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Instructor's Solutions Manual
To accompany

Reinforced Concrete Design

Eighth Edition

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ISBN-13: 978-0-13-285939-4
ISBN-10: 0-13-285939-4

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

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

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

Prob. 1-2

Spreadsheet problem: $E_c = w_c^{1.5} 33\sqrt{f'_c}$ Check value for $w_c = 145 \text{ lb/ft}^3$ and $f'_c = 4000 \text{ psi}$:
 $E_c = 3,644,000 \text{ psi}$

Prob. 1-3 $L = 24 \text{ in.}$ with 2100 lb load at midspan.

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

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

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

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 .

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

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

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

$$L = 19.65 \text{ ft}$$

Prob. 1-5

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

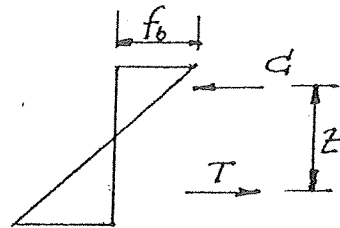
$$(a) C = \frac{f_b}{2}(8)(8) = 32f_b \text{ in.}^2$$

$$M = CZ$$

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

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

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



Prob. 1-6

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

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

$$C = T = 0.5(0.411)(8)(10) = 16.44 \text{ kips}$$

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

(b) Flexure formula check:

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

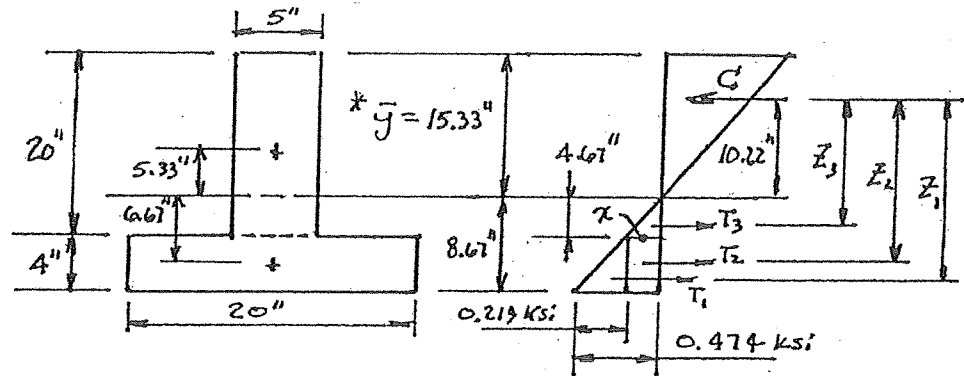
$$M_{cr} = f_r S_x = 0.411(427) = 175.5 \text{ in} \cdot \text{kips} = 14.62 \text{ ft} \cdot \text{kips} \quad (\text{O.K.})$$

Prob. 1-8

(a) $f'_c = 4000$ psi

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

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



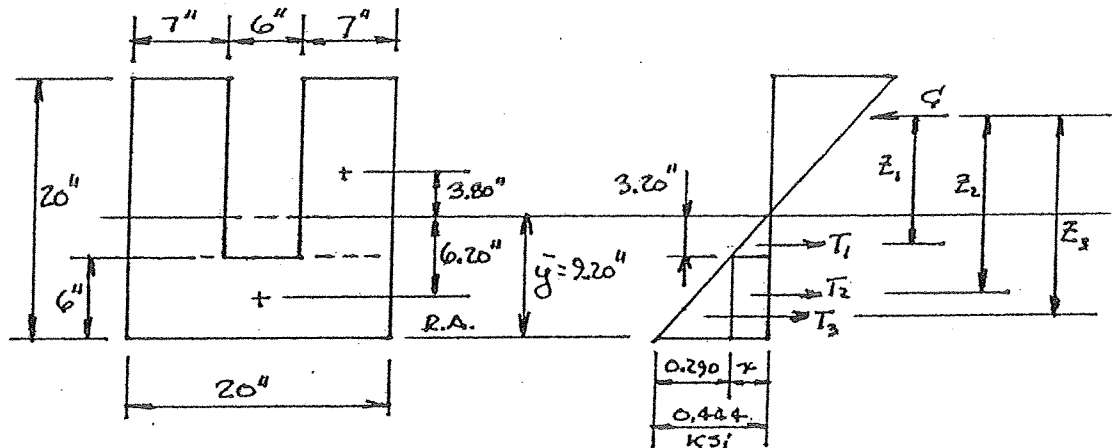
Force	Magnitude (kips)	Moment arm (in.)	I.C. (in.-kips)
T_1	$0.5(0.219)(20)(4)=8.76$	$10.22+(2/3)(4.67)=17.56$	153.8
T_2	$0.255(20)(4)=20.4$	$10.22+4.67+2=16.89$	344.6
T_3	$0.5(0.255)(4.67)=2.89$	$10.22+4.67+(2/3)(4)=12.33$	39.7
Total M_{cr}			538 in-kips

