Instructor's Solutions Manual
to accompany

Concrete Structures

Mehdi Setareh
Robert Darvas

PEARSON
Prentice Hall

Upper Saddle River, New Jersey
Columbus, Ohio

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CONCRETE STRUCTURES

Solutions Manual

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Problem 1-1

Hydration is a chemical reaction that starts when water is added to cement. It has three stages: setting, hardening, and strength development. The hydration process generates heat. It also continues throughout the life of concrete structures as long as there is free moisture available.

Problem 1-2

Since concrete is a construction material which is very strong in compression but weak in tension, it is important for the structural designer to know what the compression capacity of concrete is. The compressive strength of concrete is measured by conducting a "cylinder test". In this test, compression force is applied gradually on a standard 6"x12" concrete cylinder. The stress and strain of the specimen is measured and plotted. The maximum compressive strength is noted as f_c'.

Problem 1-3

The air-entraining admixtures are added to concrete to increase the concrete resistance against the freezing/thawing cycles. As a result, this admixture improves concrete durability.

Problem 1-4

The modulus of elasticity relates the strain to the stress in concrete. It can be determined as a result of the cylinder test or the use of the ACI approximate equation.

Problem 1-5

The modulus of rupture is the tensile strength of concrete in bending.

Problem 1-6

Deformed bars are usually used as the primary steel reinforcement of structural elements. The bars have protrusions on the surface to increase their bondage to concrete.

Welded wire reinforcements are thin wires spaced at certain distances in two orthogonal directions and fabricated in large sheets or long rolls. The welded wire reinforcements are usually used where large areas need to be reinforced such as floor slabs and walls.

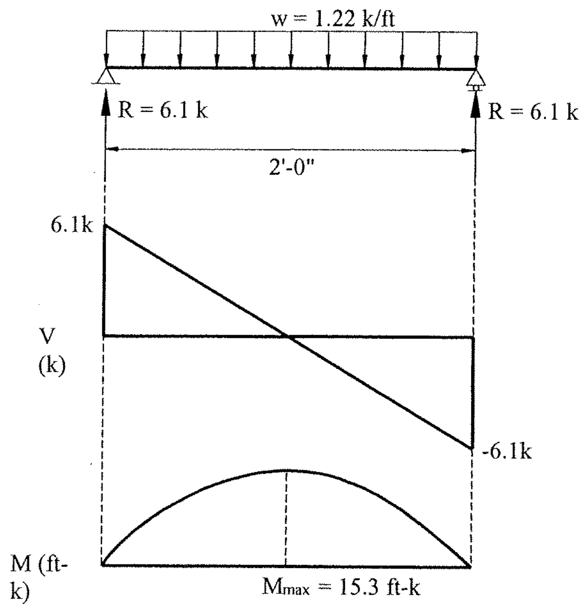
Problem 1-7

$$weight\ of\ beam = \frac{110\left(\frac{12}{12}\times\frac{24}{12}\right)}{1{,}000} = 0.22k/ft$$

$$w_T = 1.0 + 0.22 = 1.22k/ft$$

$$R = \frac{1.22(10)}{2} = 6.1k$$

$$M_{max} = \frac{wl^2}{8} = 15.3\,ft-k$$



Sketch for Problem 1-7

Problem 1-8

$$w_c = 145\,pcf$$

$$f'_c = 3{,}500\,psi$$

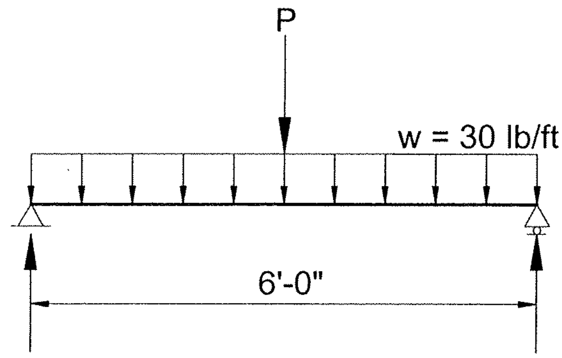
$$E_c = 57{,}000\sqrt{f'_c} = \frac{57{,}000\sqrt{3{,}500}}{1{,}000} = 3{,}372\ ksi$$

$$f_r = 7.5\sqrt{f'_c} = 7.5\sqrt{3{,}500} = 444\,psi$$

Problem 1-9

$w_c = 120\,pcf$

$f_c' = 3{,}000\,psi$



$$w = 120\left(\frac{6}{12}\times\frac{6}{12}\right) = 30\,lb/ft$$

$$M_{\max} = \frac{wl^2}{8} + \frac{Pl}{4} = \frac{30(6)^2}{8} + \frac{P(6)}{4} = 135 + 1.5P\ ft-lb$$

