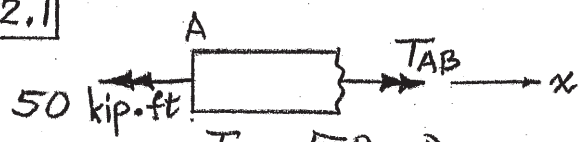
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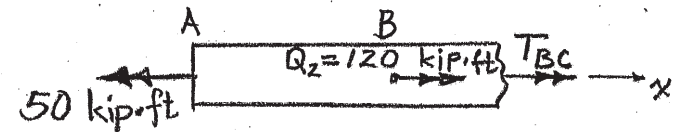
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2.1



$\Sigma T_x = 0: \quad T_{AB} - 50 = 0$

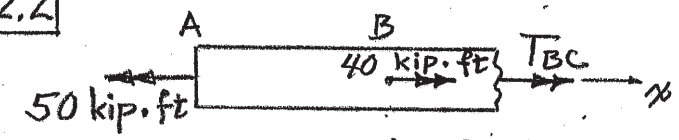
$T_{AB} = 50 \text{ kip·ft}$ ANS.



$\Sigma T_x = 0: \quad T_{BC} + 120 - 50 = 0$

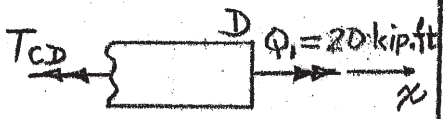
$T_{BC} = -70 \text{ kip·ft}$ ANS.

2.2



$\Sigma T_x = 0: \quad T_{BC} + 40 - 50 = 0$

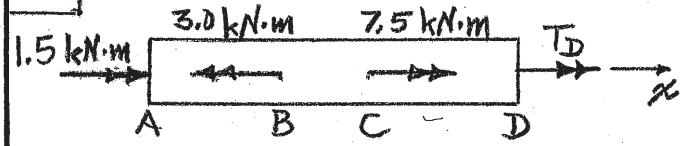
$T_{BC} = 10 \text{ kip·ft}$ ANS.



$\Sigma T_x = 0: \quad 20 - T_{CD} = 0$

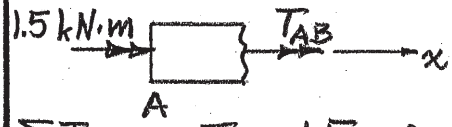
$T_{CD} = 20 \text{ kip·ft}$ ANS.

2.3



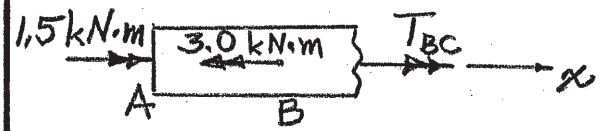
$\Sigma T_x = 0: \quad T_D + 7.5 - 3.0 + 1.5 = 0$

$T_D = -6.0 \text{ kN·m}$ ANS.



$\Sigma T_x = 0: \quad T_{AB} + 1.5 = 0$

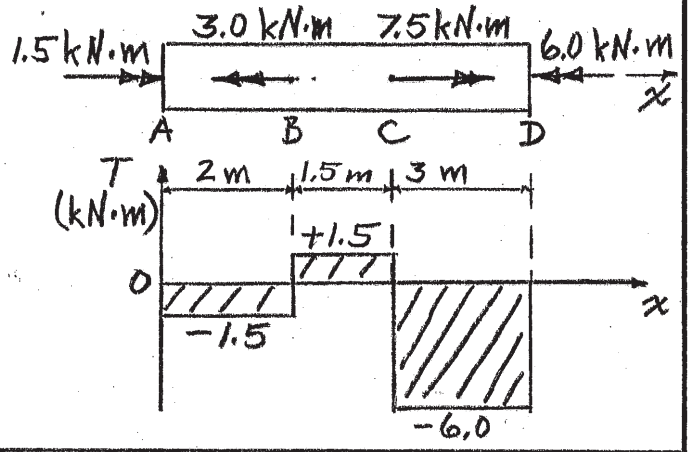
$T_{AB} = -1.5 \text{ kN·m}$ ANS.



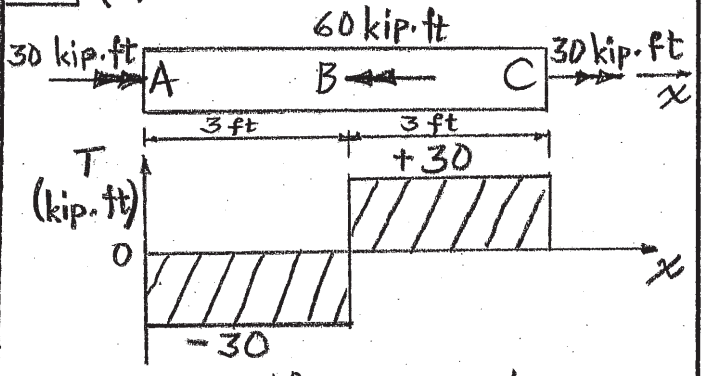
$\Sigma T_x = 0: \quad T_{BC} - 3.0 + 1.5 = 0$

$T_{BC} = 1.5 \text{ kN·m}$ ANS.

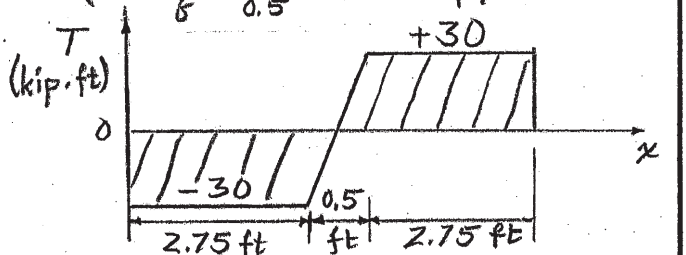
2.4



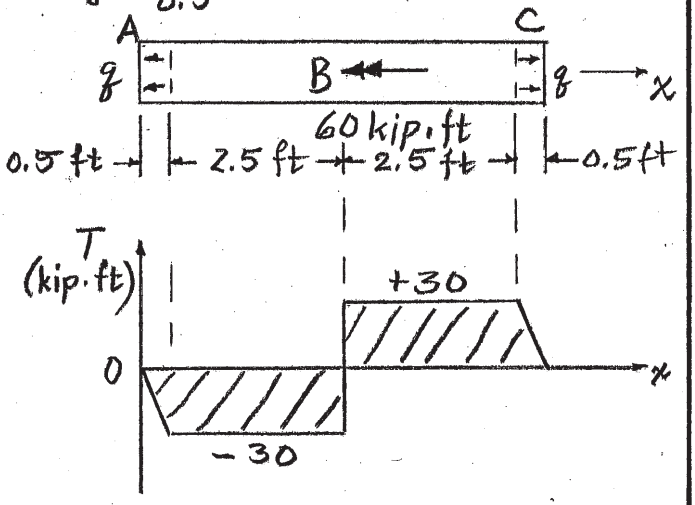
2.5 (a)



(b) $q = \frac{60}{0.5} = 120 \text{ kip/ft}$

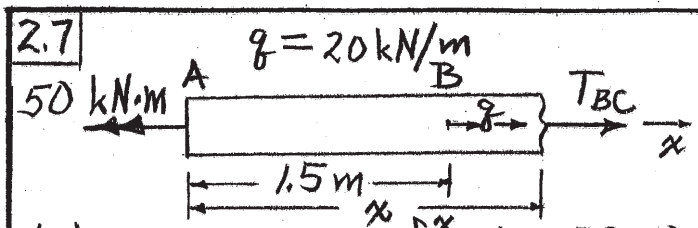


2.6 $q = \frac{30}{0.5} = 60 \text{ kip/ft}$



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2.7

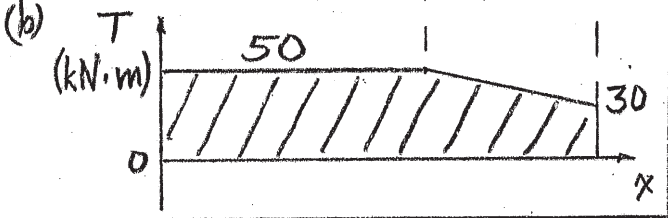


(a) $\Sigma T_x = 0$: $T_{BC} + \int_{1.5}^{x} 20\,dx - 50 = 0$

$T_{BC} = 80 - 20x$ ANS.

$T_C = 80 - 20(2.5) = 30$ kN·m ANS.

(b)



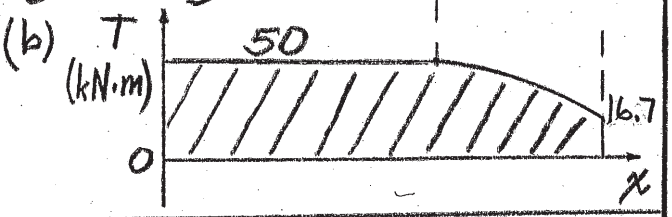
2.8 REFER TO THE F.B.D. IN PROB. 2.7. & MAKE $q = 100(x-1.5)^2$ kN/m.

(a) $\Sigma T_x = 0$: $T_{BC} + \int_{1.5}^{x} 100(x-1.5)^2\,dx - 50 = 0$

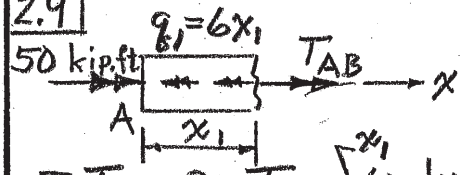
$T_{BC} = 50 - \frac{100}{3}(x-1.5)^3$ ANS.

$T_C = 50 - \frac{100}{3}(2.5-1.5)^3 = 16.7$ kN·m ANS.

(b)

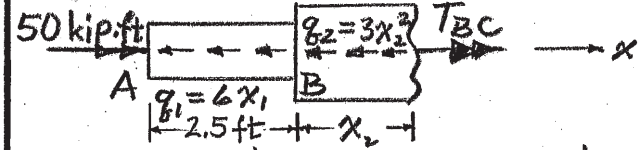


2.9



$\Sigma T_x = 0$: $T_{AB} - \int_0^{x_1} 6x_1\,dx_1 + 50 = 0$

$T_{AB} = 3x_1^2 - 50$ ANS.

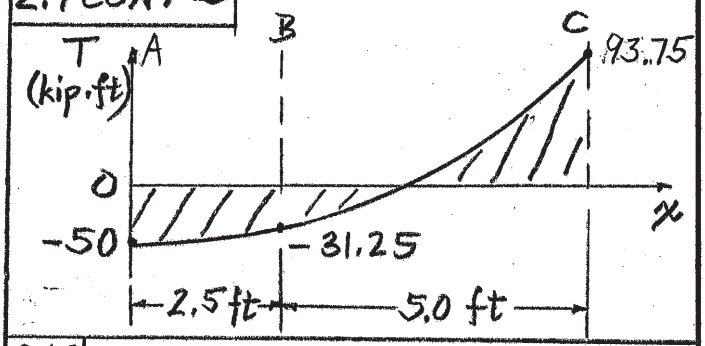


$T_B = 3(2.5^2) - 50 = -31.25$ kip·ft

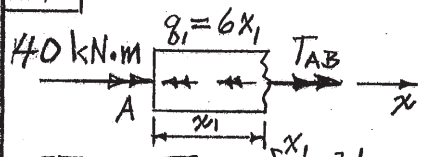
$\Sigma T_x = 0$: $T_{BC} - \int_0^{x_2} 3x_2^2\,dx_2 + 31.25 = 0$

$T_{BC} = x_2^3 - 31.25$ ANS.

2.9 CONT'D

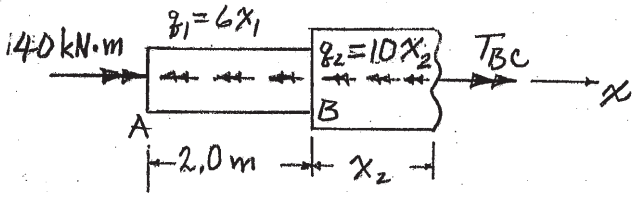


2.10



$\Sigma T_x = 0$: $T_{AB} - \int_0^{x_1} 6x_1^2\,dx_1 + 150 = 0$

$T_{AB} = 2x_1^3 - 40$ ANS.



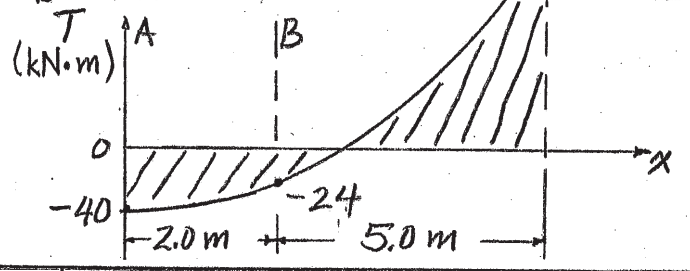
$T_B = 2(2.0^3) - 40 = -24.0$ kN·m

$\Sigma T_x = 0$: $T_{BC} - \int_0^{x_2} 10x_2\,dx_2 + 24.0 = 0$

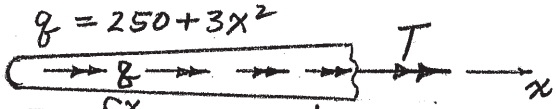
$T_{BC} = 5x_2^2 - 24$ ANS.

$T_C = 101 = 5b^2 - 24$ ANS.

$b = 5.0$ m

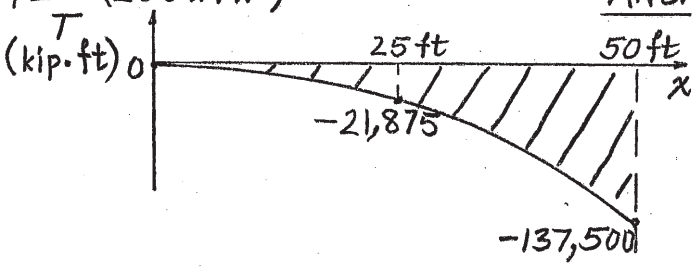


2.11



$\Sigma T_x = 0$: $T + \int_0^x (250 + 3x^2)\,dx = 0$

$T = -(250x + x^3)$ ANS.



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2.12 REFER TO F.B.D. IN PROB. 2.11

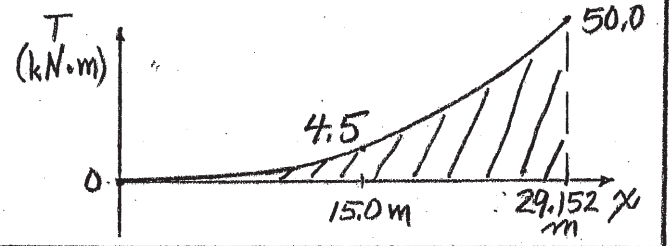
$q = 1.2 - 0.2x$

$\sum T_x = 0: \; T + \int_0^x (1.2 - 0.2x)\,dx = 0$

$T = 0.1x^2 - 1.2x$ ANS.

$T_B = 50.0 = 0.1L^2 - 1.2L$

$L^2 - 12L - 500 = 0; \; L = 29.152\,m$ ANS.



2.13

(a) $G = \dfrac{TL}{J\theta} = \dfrac{24.85\times10^3(0.25)}{(\pi/32)(0.1^4 - 0.092^4)(1.4\pi/180)}$

$G = 91.3$ GPa ANS.

$\tau_U = \dfrac{T_U R}{J} = \dfrac{46.25\times10^3(0.05)}{(\pi/32)(0.1^4 - 0.092^4)}$

$\tau_U = 830.6$ MPa ANS.

(b) $\tau_P = \dfrac{TR}{J} = \dfrac{24.85\times10^3(0.05)}{(\pi/32)(0.1^4 - 0.092^4)}$

$\tau_P = 446.3$ MPa ANS.

$\gamma_P = \dfrac{\tau_P}{G} = \dfrac{446.3\times10^6}{91.3\times10^9}$

$\gamma_P = 4.89\times10^{-3}$ ANS.

2.14

(a) $G = \dfrac{TL}{J\theta} = \dfrac{62.8\times10^3(6.0)}{(\pi/32)(2.0^4)(1.14\pi/180)}$

$G = 12.056\times10^6$ psi ANS.

(b) $u = \frac{1}{2}\tau_P\gamma_P = \frac{1}{2}\left(\dfrac{TR}{J}\right)\left(\dfrac{R\theta}{L}\right)$

$= \left(\frac{1}{2}\right)\left[\dfrac{62.8\times10^3(1.0^2)(1.14\pi/180)}{(\pi/32)(2.0^4)(6.0)}\right]$

$u = 66.3$ lb. in./in.^{3} ANS.

2.15

(a) $G = \dfrac{TL}{J\theta} = \dfrac{220(10.0)}{(\frac{\pi}{32})(4.0^4 - 3.6^4)(1.4\pi/180)}$

$G = 10.4\times10^3$ ksi ANS.

$\tau_U = \dfrac{T_U R}{J} = \dfrac{456(2.0)}{(\frac{\pi}{32})(4.0^4 - 3.6^4)}$

$\tau_U = 105.5$ ksi ANS.

(b) $\tau_P = \dfrac{TR}{J} = \dfrac{220(2.0)}{(\frac{\pi}{32})(4.0^4 - 3.6^4)}$

$\tau_P = 50.9$ ksi

$\gamma_P = \dfrac{\tau_P}{G} = \dfrac{50.9}{10.4\times10^3} = 4.894\times10^{-3}$

$u = \frac{1}{2}\tau_P\gamma_P = \left(\frac{1}{2}\right)(50.9)(4.894\times10^{-3})$

$u = 0.125$ kip. in./in. ANS.

2.16

(a) $G = \dfrac{TL}{J\theta} = \dfrac{7.35\times10^3(0.150)}{(\frac{\pi}{32})(0.04^4)(1.2\pi/180)}$

$G = 209.4$ GPa ANS.

(b) $u = \frac{1}{2}\tau_P\gamma_P = \frac{1}{2}\left(\dfrac{TR}{J}\right)\left(\dfrac{R\theta}{L}\right)$

$= \frac{1}{2}\left[\dfrac{7.35\times10^3(0.04^2)(1.2\pi/180)}{(\frac{\pi}{32})(0.04^4)(0.150)}\right]$

$u = 3266.7$ kN·m/m^3 ANS.

(c) $\tau_U = \dfrac{T_U R}{J} = \dfrac{18.25\times10^3(0.04)}{(\frac{\pi}{32})(0.04^4)}$

$\tau_U = 2904.6$ MPa ANS.

2.17 $T_{AB} = 5$ kip. in.; $T_{BC} = 10$ kip. in.

(a) $\tau_{MAX} = \dfrac{TR}{J} = \dfrac{10(1.0)}{(\frac{\pi}{32})(2.0^4 - 1.25^4)}$

$\tau_{MAX} = 7.513$ ksi ANS.

(b) $\tau_{MAX} = \dfrac{TR}{J} = \dfrac{10(1.0)}{(\frac{\pi}{32})(2.0^4)}$

$\tau_{MAX} = 6.366$ ksi ANS.

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2.18 $T_{AB} = 5$ kip·in.; $T_{BC} = 10$ kip·in.

(a) $\theta_A = \sum \frac{TL}{JG} = \theta_{AB} + \theta_{BC}$

$= \frac{5\times10^3(10)}{(\pi/32)(1.5^4 - 0.75^4)(6\times10^6)} - \frac{10\times10^3(15)}{(\pi/32)(1.5^4 - 0.75^4)(6\times10^6)}$

$= 17.885\times10^{-3} - 53.654\times10^{-3}$

$\theta_A = -35.769\times10^{-3}$ rad. CCW AS VIEWED FROM A TO C. ANS.

(b) $\theta_A = \sum \frac{TL}{JG} = \theta_{AB} + \theta_{BC}$

$= \frac{5\times10^3(10)}{(\pi/32)(1.5^4)(6\times10^6)} - \frac{10\times10^3(15)}{(\pi/32)(1.5^4)(6\times10^6)}$

$= 16.767\times10^{-3} - 50.301\times10^{-3}$

$\theta_A = -33.534\times10^{-3}$ rad. CCW AS VIEWED FROM A TO C. ANS.

2.19 $T_{AB} = 5$ kN·m; $T_{BC} = 10$ kN·m

(a) $\tau_{AB} = \frac{TR}{J} = \frac{5\times10^3(0.03)}{(\pi/32)(0.06^4)}$

$= 117.9$ MPa

$\tau_{BC} = \frac{TR}{J} = \frac{10\times10^3(0.04)}{(\pi/32)(0.08^4)}$

$= 99.5$ MPa

$\tau_{MAX} = \tau_{AB} = 117.9$ MPa ANS.

(b) $\theta_{A/C} = \sum \frac{TL}{JG} = \theta_{A/B} + \theta_{B/C}$

$= \frac{5\times10^3(0.30)}{(\pi/32)(0.06^4)(40\times10^9)} - \frac{10\times10^3(0.50)}{(\pi/32)(0.08^4)(25\times10^9)}$

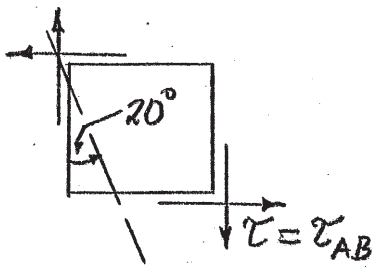
$= 2.947\times10^{-2} - 4.974\times10^{-2}$

$\theta_{A/C} = -2.027\times10^{-2}$ rad. CCW AS VIEWED FROM A TO C. ANS.

2.20 $T_{AB} = 5$ kN·m; $T_{BC} = 10$ kN·m

FROM PROB. 2.19, $\tau_{AB} = 117.9$ MPa

(a)



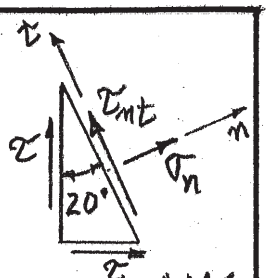
2.20 CONT'D (b)

BY EQS. (2.10a) & (2.10b),

$\sigma_m = \tau \sin 2\theta$

$= -117.9 \sin 40°$

$= -75.8$ MPa ANS.



$\tau_{mt} = \tau \cos 2\theta$

$= -117.9 \cos 40° = -90.3$ MPa ANS.

2.21 $\tau = \frac{T\rho}{J}$

$25 = \frac{50(D_1/2)}{(\pi/32)(D_1^4)}$; $D_1^3 = 10.186$

$D_1 = 2.168$ in.

AS DEDUCED FROM EQS. (2.10),

τ_{MAX} AT $\theta = 0° = (\sigma_m)_{MAX}$ AT $\theta = 45° = 40$ ksi.

$\therefore 40 = \frac{50(D_2/2)}{(\pi/32)(D_2^4)}$; $D_2^3 = 6.366$

$D_2 = 1.853$ in.

$D_{MIN} = D_1 = 2.168$ in. ANS.

2.22 EQS. (2.10) LEAD TO THE CONCLUSION THAT τ_{MAX} AT $\theta = 0° = (\sigma_m)_{MAX}$ AT $\theta = 45° = 100$ MPa.

$T_{MAX} = \frac{\tau J}{R} = \frac{100\times10^6(\pi/32)(0.05^4 - 0.03^4)}{0.025}$

$T_{MAX} = 2.136$ kN·m ANS.

2.23

$J = \frac{\pi}{32}(d_o^4 - d_i^4) = \frac{\pi}{32}(2.0^4 - d_i^4) = \frac{TL}{G\theta}$

$\frac{\pi}{32}(2.0^4 - d_i^4) = \frac{40(20)}{4\times10^3(10\pi/180)}$

$d_i^4 = 4.32780$; $d_i = 1.442$ in. ANS.

2.24 AB: $\tau = \frac{T\rho}{J}$

$25 = \frac{Q_1(1.0)}{(\pi/32)(2.0^4)}$; $Q_1 = 39.270$ kip·in.

$\therefore T_{BC} = 59.270$ kip·in.

BC: $\tau = \frac{TR}{J}$

$25 = \frac{59.270(D/2)}{(\pi/32)D^4}$; $D^3 = 12.07439$

$D = 2.294$ in. ANS.

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2.25 $T_{AB} = 25$ kip·in; $T_{BC} = 35$ kip·in.

$$\theta_{B/C} = \left(\frac{TL}{JG}\right)_{BC} = \frac{35(10)}{(\pi/32)(3.5^4)(4\times10^3)}$$
$$= 5.93931\times10^{-3} \text{ rad.}$$
$$\theta_{A/B} = \left(\frac{TL}{JG}\right) = \frac{25(6)}{(\pi/32)D_{AB}^4(10\times10^3)}$$
$$= 5.93931\times10^{-3}$$
$$D_{AB} = 2.252 \text{ in.} \quad \text{ANS.}$$

2.26

$$\tau = \frac{TR}{J} = \frac{20\times10^3(0.2)}{(\pi/32)(0.4^4 - 0.38^4)}$$
$$\tau = 8.580 \text{ MPa}$$

BY EQS. (2.10a) & (2.10b),

$$\sigma_n = \tau \sin 2\theta = -8.580 \sin 60^\circ = -7.4 \text{ MPa} \quad \text{ANS.}$$
$$\tau_{nt} = \tau \cos 2\theta = -8.580 \cos 60^\circ = -4.3 \text{ MPa} \quad \text{ANS.}$$

2.27 BY EQ. (2.10b)

$$\tau = \frac{10}{\cos 2\theta} = 57.588$$
$$57.588 = \frac{50(12)(\frac{1}{2})(D_o + \frac{1}{2})}{(\pi/32)(D_o + \frac{1}{2})^4}$$
$$(D_o + \tfrac{1}{2})^3 = 53.06270$$
$$D_o = 3.258 \text{ in.} \approx 3.3 \text{ in.} \quad \text{ANS.}$$

BY EQ. (2.10a)

$$\tau = \frac{\sigma_n}{\sin 2\theta} = \frac{15}{\sin 80^\circ} = 15.231$$
$$15.231 = \frac{50(12)(\frac{1}{2})(D_o + \frac{1}{2})}{(\pi/32)(D_o + \frac{1}{2})^4}$$
$$(D_o + \tfrac{1}{2})^3 = 200.62865$$
$$D_o = 5.354 \text{ in.}$$
$$(D_o)_{MAX} = 5.354 \approx 5.4 \text{ in.}$$

2.28 $\tau = \frac{TR}{J}$; $T_{AB} = Q_1$

AB: $100\times10^6 = \frac{Q_1(0.015/2)}{(\pi/32)(0.015^4)}$

$Q_1 = 66.267 \approx 66.3$ N·m ANS.

BC: $T_{BC} = Q_2 - 66.267$

$100\times10^6 = \frac{(Q_2 - 66.267)(0.03/2)}{(\pi/32)(0.03^4)}$

$Q_2 = 596.411 \approx 596.4$ N·m ANS.

CD: $T_{CD} = 530.144 - Q_3$

$100\times10^6 = \frac{(530.144 - Q_3)(0.045/2)}{(\pi/32)(0.045^4)}$

$Q_3 = -1259.091 \approx -1259.1$ N·m ANS.

2.29 $T_{AB} = -5$ kip·in; $T_{BC} = 5$ kip·in.

$T_{CD} = -15$ kip·in.

$$\theta_A = \sum \frac{TL}{JG}; \quad \frac{15\pi}{180} = \frac{-5(18)}{(\pi/32)D_1^4(10\times10^3)}$$
$$+ \frac{5(12)}{(\pi/32)(\frac{3}{2}D_1)^4(5\times10^3)} + \frac{-15(8)}{(\pi/32)(3D_1)^4(3\times10^3)}$$

$D_1 = 0.726$ in.; $D_2 = 1.088$ in. AND $D_3 = 2.177$ in. ANS.

2.30 BY INSPECTION, CONCLUDE THAT

$\tau_{BC} < \tau_{AB}$ AND $\tau_{CD} < \tau_{DE}$

∴ THE CHOICE IS BETWEEN SEGMENTS AB AND DE.

AB: $T_{AB} = Q_1 = 50$ kN·m

$$\tau_{AB} = \left(\frac{TR}{J}\right)_{AB} = \frac{50\times10^3(0.04)}{(\pi/32)(0.08^4 - 0.04^4)}$$
$$= 530.5 \text{ MPa}$$

DE: $T_{DE} = Q_1 + Q_2 - Q_3 = -50$ kN·m

$$|\tau_{DE}| = \left(\frac{TR}{J}\right)_{DE} = \frac{50\times10^3(0.06)}{(\pi/32)(0.12^4 - 0.04^4)}$$
$$= 149.2 \text{ MPa}$$

$\tau_{MAX} = \tau_{AB} = 530.5$ MPa ANS.

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2.31 $T_{AB}=50\ kN\cdot m$; $T_{BC}=75\ kN\cdot m$; $T_{CD}=T_{DE}=-50\ kN\cdot m$

$$\theta_A=\sum\frac{TL}{JG}=\theta_{A/B}+\theta_{B/C}+\theta_{C/E}+\theta_{E/F}$$

$$=\frac{50\times10^3(0.2)}{(\pi/32)(0.08^4-0.04^4)(70\times10^9)}+\frac{75\times10^3(0.1)}{(\pi/32)(0.08^4)(70\times10^9)}$$

$$-\frac{50\times10^3(0.15)}{(\pi/32)(0.12^4)(70\times10^9)}-\frac{50\times10^3(0.25)}{(\pi/32)(0.12^4-0.08^4)(70\times10^9)}$$

$=0.05039$ rad CCW AS VIEWED FROM F TO A ANS.

2.32 $T_{AB}=20\ kip\cdot in.$; $T_{BC}=10\ kip\cdot in.$; $T_{CD}=5\ kip\cdot in.$; $T_{DE}=0$.

$$\tau_{AB}=\left(\frac{TR}{J}\right)_{AB}=\frac{20(1.25)}{(\pi/32)(2.5^4)}=6.5\ ksi$$

$$\tau_{BC}=\left(\frac{TR}{J}\right)_{BC}=\frac{10(1.0)}{(\pi/32)(2.0^4)}=6.4\ ksi$$

$$\tau_{CD}=\left(\frac{TR}{J}\right)_{CD}=\frac{5(0.875)}{(\pi/32)(1.75^4)}=4.8\ ksi$$

$\tau_{DE}=0$

$\tau_{MAX}=\tau_{AB}=6.5\ ksi$ ANS.

2.33 $T_{BC}=1.5\ kN\cdot m$

$$\tau=\frac{1.5\times10^3(0.0325)}{(\pi/32)(0.065^4)}$$

$=27.8\ MPa$

BY EQS. (2.10a) & (2.10b),

$\sigma_M=\tau\sin2\theta$

$=-27.8\sin(-100^\circ)$

$=27.4\ MPa$ ANS.

$\tau_{nt}=\tau\cos2\theta$

$=-27.8\cos(-100^\circ)$

$=4.8\ MPa$ ANS.

2.34 USE TORQUE STATED IN PROB. 2.32.

$$\theta_{E/A}=\theta_{E/D}+\theta_{D/C}+\theta_{C/B}+\theta_{B/A}$$

$$=\frac{20(3)(12)}{(\pi/32)(2.5^4)(10\times10^3)}+\frac{10(3)(12)}{(\pi/32)(2.0^4)(10\times10^3)}$$

$$+\frac{5(3)(12)}{(\pi/32)(1.75^4)(10\times10^3)}+0$$

$=0.06124$ rad CCW AS VIEWED FROM E TO A. ANS.

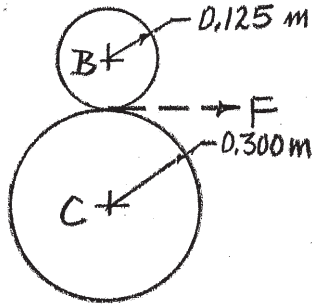
2.35

$Q=10=F(0.125)$

$F=80\ kN$

$T_{CD}=80(0.3)$

$=24\ kN\cdot m$



$$\tau_{MAX}=\tau_{CD}=\left(\frac{TP}{J}\right)_{CD}=\frac{24\times10^3(0.0375)}{(\pi/32)(0.075^4-0.045^4)}$$

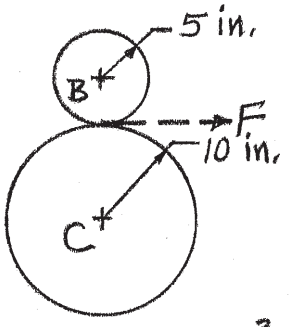
$\tau_{MAX}=332.9\ MPa$ ANS.

2.36

$Q=F(5)$

$F=\frac{Q}{5}$

$T_{CD}=F(10)=2Q$



$$\theta_{C/D}=\left(\frac{TL}{JG}\right)_{CD}=\frac{2Q(12)}{(\pi/32)(1.75^4)(4\times10^3)}=6.51627\times10^{-3}Q$$

$$\theta_B=2\theta_{C/D}=13.03254\times10^{-3}Q$$

$$\theta_{A/B}=\left(\frac{TL}{JG}\right)_{AB}=\frac{Q(12)}{(\pi/32)(1.75^4)(4\times10^3)}=3.25814\times10^{-3}Q$$

$$\theta_{A/D}=\theta_B+\theta_{A/B}=16.29068\times10^{-3}Q$$

$\therefore 16.29068\times10^{-3}Q=5\pi/180$

$Q=5.4\ kip\cdot in.$ ANS.

