Answers to Selected Problems

Chapter 1. Introduction to Design

1.1 $V_D = 4$ kips, $M_D = 4$ kip · ft.,
$V_E = 2.5$ kips, $M_E = 6$ kip · ft.

1.3 (a) $R_{Cx} = 75$ kN $\leftarrow$, $R_{Cy} = 50$ kN $\uparrow$,
$R_{Bx} = 75$ kN $\rightarrow$, $R_{By} = 10$ kN $\downarrow$.
(b) $F_D = 85$ kN, $V_D = 30$ kN,
$M_D = 37.5$ kN · m.

1.5 $R_B = 12.58$ kips.

1.6 (a) $T = 0.6$ kN · m.
(b) $R_A = 4.427$ kN,
$R_E = 8.854$ kN.

1.8 $V_y = 64$ N, $M_z = 31.2$ N · m.

1.10 $T_d = 0.3$ kN · m.

1.13 $e = 90\%$.

1.16 (a) $\varepsilon_{c,\max} = 2000\mu$.
(b) $\varepsilon_r = 1000\mu$.

1.19 $\Delta L_{BD} = 0.232$ mm.

1.21 $\varepsilon_x = \varepsilon_y = -363\mu$,
$\gamma_{xy} = 1651\mu$.

Chapter 2. Materials

2.2 (a) $E = 53$ GPa.
(b) $\nu = 0.25$.
(c) $G = 21.2$ GPa.

2.3 (a) $\nu = 0.25$.
(b) $E = 8.335 \times 10^6$ psi.
(c) $a' = 3.0015$ in.
(d) $G = 3.334 \times 10^6$ psi.

2.5 $\varepsilon_x = 1327\mu$.

2.7 $L' = 99.96$ mm, $a' = 49.98$ mm,
$b' = 9.996$ mm.

2.9 $n = 3.16$.

2.11 $d = 0.667$ in.

Chapter 3. Stress and Strain

3.2 $a_{\min} = 73$ mm.

3.4 (a) $\sigma_{BD} = -1.018$ MPa.
(b) $\tau_A = 9.697$ MPa.

3.5 $\alpha = 54.7°$.

3.8 $b = \dfrac{d}{\sqrt{3}}$, $h = d\sqrt{\dfrac{2}{3}}$.

3.11 $b = 56.5$ mm.

3.13 $h = h_1 \left(\dfrac{x}{L}\right)^{3/2}$.

3.16 $t = 0.399$ in.

3.19 $M = 38.45$ kip · in.

3.21 (a) $\sigma_x = -37.1$ kPa, $\sigma_y = -2.9$ kPa,
$\tau_{xy} = 47$ kPa.
(b) $\tau_{\max} = 50$ kPa.

3.24 (a) $\sigma_x = 25$ ksi, $\sigma_y = -5$ ksi, $\tau_{xy} = -8.66$ ksi.
(b) $\sigma_1 = 27.32$ ksi, $\sigma_2 = -7.32$ ksi, $\theta_p' = 15°$.

3.26 $\sigma_{x'} = 140.3$ MPa, $\sigma_{y'} = 1.07$ MPa,
$\tau_{x'y'} = 12.28$ MPa.

3.29 Point A: (a) $\sigma_1 = 864$ psi, $\sigma_2 = 234$ psi.
(b) $\tau_{\max} = 315$ psi.

3.31 $\sigma_{x'} = 19.6$ ksi, $\tau_{x'y'} = 2.87$ ksi.

3.35 (a) $\gamma_{\max} = 566\mu$.
(b) $\Delta L_{AC} = 1.41 \times 10^{-4}$ in.

3.37 $p_{all} = 1.281$ MPa.

3.39 $P_{all} = 29.3$ kN.

3.41 (a) $a = 0.135$ mm.
(b) $p_o = 943.1$ MPa.

3.44 $p_o = 414.9$ MPa.

3.48 $\sigma = 24.98$ MPa,
$\tau = 21.27$ MPa.

Chapter 4. Deflection and Impact

4.1 (a) $d = 8.74$ mm.
(b) $k = 2000$ kN/m.

4.2 $R_A = 7.041$ kips,
$R_B = 0.959$ kips.

4.4 (a) $P = 178.2$ kN.
(b) $\delta_a = 0.0653$ mm.

4.5 (a) $\phi_D = 6.82°$.
(b) $\tau_{AB} = 41.92$ MPa.