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

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

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

Prob. 1-9



$$f'_c = 3500 \text{ psi}; \quad f_r = 7.5\sqrt{3500} = 444 \text{ psi} = 0.444 \text{ ksi}$$

$$\bar{y} = \frac{\sum Ay}{\sum A} = \frac{20(6)(3) + 2(7)(14)(13)}{20(6) + 2(7)(14)} = 9.20 \text{ in.};$$

$$x = 0.444 \left(\frac{3.20}{9.20} \right) = 0.1544 \text{ ksi}$$

(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

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

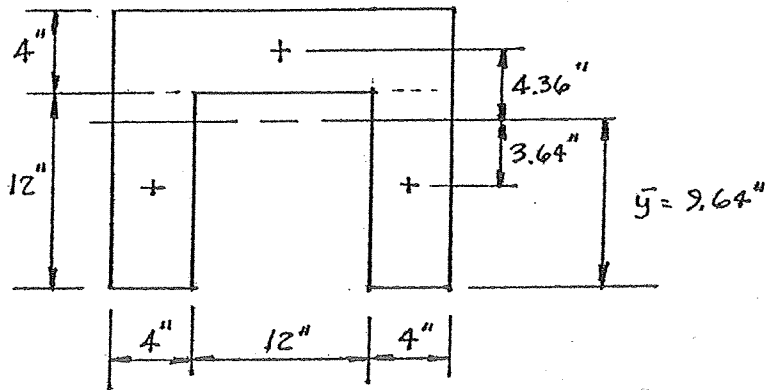
$$M_{cr} = \frac{f_r I}{c} = \frac{0.444(11,004)}{9.20} = 531 \text{ in-kips (O.K.)}$$

Prob. 1-10

$$f'_c = 3000 \text{ psi}$$

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

$$\begin{aligned} \bar{y} &= \frac{\sum Ay}{\sum A} \\ &= \frac{2(4)(12)(6) + 4(20)(14)}{2(4)(12) + 4(20)} \\ &= 9.64 \text{ in.} \end{aligned}$$



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

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

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

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

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

General notes at beginning of Chapter 2 problem-set apply

Prob. 2-1

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

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

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

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

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

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

(c) 4#9, $A_s = 4.00 \text{ in.}^2$, $a = 5.88 \text{ in.}$ (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) $f'_c = 4000 \text{ psi}$

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

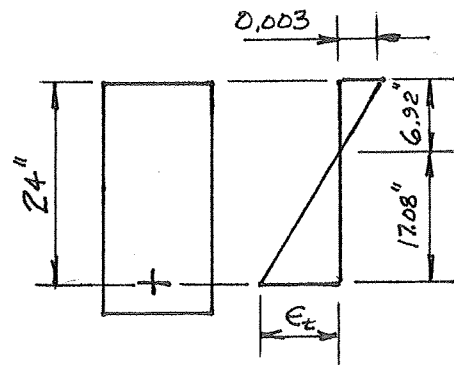
% Increase: f'_c : 33.3%; M_n : 3.6%

Prob. 2-2 Check ϵ_t for Prob. 2-1(a)

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

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

$$\epsilon_t = 0.0074 > \epsilon_y = 0.00207 \quad \therefore f_s = f_y$$



Prob. 2-3

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

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

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

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

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

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

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

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

% Increase: f_y : +50%; ϕM_n : +45.5%

Prob. 2-4 [4/60]