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2.37 $\Sigma T_x = 0$:

$$T - \int_0^x \left(\frac{3}{4}\right)x\,dx = 0$$

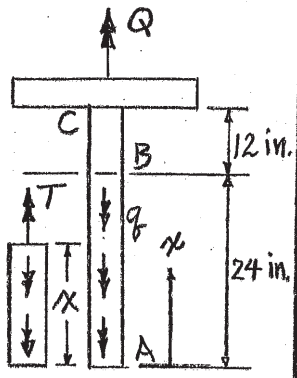
$$T = \left(\frac{3}{8}\right)x^2$$

$$T_{MAX} = T_{x=24} = 216 \text{ lb.in.}$$

$$\tau_{MAX} = \frac{T_{MAX} R}{J}$$

$$= \frac{216(1)}{\left(\frac{\pi}{32}\right)(2^4 - 1.5^4)} = 201.2 \text{ psi}$$

ANY PLACE BETWEEN B & C ON OUTSIDE SURFACE ANS.



2.38 REFER TO THE F.B.D. IN PROB. 2.37.

(a) $\Sigma T_x = 0$: $48 - q(0.7) = 0$

$$q = 68.571 \text{ N·m/m} \quad \text{ANS.}$$

(b) $\Sigma T_x = 0$: $T - \int_0^x (68.571)\,dx = 0$

$$T = 68.571x$$

$$\theta_{A/C} = \int \frac{T\,dx}{JG_1} = \int_0^{0.7} \frac{68.571x\,dx}{\left(\frac{\pi}{32}\right)(0.055^4 - 0.045^4)(25\times10^9)}$$

$$\frac{68.571}{1.2394\times10^{-4}}\left(\frac{x^2}{2}\right)\Big|_0^{0.7} = 27.108\times10^{-4} \text{ rad.} \quad \text{ANS.}$$

2.39

$$\Sigma T_x = 0$$

$$\int_0^x 3x^2\,dx - T = 0$$

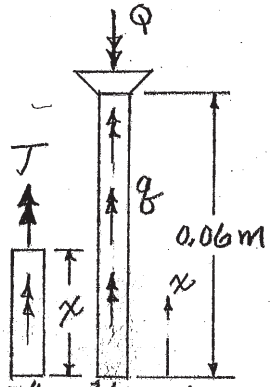
$$T = x^3$$

$$T_{MAX} = T_{x=0.06} = Q$$

$$= 2.16\times10^{-4} \text{ kN·m}$$

$$\tau_{MAX} = \frac{T_{MAX}\rho}{J} = \frac{2.16\times10^{-4}\times10^3(0.003)}{(\pi/32)(0.006^4)}$$

$$= 5.1 \text{ MPa} \quad \text{ANS.}$$



2.40 REFER TO THE F.B.D. IN PROB. 2.39.

$\Sigma T_x = 0$: $T + qx = 0$; $T = -qx$

$$|T_{MAX}| = |T_{x=0.06}| = 0.06q = Q \quad \text{——(1)}$$

$$\tau_{MAX} = \frac{T_{MAX} R}{J} = \frac{T_{MAX}(0.04)}{\left(\frac{\pi}{32}\right)(0.08^4)} = 10\times10^6$$

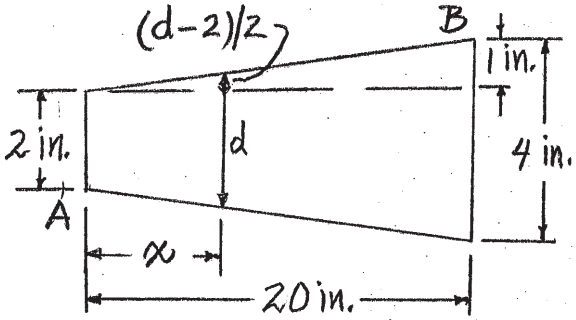
$$T_{MAX} = 1.005 \text{ kN·m} = Q \text{——(2)} \quad \text{ANS.}$$

2.40 CONT'D

(2) INTO (1) $\Rightarrow$

$$q = \frac{1.005}{0.06} = 16.75 \text{ kN·m/m} \quad \text{ANS.}$$

2.41



USING SIMILAR TRIANGLES, WE HAVE

$$\frac{(d-2)/2}{x} = \frac{1}{20};\quad d = \frac{20+x}{10}$$

(a)

$$\tau_{MAX} = \tau_A = \frac{TR}{J} = \frac{30(1)}{(\pi/32)(2^4)}$$

$$= 19.1 \text{ ksi} \quad \text{ANS.}$$

(b)

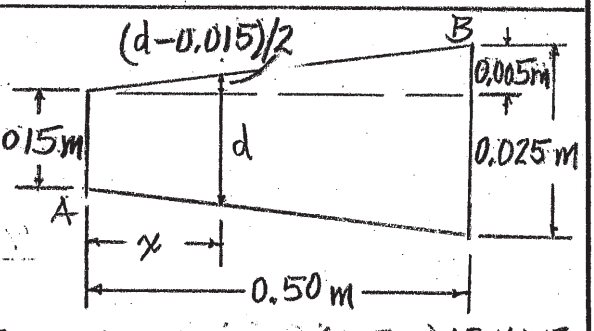
$$\theta_{A/B} = \frac{T}{G}\int_0^{20} \frac{dx}{J}$$

$$= \frac{30}{4\times10^6}\int_0^{20} \frac{dx}{\left(\frac{\pi}{32}\right)\left(\frac{20+x}{10}\right)^4}$$

$$= \frac{30(32)(10^4)}{\pi(4\times10^6)}\int_0^{20} (20+x)^{-4}\,dx$$

$$= 2.785\times10^{-5} \text{ rad} \quad \text{ANS.}$$

2.42



USING SIMILAR TRIANGLES, WE HAVE

$$\frac{(d-0.015)/2}{x} = \frac{0.005}{0.50};\quad d = \frac{x+0.75}{50}$$

$$\tau = \frac{TR}{J};\quad T = Q$$

$$70\times10^6 = \frac{Q(0.0075)}{(\pi/32)(0.015^4)}$$

$$Q = 46.387 \text{ N·m}$$

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2.42 CONT'D

$$\theta = \int \frac{T\,dx}{JG}\ ;\ T = Q$$

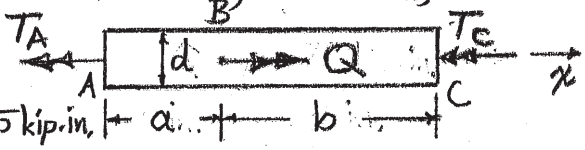
$$\frac{4\pi}{180} = \frac{Q}{50\times10^9}\int_0^{0.5}\frac{dx}{\frac{\pi}{32}\left(\frac{x+0.75}{50}\right)^4}$$

$$= \frac{32(50^4)Q}{\pi(50\times10^9)}\int_0^{0.5}(x+0.75)^{-4}\,dx$$

$$Q = 88.5\ N\cdot m$$

$$\therefore Q_{MAX} = 46.4\ N\cdot m \qquad \text{ANS.}$$

2.43 $a = 10$ in.; $b = 20$ in.; $d = 3$ in.



$$\Sigma T_x = 0:\ 75 - T_A - T_C = 0 \qquad (1)$$

$$\theta_{B/A} = \theta_{B/C}:\ \frac{T_A(10)}{\left(\frac{\pi}{32}\right)(3^4)(4\times10^3)} = \frac{T_C(20)}{\left(\frac{\pi}{32}\right)(3^4)(4\times10^3)}$$

$$T_A = 2T_C \qquad (2)$$

SOLVE (1) & (2) TO GET

$T_A = 50$ kip.in.; $T_C = 25$ kip.in.

(a) $\tau_{MAX} = (\tau)_{AB} = \frac{50(1.5)}{(\pi/32)(3^4)} = 9.4$ ksi ANS.

(b) $\theta_B = \theta_{B/C} = \frac{50(10)}{(\pi/32)(3^4)(4\times10^3)} = 0.01572$ rad ANS.

2.44 REFER TO THE F.B.D. IN PROB. 2.43.

$a = 0.5$ m; $b = 1.0$ m; $d = 0.07$ m

$$\Sigma T_x = 0:\ Q - T_A - T_C = 0 \qquad (1)$$

$$\theta_{B/A} = \theta_{B/C}:\ \frac{T_A(0.5)}{(\pi/32)(0.07^4)(25\times10^9)} = \frac{T_C(1.0)}{\left(\frac{\pi}{32}\right)(0.07^4)(40\times10^9)}$$

$$T_A = \left(\frac{5}{4}\right)T_C \qquad (2)$$

$\therefore (\tau_{MAX})_A$ CONTROLS. THUS,

$$150\times10^6 = \frac{T_A(0.035)}{(\pi/32)(0.07^4)}$$

$T_A = 10.102$ kN·m

(2) $\Rightarrow T_C = \left(\frac{4}{5}\right)(10.102) = 8.082$ kN·m

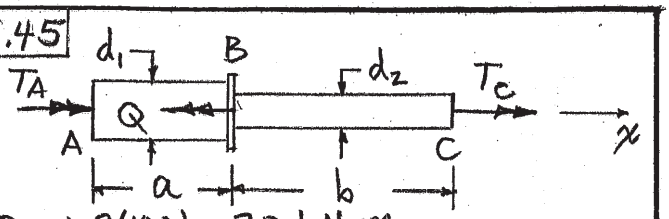
(1) $\Rightarrow Q = T_A + T_C$

$= 10.102 + 8.082$

$= 18.184$

≈ 18.2 kN·m ANS.

2.45



$Q = 0.2(100) = 20$ kN·m

$a = 0.3$ m; $b = 0.5$ m; $d_1 = 0.050$ m

$d_2 = 0.030$ m.

$$\Sigma T_x = 0:\ T_A + T_C - 20 = 0 \qquad (1)$$

$$\theta_{B/A} = \theta_{B/C}:\ \frac{T_A(0.3)}{(\pi/32)(0.05^4)(40\times10^9)} = \frac{T_C(0.5)}{(\pi/32)(0.03^4)(40\times10^9)}$$

$$T_A = 12{,}860\,T_C \qquad (2)$$

SOLVE (1) & (2) TO GET

$T_A = 18.557$ kN·m; $T_C = 1.443$ kN·m

$$\tau_{MAX} = (\tau)_{AB} = \frac{18.557(0.025)}{(\pi/32)(0.05^4)}$$

$= 756.1$ MPa ANS.

$$\theta_{MAX} = \theta_{B/A} = \frac{18.557\times10^3(0.3)}{(\pi/32)(0.05^4)(40\times10^9)}$$

$= 0.22682$ rad ANS.

2.46 REFER TO THE F.B.D. IN PROB. 2.45.

$Q = 8F$; $a = 12$ in.; $b = 20$ in.

$d_1 = 2.0$ in.; $d_2 = 1.0$ in.

$$\Sigma T_x = 0:\ T_A + T_C - 8F = 0 \qquad (1)$$

$$\theta_B = \theta_{B/A} = \frac{5\pi}{180} = \frac{T_A(12)}{(\pi/32)(2^4)(4\times10^6)}$$

$$T_A = 45.693\ \text{kip.in.} \qquad (2)$$

$$\theta_B = \theta_{B/C} = \frac{5\pi}{180} = \frac{T_C(20)}{(\pi/32)(1^4)(10\times10^6)}$$

$$T_C = 4.284\ \text{kip.in.} \qquad (3)$$

(2) & (3) INTO (1) $\Rightarrow$

$F = 6.247 \approx 6.2$ kips ANS.

2.47 REFER TO THE F.B.D. IN PROB. 2.45.

$Q = 10F$; $a = 15$ in.; $b = 25$ in.

$d_1 = 3.0$ in.; $d_2 = 2.0$ in.

$$\Sigma T_x = 0:\ T_A + T_C - 10F = 0 \qquad (1)$$

$$\theta_{B/A} = \theta_{B/C}:\ \frac{T_A(15)}{(\pi/32)(3^4)(4\times10^3)} = \frac{T_C(25)}{(\pi/32)(2^4)(10\times10^3)}$$

$$T_A = 3.375\,T_C \qquad (2)$$

$$\tau_A = 10 = \frac{T_A(1.5)}{(\pi/32)(3^4)};\ T_A = 53.014\ \text{kip.in.} \qquad (3)$$

$$\tau_C = 15 = \frac{T_C(1.0)}{(\pi/32)(2^4)};\ T_C = 23.562\ \text{kip.in.} \qquad (4)$$

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2.47 CONT'D

ASSUME $T_A = 53.014$ kip·in. CONTROLS.
THEN, BY EQ.(2),

$$T_C = \frac{53.014}{3.375} = 15.708 \text{ kip·in.} \quad \text{——(5)}$$

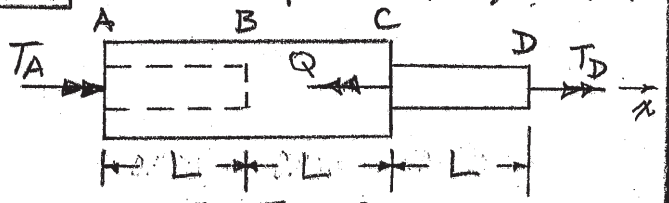
$$\tau_A = \frac{53.014(1.5)}{(\pi/32)(3^4)} = 10.0 \text{ ksi} = (\tau_{ALL})_A \quad \text{OK}$$

$$\tau_C = \frac{15.708(1.0)}{(\pi/32)(2^4)} = 10.0 \text{ ksi} < (\tau_{ALL})_S \quad \text{OK}$$

(3) $\frac{1}{4}$ (5) INTO (1) $\Rightarrow$

$$F = 6.872 \approx 6.9 \text{ kips} \quad \text{ANS.}$$

2.48 $Q = 10$ kN·m; $L = 0.4$ m



$$\Sigma T_x = 0: \quad T_A + T_D - 10 = 0 \quad \text{——(1)}$$

$$\theta_{C/A} = \theta_{C/D}: \quad \frac{T_A(0.4)}{(\frac{\pi}{32})(0.075^4 - 0.04^4)(25\times10^9)} + \frac{T_A(0.4)}{(\frac{\pi}{32})(0.04^4)(25\times10^9)} = \frac{T_D(0.4)}{(\frac{\pi}{32})(0.04^4)(25\times10^9)}$$

$$T_A = 5.919\, T_D \quad \text{——(2)}$$

SOLVE (1) & (2) TO GET

$$T_A = 8.555 \text{ kN·m}; \quad T_D = 1.445 \text{ kN·m}$$

(a) $$\tau_{MAX} = \tau_{CD} = \frac{1.445\times10^3(0.02)}{(\frac{\pi}{32})(0.04^4)} = 115.0 \text{ MPa} \quad \text{ANS.}$$

(b) $$\theta_{MAX} = \theta_{C/D} = \frac{1.445\times10^3(0.4)}{(\frac{\pi}{32})(0.04^4)(25\times10^9)} = 0.0920 \text{ rad} \quad \text{ANS.}$$

2.49 REFER TO F.B.D. IN PROB. 2.48. $L = 12$ in.

$$\Sigma T_x = 0: \quad T_A + T_D - Q = 0 \quad \text{——(1)}$$

$$\theta_{C/A} = \theta_{C/D}: \quad \frac{T_A(12)}{(\frac{\pi}{32})(4^4 - 2^4)(4\times10^3)} + \frac{T_A(12)}{(\frac{\pi}{32})(4^4)(4\times10^3)} = \frac{T_D(12)}{(\frac{\pi}{32})(2^4)(6\times10^3)}$$

$$T_A = 5.161\, T_D \quad \text{——(2)}$$

$$\tau_{AB} = 30 = \frac{T_A(2)}{(\pi/32)(4^4 - 2^4)}$$

$$T_A = 353.429 \text{ kip·in.}$$

2.49 CONT'D

$$\tau_{CD} = 60 = \frac{T_D(1)}{(\pi/32)(2^4)}; \quad T_D = 94.248 \text{ kip·in.}$$

ASSUME $T_A = 353.429$ kip·in. CONTROLS.
THEN, BY EQ.(2),

$$T_D = \frac{353.429}{5.161} = 68.481 \text{ kip·in.}$$

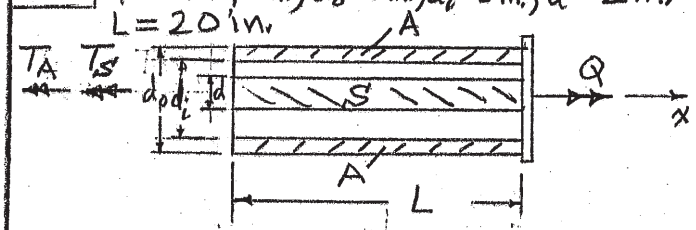
$$\tau_A = \frac{353.429(2)}{(\pi/32)(4^4 - 2^4)} = 30 \text{ ksi} = (\tau_{ALL})_A \quad \text{OK}$$

$$\tau_D = \frac{68.481(1)}{(\pi/32)(2^4)} = 43.6 \text{ ksi} < (\tau_{ALL})_T \quad \text{OK}$$

$\therefore$ (1) $\Rightarrow$ $Q = 353.429 + 68.481 = 421.91$

$$Q \approx 421.9 \text{ kip·in.} \quad \text{ANS.}$$

2.50 $Q = 50$ kip·in.; $d_o = 5$ in.; $d_i = 3$ in.; $d = 2$ in.



$$\Sigma T_x = 0: \quad 50 - T_S - T_A = 0 \quad \text{——(1)}$$

$$\theta_S = \theta_A: \quad \frac{T_S(20)}{(\pi/32)(2^4)(10\times10^3)} = \frac{T_A(20)}{(\pi/32)(5^4 - 3^4)(4\times10^3)}$$

$$T_A = 13.546\, T_S \quad \text{——(2)}$$

SOLVE (1) & (2) TO GET

$$T_A = 46.563 \text{ kip·in.}; \quad T_S = 3.437 \text{ kip·in.}$$

(a) $$\tau_A = \frac{46.563(2.5)}{(\frac{\pi}{32})(5^4 - 3^4)} \approx 2.2 \text{ ksi} \quad \text{ANS.}$$

$$\tau_S = \frac{3.437(1)}{(\frac{\pi}{32})(2^4)} \approx 2.2 \text{ ksi} \quad \text{ANS.}$$

(b) $$\theta_{PL.} = \theta_S = \frac{3.437(20)}{(\frac{\pi}{32})(2^4)(10\times10^3)} = 0.00438 \text{ rad} \quad \text{ANS.}$$

2.51 REFER TO THE F.B.D. IN PROB. 2.50.

$d_o = 120$ mm; $d_i = 80$ mm; $d = 45$ mm; $L = 0.5$ m

$$\Sigma T_x = 0: \quad Q - T_S - T_A = 0 \quad \text{——(1)}$$

$$\theta_S = \theta_A: \quad \frac{T_S(0.5)}{(\frac{\pi}{32})(0.045^4)(75\times10^9)} = \frac{T_A(0.5)}{(\frac{\pi}{32})(0.12^4 - 0.08^4)(25\times10^9)}$$

$$T_A = 13.526\, T_S \quad \text{——(2)}$$

$$\tau_A = 60\times10^6 = \frac{T_A(0.06)}{(\frac{\pi}{32})(0.12^4 - 0.08^4)}; \quad T_A = 16.336 \text{ kN·m}$$

$$\tau_S = 100\times10^6 = \frac{T_S(0.0225)}{(\frac{\pi}{32})(0.045^4)}; \quad T_S = 1.789 \text{ kN·m}$$

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2.51 CONT'D

ASSUME $T_A = 16.336$ kN·m CONTROLS. THEN, BY EQ. (2)

$$T_S = \frac{16.336}{13.526} = 1.208 \text{ kN·m}$$

$$\tau_A = \frac{16.336\times10^3(0.06)}{(\pi/32)(0.12^4-0.08^4)} = 60 \text{ MPa} = (\tau_{ALL})_A \quad \text{OK}$$

$$\tau_S = \frac{1.208\times10^3(0.0225)}{(\pi/32)(0.045^4)} = 67.5 \text{ MPa} < (\tau_{ALL})_S \quad \text{OK}$$

BY EQ. (1) $Q = T_S + T_A = 1.208 + 16.336$

$$Q \approx 17.5 \text{ kN·m} \qquad \text{ANS.}$$

2.52 AS IN PROB. 2.51

$$Q - T_S - T_A = 0 \qquad (1)$$

$$\theta = \frac{TL}{JG}$$

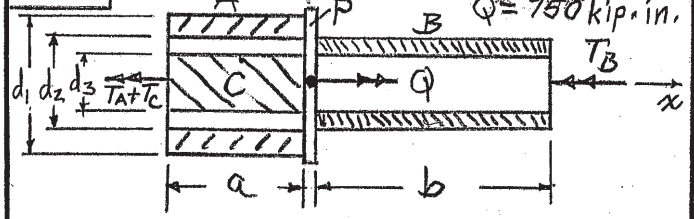
$$\frac{5\pi}{180} = \frac{T_S(0.5)}{(\pi/32)(0.045^4)(75\times10^9)}; \quad T_S = 5.269 \text{ kN·m}$$

$$\frac{5\pi}{180} = \frac{T_A(0.5)}{(\pi/32)(0.12^4-0.08^4)(25\times10^9)}; \quad T_A = 71.283 \text{ kN·m}$$

(1) $\Rightarrow$ $Q = 5.269 + 71.283 = 76.552$

$$\approx 76.6 \text{ kN·m} \qquad \text{ANS.}$$

2.53 $d_1 = 8$ in.; $d_2 = 6$ in.; $d_3 = 3$ in; $a = 6$ in.; $b = 10$ in.



$$\Sigma T_x = 0: \quad 750 - T_A - T_B - T_C = 0 \qquad (1)$$

AT P, $\theta_A = \theta_B = \theta_C$

$$\frac{T_A(6)}{(\pi/32)(8^4-5^4)(4\times10^6)} = \frac{T_B(10)}{(\pi/32)(5^4-3^4)(6\times10^6)} = \frac{T_C(6)}{(\pi/32)(3^4)(10\times10^6)}$$

$$T_B = 0.14105\,T_A \qquad (2)$$

$$T_C = 0.05834\,T_A \qquad (3)$$

(1) $\Rightarrow$ $T_A + 0.14105T_A + 0.05834T_A = 750$

$T_A = 625.318$; $T_B = 88.201$; $T_C = 36.481$

(a) $$\tau_{MAX} = \tau_A = \left(\frac{TR}{J}\right)_A = \frac{625.318(4)}{(\pi/32)(8^4-5^4)}$$

$$= 7.340 \approx 7.3 \text{ ksi} \qquad \text{ANS.}$$

(b) $$\theta_P = \theta_C = \frac{36.481\times10^3(6)}{(\pi/32)(3^4)(10\times10^6)}$$

$$= 0.00273 \text{ rad} \qquad \text{ANS.}$$

2.54 REFER TO THE F.B.D. IN PROB. 2.53. $a = 0.2$ m; $b = 0.3$ m

$d_1 = 250$ mm; $d_2 = 150$ mm; $d_3 = 70$ mm

$$\Sigma T_x = 0 \Rightarrow Q = T_A + T_B + T_C \qquad (1)$$

AT P, $\theta_A = \theta_B = \theta_C$

$$\frac{T_A(0.2)}{(\pi/32)(0.25^4-0.15^4)(25\times10^9)} = \frac{T_B(0.3)}{(\pi/32)(0.15^4-0.07^4)(40\times10^9)} = \frac{T_C(0.2)}{(\pi/32)(0.07^4)(75\times10^9)}$$

$$T_B = 0.1513\,T_A \qquad (2)$$

$$T_C = 0.0212\,T_A \qquad (3)$$

ASSUME $\tau_A = 70$ MPa CONTROLS. THEN,

$$70\times10^6 = \frac{T_A(0.125)}{(\pi/32)(0.25^4-0.15^4)}$$

$T_A = 186.925$ kN·m

(2) $\Rightarrow$ $T_B = 28.282$ kN·m

(3) $\Rightarrow$ $T_C = 3.963$ kN·m

$$\tau_B = \frac{28.282\times10^3(0.075)}{(\pi/32)(0.15^4-0.07^4)} = 44.8 \text{ MPa} < (\tau_{ALL})_B \quad \text{OK}$$

$$\tau_C = \frac{3.963\times10^3(0.035)}{(\pi/32)(0.07^4)} = 58.8 \text{ MPa} < (\tau_{ALL})_C \quad \text{OK}$$

$\therefore$ (1) $\Rightarrow$ $Q = 186.925 + 28.282 + 3.963$

$$= 219.170 \approx 219.2 \text{ kN·m} \qquad \text{ANS.}$$

2.55 REFER TO THE F.B.D. IN PROB. 2.53.

$a = 0.2$ m; $b = 0.3$ m

$d_1 = 250$ mm; $d_2 = 150$ mm; $d_3 = 70$ mm

$$\Sigma T_x = 0 \Rightarrow Q = T_A + T_B + T_C \qquad (1)$$

$$\theta = \frac{TL}{JG}$$

$$\frac{0.5\pi}{180} = \frac{T_A(0.2)}{(\pi/32)(0.25^4-0.15^4)(25\times10^9)}$$

$T_A = 364.113$ kN·m

$$\frac{0.5\pi}{180} = \frac{T_B(0.3)}{(\pi/32)(0.15^4-0.07^4)(40\times10^9)}$$

$T_B = 55.087$ kN·m

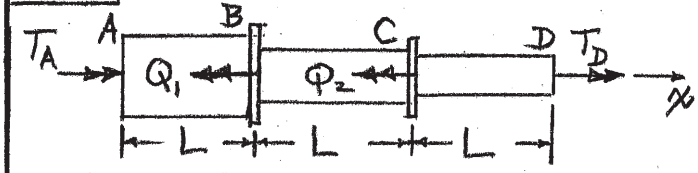
$$\frac{0.5\pi}{180} = \frac{T_C(0.2)}{(\pi/32)(0.07^4)(75\times10^9)}; \quad T_C = 7.713 \text{ kN·m}$$

(1) $\Rightarrow$ $Q = 364.113 + 55.087 + 7.713$

$$= 426.913 \approx 426.9 \text{ kN·m} \qquad \text{ANS.}$$

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2.56 $L=1.5$ ft; $Q_1=10$ kip·ft; $Q_2=15$ kip·ft



$\Sigma T_x=0$: $T_A+T_D-25=0$ ——— (1)

ALSO, $T_{BC}=10-T_A=T_D-15$ ——— (2)

$\theta_{B/A}=\theta_{B/C}+\theta_{C/D}$ $\overset{(2)}{\Rightarrow}$ $T_D=25-T_A$ ——— (3)

$$\frac{T_A(1.5)}{(\pi/32)(2.5^4)(4\times10^3)}=\frac{(10-T_A)(1.5)}{(\pi/32)(1.5^4)(6\times10^3)}+\frac{(25-T_A)(1.5)}{(\pi/32)(1.0^4)(10\times10^3)}$$

$T_A=20.307$; $T_D=4.693$; $T_{BC}=-10.307$

$$\tau_{MAX}=\tau_{CD}=\frac{4.693\times10^3(0.5)}{(\pi/32)(1.0^4)}=23.901$$

$\tau_{MAX}=\tau_{CD}\approx23.9$ ksi ANS.

$$\theta_C=\theta_{C/D}=\frac{4.693\times10^3(1.5\times12)}{(\pi/32)(1.0^4)(10\times10^6)}=86.045\times10^{-3}$$

$\theta_C=\theta_{C/D}\approx0.086$ rad ANS.

2.57 REFER TO THE F.B.D. IN PROB. 2.56

$L=1.0$m; $Q_1=50$ kN·m; $Q_2=75$ kN·m

$\Sigma T_x=0$: $T_A+T_D-125=0$ ——— (1)

ALSO, $T_{BC}=50-T_A=T_D-75$ ——— (2)

(2) $\Rightarrow$ $T_D=125-T_A$ ——— (3)

$\theta_{B/A}=\theta_{B/C}+\theta_{C/D}$

$$\frac{T_A(1.0)}{(\pi/32)d^4(30\times10^9)}=\frac{(50-T_A)(1.0)}{(\pi/32)d^4(30\times10^9)}+\frac{(125-T_A)(1.0)}{(\pi/32)d^4(30\times10^9)}$$

$T_A=58.333$; $T_D=66.667$; $T_{BC}=-8.333$

MINIMUM DIA. CONTROLLED BY SHEARING STRESS IN SEGMENT CD. THUS,

$$120\times10^6=\frac{66.667\times10^{-3}(d/2)}{(\pi/32)d^4};\quad d=0.14144\text{ m}$$

$d_{MIN}\approx141.4$ mm ANS.

2.58 $\Sigma T_{BA}=0$:

$T_{BA}+3F-20=0$ ——— (1)

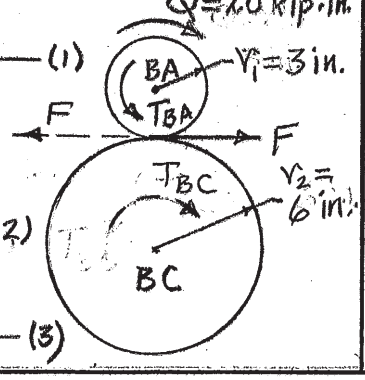
$\Sigma T_{BC}=0$:

$6F-T_{BC}=0$

$F=(\frac{1}{6})T_{BC}$ ——— (2)

(2) INTO (1) $\Rightarrow$

$T_{BA}+(\frac{1}{2})T_{BC}=20$ ——— (3)



2.58 CONT'D

$3\theta_{B/A}=6\theta_{B/C}\Rightarrow\theta_{B/A}=2\theta_{B/C}$ ——— (4)

$$(4)\Rightarrow\frac{T_{BA}(15)}{(\frac{\pi}{32})(1.0^4)(10\times10^3)}=2\left[\frac{T_{BC}(15)}{(\frac{\pi}{32})(2.0^4)(4\times10^3)}\right]$$

$T_{BC}=3.2\,T_{BA}$ ——— (5)

SOLVE (3) & (5) TO GET

$T_{BC}=24.614$; $T_{BA}=7.692$

$$\tau_{AB}=\frac{7.692(0.5)}{(\pi/32)(1.0^4)}\approx39.2\text{ ksi}$$ ANS.

$$\tau_{BC}=\frac{24.614(1.0)}{(\pi/32)(2.0^4)}\approx15.7\text{ ksi}$$ ANS.

2.59 REFER TO THE F.B.D. IN PROB. 2.58

$\Sigma T_{BA}=0$: $T_{BA}+0.1F-Q=0$ ——— (1)

$\Sigma T_{BC}=0$: $0.15F-T_{BC}=0$ ——— (2)

$F=(\frac{1}{0.15})T_{BC}$ ——— (2)

(2) INTO (1) $\Rightarrow$

$T_{BA}+(\frac{1}{1.5})T_{BC}=Q$ ——— (3)

$0.1\theta_{B/A}=0.15\theta_{B/C}$; $\theta_{B/A}=1.5\theta_{B/C}$ ——— (4)

$$\theta_{B/A}=\frac{T_{BA}(0.75)}{(\pi/32)(0.075^4)(50\times10^9)}=4.829\times10^{-6}T_{BA}$$ ——— (5)

$$\theta_{B/C}=\frac{T_{BC}(0.75)}{(\pi/32)(0.075^4)(50\times10^9)}=4.829\times10^{-6}T_{BC}$$ ——— (6)

(5) & (6) INTO (4) $\Rightarrow$ $T_{BA}=1.5\,T_{BC}$ ——— (7)

(7) INTO (3) $\Rightarrow$ $T_{BC}=0.462Q$

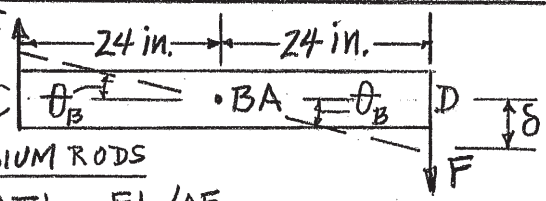
(7) $\Rightarrow$ $T_{BA}=0.692Q$

$\therefore$ SHEARING STRESS IN AB CONTROLS, THUS

$$120\times10^6=\frac{0.692Q(0.0375)}{(\pi/32)(0.075^4)}$$

$Q=14{,}364$ N·m $=14.4$ kN·m ANS.

2.60



MAGNESIUM RODS

$\delta=\alpha\Delta TL-FL/AE$

$=14.5\times10^{-6}(150)(18)-F(18)/(1)(6.5\times10^6)$

$\delta=(39{,}150-2.769F)\times10^{-6}$

$\theta_B=\delta/24=(1{,}631.25-0.11538F)\times10^{-6}$ ——— (1)

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2.60 CONT'D

ALSO, $\theta_B = \left(\frac{TL}{JG}\right)_{BA} = \frac{T_{BA}(36)}{\left(\frac{\pi}{32}\right)(4.0^4 - 3.5^4)(6\times10^6)}$

$\theta_B = 0.5769\,T_{BA}\times10^{-6}$ ——— (2)

$\Sigma T_{BA} = 0$: $T_{BA} - 48F = 0$; $F = \frac{T_{BA}}{48}$ ——— (3)

(3) INTO (1) $\Rightarrow$ $\theta_B = (1631.25 - 0.00240\,T_{BA})\times10^{-6}$ ——— (4)

(2) = (4) $\Rightarrow$

$0.5769\,T_{BA}\times10^{-6} = (1631.25 - 0.00240\,T_{BA})\times10^{-6}$

$T_{BA} = 2815.89$ lb.in. $= 2.816$ kip.in.

