One PowerPoint that includes

Solutions Manual Number		PowerPoint Number
P1.1		E1.2–1
P1.2		E1.2–2
P1.3		E1.2–3
P1.8		E1.2–4
P1.10		E1.2–5
P1.11		E1.2–6

One PowerPoint that includes

Solutions Manual Number		PowerPoint Number
P1.13		E1.3–1
P1.14		E1.3–2
P1.16		E1.3–3
P1.17		E1.3–4
P1.19		E1.3–5
P1.20		E1.3–6

One PowerPoint that includes

Solutions Manual Number		PowerPoint Number
P1.21		E1.4–1
P1.22		E1.4–2
P1.23		E1.4–3
P1.24		E1.4–4

One PowerPoint that includes

Solutions Manual Number		PowerPoint Number
P1.25		E1.4–5
P1.26		E1.4–6
P1.27		E1.4–7
P1.28		E1.4–8

One PowerPoint that includes

Solutions Manual Number		PowerPoint Number
P1.29		E1.5–1
P1.32		E1.5–2
P1.35		E1.5–3
P1.36		E1.5–4

P1.1 A stainless steel tube with an outside diameter of 60 mm and a wall thickness of 5 mm is used as a compression member. If the axial stress in the member must be limited to 340 MPa, determine the maximum load P that the member can support.

Solution

The cross-sectional area of the stainless steel tube is

$$A = \frac{\pi}{4}(D^2 - d^2) = \frac{\pi}{4}[(60\text{ mm})^2 - (50\text{ mm})^2] = 863.938\text{ mm}^2$$

The normal stress in the tube can be expressed as

$$\sigma = \frac{P}{A}$$

The maximum normal stress in the tube must be limited to 340 MPa. Using 340 MPa as the allowable normal stress, rearrange this expression to solve for the maximum load P

$$P_{\text{max}} \le \sigma_{\text{allow}} A = (340\text{ N/mm}^2)(863.938\text{ mm}^2) = 293{,}739\text{ N} = \boxed{294\text{ kN}}$$

Ans.

P1.2 A 2024-T4 aluminum tube with an outside diameter of 2.50 in. will be used to support a 12 kip load. If the axial stress in the member must be limited to 25 ksi, determine the wall thickness required for the tube.

Solution

From the definition of normal stress, solve for the minimum area required to support a 12-kip load without exceeding a stress of 25 ksi

$$\sigma = \frac{P}{A} \qquad \therefore A_{\text{min}} \geq \frac{P}{\sigma} = \frac{12 \text{ kips}}{25 \text{ ksi}} = 0.480 \text{ in.}^2$$

The cross-sectional area of the aluminum tube is given by

$$A = \frac{\pi}{4}(D^2 - d^2)$$

Set this expression equal to the minimum area and solve for the maximum inside diameter d

$$\frac{\pi}{4}[(2.50 \text{ in.})^2 - d^2] \geq 0.480 \text{ in.}^2$$

$$(2.50 \text{ in.})^2 - d^2 \geq \frac{4}{\pi}(0.480 \text{ in.}^2)$$

$$(2.50 \text{ in.})^2 - \frac{4}{\pi}(0.480 \text{ in.}^2) \geq d^2$$

$$\therefore d_{\text{max}} \leq 2.374625 \text{ in.}$$

The outside diameter D, the inside diameter d, and the wall thickness t are related by

$$D = d + 2t$$

Therefore, the minimum wall thickness required for the aluminum tube is

$$t_{\text{min}} \geq \frac{D-d}{2} = \frac{2.50 \text{ in.} - 2.374525 \text{ in.}}{2} = 0.062738 \text{ in.} = \boxed{0.0627 \text{ in.}}$$

Ans.

P1.3 Two solid cylindrical rods (1) and (2) are joined together at flange *B* and loaded, as shown in Figure P1.3. The diameter of rod (1) is $D_1 = 24$ mm and the diameter of rod (2) is $D_2 = 42$ mm. Determine the normal stresses in rods (1) and (2).

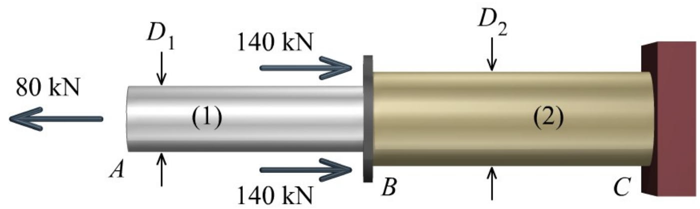
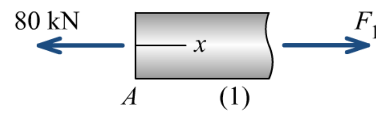


Figure P1.3

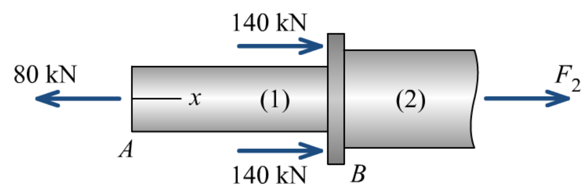
Solution

Cut a FBD through rod (1) that includes the free end of the rod at *A*. Assume that the internal force in rod (1) is tension. From equilibrium,



$$\Sigma F_x = F_1 - 80 \text{ kN} = 0 \qquad \therefore F_1 = 80 \text{ kN (T)}$$

Next, cut a FBD through rod (2) that includes the free end of the rod *A*. Assume that the internal force in rod (2) is tension. Equilibrium of this FBD reveals the internal force in rod (2):



$$\Sigma F_x = F_2 + 140 \text{ kN} + 140 \text{ kN} - 80 \text{ kN} = 0 \qquad \therefore F_2 = -200 \text{ kN} = 200 \text{ kN (C)}$$

From the given diameter of rod (1), the cross-sectional area of rod (1) is

$$A_1 = \frac{\pi}{4}(24 \text{ mm})^2 = 452.3893 \text{ mm}^2$$

and thus, the normal stress in rod (1) is

$$\sigma_1 = \frac{F_1}{A_1} = \frac{(80 \text{ kN})(1{,}000 \text{ N/kN})}{452.3893 \text{ mm}^2} = 176.8388 \text{ MPa} = \boxed{176.8 \text{ MPa (T)}}$$

Ans.

From the given diameter of rod (2), the cross-sectional area of rod (2) is

$$A_2 = \frac{\pi}{4}(42 \text{ mm})^2 = 1{,}385.4424 \text{ mm}^2$$

Accordingly, the normal stress in rod (2) is

$$\sigma_2 = \frac{F_2}{A_2} = \frac{(-200 \text{ kN})(1{,}000 \text{ N/kN})}{1{,}385.4424 \text{ mm}^2} = -144.3582 \text{ MPa} = \boxed{144.4 \text{ MPa (C)}}$$

Ans.

P1.8 Axial loads are applied with rigid bearing plates to the solid cylindrical rods shown in Figure P1.8. The normal stress in aluminum rod (1) must be limited to 25 ksi, the normal stress in brass rod (2) must be limited to 15 ksi, and the normal stress in steel rod (3) must be limited to 10 ksi. Determine the minimum diameter D required for each of the three rods.

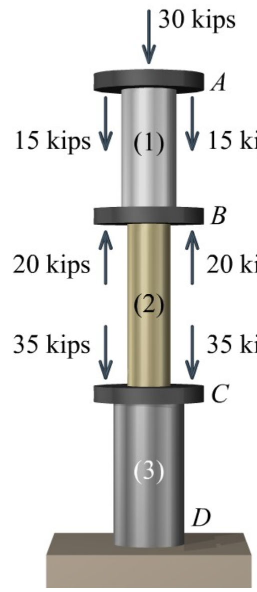
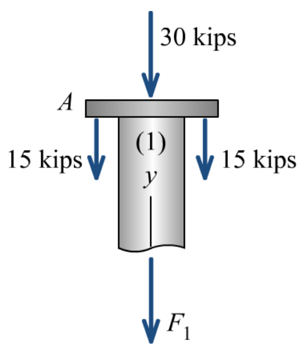


Figure P1.8

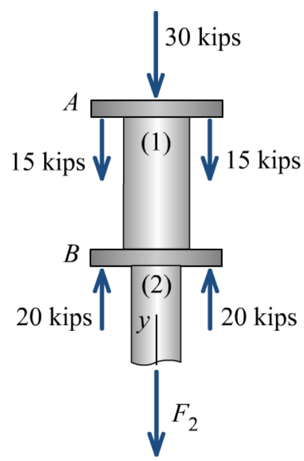
Solution

The internal forces in the three rods must be determined. Begin with a FBD cut through rod (1) that includes the free end A. We will assume that the internal force in rod (1) is tension (even though it obviously will be in compression). From equilibrium,

