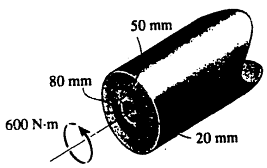
5–1 The tube is subjected to a torque of 600 N · m. Determine the amount of this torque that is resisted by the shaded section. Solve the problem two ways: (*a*) by using the torsion formula; (*b*) by finding the resultant of the shear-stress distribution.



a)

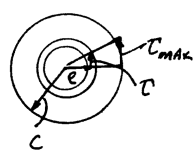
$$\tau_{max} = \frac{Tc}{J} = \frac{600\,(0.08)}{\frac{\pi}{2}(0.08^4 - 0.02^4)} = 748964 \text{ Pa}$$

$$\tau_{max} = \frac{T'c}{J'}$$

$$748\,964 = \frac{T'\,(0.08)}{\frac{\pi}{2}(0.08^4 - 0.05^4)}$$

$T' = 510$ N · m **Ans**

b)



$$\tau = \tau_{max}\left(\frac{\rho}{c}\right) \qquad dA = 2\pi\rho\, d\rho$$

$$dT' = \rho\tau\, dA = \rho\tau_{max}\left(\frac{\rho}{c}\right)2\pi\rho\, d\rho$$

$$T' = \frac{2\pi\,\tau_{max}}{c}\int \rho^3\, d\rho = \frac{2\pi\,(748964)}{0.08}\,\frac{\rho^4}{4}\Bigg|_{0.05}^{0.08}$$

$= 510$ N · m **Ans**

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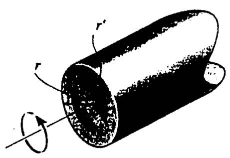
5–2 The solid shaft of radius r is subjected to a torque **T**. Determine the radius r' of the inner core of the shaft that resists one-half of the applied torque ($T/2$). Solve the problem two ways: (a) by using the torsion formula, (b) by finding the resultant of the shear-stress distribution.



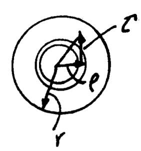
a) $\tau_{max} = \dfrac{Tc}{J} = \dfrac{Tr}{\frac{\pi}{2}r^4} = \dfrac{2T}{\pi r^3}$

$\tau = \dfrac{(\frac{T}{2})r'}{\frac{\pi}{2}(r')^4} = \dfrac{T}{\pi(r')^3}$

Since $\tau = \dfrac{r'}{r}\tau_{max}$; $\quad \dfrac{T}{\pi(r')^3} = \dfrac{r'}{r}(\dfrac{2T}{\pi r^3})$

$r' = \dfrac{r}{2^{\frac{1}{4}}} = 0.841\, r$ **Ans**

b) $\int_0^{\frac{T}{2}} dT = 2\pi\int_0^{r'} \tau\rho^2\, d\rho$



$\int_0^{\frac{T}{2}} dT = 2\pi\int_0^{r'} \dfrac{\rho}{r}\tau_{max}\rho^2\, d\rho$

$\int_0^{\frac{T}{2}} dT = 2\pi\int_0^{r'} \dfrac{\rho}{r}(\dfrac{2T}{\pi r^3})\rho^2\, d\rho$

$\dfrac{T}{2} = \dfrac{4T}{r^4}\int_0^{r'} \rho^3\, d\rho$

$r' = \dfrac{r}{2^{\frac{1}{4}}} = 0.841r$ **Ans**

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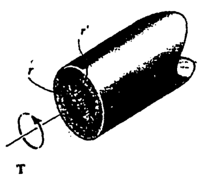
5-3. The solid shaft of radius r is subjected to a torque **T**. Determine the radius r' of the inner core of the shaft that resists one-quarter of the applied torque ($T/4$). Solve the problem two ways: (a) by using the torsion formula, (b) by finding the resultant of the shear-stress distribution.



a) $\tau_{max} = \frac{Tc}{J} = \frac{T(r)}{\frac{\pi}{2}(r^4)} = \frac{2T}{\pi r^3}$