$\tau_{BA} = \frac{2.816(2)}{\left(\frac{\pi}{32}\right)(4.0^4 - 3.5^4)} = 0.542$ ksi ANS.

(2) $\Rightarrow$ $\theta_B = 0.5769(2815.89)\times10^{-6}$

$\theta_B = 0.00162$ rad ANS.

2.61 REFER TO THE F.B.D. IN PROB. 2.60.

$\Sigma T_{BA} = 0$: $T_{BA} - 48F = 0$; $F = \frac{T_{BA}}{48}$ ——— (1)

ASSUME $\tau = 7$ ksi CONTROLS

$\tau = 7 = \frac{T_{BA}(1.5)}{\left(\frac{\pi}{32}\right)(3.0^4 - 2.5^4)}$; $T_{BA} = 19.214$ kip.in.

(1) $\Rightarrow$ $F = \frac{19.214}{48} = 0.400$ kip

$\sigma_{ROD} = \frac{F}{A} = \frac{0.400}{\left(\frac{\pi}{4}\right)(0.5^2)} = 2.04 < (\sigma_{ALL})$ OK

∴ ASSUMPTION IS CORRECT.

$\delta = \alpha\Delta T L - FL/AE$

$= 13.0\times10^{-6}\Delta T(15) - \frac{0.400\times10^3(15)}{\left(\frac{\pi}{4}\right)(0.5^2)(10\times10^6)}$

$\delta = (195\Delta T - 3055.775)\times10^{-6}$

$\theta_B = \frac{\delta}{24} = (8.125\Delta T - 127.324)\times10^{-6}$

ALSO, $\theta_B = \left(\frac{TL}{JG}\right)_{BA} = \frac{19.214\times10^3(15)}{\left(\frac{\pi}{32}\right)(3.0^4 - 2.5^4)(4\times10^6)}$

$\theta_B = 17.5\times10^{-3}$ rad

$\therefore 17.5\times10^{-3} = (8.125\Delta T - 127.324)\times10^{-6}$

$\Delta T_{MAX} = 2,170\,^{\circ}F$ ANS.

2.62 $P = T\omega$; $120 = T\left(\frac{900\times2\pi}{60}\right)$

$T = 1.273$ kN·m

$\tau_{MAX} = \frac{Tr}{J} = \frac{1.273\times10^3(0.015)}{(\pi/32)(0.03^4)}$

$= 240.1$ MPa ANS.

$\theta = \frac{TL}{JG} = \frac{1.273\times10^3(1.0)}{(\pi/32)(0.03^4)(70\times10^9)}$

$= 0.229$ rad ANS.

2.63 SHEARING STRESS LIMITATION

$\tau_{ALL} = \frac{Tr}{J}$; $T = \frac{\tau_{ALL}J}{r} = \frac{8\left(\frac{\pi}{32}\right)(2.0^4 - 1.5^4)}{1.0}$

$T = 8.590$ kip.in.

ANGLE OF TWIST LIMITATION

$\theta_{ALL} = \frac{TL}{JG}$; $T = \frac{\theta_{ALL}JG}{L}$

$T = \frac{(4\pi/180)(\pi/32)(2.0^4 - 1.5^4)(4\times10^6)}{3\times12}$

$= 8.329$ kip.in.

∴ ALLOWABLE ANGLE OF TWIST CONTROLS.

$P = T\omega = 8.329\times10^3\left(\frac{600\times2\pi}{60}\right)$

$= 523,327\times10^3$ lb.in./s

$= 79.3$ hp ANS.

2.64 $P = T\omega$; $T = \frac{P}{\omega} = \frac{30\times10^3\times60}{1200(2\pi)}$

$T = 238.732$ N·m

SHEARING STRESS LIMITATION

$\tau_{ALL} = \frac{TR}{J}$; $\frac{J}{R} = \frac{T}{\tau_{ALL}}$

$\frac{(\pi/32)d^4}{d/2} = \frac{238.732}{50\times10^6}$; $d = 0.02897$ m

ANGLE OF TWIST LIMITATION

$\theta_{ALL} = \frac{TL}{JG}$; $J = \frac{TL}{\theta_{ALL}G}$

$\left(\frac{\pi}{32}\right)d^4 = \frac{238.732(0.50)}{(0.08)(75\times10^9)}$

$d = 0.0212$ m

$\therefore d_{MIN} = 0.02897$ m ≈ 29.0 mm ANS.

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2.65 $P = T\omega$; $T = \frac{P}{\omega} = \frac{20\times10^3\times60}{1000\times2\pi}$

$T = 190.986$ N·m

SHEARING STRESS LIMITATION

$\tau_{ALL} = \frac{TR}{J}$; $J = \frac{TR}{\tau_{ALL}}$

$(\frac{\pi}{32})(0.05^4 - d_i^4) = \frac{190.986(0.025)}{65\times10^6}$

$d_i = 0.0484$ m $= 48.4$ mm

ANGLE OF TWIST LIMITION

$\theta_{ALL} = \frac{TL}{JG}$; $J = \frac{TL}{\theta_{ALL}G}$

$(\frac{\pi}{32})(0.05^4 - d_i^4) = \frac{190.986(0.75)}{0.07(75\times10^9)}$

$d_i = 0.0494$ m $= 49.4$ mm

$\therefore (d_i)_{MAX} = 48.4$ mm ANS.

2.66 $P = T\omega$; $T = \frac{P}{\omega} = \frac{20(6600)60}{600\times2\pi}$

$T = 2100.845$ lb.in.

$\tau_{ALL} = \frac{Tr}{J}$; $J = \frac{Tr}{\tau_{ALL}}$

$(\frac{\pi}{32})d^4 = \frac{2100.845(d/2)}{15\times10^3}$

$d_{MIN} = 0.893$ in. ANS.

2.67 $P = T\omega$; $\omega = P/T$ ——(1)

SHEARING STRESS LIMITATION

$\tau_{ALL} = \frac{TR}{J}$; $T = \frac{\tau_{ALL}J}{R}$

$T = \frac{25\times10^6(\pi/32)(0.055^4)}{(0.055/2)}$

$T = 816.691$ N·m

ANGLE OF TWIS LIMITATION

$\theta_{ALL} = \frac{TL}{JG}$; $T = \frac{\theta_{ALL}JG}{L}$

$T = \frac{(3\pi/180)(\pi/32)(0.055^4)(26\times10^9)}{(1)}$

$T = 1,222$ N·m

$\therefore$ SHEARING STRESS CONTROLS. THUS

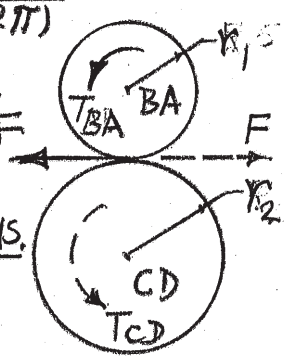
(1) $\Rightarrow$ $\omega = \frac{150\times10^3}{816.691} = 183.668$ rad/s

$= 1753.9$ rpm ANS.

2.68 $P = T\omega$; $r_1 = 2.5$ in.; $r_2 = 4.0$ in.

$T_{BA} = \frac{P}{\omega} = \frac{20(6600)(60)}{300(2\pi)}$

$T_{BA} = 4201.690$ lb.in.



$(\tau_{MAX})_{BA} = \frac{4201.690(0.75)}{\frac{\pi}{32}(1.54)}$

$(\tau_{MAX})_{BA} = 6.3$ ksi ANS.

$\theta_{BA} = \frac{4201.690(4\times12)}{(\frac{\pi}{32})(1.5^4)(4\times10^6)}$

$\theta_{BA} = 0.101$ rad ANS.

$F = \frac{T_{BA}}{r_1} = \frac{4201.690}{2.5} = 1680.676$ lb

$\therefore \frac{T_{CD}}{r_2} = 1680.676$; $T_{CD} = 1680.676(4.0)$

$T_{CD} = 6722.704$ lb.in.

$(\tau_{MAX})_{CD} = \frac{6722.704(0.75)}{(\frac{\pi}{32})(1.54)} = 10.1$ ksi ANS.

$\theta_{CD} = \frac{6722.704(3\times12)}{(\frac{\pi}{32})(1.5^4)(4\times10^6)} = 0.12174$ rad ANS.

2.69 REFER TO THE F.B.D. IN PROB. 2.68.

$P = T\omega$; $T_{BA} = \frac{P}{\omega} = \frac{10\times10^3\times60}{400(2\pi)}$

$T_{BA} = 2.387\times10^2$ N·m.

$(\tau_{ALL})_{BA} = (\frac{Tr}{J})_{BA}$; $\frac{J}{r} = \frac{T}{\tau_{ALL}} = \frac{2.387\times10^2}{50\times10^6}$

$\frac{J}{r} = 4.774\times10^{-6}$

$(\frac{\pi}{32})(\frac{d^4}{d/2}) = 4.774\times10^{-6}$

$d_{BA} = 0.02897$ m ≈ 29.0 mm ANS.

$F = \frac{T_{BA}}{r_1} = \frac{2.387\times10^2}{0.04} = 5967.5$ N

$\therefore \frac{T_{CD}}{r_2} = 5967.5$; $T_{CD} = 5967.5(0.075)$

$T_{CD} = 447.6$ N·m

$(\tau_{ALL})_{CD} = (\frac{TR}{J})_{CD}$; $\frac{J}{R} = \frac{T}{\tau_{ALL}} = \frac{447.6}{50\times10^6}$

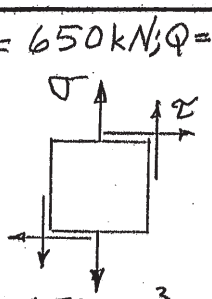
$\frac{J}{R} = 8.952\times10^{-6}$

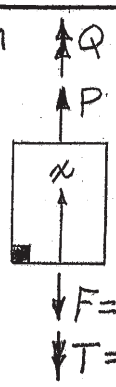
$(\frac{\pi}{32})(\frac{d^4}{d/2}) = 8952\times10^{-6}$

$d_{CD} = 0.03572$ m ≈ 35.7 mm ANS.

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2.70 $P = 650\text{ kN}; Q = 20\text{ kN·m}$





$$\sigma = \frac{F}{A} = \frac{650\times10^3}{(\pi/4)(0.12^2)}$$

$\sigma = 57.473 \approx 57.5\text{ MPa}$ ANS.

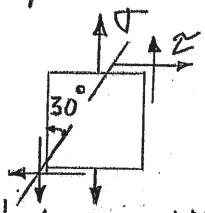
$$\tau = \frac{TR}{J} = \frac{20\times10^3(0.06)}{(\pi/32)(0.12^4)} = 58.946 \approx 58.9\text{ MPa}$$ ANS.

2.71 REFER TO THE F.B.D. IN PROB. 2.70.

$P = 150\text{ kips}; Q = 150\text{ kip·in.}$

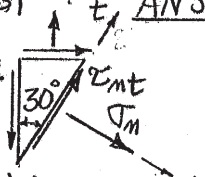
(a) $$\sigma = \frac{F}{A} = \frac{150}{(\pi/4)(5^2)}$$

$\sigma = 7.639 \approx 7.6\text{ ksi}$ ANS.



$$\tau = \frac{TR}{J} = \frac{150(2.5)}{(\pi/32)(5^4)} = 6.112 \approx 6.1\text{ ksi}$$ ANS.

(b) LET A_n BE AREA OF INCLINED PLANE.



$\Sigma F_n = 0$

$\sigma_n A + \tau(A_n\cos30)\sin30 + \tau(A_n\sin30)\cos30 - \sigma(A_n\sin30)\sin30 = 0$

$\sigma_n = \sigma\sin^2 30 - 2\tau\sin30\cos30$

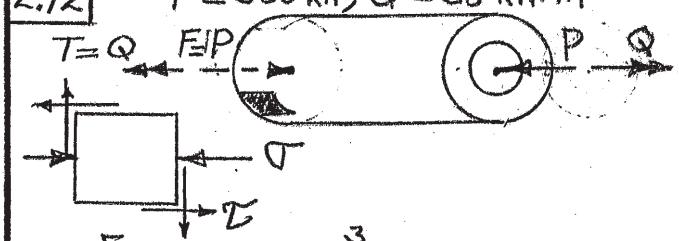
$\sigma_n = -3.383 \approx -3.4\text{ ksi}$ ANS.

$\Sigma F_t = 0: \tau_{nt}A_n - \tau(A_n\cos30)\cos30 + \tau(A_n\sin30)\sin30 + \sigma(A_n\sin30)\cos30 = 0$

$\tau_{nt} = \tau(\cos^2 30 - \sin^2 30) - \sigma\sin30\cos30$

$\tau_{nt} = -0.252 \approx -0.3\text{ ksi}$ ANS.

2.72 $P = 500\text{ kN}; Q = 30\text{ kN·m}$



$$\sigma = \frac{F}{A} = \frac{500\times10^3}{(\pi/4)(0.15^2 - 0.006^2)} = 28,340$$

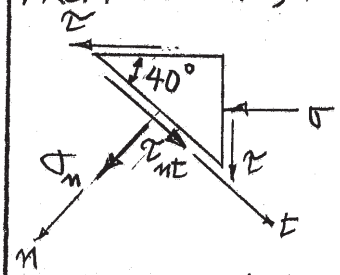
$\sigma \approx 28.3\text{ MPa}$ ANS.

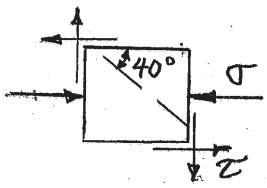
$$\tau = \frac{TR}{J} = \frac{30\times10^3(0.075)}{(\pi/32)(0.15^4 - 0.006^4)} = 45.271$$

$\tau \approx 45.3\text{ MPa}$ ANS.

2.73 REFER TO THE F.B.D. IN PROB. 2.72.

FROM PROB. 2.72; $\sigma = 28,340\text{ MP}; \tau = 45.271\text{ MPa}$.





LET A_n BE AREA OF INCLINED PLANE.

$\Sigma F_n = 0: \sigma_n A_n + \tau(A_n\cos40)\sin40 + \tau(A_n\sin40)\cos40 + \sigma(A_n\sin40)\sin40 = 0$

$\sigma_n = -2\tau\sin40\cos40 - \sigma\sin^2 40$

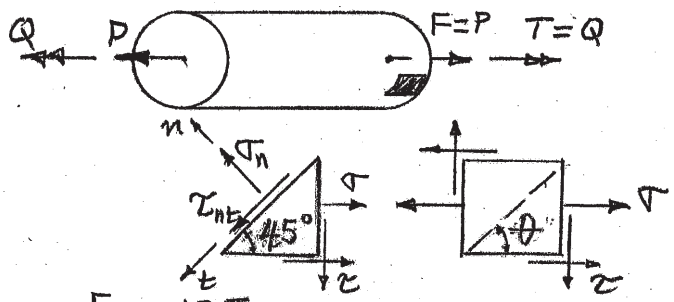
$= -56.293 \approx -56.3\text{ MPa}$ ANS.

$\Sigma F_t = 0: \tau_{nt}A_n + \tau(A_n\cos40)\cos40 + \tau(A_n\sin40)\sin40 - \sigma(A_n\sin40)\cos40 = 0$

$\tau_{nt} = \sigma\sin40\cos40 + \tau(\cos^2 40 - \sin^2 40)$

$= 21.816 \approx 21.8\text{ MPa}$ ANS.

2.74 $P = 125\text{ kips}; Q = 150\text{ kip·in.}; \theta = 45°$



$$\sigma = \frac{F}{A} = \frac{125}{(\pi/4)(3.5^2)} = 12.992\text{ ksi}$$

$$\tau = \frac{TR}{J} = \frac{150(1.75)}{(\pi/32)(3.5^4)} = 17.818\text{ ksi}$$

LET A_n BE AREA OF INCLINED PLANE.

$\Sigma F_n = 0; \sigma_n A_n - \sigma(A_n\sin45)\sin45 - \tau(A_n\sin45)\cos45 - \tau(A_n\cos45)\sin45 = 0$

$\sigma_n = \sigma\sin^2 45 + 2\tau\sin45\cos45$

$= 24.314 \approx 24.3\text{ ksi}$ ANS.

$\Sigma F_t = 0: \tau_{nt}A_n - \sigma(A_n\sin45)\cos45 + \tau(A_n\sin45)\sin45 - \tau(A_n\cos45)\cos45 = 0$

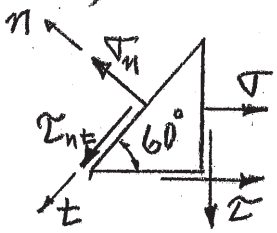
$\tau_{nt} = \sigma\sin45\cos45 + \tau(\cos^2 45 - \sin^2 45)$

$= 6.496 \approx 6.5\text{ ksi}$ ANS.

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2.75 REFER TO THE F.B.D. IN PROB. 2.74.

$P = 600\ kN;\ Q = 20\ kN\cdot m;\ \theta = 60°.$



$$\sigma = \frac{F}{A} = \frac{600\times10^3}{\frac{\pi}{4}(0.1^2)} = 76.394\ MPa$$

$$\tau = \frac{TR}{J} = \frac{20\times10^3(0.05)}{\frac{\pi}{32}(0.1^4)} = 101.859\ MPa$$

LET A_n BE AREA OF INCLINED PLANE.

$\Sigma F_n = 0: \sigma_n A_n - \sigma(A_n\sin60)\sin60 - \tau(A_n\sin60)\cos60 - \tau(A_n\cos60)\sin60 = 0$

$\sigma_n = \sigma\sin^2 60 + 2\tau\sin60\cos60$

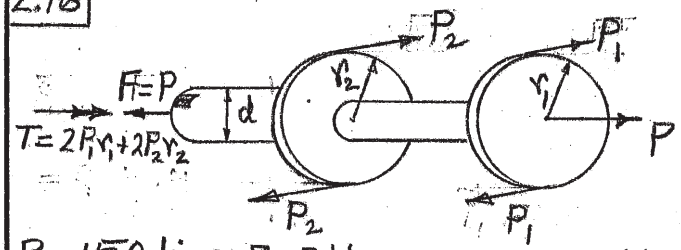
$= 145.508 \approx 145.5\ MPa$ ANS.

$\Sigma F_t = 0: \tau_{nt}A_n - \sigma(A_n\sin60)\cos60 + \tau(A_n\sin60)\sin60 - \tau(A_n\cos60)\cos60 = 0$

$\tau_{nt} = \sigma\sin60\cos60 + \tau(\cos^2 60 - \sin^2 60)$

$= -17.850 \approx -17.9\ MPa$ ANS.

2.76

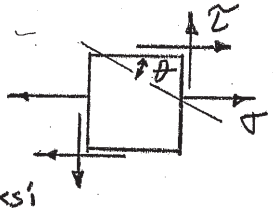


$P = 150\ kips;\ P_1 = 2\ kips;$

$P_2 = 3\ kips;\ r_1 = 0.75\ ft;$

$r_2 = 1.0\ ft.;\ d = 4\ in.;$

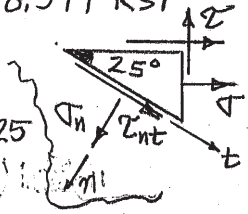
$\theta = 25°;\ T = 9\ kip\cdot ft$



$$\sigma = \frac{F}{A} = \frac{150}{\frac{\pi}{4}(4^2)} = 11.937\ ksi$$

$$\tau = \frac{TR}{J} = \frac{9(12)(2)}{\frac{\pi}{32}(4^4)} = 8.594\ ksi$$

LET A_n BE AREA OF INCLINED PLANE.



$\Sigma F_n = 0: \sigma_n A_n - \tau(A_n\cos25)\sin25 - \tau(A_n\sin25)\cos25 - \sigma(A_n\sin25)\sin25 = 0$

$\sigma_n = 2\tau\sin25\cos25 + \sigma\sin^2 25$

$= 8.715\ ksi \approx 8.7\ ksi$ ANS.

$\Sigma F_t = 0: \tau_{nt}A_n + \tau(A_n\cos25)\cos25 - \tau(A_n\sin25)\sin25 + \sigma(A_n\sin25\cos25) = 0$

$\tau_{nt} = \tau(\sin^2 25 - \cos^2 25) - \sigma\sin^2 25$

$= -7.656 \approx -7.7\ ksi$ ANS.

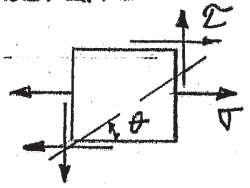
2.77 REFER TO F.B.D. IN PROB. 2.76.

$P = 550\ kN;\ P_1 = 8\ kN;$

$P_2 = 12\ kN;\ r_1 = 0.375\ m;$

$r_2 = 0.25\ m;\ d = 120\ mm;$

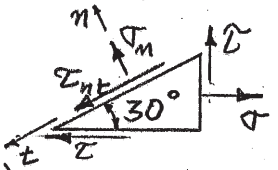
$\theta = 30°;\ T = 12\ kN\cdot m.$



$$\sigma = \frac{F}{A} = \frac{550\times10^3}{\frac{\pi}{4}(0.12^2)} = 48.631\ MPa$$

$$\tau = \frac{TR}{J} = \frac{12(10^3)(0.06)}{\frac{\pi}{32}(0.12^4)} = 35.368\ MPa$$

LET A_n BE AREA OF INCLINED PLANE.



$\Sigma F_n = 0: \sigma_n A_n - \sigma(A_n\sin30)\sin30 + \tau(A_n\sin30)\cos30 + \tau(A_n\cos30)\sin30 = 0$

$\sigma_n = \sigma\sin^2 30 - 2\tau\sin30\cos30$

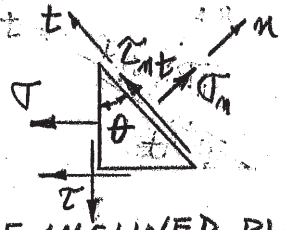
$= -18.472 \approx -18.5\ MPa$ ANS.

$\Sigma F_t = 0: \tau_{nt}A_n - \sigma(A_n\sin30)\cos30 - \tau(A_n\sin30)\sin30 + \tau(A_n\cos30)\cos30 = 0$

$\tau_{nt} = \sigma\sin30\cos30 + \tau(\sin^2 30 - \cos^2 30)$

$= 3.374 \approx 3.4\ MPa$ ANS.

2.78



$\sigma_n = 15\ ksi$

$\tau_{nt} = 10\ ksi$

$\theta = 35°$

LET A_n BE AREA OF INCLINED PLANE.

$\Sigma F_n = 0: 15A_n - \sigma(A_n\cos35)\cos35 - \tau(A_n\cos35)\sin35 - \tau(A_n\sin35)\cos35 = 0$

$0.6710\sigma + 0.9397\tau = 15 \quad (1)$

$\Sigma F_t = 0: 10A_n + \sigma(A_n\cos35)\sin35 - \tau(A_n\cos35)\cos35 + \tau(A_n\sin35)\sin35 = 0$

$-0.4698\sigma + 0.3420\tau = 10 \quad (2)$

SOLVE (1) & (2) TO GET

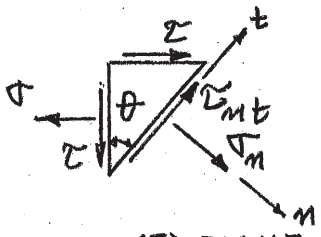
$\sigma = -6.357 \approx -6.4\ ksi$ ANS.

$\tau = 20.504 \approx 20.5\ ksi$ ANS.

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2.79

$\sigma_n = 150$ MPa
$\tau_{nt} = 100$ MPa
$\theta = 40°$



LET A_n BE AREA OF INCLINED PLANE.

$\Sigma F_n = 0$: $150A_n - \sigma(A_n\cos 40)\cos 40 + \tau(A_n\cos 40)\sin 40 + \tau(A_n\sin 40)\cos 40 = 0$

$0.5868\sigma - 0.9848\tau = 150$ ——— (1)

$\Sigma F_t = 0$: $100A_n - \sigma(A_n\cos 40)\sin 40 - \tau(A_n\cos 40)\cos 40 + \tau(A_n\sin 40)\sin 40 = 0$

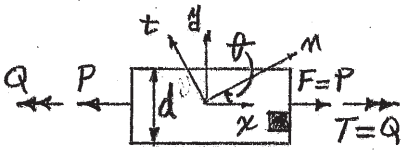
$0.4924\sigma + 0.1736\tau = 100$ ——— (2)

SOLVE (1) & (2) TO GET

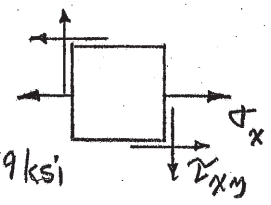
$\sigma = 212.207 \approx 212.2$ MPa ANS.

$\tau = -25.869 \approx -25.9$ MPa ANS.

2.80



$P = 60$ kips
$Q = 30$ kip.in.
$d = 2$ in.
$\theta = 30°$



$\sigma_x = \frac{F}{A} = \frac{60}{\frac{\pi}{4}(2^2)} = 19.099$ ksi

$\tau_{xy} = \frac{TR}{J} = \frac{30(1)}{\frac{\pi}{32}(2^4)} = 19.099$ ksi

$\epsilon_x = \frac{1}{E}(\sigma_x - \nu\sigma_y) = \frac{1}{30\times10^3}(19.099 - 0)$

$= 0.6366\times10^{-3} = 636.6\,\mu$ ANS.

$\epsilon_y = \frac{1}{E}(\sigma_y - \nu\sigma_x) = \frac{1}{30\times10^3}(0 - 0.33\times19.099)$

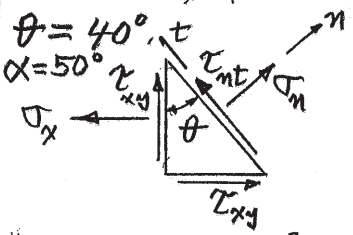
$= -0.2101\times10^{-3} = 210.1\,\mu$ ANS.

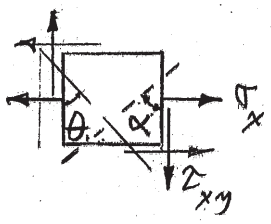
$\gamma_{xy} = \frac{\tau_{xy}}{G} = \frac{\tau_{xy}}{E/2(1+\nu)} = \frac{19.099}{30\times10^3/2(1+0.33)}$

$= 1.6934\times10^{-3} = 1693.4\,\mu$ ANS.

2.81 REFER TO THE F.B.D. IN PROB. 2.80.

$P = 150$ kN; $Q = 5$ kN.m; $d = 60$ mm;
$\theta = 40°$, $\alpha = 50°$





$\sigma_x = \frac{F}{A} = \frac{150\times10^3}{\frac{\pi}{4}(0.06^2)} = 53.052$ MPa

$\tau_{xy} = \frac{TR}{J} = \frac{5\times10^3(0.03)}{(\pi/32)(0.06^4)} = 117.893$ MPa

LET A_n BE AREA OF INCLINED PLANE.

$\Sigma F_n = 0$: $\sigma_n A_n - \sigma_x(A_n\cos^2 40) + \tau_{xy}(A_n\cos 40)\sin 40 + \tau_{xy}(A_n\sin 40)\cos 40 = 0$

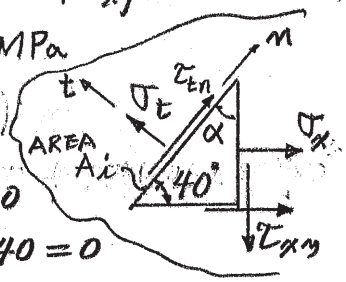
$\sigma_n = \sigma_x\cos^2 40 - 2\tau_{xy}\sin 40\cos 40$

$\sigma_n = -84.970$ MPa

$\Sigma F_t = 0$: $\tau_{nt}A_n + \tau_{xy}(A_n\cos^2 40) - \tau_{xy}(A_n\sin^2 40) + \sigma_x(A_n\cos 40)\sin 40 = 0$

$\tau_{nt} = -\sigma_x\sin 40\cos 40 + \tau_{xy}(\sin^2 40 - \cos^2 40)$

$\tau_{nt} = -46.595$ MPa



$\Sigma F_{t_{11}} = 0$:

$\sigma_t A_i - \sigma_x(A_i\sin^2 40) - \tau_{xy}(A_i\sin 40)\cos 40 - \tau_{xy}(A_i\cos 40)\sin 40 = 0$

$\sigma_t = \sigma_x\sin^2 40 + 2\tau_{xy}\sin 40\cos 40$

$= 138.022$ MPa

(a) $\epsilon_n = \frac{1}{E}(\sigma_n - \nu\sigma_t)$

$= \frac{1}{75\times10^9}[-84.970 - (0.28)(138.022)]\times10^6$

$= -1.648\times10^{-3} = -1648\,\mu$ ANS.

$\epsilon_t = \frac{1}{E}(\sigma_t - \nu\sigma_n)$

$= \frac{1}{75\times10^9}[138.022 - (0.28)(-84.970)]\times10^6$

$= 2.158\times10^{-3} = 2158\,\mu$ ANS.

(b) $\gamma_{nt} = \frac{\tau_{nt}}{G} = \frac{\tau_{nt}}{E/2(1+\nu)} = \frac{-46.595\times10^6}{75\times10^9/2(1+0.28)}$

$= -1.590\times10^{-3} = +1590\,\mu$ ANS.

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2.82 REFER TO THE F.B.D. IN PROB. 2.80.

$\epsilon_x = 400\,\mu$; $\epsilon_y = -120\,\mu$; $\gamma_{xy} = 800\,\mu$

$$\sigma_x = \frac{E}{1-\mu^2}(\epsilon_x + \mu\epsilon_y)$$
$$= \left(\frac{10\times10^6}{1-0.3^2}\right)[400+0.3(-120)]\times10^{-6}$$
$$= 4{,}000 \text{ psi}$$

$$\sigma_y = \frac{E}{1-\mu^2}(\epsilon_y + \mu\epsilon_x)$$
$$= \left(\frac{10\times10^6}{1-0.3^2}\right)[-120+0.3(400)]\times10^{-6}$$
$$= 0$$

$$P = F = \sigma_x A = 4{,}000\left(\frac{\pi}{4}\right)(2.5^2)$$
$$= 19{,}634.95 \text{ lb} \approx 19.6 \text{ kips} \quad \text{ANS.}$$

$$\tau_{xy} = \gamma_{xy} G = \gamma_{xy}\left(\frac{E}{2(1+\mu)}\right)$$
$$= 800\times10^{-6}\left(\frac{10\times10^6}{2(1+0.3)}\right) = 3{,}077 \text{ psi}$$

$$Q = T = \frac{\tau_{xy} J}{R} = \frac{3{,}077(\pi/32)(2.5^4)}{1.25}$$
$$= 9440.1 \text{ lb.in.} \approx 9.4 \text{ kip.in.} \quad \text{ANS.}$$

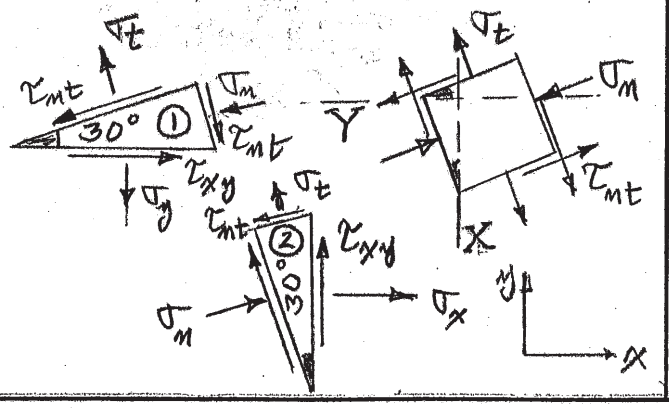
2.83 REFER TO THE F.B.D. IN PROB. 2.80.

$\epsilon_m = -336.3\,\mu$; $\epsilon_t = 858.6\,\mu$; $\gamma_{mt} = -1{,}939.8\,\mu$; $\theta = 30°$.

$$\sigma_m = \frac{E}{1-\mu^2}(\epsilon_m + \mu\epsilon_t) = \frac{200\times10^9}{1-0.3^2}[-336.3+0.3(858.6)]\times10^{-6}$$
$$= -17.301 \text{ MPa}$$

$$\sigma_t = \frac{E}{1-\mu^2}(\epsilon_t + \mu\epsilon_m) = \frac{200\times10^9}{1-0.3^2}[858.6+0.3(-336.3)]\times10^{-6}$$
$$= 166.530 \text{ MPa}$$

$$\tau_{mt} = G\gamma_{mt} = \left(\frac{E}{2(1+\mu)}\right)\gamma_{mt}$$
$$= \left(\frac{200\times10^9}{2(1+0.3)}\right)(-1{,}939.8)\times10^{-6} = -149.215 \text{ MPa}$$



2.83 CONT'D

F.B.D. ①: A IS AREA OF Y PLANE.

$\Sigma F_y = 0$

$$\sigma_y A + \tau_{mt}(A\cos30)\sin30 - \sigma_t(A\cos^2 30) + \sigma_m(A\sin^2 30) + \tau_{mt}(A\cos30)\sin30 = 0$$

$$\sigma_y = \sigma_t\cos^2 30 - \sigma_m\sin^2 30 - 2\tau_{mt}\sin30\cos30$$
$$= -0.001 \approx 0 \quad \text{OK}$$

F.B.D. ②: A IS AREA OF X PLANE.

