Instructor's Solutions Manual
To accompany

Reinforced Concrete Design

Eighth Edition

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NOTES:

This manual is intended solely as an aid for teachers and educators in their individual course preparation.

The solutions presented herein are, in general, somewhat abbreviated. The solutions follow, as closely as possible, the procedures developed in the examples in the text. They are satisfactory solutions within the scope of the text and are based on the limited tables and design aids furnished in the text.

The solutions for the design problems are generally not the only solutions, nor are they necessarily the most economical solutions.

Prob. 1-1

(a) $\dfrac{16(28)}{144}(150) = 467\text{ lb/ft}$

(b) $\dfrac{12(26-6)}{144}(150) + \dfrac{6(38)}{144}(150) = 488\text{ lb/ft}$

Prob. 1-2

Spreadsheet problem: $E_c = w_c^{1.5} 33\sqrt{f_c'}$ Check value for w_c = 145 lb/ft^3 and f_c' = 4000 psi:

E_c = 3,644,000 psi

Prob. 1-3 L = 24 in. with 2100 lb load at midspan.

Beam weight $= \dfrac{6(6)}{144}(0.145) = 0.036\text{ kip/ft}$ $I = \dfrac{1}{12}(6)^4 = 108\text{ in.}^4$

$$M = \frac{0.036(2)^2}{8} + \frac{2.1(2)}{4} = 1.068\text{ ft - kips}$$

$$f = \frac{Mc}{I} = f_r = \frac{1.068(12)(3)}{108} = 0.356\text{ ksi}$$

By ACI formula:

$$f_r = 7.5\sqrt{f_c'} = 7.5\sqrt{3000} = 411\text{ psi}$$

Prob. 1-4 Simply supported beam of length L.

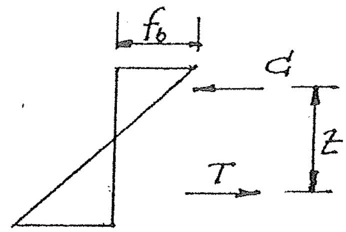
Beam weight $= \dfrac{10(10)}{144}145 = 100.7\text{ lb/ft;}$ $f_r = 350$ psi; $I = \dfrac{10(10)^3}{12} = 833\text{ in.}^4$

$$M = \frac{100.7L^2}{8} = 12.59L^2$$

$$f = \frac{Mc}{I} = f_r = \frac{12.59(12)(5)L^2}{833} = 350$$

$L = 19.65$ ft

Prob. 1-5



$$M = \frac{0.5(10)^2}{8} + \frac{2(10)}{4} = 11.25 \text{ ft - kips}$$

(a) $C = \frac{f_b}{2}(8)(8) = 32 f_b \text{ in.}^2$

$M = CZ$

$$11.25 \text{ ft - kips} = 32 f_b \,(\text{in.}^2)\left(\frac{2}{3}\right)(16 \text{ in.})$$

$$f_b = \frac{11.25 \text{ ft - kips}(12 \text{ in./ft})}{32 \text{ in.}^2\left(\frac{2}{3}\right)(16 \text{ in.})} = 0.396 \text{ ksi}$$

(b) $S_x = \frac{bh^2}{6} = \frac{8(16)^2}{6} = 341 \text{ in.}^3$; $\quad f_b = \frac{M}{S_x} = \frac{11.25(12)}{341} = 0.396 \text{ ksi}$ (O.K.)

Prob. 1-6

$f_r = 7.5\sqrt{3000} = 411 \text{ psi} = 0.411 \text{ ksi}$

(a) I.C. method: $Z = 16 - 2(2.67) = 10.67$ in.

$C = T = 0.5(0.411)(8)(10) = 16.44$ kips

$$M_{cr} = CT = TZ = \frac{16.44(10.67)}{12} = 14.62 \text{ ft - kips}$$

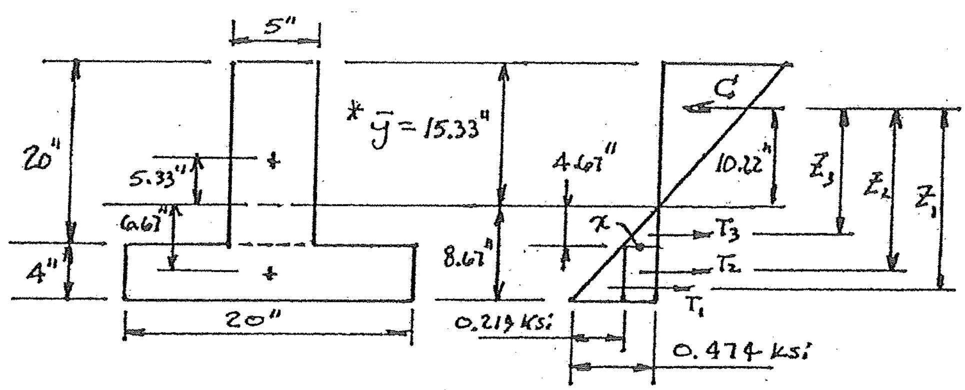
(b) Flexure formula check:

$$S_x = \frac{10(16)^2}{6} = 427 \text{ in.}^3$$

$M_{cr} = f_r S_x = 0.411(427) = 175.5 \text{ in - kips} = 14.62 \text{ ft - kips}$ (O.K.)

Prob. 1-8

(a) $f_c' = 4000$ psi



$$f_r = \frac{7.5\sqrt{4000}}{1000}$$
$$= 0.474 \text{ ksi}$$

$$x = 0.474\left(\frac{4.67}{8.67}\right)$$
$$= 0.255 \text{ ksi}$$

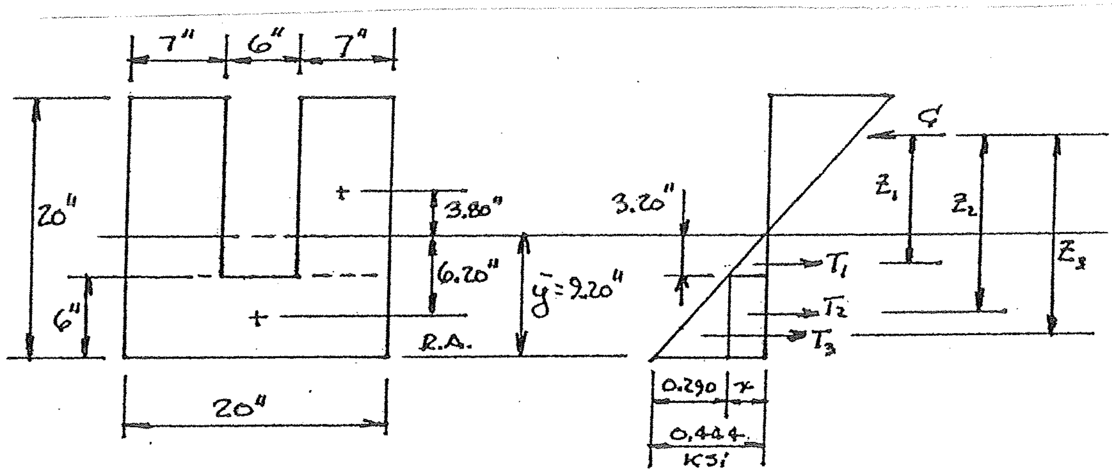
Force	Magnitude (kips)	Moment arm (in.)	I.C. (in.-kips)
T_1	0.5(0.219)(20)(4)=8.76	10.22+(2/3)(4.67) = 17.56	153.8
T_2	0.255(20)(4)=20.4	10.22 +4.67+2=16.89	344.6
T_3	0.5(0.255)(4.67)=2.89	10.22+4.67+(2/3)(4) = 12.33	39.7
		Total :M_{cr} =	538 in-kips

(b) $I = \dfrac{20(4)^3}{12} + 20(4)(6.67)^2 + \dfrac{5(20)^3}{12} + 5(20)(5.33)^2 = 9840 \text{ in.}^2$

$c = 8.67$ in. (to tension side.)

$$M_{cr} = \frac{0.474(9840)}{8.67} = 538 \text{ in - kips} \quad \text{(O.K.)}$$

Prob. 1-9



$f_c' = 3500$ psi; $\qquad f_r = 7.5\sqrt{3500} = 444 \text{ psi} = 0.444 \text{ ksi}$

$$\bar{y} = \frac{\Sigma Ay}{\Sigma A} = \frac{20(6)(3) + 2(7)(14)(13)}{20(6) + 2(7)(14)} = 9.20 \text{ in.}; \qquad x = 0.444\left(\frac{3.20}{9.20}\right) = 0.1544 \text{ ksi}$$

(a)

Force	Magnitude (kips)	Moment arm (in.)	I.C. (in.-kips)
T_1	2(0.5)(0.1544)(7)(3.20)=3.46	7.20+(2/3)(3.20)=9.33	32.3
T_2	0.1544(20)(6)=18.53	7.20+3.20+3=13.40	248.3
T_3	0.5(0.290)(20)(6)=17.40	7.20+3.20+(2/3)(6)=14.40	250.6
		Total :M_{cr} =	531 in-kips