Using Equation (1-3) for sand-lightweight concrete:

$$f_r = f_b = 0.85(7.5\sqrt{f_c'}) = 0.85(7.5\sqrt{3{,}000}) = 349\,psi$$

$$S_m = \frac{bd^2}{6} = \frac{6(6)^2}{6} = 36\,in^3$$

$$M_R = f_r S_m$$

$$M_{max} \le M_R$$

$$135 + 1.5P \le (349)\left(\frac{36}{12}\right)$$

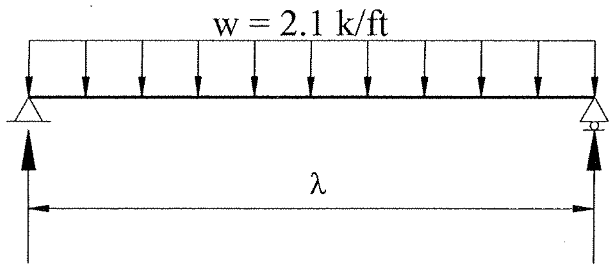
$$135 + 1.5P \le 1{,}047$$

$$P \le 608\,lb$$

$$then\ P_{max} = 608\,lb$$

Problem 1-10

$f'_c = 4{,}000 psi$



$$beamweight = 150\left(\frac{8}{12} \times \frac{12}{12}\right) = 100 lb/ft$$

$$w = 2 + \frac{100}{1{,}000} = 2.1 k/ft$$

$$M_{\max} = \frac{w\lambda^2}{8} = 0.263\lambda^2$$

$$f_r = 7.5\sqrt{f'_c} = 7.5\sqrt{4{,}000} = 474 psi$$

$$S_m = \frac{bd^2}{6} = \frac{8(12)^2}{6} = 192 in^3$$

$$M_R = f_r S_m = \frac{474(192)}{12{,}000} = 7.59 k-ft$$

$$M_{\max} \le M_R$$

$$0.263\lambda^2 \le 7.59$$

$$\lambda \le 5.37'$$

Problem 2-1

$f_c' = 4{,}000 psi$

$f_y = 60{,}000 psi$

$b = 14''$

$A_s = 4\#9 = 4.00 in^2$

Using Method I:

(a) d = 28" M_R = ?

From Figure 2-39, use Method I:

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14x28} = 0.0102$$
$$\rho_{min} = 0.0033 \ \ (from Table \ \ A2-4)$$
$$\rho_{max} = 0.0207 \ \ (from \ \ Table \ \ A2-3)$$
$$(\rho_{min} = 0.0033) \ < \ (\rho = 0.0102) \ < \ (\rho_{max} = 0.0207) \ \ \therefore O.K.$$

Step 2.

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{4.00x60,000}{0.85x4,000x14} = 5.04''$$

Step 3.

$$c = \frac{a}{\beta_1} = \frac{5.04}{0.85} = 5.93''$$

Step 4.

$$\frac{c}{d} = \frac{5.93}{28} = 0.212 < \frac{3}{8} = 0.375 \ \rightarrow section \ is \ in \ tension\text{-}controlled \ zone$$
$$\phi = 0.90$$

Step 5.

$$M_R = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.90x4.00x60x\left(28 - \frac{5.04}{2}\right) = 5,503.7 \ \ k-in \ \ = 458.6 \ \ k-ft$$

(b) d = 32” M_R = ?

Repeat same steps as in part (a)

$$M_R = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.90x4.00x60x\left(32 - \frac{5.04}{2}\right) = 6,367.7 \;\; k-in \;\; = 530.6 \;\; k-ft$$

(c) d = 36” M_R = ?

Repeat same steps as in part (a)

$$M_R = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.90x4.00x60x\left(36 - \frac{5.04}{2}\right) = 7,231.7 \;\; k-in \;\; = 602.6 \;\; k-ft$$

(d) d = 40” M_R = ?

Repeat same steps as in part (a)

$$M_R = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.90x4.00x60x\left(40 - \frac{5.04}{2}\right) = 8,095.7 \;\; k-in \;\; = 674.6 \;\; k-ft$$

Comparisons:

A linear increase in “d” leads to a proportionate linear increase of M_R

Case	d	% increase of “d” over Case (a)	M_R (k-ft)	% increase over Case (a)
a.	28”	-	458.6	-
b.	32”	14.3%	530.6	15.7%
c.	36”	28.6%	602.6	31.4%
d.	40”	42.9%	674.6	47.1%

Using Method II:

(a) d = 28" M_R = ?