$\Sigma F_x = 0$: $\sigma_x A + \sigma_m(A\cos^2 30) - \tau_{mt}(A\cos30)\sin30 - \tau_{mt}(A\sin30)\cos30 - \sigma_t(A\sin^2 30) = 0$

$$\sigma_x = 2\tau_{mt}\sin30\cos30 + \sigma_t\sin^2 30 - \sigma_m\cos^2 30$$
$$= -74.616 \text{ MPa}$$

$\Sigma F_y = 0$: $\tau_{xy} A + \sigma_t(A\sin30)\cos30 - \tau_{mt}(A\sin^2 30) + \sigma_m(A\cos30)\sin30 + \tau_{mt}(A\cos^2 30) = 0$

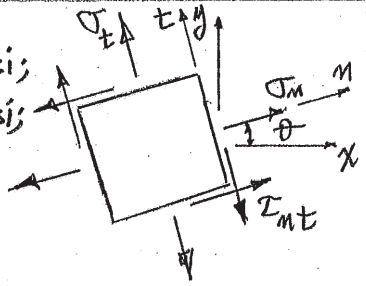
$$\tau_{xy} = \tau_{mt}(\sin^2 30 - \cos^2 30) - \sigma_t\sin30\cos30 - \sigma_m\sin30\cos30$$
$$= -9.989 \text{ MPa}$$

$$P = F = \sigma_x A = -74.616\left(\frac{\pi}{4}\right)(0.08^2)(10^6)$$
$$= -375.061 \approx -375.1 \text{ kN} \quad \text{ANS.}$$

$$Q = T = \frac{\tau_{xy} J}{R} = \frac{-9.989\,(10^6)(\pi/32)(0.08^4)}{0.04}$$
$$= -1.004 \approx -1.0 \text{ kN.m} \quad \text{ANS.}$$

2.84

$\sigma_m = 60$ ksi; $\sigma_t = -30$ ksi; $\tau_{mt} = 20$ ksi; $E = 10\times10^3$ ksi; $\mu = 0.3$; $\theta = 30°$.



(a)

$$\epsilon_m = \frac{1}{E}(\sigma_m - \mu\sigma_t)$$
$$= \frac{1}{10\times10^3}[60-0.3(-30)] = 0.0069$$
$$= 6{,}900\,\mu \quad \text{ANS.}$$

$$\epsilon_t = \frac{1}{E}(\sigma_t - \mu\sigma_m) = \frac{1}{10\times10^3}[-30-0.3(60)]$$
$$= -0.0048 = -4{,}800\,\mu \quad \text{ANS.}$$

(b)

$$\gamma_{mt} = \frac{\tau_{mt}}{G} = \frac{\tau_{mt}}{E/2(1+\mu)} = \frac{20}{10\times10^3/2(1+0.3)}$$
$$= 0.0052 = 5{,}200\,\mu \quad \text{ANS.}$$

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2.85 REFER TO THE STRESS ELEMENT IN PROB. 2.84.

$\epsilon_n = 500\,\mu;\ \epsilon_t = 400\,\mu;\ \gamma_{nt} = 0;\ \theta = 30^\circ$

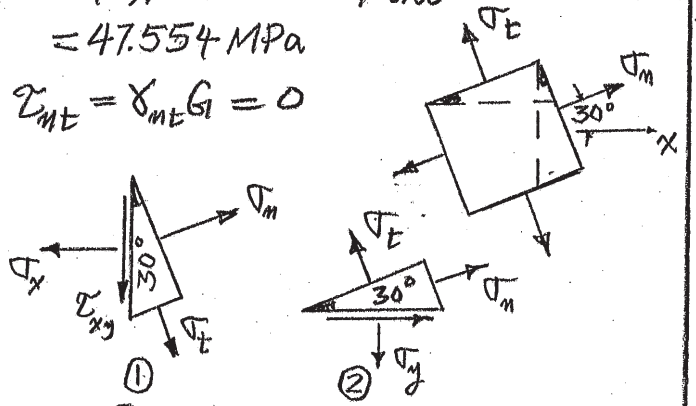
$$\sigma_n = \frac{E}{1-\nu^2}(\epsilon_n + \nu\epsilon_t) = \frac{75\times10^9}{1-0.33^2}[500+0.33(400)]\times10^{-6}$$

$$= 53.193\ \text{MPa}$$

$$\sigma_t = \frac{E}{1-\nu^2}(\epsilon_t + \nu\epsilon_n) = \frac{75\times10^9}{1-0.33^2}[400+0.33(500)]\times10^{-6}$$

$$= 47.554\ \text{MPa}$$

$\tau_{nt} = \gamma_{nt}G = 0$



F.B.D. ①:

$$\Sigma F_x = 0:\ \sigma_x A_x - \sigma_n(A_x\cos^2 30) - \sigma_t(A_x\sin^2 30) = 0$$

$$\sigma_x = \sigma_n\cos^2 30 + \sigma_t\sin^2 30$$

$$= 51.783 \approx 51.8\ \text{MPa} \qquad \text{ANS.}$$

$$\Sigma F_y = 0:\ \tau_{xy}A_x - \sigma_n(A_x\sin 30)\cos 30 + \sigma_t(A_x\sin 30)\cos 30 = 0$$

$$\tau_{xy} = (\sigma_n - \sigma_t)\sin 30\cos 30$$

$$= 2.442 \approx 2.4\ \text{MPa} \qquad \text{ANS}$$

F.B.D. ②:

$$\Sigma F_y = 0:\ \sigma_y A_y - \sigma_t(A_y\cos^2 30) - \sigma_n(A_y\sin^2 30) = 0$$

$$\sigma_y = \sigma_t\cos^2 30 + \sigma_n\sin^2 30$$

$$= 48.964 \approx 49.0\ \text{MPa} \qquad \text{ANS.}$$

2.86 REFER TO THE STRESS ELEMENT IN PROB. 2.84.

$\epsilon_x = 450\,\mu;\ \epsilon_y = 600\,\mu;\ \gamma_{xy} = -500\,\mu;\ \theta = 20^\circ$

$$\sigma_x = \frac{E}{1-\nu^2}(\epsilon_x + \nu\epsilon_y) = \frac{30\times10^3}{1-0.3^2}[450+0.3(600)]\times10^{-6}$$

$$= 20.769\ \text{ksi}$$

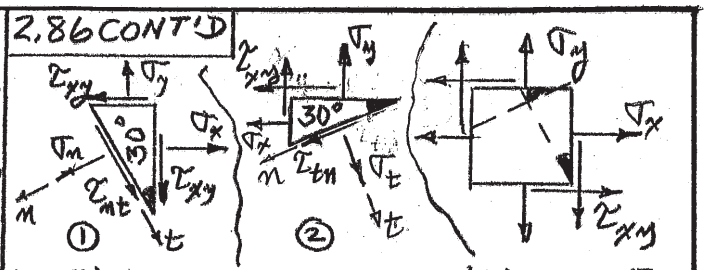
$$\sigma_y = \frac{E}{1-\nu^2}(\epsilon_y + \nu\epsilon_x) = \frac{30\times10^3}{1-0.3^2}[600+0.3(450)]\times10^{-6}$$

$$= 24.231\ \text{ksi}$$

$$\tau_{xy} = \gamma_{xy}G = \gamma_{xy}\left(\frac{E}{2(1+\nu)}\right) = -500(10^{-6})\left(\frac{30\times10^3}{2(1+0.3)}\right)$$

$$= -5.769\ \text{ksi}$$

2.86 CONT'D



LET A_n BE AREA OF INCLINED PLANE.

F.B.D. ①:

$$\Sigma F_n = 0:\ \sigma_n A_n - \sigma_x(A_n\cos^2 20) + \tau_{xy}(A_n\cos 20)\sin 20 + \tau_{xy}(A_n\sin 20)\cos 20 - \sigma_y(A_n\sin^2 20) = 0$$

$$\sigma_n = \sigma_x\cos^2 20 + \sigma_y\sin^2 20 - 2\tau_{xy}\sin 20\cos 20$$

$$= 24.882 \approx 24.9\ \text{ksi} \qquad \text{ANS.}$$

$$\Sigma F_t = 0:\ \tau_{nt}A_n + \tau_{xy}(A_n\cos^2 20) + \sigma_x(A_n\cos 20)\sin 20 - \sigma_y(A_n\sin 20)\cos 20 - \tau_{xy}(A_n\sin^2 20) = 0$$

$$\tau_{nt} = (\sigma_y - \sigma_x)\sin 20\cos 20 + \tau_{xy}(\sin^2 20 - \cos^2 20)$$

$$= 5.532 \approx 5.5\ \text{ksi} \qquad \text{ANS.}$$

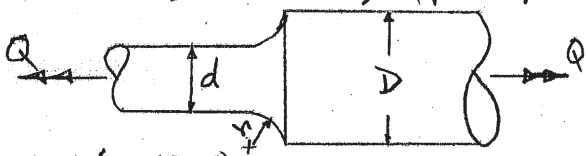
F.B.D. ②:

$$\Sigma F_t = 0:\ \sigma_t A_n - \sigma_y(A_n\cos^2 20) - \tau_{xy}(A_n\cos 20)\sin 20 - \tau_{xy}(A_n\sin 20)\cos 20 - \sigma_x(A_n\sin^2 20) = 0$$

$$\sigma_t = \sigma_x\sin^2 20 + \sigma_y\cos^2 20 + 2\tau_{xy}\sin 20\cos 20$$

$$= 20.118 \approx 20.1\ \text{ksi} \qquad \text{ANS.}$$

2.87 $D = 3.0$ in.; $d = 2.0$ in.; $T = Q = 5$ kip·in.



(a) $r = 0.15$ in.:

$$\frac{D}{d} = 1.5;\quad \frac{r}{d} = 0.075 \Rightarrow k \approx 1.5$$

$$\tau_{max} = k\left(\frac{TR}{J}\right) = 1.5\left(\frac{5(1)}{\frac{\pi}{32}(2^4)}\right)$$

$$= 4.775 \approx 4.8\ \text{ksi} \qquad \text{ANS.}$$

(b) $r = 0.05$ in.:

$$\frac{D}{d} = 1.5;\quad \frac{r}{d} = 0.025 \Rightarrow k \approx 2.0$$

$$\tau_{max} = k\left(\frac{Tr}{J}\right) = 2.0\left(\frac{5(1)}{\frac{\pi}{32}(2^4)}\right)$$

$$= 6.366 \approx 6.4\ \text{ksi} \qquad \text{ANS.}$$

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2.88 REFER TO THE SKETCH IN PROB. 2.87.

$D = 100$ mm; $d = 50$ mm; $\tau_{ALL} = 45$ MPa; $\omega = 1200$ rpm;

(a) $r = 3.0$ mm

$\frac{D}{d} = 2$; $\frac{r}{d} = 0.06 \Rightarrow k \approx 1.65$

$\tau_{MAX} = k\left(\frac{TR}{J}\right)$; $T = \frac{\tau_{MAX} J}{kR}$

$T = \frac{45\times10^6(\pi/32)(0.05^4)}{1.65(0.025)} = 0.669$ kN·m

$P = T\omega = 0.669\left(\frac{1200(2\pi)}{60}\right) = 84.1$ kW ANS.

(b) $r = 1.0$ mm

$\frac{D}{d} = 2$; $\frac{r}{d} = 0.02 \Rightarrow k \approx 3.20$

$T = \frac{45\times10^6(\pi/32)(0.05^4)}{3.20(0.025)} = 0.345$ kN·m

$P = T\omega = 0.345\left(\frac{1200(2\pi)}{60}\right) = 43.4$ kW ANS.

2.89 REFER TO THE SKETCH IN PROB. 2.87.

$D = 2.0$ in.; $d = 1.0$ in.;

$\tau_{MAX} = k\left(\frac{TR}{J}\right)$; $T = \frac{\tau_{MAX} J}{kR}$

$T = \frac{10\times10^3(\pi/32)(1.0^4)}{k(0.5)} = \frac{1963.5}{k}$ —(1)

$P = T\omega$; $T = \frac{P}{\omega} = \frac{15(6600)}{900(2\pi/60)}$

$T = 1050.4$ lb·in. —(2)

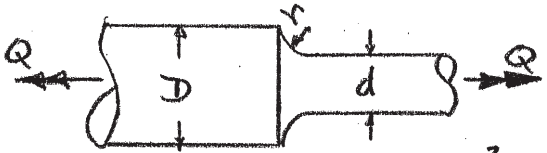
EQUATE (1) & (2) TO GET $k = 1.87$.

ALSO, $\frac{D}{d} = 2.0 \Rightarrow \frac{r}{d} \approx 0.03$

$\therefore r \approx 0.03d \approx 0.03(1.0)$

≈ 0.03 in. ANS.

2.90 $d = 70$ mm; $r = 4$ mm



$P = T\omega$; $T = \frac{P}{\omega} = \frac{50\times10^3}{180(2\pi/60)}$

$T = 2652.6$ N·m

$\tau_{MAX} = k\left(\frac{TR}{J}\right)$; $k = \frac{\tau_{MAX} J}{TR}$

$k = \frac{60\times10^6(\pi/32)(0.07^4)}{2652.6(0.035)} = 1.52$

2.90 CONT'D

$\frac{r}{d} = 0.057 \Rightarrow \frac{D}{d} \approx 1.25$

$D = 1.25d = 87.5$ mm ANS.

2.91 REFER TO THE SKETCH IN PROB. 2.90.

$D = 3.0$ in.; $d = 2.0$ in.

$P = T\omega$; $T = \frac{P}{\omega} = \frac{50(6600)}{600(2\pi/60)}$

$T = 5252.1$ lb·in.

$\tau_{MAX} = k\left(\frac{TR}{J}\right)$; $k = \frac{\tau_{MAX} J}{TR}$

$k = \frac{6\times10^3(\pi/32)(2.0^4)}{5252.1(1.0)} = 1.79$

$\frac{D}{d} = 1.5 \Rightarrow \frac{r}{d} \approx 0.04$

$r \approx 0.04d \approx 0.08$ in. ANS.

2.92 REFER TO THE SKETCH IN PROB. 2.90.

$D = 100$ mm; $d = 70$ mm; $r = 5$ mm

$\frac{D}{d} = 1.43$; $\frac{r}{d} = 0.071 \Rightarrow k \approx 1.55$

$\tau_{MAX} = k\left(\frac{TR}{J}\right)$; $T = \frac{\tau_{MAX} J}{kR}$

$T = \frac{70\times10^6(\pi/32)(0.07^4)}{1.55(0.035)} = 3042$ N·m

$P = T\omega$; $\omega = \frac{P}{T} = \frac{100\times10^3}{3042}$

$\omega = 32.873$ rad/s ≈ 314 rpm ANS.

2.93 $\Delta = \theta b = \left(\frac{TL}{JG}\right)b = \frac{Fb^2L}{JG}$

$\Delta = \frac{F(15^2)(20)}{(\pi/32)(4.0^4-3.0^4)(4\times10^6)} = 65.481\times10^{-6}F$

$0.85W(h+\Delta) = \frac{1}{2}F\Delta$

$0.85(100)(1.2+65.481\times10^{-6}F) = \frac{1}{2}F(65.481\times10^{-6}F)$

$F^2 - 169.997F - 3.115\times10^6 = 0$

$F = 1851.981$ lb

(a) $\tau_{MAX} = \frac{TR}{J} = \frac{FbR}{J} = \frac{1851.981(15)(2)}{(\pi/32)(4.0^4-3.0^4)}$

$= 3233.8$ psi ≈ 3.2 ksi ANS.

(b) $\theta = \frac{TL}{JG} = \frac{1851.981(20)}{(\pi/32)(4.0^4-3.0^4)(4\times10^6)}$

$= 5.340\times10^{-4} \approx 0.00053$ rad ANS.

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2.94

$\tau_{MAX} = \frac{TR}{J}$; $T_1 = \frac{\tau_{MAX} J}{R}$

$T_1 = \frac{100\times10^6(\pi/32)(0.05^4)}{0.025} = 2454.4$ N·m

$\theta_{MAX} = \frac{TL}{JG_1}$; $T_2 = \frac{\theta_{MAX} JG_1}{L}$

$T_2 = \frac{(5\pi/180)(\pi/32)(0.05^4)(75\times10^9)}{0.75} = 5354$ N·m

$\therefore T_1$ CONTROLS,

NOW, $T = Fb$; $F = \frac{T}{b}$

$F = \frac{2454.4}{1.25} = 1963.5$ N

$\Delta = \theta b = \left(\frac{TL}{JG_1}\right)b = \left(\frac{(Fb)L}{JG_1}\right)b = \frac{Fb^2L}{JG_1}$

$W(h+\Delta) = \frac{1}{2}F\Delta$; $W\left(h+\frac{Fb^2L}{JG_1}\right) = \frac{1}{2}\left(\frac{F^2b^2L}{JG_1}\right)$

$W\left[0.075 + \frac{1963.5(1.25^2)(0.75)}{(\pi/32)(0.05^4)(75\times10^9)}\right] = \frac{1}{2}\left[\frac{1963.5^2(1.25^2)(0.75)}{(\pi/32)(0.05^4)(75\times10^9)}\right]$

$W = 392.7$ N ANS.

2.95

$\tau_{MAX} = \frac{TR}{J}$; $T_1 = \frac{\tau_{MAX} J}{R}$

$T_1 = \frac{12(\pi/32)(6.0^4-5.5^4)}{3} = 149.6$ kip·in.

$\theta_{MAX} = \frac{TL}{JG}$; $T_2 = \frac{\theta_{MAX} JG}{L}$

$T_2 = \frac{0.2(\pi/32)(6.0^4-5.5^4)(4\times10^3)}{3(12)} = 831.1$ kip·in.

$\therefore T_1$ CONTROLS,

NOW, $T = Fb$; $F = \frac{T}{b}$

$F = \frac{149.6}{5(12)} = 2.493$ kips ≈ 2493 lb

AS IN PROB. 2.94, $\Delta = \frac{Fb^2L}{JG_1}$.

$W\left(h+\frac{Fb^2L}{JG}\right) = \frac{1}{2}\left(\frac{F^2b^2L}{JG}\right)$

$150\left[h + \frac{2493(60^2)(36)}{(\pi/32)(6.0^4-5.5^4)(4\times10^6)}\right] = \frac{1}{2}\left[\frac{2493^2(60^2)(36)}{(\pi/32)(6.0^4-5.5^4)(4\times10^6)}\right]$

$h = 15.788 \approx 15.8$ in. ANS.

2.96 $W(h+\Delta) = \frac{1}{2}F\Delta$

AS IN PROB. 2.94, $\Delta = \frac{Fa^2(L/2)}{JG_1}$

$\Delta = \frac{F(2.5^2)(1.0)}{(\frac{\pi}{32})(0.15^4-0.13^4)(75\times10^9)} = 3.847\times10^{-6}F$

$\therefore 800(0.125 + 3.847\times10^{-6}F) = \frac{1}{2}F(3.847\times10^{-6}F)$

$F^2 - 1600F - 51.989\times10^6 = 0$

$F = 8055$ N

$\tau_{MAX} = \frac{TR}{J} = \frac{(Fa)R}{J} = \frac{(8055\times2.5)(0.075)}{(\pi/32)(0.15^4-0.13^4)}$

$= 69.724$ MPa ≈ 69.7 MPa ANS.

$\theta_{MAX} = \frac{TL}{JG} = \frac{(Fa)L}{JG} = \frac{(8055\times2.5)(1.0)}{(\frac{\pi}{32})(0.15^4-0.13^4)(75\times10^9)}$

$= 0.0124$ rad ANS.

2.97 $W(h+\Delta) = \frac{1}{2}F\Delta$

AS IN PROB. 2.94, $\Delta = \frac{Fa^2(L/2)}{JG}$

$\Delta = \frac{F(10\times12)^2(8\times12)}{(\pi/32)d^4(4\times10^6)} = 3,520(F/d^4)$

$\therefore 185[6 + 3.520(F/d^4)] = \frac{1}{2}F[3,520(F/d^4)]$

$1110 + 651.2\left(\frac{F}{d^4}\right) = 1.76\left(\frac{F^2}{d^4}\right)$ ——— (1)

$\tau_{ALL} = \frac{TR}{J} = \frac{(Fa)R}{J}$

$\therefore 12\times10^3 = \frac{F(10\times12)(d/2)}{(\pi/32)d^4}$

$F = 19.635\,d^3$ ——— (2)

(2) INTO (1) $\Rightarrow$ $d^3 - 1.636d - 18.844 = 0$

A TRIAL-& ERROR SOLUTION LEADS TO

$d = 2.865 \approx 2.9$ in. ANS.

2.98 BECAUSE OF SYMMETRY, THE APPLIED TORQUE IS DIVIDED EQUALLY BY THE TWO SEGMENTS OF THE SHAFT. THUS,

$W(h+\Delta) = \frac{1}{2}F\Delta$ WHERE

$\Delta = \left[\frac{(\frac{1}{2}T)L/2}{JG_1}\right]a = \frac{\frac{1}{2}Fa^2(L/2)}{JG}$

$= \frac{F(10\times12)^2(10\times12)}{2(\frac{\pi}{32})(4.0^4-3.5^4)(10\times10^6)} = 8.307\times10^{-3}F$

$\therefore 180(5 + 8.307\times10^{-3}F) = \frac{1}{2}F(8.307\times10^{-3}F)$

$F^2 - 360F - 216,685 = 0$

$F = 679.084$ lb

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2.98 CONT'D

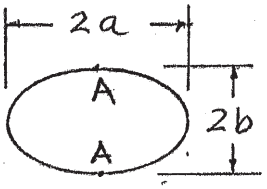
$$\tau = \frac{\frac{1}{2}TR}{J} = \frac{\frac{1}{2}(679.084)(10\times12)(2.0)}{(\pi/32)(4.0^4-3.5^4)}$$

$\tau = 7.835 \approx 7.8$ ksi ANS.

$$\theta = \frac{\frac{1}{2}T(L/2)}{JG} = \frac{\frac{1}{2}(679.084)(10\times12)(10\times12)}{(\pi/32)(4.0^4-3.5^4)(10\times10^6)}$$

$\theta = 0.047$ rad ANS.

2.99 $a = 2$ in.; $b = 1$ in.



(a)

$$\tau_{MAX} = \frac{2T}{\pi a b^2} \text{ AT A.}$$

$$= \frac{2(30)}{\pi(2)(1^2)} = 9.549 \approx 9.5 \text{ ksi ANS}$$

(b)

$$K = \frac{\pi a^3 b^3}{a^2+b^2} = \frac{\pi(2^3)(1^3)}{2^2+1^2} = 5.0265$$

$$\theta = \frac{TL}{KG} = \frac{30(1)}{5.0265(4\times10^3)} = 0.00149 \text{ rad/in. ANS.}$$

2.100 REFER TO THE SKETCH IN PROB. 2.99.

$a = 60$ mm; $b = 40$ mm; $L = 1.5$ m

$$\tau_{MAX} = \frac{2T}{\pi a b^2}; \quad T_1 = \frac{\pi a b^2 \tau_{MAX}}{2}$$

$$T_1 = \frac{\pi(0.06)(0.04^2)(60\times10^6)}{2} = 9.048 \text{ kN·m}$$

$$K = \frac{\pi a^3 b^3}{a^2+b^2} = \frac{\pi(0.06^3)(0.04^3)}{0.06^2+0.04^2} = 8.351\times10^{-6}$$

$$\theta_{MAX} = \frac{TL}{KG}; \quad T_2 = \frac{KG\theta}{L}$$

$$T_2 = \frac{8.351\times10^{-6}(75\times10^9)(12\pi/180)}{1.5} = 7.288 \text{ kN·m}$$

$\therefore \theta_{MAX}$ CONTROLS AND

$Q = T_2 = 7.288 \approx 7.3$ kN·m ANS.

2.101 REFER TO THE SKETCH IN PROB. 2.99.

$a = 3.0$ in.; $b = ?$; $L = 3.5$ ft

$$\tau_{MAX} = \frac{2T}{\pi a b^2}; \quad b = \sqrt{\frac{2T}{\pi a \tau_{MAX}}}$$

$$b = \sqrt{\frac{2(40)}{\pi(3.0)8}} = 1.030 \text{ in.} \quad \text{ANS.}$$

2.102 $T = 2V$ (CONST.)

$$= 2(3.0\times10^{-6})(80\times10^6) = 480 \text{ N·m}$$

$$\tau_{MAX} = \frac{2T}{\pi a b^2} = \frac{2(480)}{\pi(0.035)(0.025^2)}$$

$\tau_{MAX} = 13.969 \approx 14.0$ MPa ANS.

2.102 CONT'D $K = \frac{\pi a^3 b^3}{a^2+b^2}$

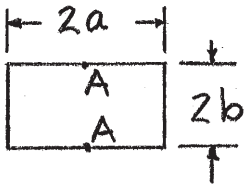
$$K = \frac{\pi(0.035^3)(0.025^3)}{0.035^2+0.025^2} = 1.137\times10^{-6}$$

$$\theta = \frac{TL}{KG_1} = \frac{480(1.5)}{1.137\times10^{-6}(25\times10^9)}$$

$\theta = 0.02533$ rad ANS.

2.103

$a = 50$ mm; $b = 30$ mm



(a) $$\tau_{MAX} = \frac{T(3a+1.8b)}{8a^2b^2}$$

$$\tau_{MAX} = \frac{500[3(0.05)+1.8(0.03)]}{8(0.05^2)(0.03^2)} = 5.667$$

≈ 5.7 MPa AT A ANS.

(b) $$K = ab^3\left[\frac{16}{3} - 3.36\left(\frac{b}{a}\right)\left(1-\frac{b^4}{12a^4}\right)\right]$$

$$K = (0.05)(0.03^3)\left[\frac{16}{3} - 3.36\left(\frac{0.03}{0.05}\right)\left(1-\frac{0.03^4}{12(0.05^4)}\right)\right]$$

$$= 4.507\times10^{-6}$$

$$\theta = \frac{TL}{KG} = \frac{500(1.20)}{4.507\times10^{-6}(30\times10^9)}$$

$\theta = 0.00444$ rad ANS.

2.104 REFER TO THE SKETCH IN PROB. 2.103.

$a = 2.5$ in.; $b = 1.5$ in.; $L = 3$ ft

$$\tau_{MAX} = \frac{T(3a+1.8b)}{8a^2b^2}; \quad T_1 = \frac{8a^2b^2\tau_{MAX}}{(3a+1.8b)}$$

$$T_1 = \frac{8(2.5^2)(1.5^2)(15)}{3(2.5)+1.8(1.5)} = 165.441 \text{ kip·in.}$$

$$K = ab^3\left[\frac{16}{3} - 3.36\left(\frac{b}{a}\right)\left(1-\frac{b^4}{12a^4}\right)\right]$$

$$K = (2.5)(1.5^3)\left[\frac{16}{3} - 3.36\left(\frac{1.5}{2.5}\right)\left(1-\frac{1.5^4}{12(2.5^4)}\right)\right]$$

$$= 28.174$$

$$\phi_{MAX} = \frac{T}{KG}; \quad T_2 = KG\phi_{MAX}$$

$$T_2 = 28.174(4\times10^3)\left(\frac{0.02}{12}\right)$$

$$= 187.827 \text{ kip·in.}$$

$\therefore \tau_{MAX}$ CONTROLS AND

$Q = T_1 = 165.441 \approx 165.4$ kip·in. ANS.

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2.105

$$\tau = \frac{T(3a+1.8b)}{8a^2b^2} \Rightarrow \frac{a^2b^2}{3a+1.8b} = \frac{T}{8\tau}$$

$$\frac{0.045b^2}{3(0.045)+1.8b} = \frac{15\times10^3}{8(35\times10^6)} = 5.35714\times10^{-5}$$

SIMPLIFYING, WE OBTAIN

$$b^2 - 2.143\times10^{-3}b - 1.607\times10^{-4} = 0$$

SOLVING THIS QUADRATIC EQ. LEADS TO

$b = 0.01379\ m = 13.8\ mm$ ANS.

2.106

$$T = 2V(2G\phi/kp/P) = 2(2.5)(20.5) = 102.5\ kip.in.$$

$$\tau = \frac{T(3a+1.8b)}{8a^2b^2} = \frac{102.5[3(2.5)+1.8(1.75)]}{8(2.5^2)(1.75^2)}$$

$= 7.129\ ksi$ ANS.

$$\theta = \frac{TL}{KG};\ K = ab^3\left[\frac{16}{3} - 3.36\left(\frac{b}{a}\right)\left(1 - \frac{b^4}{12a^4}\right)\right]$$

$$K = (2.5)(1.75^3)\left[\frac{16}{3} - 3.36\left(\frac{1.75}{2.5}\right)\left(1 - \frac{1.75^4}{12(2.5^4)}\right)\right]$$

$= 40.576\ in.^4$

$$\therefore \theta = \frac{7.129(5\times12)}{40.576(10\times10^3)} = 1.054\times10^{-3}\ rad$$ ANS.

2.107

$$\tau = \frac{20T}{a^3} = \frac{20(7.5\times10^3)}{(0.08^3)}$$

$= 292.969\ MPa$ AT MIDPOINT OF THREE SIDES ANS.

$$\theta = \frac{TL}{KG};\ K = \frac{a^4\sqrt{3}}{80} = \frac{(0.08^4)\sqrt{3}}{80} = 8.86\times10^{-7}\ m^4$$

$$\therefore \theta = \frac{7.5\times10^3(2.0)}{8.86\times10^{-7}(27\times10^9)} = 0.627\ rad$$ ANS.

2.108

$$\tau = \frac{20T}{a^3} \Rightarrow T_1 = \frac{\tau a^3}{20}$$

$$T_1 = \frac{12(3^3)}{20} = 16.2\ kip.in.$$

$$\theta = \frac{TL}{KG} = T_2 = \frac{KG\theta}{L}$$

$$K = \frac{a^4\sqrt{3}}{80} = \frac{3^4\sqrt{3}}{80} = 1.754\ in.^4$$

$$\therefore T_2 = \frac{1.754(4\times10^3)(0.15)}{3(12)} = 29.233\ kip.in.$$

$\therefore \tau$ CONTROLS AND

$Q = T_1 = 16.2\ kip.in.$ ANS.

2.109

$$\tau = \frac{20T}{a^3};\ a = \sqrt[3]{\frac{20T}{\tau}}$$

$$a_1 = \sqrt[3]{\frac{20(10\times10^3)}{20\times10^6}} = 0.2154\ m$$

$$\theta = \frac{TL}{KG};\ K = \frac{TL}{\theta G} = \frac{10\times10^3(2.0)}{(0.2)(27\times10^9)} = 3.7037\times10^{-6}\ m^4$$

$$\therefore K = \frac{a^4\sqrt{3}}{80} = 3.7037\times10^{-6}$$

$a_2 = 0.1144\ m$

$\therefore \tau$ CONTROLS AND

$a = a_1 = 0.2154\ m = 215.4\ mm$ ANS.

2.110

CIRCLE: $R = 1.5$ in.

$$\tau = \frac{TR}{J};\ T_1 = \frac{\tau J}{R} = \frac{15(\pi/2)(1.5^4)}{1.5}$$

$T_1 = 79.522\ kip.in.$

$A = \pi R^2 = \pi(1.5^2) = 7.06858\ in.^2$

ELLIPSE: $b = 1.25$ in.

$$A = \pi ab = 7.06858$$

$$a = \frac{7.06858}{\pi(1.25)} = 1.80\ in.$$

$$\tau = \frac{2T}{\pi ab^2};\ T_2 = \frac{\tau(\pi ab^2)}{2} = \frac{15\pi(1.80)(1.25^2)}{2}$$

$T_2 = 66.268\ kip.in.$

$\therefore$ THE CIRCULAR SHAFT IS CHOSEN BECAUSE IT CARRIES ABOUT 20% MORE TORQUE.

2.111

SQUARE: $2a = 65\ mm = 0.065\ m$

$$\tau = \frac{T(3a+1.8b)}{8a^2b^2} = \frac{T(4.8a)}{8a^4};\ T_1 = \frac{8a^3\tau}{4.8}$$

$$T_1 = \frac{8(0.0325^3)(75\times10^6)}{4.8} = 429.11\ N.m$$

$A = 4a^2 = 4(0.0325^2) = 0.004225\ m^2$

EQUILATERAL TRIANGLE: b ON A SIDE

$$A = \frac{\sqrt{3}\,b^2}{4} = 0.004225$$

$b = 0.09878\ m$

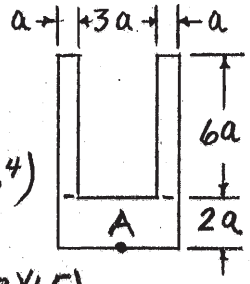
$$\tau = \frac{20T}{b^3};\ T_2 = \frac{\tau b^3}{20}$$

$$T_2 = \frac{75\times10^6(0.09878^3)}{20} = 361.4\ N.m$$

$\therefore$ THE SQUARE SHAFT IS CHOSEN BECAUSE IT CARRIES ABOUT 19% MORE TORQUE.