4.7 $h = 197$ mm.

4.11 $v_1 = \dfrac{M_o L}{6EIL}(-6aL + 3a^2 + 2L^2 + x^2)$.

4.14 $R = \dfrac{5P(E_2I_2)}{2(E_1I_1 + E_2I_2)}$.

4.18 $R_A = R_B = \dfrac{P}{2}$, $M_A = -M_B = \dfrac{PL^4}{8}$ ↻,
$v = -\dfrac{Px^2}{48EI}(3L - 4x)$.

4.22 $R_A = \dfrac{3}{4}P\downarrow$, $R_B = \dfrac{7}{4}P\uparrow$, $M_A = \dfrac{1}{2}Pa$ ↻.

4.25 (a) $\delta_{max} = 7.38$ mm.
(b) $\sigma_{max} = 198$ MPa.

4.27 $d = 1.943$ in.

4.30 (a) $\phi_{max} = 4.24°$.
(b) $\tau_{max} = 243.3$ MPa.

4.32 $M_{max} = 46.875$ lb · in.

4.34 (b) $\sigma_{max} = 0.75\, p_o \left(\dfrac{b}{t}\right)^2$.
(c) $w_{max} = 0.071$ in.,
$\sigma_{max} = 9.375$ ksi.

Chapter 5. Energy Methods in Design

5.2 $U_s = \dfrac{1}{20}\dfrac{w^2L^3}{AG}$.

5.5 $v_A = 2Pa\,(a + L)\left[\dfrac{a}{6EI} + \dfrac{3}{5AGL}\right]$.

5.7 $\delta_B = \dfrac{P}{12EI}(4L^3 + 6\pi RL^2 + 24R^2L + 3\pi R^3)$.

5.9 $R_A = \dfrac{2}{3}\dfrac{M_o}{L}\uparrow$, $R_B = 2\dfrac{M_o}{L}\downarrow$,
$R_C = \dfrac{4}{3}\dfrac{M_o}{L}\uparrow$.

5.11 $\delta_h = 60\dfrac{wa^4}{EI}\rightarrow$.

5.13 $\delta_B = \dfrac{PR^2}{2EI}$.

5.15 (b) $\phi_B = \dfrac{1}{GJ}\left(\dfrac{T_oL}{2} + PaL\right)$.

5.18 $(\delta_C)_v = 2.828\dfrac{PL}{AE}\downarrow$,
$(\delta_C)_h = 3.828\dfrac{PL}{AE}\rightarrow$.

5.22 $F = \dfrac{4P}{\pi}\uparrow$.

5.24 $\delta_C = \dfrac{PL}{3E}\left(\dfrac{11}{A} + \dfrac{8L^2}{I}\right)\downarrow$.

5.30 $v = \dfrac{w_o}{EI}\left(\dfrac{L}{\pi}\right)^4 \sin\dfrac{\pi x}{L}$.

5.32 (a) $v = \dfrac{Px^2}{6EI}(3L - x)$.

(b) $v_{\max} = \dfrac{PL^3}{3EI}, \theta_{\max} = \dfrac{PL^2}{2EI}$.

5.34 $v_A = \dfrac{Pc^2(L-c)^2}{4EIL}$.

Chapter 6. Buckling Design of Members

6.1 $d = 29$ mm.

6.2 $d = 25.7$ mm.

6.4 $P_{\text{all}} = 4.5$ kN.

6.6 $F_{\text{all}} = 129.6$ kN.

6.7 $P_{\text{all}} = 13.83$ kips.

6.12 $d = 121$ mm.

6.13 $P_{\text{all}} = 637.5$ kips.

6.16 $P_{\text{all}} = 341.3$ kN.

6.18 $L_e = 131.9$ in.

6.22 $P_{\text{cr}} = 12\dfrac{EI}{L^2}$.

6.23 $P_{\text{cr}} = \dfrac{9}{4}\dfrac{EI_o}{L^2}$.

Chapter 7. Failure Criteria and Reliability

7.1 $\sigma = 231.6$ MPa.

7.3 $P = 256$ kN,
$\sigma = 97.5$ MPa.

7.5 $M = 2.76$ kN · m.

7.7 $P = 490$ lb.

7.9 (a) $n = 2.86$.
(b) $n = 2.61$.

7.13 (a) $t = 0.208$ in.
(b) $t = 0.18$ in.