From Figure 2-40, use Method II:

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14x28} = 0.0102$$
$$\rho_{min} = 0.0033 \ (from Table \ \ A2-4)$$
$$\rho_{max} = 0.0207 \ (from \ \ Table \ \ A2-3)$$
$$(\rho_{min} = 0.0033) < (\rho = 0.0102) < (\rho_{max} = 0.0207) \ \therefore O.K.$$

Step 2.

$$\rho = 0.0102$$
$$f_y = 60{,}000psi \rightarrow Table \ A2-6b \rightarrow R = 501psi$$
$$f_c' = 4{,}000psi$$

Step 3.

$$M_R = \frac{bd^2R}{12{,}000} = \frac{(14)(28)^2(501)}{12{,}000} = 458.2k-ft$$

(b) d = 32" M_R = ?

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14 \times 32} = 0.00893$$
$$0.0033 < 0.00893 < 0.0207 \ \therefore ok$$

Step 2.

$$\rho = 0.0089$$
$$f_y = 60{,}000psi \rightarrow Table \ A2-6b \rightarrow R = 443psi$$
$$f_c' = 4{,}000psi$$

Step 3.

$$M_R = \frac{bd^2R}{12{,}000} = \frac{(14)(32)^2(443)}{12{,}000} = 529.2\,k-ft$$

(c) d = 36" M_R = ?

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14\times 36} = 0.0079$$
$$0.0033 < 0.0079 < 0.0207 \therefore ok$$

Step 2.

$$\rho = 0.0079 \rightarrow Table\ A2-6b \rightarrow R = 397\,psi$$

Step 3.

$$M_R = \frac{bd^2R}{12{,}000} = \frac{(14)(36)^2(397)}{12{,}000} = 600.2\,k-ft$$

(d) d = 40" M_R = ?

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14\times 40} = 0.0071$$
$$0.0033 < 0.0071 < 0.0207 \therefore ok$$

Step 2.

$$\rho = 0.0071 \rightarrow Table\ A2-6b \rightarrow R = 359\,psi$$

Step 3.

$$M_R = \frac{bd^2R}{12{,}000} = \frac{(14)(40)^2(359)}{12{,}000} = 670.1\,k-ft$$

Comparisons:

Case	d	% increase of "d" over Case (a)	M_R (k-ft)	% increase over Case (a)
a.	28"	-	458.6	-
b.	32"	14.3%	529.2	15.4%
c.	36"	28.6%	600.2	30.9%
d.	40"	42.9%	670.1	46.1%

Problem 2-2

$f'_c = 4{,}000\,psi$

$f_y = 60{,}000\,psi$

$d = 36''$

$A_s = 4\#9 = 4.00in^2$

(a) b = 14”; M_R = ?

Use Method I. (Flowchart on Figure 2-39)

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14x36} = 0.0079$$
$$\rho_{min} = 0.0033 \ \ (from Table \ \ A2-4)$$
$$\rho_{max} = 0.0207 \ (from \ \ Table \ \ A2-3)$$
$$(\rho_{min} = 0.0033) \ < \ (\rho = 0.0079) \ < \ (\rho_{max} = 0.0207) \ \ \therefore O.K.$$

Step 2.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{4.00x60,000}{0.85x4,000x14} = 5.04''$$

Step 3.

$$c = \frac{a}{\beta_1} = \frac{5.04}{0.85} = 5.93''$$

Step 4.

$$\frac{c}{d} = \frac{5.93}{36} = 0.165 < \frac{3}{8} = 0.375 \rightarrow section \ is \ in \ tension\text{–}controlled \ zone$$
$$\phi = 0.90$$

Step 5.

$$M_R = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.90x4.00x60x\left(36 - \frac{5.04}{2}\right) = 7{,}231.7 \ k-in = 602.6 \ k-ft$$

(b) b = 16” M_R = ?

Repeating same steps as in part (a):

$$a = \frac{4.00x60,000}{0.85x4,000x16} = 4.41''$$

$$M_R = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.90x4.00x60x\left(36 - \frac{4.41}{2}\right) = 7,300 \ \ k-in \ = 608.3 \ \ k-ft$$

(c) b = 18” M_R = ?

Repeating same steps as in part (a):

$$a = \frac{4.00x60,000}{0.85x4,000x18} = 3.92''$$

$$M_R = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.90x4.00x60x\left(36 - \frac{3.92}{2}\right) = 7,352.6 \ \ k-in \ = 612.7 \ \ k-ft$$

(d) b = 20” M_R = ?