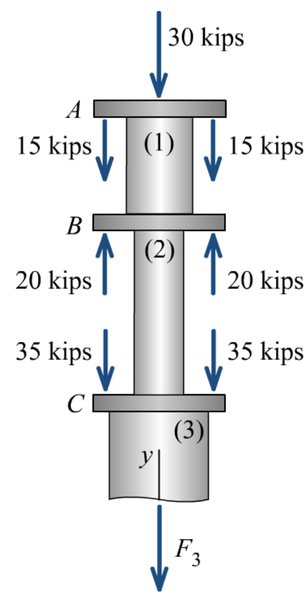
$$\Sigma F_y = -F_1 - 30\text{ kips} - 15\text{ kips} - 15\text{ kips} = 0 \qquad \therefore F_1 = -60\text{ kips} = 60\text{ kips (C)}$$



FBD through rod (1)



FBD through rod (2)



FBD through rod (3)

Next, cut a FBD through rod (2) that includes the free end A. Again, we will assume that the internal force in rod (2) is tension. Equilibrium of this FBD reveals the internal force in rod (2):

$$\Sigma F_y = -F_2 - 30\text{ kips} - 15\text{ kips} - 15\text{ kips} + 20\text{ kips} + 20\text{ kips} = 0 \qquad \therefore F_2 = -20\text{ kips} = 20\text{ kips (C)}$$

Similarly, cut a FBD through rod (3) that includes the free end A. From this FBD, the internal force in rod (3) is:

$$\Sigma F_y = -F_3 - 30\text{ kips} - 15\text{ kips} - 15\text{ kips} + 20\text{ kips} + 20\text{ kips} - 35\text{ kips} - 35\text{ kips} = 0$$
$$\therefore F_3 = -90\text{ kips} = 90\text{ kips (C)}$$

Notice that all three rods are in compression. In this situation, we are concerned only with the stress magnitude; therefore, we will use the force magnitudes to determine the minimum required cross-sectional areas, and in turn, the minimum rod diameters. The normal stress in aluminum rod (1) must be limited to 25 ksi; therefore, the minimum cross-sectional area required for rod (1) is

$$A_{1,\min} \geq \frac{F_1}{\sigma_1} = \frac{60\text{ kips}}{25\text{ ksi}} = 2.40\text{ in.}^2$$

The minimum rod diameter is therefore

$$A_{1,\min} = \frac{\pi}{4} D^2_{1,\min} \geq 2.40\text{ in.}^2 \qquad \therefore D_{1,\min} \geq 1.7481\text{ in.} = \boxed{1.748\text{ in.}}$$

Ans.

The normal stress in brass rod (2) must be limited to 15 ksi, which requires a minimum area of

$$A_{2,\min} \geq \frac{F_2}{\sigma_2} = \frac{20\text{ kips}}{15\text{ ksi}} = 1.3333\text{ in.}^2$$

which requires a minimum diameter for rod (2) of

$$A_{2,\min} = \frac{\pi}{4} D^2_{2,\min} \geq 1.3333\text{ in.}^2 \qquad \therefore D_{2,\min} \geq 1.3029\text{ in.} = \boxed{1.303\text{ in.}}$$

Ans.

The normal stress in steel rod (3) must be limited to 10 ksi. The minimum cross-sectional area required for this rod is:

$$A_{3,\min} \geq \frac{F_3}{\sigma_3} = \frac{90\text{ kips}}{10\text{ ksi}} = 9.0\text{ in.}^2$$

which requires a minimum diameter for rod (3) of

$$A_{3,\min} = \frac{\pi}{4} D^2_{3,\min} \geq 9.0\text{ in.}^2 \qquad \therefore D_{3,\min} \geq 3.3851\text{ in.} = \boxed{3.39\text{ in.}}$$

Ans.

P1.10 Two solid cylindrical rods support a load of $P = 70$ kN, as shown in Figure P1.10. If the normal stress in each rod must be limited to 165 MPa, determine the minimum diameter D required for each rod.

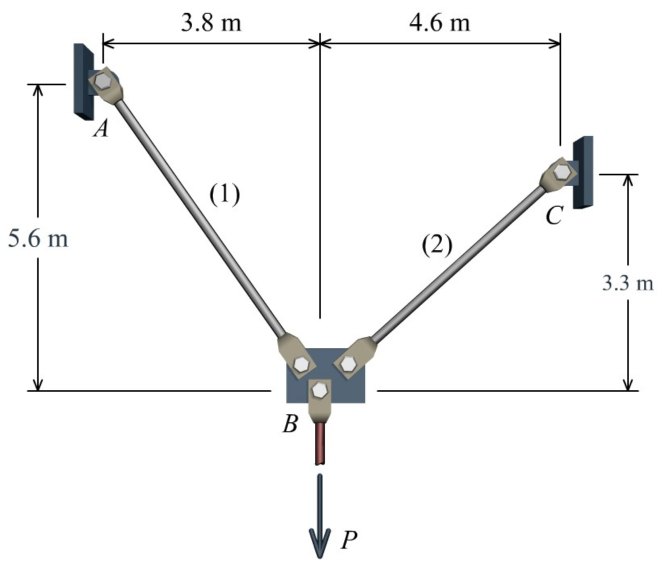


Figure P1.10

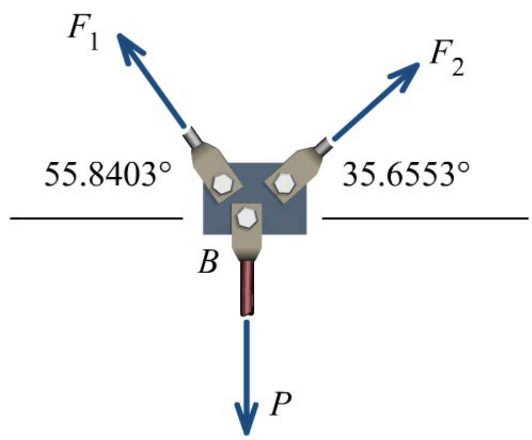
Solution

Consider a FBD of joint B. Determine the angle α between rod (1) and the horizontal axis:

$$\tan\alpha = \frac{5.6\text{ m}}{3.8\text{ m}} = 1.4737 \qquad \therefore \alpha = 55.8403°$$

and the angle β between rod (2) and the horizontal axis:

$$\tan\beta = \frac{3.3\text{ m}}{4.6\text{ m}} = 0.7174 \qquad \therefore \beta = 35.6553°$$



Write equilibrium equations for the sum of forces in the horizontal and vertical directions. Note: Rods (1) and (2) are two-force members.

$$\Sigma F_x = F_2\cos(35.6553°) - F_1\cos(55.8403°) = 0 \qquad \text{(a)}$$

$$\Sigma F_y = F_2\sin(35.6553°) + F_1\sin(55.8403°) - P = 0 \qquad \text{(b)}$$

Unknown forces F_1 and F_2 can be found from the simultaneous solution of Eqs. (a) and (b). Using the substitution method, Eq. (b) can be solved for F_2 in terms of F_1:

$$F_2 = F_1\frac{\cos(55.8403°)}{\cos(35.6553°)} \qquad \text{(c)}$$

Substituting Eq. (c) into Eq. (b) gives

$$F_1\frac{\cos(55.8403°)}{\cos(35.6553°)}\sin(35.6553°) + F_1\sin(55.8403°) = P$$

$$F_1\left[\cos(55.8403°)\tan(35.6553°) + \sin(55.8403°)\right] = P$$

$$\therefore F_1 = \frac{P}{\cos(55.8403°)\tan(35.6553°) + \sin(55.8403°)} = \frac{P}{1.2303}$$

For the given load of $P = 70$ kN, the internal force in rod (1) is therefore:

$$F_1 = \frac{70 \text{ kN}}{1.2303} = 56.8967 \text{ kN}$$

Backsubstituting this result into Eq. (c) gives force F_2:

$$F_2 = F_1 \frac{\cos(55.8403°)}{\cos(35.6553°)} = (56.8967 \text{ kN}) \frac{\cos(55.8403°)}{\cos(35.6553°)} = 39.3182 \text{ kN}$$

The normal stress in rod (1) must be limited to 165 MPa; therefore, the minimum cross-sectional area required for rod (1) is

$$A_{1,\min} \geq \frac{F_1}{\sigma_1} = \frac{(56.8967 \text{ kN})(1{,}000 \text{ N/kN})}{165 \text{ N/mm}^2} = 344.8285 \text{ mm}^2$$

The minimum rod diameter is therefore

$$A_{1,\min} = \frac{\pi}{4} D_{1,\min}^2 \geq 344.8285 \text{ mm}^2 \qquad \therefore D_{1,\min} \geq 20.9535 \text{ mm} = \boxed{21.0 \text{ mm}}$$

Ans.