(b) $I = 2\left(\dfrac{7(14)^3}{12}\right) + 2(7)(14)(3.80)^2 + \dfrac{20(6)^3}{12} + 6(20)(6.20)^2 = 11{,}004 \text{ in.}^4$

$$M_{cr} = \frac{f_r I}{c} = \frac{0.444(11{,}004)}{9.20} = 531 \text{ in - kips (O.K.)}$$

Prob. 1-10

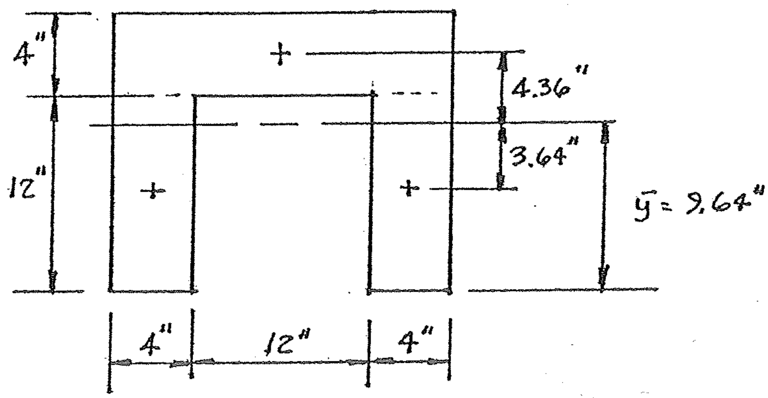
$f_c' = 3000$ psi

$$f_r = \frac{7.5\sqrt{3000}}{1000} = 0.411 \text{ ksi}$$

$$\bar{y} = \frac{\Sigma Ay}{\Sigma A}$$

$$= \frac{2(4)(12)(6) + 4(20)(14)}{2(4)(12) + 4(20)}$$

$= 9.64$ in.



$$I = 2\left(\frac{4(12)^3}{12}\right) + 2(4)(12)(3.64)^2 + \frac{20(4)^3}{12} + 4(20)(4.36)^2 = 4051 \text{ in.}^4$$

(a) $M_{cr} = \dfrac{f_r I}{c} = \dfrac{0.411(4051)}{9.64} = 172.7 \text{ in. - kips}$

(b) Beam weight $= \dfrac{4(20) + 2(4)(12)}{144}(0.145) = 0.1772$ kip/ft

$$\text{Beam weight moment} = \frac{0.1772(12)^2}{8} = 3.19 \text{ ft - kips} = 38.3 \text{ in. - kips}$$

$$\frac{PL}{4} = M_{cr} - 38.3 = 172.7 - 38.3 = 134.4 \text{ in - kips}; \qquad P = \frac{4(134.4 \text{ in - k})}{12 \text{ ft } (12 \text{ in/ft})} = 3.73 \text{ kips}$$

General notes at beginning of Chapter 2 problem-set apply

Prob. 2-1

(a) 4#9, $A_s = 4.00$ in.^{2}

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{4.00(60)}{0.85(3)(16)} = 5.88 \text{ in.}$$

$$M_n = A_s f_y \left(d - \frac{a}{2} \right) = \frac{4.00(60)\left(24 - \frac{5.88}{2}\right)}{12} = 421 \text{ ft - kips}$$

(b) 4#10, $A_s = 5.08$ in.^{2}

$$a = \frac{5.08(60)}{0.85(3)(16)} = 7.47 \text{ in.} \qquad M_n = \frac{5.08(60)\left(24 - \frac{7.47}{2}\right)}{12} = 515 \text{ ft - kips}$$

% Increase: A_s: +27%; M_n: +22%

(c) 4#9, $A_s = 4.00$ in.^{2}, $a = 5.88$ in. (from part (a))

$$M_n = \frac{4.00(60)\left(28 - \frac{5.88}{2}\right)}{12} = 501 \text{ ft - kips}$$

% Increase: d: +16.7 %; M_n: +19%

(d) $f_c' = 4000$ psi

$$a = \frac{4(60)}{0.85(4)(16)} = 4.41 \text{ in.} \qquad M_n = \frac{4.00(60)\left(24 - \frac{4.41}{2}\right)}{12} = 436 \text{ ft - kips}$$