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2.112



$$K=\frac{1}{3}\sum Lt^3$$
$$=\frac{1}{3}[2(6a)a^3+5a(2a)^3]$$
$$=\frac{1}{3}(52a^4)=\frac{1}{3}(52)(1.5^4)$$
$$=87.75\ \text{in.}^4$$

(a) $\tau_{MAX}=\frac{Tt}{K}=\frac{150(2)(1.5)}{87.75}$

$=5.128$ ksi AT A. ANS.

(b) $\theta=\frac{TL}{KG}=\frac{150(4\times12)}{87.75(4\times10^3)}$

$=20.5\times10^{-3}$ rad ANS.

2.113 AS IN PROB. 2.112, $K=\frac{1}{3}(52a^4)$

$K=\frac{1}{3}(52)(0.05^4)=1.083\times10^{-4}\ m^4$

$\tau_{MAX}=\frac{Tt}{K}$; $T_1=\frac{\tau K}{t}=\frac{40\times10^6(1.083\times10^{-4})}{2(0.05)}$

$T_1=433.2\times10^2\ N\cdot m$

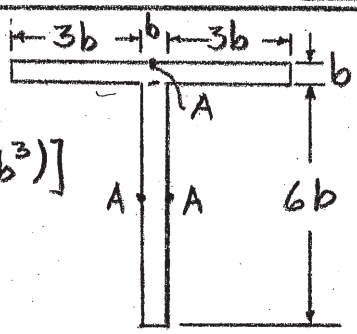
$\theta_{MAX}=\frac{TL}{KG}$; $T_2=\frac{KG\theta}{L}$

$T_2=\frac{1.083\times10^{-4}(25\times10^9)(6\pi/180)}{3.0}=945.1\times10^2\ N\cdot m$

$\therefore\ \tau$ CONTROLS AND

$Q=T_1=433.2\times10^2\ N\cdot m\approx43.3\ kN\cdot m$ ANS.

2.114 (a)



$K=\frac{1}{3}\sum Lt^3$

$=\frac{1}{3}[7b(b^3)+6b(b^3)]$

$=\frac{1}{3}(13b^4)$

$=\frac{1}{3}(13)(1.25^4)$

$=10.579\ \text{in.}^4$ ANS.

$\tau_{MAX}=\frac{Tt}{K}=\frac{100(1.25)}{10.579}$

$=11.816$ ksi AT POINTS A ANS.

(b)

$\theta=\frac{TL}{KG}=\frac{100(3\times12)}{10.579(10\times10^3)}$

$=3.403\times10^{-2}$ rad ANS.

2.115 AS IN PROB. 2.114, $K=\frac{1}{3}(13b^4)$

$K=\frac{1}{3}(13)(0.04^4)=11.093\times10^{-6}\ m^4$

$\tau_{MAX}=\frac{Tt}{K}$; $T_1=\frac{K\tau}{t}=\frac{11.093\times10^{-6}(50\times10^6)}{0.04}$

$T_1=13,866\ N\cdot m$

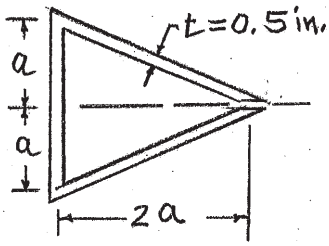
$\theta_{MAX}=\frac{TL}{KG}$; $T_2=\frac{KG\theta}{L}$

$T_2=\frac{11.093\times10^{-6}(27\times10^9)(5\pi/180)}{2}=13,069\ N\cdot m$

$\therefore\ \theta$ CONTROLS AND

$Q=T_2=13,069\ N\cdot m\approx13.1\ kN\cdot m$ ANS.

2.116 $K=\frac{1}{3}\sum Lt^3$;



$K=\frac{1}{3}[2(2.236a)t^3+(2a)t^3]$

$=\frac{1}{3}(6.472at^3)$

$=\frac{1}{3}(6,472)(0.5^3)a$

$=0.26967a$

$\tau=\frac{Tt}{K}$; $K=\frac{Tt}{\tau}=\frac{12(0.5)}{12}=0.5\ \text{in.}^4$

$\therefore\ 0.26967a=0.5$

$a=1.854$ in. ANS.

2.117 AS IN PROB. 2.116, $K=\frac{1}{3}(6.472at^3)$

$K=\frac{1}{3}(6.472)(0.1)(0.015^3)=7.28\times10^{-7}\ m^4$

$\tau_{MAX}=\frac{Tt}{K}$; $T_1=\frac{\tau K}{t}=\frac{80\times10^6(7.28\times10^{-7})}{0.015}$

$T_1=3,882.7\ N\cdot m$

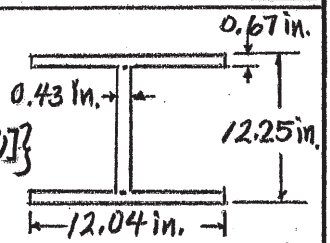
$\theta_{MAX}=\frac{TL}{KG}$; $T_2=\frac{KG\theta}{L}=\frac{7.28\times10^{-7}(77\times10^9)(0.10)}{1.5}$

$T_2=3,737.1\ N\cdot m$

$\therefore\ \theta$ CONTROLS AND

$Q=T_2=3,737.1\ N\cdot m\approx3.737\ kN\cdot m$ ANS.

2.118 $K=\frac{1}{3}\sum Lt^3$



$K=\frac{1}{3}[2(12.04)(0.67^3)+[12.25-2(0.67)](0.43^3)]$

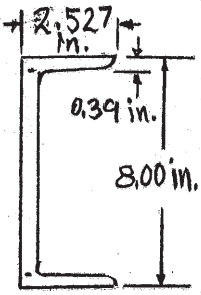
$K=2.70326\ \text{in.}^4$

(a) $\tau_{MAX}=\frac{Tt}{K}=\frac{10\times12(0.67)}{2.70326}=29.742$ ksi ANS.

(b) $\theta=\frac{TL}{KG}=\frac{10\times12(5\times12)}{2.70326(10\times10^3)}=0.266$ rad ANS.

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2.119 $K=\frac{1}{3}\sum Lt^3$



$K=\frac{1}{3}\{2(2.527)(0.39^3)+[8.00-2(0.39)](0.487^3)]\}$

$=0.37791\ \text{in.}^4$

$\tau_{MAX}=\frac{Tt}{K}$; $T_1=\frac{\tau K}{t}$

$T_1=\frac{10(0.37791)}{0.487}=7.760\ \text{kip·in.}$

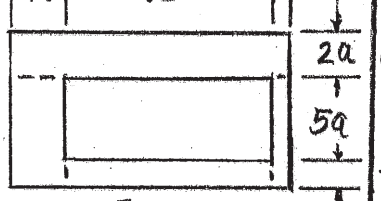
$\theta_{MAX}=\frac{TL}{KG}$; $T_2=\frac{KG\theta}{L}$

$T_2=\frac{0.37791(10\times10^3)(10\pi/180)}{4\times12}=13.741\ \text{kip·in.}$

$\therefore \tau$ CONTROLS AND

$Q=T_1=7.760\ \text{kip·in.}$ ANS.

2.120 $a=20\ \text{mm}$



$A_m=\frac{1}{2}[10a(8.5a)+5a(7a)]$

$A_m=60a^2$

$=60(0.02^2)=0.024\ \text{m}^2$

(a) $\tau=\frac{T}{2A_m t}=\frac{7.5\times10^3}{2(0.024)(0.02)}=7.813\ \text{MPa}$ ANS.

(b) $q=t\tau=(0.02)(7.813\times10^6)$

$=156.3\ \text{kN/m}$ ANS.

(c) $\theta=\frac{TL}{4GA_m^2}\sum\left(\frac{s}{t}\right)$

$\theta=\frac{7.5\times10^3(1.0)}{4(27\times10^9)(0.024^2)}\left[\frac{10\alpha}{2\alpha}+\frac{6.5\alpha}{2\alpha}+\frac{7\alpha}{1.5\alpha}+\frac{6.5\alpha}{\alpha}\right]$

$=120.563\times10^{-6}(19.417)=2.34\times10^{-3}\ \text{rad}$ ANS.

2.121 AS IN PROB. 2.120, $A_m=60a^2$

$\tau=\frac{T}{2A_m t}$; $A_m=\frac{T}{2\tau t}=\frac{5}{2(8)(a)}=\frac{5}{16a}$

$\therefore \frac{5}{16a}=60a^2 \Rightarrow a_1=0.173\ \text{in.}$

$\theta=\frac{TL}{4GA_m^2}\sum\left(\frac{s}{t}\right)=\frac{5(5\times12)}{4(10\times10^3)A_m^2}\left[\frac{16.5\alpha}{2\alpha}+\frac{7\alpha}{1.5\alpha}+\frac{6.5\alpha}{\alpha}\right]$

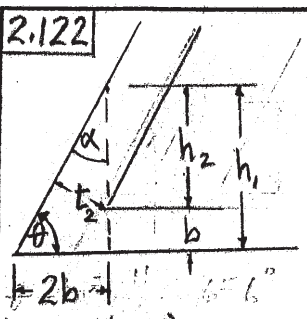
$0.15=\frac{7.5\times10^{-3}}{A_m^2}(19.416\,67)$; $A_m^2=0.97083$

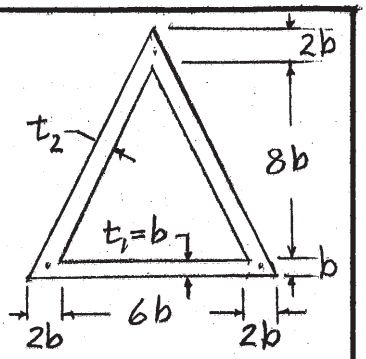
$A_m=0.9853=60a^2$; $a_2=0.128\ \text{in.}$

$\therefore \tau$ CONTROLS AND

$a=a_1=0.173\ \text{in.}$ ANS.

2.122





$h_1=2b(\tan\theta)$

$=2b\left(\frac{11}{5}\right)=4.4b$

$\therefore h_2=3.4b$; $\alpha=\tan^{-1}\left(\frac{2h_1}{4.4b}\right)=24.444°$

$t_2=3.4b\sin\alpha=1.407b.$

$\therefore \tau_{MAX}$ IN RECTANGLE OF THICKNESS $t_1=b.$

$A_m=\frac{1}{2}\left[\frac{1}{2}(10b)(11b)+\frac{1}{2}(6b)(8b)\right]=39.5b^2$

$=39.5\ \text{in.}^2$

(a) $\tau_{MAX}=\frac{T}{2A_m t_1}=\frac{10(12)}{2(39.5)(1.0)}=1.519\ \text{ksi}$ ANS.

(b) $\theta=\frac{TL}{4GA_m^2}\sum\left(\frac{s}{t}\right)$ (15.326)

$\theta=\frac{1.0(12)(6\times12)}{4(6.4\times10^3)(39.5)}\left[\frac{8b}{b}+\frac{\sqrt{(9.5b)^2+(4.0b)^2}}{(1.407b)}\right]$

$=0.131\ \text{rad.}$ ANS.

2.123 AS IN PROB. 2.122, $A_m=39.5b^2$

$A_m=39.5(0.02^2)=0.0158\ \text{m}^2$

$\tau_{MAX}=\frac{T}{2A_m t_1}$; $T_1=2\tau_{MAX}A_m t_1$

$T_1=2(40\times10^6)(0.0158)(0.02)=25.280\ \text{kN·m}$

$\theta_{MAX}=\frac{TL}{4GA_m^2}\sum\left(\frac{s}{t}\right)$; $T_2=\frac{4\theta GA_m^2}{L}\left[\frac{1}{\sum\left(\frac{s}{t}\right)}\right]$

$T_2=\frac{4(\pi/180)(50\times10^9)(0.0158^2)}{1.5}\left[\frac{1}{15.326}\right]=37.905\ \text{kN·m}$

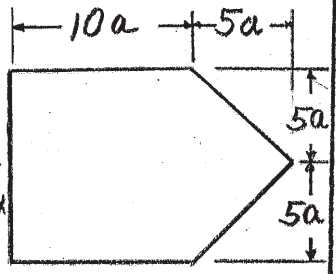
NOTE THAT $\sum\left(\frac{s}{t}\right)=15.326$ WAS OBTAINED IN PROB. 2.122.

$\therefore \tau_{MAX}$ CONTROLS AND

$Q=T_1=25.280\ \text{kN·m}$ ANS.

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2.124



$A_m=(10a)(10a)+\frac{1}{2}(10a)(5a)$

$=125a^2$

$\tau_{MAX}=\frac{T}{2A_m t}$; $A_m=\frac{T}{2t\tau_{MAX}}$

$A_m=\frac{100}{2(a)(12)}=125a^2$

$\therefore a=\sqrt[3]{\frac{100}{2(12)(125)}}=0.322$ in.

$\theta_{MAX}=\frac{TL}{4GA_m^2}\sum\left(\frac{s}{t}\right)$; $A_m^2=\frac{TL}{4G\theta}\sum\left(\frac{s}{t}\right)$

$A_m^2=\frac{100(4\times12)}{4(4\times10^3)(10\pi/180)}\underbrace{\left[\frac{30\alpha}{\alpha}+2\left(\frac{\sqrt{5^2+5^2}\,\alpha}{\alpha}\right)\right]}_{44.142}$

$A_m^2=75.875=(125a^2)^2$

$a=0.264$ in.

$\therefore \tau$ CONTROLS AND $a=0.322$ in. ANS.

2.125 AS IN PROB. 2.124, $A_m=125a^2$

$A_m=125(0.015^2)=0.028125\ m^2$.

ALSO, FROM PROB. 2.124, $\sum\left(\frac{s}{t}\right)=44.142$.

$\tau_{MAX}=\frac{T}{2A_m t}$; $T_1=2A_m t\tau_{MAX}$

$T_1=2(0.028125)(0.015)(25\times10^6)$

$=21.094$ kN.m

$\theta_{MAX}=\frac{TL}{4GA_m^2}\sum\left(\frac{s}{t}\right)$; $T_2=\frac{4GA_m^2\theta}{L\sum\left(\frac{s}{t}\right)}$

$T_2=\frac{4(27\times10^9)(0.028125^2)(0.05)}{2(44.142)}$

$=48.388$ kN.m

$\therefore \tau_{MAX}$ CONTROLS AND

$Q=T_1=21.094$ kN.m ANS.

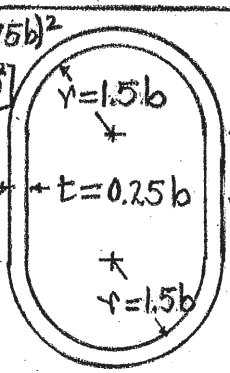
2.126 $A_m=\frac{1}{2}\left[3.5b(2b)+2\left(\frac{\pi}{2}\right)(1.75b)^2+(3.0b)(2b)+2\left(\frac{\pi}{2}\right)(1.5b)^2\right]$

$A_m=14.845b^2$

$\tau_{MAX}=\frac{T}{2A_m t}$; $A_m=\frac{T}{2\tau_{MAX}t}$

$A_m=\frac{15}{2(10)(0.25b)}=14.845b^2$

$b_1=0.587$ in.



2.126 CONT'D

$\theta=\frac{TL}{4GA_m^2}\sum\left(\frac{s}{t}\right)$; $A_m^2=\frac{TL}{4G\theta}\sum\left(\frac{s}{t}\right)$

$A_m^2=\frac{15(3\times12)}{4(5.5\times10^3)(15\pi/180)}\underbrace{\left[2\left(\frac{2b}{0.25b}\right)+2\left(\frac{\pi(1.625b)}{0.25b}\right)\right]}_{56.841}$

$A_m=2.309\ in.^2=14.845b^2$

$b_2=0.394$ in.

$\therefore \tau_{MAX}$ CONTROLS AND

$b_{MIN}=b_1=0.587$ in. ANS.

2.127 AS IN PROB. 2.126, $A_m=14.845b^2$

$A_m=14.845(0.03^2)=1.336\times10^{-2}\ m^2$

$\tau_{MAX}=\frac{T}{2A_m t}$; $T_1=2\tau_{MAX}A_m t$

$T_1=2(30\times10^6)(1.336\times10^{-2})(7.5\times10^{-3})$

$=6.012$ kN.m

$\theta_{MAX}=\frac{TL}{4GA_m^2}\sum\left(\frac{s}{t}\right)$; $T_2=\frac{4\theta_{MAX}GA_m^2}{L\sum\left(\frac{s}{t}\right)}$

$\sum\left(\frac{s}{t}\right)=56.841$ FROM PROB. 2.126.

$\therefore T_2=\frac{4(4\pi/180)(26\times10^9)(1.336\times10^{-2})^2}{1.5(56.841)}$

$=15.199$ kN.m

$\therefore \tau_{MAX}$ CONTROLS AND

$Q=T_1=6.012$ kN.m ANS.

2.128 $\tau_y=12.0$ ksi; $\gamma_y=2\times10^{-3}$

(a) $G=\frac{\tau_y}{\gamma_y}=\frac{12.0}{2\times10^{-3}}=6\times10^3$ ksi ANS.

(b) $\tau_y=\frac{T_y R_o}{J}$; $T_y=\frac{\tau_y J}{R_o}$

$T_y=\frac{12.0(\pi/32)(2.5^4-1.5^4)}{2.5}$

$=16.022$ ksi ANS.

(c) $\theta_y=\frac{T_y L}{JG}=\frac{16.022(2\times12)}{(\pi/32)(2.5^4-1.5^4)(6\times10^3)}$

$\theta_y=19.200\times10^{-3}$ rad ANS.

(d) $u_r=\frac{1}{2}\tau_y\gamma_y=\frac{1}{2}(12.0)(2\times10^{-3})$

$=12.0\times10^{-3}$ kip.in./in.^{3} ANS.

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2.129 $T_y = 30.0\ \text{kN·m};\ \tau_y = 350\ \text{MPa}$

(a) $\tau_y = \dfrac{T_y R}{J} = \dfrac{T_y(D/2)}{(\pi/32)D^4} = \dfrac{16\,T_y}{\pi D^3}$

$D^3 = \dfrac{16\,T_y}{\pi \tau_y} = \dfrac{16(30.0\times10^3)}{\pi(350\times10^6)} = 0.436539\times10^{-3}$

$D = 0.0759\ \text{m} = 75.9\ \text{mm}$ ANS.

(b) $\theta = \dfrac{TL}{JG};\ G = \dfrac{TL}{J\theta} = \dfrac{30.0\times10^3(1.5)}{(\pi/32)(0.0759^4)(8\pi/180)}$

$G = 98.919\times10^9 \approx 98.9\ \text{GPa}$ ANS.

2.130 $T_y = \dfrac{\tau_y J}{R} = \dfrac{17(\pi/32)(3.54)}{3.5} = 71.557\ \text{kip·in}$

(a) $\dfrac{T}{T_y} = \left(\dfrac{4}{3}\right)\left[1 - \left(\dfrac{1}{4}\right)\left(\dfrac{\rho_y}{R}\right)^3\right];\ \dfrac{T}{T_y} = \dfrac{90}{71.557} = 1.258$

$\therefore 1.258 = \left(\dfrac{4}{3}\right)\left[1 - \left(\dfrac{1}{4}\right)\left(\dfrac{\rho_y}{R}\right)^3\right]$

$\left(\dfrac{\rho_y}{R}\right)^3 = 4 - 3\left(\dfrac{T}{T_y}\right) = 4 - 3(1.258) = 0.226$

$\dfrac{\rho_y}{R} = 0.609;\ \rho_y = 0.609R = 0.609(1.75)$

$\rho_y = 1.066\ \text{in.}$

$\therefore d = 1.75 - 1.066 = 0.684\ \text{in.}$ ANS.

(b) AS IN PART (a),

$\left(\dfrac{\rho_y}{R}\right)^3 = 4 - 3\left(\dfrac{T}{T_y}\right) = 4 - 3\left(\dfrac{80}{71.557}\right) = 0.646$

$\dfrac{\rho_y}{R} = 0.864;\ \rho_y = 0.864R = 0.864(1.75)$

$\rho_y = 1.512\ \text{in.}$

$\therefore d = 1.75 - 1.512 = 0.238\ \text{in.}$ ANS.

2.131 $T = \dfrac{\pi\tau_y}{6}(4R^3 - \rho_y^3)$

(a) $\rho_y = 2.0 - 0.5 = 1.5\ \text{in.}$

$T = \dfrac{\pi(20)}{6}\left[4(2.0)^3 - (1.5)^3\right] = 299.760\ \text{kip·in}$ ANS.

(b) $\rho_y = 2.0 - 1.0 = 1.0\ \text{in.}$

$T = \dfrac{\pi(20)}{6}\left[4(2.0)^3 - (1.0)^3\right] = 324.631\ \text{kip·in.}$ ANS.

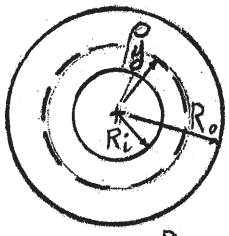
(c) $\rho_y = 2.0 - 1.5 = 0.5\ \text{in.}$

$T = \dfrac{\pi(20)}{6}\left[4(2.0)^3 - (0.5)^3\right] = 333.794\ \text{kip·in.}$ ANS.

(d) $\rho_y = 2.0 - 2.0 = 0$

$T = \dfrac{\pi(20)}{6}\left[4(2.0)^3 - 0\right] = 335.103\ \text{kip·in.}$ ANS.

2.132 SEE DEVELOPMENT OF EQ. (2.38).



$T = \left(\dfrac{2\pi\tau_y}{\rho_y}\right)\int_{R_i}^{\rho_y}\rho^3 d\rho + (2\pi\tau_y)\int_{\rho_y}^{R_o}\rho^2 d\rho$

$T = \left(\dfrac{2\pi\tau_y}{\rho_y}\right)\left[\dfrac{\rho^4}{4}\right]_{R_i}^{\rho_y} + (2\pi\tau_y)\left[\dfrac{\rho^3}{3}\right]_{\rho_y}^{R_o}$

$= \left(\dfrac{2\pi\tau_y}{\rho_y}\right)\left(\dfrac{\rho_y^4 - R_i^4}{4}\right) + 2\pi\tau_y\left(\dfrac{R_o^3 - \rho_y^3}{3}\right)$

$T = \dfrac{\pi\tau_y}{2}\left[\dfrac{4R_o^3 - \rho_y^3}{3} - \dfrac{R_i^4}{\rho_y}\right]$ ANS.

2.133 FROM STATEMENT OF PROB. 2.132,

$T = \dfrac{\pi\tau_y}{2}\left[\dfrac{4R_o^3 - \rho_y^3}{3} - \dfrac{R_i^4}{\rho_y}\right]$

$32\times10^3 = \pi(175\times10^6)\left[\dfrac{4(0.05^3) - \rho_y^3}{6} - \dfrac{0.03^4}{2\rho_y}\right]$

SIMPLIFYING, WE OBTAIN

$\rho_y^4 - 15.078\times10^{-5}\rho_y + 0.243\times10^{-5} = 0$

A TRIAL-AND-ERROR SOLUTION YIELDS

$\rho_y = 0.0461\ \text{m}$

$d = 0.05 - 0.0461 = 0.0039\ \text{m}$

$= 3.9\ \text{mm}$ ANS.

2.134 $\dfrac{T}{T_y} = \dfrac{4}{3}\left[1 - \dfrac{1}{4(\theta/\theta_y)^3}\right]$

$T_y = \dfrac{\pi\tau_y R^3}{2} = \dfrac{\pi(15)(3.5^3)}{2} = 1010.218\ \text{kip·in.}$

$\theta_y = \dfrac{T_y L}{JG} = \dfrac{1010.218(2.0\times12)}{(\pi/32)(3.54^4)(10.5\times10^3)} = 0.157\ \text{rad}$

$T = \left(\dfrac{4}{3}\right)T_y\left[1 - \dfrac{1}{4(\theta/\theta_y)^3}\right]$

(a) $\theta = 0.2\ \text{rad}$

$T = \left(\dfrac{4}{3}\right)(1010.218)\left[1 - \dfrac{1}{4(0.2/0.157)^3}\right]$

$= 1084.064\ \text{kip·in.}$ ANS.

(b) $\theta = 0.4\ \text{rad}$

$T = \left(\dfrac{4}{3}\right)(1010.218)\left[1 - \dfrac{1}{4(0.4/0.157)^3}\right]$

$= 1326.596\ \text{kip·in.}$ ANS.

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2.135 $\frac{T}{T_y} = \left(\frac{4}{3}\right)\left[1 - \left(\frac{1}{4}\right)\left(\frac{\rho_y}{R}\right)^3\right]$

$\rho_y = R\left[4 - 3\left(\frac{T}{T_y}\right)\right]^{1/3}$; $R = 3.5$ in.

(a) FROM PROB. 2.134, $T = 1084.064$ kip.in.

$T_y = 1010.218$ kip.in. FOR $\theta = 0.20$ rad.

$\therefore \rho_y = 3.5\left[4 - 3\left(\frac{1084.064}{1010.218}\right)\right]^{1/3}$

$= 3.223$ in. ANS.

(b) FROM PROB. 2.134, $T = 1326.596$ kip.in.

$T_y = 1010.218$ kip.in. FOR $\theta = 0.40$ rad.

$\therefore \rho_y = 3.5\left[4 - 3\left(\frac{1326.596}{1010.218}\right)\right]^{1/3}$

$= 1.374$ in. ANS.

2.136 $T = \frac{\pi \tau_y}{6}\left(4R^3 - \rho_y^3\right)$

$\rho_y = \left[4R^3 - \frac{6T}{\pi \tau_y}\right]^{1/3} = \left[4(0.045^3) - \frac{6(25\times10^3)}{\pi(150\times10^6)}\right]^{1/3}$

$= 0.0359$ m $= 35.9$ mm ANS.

$\frac{\rho_y}{R} = \frac{\theta_y}{\theta}$; $\theta = \left(\frac{R}{\rho_y}\right)\theta_y$

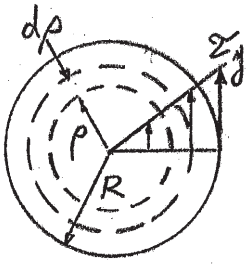
$\theta_y = \frac{T_y L}{JG} = \frac{(\tau_y J/R)L}{JG} = \frac{\tau_y L}{RG}$

$= \frac{150\times10^6(0.75)}{0.045(75\times10^9)} = 0.0333$ rad.

$\therefore \theta = \left(\frac{0.75}{0.0359}\right)(0.0333)$

$= 0.696$ rad ANS.

2.137 (a)



$dF_y = (2\pi\rho\, d\rho)\tau$

$= (2\pi\rho\, d\rho)\left(\frac{\rho}{R}\tau_y\right)$

$= (2\pi\tau_y \rho^2 d\rho)/R$

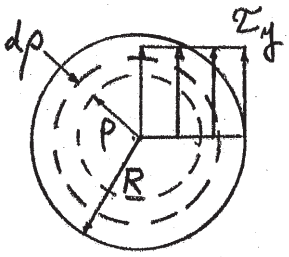
$dT_y = (2\pi\tau_y \rho^3 d\rho)/R$

$T_y = \frac{2\pi\tau_y}{R}\int_0^R \rho^3 d\rho = \frac{2\pi\tau_y}{R}\left[\frac{\rho^4}{4}\right]_0^R$

$T_y = \frac{\pi\tau_y R^3}{2} = \frac{\pi(25)(2^3)}{2}$

$= 314.159$ kip.in. ANS.

2.137 CONT'D



$dF_\rho = (2\pi\rho\, d\rho)\tau_y$

$dT_\rho = (2\pi\tau_y \rho^2 d\rho$

$T_\rho = 2\pi\tau_y \int_0^R \rho^2 d\rho$

$= 2\pi\tau_y\left[\frac{\rho^3}{3}\right]_0^R = \left(\frac{2}{3}\right)\pi R^3 \tau_y$

$T_\rho = \left(\frac{2}{3}\right)\pi(2^3)(25) = 418.879$ kip.in. ANS.

(b)

$T = 1.15\, T_y = 1.15(314.159) = 361.283$ kip.in

$T = \frac{\pi\tau_y}{6}\left(4R^3 - \rho_y^3\right)$

$\rho_y = \left[4R^3 - \frac{6T}{\pi\tau_y}\right]^{1/3} = \left[4(2^3) - \frac{6(361.283)}{\pi(25)}\right]^{1/3}$

$\rho_y = 1.639$ in.

$d = 2.0 - 1.639 = 0.361$ in. ANS.

$T = 1.25\, T_y = 1.25(314.159) = 392.699$ kip.in.

$\rho_y = \left[4(2^3) - \frac{6(392.699)}{\pi(25)}\right]^{1/3} = 1.260$ in.

$d = 2.0 - 1.260 = 0.740$ in. ANS.

2.138 (a)

FROM PROB. 2.137, $T_y = \frac{\pi\tau_y R^3}{2}$

$T_y = \frac{\pi(160\times10^6)(0.04^3)}{2} = 16.085$ kN.m

FOR $d = 0.02$ m; $\rho_y = 0.04 - 0.02 = 0.02$ m

$T = \frac{\pi\tau_y}{6}\left(4R^3 - \rho_y^3\right) = \frac{\pi(160\times10^6)}{6}\left[4(0.04^3) - (0.02^3)\right]$

$T = 20.776$ kN.m

$\frac{T}{T_y} = \frac{20.776}{16.085} = 1.292$ ANS.

FOR $d = 0.04$ m; $\rho_y = 0.04 - 0.04 = 0$

$T = T_\rho = \left(\frac{2}{3}\right)\pi R^3 \tau_y$ (SEE PROB. 2.137)

$= \left(\frac{2}{3}\right)(\pi)(0.043)(160\times10^6) = 21.447$ kN.m

$\frac{T}{T_y} = \frac{21.447}{16.085} = 1.333$ ANS.

(b)

$\frac{\rho_y}{R} = \frac{\theta_y}{\theta}$; $\theta = \left(\frac{R}{\rho_y}\right)\theta_y$; $\theta_y = \frac{T_y L}{JG}$

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2.138 CONT'D

$\therefore \theta = \frac{R T_y L}{\rho_y J G}$; FOR $d = 0.02$m; $\rho_y = 0.02$ m

$\theta = \frac{(0.04)(16.085\times10^3)(0.80)}{(0.02)(\pi/32)(0.08^4)(70\times10^9)} = 0.0914$ rad

$\theta = 0.0914$ rad ANS.

FOR $d = 0.04$m; $\rho_y = 0$

$\theta = \infty$ ANS.

2.139 FROM PROB. 2.132,

$T = \frac{\pi \tau_y}{2}\left[\frac{4R_o^3 - \rho_y^3}{3} - \frac{R_i^4}{\rho_y}\right]$

$R_o = \left[\frac{\rho_y^3 + (6T/\pi\tau_y) + 3R_i^4/\rho_y}{4}\right]^{1/3}$

$= \left[\frac{(3.5)^3 + 6(250)/\pi(20) + 3(3.0)^4/3.5}{4}\right]^{1/3}$

$= 3.241$ in. ANS.

2.140 FROM PROB. 2.132,

$T = \frac{\pi \tau_0}{2}\left[\frac{4R_o^3 - \rho_y^3}{3} - \frac{R_i^4}{\rho_y}\right]$

$R_i = \left\{\rho_y\left[\left(\frac{4R_o^3 - \rho_y^3}{3}\right) - \left(\frac{2T}{\pi\tau_y}\right)\right]\right\}^{1/4}$

$= \left\{3.3\left[\frac{4(3.5)^3 - (3.3)^3}{3} - \frac{2(200)}{\pi(10)}\right]\right\}^{1/4}$

$= 3.217$ in. ANS.

2.141 FROM PROB. 2.132,

$T = \frac{\pi \tau_y}{2}\left[\frac{4R_o^3 - \rho_y^3}{3} - \frac{R_i^4}{\rho_y}\right]$

(a) $d = 0.010$m; $\rho_y = 0.05 - 0.01 = 0.04$m

$T = \frac{\pi(150\times10^6)}{2}\left[\frac{4(0.05)^3 - (0.04)^3}{3} - \frac{(0.02)^4}{0.04}\right]$

$= 33.301$ kN·m ANS.

$\theta = \frac{R_o \theta_y}{\rho_y} = \frac{R_o(T_y L/JG)}{\rho_y}$; $T_y = \frac{\tau_y J}{R_o}$

$\therefore \theta = \frac{L\tau_y}{G\rho_y} = \frac{(0.6)(150\times10^6)}{75\times10^9(0.04)}$

$= 0.030$ rad ANS.

(b) $d = 0.020$m; $\rho_y = 0.05 - 0.02 = 0.03$ m

$T = \frac{\pi(150\times10^6)}{2}\left[\frac{4(0.05)^3 - (0.03)^3}{3} - \frac{(0.02)^4}{0.03}\right]$

$T = 35.893$ kN·m ANS.

AS IN PART (a), $\theta = \frac{L\tau_y}{G\rho_y}$

$\theta = \frac{(0.6)(150\times10^6)}{75\times10^9(0.03)} = 0.040$ rad ANS.

2.142

(a) $T_y = \frac{\tau_y J}{R_o} = \frac{(160\times10^6)(\frac{\pi}{2})(0.07^4 - 0.04^4)}{0.07}$

$T_y = 77.014$ kN·m. ANS.

FROM PROB. 2.132,

$T = \frac{\pi\tau_y}{2}\left[\frac{4R_o^3 - \rho_y^3}{3} - \frac{R_i^4}{\rho_y}\right]$ .... (a)

$T = T_p$ WHEN $\rho_y = R_i$

$\therefore T_p = \frac{2\pi\tau_y}{3}(R_o^3 - R_i^3)$

$= \frac{2\pi(160\times10^6)}{3}[0.07^3 - (0.04)^3]$

$= 93.494$ kN·m ANS.