The minimum area required for rod (2) is

$$A_{2,\min} \geq \frac{F_2}{\sigma_2} = \frac{(39.3182 \text{ kN})(1{,}000 \text{ N/kN})}{165 \text{ N/mm}^2} = 238.2921 \text{ mm}^2$$

which requires a minimum diameter for rod (2) of

$$A_{2,\min} = \frac{\pi}{4} D_{2,\min}^2 \geq 238.2921 \text{ mm}^2 \qquad \therefore D_{2,\min} \geq 17.4185 \text{ mm} = \boxed{17.42 \text{ mm}}$$

Ans.

P1.11 Bar (1) in Figure P1.11 has a cross-sectional area of 0.75 in.^{2}. If the stress in bar (1) must be limited to 30 ksi, determine the maximum load P that may be supported by the structure.

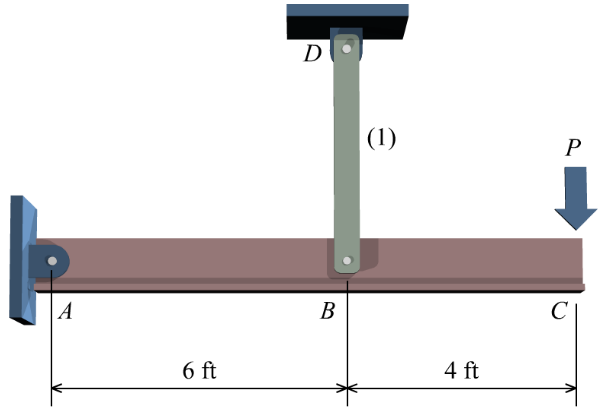


Figure P1.11

Solution

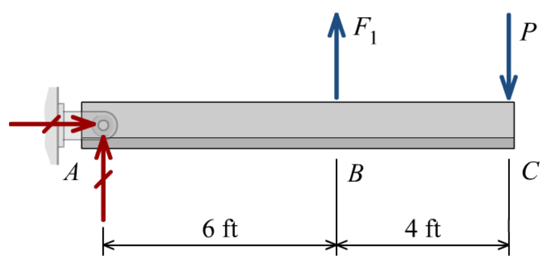
Given that the cross-sectional area of bar (1) is 0.75 in.^{2} and its normal stress must be limited to 30 ksi, the maximum force that may be carried by bar (1) is

$$F_{1,\max} = \sigma_1 A_1 = (30 \text{ ksi})(0.75 \text{ in.}^2) = 22.5 \text{ kips}$$

Consider a FBD of ABC. From the moment equilibrium equation about joint A, the relationship between the force in bar (1) and the load P is:

$$\Sigma M_A = (6 \text{ ft})F_1 - (10 \text{ ft})P = 0$$

$$\therefore P = \frac{6 \text{ ft}}{10 \text{ ft}} F_1$$



Substitute the maximum force $F_{1,\max} = 22.5$ kips into this relationship to obtain the maximum load that may be applied to the structure:

$$P = \frac{6 \text{ ft}}{10 \text{ ft}} F_1 = \frac{6 \text{ ft}}{10 \text{ ft}}(22.5 \text{ kips}) = \boxed{13.50 \text{ kips}}$$

Ans.

P1.13 For the clevis connection shown in Figure P1.13, determine the average shear stress in the 24 mm diameter bolt for an applied load of P = 175 kN.

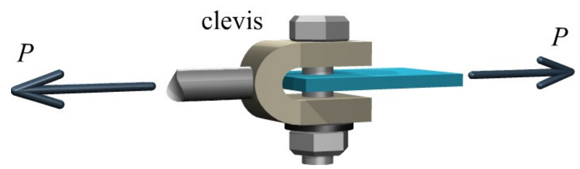
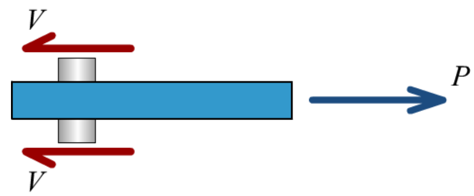


Figure P1.13

Solution

Consider a FBD of the bar that is connected by the clevis, including a portion of the bolt. If the shear force acting on each exposed surface of the bolt is denoted by V, then the shear force on each bolt surface is



$$\Sigma F_x = P - V - V = 0 \qquad \therefore V = \frac{175 \text{ kN}}{2} = 87.5 \text{ kN}$$

The area of the bolt surface exposed by the FBD is simply the cross-sectional area of the bolt:

$$A_{\text{bolt}} = \frac{\pi}{4} D_{\text{bolt}}^2 = \frac{\pi}{4}(24 \text{ mm})^2 = 452.3893 \text{ mm}^2$$

Therefore, the shear stress in the bolt is

$$\tau = \frac{V}{A_{\text{bolt}}} = \frac{(87.5 \text{ kN})(1{,}000 \text{ N/kN})}{452.3893 \text{ mm}^2} = 193.4175 \text{ N/mm}^2 = \boxed{193.4 \text{ MPa}}$$

Ans.

P1.14 For the clevis connection shown in Figure P1.14, the average shear stress in the 5/16 in. diameter bolt must be limited to 40 ksi. Determine the maximum load P that may be applied to the connection.

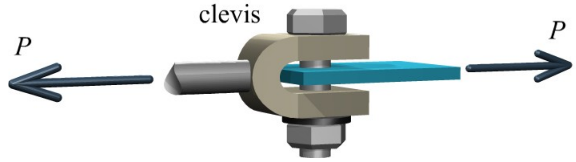
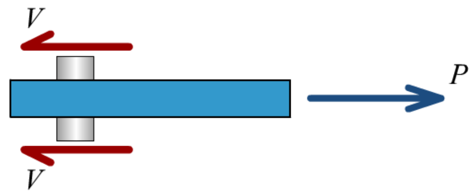


Figure P1.14

Solution

Consider a FBD of the bar that is connected by the clevis, including a portion of the bolt. If the shear force acting on each exposed surface of the bolt is denoted by V, then the shear force on each bolt surface is related to the load P by:

$$\Sigma F_x = P - V - V = 0 \qquad \therefore P = 2V$$



The area of the bolt surface exposed by the FBD is simply the cross-sectional area of the bolt:

$$A_{\text{bolt}} = \frac{\pi}{4} D_{\text{bolt}}^2 = \frac{\pi}{4}(5/16 \text{ in.})^2 = \frac{\pi}{4}(0.3125 \text{ in.})^2 = 0.076699 \text{ in.}^2$$

If the shear stress in the bolt must be limited to 40 ksi, the maximum shear force V on a single cross-sectional surface must be limited to

$$V = \tau A_{\text{bolt}} = (40 \text{ ksi})(0.076699 \text{ in.}^2) = 3.067962 \text{ kips}$$

Therefore, the maximum load P that may be applied to the connection is

$$P = 2V = 2(3.067962 \text{ kips}) = 6.135923 \text{ kips} = \boxed{6.14 \text{ kips}}$$

Ans.

P1.16 The five-bolt connection shown in Figure P1.16 must support an applied load of $P = 550$ kN. If the average shear stress in the bolts must be limited to 270 MPa, determine the minimum bolt diameter that may be used in the connection.

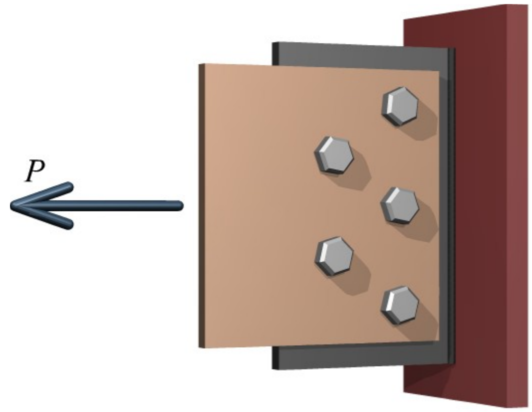


Fig P1.16

Solution

We assume that each bolt carries an equal share of load P. Thus, the shear force that acts in each bolt is

$$V = \frac{P}{5 \text{ bolts}} = \frac{550 \text{ kN}}{5 \text{ bolts}} = 110 \text{ kN/bolt}$$

To support a shear force of 110 kN while not exceeding an average shear stress of 270 MPa, the shear area provided by a bolt must be at least

$$A_{\text{bolt}} \geq \frac{P}{\tau} = \frac{(110 \text{ kN})(1{,}000 \text{ N/kN})}{270 \text{ N/mm}^2} = 407.4074 \text{ mm}^2$$

The minimum bolt diameter is therefore

$$A_{\text{bolt}} \geq 407.4074 \text{ mm}^2 = \frac{\pi}{4} D_{\text{bolt}}^2 \qquad \therefore D_{\text{bolt}} \geq 22.7756 \text{ mm} = \boxed{22.8 \text{ mm}}$$

Ans.