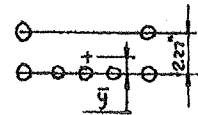
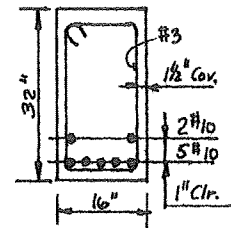
$$\bar{y} = \frac{2A(2.27)}{7A} = 0.649 \text{ in.}$$

$$d = 32 - 1.5 - 0.375 - 1.27/2 - 0.649 = 28.8 \text{ in.}$$

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

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

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



Prob. 2-5 [3/40], $b = 20$ in., $d = 42$ in., $h = 45$ in., $L = 28$ ft

Beam is adequate if $\phi M_n \geq M_u$

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\rho = \frac{2.37}{12(17.62)} = 0.0112; \quad \bar{k} = 0.6056 \text{ ksi}, \quad \epsilon_t > 0.005, \quad \phi = 0.90$$

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

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

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, $A_s = 5.00 \text{ in.}^2$, $d = 35$ in., $\rho = \frac{5.00}{16(35)} = 0.0089$

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

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

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

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

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

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

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

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

$$d = 26 - 1.5 - 0.38 - 1.27/2 = 23.5 \text{ in.}$$

$$\text{Calculated beam weight} = 0.393 \text{ k/ft}$$

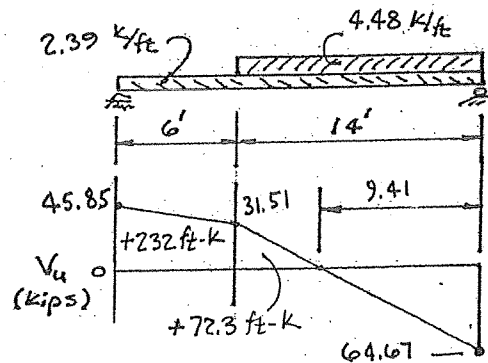
$$\text{Max. } M_u \text{ from diag.} = 304 \text{ ft-kips}$$

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

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

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

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



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

$$d = 24 - 1.5 - 0.38 - 1.13/2 = 21.6 \text{ in.}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

As designed: #7@11, $A_s = 0.65 \text{ in.}^2/\text{ft}$, $d = 8.5 - 1 - 0.875/2 = 7.06 \text{ in.}$

$A_{s,\min} = 0.0018(12)(8.50) = 0.18 \text{ in.}^2/\text{ft}$ (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: $d = 8.5 - 3.5 - 0.875/2 = 4.56 \text{ in.}$

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

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

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

Est. $d = 20 \text{ in.}$, 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 ($A_s = 1.80 \text{ in.}^2$, $b_{\min} = 8.5 \text{ in.}$)

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

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

Est. $d = 25 \text{ in.}$, 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 ($A_s = 4.00 \text{ in.}^2$, $b_{\min} = 12 \text{ in.}$)

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

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 $\phi = 0.90$.

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

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

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

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

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

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

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

Estimated $d = 23$ in.

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

Required $\rho = 0.0164$

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

Select 3#11 in one layer ($A_s = 4.68 \text{ in.}^2$, $b_{\min} = 11$ in.)

Calculated $d = 26 - 1.5 - 0.38 - 1.41/2 = 23.4$ in. > 23 in. (O.K.)

Check ϕM_n :

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

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

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

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

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

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

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

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

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

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

Check ϕM_n :

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

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

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. $d = 24 \text{ in.}$, assume $\phi = 0.90$

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

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

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

$$\text{Calculated } d = 27 - 1.5 - 0.38 - 1.13 - 0.5 = 23.5 \text{ in.} < 24 \text{ in. (Check } \phi M_n)$$

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

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

Prob. 2-20 [3/60] $L = 22 \text{ ft}$, $b = 15 \text{ in.}$, 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 $\rho = 0.0090$, $\bar{k} = 0.4828 \text{ ksi}$ ($\epsilon_t > 0.005$, $\phi = 0.90$)

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

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

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

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

$$\text{Check } \phi M_n: d = 21.6 \text{ in., } \rho = \frac{3.00}{15(21.6)} = 0.0093, \bar{k} = 0.4970 \text{ ksi, } (\epsilon_t > 0.005, \phi = 0.90)$$

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