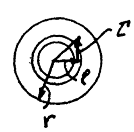
Since $\tau = \frac{r'}{r}\tau_{max} = \frac{2Tr'}{\pi r^4}$

$\tau' = \frac{T'c'}{J'}$; $\quad \frac{2Tr'}{\pi r^4} = \frac{(\frac{T}{4})r'}{\frac{\pi}{2}(r')^4}$

$r' = \frac{r}{4^{\frac{1}{4}}} = 0.707\,r$ **Ans**

b) $\tau = \frac{\rho}{c}\tau_{max} = \frac{\rho}{r}(\frac{2T}{\pi r^3}) = \frac{2T}{\pi r^4}\rho$; $\quad dA = 2\pi\rho\, d\rho$

$dT = \rho\tau\, dA = \rho[\frac{2T}{\pi r^4}\rho](2\pi\rho\, d\rho) = \frac{4T}{r^4}\rho^3 d\rho$



$\int_0^{\frac{T}{4}} dT = \frac{4T}{r^4}\int^{r'} \rho^3 d\rho$

$\frac{T}{4} = \frac{4T}{r^4}\frac{\rho^4}{4}\Big|_0^{r'}$; $\quad \frac{1}{4} = \frac{(r')^4}{r^4}$

$r' = 0.707\,r$ **Ans**

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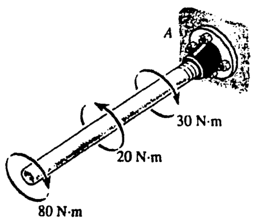
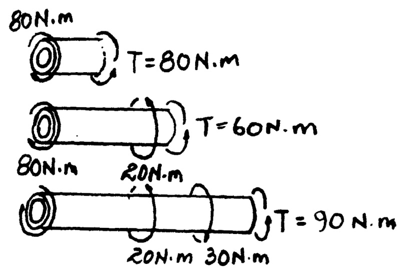
•5–4 The copper pipe has an outer diameter of 40 mm and an inner diameter of 37 mm. If it is tightly secured to the wall at A and three torques are applied to it as shown, determine the absolute maximum shear stress developed in the pipe.





$$\tau_{max} = \frac{T_{max}\,c}{J} = \frac{90(0.02)}{\frac{\pi}{2}(0.02^4 - 0.0185^4)}$$

$$= 26.7 \text{ MPa} \qquad \textbf{Ans}$$

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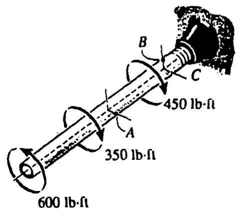
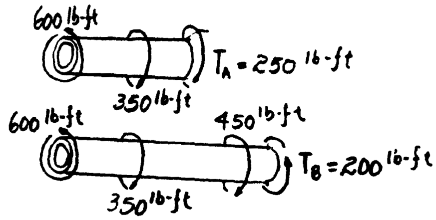
5–5 The copper pipe has an outer diameter of 2.50 in. and an inner diameter of 2.30 in. If it is tightly secured to the wall at C and three torques are applied to it as shown, determine the shear stress developed at points A and B. These points lie on the pipe's outer surface. Sketch the shear stress on volume elements located at A and B.





$$\tau_A = \frac{Tc}{J} = \frac{250(12)(1.25)}{\frac{\pi}{2}(1.25^4 - 1.15^4)} = 3.45 \text{ ksi} \qquad \textbf{Ans}$$

$$\tau_B = \frac{Tc}{J} = \frac{200(12)(1.25)}{\frac{\pi}{2}(1.25^4 - 1.15^4)} = 2.76 \text{ ksi} \qquad \textbf{Ans}$$

