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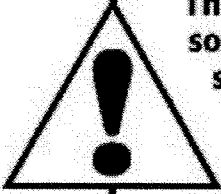
Instructor's Solutions Manual
to accompany

Concrete Structures

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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.

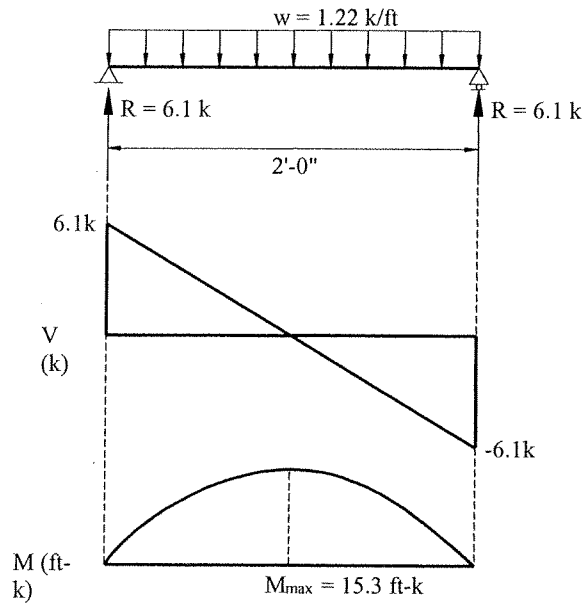
Problem 1-7

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

$$w_T = 1.0 + 0.22 = 1.22 \text{ k / ft}$$

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

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



Sketch for Problem 1-7

Problem 1-8

$$w_c = 145 \text{ pcf}$$

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

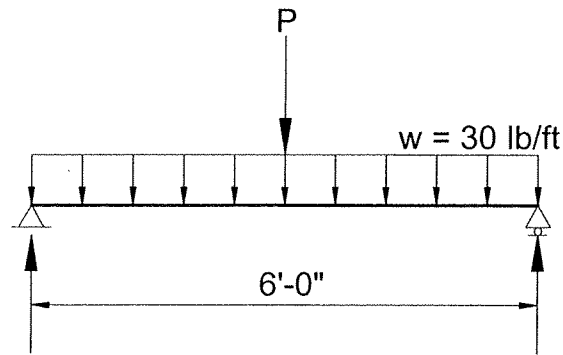
$$E_c = 57,000 \sqrt{f'_c} = \frac{57,000 \sqrt{3,500}}{1,000} = 3,372 \text{ ksi}$$

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

Problem 1-9

$$w_c = 120 \text{ pcf}$$

$$f'_c = 3,000 \text{ psi}$$



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

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

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

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

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

$$M_R = f_r S_m$$

$$M_{\max} \leq M_R$$

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

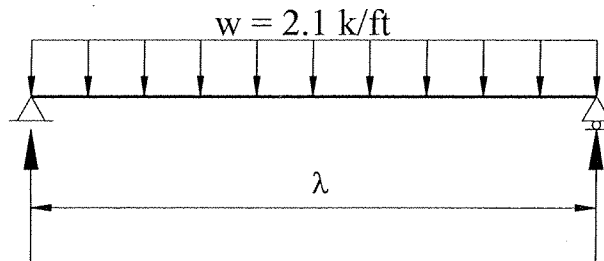
$$135 + 1.5P \leq 1,047$$

$$P \leq 608 \text{ lb}$$

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

Problem 1-10

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



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

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

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

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

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

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

$$M_{\max} \leq M_R$$

$$0.263\lambda^2 \leq 7.59$$

$$\lambda \leq 5.37'$$

Problem 2-1

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

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

$$b = 14''$$

$$A_s = 4\#9 = 4.00 \text{ in}^2$$

Using Method I:

(a) $d = 28''$ $M_R = ?$

From Figure 2-39, use Method I:

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14 \times 28} = 0.0102$$

$$\rho_{min} = 0.0033 \text{ (from Table A2-4)}$$

$$\rho_{max} = 0.0207 \text{ (from Table A2-3)}$$

$$(\rho_{min} = 0.0033) < (\rho = 0.0102) < (\rho_{max} = 0.0207) \therefore O.K.$$

Step 2.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{4.00 \times 60,000}{0.85 \times 4,000 \times 14} = 5.04''$$

Step 3.

