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Solutions Manual

Engineering Mechanics of Solids

Second Edition

Egor P. Popov

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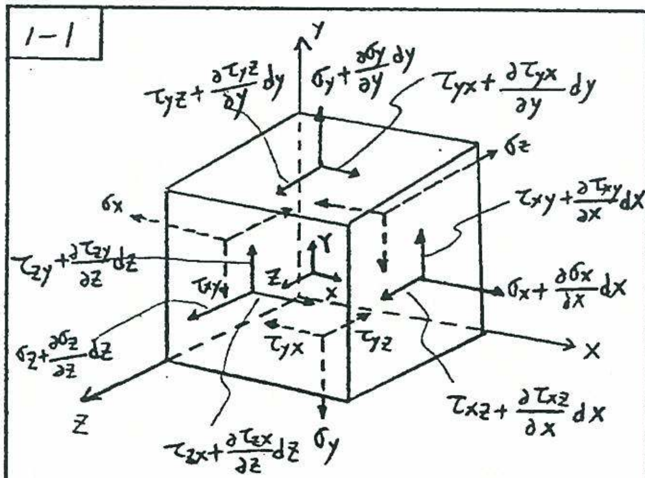
1-1



$$\Sigma F_x = \left(\sigma_x + \frac{\partial \sigma_x}{\partial x} dx\right) dy \cdot dz + \left(\tau_{yx} + \frac{\partial \tau_{yx}}{\partial y} dy\right) dx dz + \left(\tau_{zx} + \frac{\partial \tau_{zx}}{\partial z} dz\right) dx \cdot dy - \sigma_x \cdot dy \cdot dz - \tau_{yx} \cdot dx \cdot dz - \tau_{zx} \cdot dx \cdot dy + X = 0$$

$$\partial \sigma_x \, dx \cdot dy \cdot dz + \frac{\partial \tau_{yx}}{\partial y} dx \cdot dy \cdot dz + \frac{\partial \tau_{zx}}{\partial z} dx \cdot dy \cdot dz + X = 0$$

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + X = 0$$

1-2

$$\Sigma F_r = \left(\sigma_r + \frac{\partial \sigma_r}{\partial r} dr\right)(r + dr)\, d\theta + \left(\tau_{\theta r} + \frac{\partial \tau_{\theta r}}{\partial \theta} d\theta\right) dr - \tau_{\theta r} dr - \sigma_r r\, d\theta - \left(\sigma_\theta + \frac{\partial \sigma_\theta}{\partial \theta} d\theta\right) dr \frac{d\theta}{2} - \sigma_\theta dr \frac{d\theta}{2} = 0$$

$$\sigma_r dr d\theta + r \frac{\partial dr}{\partial r} dr\, d\theta + \frac{\partial \sigma_r}{\partial r} (dr)^2 d\theta + \frac{\partial \tau_{\theta r}}{\partial \theta} dr d\theta - \sigma_\theta dr d\theta - \frac{1}{2} \frac{\partial \sigma_\theta}{\partial \theta} (d\theta)^2 dr = 0$$

$$\sigma_r + r \frac{\partial \sigma_r}{\partial r} + \frac{\partial \sigma_r}{\partial r} \cancelto{0}{dr} + \frac{\partial \tau_{\theta r}}{\partial \theta} - \sigma_\theta - \frac{1}{2} \frac{\partial \sigma_\theta}{\partial \theta} \cancelto{0}{d\theta} = 0$$

$$\rightarrow \frac{\partial \sigma_r}{\partial r} + \frac{1}{r} \frac{\partial \tau_{\theta r}}{\partial \theta} + \frac{\sigma_r - \sigma_\theta}{r} = 0$$

$$\Sigma F_\theta = \left(\tau_{r\theta} + \frac{\partial \tau_{r\theta}}{\partial r} dr\right)(r + dr)\, d\theta + \left(\sigma_\theta + \frac{\partial \sigma_\theta}{\partial \theta} d\theta\right) dr + \left(\tau_{\theta r} + \frac{\partial \tau_{\theta r}}{\partial \theta} d\theta\right) dr \frac{d\theta}{2} + \tau_{\theta r} dr \frac{d\theta}{2} - \tau_{r\theta} r\, d\theta - \sigma_\theta dr = 0$$