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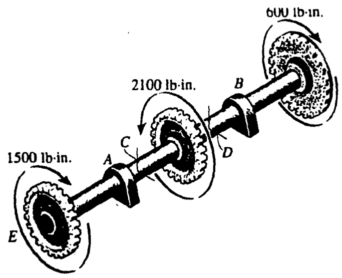
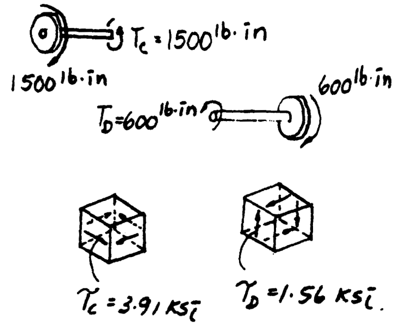
5–6 The solid 1.25-in.-diameter shaft is used to transmit the torques applied to the gears. If it is supported by smooth bearings at *A* and *B*, which do not resist torque, determine the shear stress developed in the shaft at points *C* and *D*. Indicate the shear stress on volume elements located at these points.





$$\tau_C = \frac{Tc}{J} = \frac{1500(0.625)}{\frac{\pi}{2}(0.625^4)} = 3.91\text{ ksi} \qquad \textbf{Ans}$$

$$\tau_D = \frac{Tc}{J} = \frac{600(0.625)}{\frac{\pi}{2}(0.625^4)} = 1.56\text{ ksi} \qquad \textbf{Ans}$$

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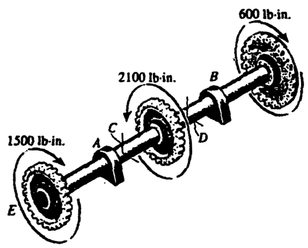
5-7. The shaft has an outer diameter of 1.25 in. and an inner diameter of 1 in. If it is subjected to the applied torques as shown, determine the absolute maximum shear stress developed in the shaft. The smooth bearings at A and B do not resist torque.



$T_{max} = 1500 \text{ lb} \cdot \text{in.}$

$$\tau_{max} = \frac{Tc}{J} = \frac{1500(0.625)}{\frac{\pi}{2}\left[(0.625)^4 - (0.5)^4\right]} = 6.62 \text{ ksi} \qquad \textbf{Ans}$$

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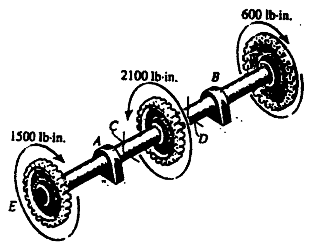
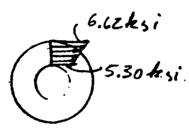
***5-8.** The shaft has an outer diameter of 1.25 in. and an inner diameter of 1 in. If it is subjected to the applied torques as shown, plot the shear-stress distribution acting along a radial line lying within region *EA* of the shaft. The smooth bearings at *A* and *B* do not resist torque.



$T = 1500\ \text{lb}\cdot\text{in.}$

$$\tau_{max} = \frac{Tc}{J} = \frac{1500(0.625)}{\frac{\pi}{2}\left[(0.625)^4 - (0.5)^4\right]} = 6.62\ \text{ksi}$$

$$\tau_2 = \frac{T\rho}{J} = \frac{1500(0.5)}{\frac{\pi}{2}\left[(0.625)^4 - (0.5)^4\right]} = 5.30\ \text{ksi}$$



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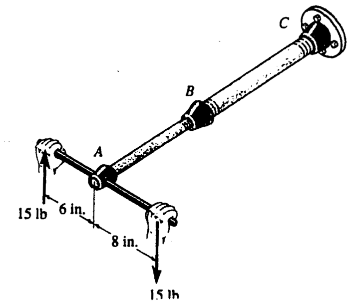
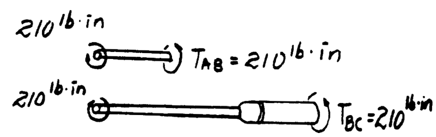
5–9 The assembly consists of two sections of galvanized steel pipe connected together using a reducing coupling at *B*. The smaller pipe has an outer diameter of 0.75 in. and an inner diameter of 0.68 in., whereas the larger pipe has an outer diameter of 1 in. and an inner diameter of 0.86 in. If the pipe is tightly secured to the wall at *C*, determine the maximum shear stress developed in each section of the pipe when the couple shown is applied to the handles of the wrench.





