# *Reinforced Concrete Design 9th edition Aghayere Solutions Manual*

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**Instructor's Solutions Manual**
*To accompany*

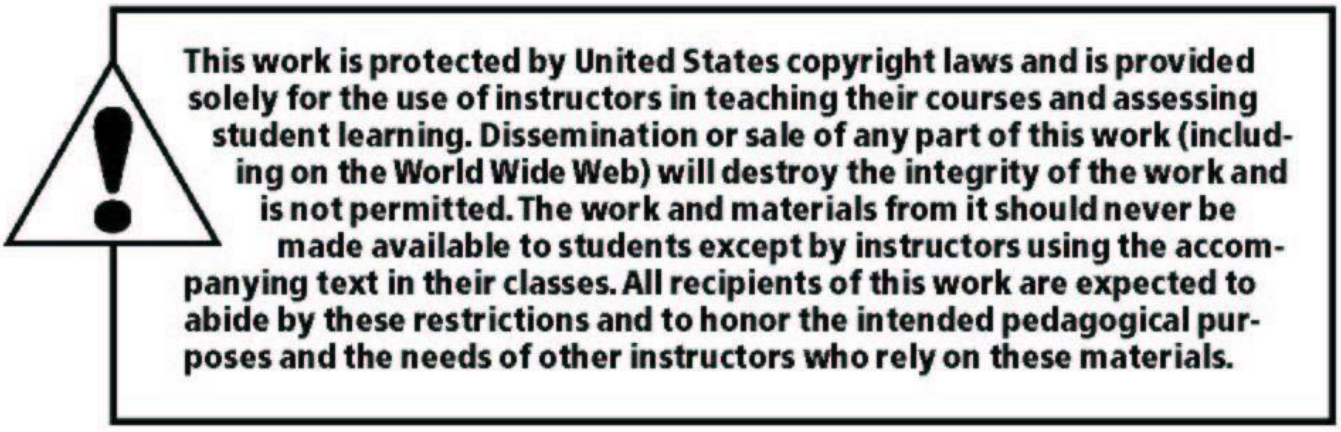
# Reinforced Concrete Design

**Ninth 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.

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Prob. 1-1

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

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

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

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

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

By ACI formula:

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

---

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

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

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

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

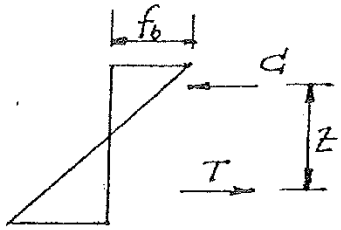
$L = 19.65$ ft



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

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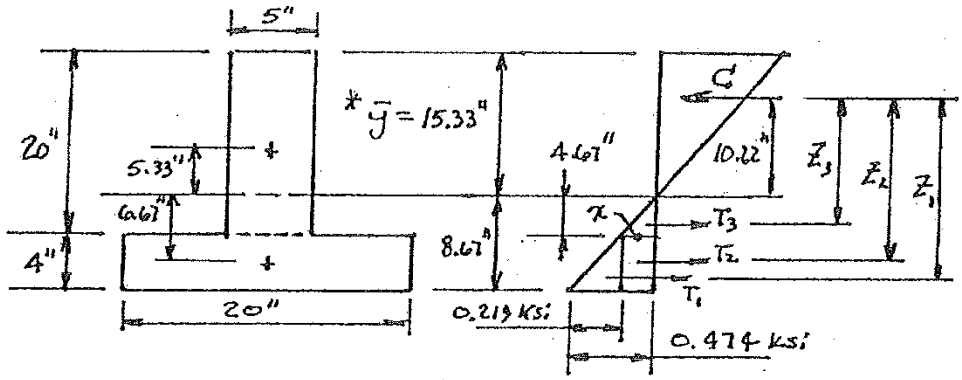
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Prob. 1-8

(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 |

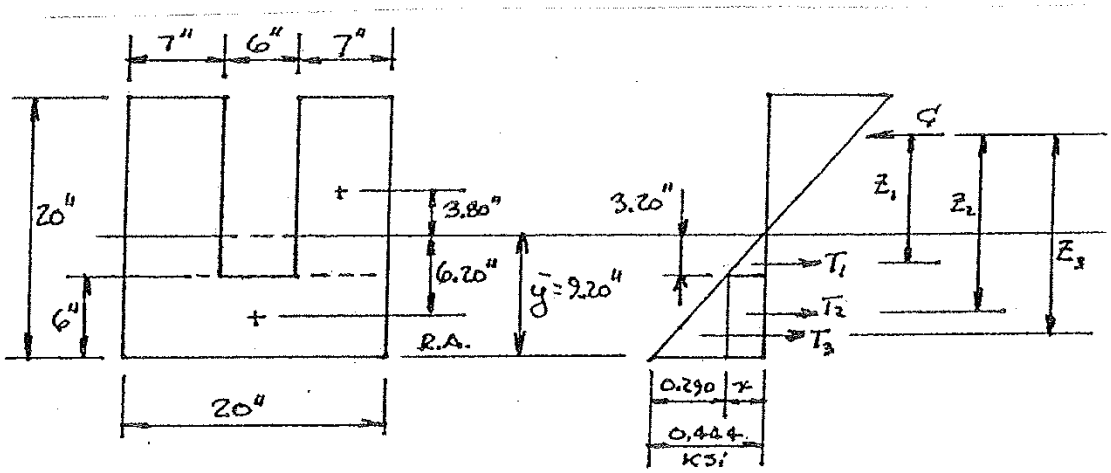
(b) $I = \frac{20(4)^3}{12} + 20(4)(6.67)^2 + \frac{5(20)^3}{12} + 5(20)(5.33)^2 = 9840 \text{ in.}^2$

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

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

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Prob. 1-9




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

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



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

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

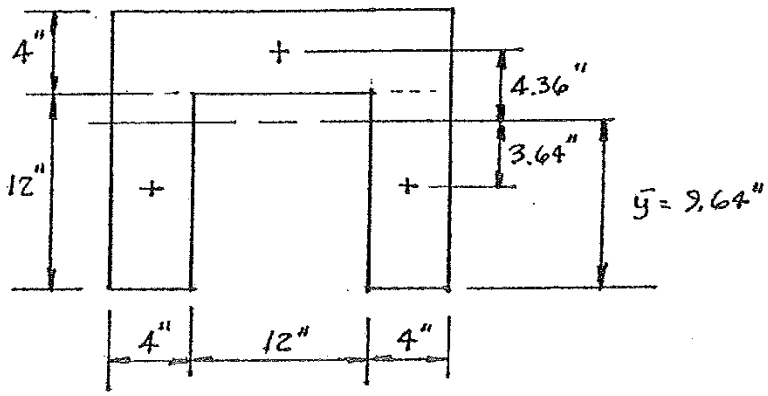
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Prob. 1-10

$f_c' = 3000$ psi

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

$$\bar{y} = \frac{\Sigma Ay}{\Sigma A} = \frac{2(4)(12)(6) + 4(20)(14)}{2(4)(12) + 4(20)} = 9.64 \text{ in.}$$




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

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

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

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

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



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# Prob 1-11

**Part (a):** Dead Loads

| | | | |
|---|---|---|---|
| Slab weight | | | |
| (8”/12)(150pcf) | = | 100psf | |
| ½” light wt. floor finish | = | 4psf | |
| susp. ceiling | | = | 2psf |
| M/E (industrial) | = | 20psf | |
| Partitions | | = | 20psf |