$\theta_y = \frac{T_y L}{JG} = \frac{77.014\times10^3(0.6)}{\frac{\pi}{2}(0.07^4 - 0.04^4)(70\times10^9)}$

$= 0.0196$ rad ANS.

$\theta_p = \infty$ (SEE PROB. 2.138) ANS.

(b) $\frac{T}{T_y} = 1.20$

$T = 1.20\,T_y = 1.20(77.014) = 92.417$ kN·m

FROM EQ. (a) ABOVE, WE CONCLUDE THAT

$\rho_y^4 + \left[\frac{6T}{\pi\tau_y} - 4R_o^3\right]\rho_y + 3R_i^4 = 0$

SUBSTITUTING NUMERICAL VALUES WE OBTAIN

$\rho_y^4 - 2.689\times10^{-4}\rho_y + 7.68\times10^{-6} = 0$

A TRIAL-AND-ERROR SOLUTION YIELDS

$\rho_y = 0.0475$ m ; $\frac{\rho_y}{R_o} = \frac{\theta_y}{\theta}$

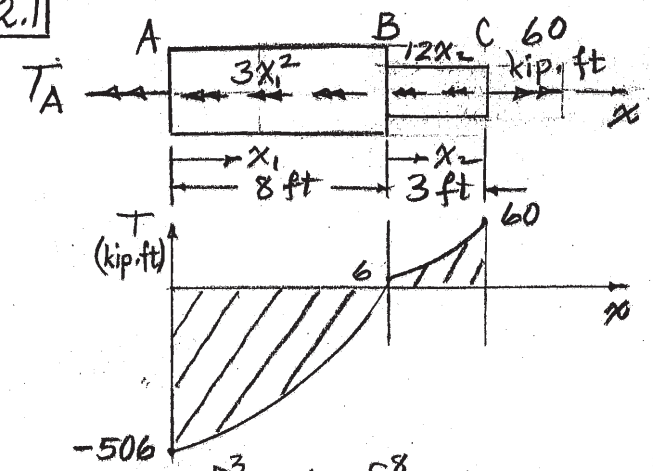
$\therefore \theta = \frac{R_o\theta_y}{\rho_y}$

$= \frac{(0.07)(0.0196)}{0.0475}$

$= 0.02888$ rad ANS.

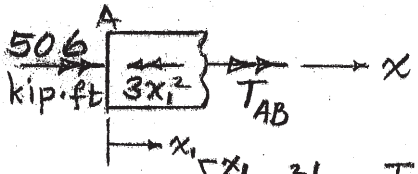
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R2.1



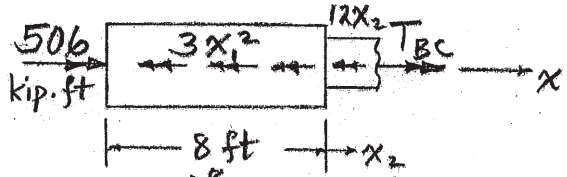
$$\Sigma T_x = 0: \quad 60 - \int_0^3 12x_2\,dx_2 - \int_0^8 3x_1^2\,dx_1 - T_A = 0$$

$$T_A = 60 - 54 - 512 = -506 \text{ kip·ft}$$



$$\Sigma T_x = 0: \quad 506 - \int_0^{x_1} 3x_1^2\,dx_1 + T_{AB} = 0$$

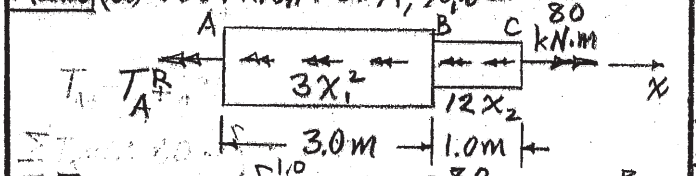
$$T_{AB} = x_1^3 - 506 \qquad \text{ANS.}$$



$$\Sigma T_x = 0: \quad 506 - \int_0^8 3x_1^2\,dx_1 - \int_0^{x_2} 12x_2\,dx_2 + T_{BC} = 0$$

$$T_{BC} = 6x_2^2 + 6 \qquad \text{ANS.}$$

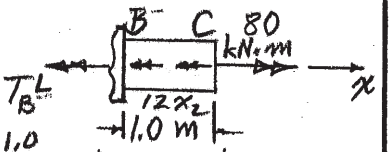
R2.2 (a) JUST RIGHT OF A, $x_1 \approx 0$.



$$\Sigma T_x = 0: \quad 80 - \int_0^{1.0} 12x_2\,dx_2 - \int_0^{3.0} 3x_1^2\,dx_1 - T_A^R = 0$$

$$T_A^R = 47 \text{ kN·m} \qquad \text{ANS.}$$

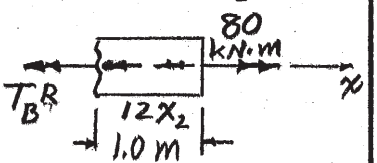
(b) JUST LEFT OF B, $x_1 \approx 3.0$ m



$$\Sigma T_x = 0: \quad 80 - \int_0^{1.0} 12x_2\,dx_2 - T_B^L = 0$$

$$T_B^L = 74 \text{ kN·m} \qquad \text{ANS.}$$

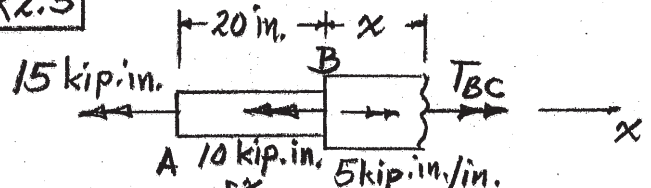
R2.2 CONT'D (c) JUST RIGHT OF B, $x_2 \approx 1.0$ m



$$\Sigma T_x = 0: \quad 80 - \int_0^{1.0} 12x_2\,dx_2 - T_B^R = 0$$

$$T_B^R = 74 \text{ kN·m} \qquad \text{ANS.}$$

R2.3



$$\Sigma T_x = 0: \quad T_{BC} + \int_0^x 5\,dx - 10 - 15 = 0$$

$$T_{BC} = 25 - 5x\Big|_0^x = 25 - 5x$$

(a) $\theta_A = \theta_{AB} + \theta_{BC}$

$$\theta_{AB} = \left(\frac{TL}{JG}\right)_{AB} = \frac{15(20)}{(\pi/32)(2^4)(12\times10^3)}$$

$$= 0.015915 \text{ rad}$$

$$\theta_{BC} = \int \left(\frac{T\,dx}{JG}\right)_{BC} = \frac{1}{JG}\int_0^{30} (25 - 5x)\,dx$$

$$= \frac{1}{(\pi/32)(3^4)(4\times10^3)}\left[25x - 2.5x^2\Big|_0^{30}\right]$$

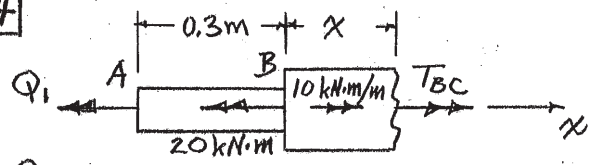
$$= -0.047157 \text{ rad}$$

$\theta_A = -0.0312$ rad WHEN VIEWED FROM A TO C. ANS.

(b) $(T_{BC})_{x=10''} = 25 - 5(10) = -25$ kip·in.

$$\left|\tau_{x=10''}\right| = \left|\frac{TR}{J}\right| = \frac{25(1.5)}{(\pi/32)(3^4)} = 4.716 \text{ ksi} \qquad \text{ANS.}$$

R2.4



$$T_{AB} = Q_1$$

$$\tau_{AB} = \left(\frac{TR}{J}\right)_{AB}; \quad 120\times10^6 = \frac{Q_1(0.03)}{(\pi/32)(0.06^4)}$$

$$Q_1 = 5.089 \text{ kN·m}$$

$$\Sigma T_x = 0: \quad T_{BC} + \int_0^x 10\,dx - 20 - Q_1 = 0$$

$$T_{BC} = 20 + Q_1 - 10x; \quad (T_{BC})_{MAX} = 20 + Q_1 \text{ JUST RIGHT OF B.}$$

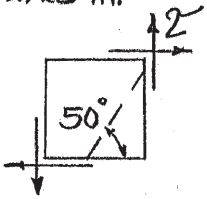
$$\tau_{BC} = \left(\frac{TR}{J}\right)_{BC}; \quad 70\times10^6 = \frac{(20+Q_1)(0.06)}{(\pi/32)(0.120^4)}$$

$$Q_1 = 3.750 \text{ kN·m}; \quad \therefore (Q_1)_{MAX} = 3.750 \text{ kN·m} \qquad \text{ANS.}$$

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R2.5 $T = Q$; $R = 12 + 0.25 = 12.25$ in.

$$\tau = \frac{TR}{J} = \frac{Q(12.25)}{(\pi/32)(24.5^4)} = 3.463\times10^{-4}Q$$



$\sigma_n = \tau \sin 2\theta$

$20 = (3.463\times10^{-4}Q)\sin(100°)$

$Q_1 = 58,644.3$ kip.in.

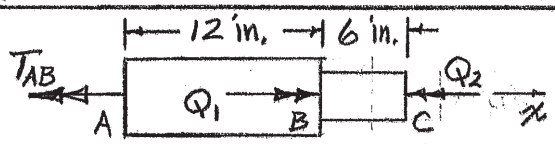
$\tau_{nt} = \tau \cos 2\theta$

$14 = (3.463\times10^{-4}Q)\cos(100°)$

$|Q_2| = 232,812.0$ kip.in.

$\therefore Q_{MAX} = Q_1 = 58,644.3$ kip.in. ANS.

R2.6



$\Sigma T_x = 0$: $Q_1 - Q_2 - T_{AB} = 0$

$T_{AB} = Q_1 - Q_2$

$\tau_{MAX} = \frac{TR}{J}$; $\theta = \frac{TL}{JG}$

AB: $15 = \frac{(Q_1 - Q_2)(2)}{(\pi/32)(4^4)}$; $Q_1 - Q_2 = 188.496$ kip.in. — ①

$\theta_C = \theta_{C/B} + \theta_{B/A}$

$$0.03 = \frac{Q_2(6)}{(\pi/32)(2^4)(4\times10^3)} + \frac{(Q_1 - Q_2)(12)}{(\pi/32)(4^4)(4\times10^3)}$$

$0.03 = 0.000955Q_2 + 0.000119(Q_1 - Q_2)$

$\therefore 300 = 8.36Q_2 + 1.19Q_1$ — ②

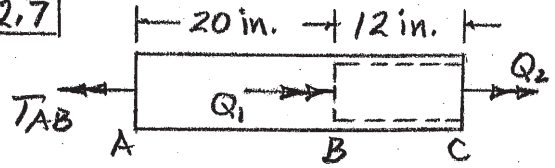
SOLVE ① AND ② TO GET

$Q_1 = 196.4$ kip.in. ANS.

$Q_2 = 7.9$ kip.in. ANS.

BC: $\tau = \frac{7.9(1)}{(\pi/32)(2^4)} = 5.0$ ksi $< \tau_{ALL}$ OK

R2.7



$$\tau_{BC} = \frac{Q_2(2)}{(\pi/32)(4.0^4 - 3.5^4)} = 0.19230Q_2$$

$$\tau_{AB} = \frac{(Q_1 + Q_2)(2)}{(\pi/32)(4.0^4)} = 0.07958(Q_1 + Q_2)$$

$\therefore 0.19230Q_2 = 0.07958(Q_1 + Q_2)$

R2.7 CONT'D

$\therefore 0.11272Q_2 = 0.07958Q_1$

$Q_1/Q_2 = 1.416$ ANS.

$$\theta_{C/B} = \frac{Q_2(12)}{(\pi/32)(4.0^4 - 3.5^4)G} = \frac{1.1538Q_2}{G}$$

$$\theta_{B/A} = \frac{(Q_1 + Q_2)(20)}{(\pi/32)(4^4)G} = \frac{0.7958(Q_1 + Q_2)}{G}$$

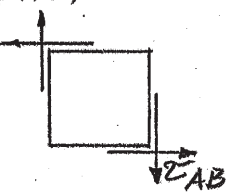
$$\frac{\theta_{B/A}}{\theta_{C/B}} = \frac{0.7958(Q_1 + Q_2)}{1.1538Q_2} = \frac{0.7958\left(\frac{Q_1}{Q_2} + 1\right)}{1.1538}$$

$$= \frac{0.7958(1.416 + 1)}{1.1538} = 1.666$$ ANS.

R2.8 REFER TO THE SKETCH IN PROB. R2.7.

(a) $\tau_{AB} = \left(\frac{TR}{J}\right)_{AB} = \frac{(25+15)(10^3)(0.06)}{(\pi/32)(0.120^4)}$

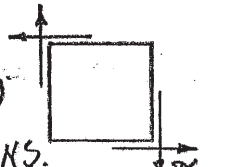
$\tau_{AB} = 117.893$ MPa ANS.



(b) $\tau_{BC} = \left(\frac{TR}{J}\right)_{BC}$

$$= \frac{15(10^3)(0.06)}{(\pi/32)(0.120^4 - 0.100^4)}$$

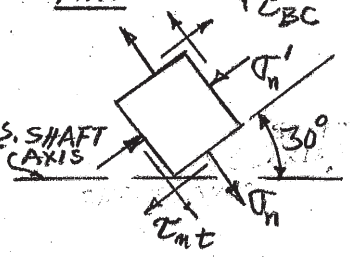
$= 85.389$ MPa ANS.



$\sigma_n = \tau \sin 2\theta$

$= 85.389 \sin 60°$

$= 73.949$ MPa. ANS.



$\sigma_n' = \tau \sin 2(\theta + 90°)$

$= 85.389 \sin 240°$

$= -73.949$ MPa ANS.

$\tau_{nt} = \tau \cos 2\theta = 85.389 \cos 60 = 42.695$ MPa

R2.9 $\Sigma T_{CD} = 0$

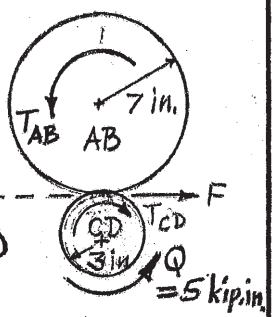
$5 - T_{CD} - 3F = 0$ — ①

$\Sigma T_{AB} = 0$: $T_{AB} - 7F = 0$

$F = (1/7)T_{AB}$ — ②

② INTO ① YIELDS:

$5 - T_{CD} - (3/7)T_{AB} = 0$ — ③



$3\theta_{C/D} = 7\theta_{B/A}$

$$3\left[\frac{T_{CD}(24)}{(\pi/32)d^4G}\right] = 7\left[\frac{T_{AB}(20)}{(\pi/32)d^4G}\right]$$

$T_{CD} = (140/72)T_{AB}$ — ④

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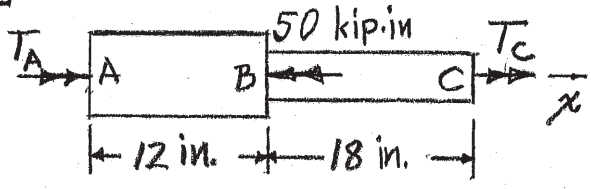
R2.9 CONT'D SOLVE ③ AND ④ TO GET

$T_{AB} = 2.107$ kip·in.; $T_{CD} = 4.097$ kip·in.

$\therefore \tau_{MAX} = 20$ ksi IN CD.

$20 = \dfrac{4.097(d/2)}{(\pi/32)\,d^4}$; $d = 1.014$ in. ANS.

R2.10



$\Sigma T_x = 0$: $T_A + T_C = 50$ ——— ①

$\theta_{B/A} = \theta_{B/C}$; $\left(\dfrac{TL}{JG}\right)_{AB} = \left(\dfrac{TL}{JG}\right)_{BC}$

$\dfrac{T_A(12)}{(\pi/32)d^4(4\times10^3)} = \dfrac{T_C(18)}{(\pi/32)(3.0^4)(6.4\times10^3)}$

$86.400\,T_A = d^4 T_C$ ——— ②

ASSUME BRASS CONTROLS.

$\therefore 18 = \dfrac{T_C(1.5)}{(\pi/32)(3.0^4)}$; $T_C = 42.412$ kip·in.

① ⇒ $T_A = 50 - 42.412 = 7.588$ kip·in.

② ⇒ $86.400(7.588) = d^4(42.412)$

$d = 1.983$ in.

$\tau_{AL} = \dfrac{7.588(1.983/2)}{(\pi/32)(1.983^4)} = 4.956$ ksi $< \tau_{ALL}$

$\therefore d_{MIN} = 1.983$ in. ANS.

R2.11 $\Sigma T_{AB} = 0$

$T_{AB} + 0.18F - Q = 0$ ——— ①

$\Sigma T_{CD} = 0$

$0.09F - T_{CD} = 0$

$F = 11.111\,T_{CD}$ ——— ②

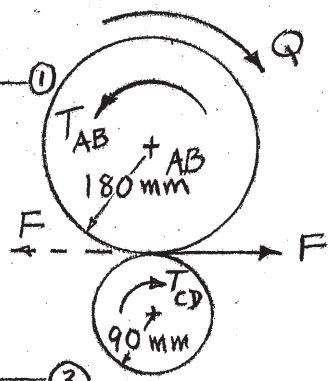
② INTO ① ⇒

$T_{AB} + 2T_{CD} = Q$ ——— ③

NOW $0.18\,\theta_{AB} = 0.09\,\theta_{CD}$; $\theta_{CD} = 2\theta_{AB}$

$\therefore \dfrac{T_{CD}(0.3)}{(\pi/32)(0.06^4)(25\times10^9)} = 2\left[\dfrac{T_{AB}(0.3)}{(\pi/32)(0.03^4)(70\times10^9)}\right]$

$T_{CD} = 11.429\,T_{AB}$ ——— ④



R2.11 CONT'D

ASSUME ALUMINUM CONTROLS. THUS,

$80\times10^6 = \dfrac{T_{CD}(0.03)}{(\pi/32)(0.06^4)}$; $T_{CD} = 3,393$ kN·m

④ ⇒ $T_{AB} = 0.297$ kN·m

$\tau_{AB} = \dfrac{(0.297)(10^3)(0.015)}{(\pi/32)(0.03^4)} = 56.0$ MPa $< \tau_{ALL}$

③ ⇒ $Q = 0.297 + 2(3,393) = 7.083$ kN·m ANS.

R2.12 $P = T\omega$; $T = \dfrac{P}{\omega}$

$T = \dfrac{500(6600)}{(400)(2\pi/60)} = 78,781.697$ lb·in.

$\tau = \dfrac{78,781.697(3.0)}{(\pi/32)(6.0^4 - d_i^4)} = 10\times10^3$

$d_i = 5.1895 \approx 5.7$ in.

$\theta = \dfrac{78,781.697(12)}{(\pi/32)(6.0^4 - d_i^4)(4\times10^6)} = 0.015$

$d_i = 5.8049 \approx 5.8$ in

$\therefore (d_i)_{MAX} = 5.7$ in. ANS.

R2.13 $U = \frac{1}{2}F\Delta$

$500(0.05 + \Delta) = \frac{1}{2}F\Delta$ ——— ①

$\Delta = \theta b = \left(\dfrac{TL}{JG}\right)b = \dfrac{Fb^2L}{JG} = \dfrac{F(0.4^2)(0.6)}{\left(\frac{\pi}{32}\right)(0.11^4 - d_i^4)(25\times10^9)}$

$\Delta = \dfrac{3.91139\times10^{-11}F}{X}$ WHERE $X = (0.11^4 - d_i^4)$

SUBSTITUTING INTO ① AND SIMPLIFYING YIELDS

$F^2 - 1\times10^3 F - 12.78317\times10^{11}X = 0$ ——— ②

$\tau = \dfrac{TR}{J}$; $100\times10^6 = \dfrac{0.4F(0.055)}{(\pi/32)X}$

$X = 2.241\times10^{-9}F$ ——— ③

③ INTO ② LEADS TO

$F^2 - 3,8647\times10^3 F = 0$; $F = 3,865$ N

③ ⇒ $X = 2.241\times10^{-9}(3,865) = 866.1\times10^{-8}$

$\therefore 0.11^4 - d_i^4 = 866.1\times10^{-8}$; $d_i = 0.108$ m

$\theta = \dfrac{TL}{JG}$; $0.05 = \dfrac{0.4F(0.6)}{(\pi/32)X(25\times10^9)}$

$X = 1.956\times10^{-9}F$ ——— ④

④ INTO ② YIELDS

$F^2 - 26\times10^3 F = 0$; $F = 3,500$ N

④ ⇒ $X = 6.825\times10^{-6}$

$\therefore 0.11^4 - d_i^4 = 6.825\times10^{-6}$; $d_i = 0.109$ m

$(d_i)_{MAX} = 0.108$ m $= 108$ mm ANS.

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R2.14

$$\sigma_n = \frac{75\times10^9}{(1-0.33^2)}\left[500+0.33(-300)\right]\times10^{-6}$$
$$= 33.750\ \text{MPa}$$

$$\sigma_t = \frac{75\times10^9}{(1-0.33^2)}\left[-300+0.33(500)\right]\times10^{-6}$$
$$= -11.362\ \text{MPa}$$

FROM EXAMPLE 2.12, WE HAVE

$$\sigma_n = \frac{1}{2}\sigma_x(1+\cos2\theta)+\tau_{xy}\sin2\theta$$

$$33.750 = \frac{1}{2}\sigma_x(1+\cos100)+\tau_{xy}\sin100$$

$$33.750 = 0.413\sigma_x + 0.985\tau_{xy} \quad \text{——①}$$

$$\sigma_t = \frac{1}{2}\sigma_x(1+\cos2(\theta+90))+\tau_{xy}\sin2(\theta+90)$$

$$-11.362 = \frac{1}{2}\sigma_x(1+\cos280)+\tau_{xy}\sin280$$

$$-11.362 = 0.587\sigma_x - 0.985\tau_{xy} \quad \text{——②}$$

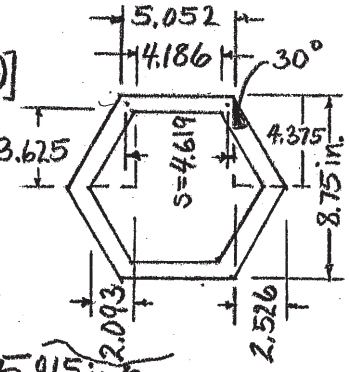
SOLVE ① & ② TO GET

$$\sigma_x = 22.388\ \text{MPa};\quad \tau_{xy} = 24.883\ \text{MPa}$$

$$\sigma_x = \frac{P}{A};\quad P = \sigma_x A = 22.388\times10^6\left(\frac{\pi}{4}\right)(0.1^2)$$
$$P \approx 175.8\ \text{kN} \qquad \text{ANS.}$$

$$\tau_{xy} = \frac{TR}{J};\quad T = \frac{\tau_{xy}J}{R} = \frac{24.883\times10^6(\pi/32)(0.14)}{0.05}$$
$$Q = T = 4.886\ \text{kN·m} \qquad \text{ANS.}$$

R2.15



$$A_o = 2\left[\left(\tfrac{1}{2}\right)(8.75)(2.526)\right] + 5.052(8.75)$$
$$A_o = 66.3075\ \text{in}^2$$

$$A_i = 2\left[\left(\tfrac{1}{2}\right)(7.25)(2.093)\right] + 4.186(7.25)$$
$$A_i = 45.5228\ \text{in}^2$$

$$A_m = \frac{1}{2}(A_o+A_i) = 55.915\ \text{in}^2$$

$$\tau = \frac{T}{2tA_m};\quad T = 2tA_m\tau$$

$$T = 2(0.75)(55.915)(12) = 1006.5\ \text{kip·in.}$$

$$\theta = \frac{TL}{4GA_m^2\sum(s/t)};\quad T = \frac{4GA_m^2\theta}{L\sum(s/t)}$$

$$T = \frac{4(5.0\times10^3)(55.915^2)(2\pi/180)}{4(12)\left[6(4.619/0.75)\right]} = 1230.6\ \text{kip·in}$$

$$Q_{MAX} = 1006.5\ \text{kip·in.} \qquad \text{ANS.}$$

R2.16

$$K = \frac{1}{3}\sum Lt^3 = \frac{1}{3}\left[6(4.619)(0.75^3)\right] = 3.897\ \text{in}^4$$

$$\tau = \frac{Tt}{K};\quad T = \frac{\tau K}{t} = \frac{12(3.897)}{0.75} = 62.352\ \text{kip·in}$$

$$\theta = \frac{TL}{KG};\quad T = \frac{KG\theta}{L} = \frac{3.897(5\times10^3)(2\pi/180)}{4(12)}$$
$$= 14.170\ \text{kip·in.}$$

$$\therefore Q_{MAX} = 14.170\ \text{kip·in.} \qquad \text{ANS.}$$

R2.17

FROM PROBLEM 2.132 WE HAVE

$$T = \frac{\pi\tau_y}{2}\left[\frac{4R_o^3-\rho_y^3}{3} - \frac{R_i^4}{\rho_y}\right]$$

REWRITING THIS EQ. WE OBTAIN THE FOLLOWING POLYNOMIAL:

$$\rho_y^4 + \left(\frac{6T}{\pi\tau_y} - 4R_o^3\right)\rho_y + 3R_i^4 = 0$$

SUBSTITUTING GIVEN NUMERICAL VALUES, THE ABOVE EQ. REDUCES TO

$$\rho_y^4 - 5.313\times10^{-4}\rho_y + 7.68\times10^{-6} = 0$$

A TRIAL-AND-ERROR SOLUTION YIELDS

$$\rho_y = 0.07545\ \text{m}$$

$$d = R_o - \rho_y = 0.08 - 0.07545$$
$$= 0.00455\ \text{m} = 4.55\ \text{mm} \qquad \text{ANS.}$$

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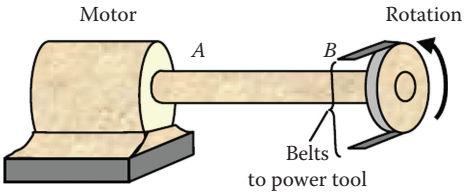


FIGURE 2.1 Example of a motor transmitting power, through shaft AB, to a power tool.

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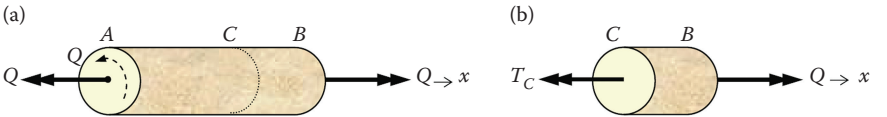


FIGURE 2.3 Representation of a concentrated torque Q at the center point in a circular shaft.

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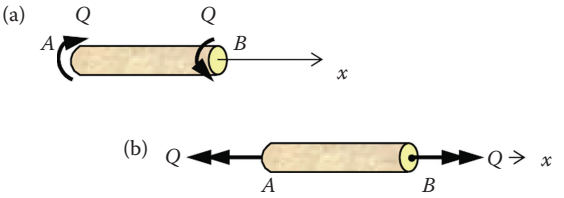


FIGURE 2.2 Representation of a three-dimensional torque Q by a double-headed arrow. Interpretation is made by the right-hand rule.

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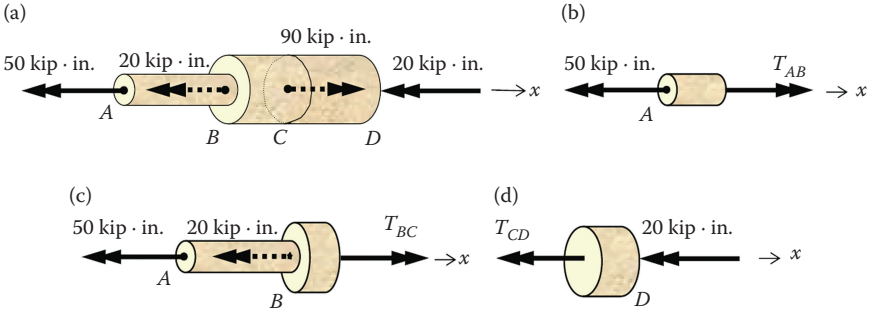


FIGURE 2.4 Shaft subjected to concentrated torques at a number of positions along its length, and determination of internal torques in segments *AB*, *BC*, and *CD* using equilibrium.

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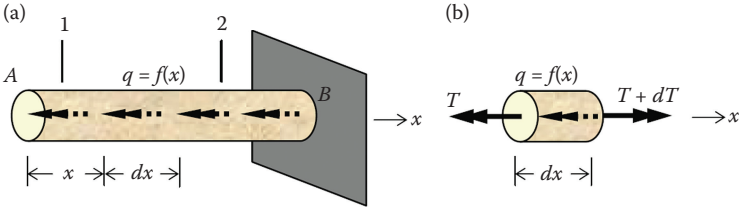


FIGURE 2.6 Example of a variably distributed torque $q = f(x)$ over the length of shaft AB and determination, using equilibrium, of internally distributed torque at any position in the shaft.

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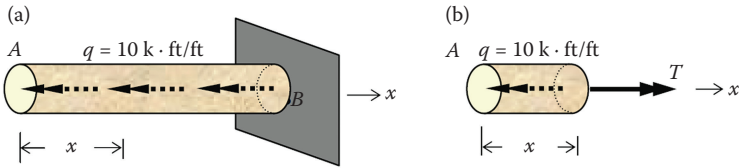


FIGURE 2.5 Example of a constantly distributed torque $q = 10$ k · ft/ft over the entire length of the shaft AB and determination, by equilibrium, of internally distributed torque at any position a distance x from end A.

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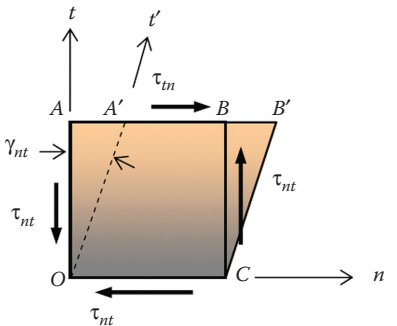


FIGURE 2.7 Definition of shearing strain γ_{nt} as being approximately equal to the tangent of the shearing angle γ_{nt}.

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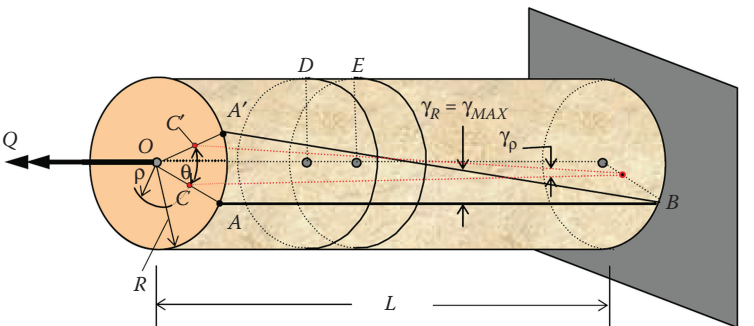


FIGURE 2.8 Shaft showing distortion under the influence of a torque Q and the definition of the angle of twist θ.

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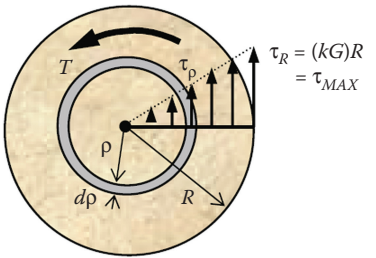


FIGURE 2.9 Circular cross section of a circular shaft showing the stress distribution due to a torque T.

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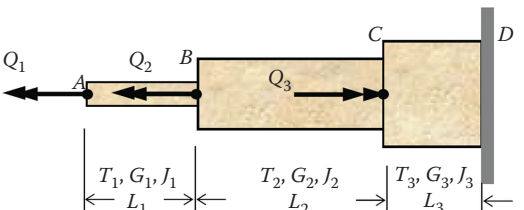


FIGURE 2.10 Shaft consisting of three component parts, each having its own properties T, G, and J, showing that the total angle of twist is the sum of three angles of twist.

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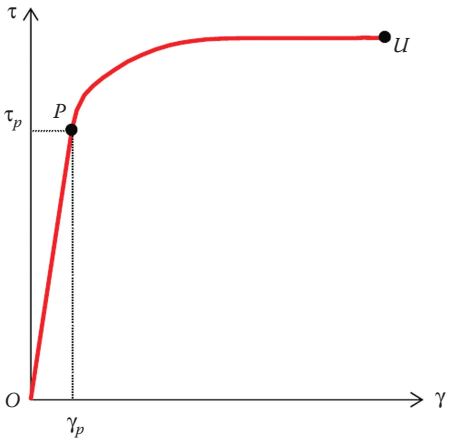


FIGURE 2.11 Shearing stress–strain diagram for a given ductile material, defining the properties: modulus of rigidity G and the modulus of rupture τ_U.