P1.17 For the connection shown in Figure P1.17, the average shear stress in the 16 mm diameter bolts must be limited to 210 MPa. Determine the maximum load P that may be applied to the connection.

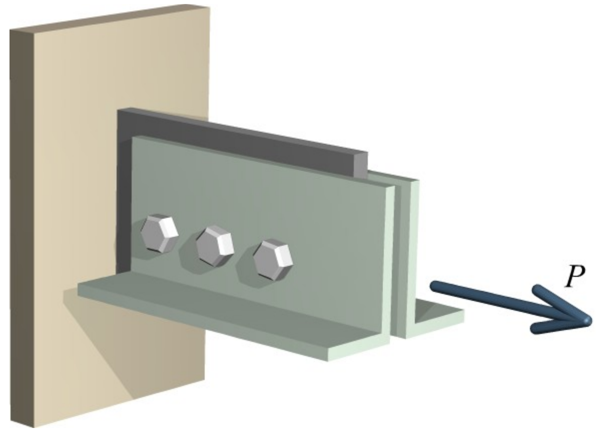


Figure P1.17

Solution

The cross-sectional area of a 16 mm diameter bolt is

$$A_{\text{bolt}} = \frac{\pi}{4} D_{\text{bolt}}^2 = \frac{\pi}{4}(16 \text{ mm})^2 = 201.0619 \text{ mm}^2$$

This is a double-shear connection. Therefore, each bolt provides a shear area of

$$A_V = 2A_{\text{bolt}} = 2(201.0619 \text{ mm}^2) = 402.1238 \text{ mm}^2$$

Since the shear stress must be limited to 210 MPa, the shear force that can be resisted by one bolt is

$$V_{\text{bolt}} = \tau A_V = (210 \text{ N/mm}^2)(402.1238 \text{ mm}^2) = 84{,}445.9980 \text{ N}$$

There are three bolts in this connection. The total shear force that can be resisted by three bolts is

$$V_{\max} = (3 \text{ bolts})V_{\text{bolt}} = (3 \text{ bolts})(84{,}445.9980 \text{ N/bolt}) = 253{,}337.9940 \text{ N}$$

The maximum load P that can be applied to this connection is equal to the total shear force; therefore,

$$P_{\max} = 253{,}337.9940 \text{ N} = \boxed{253 \text{ kN}}$$

Ans.

P1.19 A hydraulic punch press is used to punch a slot in a 10 mm thick plate, as illustrated in Figure P1.19. If the plate shears at a stress of 250 MPa, determine the minimum force P required to punch the slot.

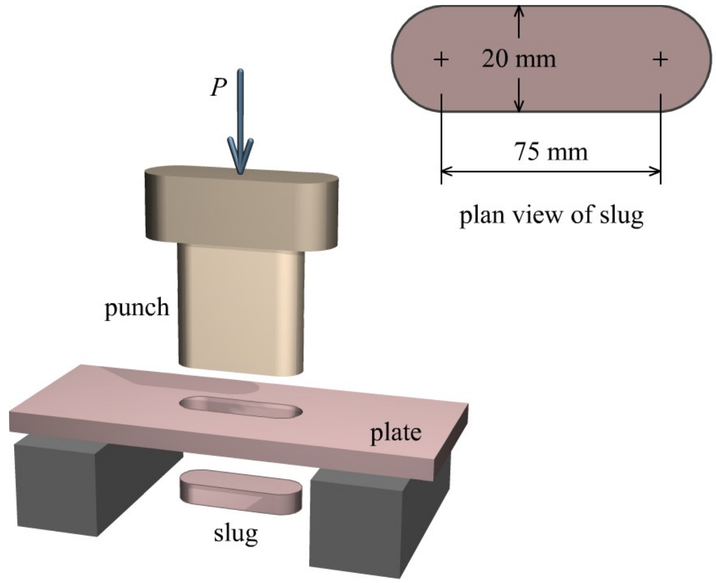


Figure P1.19

Solution

The shear stress associated with removal of the slug exists on its perimeter. The perimeter of the slug is given by

$$\text{perimeter} = 2(75\text{ mm}) + \pi(20\text{ mm}) = 212.8319\text{ mm}$$

Thus, the area subjected to shear stress is

$$A_V = \text{perimeter} \times \text{plate thickness} = (212.8319\text{ mm})(10\text{ mm}) = 2{,}128.319\text{ mm}^2$$

Given that the plate shears at $\tau = 250$ MPa, the force required to remove the slug is therefore

$$P_{\min} = \tau A_V = (250\text{ N/mm}^2)(2{,}128.319\text{ mm}^2) = 532{,}080\text{ N} = \boxed{532\text{ kN}}$$

Ans.

P1.20 A coupling is used to connect a 2 in. diameter plastic pipe (1) to a 1.5 in. diameter pipe (2), as shown in Figure P1.20. If the average shear stress in the adhesive must be limited to 400 psi, determine the minimum lengths L_1 and L_2 required for the joint if the applied load P is 5,000 lb.

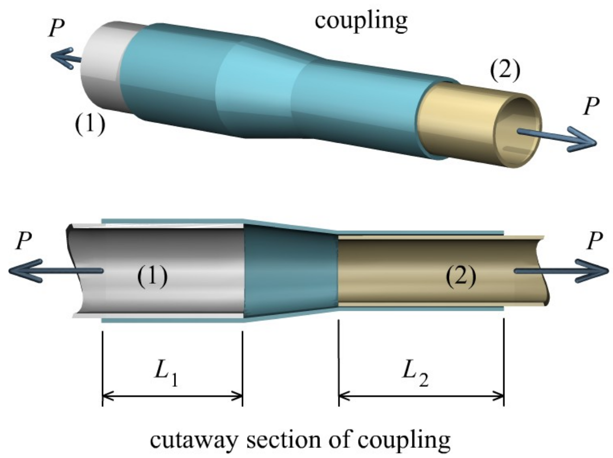


Figure P1.20

Solution

To resist a shear force of 5,000 lb, the area of adhesive required on each pipe is

$$A_V = \frac{V}{\tau_{\text{adhesive}}} = \frac{5{,}000 \text{ lb}}{400 \text{ psi}} = 12.5 \text{ in.}^2$$

Consider the coupling on pipe (1). The adhesive is applied to the circumference of the pipe, and the circumference C_1 of pipe (1) is

$$C_1 = \pi D_1 = \pi(2.0 \text{ in.}) = 6.2832 \text{ in.}$$

The minimum length L_1 is therefore

$$L_1 \geq \frac{A_V}{C_1} = \frac{12.5 \text{ in.}^2}{6.2832 \text{ in.}} = 1.9894 \text{ in.} = \boxed{1.989 \text{ in.}}$$

Ans.

Consider the coupling on pipe (2). The circumference C_2 of pipe (2) is

$$C_2 = \pi D_2 = \pi(1.5 \text{ in.}) = 4.7124 \text{ in.}$$

The minimum length L_2 is therefore

$$L_2 \geq \frac{A_V}{C_2} = \frac{12.5 \text{ in.}^2}{4.7124 \text{ in.}} = 2.6526 \text{ in.} = \boxed{2.65 \text{ in.}}$$

Ans.

P1.21 An axial load P is supported by a short steel column, which has a cross-sectional area of 11,400 mm^2. If the average normal stress in the steel column must not exceed 110 MPa, determine the minimum required dimension "a" so that the bearing stress between the base plate and the concrete slab does not exceed 8 MPa.