$$\tau_{AB} = \frac{Tc}{J} = \frac{210(0.375)}{\frac{\pi}{2}(0.375^4 - 0.34^4)} = 7.82\text{ ksi} \qquad \textbf{Ans}$$

$$\tau_{BC} = \frac{Tc}{J} = \frac{210(0.5)}{\frac{\pi}{2}(0.5^4 - 0.43^4)} = 2.36\text{ ksi} \qquad \textbf{Ans}$$

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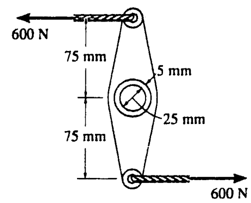
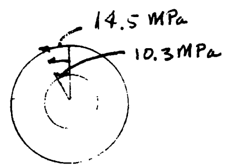
5–10 The link acts as part of the elevator control for a small airplane. If the attached aluminum tube has an inner diameter of 25 mm and a wall thickness of 5 mm, determine the maximum shear stress in the tube when the cable force of 600 N is applied to the cables. Also, sketch the shear-stress distribution over the cross section.



$T = 600(0.15) = 90\ \text{N}\cdot\text{m}$

$$\tau_{max} = \frac{Tc}{J} = \frac{90(0.0175)}{\frac{\pi}{2}[(0.0175)^4 - (0.0125)^4]} = 14.5\ \text{MPa} \qquad \textbf{Ans}$$

$$\tau_i = \frac{T\rho}{J} = \frac{90(0.0125)}{\frac{\pi}{2}[(0.0175)^4 - (0.0125)^4]} = 10.3\ \text{MPa}$$



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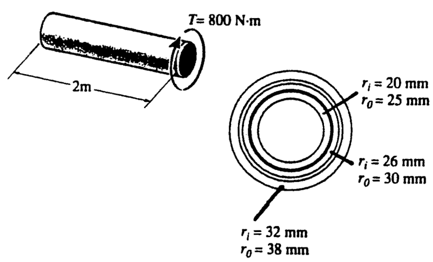
5–11 The shaft consists of three concentric tubes, each made from the same material and having the inner and outer radii shown. If a torque of $T = 800\ \text{N}\cdot\text{m}$ is applied to the rigid disk fixed to its end, determine the maximum shear stress in the shaft.



$$J = \frac{\pi}{2}((0.038)^4 - (0.032)^4) + \frac{\pi}{2}((0.030)^4 - (0.026)^4) + \frac{\pi}{2}((0.025)^4 - (0.020)^4)$$

$$J = 2.545(10^{-6})\text{m}^4$$

$$\tau_{max} = \frac{Tc}{J} = \frac{800(0.038)}{2.545(10^{-6})} = 11.9\ \text{MPa} \qquad \textbf{Ans}$$

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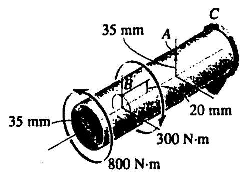
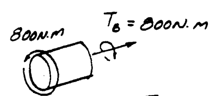
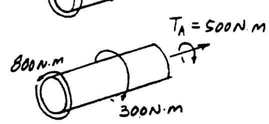
***5–12** The solid shaft is fixed to the support at C and subjected to the torsional loadings shown. Determine the shear stress at points A and B and sketch the shear stress on volume elements located at these points.