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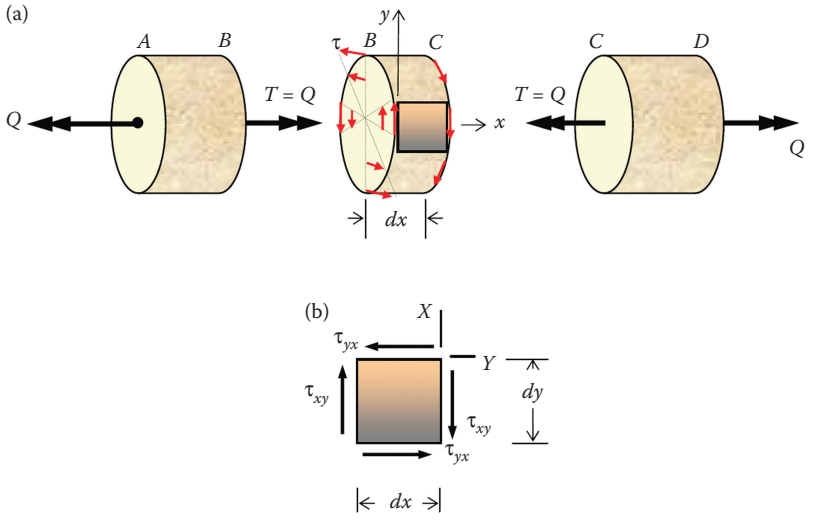


FIGURE 2.12 Diagram showing the state of pure shear in a shaft subjected to a torque Q.

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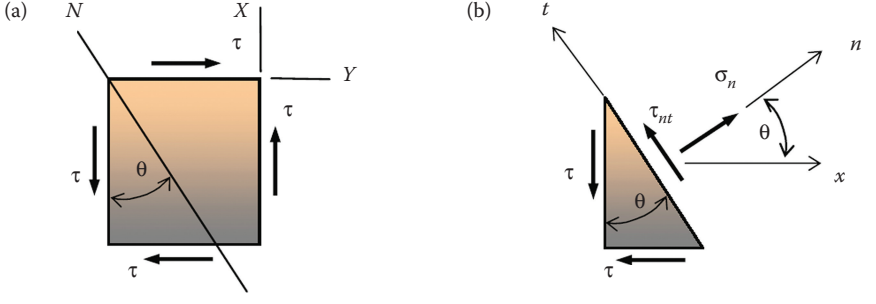


FIGURE 2.13 (a) The state of pure shear and (b) determination of normal and shearing stresses on inclined planes.

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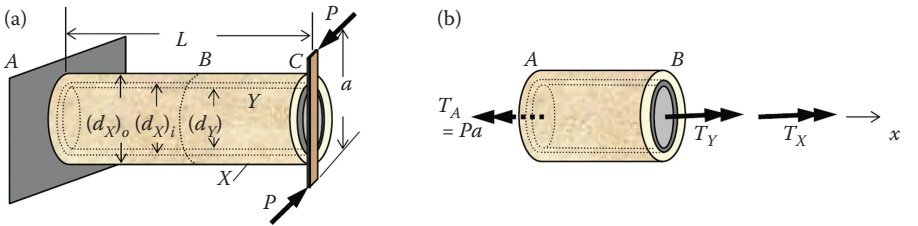


FIGURE 2.14 (a) A two-material shaft subjected to a torque Pa and (b) the free-body diagram of segment AB.

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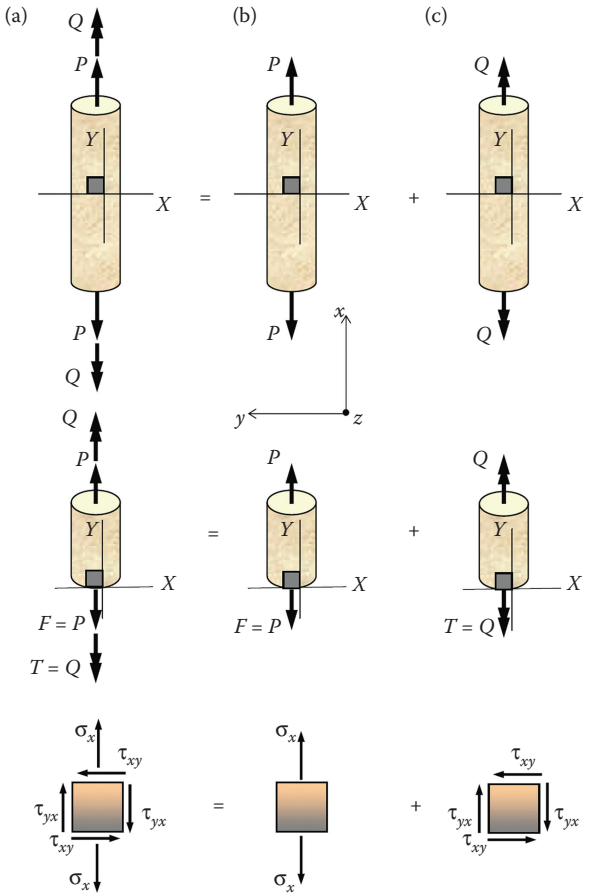


FIGURE 2.15 Analysis of stresses in a shaft subjected to the combined loads, axial force P and a torque Q.

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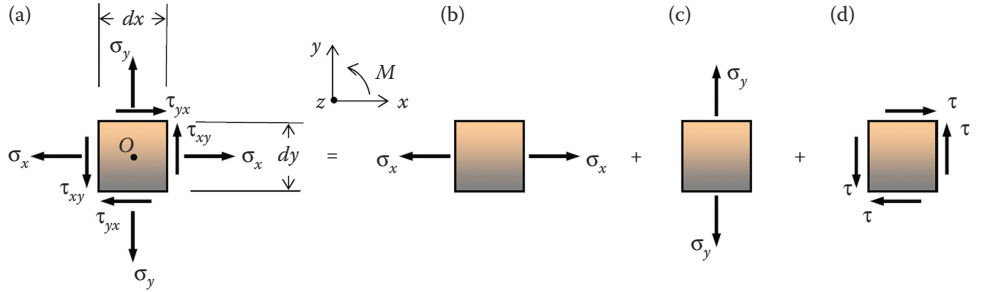


FIGURE 2.16 A general plane-stress condition broken down into three simple components, two uniaxial σx and σy, and one pure shear τ.

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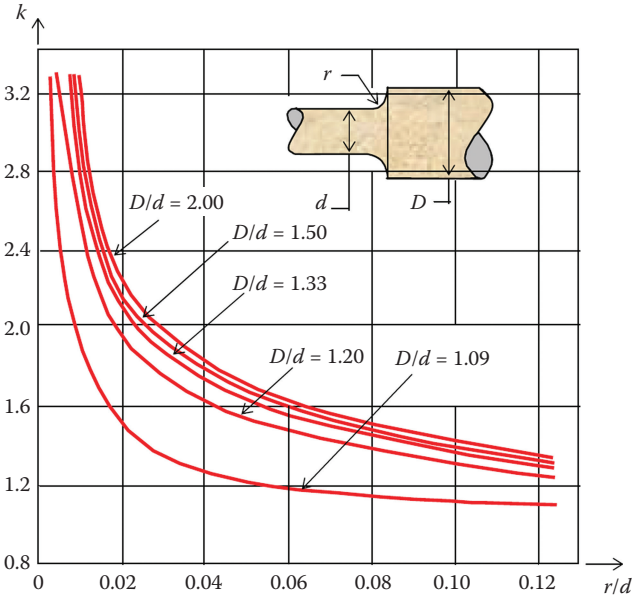


FIGURE 2.17 Stress-concentration factors for torsional loads. (Adapted from the work of L.S. Jacobsen, Torsional stress concentrations in shafts of circular cross section and variable diameter, *Trans ASME*, 47, 619–641, 1925.)

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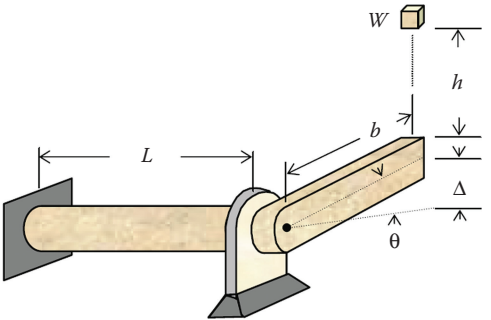


FIGURE 2.18 Diagram showing a shaft of length L subjected to impact loading due to a weight W dropping through a height h.

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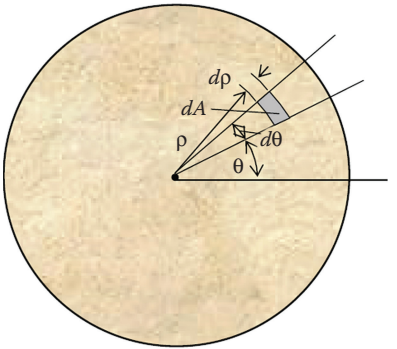


FIGURE 2.20 Cross section of a shaft subjected to a torque T and used to determine the total strain energy U.

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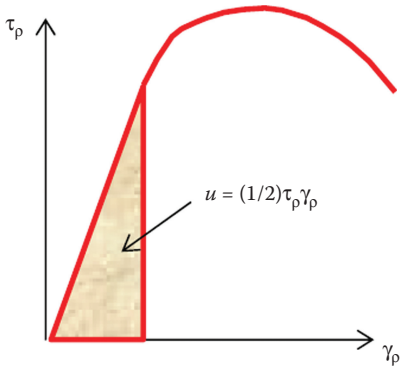


FIGURE 2.19 A shearing stress–strain diagram showing determination of the elastic strain energy u.

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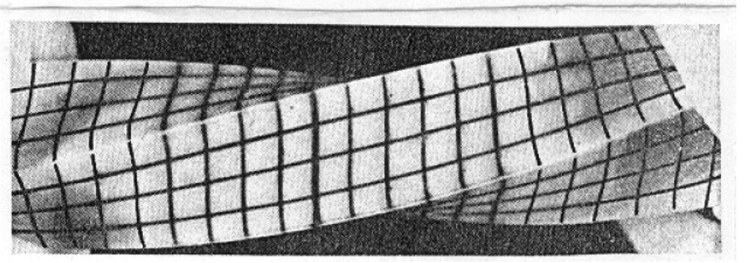


FIGURE 2.22 Diagram showing that, for a shaft of a noncircular cross section, plane sections before twisting do not remain plane after twisting.

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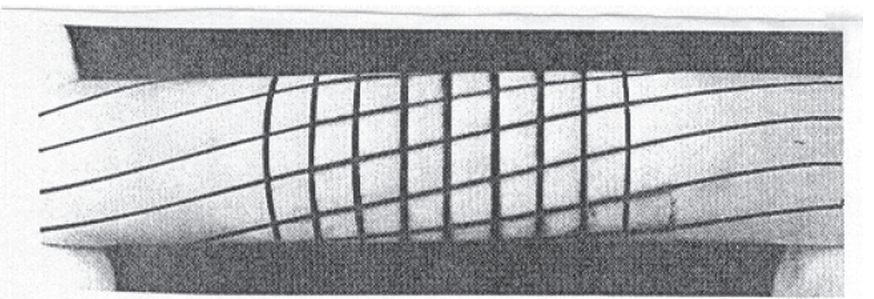


FIGURE 2.21 Diagram showing that, for a shaft of circular cross section, plane sections before twisting remain plane after twisting.

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$$\tau_{MAX} = \frac{T(3a + 1.8b)}{8a^2b^2}; \quad \text{occurs at } A$$

$$\theta = \frac{TL}{KG}; \quad K = ab^3 \left[\left(\frac{16}{3} \right) - 3.36 \left(\frac{b}{a} \right) \left(1 - \frac{b^4}{12a^4} \right) \right]$$

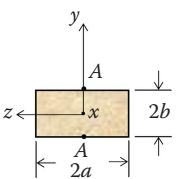


FIGURE 2.24 Mathematically obtained solutions for a shaft of a rectangular cross section.

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$$\tau_{MAX} = \frac{2T}{\pi ab^2}; \quad \text{occurs at } A$$

$$\theta = \frac{TL}{KG}; \quad K = \frac{\pi a^3 b^3}{a^2 + b^2}$$

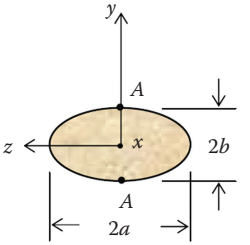


FIGURE 2.23 Mathematically obtained solutions for a shaft of an elliptical cross section.

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$$\tau_{MAX} = \frac{20T}{a^3}; \quad \text{occurs at } A$$

$$\theta = \frac{TL}{KG}; \quad K = \frac{\left(\sqrt{3}\right)a^4}{80}$$

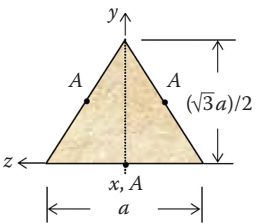


FIGURE 2.25 Mathematically obtained solutions for a shaft of an equilateral triangular cross section.

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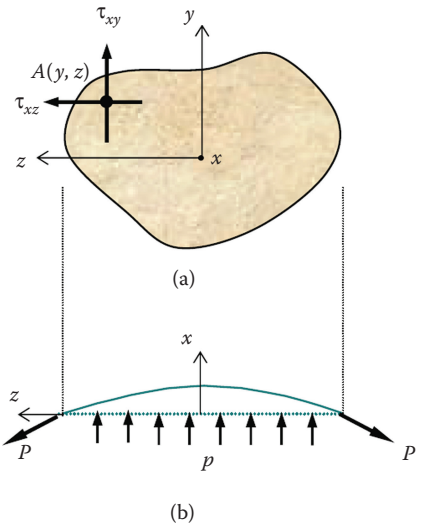


FIGURE 2.26 (a,b) The two views of a distended thin membrane subjected to a pressure p used to experimentally solve the torsion problem of noncircular shafts.

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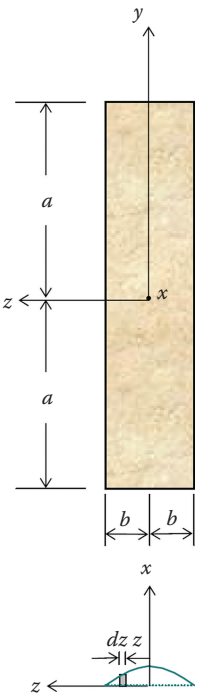


FIGURE 2.27 Experimental solution of the torsion problem of a shaft having a long and thin rectangular cross section.

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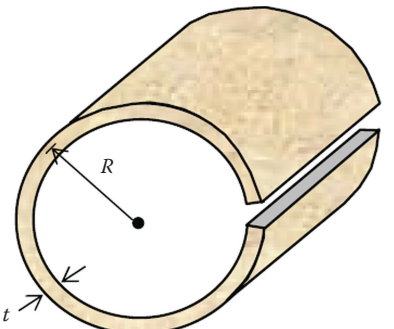


FIGURE 2.28 Solution of the torsion problem of a shaft with a narrow circular section having a thin slit.

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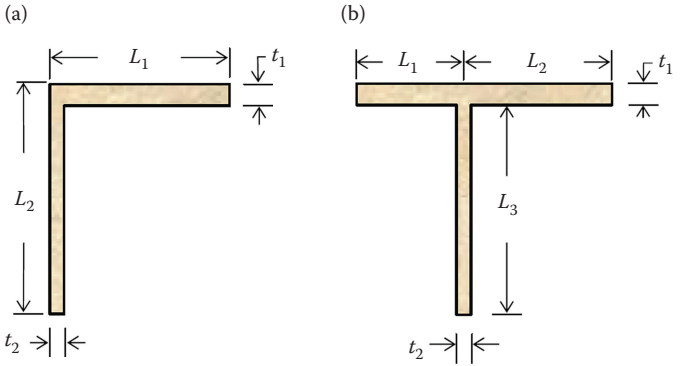


FIGURE 2.29 Diagrams showing cross sections composed of narrow rectangles for which solutions can be obtained.

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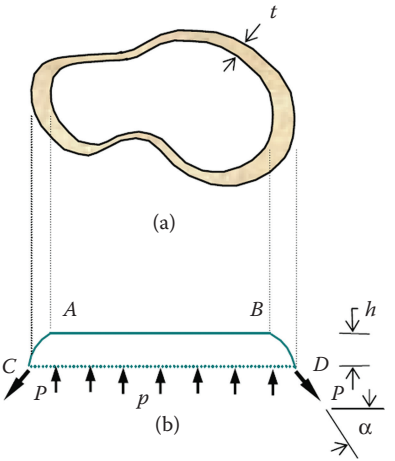


FIGURE 2.30 (a,b) The two views of a distended thin membrane subjected to a pressure p used to experimentally solve the torsion problem of thin-walled tubes of noncircular shafts.

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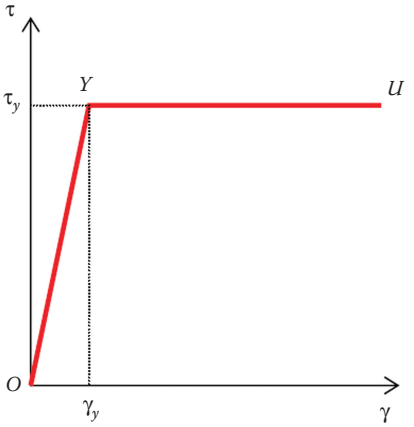


FIGURE 2.31 Stress–strain diagram for an elastoplastic material in which τ_y is the yield stress.

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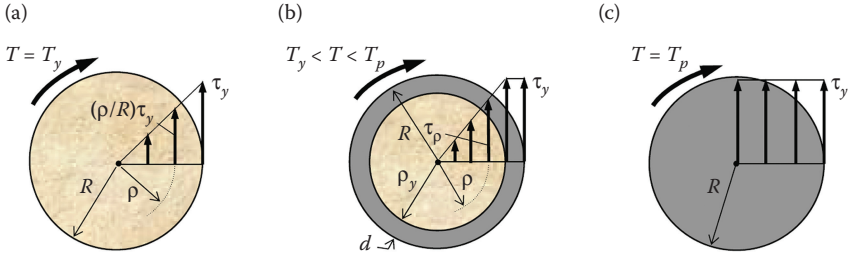


FIGURE 2.32 (a) The shearing stress distribution in a circular shaft when it reaches the yield stress τ_y. (b) The stress distribution when plastic action has reached the outer layers of the circular shaft. (c) The stress distribution when the entire shaft is under plastic action.

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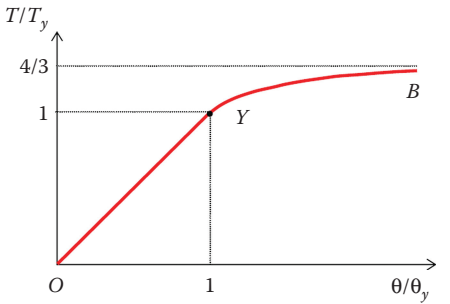


FIGURE 2.33 Diagram showing a plot of Equation 2.65.

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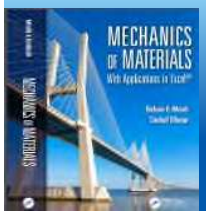
MECHANICS OF MATERIALS: WITH APPLICATIONS IN EXCEL

CHAPTER 2: TORSIONAL LOADS

LECTURE 7

2.1 INTRODUCTION

2.2 INTERNAL TORQUE

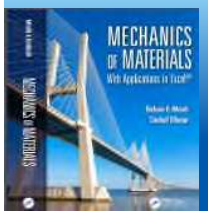


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Lecture Outline

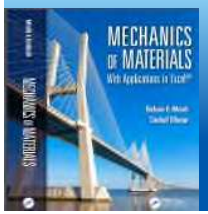
- Introduction
- Internal Torque
- Examples



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Introduction

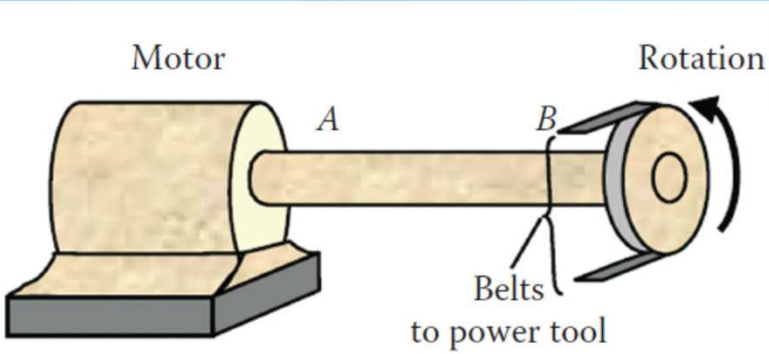
- This topic deals with members subjected to torsional loads, namely, moments (couples) about the centroidal axes of such members.
- These types of moments or couples are generally referred to as torques and the members subjected to torques are generally known as shafts.
- Examples of these types of members include propeller shafts of ships and aircraft and drive shafts of automobiles, power tools, and other equipment.

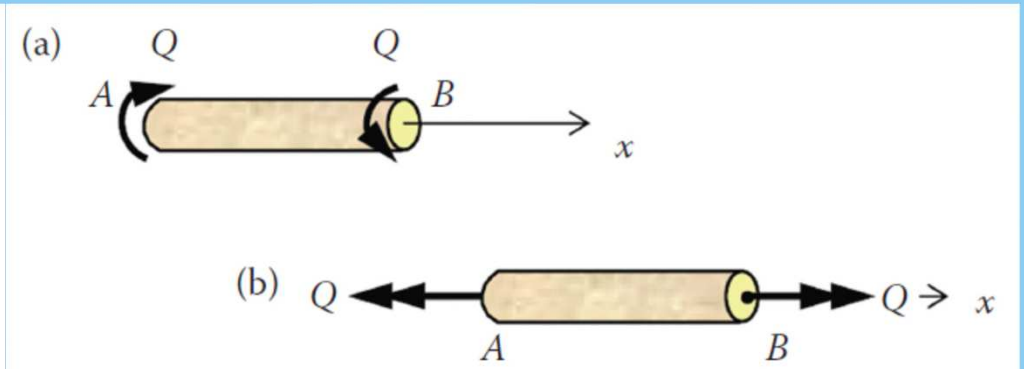


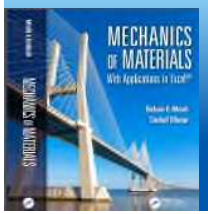
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Concentrated Torque

- A concentrated torque may be defined as one that is applied over a very small area (assumed to be a point) of the member on which it acts.





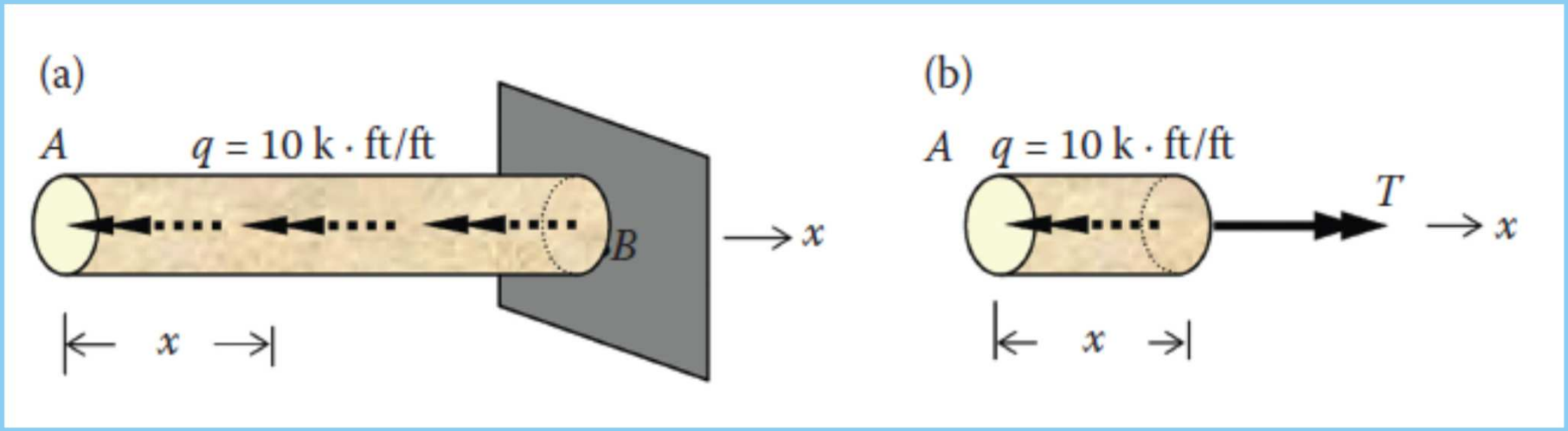


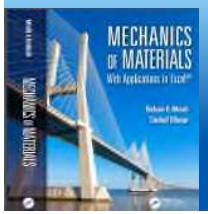
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Distributed Torque

- A distributed torque is applied over the length of a member.



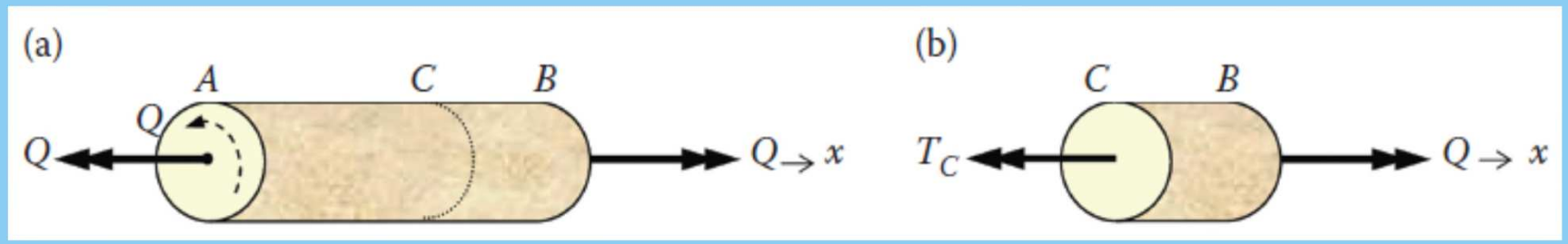


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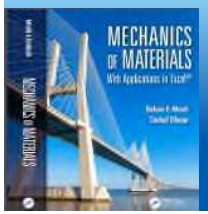
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Internal Torque

- Internal torque at any location along the member is obtained by introducing a section at the location and applying equilibrium. The figure below illustrates the internal torque at C, T_C.



$$\sum T_x = 0 \Rightarrow Q - T_C = 0; \quad T_C = Q$$

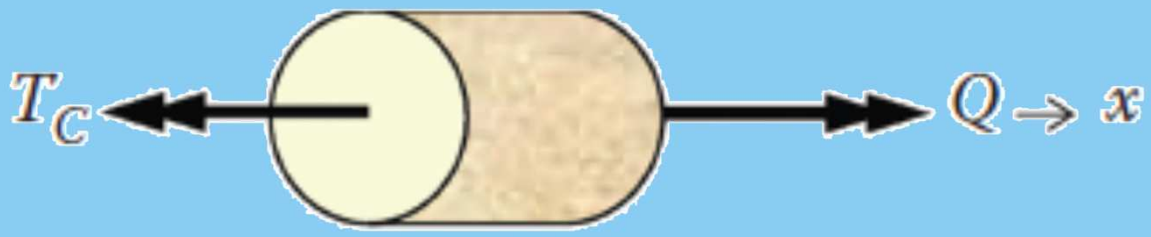


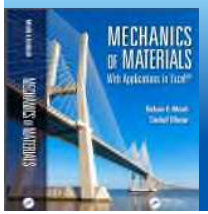
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Sign Convention

- Torque is positive, if the two-headed vector representing it points away from the surface on which it acts, and negative, if it points into this surface.



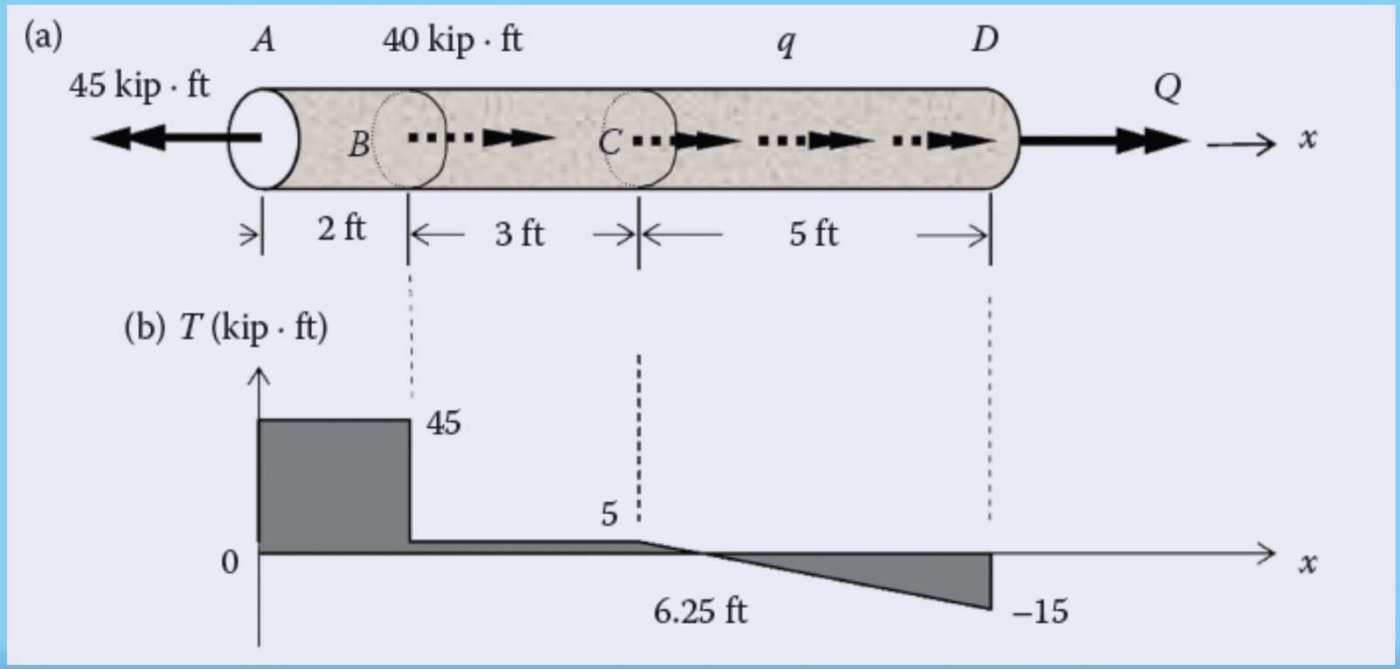


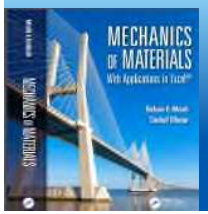
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Internal Torque Diagram

- An internal torque diagram is a diagram that shows, at a glance, how the internal torque changes from point to point along the length of the shaft

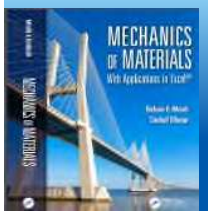




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Examples



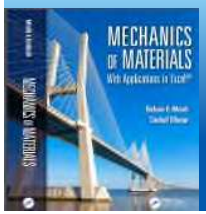
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MECHANICS OF MATERIALS: WITH APPLICATIONS IN EXCEL

CHAPTER 2: TORSIONAL LOADS

LECTURE 8

2.3 STRESSES AND DEFORMATIONS IN CIRCULAR SHAFTS

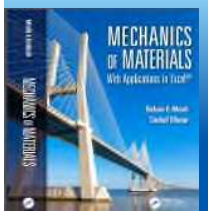


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Lecture Outline

- Introduction
- Stresses and Deformation in Circular Shafts
- Material Properties in Shear
- Stress Element
- Examples

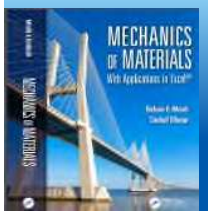


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Introduction

- The torsion of circular shafts represents the simplest of all torsion problems.
- Pure torsion causes shear strain and shear stress.