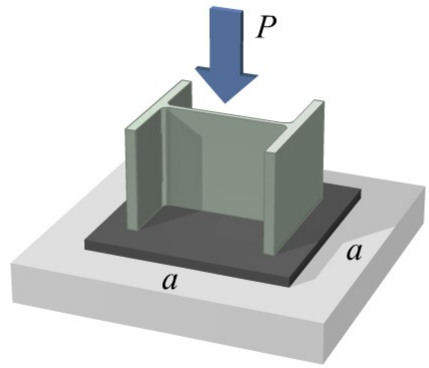


Figure P1.21

Solution

Since the normal stress in the steel column must not exceed 110 MPa, the maximum column load is

$$P_{\text{max}} = \sigma A = (110 \text{ N/mm}^2)(11{,}400 \text{ mm}^2) = 1{,}254{,}000 \text{ N}$$

The maximum column load must be distributed over a large enough area so that the bearing stress between the base plate and the concrete slab does not exceed 8 MPa; therefore, the minimum plate area is

$$A_{\text{min}} = \frac{P}{\sigma_b} = \frac{1{,}254{,}000 \text{ N}}{8 \text{ N/mm}^2} = 156{,}750 \text{ mm}^2$$

Since the plate is square, the minimum plate dimension a must be

$$A_{\text{min}} = 156{,}750 \text{ mm}^2 = a \times a$$

$$\therefore a \geq 395.9167 \text{ mm} = \boxed{396 \text{ mm}}$$

Ans.

P1.22 For the beam shown in Figure P1.22 the allowable bearing stress for the material under the supports at *A* and *B* is $\sigma_b = 800$ psi. Assume $w = 2{,}100$ lb/ft, $P = 4{,}600$ lb, $a = 20$ ft, and $b = 8$ ft. Determine the size of *square* bearing plates required to support the loading shown. Dimension the plates to the nearest ½ in.

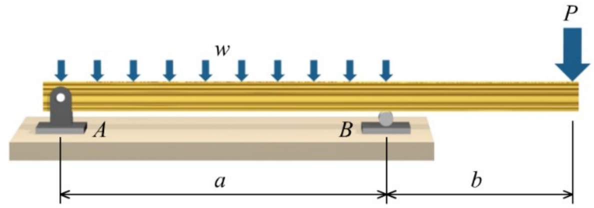
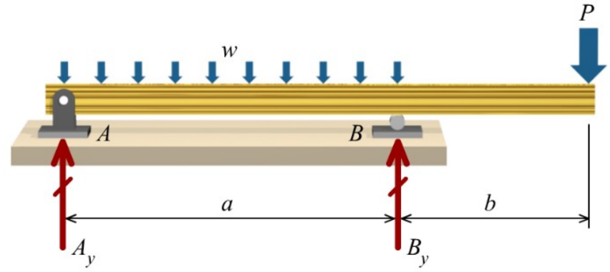


FIGURE P1.22



Solution

Equilibrium: Using the FBD shown, calculate the beam reaction forces.

$$\Sigma M_A = B_y(20\text{ ft}) - (2{,}100\text{ lb/ft})(20\text{ ft})\left(\frac{20\text{ ft}}{2}\right) - (4{,}600\text{ lb})(28\text{ ft}) = 0$$

$$\therefore B_y = 27{,}440\text{ lb}$$

$$\Sigma M_B = -A_y(20\text{ ft}) + (2{,}100\text{ lb/ft})(20\text{ ft})\left(\frac{20\text{ ft}}{2}\right) - (4{,}600\text{ lb})(8\text{ ft}) = 0$$

$$\therefore A_y = 19{,}160\text{ lb}$$

Bearing plate at *A*: The area of the bearing plate required for support *A* is

$$A_A \geq \frac{19{,}160\text{ lb}}{800\text{ psi}} = 23.950\text{ in.}^2$$

Since the plate is to be square, its dimensions must be

$$width \geq \sqrt{23.950\text{ in.}^2} = 4.894\text{ in.} \qquad \boxed{\text{use 5 in.} \times \text{5 in. bearing plate at } A}$$

Ans.

Bearing plate at *B*: The area of the bearing plate required for support *B* is

$$A_B \geq \frac{27{,}440\text{ lb}}{800\text{ psi}} = 34.300\text{ in.}^2$$

Since the plate is to be square, its dimensions must be

$$width \geq \sqrt{34.300\text{ in.}^2} = 5.857\text{ in.} \qquad \boxed{\text{use 6 in.} \times \text{6 in. bearing plate at } B}$$

Ans.

P1.23 The steel pipe column shown in Figure P1.23 has an outside diameter of 8.625 in. and a wall thickness of 0.25 in. The timber beam is 10.75 in wide, and the upper plate has the same width. The load imposed on the column by the timber beam is 80 kips. Determine

(a) The average bearing stress at the surfaces between the pipe column and the upper and lower steel bearing plates.

(b) The length L of the rectangular upper bearing plate if its width is 10.75 in. and the average bearing stress between the steel plate and the wood beam is not to exceed 500 psi.

(c) The dimension "a" of the square lower bearing plate if the average bearing stress between the lower bearing plate and the concrete slab is not to exceed 900 psi.

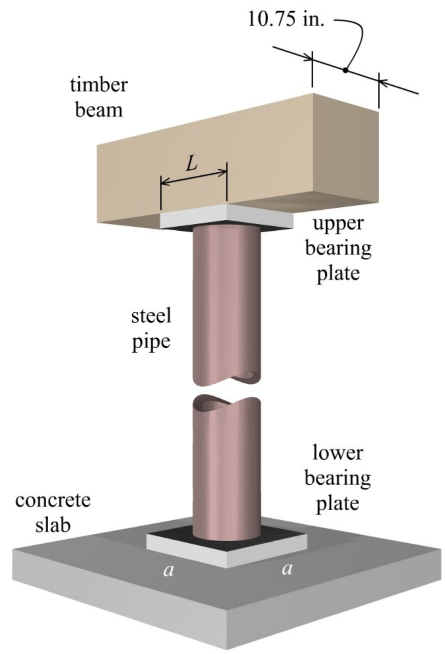


Figure P1.23

Solution

(a) The area of contact between the pipe column and one of the bearing plates is simply the cross-sectional area of the pipe. To calculate the pipe area, we must first calculate the pipe inside diameter d:

$$D = d + 2t \qquad \therefore d = D - 2t = 8.625 \text{ in.} - 2(0.25 \text{ in.}) = 8.125 \text{ in.}$$

The pipe cross-sectional area is

$$A_{\text{pipe}} = \frac{\pi}{4}\left[D^2 - d^2\right] = \frac{\pi}{4}\left[(8.625 \text{ in.})^2 - (8.125 \text{ in.})^2\right] = 6.5777 \text{ in.}^2$$

Therefore, the bearing stress between the pipe and one of the bearing plates is

$$\sigma_b = \frac{P}{A_b} = \frac{80 \text{ kips}}{6.5777 \text{ in.}^2} = 12.1623 \text{ ksi} = \boxed{12.16 \text{ ksi}}$$

Ans.

(b) The bearing stress between the timber beam and the upper bearing plate must not exceed 500 psi (i.e., 0.5 ksi). To support a load of 80 kips, the contact area must be at least

$$A_b \geq \frac{P}{\sigma_b} = \frac{80 \text{ kips}}{0.5 \text{ ksi}} = 160 \text{ in.}^2$$

If the width of the timber beam is 10.75 in., then the length L of the upper bearing plate must be

$$L \geq \frac{A_b}{\text{beam width}} = \frac{160 \text{ in.}^2}{10.75 \text{ in.}} = 14.8837 \text{ in.} = \boxed{14.88 \text{ in.}}$$

(c) The bearing stress between the concrete slab and the lower bearing plate must not exceed 900 psi (i.e., 0.9 ksi). To support the 80-kip pipe load, the contact area must be at least

$$A_b \geq \frac{P}{\sigma_b} = \frac{80 \text{ kips}}{0.9 \text{ ksi}} = 88.8889 \text{ in.}^2$$

Since the lower bearing plate is square, its dimension a must be

$$A_b = a \times a = 88.8889 \text{ in.}^2 \qquad \therefore a \geq 9.4281 \text{ in.} = \boxed{9.43 \text{ in.}}$$

Ans.

P1.24 The rectangular bar is connected to the support bracket with a circular pin, as shown in Figure P1.24. The bar width is $w = 1.75$ in. and the bar thickness is 0.375 in. For an applied load of $P =$ 5,600 lb, determine the average bearing stress produced in the bar by the 0.625-in.-diameter pin.

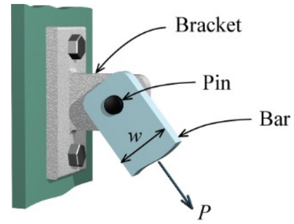


FIGURE P1.24

Solution

The average bearing stress produced in the bar by the pin is based on the **projected area** of the pin. The projected area is equal to the pin diameter times the bar thickness. Therefore, the average bearing stress in the bar is

$$\sigma_b = \frac{5{,}600 \text{ lb}}{(0.625 \text{ in.})(0.375 \text{ in.})} = 23{,}893.33 \text{ psi} = \boxed{23{,}900 \text{ psi}}$$

Ans.