_____

**$\Sigma_{DL}$ = 146psf (with partitions)**
**$\Sigma_{DL}$ = 126psf (without partitions)**

**Part (b):** Live Load = 100psf

1.4D = (1.4)(126) = 176.4psf

1.2D + 1.6L = (1.2)(126) + (1.6)(100)= **311ps**f ← controls

**Part (c):** Load on spandrel beam

Trib. width = (18 ft/2) + 1.0 ft = 10 ft

Cladding:
Block: (55psf)(10 ft. – 2’-2”) = 431 plf
Brick: (40psf)(10 ft.) = 400 plf

Beam Stem:
(8”/12)(12”/12)(150pcf) = 225 plf

Service Dead Load:

(126psf)(10 ft) + 431plf + 400 + 225 plf = 2316 plf = **2.32 k/ft**

Service Live Load:

(100psf)(10 ft) = 1000 plf = **1.0 k/ft**

**Part (d):** Factored Load on spandrel beam:

1.2D + 1.6L = (1.2)(2.32) + (1.6)(1.0)= **4.4plf**



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**Part (e):** Load on interior beam

Trib. width = (18 ft/2) + (18 ft/2) + 1.0 ft = 19 ft

Beam Stem:

(8”/12)(12”/12)(150pcf) = 225 plf

Service Dead Load:

(126psf)(19 ft) + 225 plf = 2619 plf = **2.62 k/ft**

Service Live Load:

(100psf)(19 ft) = 1000 plf = **1.9 k/ft**

**Part (f):** Factored Load on interior beam:

1.2D + 1.6L = (1.2)(2.62) + (1.6)(1.9)= **6.2k/ft**

**Part (g):**

Spandrel Beam:

$$V_u = \frac{w_u L}{2} = \frac{(4.4)(36)}{2} = \textbf{79.2 k}$$

$$M_u = \frac{w_u L^2}{8} = \frac{(4.4)(36)^2}{8} = \textbf{713 k-ft}$$



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## Prob 1-12

| **Roof Loads** | | **Typical Floor Loads** | |
|---|---|---|---|
| Dead Load: | | Dead Load: | |
| 7" slab (7"/12 x 150 pcf) | = 87.5 psf | 7" slab (7"/12 x 150 pcf) | = 87.5 psf |
| 5 ply + gravel | = 6.5 psf | 0.5" light wt floor finish = 4 psf | |
| Insulation | = 3.5 psf | Partitions | = 20 psf |
| M & E | = 10 psf | M & E | = 10 psf |
| Suspended ceiling | = 2 psf | Suspended ceiling | = 2 psf |
| Total roof dead load, D | = 109.5 psf | Total roof dead load, D | = 123.5 psf |
| Roof live load (snow) S | = 35 psf | Floor live load (office) L | = 50 psf |

**A.**

**Roof:** $w_{DL\ slab}$ = 109.5 psf; $w_{LL\ slab}$= 35 psf
Using the load combinations, we find the maximum factored load to be,
**$w_{u\ slab}$ = 1.2 (109.5psf) + 1.6 (35 psf) = 188 psf**

**Floor:** $w_{DL\ slab}$ = 123.5 psf; $w_{LL\ slab}$= 50 psf
Using the load combinations, we find the maximum factored load to be,
**$w_{u\ slab}$ = 1.2 (123.5 psf) + 1.6 (50 psf) = 229 psf**

**B.**

**(i) TYPICAL INTERIOR *FLOOR* BEAM**

Tributary width of beam = 16 ft
Beam stem weight = (16"/12) [(26" – 7")/12] x 150 pcf = 317 lb/ft = 0.32 kip/ft

$w_{DLbeam}$ = 123.5 psf x 16 ft + 317 lb/ft = 2293 lb/ft = 2.3 kip/ft
$w_{LLbeam}$ = 50 psf x 16 ft = 800 lb/ft = 0.8 kip/ft
$w_{s\ beam} = w_{DLbeam} + w_{LLbeam}$ = **3.1 kip/ft**

**$w_{u\ beam}$** = $w_{u\ slab}$ x beam trib width + 1.2 x beam stem weight
= 229 psf x 16 ft + 1.2 (317 lb/ft) = 4045 lb/ft = **4.1 kip/ft**

For a beam subjected to a uniformly distributed load, the beam reactions, assuming simple supports, are:

$R_{DL} = w_{DLbeam} \times L/2$ = 2.3 kip/ft x 32 ft /2 = 37 kip
$R_{LL} = w_{LLbeam} \times L/2$ = 0.8 kip/ft x 32 ft /2 = 12.8 kip

$R_u = w_{u\ beam} \times L/2$ or $1.2 (R_{DL}) + 1.6 (R_{LL})$

= 4.1 kip/ft x 32 ft/2 = **66 kip** or 1.2 (37 kip) + 1.6 (12.8 kip) = **66 kip (same!)**



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**(ii) TYPICAL INTERIOR *ROOF* BEAM**

Tributary width of beam = 16 ft

Beam stem weight = (16”/12) [(26” – 7”)/12] x 150 pcf = 317 lb/ft = 0.32 kip/ft

$w_{DLbeam}$ = 109.5 psf x 16 ft + 317 lb/ft = 2070 lb/ft = 2.1 kip/ft

$w_{LLbeam}$ = 35 psf x 16 ft = 560 lb/ft = 0.56 kip/ft

$w_{s\ beam} = w_{DLbeam} + w_{LLbeam}$ = **2.7 kip/ft**

$\mathbf{w_{u\ beam}}$ = $w_{u\ slab}$ x beam trib width + 1.2 x beam stem weight

= 188 psf x 16 ft + 1.2 (317 lb/ft) = 3389 lb/ft = **3.4 kip/ft**

For a beam subjected to a uniformly distributed load, the beam reactions, assuming simple supports, are:

$R_{DL} = w_{DLbeam}$ x L/2 = 2.1 kip/ft x 32 ft /2 = 34 kip

$R_{LL} = w_{LLbeam}$ x L/2 = 0.56 kip/ft x 32 ft /2 = 9 kip

$R_u = w_{u\ beam}$ x L/2 or 1.2 ($R_{DL}$) + 1.6 ($R_{LL}$)

= 3.4 kip/ft x 32 ft/2 = **55 kip** or 1.2 (34 kip) + 1.6 (9 kip) = **55 kip (same!)**

**(iii) TYPICAL *FLOOR* SPANDREL BEAM**

Tributary width of beam = (16 ft / 2 ) + [(16”/12)/2] = 8.67 ft

Beam stem weight = (16”/12) [(26” – 7”)/12] x 150 pcf = 317 lb/ft = 0.32 kip/ft

Exterior Cladding load = 55 psf block x 7.83’ height + 40 psf brick x 10’ height = 0.83 kip/ft

$w_{DLbeam}$ = 123.5 psf x 8.67 ft + 317 lb/ft + 830 lb/ft = 2218 lb/ft = 2.2 kip/ft

$w_{LLbeam}$ = 50 psf x 8.67 ft = 434 lb/ft = 0.44 kip/ft

$w_{s\ beam} = wDL_{beam} + wLL_{beam}$ = **2.7 kip/ft**

$\mathbf{w_{u\ beam}}$ = $w_{u\ slab}$ x beam trib width + 1.2 x beam stem weight

= 229 psf x 8.67 ft + 1.2 (317 lb/ft + 830 lb/ft) = 3362 lb/ft = **3.4 kip/ft**

For a beam subjected to a uniformly distributed load, the beam reactions, assuming simple supports, are:

$R_{DL} = wDL_{beam}$ x L/2 = 2.2 kip/ft x 32 ft /2 = 36 kip

$R_{LL} = wLL_{beam}$ x L/2 = 0.44 kip/ft x 32 ft /2 = 7 kip

$R_u = w_{u\ beam}$ x L/2 or 1.2 ($R_{DL}$) + 1.6 ($R_{LL}$)

= 3.4 kip/ft x 32 ft/2 = **55 kip** or 1.2 (36 kip) + 1.6 (7 kip) = **55 kip (same!)**



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**(iv) TYPICAL *ROOF* SPANDREL BEAM**

Tributary width of beam = (16 ft / 2 ) + [(16"/12)/2] = 8.67 ft
Beam stem weight = (16"/12) [(26" – 7")/12] x 150 pcf = 317 lb/ft = 0.32 kip/ft

*On the roof beam and girder, there is usually a one to two feet high parapet. However, if we assume **NO PARAPET** in this example, the exterior cladding load on the roof spandrel beam will be:*
*Exterior Cladding load = 55 psf block x 0' height + 40 psf brick x 0' height = 0 kip/ft*

$w_{DLbeam}$ = 109.5 psf x 8.67 ft + 317 lb/ft + 0 lb/ft = 1267 lb/ft = 1.3 kip/ft
$w_{LLbeam}$ = 35 psf x 8.67 ft = 303 lb/ft = 0.3 kip/ft
$w_{s\ beam} = w_{DLbeam} + wLL_{beam}$ = **1.6 kip/ft**

$\mathbf{w_{u\ beam}}$ = $w_{u\ slab}$ x beam trib width + 1.2 x beam stem weight
= 188 psf x 8.67 ft + 1.2 (317 lb/ft + 0 lb/ft) = 2010 lb/ft = **2.0 kip/ft**

For a beam subjected to a uniformly distributed load, the beam reactions, assuming simple supports, are:

$R_{DL} = w_{DLbeam}$ x L/2 = 1.3 kip/ft x 32 ft /2 = 21 kip
$R_{LL} = w_{LLbeam}$ x L/2 = 0.3 kip/ft x 32 ft /2 = 5 kip

$R_u = w_{u\ beam}$ x L/2 or 1.2 ($R_{DL}$) + 1.6 ($R_{LL}$)
= 2.0 kip/ft x 32 ft/2 = **32 kip** or 1.2 (21 kip) + 1.6 (5 kip) = **33 kip (same!)**

**C.**

**(i) TYPICAL INTERIOR *FLOOR* GIRDER**

Girder stem weight = (18"/12) [(26" – 7")/12] x 150 pcf = 357 lb/ft = 0.36 kip/ft

This girder has TWO interior beams framing into it at the MIDSPA, in addition to a uniformly distributed loading (UDL) due to the girder stem weight. Therefore, the total concentrated loads acting on the girder are:

$P_{DL\ girder}$ = 2 beams x $R_{DL\ beam}$ = 2 x 37 kip = 74 kip (acts at midspan)
$P_{LL\ girder}$ = 2 x $R_{LL\ beam}$ = 2 x 12.8 kip = 26 kip (acts at midspan)
$P_{s\ girder} = P_{DL\ girder} + P_{LL\ girder}$ = 74 + 26 = **100 kip** (acts at midspan)
$P_{u\ girder} = 1.2\ P_{DL\ girder} + 1.6\ P_{LL\ girder}$ = 1.2(74) + 1.6(26) = **131 kip** (acts at midspan)



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The uniformly distributed load (UDL) on this girder is due to the girder stem weight. Thus,

$\mathbf{w_{DLgirder}}$ = girder stem weight = 357 lb/ft

$\mathbf{w_{LL\ girder}}$ = 0

The total UDL on the girder are:

$\mathbf{w_{s\ girder}}$ = $\mathbf{w_{DLgirder}}$ + $\mathbf{w_{LLgirder}}$ = 357 lb/ft

$\mathbf{w_{u\ girder}}$ = 1.2 $\mathbf{w_{DLgirder}}$ + 1.6 $\mathbf{w_{LLgirder}}$

= 1.2 (357 lb/ft) + 1.6 (0) = 430 lb/ft = **0.43 kip/ft**

The REACTIONS for a GIRDER subjected to a uniformly distributed load, w, in addition to concentrated loads at MIDSPAN (see plan) from the beam reactions, assuming simple supports, are:

$R_{DL}$ = $w_{DLgirder}$ x L/2 + $P_{DLgirder}$ /2 = (0.36 kip/ft x 32 ft /2) + (74 kip /2 ) = 43 kip

$R_{LL}$ = $w_{LLgirder}$ x L/2 + $P_{LLgirder}$ /2 = (0 kip/ft x 32 ft /2) + (26 kip /2 ) = 13 kip

$R_u$ = $w_{u\ girder}$ x L/2 + $P_{u\ girder}$ /2 = (0.43 kip/ft x 32 ft /2) + (131 kip /2 ) = **73 kip**

**(ii) TYPICAL INTERIOR *ROOF* GIRDER**

Girder stem weight = (18”/12) [(26” – 7”)/12] x 150 pcf = 357 lb/ft = 0.36 kip/ft

This girder has TWO interior beams framing into it at the MIDSPAN, in addition to a uniformly distributed loading (UDL) due to the girder stem weight. Therefore, the total concentrated loads acting on the girder are:

$P_{DL\ girder}$ = 2 beams x $R_{DL\ beam}$ = 2 x 34 kip = 68 kip (acts at midspan)

$P_{LL\ girder}$ = 2 x $R_{LL\ beam}$ = 2 x 9 kip = 18 kip (acts at midspan)

$P_{s\ girder}$ = $P_{DL\ girder}$ + $P_{LL\ girder}$ = 68 + 18 = **86 kip** (acts at midspan)

$P_{u\ girder}$ = 1.2 $P_{DL\ girder}$ + 1.6 $P_{LL\ girder}$ = 1.2(68) + 1.6(18) = **111 kip** (acts at midspan)

The uniformly distributed load (UDL) on this girder is due to the girder stem weight. Thus,

$\mathbf{w_{DLgirder}}$ = girder stem weight = 357 lb/ft; $\mathbf{w_{LL\ girder}}$ = 0

The total UDL on the girder are:

$\mathbf{w_{s\ girder}}$ = $\mathbf{w_{DLgirder}}$ + $\mathbf{w_{LLgirder}}$ = 357 lb/ft

$\mathbf{w_{u\ girder}}$ = 1.2 $\mathbf{w_{DLgirder}}$ + 1.6 $\mathbf{w_{LLgirder}}$

= 1.2 (357 lb/ft) + 1.6 (0) = 430 lb/ft = **0.43 kip/ft**

*The REACTIONS for a GIRDER subjected to a uniformly distributed load, w, in addition to concentrated loads at MIDSPAN (see plan) from the beam reactions, assuming simple supports, are:*



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$R_{DL}$ = $w_{DLgirder}$ x L/2 + $P_{DLgirder}$ /2 = (0.36 kip/ft x 32 ft /2) + (68 kip /2 ) = 40 kip
$R_{LL}$ = $w_{LLgirder}$ x L/2 + $P_{LLgirder}$ /2 = (0 kip/ft x 32 ft /2) + (18kip /2 ) = 9 kip

$R_u$ = $w_{u\ girder}$ x L/2 + $P_{ugirder}$ /2 = (0.43 kip/ft x 32 ft /2) + (111 kip /2 ) = **63 kip**