7.15 (a) $n = 1.94$.
(b) $n = 1.82$.

7.17 (a) $n = 1.21$.
(b) $n = 1.06$.

7.20 $T = 14.11$ kips · in.

7.23 $\tau = 111.1$ MPa.

7.26 $R \approx 99.94\%$.

7.29 (a) $\sigma = 7.645$ ksi.
(b) $R \approx 76\%$.

7.31 10%.

Chapter 8. Fatigue

8.5 $S_e = 38.5$ MPa.

8.8 (a) $n = 4.64$.
(b) $n = 1.57$.

8.12 (a) $T = 624.9$ N · m.

8.15 $n = 1.98$.

8.17 $t = 0.736$ in.

8.19 $h = 1.45$ mm.

8.21 $h = 0.021$ in.

8.22 $P_o = 30.23$ N.

8.24 $n = 1.63$.

8.27 $n = 1.4$.

Chapter 9. Shafts and Associated Parts

9.2 (a) $D_{AC} = 14.22$ mm, $D_{BC} = 20.52$ mm.
(b) $\phi_{AB} = 49.25°$.

9.3 $W_a/W_s = 0.598$.

9.5 (a) $D = 42.71$ mm.
(b) $D = 42.3$ mm.

9.7 $D = 63.5$ mm.

9.9 $n = 2.07$.

9.11 $n = 1.93$.

9.14 $D = 2.24$ in.

9.16 $n_{cr} = 594$ rpm.

9.18 $n_{cr} = 966$ rpm.

9.20 $n = 1.205$.

Chapter 10. Bearings and Lubrication

10.2 (a) $T_f = 42.64$.
(b) hp $= 16.24$.
(c) $f = 0.057$.

10.4 $\eta = 25.95$ mPa · s.

10.6 $W = 563$ lb.

10.8 (a) $f = 0.02$.
(b) hp $= 0.714$.

10.10 (a) $h_0 = 0.008$ mm.
(b) kW $= 0.017$.

10.11 (a) $h_0 = 0.013$ mm.
(b) $p_{max} = 4.808$ MPa.

10.13 (a) $\eta = 52.8$ mPa · s.
(b) kW $= 0.377$.

10.14 $t = 85.2°C$.

10.16 $L_{10} = 344.8$ hr.

10.18 $L_{10} = 119.5$ hr.

10.20 18.8%.

10.22 $L_{10} = 949.3$ hr. (for 03 series)

10.26 $L_5 = 267$ hr.

Chapter 11. Spur Gears

11.1 $h = 0.562$ in., $h_k = 0.5$ in.,
$r_b = 3.759$ in., $r_o = 4.25$ in.

11.2 $N_1 = 60$, $N_2 = 180$.

11.4 $N_g = 88$, $d_p = 88$ mm, $c = 220$ mm.

11.6 (a) $F_{t1} = 210$ lb, $F_{r1} = 76.43$ lb.
(b) $R_C = 223.5$ lb, $T_C = 630$ lb · in.

11.8 (a) $F_{t1} = 8.843$ kN, $F_{r1} = 3.219$ kN.
(b) $R_C = 9.411$ kN, $T_C = 1.326$ kN · m.

11.10 (a) $F_{t2} = 280$ lb, $F_{r2} = 130.6$ lb,
$F_{t3} = 490$ lb, $F_{r3} = 278.5$ lb.
(b) $R_C = 540.7$ lb,
$T_C = 1960$ lb · in.

11.12 (a) $F_b = 692.2$ lb.
(b) $F_w = 340.2$ lb.
(c) $F_t = 114.8$ lb.

11.13 (a) $F_b = 2.75$ kN.
(b) $F_w = 1.81$ kN.
(c) $F_t = 617.5$ kN.

11.15 (a) $F_b = 6.76$ kN.
(b) $F_w = 2.35$ kN.

11.16 No.

11.18 hp $= 6.95$.

11.20 hp $= 19.59$.

11.23 hp $= 36.33$.

Chapter 12. Helical, Bevel, and Worm Gears

12.1 (a) $p_n = 0.524$ in., $p = 0.605$ in.,
$p_a = 1.048$ in.
(b) $P = 5.196$, $\phi = 28.3°$.
(c) $d_p = 3.849$ in., $d_g = 7.698$ in.

12.3 kW $= 75.58$.