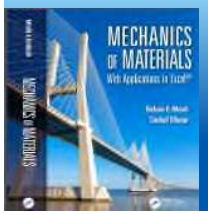
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Stresses and Deformations in Circular Shafts

- Shear stress-strain relations are used to study the behavior of torsional shafts. Stress-Strain relations are governed by Hooke's Law:

$$\tau = G\gamma$$



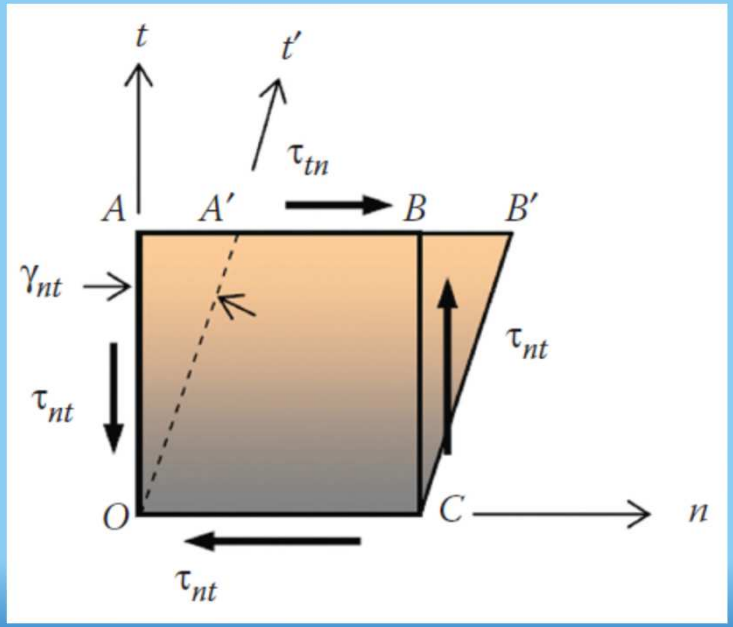
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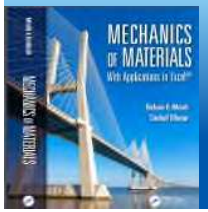
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Shearing Strain

- Shear strain is a distortion – it represents a change in the initial shape of the body.
- Distortion can best be represented by the change in the angle between two initially perpendicular lines

$$\gamma_{nt} \approx \tan \gamma_{nt} = \frac{AA'}{OA}$$

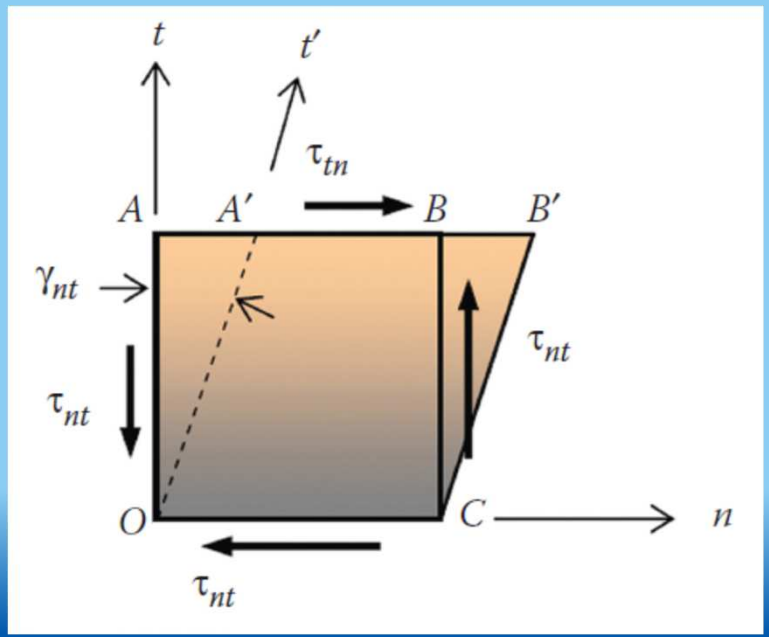


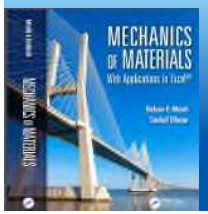


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Shearing Strain – Sign Convention

- A positive shearing strain represents a decrease in the 90° angle and a negative shearing strain represents an increase in this angle.
- The shearing strain shown below is positive since it represents a decrease in the 90° angle between OA and OC.

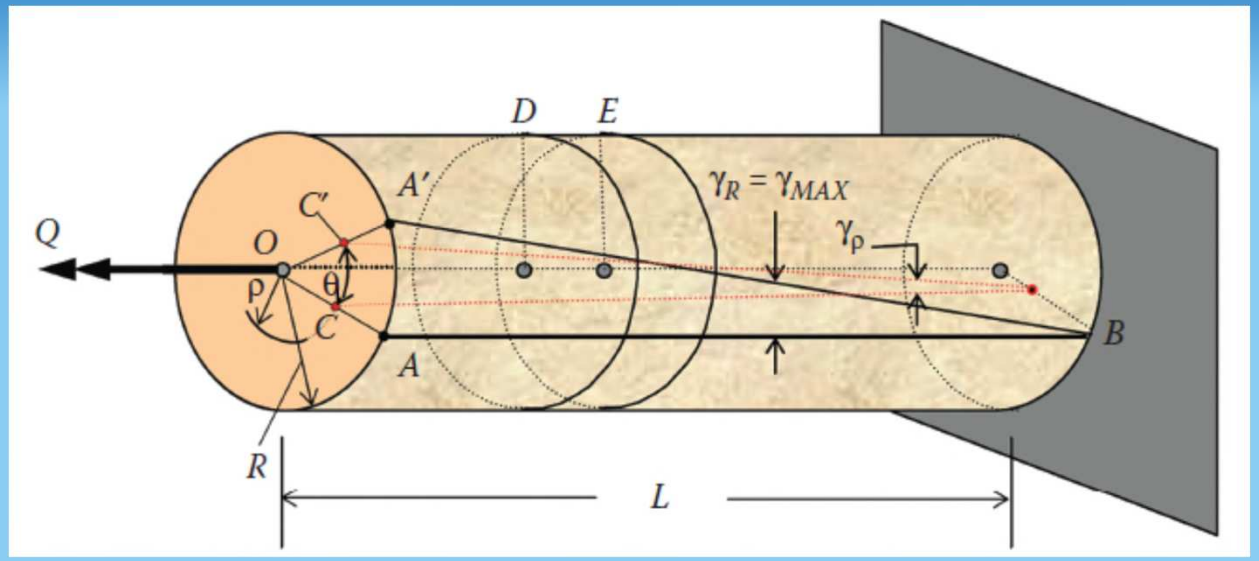




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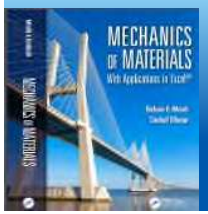
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Shearing Stress and Shearing Deformation



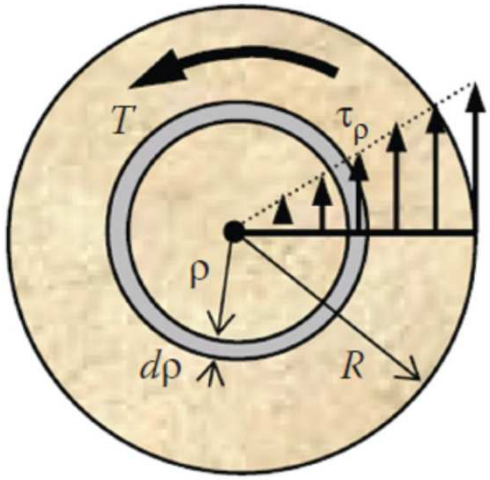
Assumptions:

1. Cross sections such as those at D and E are plane prior to twisting and remain plane after twisting of the circular shaft.
2. Straight line elements on the surface of the shaft such as line AB are assumed to remain straight after twisting occurs. Point A moves to A′ and line A′B is assumed to be straight for small angles θ even though its true shape is helical.
3. The material is assumed to behave elastically in order to be able to use Hooke's law.



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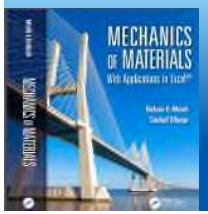
Torque to Shearing Stress Relationship



$$\tau_R = (kG)R = \tau_{MAX}$$

$$T = \int \tau_\rho \rho \, dA = 2\pi \int_0^R \tau_\rho \rho^2 d\rho = 2\pi \int_0^R \left(\frac{\tau_\rho}{\rho}\right) \rho^3 \, d\rho$$

$$T = 2\pi \left(\frac{\tau_\rho}{\rho}\right) \int_0^R \rho^3 d\rho = \left(\frac{\tau_\rho}{\rho}\right)\left(\frac{\pi R^4}{2}\right) = \left(\frac{\tau_\rho}{\rho}\right) J$$



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Maximum Shearing Stress and Angle of Twist

- Maximum Shearing Stress:

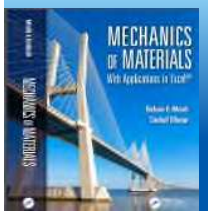
$$\tau_{MAX} = \tau_R = \frac{TR}{J}$$

- Angle of Twist:

$$\theta = \frac{TL}{JG}$$

For a shaft with multiple segments: $$\theta = \sum \frac{TL}{JG}$$

J= Polar Moment of Inertia of the Cross-Section

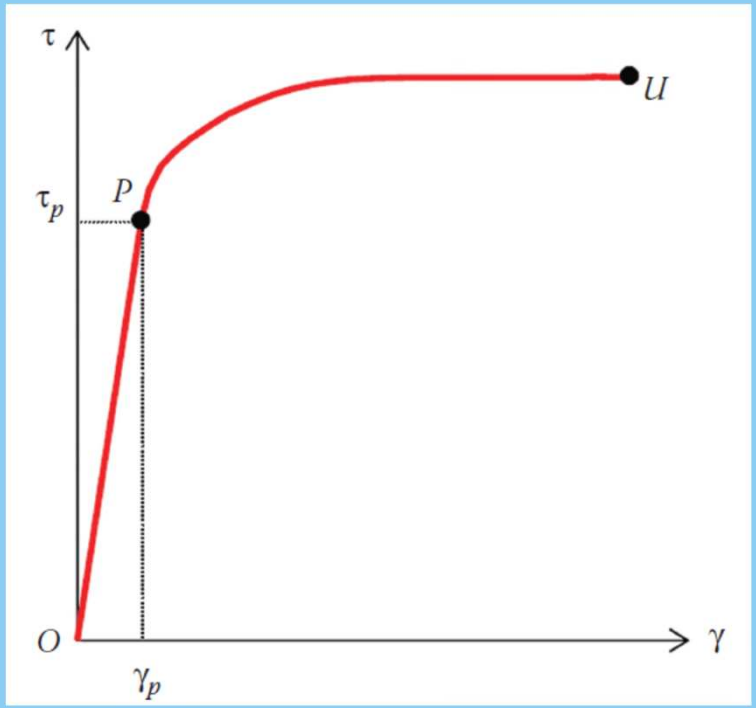


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Material Properties in Shear

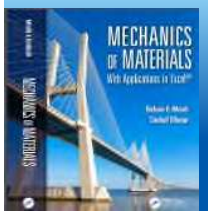
Shear Stress-Strain Diagram:



Hooke's Law applies in the linear-elastic region O-P:

$$\tau = G\gamma$$

G: Shear Modulus of Elasticity

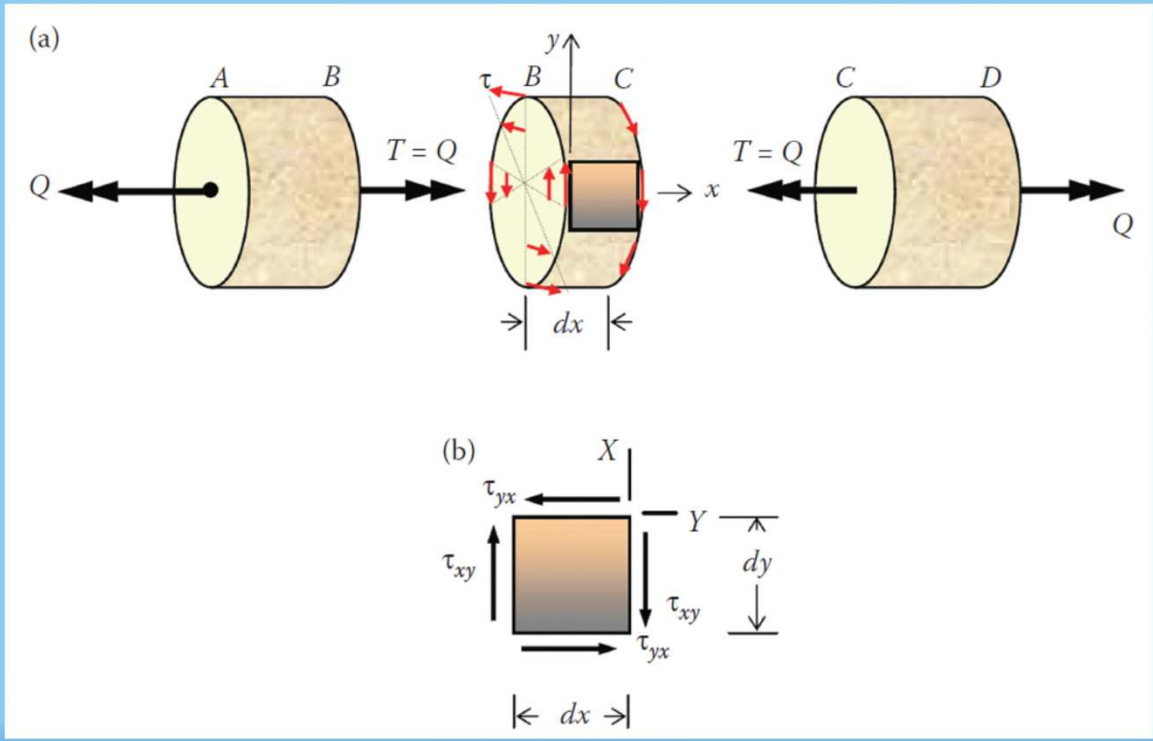


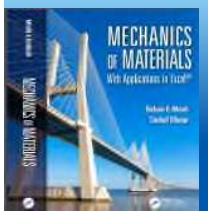
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Stress Element

- State of pure shear in a shaft subjected to a torque Q



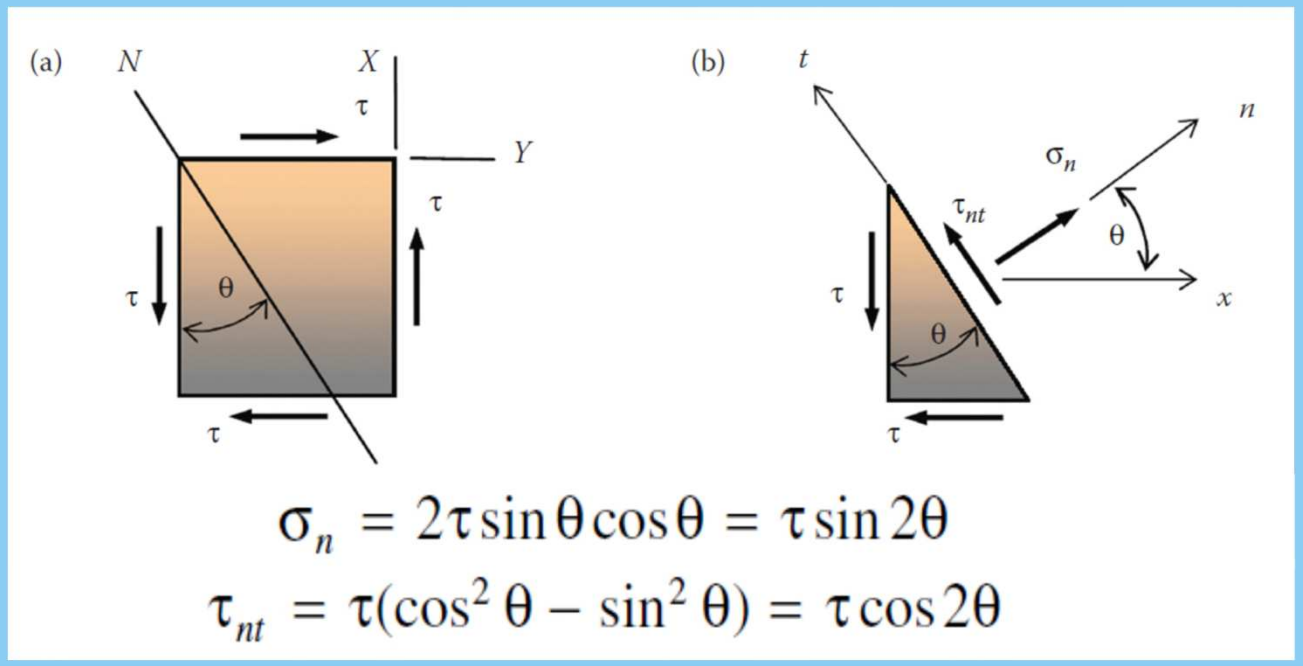


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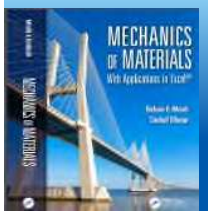
Stresses on Inclined Planes

- From a state of pure shear to the determination of normal and shearing stresses on an inclined plane



$$\sigma_n = 2\tau \sin\theta \cos\theta = \tau \sin 2\theta$$

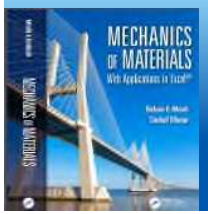
$$\tau_{nt} = \tau(\cos^2\theta - \sin^2\theta) = \tau \cos 2\theta$$



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Examples



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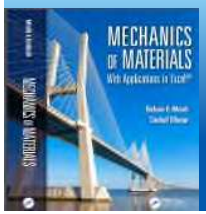
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CHAPTER 2: TORSIONAL LOADS

LECTURE 9

2.4 STATICALLY INDETERMINATE SHAFTS

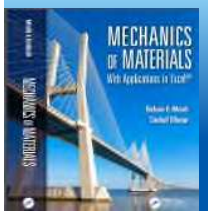


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Lecture Outline

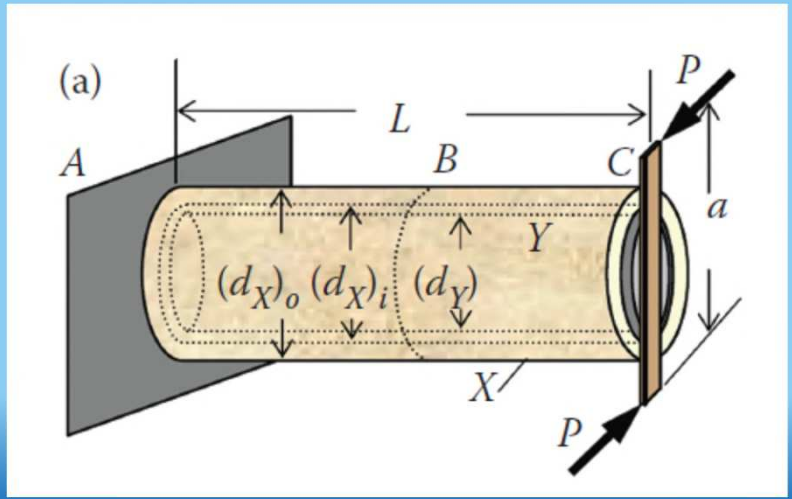
- Definition
- Solution Procedure
- Examples

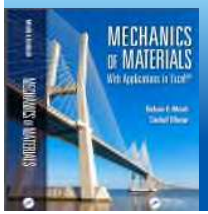


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Definition

- statically indeterminate shaft is one in which the number of unknown quantities exceeds the number of available equilibrium equations.
- Situation may happen when more than one material are involved or there are too many torsional reactions.





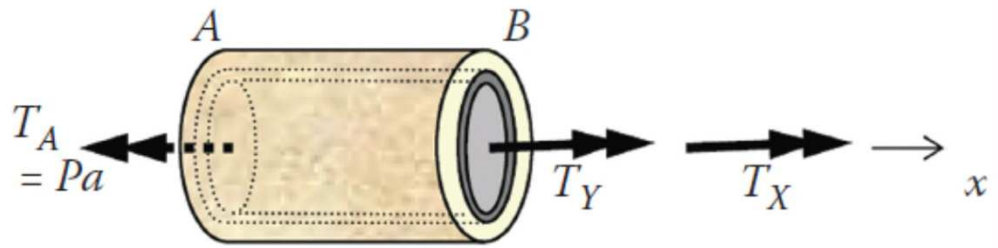
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Solution Procedure

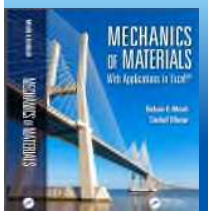
- Supplement the conditions of equilibrium with relations arising from the deformation characteristics of the shaft under consideration

(b)



$$\sum T_x = 0 \Rightarrow T_X + T_Y - Pa = 0$$

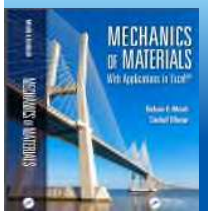
$$\theta_X = \theta_Y \Rightarrow \left(\frac{TL}{JG}\right)_X = \left(\frac{TL}{JG}\right)_Y$$



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Examples



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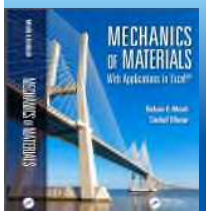
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CHAPTER 2: TORSIONAL LOADS

LECTURE 10

2.5 DESIGN OF POWER-TRANSMISSION SHAFTS

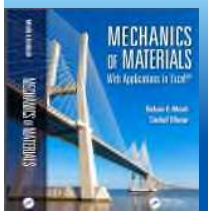


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Lecture Outline

- Definitions
- Units of Power
- Examples



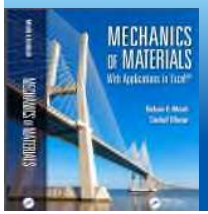
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Definitions

- Shafts are primarily used to transmit power from one location to another:

$$P = T\omega$$

- P: Transmitted power; i.e. the rate at which work is performed by the transmission shaft
- T: Internal torque in the transmission shaft
- ω: Angular speed



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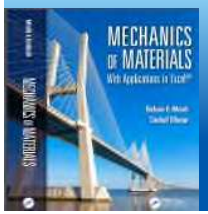
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Units of Power

- SI System of Units:

  m·N/s = joules/s = watt (W)
  or
  m·kN/s = kilowatt (kW)

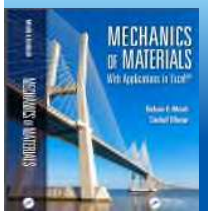
- US Customary System:
  in·lb/s or ft·lb/s
  or
  horsepower (hp) where 1 hp = 550 ft·lb/s = 6600 in·lb/s



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Examples



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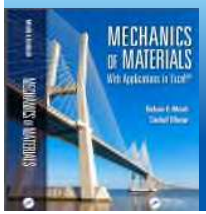
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MECHANICS OF MATERIALS: WITH APPLICATIONS IN EXCEL

CHAPTER 2: TORSIONAL LOADS

LECTURE 11

2.6 STRESSES UNDER COMBINED LOADS

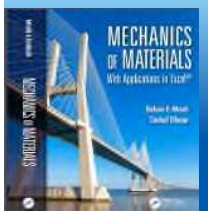


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Lecture Outline

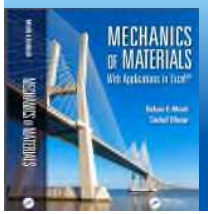
- Superposition
- Hooke's Law in two dimensions
- Examples



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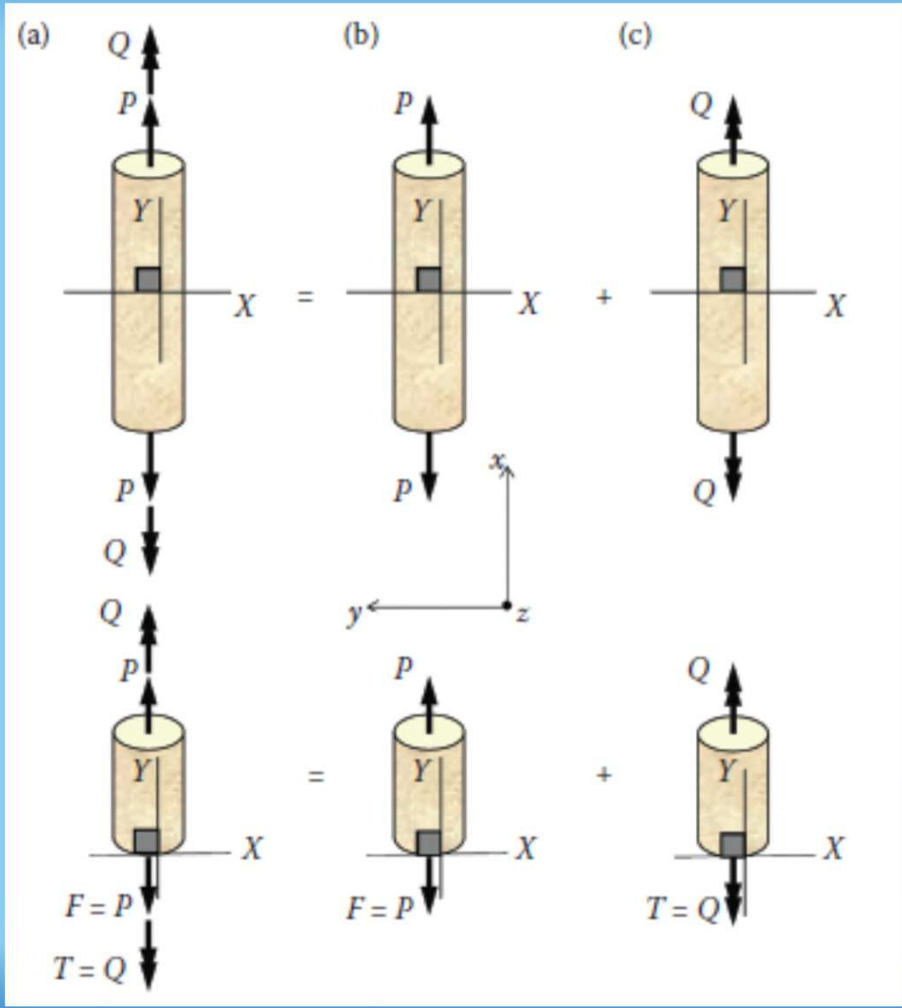
Superposition

- Analysis of combined axial and torsional loads is most conveniently accomplished by using the principle of superposition.
- The method of superposition is equally applicable to any cross-sectional form as long as the material is not stressed beyond the elastic limit.



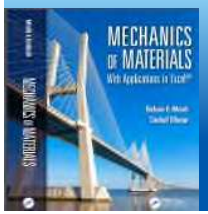
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Combined Axial Force and Torque



Applied Loads

Internal Loads

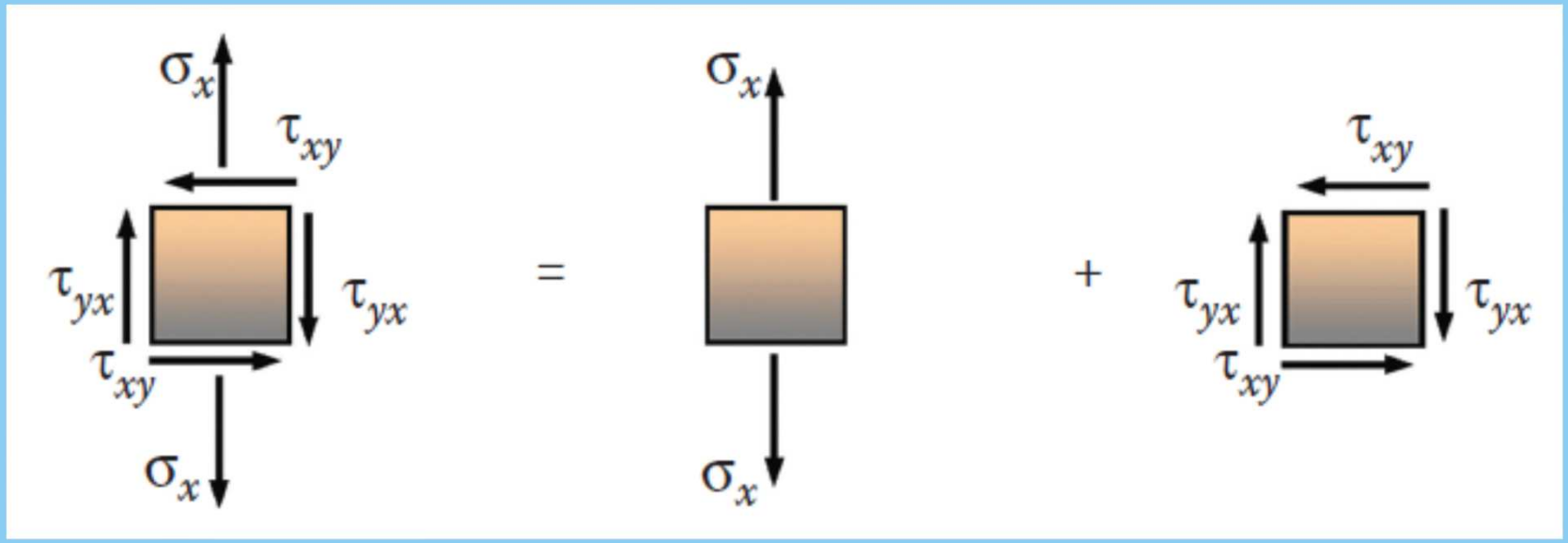


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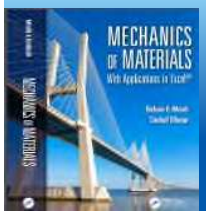
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Combined Axial Force and Torque - Srtesses

From Both Loads From Axial Load From Torque



Normal Stress Shear Stress

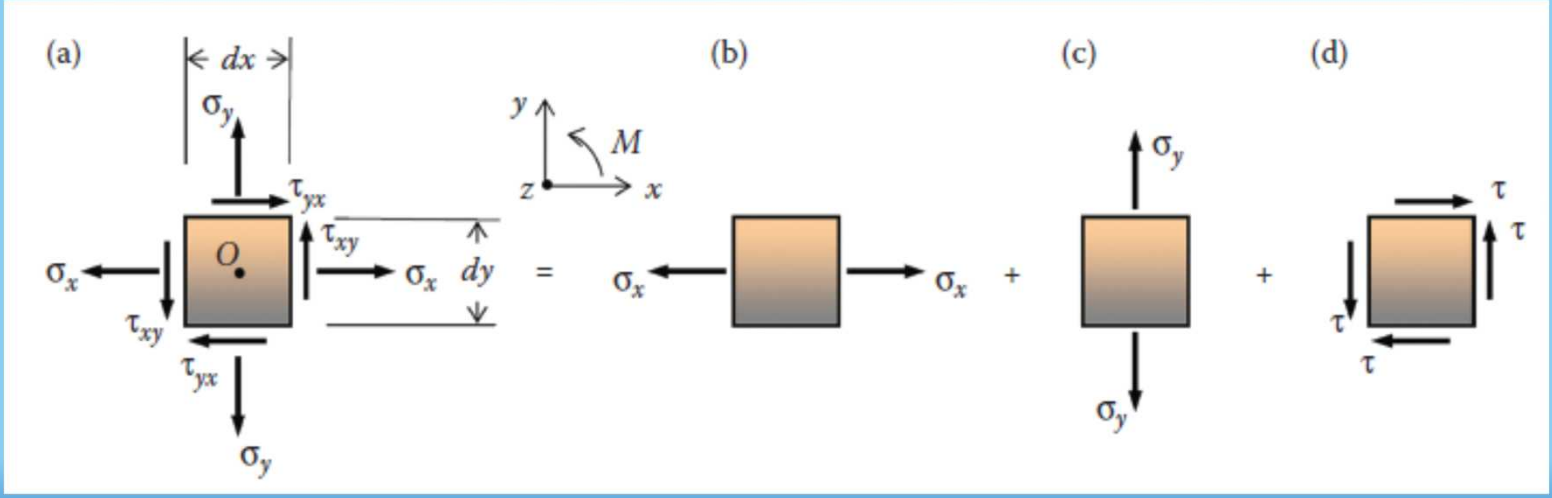


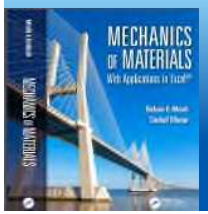
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Hooke's Law in Two Dimensions

- Condition is referred to as a state of plane stress
- Although stresses exist on one plane only (two-dimensions), strain components will be in three-dimensions because of Poisson's ratio





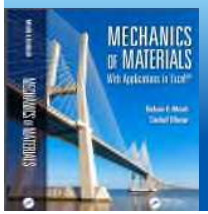
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Hooke's Law in Two Dimensions

- Applying Hooke's Law and the definition of Poisson's ratio:

$$\left.\begin{aligned} \varepsilon_x &= \frac{\sigma_x}{E} - \mu\left(\frac{\sigma_y}{E}\right) = \frac{1}{E}(\sigma_x - \mu\sigma_y) \\ \varepsilon_y &= \frac{\sigma_y}{E} - \mu\left(\frac{\sigma_x}{E}\right) = \frac{1}{E}(\sigma_y - \mu\sigma_x) \\ \varepsilon_z &= -\frac{\mu}{E}(\sigma_x + \sigma_y); \quad \gamma_{xy} = \frac{\tau_{xy}}{G} \end{aligned}\right\} \qquad (2.22)$$



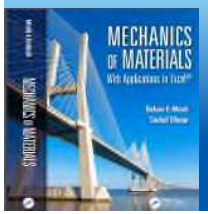
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Hooke's Law in Two Dimensions

- Expressing stresses in terms of strains:

$$\left.\begin{aligned}\sigma_x &= \frac{E}{1-\mu^2}(\varepsilon_x + \mu\varepsilon_y)\\ \sigma_y &= \frac{E}{1-\mu^2}(\varepsilon_y + \mu\varepsilon_x)\\ \sigma_z &= 0\end{aligned}\right\} \qquad (2.23)$$



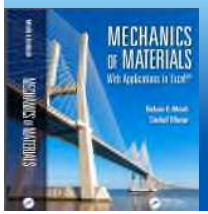
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Hooke's Law in Two Dimensions

- Relationship between the Modulus of Elasticity and the Shear Modulus:

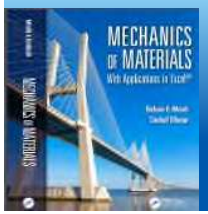
$$G = \frac{E}{2(1+\mu)} \qquad (2.24)$$



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Examples



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