### (iii) TYPICAL *FLOOR* SPANDREL GIRDER

Girder stem weight = (18"/12) [(26" – 7")/12] x 150 pcf = 357 lb/ft = 0.36 kip/ft
Exterior Cladding load = 55 psf block x 7.83' height + 40 psf brick x 10' height = 0.83 kip/ft

*This girder has ONE interior beam framing into it at the MIDSPAN, in addition to a uniformly distributed loading (UDL) due to the girder stem weight, the girder edge distance, AND the exterior cladding. Therefore, the total concentrated loads acting on the girder are:*

$P_{DL\ girder}$ = 1 beam x $R_{DL\ beam}$ = 1x 37 kip = 37kip (acts at midspan)
$P_{LL\ girder}$ = 1 x $R_{LL\ beam}$ = 1 x 12.8 kip = 13 kip (acts at midspan)
$P_{s\ girder}$ = $P_{DL\ girder}$ + $P_{LL\ girder}$ = 37 + 13 = **50 kip** (acts at midspan)
$P_{u\ girder}$ = 1.2 $P_{DL\ girder}$ + 1.6 $P_{LL\ girder}$ = 1.2(37) + 1.6(13) = **65 kip** (acts at midspan)

**Uniform floor load on Girder edge distance:**

$w_{DL\ edge\ distance}$ = (9"/12) x 123.5 psf = 93 lb/ft
$w_{LL\ edge\ distance}$ = 0 (Because the WHOLE girder edge distance is occupied by the block wall cladding and thus there can be no live load in that edge distance)

The uniformly distributed load (UDL) on this girder is due to the girder stem weight, the load on the girder edge distance, AND the exterior cladding. Thus,
$\mathbf{w_{DLgirder}}$ = girder stem weight + girder edge distance + exterior cladding
= 357 lb/ft + 93 + 830 lb/ft = 1280 lb/ft ; $\mathbf{w_{LL\ girder}}$ = 0

The total uniformly distributed load (UDL) on the girder is:
$\mathbf{w_{s\ girder}}$ = $\mathbf{w_{DLgirder}}$ + $\mathbf{w_{LLgirder}}$ = 1280 lb/ft

$\mathbf{w_{u\ girder}}$ = 1.2 $\mathbf{w_{DLgirder}}$ + 1.6 $\mathbf{w_{LLgirder}}$
= 1.2 (1280 lb/ft) + 1.6 (0) = 1536 lb/ft = **1.54 kip/ft**

The REACTIONS for a GIRDER subjected to a uniformly distributed load, w, in addition to concentrated loads at MIDSPAN (see plan) from the beam reactions, assuming simple supports, are:

$R_{DL}$ = $w_{DLgirder}$ x L/2 + $P_{DLgirder}$ /2 = (1.28 kip/ft x 32 ft /2) + (37 kip /2 ) = 39 kip
$R_{LL}$ = $w_{LLgirder}$ x L/2 + $P_{LLgirder}$ /2 = (0 kip/ft x 32 ft /2) + (13 kip /2 ) = 6.5 kip

$R_u$ = $w_{u\ girder}$ x L/2 + $P_{ugirder}$ /2 = (1.54 kip/ft x 32 ft /2) + (65 kip /2 ) = **57 kip**



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(iv) **TYPICAL *ROOF* SPANDREL GIRDER**

Girder stem weight = (18”/12) [(26” – 7”)/12] x 150 pcf = 357 lb/ft = 0.36 kip/ft *(no parapet)*

*This girder has ONE interior beam framing into it at the MIDSPAN, in addition to a uniformly distributed loading (UDL) due to the girder stem weight, the load on the girder edge distance, AND the exterior cladding. Therefore, the total concentrated loads acting on the girder are:*

$P_{DL\ girder}$ = 1 beam x $R_{DL\ beam}$ = 1x 34 kip = 34kip (acts at midspan)
$P_{LL\ girder}$ = 1 x $R_{LL\ beam}$ = 1 x 9 kip = 9 kip (acts at midspan)
$P_{s\ girder}$ = $P_{DL\ girder}$ + $P_{LL\ girder}$ = 34 + 9 = **43 kip** (acts at midspan)
$P_{u\ girder}$ = 1.2 $P_{DL\ girder}$ + 1.6 $P_{LL\ girder}$ = 1.2(34) + 1.6(9) = **55 kip** (acts at midspan)

**Uniform roof load on Girder edge distance:**

$w_{DL\ edge\ distance}$ = (9”/12) x 109.5 psf = 82 lb/ft
$w_{LL\ edge\ distance}$ = (9”/12) x 35 psf = 26 lb/ft

The uniformly distributed load (UDL) on this girder is due to the girder stem weight, the load on the girder edge distance, AND the exterior cladding. Thus,

$\mathbf{w_{DLgirder}}$ = girder stem weight + girder edge distance + exterior cladding/parapet
= 357 lb/ft + 82 lb/ft + 0 lb/ft = 439 lb/ft (assuming no parapet)

$\mathbf{w_{LL\ girder}}$ = 26 lb/ft

The total UDL on the girder are:

$\mathbf{w_{s\ girder}}$ = $\mathbf{w_{DLgirder}}$ + $\mathbf{w_{LLgirder}}$ = 465 lb/ft

$\mathbf{w_{u\ girder}}$ = 1.2 $\mathbf{w_{DLgirder}}$ + 1.6 $\mathbf{w_{LLgirder}}$
= 1.2 (439 lb/ft) + 1.6 (26 lb/ft) = 568 lb/ft = **0.57 kip/ft**

The REACTIONS for a GIRDER subjected to a uniformly distributed load, w, in addition to concentrated loads at MIDSPAN (see plan) from the beam reactions, assuming simple supports, are:

$R_{DL}$ = $w_{DLgirder}$ x L/2 + $P_{DLgirder}$ /2 = (0.44 kip/ft x 32 ft /2) + (34 kip /2 ) = 24 kip
$R_{LL}$ = $wLL_{girder}$ x L/2 + $P_{LLgirder}$ /2 = (0.026 kip/ft x 32 ft /2) + (9 kip /2 ) = 4.9 kip

$R_u$ = $wu_{girder}$ x L/2 + $P_{ugirder}$ /2 = (0.57 kip/ft x 32 ft /2) + (55 kip /2 ) = **36.6 kip**


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*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, $A_s = 5.08 \text{ in.}^2$

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

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

(c) 4#9, $A_s = 4.00 \text{ in.}^2$, $a = 5.88$ 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%

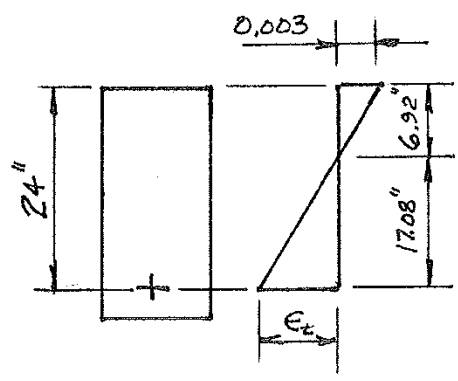
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Prob. 2-2 Check $\varepsilon_t$ for Prob. 2-1(a)

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

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

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






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Prob. 2-3

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

$A_{s,\min} = 0.005(13)(24) = 1.56$ in.$^2 < 3.16$ 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, $A_s = 3.16$ in.$^2$, $b = 13$ in., $d = 24$ in. $\rho = \dfrac{3.16}{13(24)} = 0.0101$

$A_{s,\min} = 0.0033(13)(24) = 1.03$ in.$^2 < 3.16$ 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%; $\phi M_n$: +45.5%

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Prob. 2-4 [4/60]

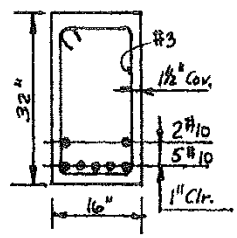
$$\bar{y} = \frac{2A(2.27)}{7A} = 0.649 \text{ in.}$$

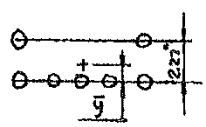
$d = 32 - 1.5 - 0.375 - 1.27/2 - 0.649 = 28.8$ in.