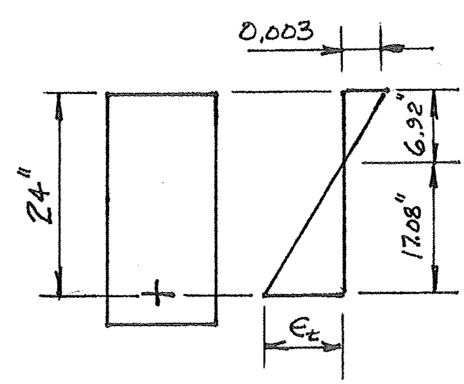
% Increase: f_c' : 33.3%; M_n: 3.6%

Prob. 2-2 Check ε_t for Prob. 2-1(a)

$c = \frac{a}{\beta_1} = \frac{5.88}{0.85} = 6.92$ in. then, from a strain diagram :

$$\frac{\varepsilon_t}{(24 - 6.92)} = \frac{0.003}{6.92}$$

$$\varepsilon_t = 0.0074 > \varepsilon_y = 0.00207 \quad \therefore \quad f_s = f_y$$



Prob. 2-3

(a) [4/40], 4#8, $A_s = 3.16 \text{ in.}^2$, $b = 13$ in., $d = 24$ in. $\rho = \dfrac{3.16}{13(24)} = 0.0101$

$A_{s,\min} = 0.005(13)(24) = 1.56 \text{ in.}^2 < 3.16 \text{ in.}^2$ (O.K.)

(Table A-9) $\bar{k} = 0.3800$ ksi and $\varepsilon_t > 0.005$, $\therefore\ \phi = 0.90$

$$\phi M_n = \phi b d^2 \bar{k} = \frac{0.90(13)(24)^2(0.3800)}{12} = 213 \text{ ft - kips}$$

(b) [4/60], 4#8, $A_s = 3.16 \text{ in.}^2$, $b = 13$ in., $d = 24$ in. $\rho = \dfrac{3.16}{13(24)} = 0.0101$

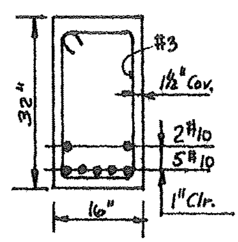
$A_{s,\min} = 0.0033(13)(24) = 1.03 \text{ in.}^2 < 3.16 \text{ in.}^2$ (O.K.)

(Table A-10) $\bar{k} = 0.5520$ ksi and $\varepsilon_t > 0.005$, $\therefore\ \phi = 0.90$

$$\phi M_n = \phi b d^2 \bar{k} = \frac{0.90(13)(24)^2(0.5520)}{12} = 310 \text{ ft - kips}$$

% Increase: f_y: +50%; ϕM_n: +45.5%

Prob. 2-4 [4/60]

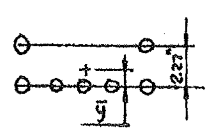


$$\bar{y} = \frac{2A(2.27)}{7A} = 0.649 \text{ in.}$$

$d = 32 - 1.5 - 0.375 - 1.27/2 - 0.649 = 28.8$ in.

$$\rho = \frac{8.89}{16(28.8)} = 0.0193, \quad \bar{k} = 0.9609 \text{ ksi}, \quad \varepsilon_t = 0.00449$$

$$\therefore\ \phi = 0.65 + (0.00449 - 0.002)\left(\frac{250}{3}\right) = 0.858$$



$$\phi M_n = \phi b d^2 \bar{k} = \frac{0.858(16)(28.8)^2(0.9609)}{12} = 912 \text{ ft - kips}$$

Prob. 2-5 [3/40], $b = 20$ in., $d = 42$ in., $h = 45$ in., $L = 28$ ft
Beam is adequate if $\phi M_n \geq M_u$

$$\text{Beam weight} = \frac{20(45)}{144}(0.150) = 0.938 \text{ kip/ft}$$

$w_u = 1.2(0.938 + 2.20) + 1.6(3.60) = 9.53$ kips/ft; $\quad M_u = \dfrac{9.53(28)^2}{8} = 939 \text{ ft-kips}$

(a) 6#10, $A_s = 7.62 \text{ in.}^2$, $\rho = \dfrac{7.62}{20(42)} = 0.00907$

$A_{s,\min} = 0.005(20)(42) = 4.20\text{in.}^2 < 7.62 \text{ in.}^2$ (O.K.)

(Table A-7) $\bar{k} = 0.3380$ ksi and $\varepsilon_t > 0.005$, $\therefore \phi = 0.90$

$$\phi M_n = \phi b d^2 \bar{k} = \frac{0.90(20)(42)^2(0.3380)}{12} = 894 \text{ ft-kips} < 939 \text{ ft-kips} \quad \text{(N.G.)}$$

(b) 6#11, $A_s = 9.36 \text{ in.}^2$, $\rho = \dfrac{9.36}{20(42)} = 0.0111$

$A_{s,\min} = 4.20 \text{ in.}^2 < 9.36 \text{ in.}^2$ (O.K.)