$$\tau_{r\theta} dr d\theta + \frac{\partial \tau_{r\theta}}{\partial r} r\, dr d\theta + \frac{\partial \tau_{r\theta}}{\partial r} (dr)^2 d\theta + \frac{\partial \sigma_\theta}{\partial \theta} dr d\theta + \tau_{\theta r} dr d\theta + \frac{1}{2} \frac{\partial \tau_{\theta r}}{\partial \theta} (d\theta)^2 dr = 0$$

$$\tau_{r\theta} + \frac{\partial \tau_{r\theta}}{\partial r} r + \frac{\partial \tau_{r\theta}}{\partial r} \cancelto{0}{dr} + \frac{\partial \sigma_\theta}{\partial \theta} + \tau_{\theta r} + \frac{1}{2} \frac{\partial \tau_{\theta r}}{\partial \theta} \cancelto{0}{d\theta} = 0$$

$$\rightarrow \frac{\partial \tau_{r\theta}}{\partial r} + \frac{1}{r} \frac{\partial \sigma_\theta}{\partial \theta} + \frac{2 \tau_{r\theta}}{r} = 0$$

1-3

$$\sigma = \frac{P}{A} = \frac{110}{7.08} = 15.54 \text{ ksi}$$

$$\sigma = \frac{P}{A} = \frac{110}{6.09} = 18.06 \text{ ksi}$$

1-4

$$P = 50 \times 40 = 2000 \text{ lb}$$

$$\sigma_1 = \frac{2000}{5.5^2} = 66.1 \text{ psi}$$

$$\sigma_2 = \frac{2000}{6^2} = 55.6 \text{ psi}$$

$$\sigma_3 = \frac{2000}{16^2} = 7.8 \text{ psi}$$

1-5

magnitude of the applied force:

$$P = \sigma A = 150 \times (30 \times 10 + 30 \times 12) = 150 \times 660 = 99000 \text{ N}$$

$$A_2 = \frac{1+\nu}{E}\left(\frac{P_i r_i^2 r_o^2}{r_o^2 - r_i^2}\right) = \frac{1.25}{200\times10^3}\left(\frac{150\times75^2\times225^2}{225^2-75^2}\right)$$
$$= 5.93$$

$$u = A_1 r + A_2\left(\frac{1}{r}\right)$$

$$u_i = 5.86\times10^{-5}(75) + \frac{5.93}{75} = 8.35\times10^{-2}\ mm$$

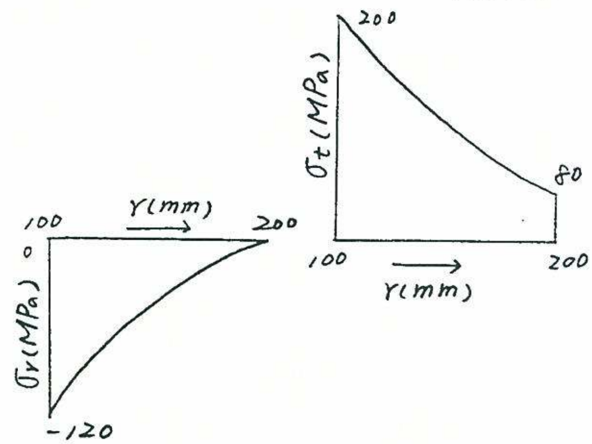
$$u_o = 5.86\times10^{-5}(225) + \frac{5.93}{225} = 3.96\times10^{-2}\ mm$$

5-32 $r_i = 100\ mm$, $r_o = 200\ mm$, $P_i = 120\ MPa$

(a) $$\sigma_r = \frac{P_i r_i^2}{r_o^2 - r_i^2}\left(1 - \frac{r_o^2}{r^2}\right) = 40\left(1 - \frac{40000}{r^2}\right) MPa$$

$$\sigma_t = \frac{P_i r_i^2}{r_o^2 - r_i^2}\left(1 + \frac{r_o^2}{r^2}\right) = 40\left(1 + \frac{40000}{r^2}\right) MPa$$

r (mm)	100	125	150	175	200
$-\sigma_r$ (MPa)	120	62.4	31.1	12.2	0
σ_t (MPa)	200	142.4	111.1	92.2	80



(b) $$\tau_{max} = \frac{P_i r_o^2}{r_o^2 - r_i^2} = \frac{120\times200^2}{200^2-100^2} = 160\ MPa$$