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

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

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




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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; $\quad M_u = \dfrac{9.53(28)^2}{8} = 939$ ft - kips

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

$A_{s,\min} = 0.005(20)(42) = 4.20$in.$^2 < 7.62$ 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, $A_s = 9.36$ in.$^2$, $\rho = \dfrac{9.36}{20(42)} = 0.0111$

$A_{s,\min} = 4.20$ in.$^2 < 9.36$ 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 ($A_s = 2.37$ 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.; $\quad A_{s,\min} = 0.0033(12)(17.62) = 0.700$ in.$^2$ (O.K.)

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

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

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



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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., $\rho = \dfrac{5.00}{16(35)} = 0.0089$

$A_{s,\min} = 0.0033(16)(35) = 1.85$ in.$^2$ $< 5.00$ 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., $\rho = \dfrac{6.00}{16(34.4)} = 0.0109$

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

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

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

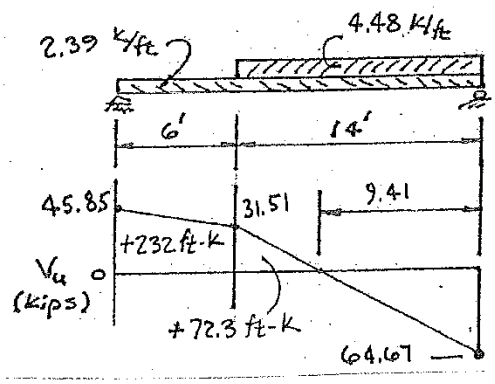
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Prob. 2-9 [3/60] 3#10, $A_s = 3.81$ in.$^2$, $b = 14.5$ in., $h = 26$ in. check moment adequacy.

$d = 26 - 1.5 - 0.38 - 1.27/2 = 23.5$ in.

Calculated beam weight = 0.393 k/ft

Max. $M_u$ from diag. = 304 ft-kips




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

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

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

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

---



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

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

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

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

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

---

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

Slab weight=$\frac{10(12)}{144}(0.150) = 0.125$ 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.; $\rho = \frac{1.20}{12(8.81)} = 0.0113$

$A_{s,\min} = 0.0018(12)(8.81) = 0.19$ in.$^2$/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=$\frac{8(12)}{144}(0.150) = 0.100$ k/ft;

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

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

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

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

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



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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, $b = 11½$ 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 $A_s = 0.007(11.5)(20) = 1.61$ in.$^2$, $A_{s,\min} = 0.0033(11.5)(20) = 0.76$ in.$^2$ (O.K.)

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

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

---

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

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

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



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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 $= \frac{11.5(26)}{144}(0.150) = 0.312$ 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 $A_s = 0.0164(11.5)(23) = 4.34 \text{ in.}^2$  $A_{s,\min} = 0.0033(11.5)(23) = 0.87 \text{ in.}^2$

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 $\phi M_n$:

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

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

---

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 $\phi = 0.90$

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



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

Required $A_s = 0.0100(12)(24) = 2.88$ in.$^2$, $A_{s,\min} = 0.0035(12)(24) = 1.01$ 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 $\phi M_n$:

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

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

---

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 $\phi = 0.90$

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

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

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

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

---

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 $(\varepsilon_t > 0.005, \phi = 0.90)$

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

Required $A_s = 0.009(15)(21.5) = 2.90$ in.$^2$, $A_{s,\min} = 0.0033(15)(21.5) = 1.06$ 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 $\phi M_n$: $d = 21.6$ in., $\rho = \dfrac{3.00}{15(21.6)} = 0.0093$, $\bar{k} = 0.4970$ ksi, $(\varepsilon_t > 0.005, \ \phi = 0.90)$

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



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Prob. 2-21 Design, [3/60], $L = 30$ ft, $b \le 16$ in., beam wt. not incl. in given loads.

Neglecting beam weight: $M_u = \dfrac{[1.2(1.0)+1.6(2.0)30^2}{8} = 495$ ft - kips

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

For $b = 16$ in.: Req'd $d = \sqrt{\dfrac{495(12)}{0.90(16)(0.4828)}} = 29.2$ in. $\left(\dfrac{d}{b} = \dfrac{29.2}{16} = 1.8 \text{ (O.K.)}\right)$

Estimate $h$ assuming #8 bars: $h = 29.2 + 0.5 + 0.38 + 1.5 = 31.6$ in. Use $h = 32$ in.

Beam wt. $= \dfrac{16(32)}{144}(0.150) = 0.533$ kips/ft, new $M_u = 495 + \dfrac{1.2(0.533)(30)^2}{8} = 567$ ft - kips

With $b = 16$ in., $d = 29$ in., solve for $A_s$

Required $\bar{k} = \dfrac{567(12)}{0.90(16)(29)^2} = 0.5618$ ksi, required $\rho = 0.0108$, $(\varepsilon_t > 0.005, \phi = 0.90)$

Required $A_s = 0.0108(16)(29) = 5.01$ in.$^2$, $A_{s,\min} = 0.0033(16)(29) = 1.53$ in.$^2$ (O.K.)

Select 5#9 ($A_s = 5.00$ in.$^2$, $b_{\min} = 14$ in.)

Calculated $d = 32 - 1.5 - 0.38 - 1.13/2 = 29.6$ in. $> 29$ in. (O.K.)

Use $b = 16$ in., $h = 32$ in., 5#9 bars.

---

Prob. 2-22 Redo Prob. 2-21 with $h \le 30$ in. and no limitation on $b$.

Try estimated beam wt. of 0.533 k/ft and $M_u = 567$ ft-kips from Prob. 2-21.

Assume $h = 30$ in., $d = 27$ in.; try $\rho = 0.0090$, $\bar{k} = 0.4828$ ksi and $\phi = 0.90$

Required $b = \dfrac{567(12)}{0.90(27)^2(0.4828)} = 21.5$ in. Use $b = 21$ in.

$\dfrac{d}{b} = \dfrac{27}{21} = 1.29$ Low due to restricted $h$. (Use)

Beam weight $= \dfrac{30(21)}{144}(0.150) = 0.656$ kips/ft

New $M_u = 567 + \dfrac{1.2(0.656 - 0.533)(30)^2}{8} = 584$ ft - kips

Required $\bar{k} = \dfrac{584(12)}{0.90(21)(27)^2} = 0.5086$ ksi, req'd $\rho = 0.0096$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0096(21)(27) = 5.44$ in.$^2$

Select 7#8 ($A_s = 5.53$ in.$^2$, $b_{\min} = 17$ in.) $A_{s,\min} = 0.0033(21)(27) = 1.87$ in.$^2$ (O.K.)

Calculated $d = 30 - 1.5 - 0.38 - 0.5 = 27.6$ in. $> 27$ in. (O.K.)

Use $b = 21$ in., $h = 30$ in., 7#8 bars

---



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Prob. 2-23 Design, [3/60], $L = 32$ ft, $b \le 18$ in.