(Table A-7) $\bar{k} = 0.4053$ ksi and $\varepsilon_t > 0.005$, $\therefore \phi = 0.90$

$$\phi M_n = \phi b d^2 \bar{k} = \frac{0.90(20)(42)^2(0.4053)}{12} = 1072 \text{ ft-kips} > 939 \text{ ft-kips} \quad \text{(O.K.)}$$

Prob. 2-7 [4/60] $b = 12$ in., $h = 20$ in., 3#8 ($A_s = 2.37 \text{ in.}^2$)

$$\text{Beam weight} = \frac{12(20)}{144}(0.150) = 0.250 \text{ k/ft}$$

$d = 20 - 1.5 - 0.38 - 0.50 = 17.62$ in.; $\quad A_{s,\min} = 0.0033(12)(17.62) = 0.700 \text{ in.}^2$ (O.K.)

$\rho = \dfrac{2.37}{12(17.62)} = 0.0112$; $\bar{k} = 0.6056$ ksi, $\varepsilon_t > 0.005$, $\phi = 0.90$

$$\phi M_n = \frac{0.90(12)(17.62)^2(0.6056)}{12} = 169 \text{ ft-kips}$$

$$M_u = \frac{[1.2(0.7 + 0.250) + 1.6(2.5)](16)^2}{8} = 164.5 \text{ ft-kips} < 169 \text{ ft-kips} \quad \text{(O.K.)}$$

Prob. 2-8

[3/60] $b = 16$ in., $h = 38$ in., $L = 26.5$ ft simple span. Check moment adequacy.

$$\text{Beam weight} = \frac{16(38)}{144}(0.150) = 0.633 \text{ k/ft}$$

$$M_u = \frac{[1.2(1.80 + 0.633) + 1.6(3.20)]}{8}(26.5)^2 = 706 \text{ ft-kips}$$

(a) 5#9, $A_s = 5.00$ in.^{2}, $d = 35$ in., $\rho = \dfrac{5.00}{16(35)} = 0.0089$

$A_{s,\min} = 0.0033(16)(35) = 1.85 \text{ in.}^2 < 5.00 \text{ in.}^2$ (O.K.)

$\bar{k} = 0.4781$ ksi, $\varepsilon_t > 0.005$, $\phi = 0.90$

$$\phi M_n = \frac{0.90(16)(35)^2(0.4781)}{12} = 703 \text{ ft-kips} < 706 \text{ ft-kips} \quad \text{(N.G.)}$$

(a) 6#9, $A_s = 6.00$ in.^{2}, $d = 34.4$ in., $\rho = \dfrac{6.00}{16(34.4)} = 0.0109$

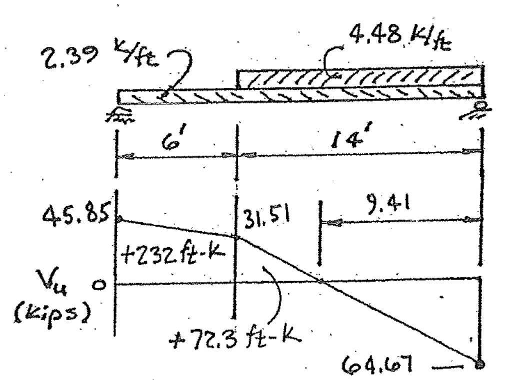
$A_{s,\min} = 0.0033(16)(34.4) = 1.82 \text{ in.}^2 < 6.00 \text{ in.}^2$ (O.K.)

$\bar{k} = 0.5702$ ksi, $\varepsilon_t > 0.005$, $\phi = 0.90$

$$\phi M_n = \frac{0.90(16)(34.4)^2(0.5702)}{12} = 808 \text{ ft-kips} > 706 \text{ ft-kips} \quad \text{(O.K.)}$$

Prob. 2-9 [3/60] 3#10, $A_s = 3.81$ in.^{2}, $b = 14.5$ in., $h = 26$ in. check moment adequacy.