12.5 (a) $F_{t1} = F_{t2} = F_{t3} = 263.1$ lb.
(b) $T_1 = 840$ lb · in., $T_2 = 0$, $T_3 = 1680$ lb · in.

12.7 $n = 1.21$.

12.9 (a) hp = 17.63.
(b) hp = 31.1.

12.10 (a) $d_p = 2.5$ in., $d_g = 5.25$ in.
(b) $\alpha_p = 25.46°$, $\alpha_g = 64.54°$.
(c) $b = 0.969$ in.
(d) $c = 0.026$ in.

12.12 The gears are safe.

12.15 kW = 29.25.

12.17 $F_t = 10.08$ kips.

12.19 (a) $\lambda = 10.39°$.
(b) $F_{wt} = F_{ga} = 420.2$ lb.
(c) $(\text{hp})_m = 8.74$.

12.22 $(\text{hp})_d = 1.392$. No.

Chapter 13. Belts, Chains, Clutches, and Brakes

13.1 (a) $F_1 = 296.6$ lb, $F_2 = 128.5$ lb.
(b) $L = 151.8$ in.

13.3 kW = 34.6.

13.5 $F_{\max} = 1.143$ kN.

13.6 $c = 13.132$ in.

13.8 (a) $p_{\max} = 254.6$ kPa, $T = 180$ N · m.
(b) $p_{\max} = 191$ kPa, $T = 183.8$ N · m.

13.10 (a) $d = 17.64$ in.
(b) $F_a = 1.833$ kips.

13.12 $w = 1.451$ in.

13.15 $T = 602$ N · m.

13.17 $F_1 = 14$ kN, $F_2 = 3.987$ kN, kW = 31.46.

13.19 $F_1 = 3{,}085$ N, $F_2 = 538.6$ N.

13.22 hp = 12.76.

13.24 $F_a = 366.04$ N. No.

13.25 (a) $F_a = 1.542$ kN. No.
(b) $R_A = 2.632$ kN.

13.28 $b = 1.414r$.

Chapter 14. Springs

14.1 (a) $T = 35.48$ N · m.
(b) $\tau = 353$ MPa.

14.3 $N_a = 7.49$.

14.4 (a) $h_s = 39$ mm.
(b) $P_{\max} = 320.4$ N.

14.6 (a) $h_f = 45.53$ mm.
(b) The spring is safe.

14.9 (a) $d = 14.94$ mm.
(b) $h_f = 274.6$ mm.
(c) The spring is safe. $f_n = 4370$ cpm.

14.11 $P_{\min} = 72.4$ lb, $P_{\max} = 127.6$ lb.

14.12 (a) $n = 2.49$.
(b) $N_a = 17.3$.

14.13 (a) $d = 0.103$ in.
(c) $f_n = 9270$ cpm.
(d) The spring is safe.

14.15 (a) $d = 5.41$ mm.
(b) $N_a = 9.89$.

14.18 $n = 1.30$.

14.20 (a) $M = 6.016$ lb · in.
(b) $\theta = 64.6°$.

Chapter 15. Power Screws, Fasteners, and Connections

15.4 kW = 1.23.

15.6 (a) $n = 48$ rpm.
(b) $(\text{hp})_{\text{req}} = 12.1$.

15.7 $T_o = 145.3\ \text{N} \cdot \text{m}$.

15.10 (a) $\sigma = 10.8$ MPa.
(b) $L_{\text{ne}} = 20.8$ mm.
(c) Nut: $\tau = 13.8$ MPa,
screw: $\tau = 16.4$ MPa.

15.11 $P = 54.67$ kN.

15.13 (a) $P_{\max} = 37.27$ kN, $P_{\min} = 21.53$ kN.
(b) $T = 75\ \text{N} \cdot \text{m}$.

15.15 $n = 2.77$.

15.16 (a) $P_b = 118.5$ kN.
(b) $T = 312.6\ \text{N} \cdot \text{m}$.

15.18 $n = 2.07$ (with preload),
$n = 1.40$ (without preload).

15.20 (a) $n = 4.5$ (with preload),
$n = 2.19$ (no preload).
(b) $n_s = 5.37$.

15.22 $e = 64.3\%$.

15.25 $P_{\text{all}} = 4.57$ kips.

15.27 $V_B = 2.15$ kN, $\tau_B = 6.843$ MPa,
$\sigma_B = 7.167$ MPa.