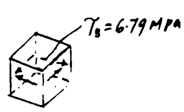


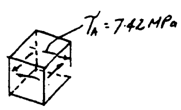
$$\tau_B = \frac{T_B\rho}{J} = \frac{800(0.02)}{\frac{\pi}{2}(0.035^4)} = 6.79 \text{ MPa} \qquad \textbf{Ans}$$



$$\tau_A = \frac{T_A\, c}{J} = \frac{500(0.035)}{\frac{\pi}{2}(0.035^4)} = 7.42 \text{ MPa} \qquad \textbf{Ans}$$







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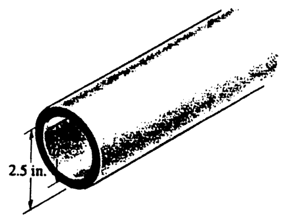
5-13. A steel tube having an outer diameter of 2.5 in. is used to transmit 350 hp when turning at 27 rev/min. Determine the inner diameter d of the tube to the nearest $\frac{1}{8}$ in. if the allowable shear stress is $\tau_{allow} = 10$ ksi.



$$\omega = \frac{27(2\pi)}{60} = 2.8274 \text{ rad/s}$$

$$P = T\omega$$

$$350(550) = T(2.8274)$$

$$T = 68\ 082.9 \text{ lb}\cdot\text{ft}$$

$$\tau_{max} = \tau_{allow} = \frac{Tc}{J}$$

$$10(10^3) = \frac{68\ 082.9\ (12)(1.25)}{\frac{\pi}{2}(1.25^4 - c_i^4)}$$

$$c_i = 1.2416 \text{ in.}$$

$$d = 2.48 \text{ in.}$$

Use $d = 2\frac{3}{8}$ in. **Ans**

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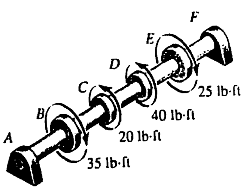
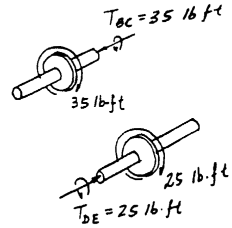
5–14 The solid shaft has a diameter of 0.75 in. If it is subjected to the torques shown, determine the maximum shear stress developed in regions BC and DE of the shaft. The bearings at A and F allow free rotation of the shaft.





$$(\tau_{BC})_{\max} = \frac{T_{BC}\,c}{J} = \frac{35(12)(0.375)}{\frac{\pi}{2}(0.375)^4} = 5070\text{ psi} = 5.07\text{ ksi}$$ **Ans**

$$(\tau_{DE})_{\max} = \frac{T_{DE}\,c}{J} = \frac{25(12)(0.375)}{\frac{\pi}{2}(0.375)^4} = 3621\text{ psi} = 3.62\text{ ksi}$$ **Ans**

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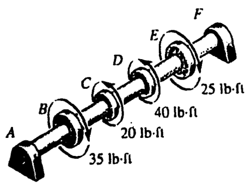
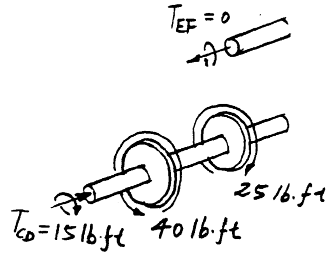
5–15 The solid shaft has a diameter of 0.75 in. If it is subjected to the torques shown, determine the maximum shear stress developed in regions *CD* and *EF* of the shaft. The bearings at *A* and *F* allow free rotation of the shaft.





$$(\tau_{EF})_{max} = \frac{T_{EF}\,c}{J} = 0 \qquad \textbf{Ans}$$

$$(\tau_{CD})_{max} = \frac{T_{CD}\,c}{J} = \frac{15(12)(0.375)}{\frac{\pi}{2}(0.375)^4}$$

$$= 2173 \text{ psi} = 2.17 \text{ ksi} \qquad \textbf{Ans}$$

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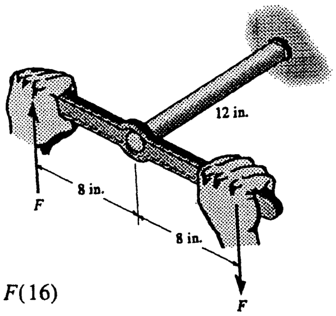
***5–16** The steel shaft has a diameter of 1 in. and is screwed into the wall using a wrench. Determine the largest couple forces F that can be applied to the shaft without causing the steel to yield. $\tau_Y = 8$ ksi.



