INSTRUCTOR'S SOLUTIONS MANUAL

Shigley's

Mechanical Engineering Design

Ninth Edition

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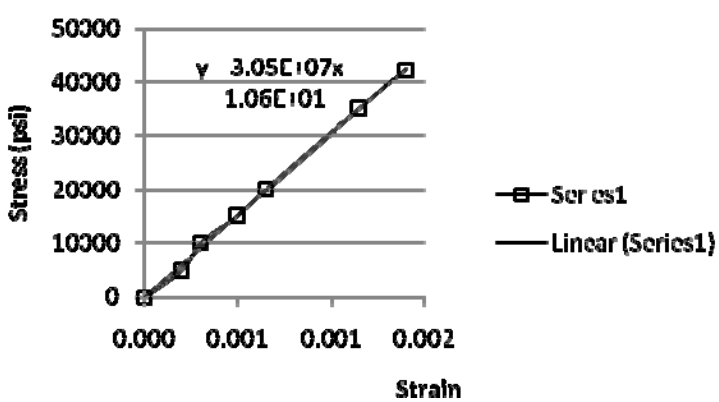
Solving Eqs. (1) and (2) simultaneously yields σ = 45.6 kpsi which is the 0.2 percent offset yield strength. Thus, S_y = 45.6 kpsi *Ans.*

The ultimate strength from Figure (*c*) is S_u = 85.6 kpsi *Ans.*

The reduction in area is given by Eq. (2-12) is

$$R = \frac{A_0 - A_f}{A_0}(100) = \frac{0.1987 - 0.1077}{0.1987}(100) = 45.8\ \% \qquad \textit{Ans.}$$

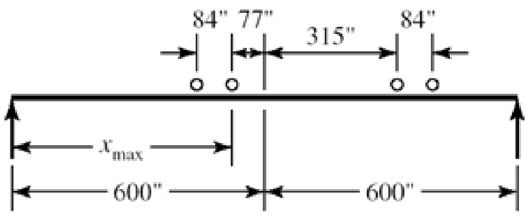
Data Point	P_i	Δl, A_i	ϵ	σ
1	0	0	0	0
2	1000	0.0004	0.00020	5032
3	2000	0.0006	0.00030	10065
4	3000	0.001	0.00050	15097
5	4000	0.0013	0.00065	20130
6	7000	0.0023	0.00115	35227
7	8400	0.0028	0.00140	42272
8	8800	0.0036	0.00180	44285
9	9200	0.0089	0.00445	46298
10	8800	0.1984	0.00158	44285
11	9200	0.1978	0.00461	46298
12	9100	0.1963	0.01229	45795
13	13200	0.1924	0.03281	66428
14	15200	0.1875	0.05980	76492
15	17000	0.1563	0.27136	85551
16	16400	0.1307	0.52037	82531
17	14800	0.1077	0.84506	74479



(*a*) Linear range

$$M_2 = \frac{(1200-154)^2}{4(1200)}(104.4) - 26.1(84) = 21\,605 \text{ kip}\cdot\text{in} = M_{\max} \qquad Ans.$$

Check if all of the wheels are on the rail.



(b) $x_{\max} = 600 - 77 = 523$ in *Ans.*

(c) See above sketch.

(d) Inner axles

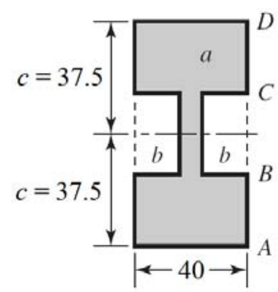
3-34

(a) Let a = total area of entire envelope
Let b = area of side notch

$$A = a - 2b = 40(3)(25) - 25(34) = 2150 \text{ mm}^2$$

$$I = I_a - 2I_b = \frac{1}{12}(40)(75)^3 - \frac{1}{12}(34)(25)^3$$

$$I = 1.36(10^6) \text{ mm}^4 \qquad Ans.$$



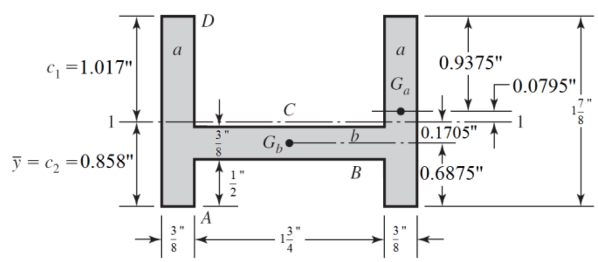
Dimensions in mm.