15.28 $d = 54.3$ mm.

15.30 $P = 23.76$ kN.

15.32 $h = 0.19$ in.

15.34 $L = 199.6$ mm.

15.37 $h = 0.22$ in.

Chapter 16. Axisymmetric Problems in Design

16.4 (a) $p = 30.71$ MPa.
(b) $2c = 220$ mm.

16.6 Steel: $\sigma_{\theta,\max} = 62.2$ MPa,
bronze: $\sigma_{\theta,\max} = -116.8$ MPa.

16.8 $\Delta d_s = 0.356\lambda$.

16.10 (a) $p = 5.167$ MPa.
(b) $\sigma_\theta = 5.596$ MPa.

16.11 (a) $\sigma_{\theta,\max} = 41.11$ MPa.
(b) $\omega = 3539$ rpm.

16.14 (a) $p_y = 38.89$ MPa.
(b) $p_u = 65.55$ MPa.
(c) $(\sigma_\theta)_{\text{res}} = 56.8$ MPa.

16.16 $P = 1.949$ kN.

16.18 (a) $P = 84.59$ kN.
(b) $(\sigma_\theta)_B = -50$ MPa.

16.21 $t = 0.108$ in.

16.22 $a = 238.1$ mm.

16.23 $\sigma_\theta = 2.93$ MPa.

16.26 (a) $t = 14.67$ mm.
(b) $t = 12.67$ mm.
(c) Top end: $t = 158$ mm,
bottom end: $t = 235$ mm.

Chapter 17. Finite Element Analysis in Design

17.5 (c) $\begin{Bmatrix} u_2 \\ v_2 \end{Bmatrix} = \begin{Bmatrix} 1.0 \\ -3.9 \end{Bmatrix}$ mm.

(d) $\begin{Bmatrix} F_{1x} \\ F_{1y} \\ F_{3x} \\ F_{3y} \end{Bmatrix} = \begin{Bmatrix} 7632 \\ 10176 \\ -7500 \\ 0 \end{Bmatrix}$ N.

(e) $F_{12} = 22.32$ kN (T),
$F_{23} = -7.5$ kN (C).

17.6 (c) $\begin{Bmatrix} u_1 \\ v_1 \end{Bmatrix} = \begin{Bmatrix} 2.30 \\ -8.81 \end{Bmatrix} (10^{-3})$ in.

(d) $\begin{Bmatrix} R_{2y} \\ R_{3x} \\ R_{3y} \\ R_{4x} \end{Bmatrix} = \begin{Bmatrix} 5964.5 \\ 1037 \\ 1037 \\ -1035 \end{Bmatrix}$ lb.

(e) $F_{12} = 3964.5$ lb (T),
$F_{13} = 1464.5$ lb (T),
$F_{14} = -1035$ lb (C).

17.7 (c) $\begin{Bmatrix} u_2 \\ v_2 \end{Bmatrix} = \begin{Bmatrix} 18 \\ -60.4 \end{Bmatrix}$ mm.

(d) $\begin{Bmatrix} R_{1x} \\ R_{1y} \\ R_{3x} \end{Bmatrix} = \begin{Bmatrix} 45.024 \\ 60.032 \\ -45 \end{Bmatrix}$ kN.

(e) $F_{12} = -404$ kN (C),
$F_{23} = 180$ kN (T).

17.9 (c) $v_1 = 8.87$ mm.

(d) $\begin{Bmatrix} F_{2x} \\ F_{2y} \\ F_{3x} \\ F_{3y} \end{Bmatrix} = \begin{Bmatrix} 99.59 \\ 132.79 \\ 0 \\ -232.84 \end{Bmatrix}$ kN.

(e) $F_{12} = 166$ kN (T),
$F_{13} = -232.8$ kN (C).

17.11 (b) $\begin{Bmatrix} v_2 \\ \theta_2 \\ \theta_3 \end{Bmatrix} = \begin{Bmatrix} -0.729 \text{ in.} \\ 0.0052 \text{ rad} \\ 0.02083 \text{ rad} \end{Bmatrix}$

(c) $\begin{Bmatrix} F_{1y} \\ M_1 \\ F_{3y} \end{Bmatrix} = \begin{Bmatrix} 6.876 \text{ kips} \\ 225 \text{ kip} \cdot \text{in} \\ 3.125 \text{ kips} \end{Bmatrix}$