$d = 26 - 1.5 - 0.38 - 1.27/2 = 23.5$ in.
Calculated beam weight = 0.393 k/ft
Max. M_u from diag. = 304 ft-kips



$$\rho = \frac{3.81}{14.5(23.5)} = 0.0112$$

$A_{s,\min} = 0.0033(14.5)(23.5) = 1.12 \text{ in.}^2$

$\bar{k} = 0.5835$, $\varepsilon_t > 0.005$, $\phi = 0.90$

$$\phi M_n = \frac{0.90(14.5)(23.5)^2 0.5835}{12} = 350 \text{ ft-kips} > 304 \text{ ft-kips} \quad \text{(O.K.)}$$

Prob. 2-10 [4/60] 4#9, $b = 14$ in., $h = 24$ in., find max simple span L

$d = 24 - 1.5 - 0.38 - 1.13/2 = 21.6$ in.

Beam wt. $= \dfrac{14(24)}{144}(0.150) = 0.350$ k/ft; $\qquad \rho = \dfrac{4.00}{14(21.6} = 0.0132$

$A_{s,\min} = 0.0033(14)(21.6) = 1.00 \text{ in.}^2$

$\bar{k} = 0.6998 \text{ ksi}, \quad \varepsilon_t > 0.005, \quad \phi = 0.90$

$$\phi M_n = \frac{0.90(14)(21.6)^2 0.6998}{12} = 343 \text{ ft - kips}$$

$$M_u = \frac{[1.2(0.60+0.35)+1.6(1.4)]L^2}{8} = 343 \text{ ft - kips, from which } L = 28.5 \text{ ft}$$

Prob. 2-11 [3/60] One-way slab analysis. #7@6 in., A_s=1.20 in.^{2}/ft, $h = 10$ in., $L = 16$ ft

Slab weight$= \dfrac{10(12)}{144}(0.150) = 0.125$ k/ft;

$$M_u = \frac{[1.2(0.125)+1.6(0.600)]16^2}{8} = 35.5 \text{ ft - kips}$$

$d = 10 - 0.75 - 0.875/2 = 8.81$ in.; $\qquad \rho = \dfrac{1.20}{12(8.81)} = 0.0113$

$A_{s,\min} = 0.0018(12)(8.81) = 0.19 \text{ in.}^2\text{/ft}$ (O.K.); $\bar{k} = 0.5879$ ksi, $\varepsilon_t > 0.005$, $\phi = 0.90$

$$\phi M_n = \frac{0.90(12)(8.81)^2(0.5879)}{12} = 41.4 \text{ ft - kips} > 35.5 \text{ ft - kips} \quad \text{(O.K.)}$$

Prob. 2-12 [3/40] One-way slab analysis, $h = 8$ in., #8@6 in., $A_s = 1.58$ in.^{2}/ft, $L = 12$ ft

Slab weight$= \dfrac{8(12)}{144}(0.150) = 0.100$ k/ft;

$d = 8 - 0.75 - 1.00/2 = 6.75$ in.; $\qquad A_{s,\min} = 0.0020(12)(6.75) = 0.16 \text{ in.}^2\text{/ft}$ (O.K.)

$\rho = \dfrac{1.20}{12(6.75)} = 0.0195, \quad \bar{k} = 0.6608 \text{ ksi}, \quad \varepsilon_t > 0.005, \phi = 0.90$

$$\phi M_n = \frac{0.90(12)(6.75)^2(0.6608)}{12} = 27.1 \text{ ft - kips}$$

$$M_{u(\text{D.L.})} = \frac{1.2(0.100)(12)^2}{8} = 2.16 \text{ ft - kips}, \quad M_{u(\text{L.L.})} = \frac{1.6 w_{\text{LL}} L^2}{8} = 27.1 - 2.16 = 24.9 \text{ ft - kips}$$

From which, $w_{LL} = 0.865$ k/ft $= 865$ psf

Prob. 2-13 [4/60] One-way slab w/ construction errors.

As designed: #7@11, $A_s = 0.65$ in.^{2}/ft, $d = 8.5 - 1 - 0.875/2 = 7.06$ in.
$A_{s,\min} = 0.0018(12)(8.50) = 0.18$ in.^{2}/ft (O.K.)

$$\rho = \frac{0.65}{12(7.06)} = 0.0077; \quad \bar{k} = 0.4306\,\text{ksi}, \quad \varepsilon_t > 0.005, \quad \phi = 0.90$$

$$\phi M_n = \frac{0.90(12)(7.06)^2(0.4306)}{12} = 19.3\,\text{ft - kips}$$

As built: $d = 8.5 - 3.5 - 0.875/2 = 4.56$ in.

$$\rho = \frac{0.65}{12(4.56)} = 0.0119; \quad \bar{k} = 0.6391\,\text{ksi}, \quad \varepsilon_t > 0.005, \quad \phi = 0.90$$

$$\phi M_n = \frac{0.90(12)(4.56)^2(0.6391)}{12} = 11.96\,\text{ft - kips} \qquad (\%\,\text{Change} = -38\%)$$