(b)

$$A_a = 0.375(1.875) = 0.703\,125 \text{ in}^2$$

$$A_b = 0.375(1.75) = 0.656\,25 \text{ in}^2$$

$$A = 2(0.703125) + 0.656\,25 = 2.0625 \text{ in}^2$$



$$\bar{y} = \frac{2(0.703\,125)(0.9375) + 0.656\,25(0.6875)}{2.0625} = 0.858 \text{ in} \qquad Ans.$$

$$I_a = \frac{0.375(1.875)^3}{12} = 0.206 \text{ in}^4$$

$$I_b = \frac{1.75(0.375)^3}{12} = 0.007\,69 \text{ in}^4$$

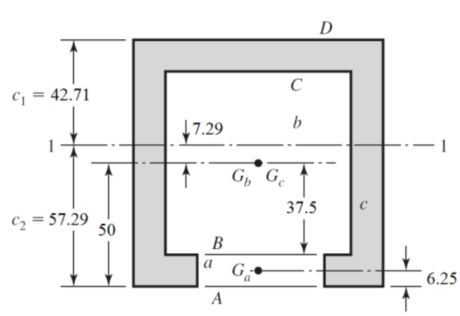
$$I_1 = 2\left[0.206 + 0.703\,125(0.0795)^2\right] + \left[0.00769 + 0.656\,25(0.1705)^2\right] = 0.448 \text{ in}^4 \qquad Ans.$$

(c)

Use two negative areas.

$$A_a = 625 \text{ mm}^2,\ A_b = 5625 \text{ mm}^2,\ A_c = 10\,000 \text{ mm}^2$$

$$A = 10\,000 - 5625 - 625 = 3750 \text{ mm}^2;$$



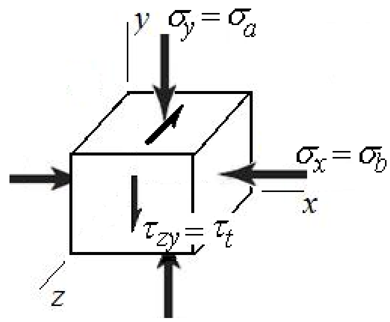
$$\sigma_b = \pm\frac{Mc}{I} = \pm\frac{\left[F\left(p/4\right)\right]\left(p/4\right)}{bh^3/12} = \pm\frac{Fp^2}{16\left(\pi d_r n_t\right)\left(p/2\right)^3/12}$$

$$\sigma_b = \pm\frac{6F}{\pi d_r n_t p} \qquad Ans.$$

(b) $\sigma_a = -\frac{F}{A} = -\frac{F}{\pi d_r^2/4} = -\frac{4F}{\pi d_r^2} \qquad Ans.$

$$\tau_t = \frac{Tr}{J} = \frac{T\left(d_r/2\right)}{\pi d_r^4/32} = \frac{16T}{\pi d_r^3} \qquad Ans.$$

(c) The bending stress causes compression in the *x* direction. The axial stress causes compression in the *y* direction. The torsional stress shears across the *y* face in the negative *z* direction.



(d) Analyze the stress element from part (c) using the equations developed in parts (a) and (b).

$d_r = d - p = 1.5 - 0.25 = 1.25$ in

$$\sigma_x = \sigma_b = -\frac{6F}{\pi d_r n_t p} = -\frac{6(1500)}{\pi(1.25)(2)(0.25)} = -4584 \text{ psi} = -4.584 \text{ kpsi}$$

$$\sigma_y = \sigma_a = -\frac{4F}{\pi d_r^2} = -\frac{4(1500)}{\pi\left(1.25^2\right)} = -1222 \text{ psi} = -1.222 \text{ kpsi}$$

$$\tau_{yz} = -\tau_t = -\frac{16T}{\pi d_r^3} = -\frac{16(235)}{\pi\left(1.25^3\right)} = -612.8 \text{ psi} = -0.6128 \text{ kpsi}$$

Use Eq. (3-15) for the three-dimensional stress element.

$$\sigma^3 - (-4.584 - 1.222)\sigma^2 + \left[(-4.584)(-1.222) - (-0.6128)^2\right]\sigma - \left[-(-4.584)(-0.6128)^2\right] = 0$$

$$\sigma^3 + 5.806\sigma^2 + 5.226\sigma - 1.721 = 0$$

The roots are at 0.2543, – 4.584, and –1.476. Thus, the ordered principal stresses are

$\sigma_1 = 0.2543$ kpsi, $\sigma_2 = -1.476$ kpsi, and $\sigma_3 = -4.584$ kpsi. *Ans.*

From Eq. (3-16), the principal shear stresses are

$R_C + F_{BE} - F_{DF} = 2\,000$ (1)

$R_C + 2F_{BE} = 6\,000$ (2)