P1.25 A vertical shaft is supported by a thrust collar and bearing plate, as shown in Figure P1.25. The average shear stress in the collar must be limited to 18 ksi. The average bearing stress between the collar and the plate must be limited to 24 ksi. Based on these limits, determine the maximum axial load P that can be applied to the shaft.

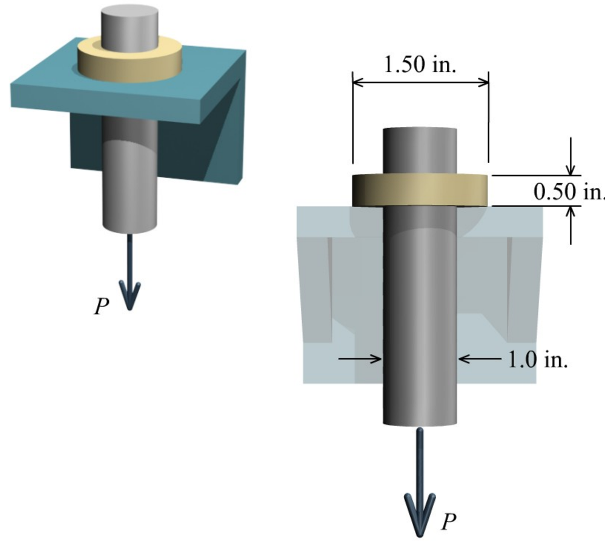


Figure P1.25

Solution

Consider collar shear stress: The area subjected to shear stress in the collar is equal to the product of the shaft circumference and the collar thickness; therefore,

$$A_V = \text{shaft circumference} \times \text{collar thickness} = \pi(1.0 \text{ in.})(0.5 \text{ in.}) = 1.5708 \text{ in.}^2$$

If the shear stress must not exceed 18 ksi, the maximum load that can be supported by the vertical shaft is:

$$P \leq \tau A_V = (18 \text{ ksi})(1.5708 \text{ in.}^2) = 28.2743 \text{ kips}$$

Consider collar bearing stress: We must determine the area of contact between the collar and the plate. The overall cross-sectional area of the collar is

$$A_{\text{collar}} = \frac{\pi}{4}(1.5 \text{ in.})^2 = 1.7671 \text{ in.}^2$$

is reduced by the area taken up by the shaft

$$A_{\text{shaft}} = \frac{\pi}{4}(1.0 \text{ in.})^2 = 0.7854 \text{ in.}^2$$

Therefore, the area of the collar that actually contacts the plate is

$$A_b = A_{\text{collar}} - A_{\text{shaft}} = 1.7671 \text{ in.}^2 - 0.7854 \text{ in.}^2 = 0.9817 \text{ in.}^2$$

If the bearing stress must not exceed 24 ksi, the maximum load that can be supported by the vertical shaft is:

$$P \leq \sigma_b A_b = (24 \text{ ksi})(0.9817 \text{ in.}^2) = 23.5619 \text{ kips}$$

Controlling P: Considering both shear stress in the collar and bearing stress between the collar and the plate, the maximum load that can be supported by the shaft is

$$P_{\max} = \boxed{23.6 \text{ kips}}$$

Ans.

P1.26 Rigid bar *ABC* shown in Figure P1.26 is supported by a pin at bracket *A* and by tie rod (1). Tie rod (1) has a diameter of 5 mm, and it is supported by double-shear pin connections at *B* and *D*. The pin at bracket *A* is a single-shear connection. All pins are 7 mm in diameter. Assume $a = 600$ mm, $b = 300$ mm, $h = 450$ mm, $P = 900$ N, and $\theta = 55°$. Determine the following:
(a) the normal stress in rod (1)
(b) the shear stress in pin *B*
(c) the shear stress in pin *A*

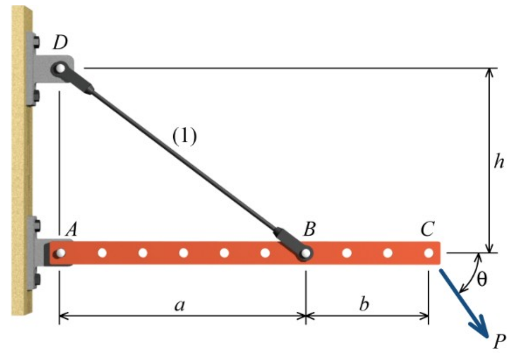
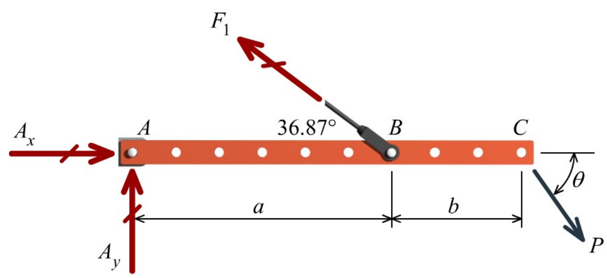


FIGURE P1.26

Solution

Equilibrium: Using the FBD shown, calculate the reaction forces that act on rigid bar *ABC*.



$$\Sigma M_A = F_1 \sin(36.87°)(600 \text{ mm}) - (900 \text{ N})\sin(55°)(900 \text{ mm}) = 0$$
$$\therefore F_1 = 1{,}843.092 \text{ N}$$

$$\Sigma F_x = A_x - (1{,}843.092 \text{ N})\cos(36.87°) + (900 \text{ N})\cos(55°) = 0$$
$$\therefore A_x = 958.255 \text{ N}$$

$$\Sigma F_y = A_y + (1{,}843.092 \text{ N})\sin(36.87°) - (900 \text{ N})\sin(55°) = 0$$
$$\therefore A_y = -368.618 \text{ N}$$

The resultant force at *A* is
$$|A| = \sqrt{(958.255 \text{ N})^2 + (-368.618 \text{ N})^2} = 1{,}026.709 \text{ N}$$

(a) Normal stress in rod (1).

$$A_{\text{rod}} = \frac{\pi}{4}(5 \text{ mm})^2 = 19.635 \text{ mm}^2$$

$$\sigma_{\text{rod}} = \frac{1{,}843.092 \text{ N}}{19.635 \text{ mm}^2} = \boxed{93.9 \text{ MPa}}$$

Ans.

(b) Shear stress in pin *B*. The cross-sectional area of a 7-mm-diameter pin is:

$$A_{\text{pin}} = \frac{\pi}{4}(7 \text{ mm})^2 = 38.485 \text{ mm}^2$$

Pin *B* is a double shear connection; therefore, its average shear stress is

$$\tau_{\text{pin } B} = \frac{1{,}843.092 \text{ N}}{2(38.485 \text{ mm}^2)} = \boxed{23.9 \text{ MPa}}$$

Ans.

(c) Shear stress in pin *A*.
Pin *A* is a single shear connection; therefore, its average shear stress is

$$\tau_{\text{pin } A} = \frac{1{,}026.709 \text{ N}}{38.485 \text{ mm}^2} = \boxed{26.7 \text{ MPa}}$$

Ans.

P1.27 The bell crank shown in Figure P1.27 is in equilibrium for the forces acting in rods (1) and (2). The bell crank is supported by a 10-mm-diameter pin at B that acts in single shear. The thickness of the bell crank is 5 mm. Assume $a = 65$ mm, $b = 150$ mm, $F_1 = 1{,}100$ N, and $\theta = 50°$. Determine the following:
(a) the shear stress in pin B
(b) the bearing stress in the bell crank at B

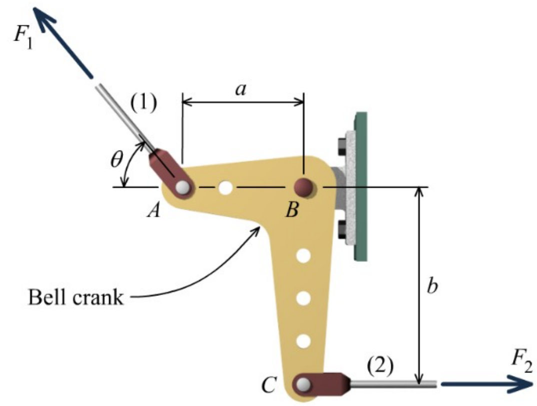
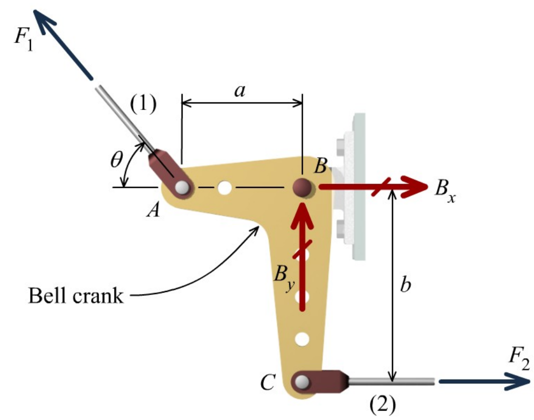