(c) $$A_1 = \frac{(1+\nu)(1-2\nu)}{E}\left(\frac{P_i r_i^2 - P_o r_o^2}{r_o^2 - r_i^2}\right)$$
$$= \frac{1.25\times0.5}{200\times10^3}\left(\frac{120\times100^2}{200^2-100^2}\right) = 1.25\times10^{-4}$$

$$A_2 = \frac{1+\nu}{E}\left(\frac{P_i r_i^2 r_o^2}{r_o^2 - r_i^2}\right) = \frac{1.25}{200\times10^3}\left(\frac{120\times200^2\times100^2}{200^2-100^2}\right)$$
$$= 10$$

$$u_i = 1.25\times10^{-4}(100) + \frac{10}{1000} = 11.25\times10^{-2}\ mm$$

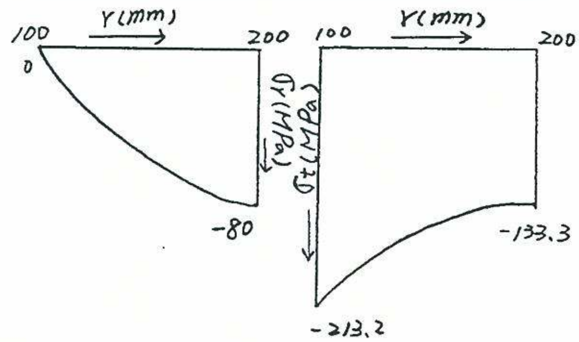
$$u_o = 1.25\times10^{-4}(200) + \frac{10}{200} = 7.5\times10^{-2}\ mm$$

5-33 $r_i = 100\ mm$, $r_o = 200\ mm$, $P_o = 80\ MPa$

(a) $$\sigma_r = -\frac{P_o r_o^2}{r_o^2 - r_i^2}\left(1 - \frac{r_i^2}{r^2}\right) = -106.6\left(1 - \frac{10000}{r^2}\right) MPa$$

$$\sigma_t = -\frac{P_o r_o^2}{r_o^2 - r_i^2}\left(1 + \frac{r_i^2}{r^2}\right) = -106.6\left(1 + \frac{10000}{r^2}\right) MPa$$

r (mm)	100	125	150	175	200
$-\sigma_r$ (MPa)	0	38.8	59.2	71.8	80.0
$-\sigma_t$ (MPa)	213.2	174.8	154.0	141.4	133.3



(b) $$\tau_{max} = \frac{(\sigma_t)_{max}}{2} = -\frac{213.2}{2} = -106.6\ MPa$$

(c) $$A_1 = \frac{(1+\nu)(1-2\nu)}{E}\left(-\frac{P_o r_o^2}{r_o^2 - r_i^2}\right)$$
$$= \frac{1.25\times0.5}{200\times10^3}\times\frac{(-80)(200^2)}{200^2-100^2} = -3.33\times10^{-4}$$

$$A_2 = \frac{1+\nu}{E}\left(\frac{-P_o r_i^2 r_o^2}{r_o^2 - r_i^2}\right) = \frac{1.25}{200\times10^3}\left(\frac{-80\times100^2\times200^2}{200^2-100^2}\right)$$
$$= -6.67$$

$$u = A_1 r + \frac{A_2}{r}$$

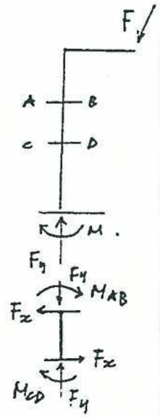
$$u_i = -3.33\times10^{-4}(100) - \frac{6.67}{100} = -0.1\ mm$$

$$u_o = -3.33\times10^{-4}(200) - \frac{6.67}{200} = -0.1\ mm$$

9-17

$$\sigma_A = -\frac{F_y}{A} + \frac{M_{AB}}{S} = 0$$

$$\sigma_B = -\frac{F_y}{A} - \frac{M_{AB}}{S} = -30$$



$$\sigma_A - \sigma_B = \frac{2M_{AB}}{S} = 30$$

$$M_{AB} = \frac{1}{2} \times 30 \times \frac{1}{6} \times 0.08 \times 1^2$$

$$= 2\ kN\text{-}m$$

$$\sigma_C = -\frac{F_y}{A} + \frac{M_{CD}}{S} = -24$$

$$\sigma_D = -\frac{F_y}{A} - \frac{M_{CD}}{S} = -6$$

$$\therefore \frac{2M_{CD}}{S} = -18 \longrightarrow M_{CD} = \frac{1}{2}(-18) \times \frac{1}{6} \times 0.08 \times 0.1^2$$