Repeating same steps as in part (a):

$$a = \frac{4.00x60,000}{0.85x4,000x20} = 3.53''$$

$$M_R = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.90x4.00x60x\left(36 - \frac{3.53}{2}\right) = 7,394.8 \ \ k-in \ = 616.2 \ \ k-ft$$

Comparisons:

Due to the increased width, the depth of the equivalent stress block becomes slightly less, leading to a slight increase in M_R

Case	b (in)	% increase of “b” over Case (a)	M_R (k-ft)	% increase over Case (a)
a.	14”	-	602.6	-
b.	16”	14.3%	608.3	0.9%
c.	18”	28.6%	612.7	1.7%
d.	20”	42.9%	616.2	2.3%

Using Method II:

(a) b = 14" M_R = ?

From Figure 2-40, use Method II:

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14 \times 36} = 0.0079$$
$$(\rho_{min} = 0.0033) < (\rho = 0.0079) < (\rho_{max} = 0.0207) \therefore O.K.$$

Step 2.

$$\rho = 0.0079$$
$$f_y = 60{,}000psi \rightarrow Table\ A2-6b \rightarrow R = 397\,psi$$
$$f_c' = 4{,}000psi$$

Step 3.

$$M_R = \frac{bd^2R}{12{,}000} = \frac{(14)(36)^2(397)}{12{,}000} = 600.3\,k-ft$$

(b) b = 16" M_R = ?

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.0}{16 \times 36} = 0.0069$$
$$0.0033 < 0.0069 < 0.0207 \therefore ok$$

Step 2.

$$\rho = 0.0069$$
$$f_y = 60{,}000\ psi \rightarrow Table\ A2-6b \rightarrow R = 350\,psi$$
$$f_c' = 4{,}000\ psi$$

Step 3.

$$M_R = \frac{bd^2R}{12{,}000} = \frac{(16)(36)^2(350)}{12{,}000} = 604.8k - ft$$

(c) b = 18" $M_R = ?$

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{18 \times 36} = 0.0062$$
$$0.0033 < 0.0062 < 0.0207 \therefore ok$$

Step 2.

$$\rho = 0.0062 \rightarrow \text{TableA2} - 6\text{b} \rightarrow \text{R} = 316\text{psi}$$

Step 3.

$$M_R = \frac{bd^2R}{12{,}000} = \frac{(18)(36)^2(316)}{12{,}000} = 614.3k - ft$$

(d) b = 20" $M_R = ?$

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{20 \times 36} = 0.0056$$
$$0.0033 < 0.0056 < 0.0207 \therefore ok$$

Step 2.

$$\rho = 0.0056 \rightarrow \text{TableA2} - 6\text{b} \rightarrow \text{R} = 287\text{psi}$$

Step 3.

$$M_R = \frac{bd^2R}{12{,}000} = \frac{(20)(36)^2(287)}{12{,}000} = 619.9k - ft$$

Comparisons:

Case	b (in)	% increase of "b" over Case (a)	M_R (k-ft)	% increase over Case (a)
a.	14	-	600.3	-
b.	16	14.3%	604.8	0.7%
c.	18	28.6%	614.3	2.3%
d.	20	42.9%	619.9	3.3%

Problem 2-3

$f'_c = 4{,}000\,psi$
$f_y = 60{,}000\,psi$
$d = 36''$
$b = 14''$

Using Method I:

(a) $A_s = 4\#6 = 1.76\ in^2$; $M_R = ?$

Use Method I. (Figure 2-39)

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{1.76}{14x36} = 0.0035$$
$$\rho_{min} = 0.0033\ (from Table\ A2-4)$$
$$\rho_{max} = 0.0207\ (from\ Table\ A2-3)$$
$$(\rho_{min} = 0.0033) < (\rho = 0.0035) < (\rho_{max} = 0.0207)\ \therefore O.K.$$

Step 2.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{1.76x60{,}000}{0.85x4{,}000x14} = 2.22''$$

Step 3.

$$c = \frac{a}{\beta_1} = \frac{2.22}{0.85} = 2.61''$$

Step 4.

$$\frac{c}{d} = \frac{2.61}{36} = 0.073 < \frac{3}{8} = 0.375 \rightarrow section\ is\ in\ tension\text{–}controlled\ zone$$
$$\phi = 0.90$$

Step 5.

$$M_R = \phi A_s f_y\left(d - \frac{a}{2}\right) = 0.90x1.76x60x\left(36 - \frac{2.22}{2}\right) = 3{,}316\ \ k-in\ \ = 276.3\ \ k-ft$$