FIGURE P1.27

Solution

Equilibrium: Using the FBD shown, calculate the reaction forces that act on the bell crank.



$$\Sigma M_B = -(1{,}100\text{ N})\sin(50°)(65\text{ mm}) + F_2(150\text{ mm}) = 0$$
$$\therefore F_2 = 365.148\text{ N}$$

$$\Sigma F_x = B_x - (1{,}100\text{ N})\cos(50°) + 365.148\text{ N} = 0$$
$$\therefore B_x = 341.919\text{ N}$$

$$\Sigma F_y = B_y + (1{,}100\text{ N})\sin(50°) = 0$$
$$\therefore B_y = -842.649\text{ N}$$

The resultant force at B is
$$|B| = \sqrt{(341.919\text{ N})^2 + (-842.649\text{ N})^2} = 909.376\text{ N}$$

(a) Shear stress in pin *B*. The cross-sectional area of the 10-mm-diameter pin is:
$$A_{\text{pin}} = \frac{\pi}{4}(10\text{ mm})^2 = 78.540\text{ mm}^2$$
Pin B is a single shear connection; therefore, its average shear stress is
$$\tau_{\text{pin }B} = \frac{909.376\text{ N}}{78.540\text{ mm}^2} = \boxed{11.58\text{ MPa}}$$
Ans.

(b) Bearing stress in the bell crank at *B*. The average bearing stress produced in the bell crank by the pin is based on the **projected area** of the pin. The projected area is equal to the pin diameter times the bell crank thickness. Therefore, the average bearing stress in the bell crank is
$$\sigma_b = \frac{909.376\text{ N}}{(10\text{ mm})(5\text{ mm})} = \boxed{18.19\text{ MPa}}$$
Ans.

P1.28 The bell-crank mechanism shown in Figure P1.28 is in equilibrium for an applied load of $P = 7$ kN applied at A. Assume $a = 200$ mm, $b = 150$ mm, and $\theta = 65°$. Determine the minimum diameter d required for pin B for each of the following conditions:

(a) The average shear stress in the pin may not exceed 40 MPa.
(b) The bearing stress in the bell crank may not exceed 100 MPa.
(c) The bearing stress in the support bracket may not exceed 165 MPa.

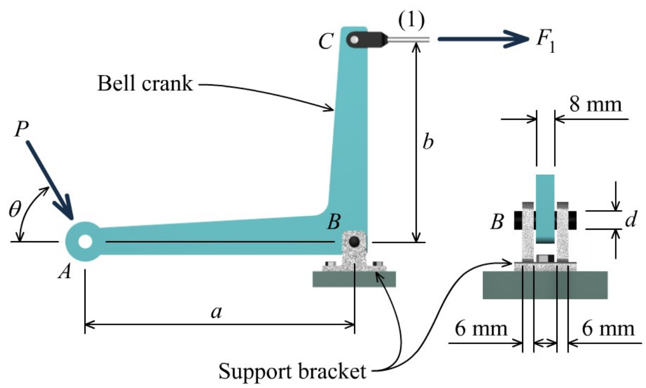


FIGURE P1.28

Solution

Equilibrium: Using the FBD shown, calculate the reaction forces that act on the bell crank.

$$\Sigma M_B = (7{,}000 \text{ N})\sin(65°)(200 \text{ mm}) - F_1(150 \text{ mm}) = 0$$

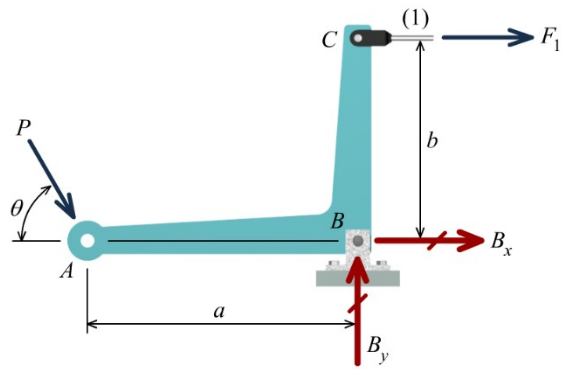
$$\therefore F_1 = 8{,}458.873 \text{ N}$$

$$\Sigma F_x = B_x + (7{,}000 \text{ N})\cos(65°) + 8{,}458.873 \text{ N} = 0$$

$$\therefore B_x = -11{,}417.201 \text{ N}$$

$$\Sigma F_y = B_y - (7{,}000 \text{ N})\sin(65°) = 0$$

$$\therefore B_y = 6{,}344.155 \text{ N}$$



The resultant force at B is

$$|B| = \sqrt{(-11{,}417.201 \text{ N})^2 + (6{,}344.155 \text{ N})^2} = 13{,}061.423 \text{ N}$$

(a) The average shear stress in the pin may not exceed 40 MPa. The shear area required for the pin at B is

$$A_V \geq \frac{13{,}061.423 \text{ N}}{40 \text{ N/mm}^2} = 326.536 \text{ mm}^2$$

Since the pin at B is supported in a double shear connection, the required cross-sectional area for the pin is

$$A_{\text{pin}} = \frac{A_V}{2} = 163.268 \text{ mm}^2$$

and therefore, the pin must have a diameter of

$$d \geq \sqrt{\frac{4}{\pi}(163.268 \text{ mm}^2)} = \boxed{14.42 \text{ mm}}$$

Ans.

(b) The bearing stress in the bell crank may not exceed 100 MPa. The projected area of pin B on the bell crank must equal or exceed

$$A_b \geq \frac{13{,}061.423 \text{ N}}{100 \text{ N/mm}^2} = 130.614 \text{ mm}^2$$

The bell crank thickness is 8 mm; therefore, the projected area of the pin is $A_b = (8 \text{ mm})d$. Calculate the required pin diameter d:

$$d \geq \frac{130.614 \text{ mm}^2}{8 \text{ mm}} = \boxed{16.33 \text{ mm}}$$

Ans.

(c) The bearing stress in the support bracket may not exceed 165 MPa. The pin at B bears on two 6-mm-thick support brackets. Thus, the minimum pin diameter required to satisfy the bearing stress limit on the support bracket is

$$A_b \geq \frac{13{,}061.423 \text{ N}}{165 \text{ N/mm}^2} = 79.160 \text{ mm}^2$$

$$d \geq \frac{79.160 \text{ mm}^2}{2(6 \text{ mm})} = \boxed{6.60 \text{ mm}}$$

Ans.

P1.29 An axial load P is applied to the rectangular bar shown in Figure P1.29. The cross-sectional area of the bar is 300 mm^2. Determine the normal stress perpendicular to plane AB and the shear stress parallel to plane AB if the bar is subjected to an axial load of $P = 25$ kN.

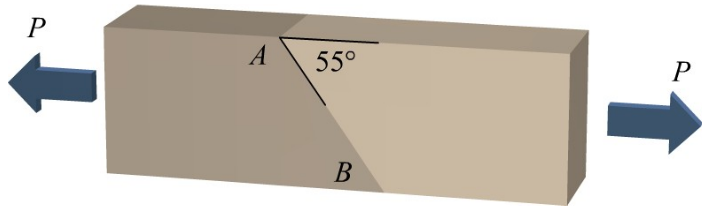


Figure P1.29

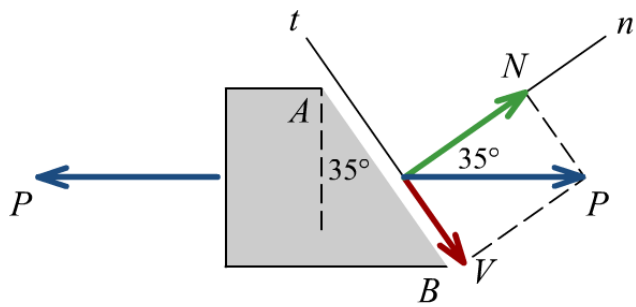
Solution

The angle θ for the inclined plane is 35°. The normal force N perpendicular to plane AB is found from

$$N = P\cos\theta = (25\text{ kN})\cos 35° = 20.4788\text{ kN}$$

and the shear force V parallel to plane AB is

$$V = P\sin\theta = (25\text{ kN})\sin 35° = 14.3394\text{ kN}$$



The cross-sectional area of the bar is 300 mm^2, but the area along inclined plane AB is

$$A_n = \frac{A}{\cos\theta} = \frac{300\text{ mm}^2}{\cos 35°} = 366.2324\text{ mm}^2$$

The normal stress σ_n perpendicular to plane AB is

$$\sigma_n = \frac{N}{A_n} = \frac{(20.4788\text{ kN})(1{,}000\text{ N/kN})}{366.2324\text{ mm}^2} = 55.9175\text{ MPa} = \boxed{55.9\text{ MPa}}$$

Ans.