$$= -1.2\ kN\text{-}m$$

$$\sigma_A = 0.2F_x - M_{CD}$$

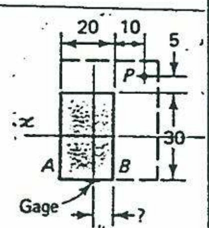
$$\therefore F_x = \frac{M_{AB} + M_{CD}}{0.2} = \frac{2 - 1.2}{0.2} = 4\ kN$$

9-18

$$I_x = \frac{1}{12} \times 0.2 \times 0.3^3 = 45 \times 10^{-9}\ m^4$$

$$I_y = \frac{1}{12} \times 0.3 \times 0.2^3 = 20 \times 10^{-9}\ m^4$$

$$A = 0.03 \times 0.02 = 0.0006\ m^2$$



Top view and section

$$\sigma_G = \frac{-P}{0.0006} + \frac{P \times 0.02 \times 0.015}{45 \times 10^{-9}} - \frac{P \times 0.02 \times x}{20 \times 10^{-9}} = 0$$

$\therefore x = 5\ mm$ does not depend on P.

9-19

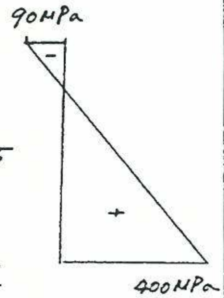
$$\sigma_A = E\varepsilon_A = 70 \times 10^9 \times 20 \times 10^{-6} = 1.4\ N/mm^2$$

$$\sigma_A = \frac{P}{A} + \frac{M_x c_x}{I_x} + \frac{M_y c_y}{I_y} = 1.4$$

$$= \frac{\frac{2}{3}F}{1200} + \frac{\frac{F}{3} \times 500 \times 15}{\frac{1}{12} \times 40 \times 30^3} + \frac{\frac{2F}{3} \times 500 \times (-12)}{\frac{1}{12} \times 30 \times 40^3}$$

$$\therefore F = 420\ N$$

9-20



a. $P = \frac{1}{2} \times 400 \times 10^6 \times 0.02 \times 0.015 - \frac{1}{2} \times 90 \times 10^6 \times 0.02 \times 0.015$

$= 46.5\ kN$

b. $\varepsilon_{mg} = \varepsilon_{st} \longrightarrow \sigma_{mg} = \frac{E_{mg}\sigma_{st}}{E_{st}} = 0.225\ \sigma_{st}$

$$P_a = A \times 0.225\sigma_{st} \times 30 + A\sigma_{st} \times 10 = 16.75 A\sigma_{st}$$

$$P = A \times 0.225\sigma_{st} + A\sigma_{st} = 1.225 A\sigma_{st}$$

$$a = 13.7\ mm$$

9-21

$$R = \frac{\bar{r}}{\ln\frac{r_o}{r_i}} = \frac{6.5}{\ln\frac{9.5}{3.5}} = 6.51$$

$$\sigma_i = \frac{P}{A} + \frac{M(R - r_i)}{r_i A(\bar{r} - R)} = \frac{19}{2 \times 6} + \frac{19 \times 6.5 \times (6.51 - 3.5)}{3.5 \times 2 \times 6 \times (6.5 - 6.51)}$$

$$= -922\ ksi$$

$$\sigma_o = \frac{P}{A} + \frac{M(R - r_o)}{r_o A(\bar{r} - R)} = \frac{19}{12} + \frac{19 \times 6.5 \times (6.51 - 9.5)}{9.5 \times 12 \times (6.5 - 6.51)}$$

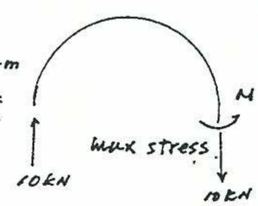
$$= 340\ ksi < 922\ ksi$$

9-22

$$M = 10 \times (0.3 - 0.04) = 2.6\ kN\text{-}m$$

$$R = \frac{\bar{r} + \sqrt{\bar{r}^2 - c^2}}{2} = \frac{130 + \sqrt{130^2 - 20^2}}{2}$$

$$= 129\ mm$$



a. $\sigma_i = \frac{P}{A} + \frac{M(R - r_i)}{r_i A(\bar{r} - R)} = \frac{10}{\pi(0.02)^2} + \frac{2.6 \times (0.129 - 0.11)}{0.11\pi \times 0.2^2 \times (0.13 - 0.129)}$