2. Bending moment equation.

$M = -\,2\,000\,x + F_{BE}\,\langle x - 75\,\rangle^1 + R_C\,\langle x - 150\,\rangle^1$

$$EI\frac{dy}{dx} = -1000x^2 + \frac{1}{2}F_{BE}\left\langle x-75\right\rangle^2 + \frac{1}{2}R_C\left\langle x-150\right\rangle^2 + C_1 \qquad (3)$$

$$EIy = -\frac{1000}{3}x^3 + \frac{1}{6}F_{BE}\left\langle x-75\right\rangle^3 + \frac{1}{6}R_C\left\langle x-150\right\rangle^3 + C_1x + C_2 \qquad (4)$$

3. B.C 1. At x = 75 mm,

$$y_B = -\left(\frac{Fl}{AE}\right)_{BE} = -\frac{F_{BE}(50)}{50.27(207)10^3} = -4.805\left(10^{-6}\right)F_{BE}$$

Substituting into Eq. (4) at x = 75 mm,

$$4.347\left(10^9\right)\left[-4.805\left(10^{-6}\right)F_{BE}\right] = -\frac{1000}{3}\left(75^3\right) + C_1(75) + C_2$$

Simplifying gives

$$20.89\left(10^3\right)F_{BE} + 75C_1 + C_2 = 140.6\left(10^6\right) \qquad (5)$$

B.C 2. At x = 150 mm, y = 0. From Eq. (4),

$$-\frac{1000}{3}\left(150^3\right) + \frac{1}{6}F_{BE}\left(150-75\right)^3 + C_1(150) + C_2 = 0$$

or,

$$70.31\left(10^3\right)F_{BE} + 150C_1 + C_2 = 1.125\left(10^9\right) \qquad (6)$$

B.C 3. At x = 225 mm,

$$y_D = \left(\frac{Fl}{AE}\right)_{DF} = \frac{F_{DF}(65)}{50.27(207)10^3} = 6.246\left(10^{-6}\right)F_{DF}$$

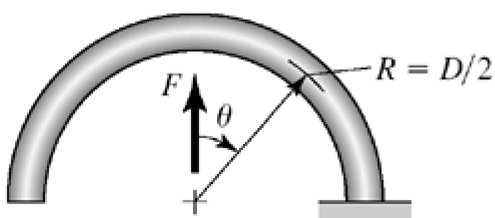
Substituting into Eq. (4) at x = 225 mm,

$(n_f)_B$	2.519	2.463	2.388	2.341	2.298	2.235
S_y	134.156	133.215	131.685	130.476	129.168	126.674
$(\sigma_A)_{\max}$	84.273	83.682	82.720	81.961	81.139	79.573
$(n_y)_A$	1.592	1.592	1.592	1.592	1.592	1.592
τ_i	21.663	23.820	25.741	27.723	29.629	31.097
r	0.945	1.157	1.444	1.942	2.906	4.703
$(S_{sy})_{\text{body}}$	85.372	84.773	83.800	83.030	82.198	80.611
$(S_{sa})_y$	30.958	32.688	34.302	36.507	39.109	40.832
$(n_y)_{\text{body}}$	2.779	2.973	3.183	3.438	3.740	4.012
$(S_{sy})_B$	73.176	72.663	71.828	71.169	70.455	69.095
$(\tau_B)_{\max}$	42.819	43.486	44.321	44.801	45.177	45.564
$(n_y)_B$	1.709	1.671	1.621	1.589	1.560	1.516
fom	−1.246	−1.234	−1.245	−1.283	−1.357	−1.639

optimal fom

The shaded areas show the conditions not satisfied.

10-38 For the hook,



$$M = FR\sin\theta, \quad \partial M/\partial F = R\sin\theta$$

$$\delta_F = \frac{1}{EI}\int_0^{\pi/2} F\left(R\sin\theta\right)^2 R\,d\theta = \frac{\pi}{2}\frac{FR^3}{EI}$$

The total deflection of the body and the two hooks

$$\delta = \frac{8FD^3N_b}{d^4G} + 2\left(\frac{\pi}{2}\frac{FR^3}{EI}\right) = \frac{8FD^3N_b}{d^4G} + \frac{\pi F(D/2)^3}{E(\pi/64)(d^4)}$$

$$= \frac{8FD^3}{d^4G}\left(N_b + \frac{G}{E}\right) = \frac{8FD^3N_a}{d^4G}$$

$$\therefore\ N_a = N_b + \frac{G}{E} \qquad \text{Q.E.D.}$$

10-39 Table 10-5 (d = 4 mm = 0.1575 in): E = 196.5 GPa

Table 10-4 for A227:

$$A = 1783\ \text{MPa}\cdot\text{mm}^m, \qquad m = 0.190$$

Eq. (10-14): $S_{ut} = \dfrac{A}{d^m} = \dfrac{1783}{4^{0.190}} = 1370$ MPa

Eq. (10-57): $S_y = \sigma_{\text{all}} = 0.78\,S_{ut} = 0.78(1370) = 1069$ MPa

P	d	V	K_v	W^t	F
2	9.000	1413.717	2.178	58.356	0.082
3	6.000	942.478	1.785	87.535	0.152
4	4.500	706.858	1.589	116.713	0.240
6	3.000	471.239	1.393	175.069	0.473
8	2.250	353.429	1.295	233.426	0.782
10	1.800	282.743	1.236	291.782	1.167
12	1.500	235.619	1.196	350.139	1.627
16	1.125	176.715	1.147	466.852	2.773

