf}$

$$\tau_{\max} = \frac{4F_2}{\pi d^2} \Rightarrow d = \sqrt{\frac{4F_2}{\pi \tau_{\max}}} = \sqrt{\frac{4(1050.4)}{\pi(20)10^3}} = 0.258 \text{ in}$$

From Table A-17 select  $d = \frac{5}{16} \text{ in} \quad \text{Ans.}$

$$(b) F = \frac{\tau_{\max} \pi d^2}{4} = \frac{20(10^3) \pi \left(\frac{5}{16}\right)^2}{4} = 1534 \text{ lbf}$$

$$nFr_2 = T \quad \Rightarrow \quad n(1534)5 = 26.26(10^3) \quad \Rightarrow \quad n = 3.4 \text{ bolts}$$

Use four bolts without need of the inner bolts *Ans.*

**8-82 to 8-84** Specifying bolts, screws, dowels and rivets is the way a student learns about such components. However, choosing an array a priori is based on experience. Here is a chance for students to build some experience.

**8-85** Assume tensile forces to be proportional to deflections. Thus,

$$\frac{F_1}{1} = \frac{F_2}{9} \quad \Rightarrow \quad F_2 = 9F_1 \quad (1)$$

$$\Sigma M_A = 0 = 2F_1(1) + 2F_2(9) - 1000(10)$$

Substitute Eq. (1) in,

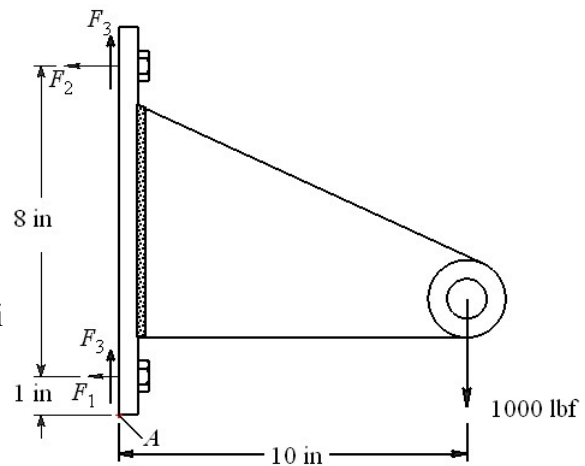
$$2F_1(1) + 2(9F_1)(9) - 1000(10) = 0$$

Yields  $F_1 = 60.98 \text{ lbf}$ ,  $F_2 = 548.8 \text{ lbf}$ .

Combining the preload,

$$\sigma = \frac{5000 + 548}{0.2} = 27.7(10^3) \text{ psi} = 27.7 \text{ kpsi}$$

The shear forces are  $F_3 = 1000/4 = 250 \text{ lbf}$ .



The shear stress is,

$$\tau = \frac{F_3}{A} = \frac{250}{0.2} = 1250 \text{ psi} = 1.25 \text{ kpsi}$$

The maximum tensile stress is,

$$\sigma_{\max} = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = \frac{27.7}{2} + \sqrt{\left(\frac{27.7}{2}\right)^2 + 1.25^2} = 27.8 \text{ kpsi} \quad \text{Ans.}$$