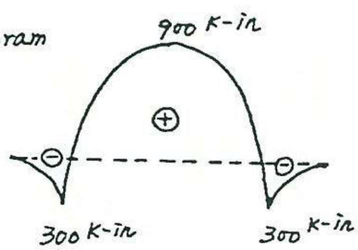
$= 475\ MN/m^2$

$$\sigma_o = \frac{P}{A} + \frac{M(R - r_o)}{r_o A(\bar{r} - R)} = \frac{10}{\pi(0.02)^2} + \frac{2.6 \times (0.129 - 0.15)}{0.15\pi \times 0.2^2 \times (0.13 - 0.129)}$$

$= -362\ MN/m^2 \quad \therefore \sigma_{max} = 475\ MN/m^2$

b. $\frac{\sigma_{max}}{\sigma_{comp}} = \frac{475}{362} = 1.31$

M- diagram



$M_{max} = 900^{\,K\text{-}in}$

$V_{max} = 20^{\,K}$

$S_{req} = \dfrac{M_{max}}{\sigma_{awB}} = \dfrac{900}{24} = 37.5 \ in^3$

$A_{req} = \dfrac{3}{2}\dfrac{V_{max}}{\tau_{aw}} = 1.5 \times \dfrac{20}{14.4} = 2.08 \ in^2$

choose W 12 × 30

$A = 8.79 \ in^2 > A_{req} = 2.08 \ in^2$

$S = 38.6 \ in^3 > S_{req} = 37.5 \ in^3$

13-44

$q_L = 75 \ lb/ft^2, \quad q_D = 25 \ lb/ft^2$

(a) design for wooden joists

$W_L = 75 \times \dfrac{16}{12} = 100 \ lb/ft$

$W_D = 25 \times \dfrac{16}{12} = 33.33 \ lb/ft$

$W_T = W_L + W_D = 133.33 \ lb/ft$

$M_{max} = \dfrac{1}{8} W_T \ell^2 = \dfrac{1}{2} \times 133.33 \times (12)^2 \times 12$

$= 28800 \ lb\text{-}in$

$V_{max} = \dfrac{1}{2} W_T \ell = \dfrac{1}{2} \times 133.33 \times 12$

$= 800 \ lb$

choose Nominal Size 2" × 12"

$S = 31.6 \ in^3 > S_{req} = \dfrac{M_{max}}{\sigma_{awB}} = \dfrac{28800}{1200}$

$= 24 \ in^3$

$A = 16.9 \ in^2 > A_{req} = \dfrac{3}{2}\dfrac{V_{max}}{\tau_{aw}}$

$= 1.5 \times \dfrac{800}{100}$

$= 12 \ in^2$ O.K.

(b) design for steel beam

$W_T = (q_D + q_L) \times 12$

$= (100) \times 12 = 1200 \ lb/ft$

$M_{max} = \dfrac{1}{8} W_T \ell^2 = \dfrac{1}{8} \times 1200 \times (20)^2 \times 12$

$= 720^{\,K\text{-}in}$

$V_{max} = \dfrac{1}{2} W_T \cdot \ell = \dfrac{1}{2} \times 1200 \times 20$

$= 12^{\,K}$

choose $W_{12 \times 26}$

$V_D = \dfrac{1}{2} \times 26 \times 20 = 0.26^{\,K}$

$M_D = \dfrac{1}{8} \times 26 \times (20)^2 \times 12$

$= 15.6^{\,K\text{-}in}$

$S = 33.4 \ in^3 > S_{req} = \dfrac{M_{max} + M_D}{\sigma_{awB}}$

$= \dfrac{720 + 15.6}{24}$

$= 30.65 \ in^3$

$A = 7.65 \ in^2 > A_{req} = \dfrac{3}{2}\dfrac{(V_{max} + V_D)}{\tau_{aw}}$

$= 1.5 \times \dfrac{12 + 0.26}{14.4}$

$= 1.277 \ in^3$ O.K

13-45

Design Load $= 75 + 75 = 150 \ lb/ft^2$

$w = 150 \times 5 = 750 \ lb/ft$