$T = F(16)$

$\tau_{max} = \frac{Tc}{J}; \quad 8(10^3) = \frac{F(16)(0.5)}{\frac{\pi}{2}(0.5)^4}$

$F = 98.2$ lb **Ans**

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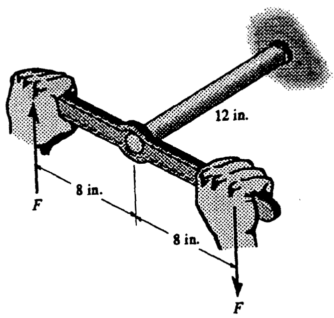
5–17 The steel shaft has a diameter of 1 in. and is screwed into the wall using a wrench. Determine the maximum shear stress in the shaft if the couple forces have a magnitude of $F = 30$ lb.



$$T = 30(16) = 480 \text{ lb} \cdot \text{in.}$$

$$\tau_{max} = \frac{Tc}{J} = \frac{480(0.5)}{\frac{\pi}{2}(0.5)^4} = 2.44 \text{ ksi} \qquad \textbf{Ans}$$

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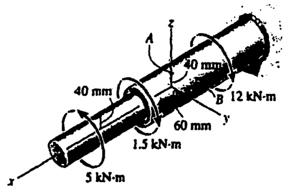
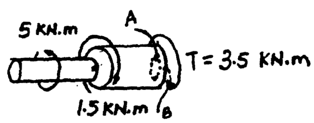
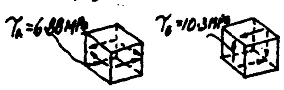
5–18. The steel shaft is subjected to the torsional loading shown. Determine the shear stress developed at points A and B and sketch the shear stress on volume elements located at these points. The shaft where A and B are located has an outer radius of 60 mm.



$$\tau_A = \frac{T\rho}{J} = \frac{3.5(10^3)(0.04)}{\frac{\pi}{2}(0.06)^4} = 6.88 \text{ MPa} \qquad \textbf{Ans}$$



$$\tau_B = \frac{Tc}{J} = \frac{3.5(10^3)(0.06)}{\frac{\pi}{2}(0.06)^4} = 10.3 \text{ MPa} \qquad \textbf{Ans}$$



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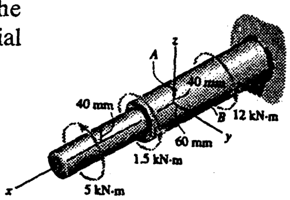
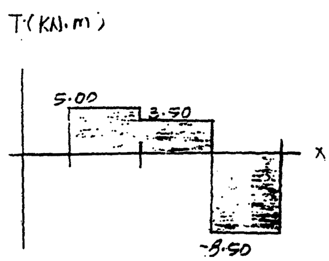
5–19. The steel shaft is subjected to the torsional loading shown. Determine the absolute maximum shear stress in the shaft and sketch the shear-stress distribution along a radial line where it is maximum.



Maximum torque is 8.5 kN · m; however, two sections of the shaft should be considered since J is different.

$$\tau_{max} = \frac{Tc}{J} = \frac{5(10^3)(0.04)}{\frac{\pi}{2}(0.04)^4} = 49.7 \text{ MPa}$$

$$\tau_{max} = \frac{Tc}{J} = \frac{8.5(10^3)(0.06)}{\frac{\pi}{2}(0.06)^4} = 25.1 \text{ MPa}$$



$\tau_{max}^{abs} = 49.7$ MPa **Ans**

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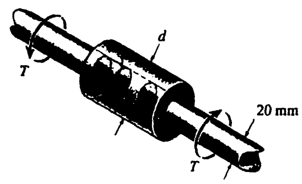
***5–20** The 20-mm-diameter steel shafts are connected using a brass coupling. If the yield point for the steel is $(\tau_Y)_{st} = 100$ MPa and for the brass $(\tau_Y)_{br} = 250$ MPa, determine the required outer diameter d of the coupling so that the steel and brass begin to yield at the same time when the assembly is subjected to a torque **T**. Assume that the coupling has an inner diameter of 20 mm.