Neglect beam weight: $M_u = \dfrac{[1.2(1.5)+1.6(2.0)](32)^2}{8} = 640$ ft - kips

Try $b = 18$ in., $\rho = 0.0090$, $\bar{k} = 0.4828$ ksi $(\varepsilon_t > 0.005, \phi = 0.90)$

Req'd $d = \sqrt{\dfrac{640(12)}{0.90(18)(0.4828)}} = 31.3$ in. $\left(\dfrac{d}{b} = \dfrac{31.3}{18} = 1.74 \text{ (O.K.)}\right)$

Estimated $h = 31.3 + 0.5 + 0.38 + 1.5 = 33.7$ Use $h = 35$ in.

Beam weight $= \dfrac{18(35)}{144}(0.150) = 0.656$ kip/ft

New $M_u = 640 + \dfrac{1.2(0.656)(32)^2}{8} = 741$ ft - kips

Estimated $d = 32$ in.

Required $\bar{k} = \dfrac{741(12)}{0.90(18)(32)^2} = 0.5361$ ksi, required $\rho = 0.0102$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0102(18)(32) = 5.87$ in.$^2$, $A_{s,\min} = 0.0033(18)(32) = 1.90$ in.$^2$ (O.K.)
Select 6#9 ($A_s = 6.00$ in.$^2$, $b_{\min} = 16.5$ in.)
Calculated $d = 35 - 1.5 - 0.38 - 1.13/2 = 32.6$ in $> 32$ in. (O.K.)
Use $b = 18$ in. $h = 35$ in., 6#9 bars

---

Prob. 2-24 Redo Prob. 2-23 with $h \le 32$ in. and no limitation on $b$.
Neglect beam weight. $M_u = 640$ ft-kips from Prob. 2-23.
Assume $h = 32$ in., $d = 29$ in.; try $\rho = 0.0090$, $\bar{k} = 0.4828$ ksi and $\phi = 0.90$

Required $b = \dfrac{640(12)}{0.90(29)^2(0.4828)} = 21$ in. Use $b = 21$ in.

$\dfrac{d}{b} = \dfrac{29}{21} = 1.38$ Low due to restricted $h$. (Use)

Beam weight $= \dfrac{32(21)}{144}(0.150) = 0.700$ kips/ft

New $M_u = 640 + \dfrac{1.2(0.700(32)^2}{8} = 748$ ft - kips

Required $\bar{k} = \dfrac{748(12)}{0.90(21)(29)^2} = 0.5647$ ksi, req'd $\rho = 0.0108$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0108(21)(29) = 6.58$ in.$^2$
Select 7#9 ($A_s = 7.00$ in.$^2$, $b_{\min} = 18.5$ in.) $A_{s,\min} = 0.0033(21)(29) = 2.01$ in.$^2$ (O.K.)
Calculated $d = 32 - 1.5 - 0.38 - 1.13/2 = 29.6$ in. $> 29$ in. (O.K.)
Use $b = 21$ in., $h = 32$ in., 7#9 bars



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Prob. 2-25 [4/60] Design, $L = 40$ ft

Neglect beam weight: $M_u = \dfrac{[1.2(0.8)+1.6(1.4)](40)^2}{8} = 640$ ft - kips

Try $\rho = 0.0120$, $\bar{k} = 0.6438$ ksi ($\varepsilon_t > 0.005$, $\phi = 0.90$,) and $d/b \approx 2$.

Required $d = \sqrt[3]{\dfrac{2(640)(12)}{0.90(0.6438)}} = 29.8$ in. (make $b = 16$ in. and $h = 34$ in.)

Beam weight $= \dfrac{16(34)}{144}(0.150) = 0.567$ kip/ft

New $M_u = 640 + \dfrac{1.2(0.567)(40)^2}{8} = 776$ ft - kips

Estimated $d = 31$ in.

Required $\bar{k} = \dfrac{776(12)}{0.90(16)(31)^2} = 0.6729$ ksi, req'd. $\rho = 0.0127$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0127(16)(31) = 6.30$ in.$^2$

Select 5#10 ($A_s = 6.35$ in.$^2$, $b_{min} = 15.5$ in.) $A_{s,min} = 0.0033(16)(31) = 1.64$ in.$^2$ (O.K.)

Calculated $d = 34 - 1.5 - 0.38 - 1.27/2 = 31.5$ in. $> 31$ in. (O.K.)

Use $b = 16$ in., $h = 34$ in., 5#10 bars

---

Prob. 2-26 [5/60] Design. Unsymmetrical load.

From $V_u$ diag. (neg. bm. wt.): $M_{u(max)} = 504$ ft-kips

Try $\rho = 0.0150$, $\bar{k} = 0.8047$ ksi and $d/b \approx 2$.

($\varepsilon_t > 0.005$, $\phi = 0.90$,)

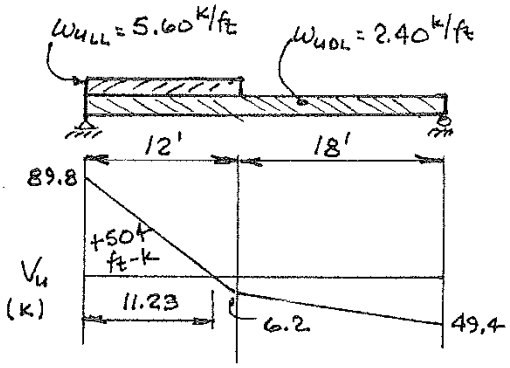
Required $d = \sqrt[3]{\dfrac{2(504)(12)}{0.90(0.8047)}} = 25.6$ in.

Make $b = 13$ in. and $h = 28$ in.

Beam weight $= \dfrac{13(28)}{144}(0.150) = 0.379$ kip/ft

New $w_{uDL} = 2.40 + 1.2(.379) = 2.86$ k/ft :

new diagram yields $M_{u(max)} = 553$ ft-kips.




Estimated $d = 25$ in.

Required $\bar{k} = \dfrac{553(12)}{0.90(13)(25)^2} = 0.9075$ ksi, req'd. $\rho = 0.0173$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0173(13)(25) = 5.62$ in.$^2$

Select 6#9 (two layers, 3 each, 1 in. clear) ($A_s = 6.00$ in.$^2$, $b_{min} = 9.5$ in.)

$A_{s,min} = 0.0035(13)(25) = 1.14$ in.$^2$ (O.K.)

Calculated $d = 28 - 1.5 - 0.38 - 1.13 - 0.50 = 24.5$ in. $< 25$ in. (N.G., check $\phi M_n$)

$\rho = \dfrac{6.00}{13(24.5)} = 0.0188$, $\bar{k} = 0.9783$ ksi, ($\varepsilon_t > 0.005$, $\phi = 0.90$ )



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Prob. 2-26 (cont.)

$$\phi M_n = \frac{0.90(13)(24.5)^2(0.9783)}{12} = 572 \text{ ft - kips} \quad > 553 \text{ ft - kips} \quad \text{(O.K.)}$$

Use $b = 13$ in., $h = 28$ in., 6#9 bars in two layers

---

Prob. 2-27 [5/60] Design, $L = 28$ ft

Neglect beam weight: $M_u = \frac{1.6(0.8)(28)^2}{8} + \frac{[1.2(10)+1.6(14)](28)}{4} = 366$ ft - kips

Try $\rho = 0.0150$, $\bar{k} = 0.8047$ ksi ($\varepsilon_t > 0.005$, $\phi = 0.90$,) and $d/b \approx 2$.