Other considerations may dictate the selection. Good candidates are $P = 8$ ($F = 7/8$ in) and $P = 10$ ($F = 1.25$ in). *Ans.*

14-10 Try $m = 2$ mm which gives $d = 2(18) = 36$ mm and $Y = 0.309$.

$$V = \frac{\pi dn}{60} = \frac{\pi(36)(10^{-3})(900)}{60} = 1.696 \text{ m/s}$$

Eq. (14-6*b*): $$K_v = \frac{6.1 + 1.696}{6.1} = 1.278$$

Eq. (13-36): $$W^t = \frac{60\,000H}{\pi dn} = \frac{60\,000(1.5)}{\pi(36)(900)} = 0.884 \text{ kN} = 884 \text{ N}$$

Eq. (14-8): $$F = \frac{1.278(884)}{75(2)(0.309)} = 24.4 \text{ mm}$$

Using the preferred module sizes from Table 13-2:

m	d	V	K_v	W^t	F
1.00	18.0	0.848	1.139	1768.388	86.917
1.25	22.5	1.060	1.174	1414.711	57.324
1.50	27.0	1.272	1.209	1178.926	40.987
2.00	36.0	1.696	1.278	884.194	24.382
3.00	54.0	2.545	1.417	589.463	12.015
4.00	72.0	3.393	1.556	442.097	7.422
5.00	90.0	4.241	1.695	353.678	5.174
6.00	108.0	5.089	1.834	294.731	3.888
8.00	144.0	6.786	2.112	221.049	2.519
10.00	180.0	8.482	2.391	176.839	1.824
12.00	216.0	10.179	2.669	147.366	1.414
16.00	288.0	13.572	3.225	110.524	0.961
20.00	360.0	16.965	3.781	88.419	0.721
25.00	450.0	21.206	4.476	70.736	0.547
32.00	576.0	27.143	5.450	55.262	0.406
40.00	720.0	33.929	6.562	44.210	0.313
50.00	900.0	42.412	7.953	35.368	0.243

$$\theta_d = \pi - 2\sin^{-1}\left[\frac{12 - 6.2}{2(31.47)}\right] = 2.9570 \text{ rad}$$

$$\exp(f\theta_d) = \exp[0.5123(2.9570)] = 4.5489$$

$$V = \frac{\pi dn}{12} = \frac{\pi(6.2)(3100)}{12} = 5031.8 \text{ ft/min}$$

Table 17-13:

$$\text{Angle}\,\theta = \theta_d \frac{180°}{\pi} = (2.957 \text{ rad})\left(\frac{180°}{\pi}\right) = 169.42°$$

The footnote regression equation of Table 17-13 gives K_1 without interpolation:

$$K_1 = 0.143\,543 + 0.007\,468(169.42°) - 0.000\,015\,052(169.42°)^2 = 0.9767$$

The design power is

$$H_d = H_{\text{nom}} K_s n_d = 3(1.3)(1) = 3.9 \text{ hp}$$

From Table 17-14 for B90, $K_2 = 1$. From Table 17-12 take a marginal entry of $H_{\text{tab}} = 4$, although extrapolation would give a slightly lower H_{tab}.

Eq. (17-17): $H_a = K_1 K_2 H_{\text{tab}} = 0.9767(1)(4) = 3.91$ hp

The allowable ΔF_a is given by

$$\Delta F_a = \frac{63\,025 H_a}{n(d/2)} = \frac{63\,025(3.91)}{3100(6.2/2)} = 25.6 \text{ lbf}$$

The allowable torque T_a is

$$T_a = \frac{\Delta F_a d}{2} = \frac{25.6(6.2)}{2} = 79.4 \text{ lbf} \cdot \text{in}$$

From Table 17-16, $K_c = 0.965$. Thus, Eq. (17-21) gives,

$$F_c = K_c\left(\frac{V}{1000}\right)^2 = 0.965\left(\frac{5031.8}{1000}\right)^2 = 24.4 \text{ lbf}$$

At incipient slip, Eq. (17-9) provides:

$$F_i = \left(\frac{T}{d}\right)\left[\frac{\exp(f\theta) + 1}{\exp(f\theta) - 1}\right] = \left(\frac{79.4}{6.2}\right)\left(\frac{4.5489 + 1}{4.5489 - 1}\right) = 20.0 \text{ lbf}$$

Eq. (17-10):