The shear stress τ_{nt} parallel to plane AB is

$$\tau_{nt} = \frac{V}{A_n} = \frac{(14.3394\text{ kN})(1{,}000\text{ N/kN})}{366.2324\text{ mm}^2} = 39.1539\text{ MPa} = \boxed{39.2\text{ MPa}}$$

Ans.

P1.32 Specifications for the 6 in. × 6 in. square post shown in Figure P1.32 require that the normal and shear stresses on plane *AB* not exceed 800 psi and 400 psi, respectively. Determine the maximum load *P* that can be applied without exceeding the specifications.

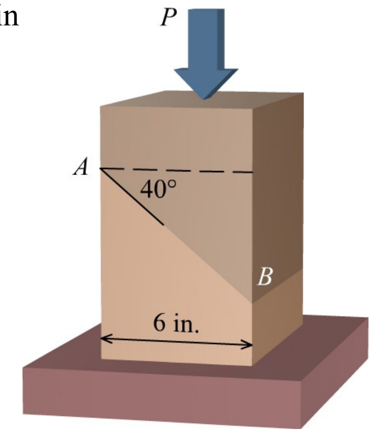


Figure P1.32

Solution

The general equations for normal and shear stresses on an inclined plane in terms of the angle θ are

$$\sigma_n = \frac{P}{2A}(1+\cos 2\theta) \tag{a}$$

and

$$\tau_{nt} = \frac{P}{2A}\sin 2\theta \tag{b}$$

The cross-sectional area of the square post is $A = (6 \text{ in.})^2 = 36 \text{ in.}^2$, and the angle θ for plane *AB* is 40°.

The normal stress on plane *AB* is limited to 800 psi; therefore, the maximum load *P* that can be supported by the square post is found from Eq. (a):

$$P \leq \frac{2A\sigma_n}{1+\cos 2\theta} = \frac{2(36 \text{ in.}^2)(800 \text{ psi})}{1+\cos 2(40°)} = 49{,}078 \text{ lb}$$

The shear stress on plane *AB* is limited to 400 psi. From Eq. (b), the maximum load *P* based the shear stress limit is

$$P \leq \frac{2A\tau_{nt}}{\sin 2\theta} = \frac{2(36 \text{ in.}^2)(400 \text{ psi})}{\sin 2(40°)} = 29{,}244 \text{ lb}$$

Thus, the maximum load that can be supported by the post is

$$P_{\max} = 29{,}200 \text{ lb} = \boxed{29.2 \text{ kips}}$$

Ans.

P1.35 In Figure P1.35, a rectangular bar having width $w = 2.50$ in. and thickness t is subjected to a tension load of $P = 85$ kips. The normal and shear stresses on plane AB must not exceed 16 ksi and 8 ksi, respectively. Determine the minimum bar thickness t required for the bar.

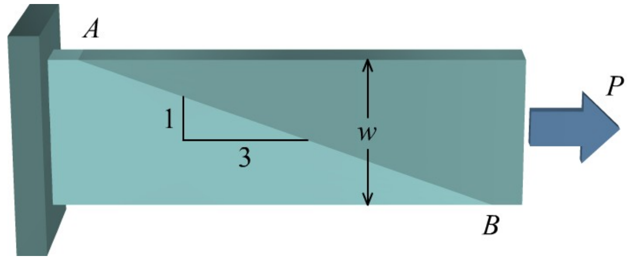


Figure P1.35

Solution

The general equations for normal and shear stresses on an inclined plane in terms of the angle θ are

$$\sigma_n = \frac{P}{2A}(1+\cos 2\theta) \tag{a}$$

and

$$\tau_{nt} = \frac{P}{2A}\sin 2\theta \tag{b}$$

The angle θ for inclined plane AB is calculated from

$$\tan\theta = \frac{3}{1} = 3 \qquad \therefore \theta = 71.5651°$$

The normal stress on plane AB is limited to 16 ksi; therefore, the minimum cross-sectional area A required to support $P = 85$ kips can be found from Eq. (a):

$$A \geq \frac{P}{2\sigma_n}(1+\cos 2\theta) = \frac{85 \text{ kips}}{2(16 \text{ ksi})}(1+\cos 2(71.5651°)) = 0.5312 \text{ in.}^2$$

The shear stress on plane AB is limited to 8 ksi; therefore, the minimum cross-sectional area A required to support $P = 85$ kips can be found from Eq. (b):

$$A \geq \frac{P}{2\tau_{nt}}\sin 2\theta = \frac{85 \text{ kips}}{2(8 \text{ ksi})}\sin 2(71.5651°) = 3.1875 \text{ in.}^2$$

To satisfy both the normal and shear stress requirements, the cross-sectional area must be at least $A_{\text{min}} = 3.1875$ in.^{2}. Since the bar width is 2.50 in., the minimum bar thickness t must be

$$t_{\text{min}} = \frac{3.1875 \text{ in.}^2}{2.50 \text{ in.}} = 1.2750 \text{ in.} = \boxed{1.275 \text{ in.}}$$

Ans.

P1.36 The rectangular bar has a width of w = 3.00 in. and a thickness of t = 2.00 in. The normal stress on plane AB of the rectangular block shown in Figure P1.36 is 6 ksi (C) when the load P is applied. Determine:

(a) the magnitude of load P.
(b) the shear stress on plane AB.
(c) the maximum normal and shear stresses in the block at any possible orientation.

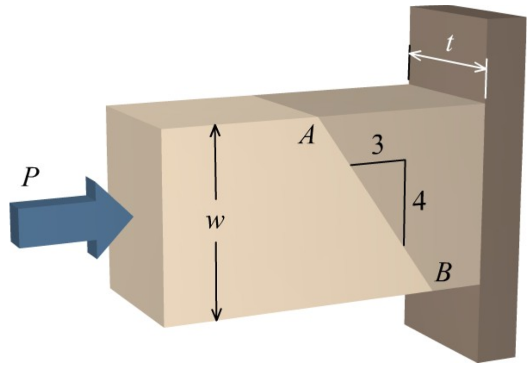


Figure P1.36

Solution

The general equation for normal stress on an inclined plane in terms of the angle θ is

$$\sigma_n = \frac{P}{2A}(1+\cos 2\theta) \qquad \text{(a)}$$

and the angle θ for inclined plane AB is

$$\tan\theta = \frac{3}{4} = 0.75 \qquad \therefore \theta = 36.8699°$$

The cross-sectional area of the rectangular bar is A = (3.00 in.)(2.00 in.) = 6.00 in.^{2}.

(a) Since the normal stress on plane AB is given as 6 ksi, the magnitude of load P can be calculated from Eq. (a):

$$P = \frac{2A\sigma_n}{1+\cos 2\theta} = \frac{2(6.0 \text{ in.}^2)(6 \text{ ksi})}{1+\cos 2(36.8699°)} = 56.25 \text{ kips} = \boxed{56.3 \text{ kips}}$$

Ans.

(b) The general equation for shear stress on an inclined plane in terms of the angle θ is

$$\tau_{nt} = \frac{P}{2A}\sin 2\theta$$

therefore, the shear stress on plane AB is

$$\tau_{nt} = \frac{56.25 \text{ kips}}{2(6.00 \text{ in.}^2)}\sin 2(36.8699°) = \boxed{4.50 \text{ ksi}}$$

Ans.

(c) The maximum normal stress at any possible orientation is

$$\sigma_{\max} = \frac{P}{A} = \frac{56.25 \text{ kips}}{6.00 \text{ in.}^2} = 9.3750 \text{ ksi} = \boxed{9.38 \text{ ksi}}$$

Ans.

and the maximum shear stress at any possible orientation in the block is

$$\tau_{\max} = \frac{P}{2A} = \frac{56.25 \text{ kips}}{2(6.00 \text{ in.}^2)} = 4.6875 \text{ ksi} = \boxed{4.69 \text{ ksi}}$$

Ans.