Required $d = \sqrt[3]{\frac{2(366)(12)}{0.90(0.8047)}} = 23$ in. (try $b = 12$ in. and $h = 27$ in., est $d = 24$ in.)

Beam weight $= \frac{12(27)}{144}(0.150) = 0.338$ kip/ft

New $M_u = 366 + \frac{1.2(0.338)(28)^2}{8} = 406$ ft - kips

Required $\bar{k} = \frac{406(12)}{0.90(12)(24)^2} = 0.7832$ ksi, req'd. $\rho = 0.0146$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0146(12)(24) = 4.20$ in.$^2$

Select 3#11 ($A_s = 4.68$ in.$^2$, $b_{min} = 11$ in.) $A_{s,min} = 0.0035(12)(24) = 1.01$ in.$^2$ (O.K.)

Calculated $d = 27 - 1.5 - 0.38 - 1.41/2 = 24.4$ in. $> 24$ in. (O.K.)

Use $b = 12$ in., $h = 27$ in., 3#11 bars

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Prob. 2-28 [3/60]

$P_u = 1.2(8) + 1.6(10) = 25.6$ kips

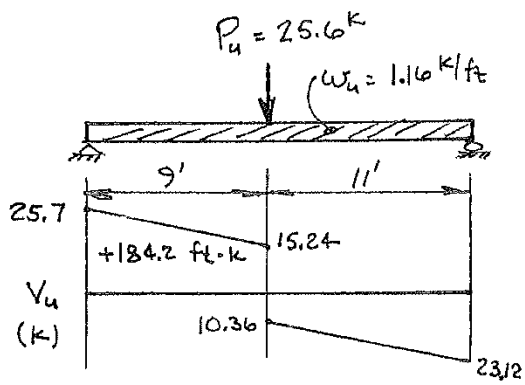
$w_u = 1.2(0.3) + 1.6(0.5) = 1.16$ kips/ft

$V_u$ diag. (neg. bm. wt.): $M_{u(max)} = 184.2$ ft-kips

Try $\rho = 0.0090$, $\bar{k} = 0.4828$ ksi and $d/b \approx 2$.

($\varepsilon_t > 0.005$, $\phi = 0.90$,)

Required $d = \sqrt[3]{\frac{2(184.2)(12)}{0.90(0.4828)}} = 21.7$ in.




Make $b = 11$ in. and $h = 25$ in.

Beam weight $= \frac{11(25)}{144}(0.150) = 0.287$ kip/ft

New $w_{uDL} = 1.16 + 1.2(0.287) = 1.504$ k/ft :

new diagram yields $M_{u(max)} = 201$ ft-kips.

Estimated $d = 22$ in.

Required $\bar{k} = \frac{201(12)}{0.90(11)(22)^2} = 0.5034$ ksi, req'd. $\rho = 0.0095$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0095(11)(22) = 2.30$ in.$^2$

Select 2#10 ($A_s = 2.54$ in.$^2$, $b_{min} = 8.0$ in.)



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Prob. 2-28 (cont.)

$A_{s,\min} = 0.0033(11)(22) = 0.80$ in.$^2$ (O.K.)

Calculated $d = 25 - 1.5 - 0.38 - 1.27/2 = 22.5$ in. $> 22$ in. (O.K.)

Use $b = 11$ in., $h = 25$ in., 2#10 bars

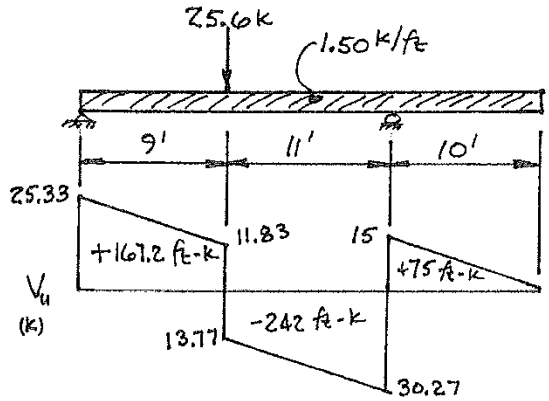
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Prob. 2-29 [3/60] Rework Prob. 2-28 w/ addition of an overhanging span.

Assume bm. wt. = 0.287 k/ft from Prob. 2-28.

$V_u$ diag.: $+M_{u(\max)} = 167.2$ ft-kips

$-M_{u(\max)} = 75$ ft-kips




Design for positive moment:

Try $\rho = 0.0090$, $\bar{k} = 0.4828$ ksi and $d/b \approx 2$.

($\varepsilon_t > 0.005$, $\phi = 0.90$)

Required $d = \sqrt[3]{\dfrac{2(167.2)(12)}{0.90(0.4828)}} = 21$ in. (Use)

Make $b = 11$ in. and $h = 24$ in.

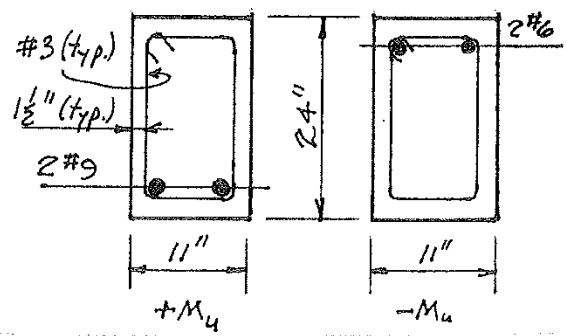
Beam weight $= \dfrac{11(24)}{144}(0.150) = 0.275$ kip/ft

0.275 k/ft < 0.287 k/ft (O.K.)

Required $\bar{k} = \dfrac{167.2(12)}{0.90(11)(21)^2} = 0.4596$ ksi

req'd. $\rho = 0.0086$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0086(11)(21) = 1.99$ in.$^2$




Select 2#9 ($A_s = 2.00$ in.$^2$, $b_{\min} = 7.5$ in.)

$A_{s,\min} = 0.0033(11)(21) = 0.76$ in.$^2$ (O.K.)

Calculated $d = 24 - 1.5 - 0.38 - 1.13/2 = 21.6$ in. $> 21$ in. (O.K.)

Design for negative moment: Use $b = 11$ in., $h = 24$ in., est. $d = 21$ in.

Required $\bar{k} = \dfrac{75(12)}{0.90(11)(21)^2} = 0.2061$ ksi  req'd. $\rho = 0.0036$, $\varepsilon_t > 0.005$, $\phi = 0.90$

Required $A_s = 0.0036(11)(21) = 0.83$ in.$^2$

Select 2#6 ($A_s = 0.88$ in.$^2$, $b_{\min} = 6.5$ in.)  $A_{s,\min} = 0.0033(11)(21) = 0.76$ in.$^2$ (O.K.)

Calculated $d = 24 - 1.5 - 0.38 - 0.75/2 = 21.7$ in. $> 21$ in. (O.K.)

See design sketches.

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Prob. 2-30 [3/60] One-way slab design for $h_{min}$. $L = 8$ ft

ACI $h_{min} = L/20 = [8(12)]/20 = 4.8$ in. Use 5 in.

$$\text{Slab weight} = \frac{5(12)}{144}(0.150) = 62.5 \text{ psf}, \quad w_u = \frac{1.2(62.5) + 1.6(300)}{1000} = 0.555 \text{ kip/ft}$$

$$M_u = \frac{0.555(8)^2}{8} = 4.44 \text{ ft - kip}$$

Estimated $d = 5 - 0.75 - 0.75/2 = 3.88$ in. (Assume #6 bars)

$$\text{Required } \bar{k} = \frac{4.44(12)}{0.90(12)(3.88)^2} = 0.3277 \text{ ksi}, \ \rho = 0.0059, \ \varepsilon_t > 0.005, \ \phi = 0.90$$

Required $A_s = 0.0059(3.88)(12) = 0.27$ in.$^2$/ft

$A_{s,min} = 0.0018(5)(12) = 0.11$ in.$^2$/ft (O.K.)