Prob. 2-14 Design. [3/60] $M_u = 133$ ft-kips, $b = 11\frac{1}{2}$ in., $h = 23$ in.
Est. $d = 20$ in., Assume $\phi = 0.90$.

$$\text{Required } \bar{k} = \frac{133(12)}{0.90(11.5)(20)^2} = 0.3855\,\text{ksi}$$

Required $\rho = 0.0070$ ($\varepsilon_t > 0.005$, $\phi = 0.90$)

Required $A_s = 0.007(11.5)(20) = 1.61\,\text{in.}^2$, $A_{s,\min} = 0.0033(11.5)(20) = 0.76\,\text{in.}^2$ (O.K.)

Select 3#7, one layer ($A_s = 1.80\,\text{in.}^2$, $b_{\min} = 8.5$ in.)

$$\text{Calculated } d = 23 - 1.5 - 0.38 - \frac{0.875}{2} = 20.7\,\text{in.} > 20\,\text{in.} \quad (\text{O.K.})$$

Prob. 2-15 Design. [4/60] $M_u = 400$ ft-kips, $b = 16$ in., $h = 28$ in.

Est. $d = 25$ in., Assume $\phi = 0.90$.

$$\text{Required } \bar{k} = \frac{400(12)}{0.90(16)(25)^2} = 0.5333\,\text{ksi}$$

Required $\rho = 0.0098$ ($\varepsilon_t > 0.005$, $\phi = 0.90$)

Required $A_s = 0.0098(16)(25) = 3.92\,\text{in.}^2$, $A_{s,\min} = 0.0033(16)(25) = 1.32\,\text{in.}^2$ (O.K.)

Select 4#9, one layer ($A_s = 4.00\,\text{in.}^2$, $b_{\min} = 12$ in.)

$$\text{Calculated } d = 28 - 1.5 - 0.38 - \frac{1.13}{2} = 25.6\,\text{in.} > 25\,\text{in.} \quad (\text{O.K.})$$

Prob. 2-16 (Prob. 2-15 with incorrectly placed steel making $d = 24$ in.)
[4/60] $M_u = 400$ ft-kips, $b = 16$ in.,

$d = 24$ in., Assume $\phi = 0.90$.

$$\rho = \frac{4.00}{16(24)} = 0.0104$$

$$A_{s,\min} = 0.0033(16)(24) = 1.27 \text{ in.}^2$$

$$\bar{k} = 0.5667, \quad \varepsilon_t > 0.005, \quad \phi = 0.90$$

$$\phi M_n = \frac{0.90(16)(24)^2 0.5667}{12} = 392 \text{ ft-kips} < 400 \text{ ft-kips} \quad \text{(N.G.)}$$

Prob. 2-17 [4/60] $L = 32$ ft, $b = 11\frac{1}{2}$ in., $h = 26$ in.

Beam weight $= \dfrac{11.5(26)}{144}(0.150) = 0.312$ kip/ft Assume $\phi = 0.90$

$$M_u = \frac{[1.2(0.85 + 0.312) + 1.6(1.0)](32)^2}{8} = 383 \text{ ft-kips}$$

Estimated $d = 23$ in.

$$\text{Required } \bar{k} = \frac{383(12)}{0.90(11.5)(23)^2} = 0.8394 \text{ ksi} \quad (\varepsilon_t > 0.005, \ \phi = 0.90)$$

Required $\rho = 0.0164$

Required $A_s = 0.0164(11.5)(23) = 4.34$ in.^{2} $A_{s,\min} = 0.0033(11.5)(23) = 0.87$ in.^{2}

Select 3#11 in one layer ($A_s = 4.68$ in.^{2}, $b_{\min} = 11$ in.)
Calculated $d = 26 - 1.5 - 0.38 - 1.41/2 = 23.4$ in. > 23 in. (O.K.)
Check ϕM_n:

$$\rho = \frac{4.68}{11.5(23.4)} = 0.0174, \quad \bar{k} = 0.8838 \text{ ksi}, \quad (\varepsilon_t > 0.005, \ \phi = 0.90)$$

$$\phi M_n = \frac{0.90(11.5)(23.4)^2(0.8838)}{12} = 417 \text{ ft-kips} \quad > 383 \text{ ft-kips} \quad \text{(O.K.)}$$

Prob. 2-18 [5/60] $L = 30$ ft, $b = 12$ in., $h = 27$ in.