For the steel shaft :

$$\tau_{max} = \frac{Tc}{J}; \qquad 100(10^6) = \frac{T(0.01)}{\frac{\pi}{2}(0.01)^4}; \qquad T = 157.08 \text{ N}\cdot\text{m}$$

For the brass coupling :

$$\tau_{max} = \frac{Tc}{J}; \qquad 250(10^6) = \frac{157.08(\frac{d}{2})}{\frac{\pi}{2}[(\frac{d}{2})^4 - (0.01)^4]}$$

$$24.5437(10^6)(d^4) - 78.54d - 3.9270 = 0$$

Solving,

$d = 0.0219\text{ m} = 21.9\text{ mm}$ **Ans**

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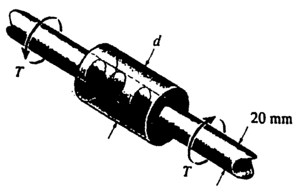
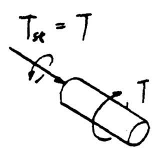
5–21 The 20-mm-diameter steel shafts are connected using a brass coupling. If the yield point for the steel is $(\tau_Y)_{st} = 100$ MPa, determine the applied torque **T** necessary to cause the steel to yield. If $d = 40$ mm, determine the maximum shear stress in the brass. The coupling has an inner diameter of 20 mm.



For the steel shaft :

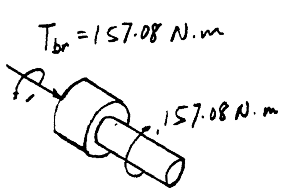
$$(\tau_Y)_{st} = \frac{Tc}{J}; \qquad 100(10^6) = \frac{T(0.01)}{\frac{\pi}{2}(0.01)^4}$$



$T = 157.08\ \text{N}\cdot\text{m} = 157\ \text{N}\cdot\text{m}$ **Ans**

For the brass shaft :

$$(\tau_{max})_{br} = \frac{Tc}{J} = \frac{157.08(0.02)}{\frac{\pi}{2}[0.02^4 - 0.01^4]} = 13.3\ \text{MPa}$$ **Ans**



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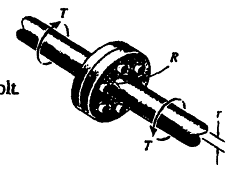
5-22. The coupling is used to connect the two shafts together. Assuming that the shear stress in the bolts is *uniform*, determine the number of bolts necessary to make the maximum shear stress in the shaft equal to the shear stress in the bolts. Each bolt has a diameter d.



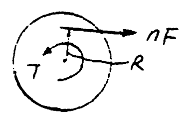
n is the number of bolts and F is the shear force in each bolt.

$$T - nFR = 0; \qquad F = \frac{T}{nR}$$

$$\tau_{avg} = \frac{F}{A} = \frac{\frac{T}{nR}}{(\frac{\pi}{4})d^2} = \frac{4T}{nR\pi d^2}$$

Maximum shear stress for the shaft :

$$\tau_{max} = \frac{Tc}{J} = \frac{Tr}{\frac{\pi}{2}r^4} = \frac{2T}{\pi r^3}$$



$$\tau_{avg} = \tau_{max}; \qquad \frac{4T}{nR\pi d^2} = \frac{2T}{\pi r^3}$$

$$n = \frac{2r^3}{Rd^2} \qquad \textbf{Ans}$$

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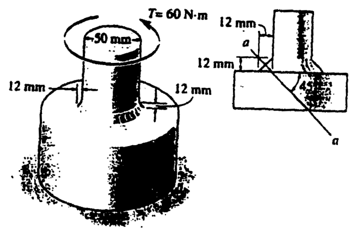
5-23. The steel shafts are connected together using a fillet weld as shown. Determine the average shear stress in the weld along section *a–a* if the torque applied to the shafts is $T = 60\ \text{N}\cdot\text{m}$. *Note:* The critical section where the weld fails is along section *a–a*.