Main steel: select #5@14 in. o/c

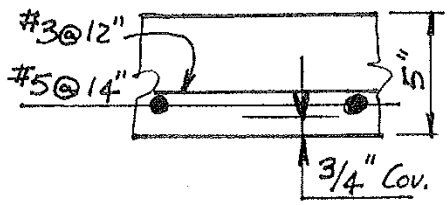
($A_s = 0.27$ in.$^2$/ft, $s_{max} = 3h = 15$ in. $\le 18$ in. (O.K.))

Calc. $d = 5 - 0.75 - 0.625/2 = 3.94$ in. $> 3.88$ in. (O.K.)

($A_{s,min}$ = required S&T steel)

S&T steel: select #3@12 in. o/c

($A_s = 0.11$ in.$^2$/ft, $s_{max} = 5h = 25$ in. $\le 18$ in. (O.K.))




---

Prob. 2-31 [3/60] One-way slab design. $L = 10$ ft

(a) Design for $h_{min}$.

ACI $h_{min} = L/20 = [10(12)]/20 = 6$ in. Use 6 in.

$$\text{Slab weight} = \frac{6(12)}{144}(0.150) = 75 \text{ psf}, \quad w_u = \frac{1.2(25 + 75) + 1.6(175)}{1000} = 0.400 \text{ kip/ft}$$

$$M_u = \frac{0.400(10)^2}{8} = 5.00 \text{ ft - kips}$$

Estimated $d = 6 - 0.75 - 0.75/2 = 4.88$ in. (Assume #6 bars)

$$\text{Required } \bar{k} = \frac{5.00(12)}{0.90(12)(4.88)^2} = 0.2333 \text{ ksi}, \quad \rho = 0.0041, \ \varepsilon_t > 0.005, \ \phi = 0.90$$

Required $A_s = 0.0041(4.88)(12) = 0.24$ in.$^2$/ft

$A_{s,min} = 0.0018(6)(12) = 0.13$ in.$^2$/ft (O.K.)

Main steel: select #5@15 in. o/c

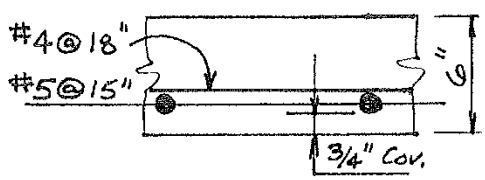
($A_s = 0.25$ in.$^2$/ft, $s_{max} = 3h = 18$ in. $\le 18$ in. (O.K.))

Calc. $d = 6 - 0.75 - 0.625/2 = 4.94$ in. $> 4.88$ in. (O.K.)

($A_{s,min}$ = required S&T steel)

S&T steel: select #4@18 in. o/c

($A_s = 0.13$ in.$^2$/ft, $s_{max} = 5h = 30$ in. $\le 18$ in. (O.K.))




(b) Design thinnest slab based on moment strength (max. $\rho$ with $\varepsilon_t \ge 0.005$)

Estimated slab weight: assume $h = 5$ in. and slab weight = 62.5 psf

$$w_u = \frac{1.2(62.5 + 25) + 1.6(175)}{1000} = 0.385 \text{ k/ft}$$



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Prob. 2-31(b) (cont.)

$$M_u = \frac{0.385(10)^2}{8} = 4.81 \text{ ft - kips}$$

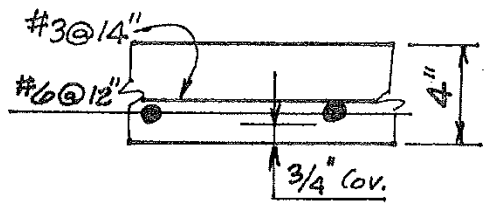
Use $\rho = 0.01355$ ($\bar{k} = 0.6835$ ksi, $\varepsilon_t = 0.005$, $\phi = 0.90$)

$$\text{Required } d = \sqrt{\frac{4.81(12)}{0.90(12)(0.6835)}} = 2.79 \text{ in.}$$

Est. $h = 2.79 + 0.75/2 + 0.75 = 3.92$ in. (Use 4 in., neglect decrease in D.L.)
Est. $d = 4.00 - 0.75/2 - 0.75 = 2.88$ in.

$$\text{Required } \bar{k} = \frac{4.81(12)}{0.90(12)(2.88)^2} = 0.6443 \text{ ksi}, \quad \rho = 0.0127, \ \varepsilon_t > 0.005, \ \phi = 0.90$$

Required $A_s = 0.0127(2.88)(12) = 0.44$ in.$^2$/ft
$A_{s,\min} = 0.0018(4)(12) = 0.09$ in.$^2$/ft (O.K.)
Main steel: select #6@12 in. o/c
($A_s = 0.44$ in.$^2$/ft, $s_{\max} = 3h = 12$ in. $\le 18$ in. (O.K.))
Calc. $d = 4 - 0.75 - 0.75/2 = 2.88$ in. (O.K.)
($A_{s,\min}$ = required S&T steel)
S&T steel: select #3@14 in. o/c
($A_s = 0.09$ in.$^2$/ft, $s_{\max} = 5h = 20$ in. $\le 18$ in. (O.K.))




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Prob. 2-32 [3/60] One-way slab design. $L = 13$ ft

ACI $h_{\min} = L/20 = [13(12)]/20 = 7.8$ in. Use 8 in.

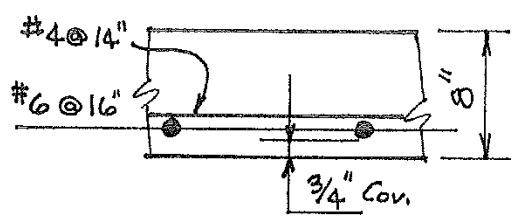
$$\text{Slab weight} = \frac{8(12)}{144}(0.150) = 100 \text{ psf}, \quad w_u = \frac{1.2(100) + 1.6(200)}{1000} = 0.440 \text{ kip/ft}$$

$$M_u = \frac{0.440(13)^2}{8} = 9.30 \text{ ft - kip}$$

Estimated $d = 8 - 0.75 - 0.75/2 = 6.88$ in. (Assume #6 bars)

$$\text{Required } \bar{k} = \frac{9.30(12)}{0.90(12)(6.88)^2} = 0.2183 \text{ ksi}, \quad \rho = 0.0039, \ \varepsilon_t > 0.005, \ \phi = 0.90$$

Required $A_s = 0.0039(6.88)(12) = 0.32$ in.$^2$/ft
$A_{s,\min} = 0.0018(8)(12) = 0.17$ in.$^2$/ft (O.K.)
Main steel: select #6@16 in. o/c
($A_s = 0.33$ in.$^2$/ft, $s_{\max} = 3h = 24$ in. $\le 18$ in. (O.K.))
Calc. $d = 8 - 0.75 - 0.75/2 = 6.88$ in. (O.K.)
($A_{s,\min}$ = required S&T steel)
S&T steel: select #4@14 in. o/c
($A_s = 0.17$ in.$^2$/ft, $s_{\max} = 5h = 40$ in. $\le 18$ in. (O.K.))






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