Beam weight $= \dfrac{12(27)}{144} = 0.338$ k/ft

Estimated $d = 24$ in., assume $\phi = 0.90$

$$M_u = \frac{[1.2(0.338) + 1.6(1.35)30^2}{8} = 289 \text{ ft-kips}$$

$$\text{Required } \bar{k} = \frac{289(12)}{0.90(12)(24)^2} = 0.5575 \text{ ksi}, \quad \text{required } \rho = 0.0100, \quad (\varepsilon_t > 0.005, \phi = 0.90)$$

Required $A_s = 0.0100(12)(24) = 2.88 \text{ in.}^2$, $\quad A_{s,\min} = 0.0035(12)(24) = 1.01 \text{ in.}^2$ (O.K.)

Select 3#9 ($A_s = 3.00$ in.^{2}, $b_{\min} = 9.5$ in.)

Calculated $d = 27 - 1.5 - 0.38 - 1.13/2 = 24.6$ in. > 24 in. (O.K.)

Check ϕM_n:

$$\rho = \frac{3.00}{12(24.6)} = 0.0102, \quad \bar{k} = 0.5679 \text{ ksi}, \quad (\varepsilon_t > 0.005, \quad \phi = 0.90)$$

$$\phi M_n = \frac{0.90(12)(24.6)^2(0.5679)}{12} = 309 \text{ ft-kips} \quad > 289 \text{ ft-kips} \quad \text{(O.K.)}$$

Prob. 2-19 (Redo Prob. 2-18 using superimposed loads: L.L. = 1.75 k/ft, D.L. = 1.0 k/ft)

$$M_u = \frac{[1.2(1.0 + 0.338) + 1.6(1.75)]30^2}{8} = 496 \text{ ft-kips}$$

Est. $d = 24$ in., assume $\phi = 0.90$

$$\text{Required } \bar{k} = \frac{496(12)}{0.90(12)(24)^2} = 0.9568 \text{ ksi}, \quad \text{required } \rho = 0.0184, \quad (\varepsilon_t > 0.005, \phi = 0.90)$$

Required $A_s = 0.0184(12)(24) = 5.30 \text{ in.}^2$, $\quad A_{s,\min} = 0.0035(12)(24) = 1.01 \text{ in.}^2$ (O.K.)

Select 6#9, two layers, 1 in. clear ($A_s = 6.00$ in.^{2}, $b_{\min} = 9.5$ in.)

Calculated $d = 27 - 1.5 - 0.38 - 1.13 - 0.5 = 23.5$ in. < 24 in. (Check ϕM_n)

$$\rho = \frac{6.00}{12(23.5)} = 0.0213, \quad \bar{k} = 1.0859 \text{ ksi}, \quad (\varepsilon_t > 0.005, \quad \phi = 0.90)$$

$$\phi M_n = \frac{0.90(12)(23.5)^2(1.0859)}{12} = 540 \text{ ft-kips} \quad > 496 \text{ ft-kips} \quad \text{(O.K.)}$$

Prob. 2-20 [3/60] $L = 22$ ft, $b = 15$ in., h: full inches.

$$M_u = \frac{[1.2(1.6) + 1.6(1.4)](22)^2}{8} = 252 \text{ ft-kips (Estimated beam weight included.)}$$

Try $\rho = 0.0090$, $\bar{k} = 0.4828$ ksi $(\varepsilon_t > 0.005, \phi = 0.90)$

$$\text{Req'd } d = \sqrt{\frac{252(12)}{0.90(15)(0.4828)}} = 21.5 \text{ in.} \qquad \left(\frac{d}{b} = \frac{21.5}{15} = 1.4 \text{ (Say O.K.)}\right)$$

Required $A_s = 0.009(15)(21.5) = 2.90 \text{ in.}^2$, $\quad A_{s,\min} = 0.0033(15)(21.5) = 1.06 \text{ in.}^2$ (O.K.)

Select 3#9 (A_s =3.00 in.^{2}, $b_{\min} = 9.5$ in.)

Req'd $h = 21.5 + 1.13/2 + 0.38 + 1.5 = 23.9$ in. Use 24 in.

Check ϕM_n: $d = 21.6$ in., $\rho = \dfrac{3.00}{15(21.6)} = 0.0093$, $\bar{k} = 0.4970$ ksi, $(\varepsilon_t > 0.005, \phi = 0.90)$

$$\phi M_n = \frac{0.90(15)(21.6)^2(0.4970)}{12} = 261 \text{ ft-kips} \quad > 252 \text{ ft-kips} \quad \text{(O.K.)}$$