$$\tau_{avg} = \frac{V}{A} = \frac{(60/(0.025+0.006))}{2\pi(0.025+0.006)(0.012\sin 45^\circ)}$$

$\tau_{avg} = 1.17\ \text{MPa}$ **Ans**

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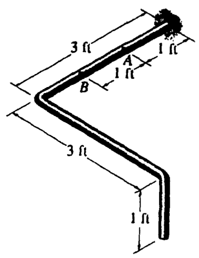
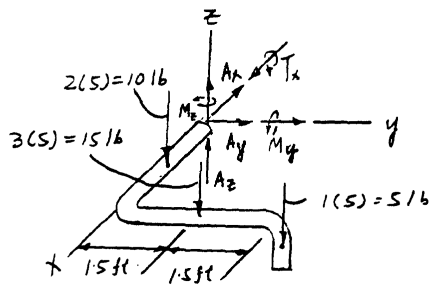
•5–24 The rod has a diameter of 0.5 in. and a weight of 5 lb/ft. Determine the maximum torsional stress in the rod at a section located at A due to the rod's weight.





$\Sigma M_x = 0; \qquad T_x - 15(1.5) - 5(3) = 0;$

$$T_x = 37.5 \text{ lb} \cdot \text{ft}$$

$$(\tau_A)_{max} = \frac{T\,c}{J} = \frac{37.5(12)(0.25)}{\frac{\pi}{2}(0.25)^4}$$

$$= 18.3 \text{ ksi}$$ **Ans**

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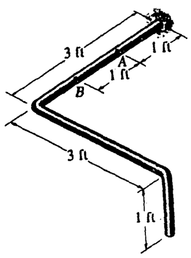
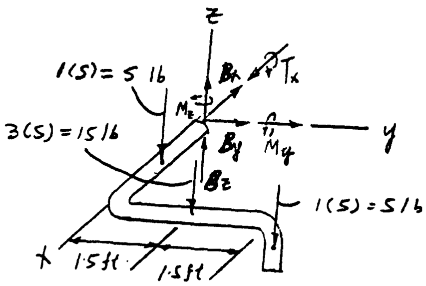
5–25 Solve Prob. 5–24 for the maximum torsional stress at B.





$$\Sigma M_x = 0; \qquad -15(1.5) - 5(3) + T_x = 0;$$

$$T_x = 37.5 \text{ lb}\cdot\text{ft} = 450 \text{ lb}\cdot\text{in.}$$

$$(\tau_B)_{\max} = \frac{Tc}{J} = \frac{450(0.25)}{\frac{\pi}{2}(0.25)^4} = 18.3 \text{ ksi}$$ **Ans**

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Because of the number and variety of potential correct solutions to this problem, no solution is being given.

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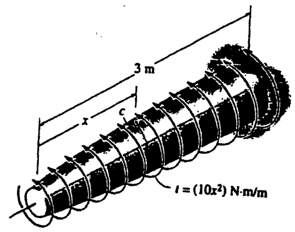
5-27. The shaft is subjected to a distributed torque along its length of $t = (10x^2)\ \text{N}\cdot\text{m/m}$, where x is in meters. If the maximum stress in the shaft is to remain constant at 80 MPa, determine the required variation of the radius c of the shaft for $0 \le x \le 3$ m.

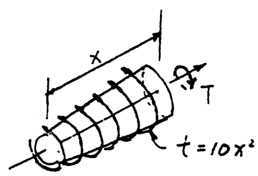


$$T = \int t\,dx = \int_0^x 10x^2 dx = \frac{10}{3}x^3$$

$$\tau = \frac{Tc}{J}; \qquad 80(10^6) = \frac{(\frac{10}{3})x^3 c}{\frac{\pi}{2}c^4}$$

$$c^3 = 26.526\,(10^{-9})\,x^3$$

$$c = (2.98\,x)\ \text{mm} \qquad \textbf{Ans}$$



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