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

Step 4.

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

$$\phi = 0.90$$

Step 5.

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 4.00 \times 60 \times \left(28 - \frac{5.04}{2} \right) = 5,503.7 \text{ k-in} = 458.6 \text{ k-ft}$$

(b) $d = 32''$ $M_R = ?$

Repeat same steps as in part (a)

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 4.00 \times 60 \times \left(32 - \frac{5.04}{2} \right) = 6,367.7 \text{ k-in} = 530.6 \text{ k-ft}$$

(c) $d = 36''$ $M_R = ?$

Repeat same steps as in part (a)

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 4.00 \times 60 \times \left(36 - \frac{5.04}{2} \right) = 7,231.7 \text{ k-in} = 602.6 \text{ k-ft}$$

(d) $d = 40''$ $M_R = ?$

Repeat same steps as in part (a)

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 4.00 \times 60 \times \left(40 - \frac{5.04}{2} \right) = 8,095.7 \text{ k-in} = 674.6 \text{ k-ft}$$

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.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14 \times 28} = 0.0102$$

$$\rho_{min} = 0.0033 \text{ (from Table A2-4)}$$

$$\rho_{max} = 0.0207 \text{ (from Table A2-3)}$$

$$(\rho_{min} = 0.0033) < (\rho = 0.0102) < (\rho_{max} = 0.0207) \therefore O.K.$$

Step 2.

$$\rho = 0.0102$$

$$f_y = 60,000psi \rightarrow \text{Table A2-6b} \rightarrow R = 501psi$$

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

Step 3.

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

(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.

$$\rho = 0.0089$$

$$f_y = 60,000psi \rightarrow \text{Table A2-6b} \rightarrow R = 443psi$$

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

Step 3.

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

(c) $d = 36''$ $M_R = ?$

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14 \times 36} = 0.0079$$

$$0.0033 < 0.0079 < 0.0207 \therefore \text{ok}$$

Step 2.

$$\rho = 0.0079 \rightarrow \text{Table A2-6b} \rightarrow R = 397 \text{ psi}$$

Step 3.

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

(d) $d = 40''$ $M_R = ?$

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14 \times 40} = 0.0071$$

$$0.0033 < 0.0071 < 0.0207 \therefore \text{ok}$$

Step 2.

$$\rho = 0.0071 \rightarrow \text{Table A2-6b} \rightarrow R = 359 \text{ psi}$$

Step 3.

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

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

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

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

$$d = 36''$$

$$A_s = 4\#9 = 4.00 \text{ in}^2$$

(a) $b = 14''$; $M_R = ?$

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

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{4.00}{14 \times 36} = 0.0079$$

$$\rho_{min} = 0.0033 \text{ (from Table A2-4)}$$

$$\rho_{max} = 0.0207 \text{ (from Table A2-3)}$$

$$(\rho_{min} = 0.0033) < (\rho = 0.0079) < (\rho_{max} = 0.0207) \therefore O.K.$$

Step 2.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{4.00 \times 60,000}{0.85 \times 4,000 \times 14} = 5.04''$$

Step 3.

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

Step 4.

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

Step 5.

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 4.00 \times 60 \times \left(36 - \frac{5.04}{2} \right) = 7,231.7 \text{ k-in} = 602.6 \text{ k-ft}$$

(b) $b = 16''$ $M_R = ?$

Repeating same steps as in part (a):

$$a = \frac{4.00 \times 60,000}{0.85 \times 4,000 \times 16} = 4.41''$$

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 4.00 \times 60 \times \left(36 - \frac{4.41}{2} \right) = 7,300 \text{ k-in} = 608.3 \text{ k-ft}$$

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

Repeating same steps as in part (a):

$$a = \frac{4.00 \times 60,000}{0.85 \times 4,000 \times 18} = 3.92''$$

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 4.00 \times 60 \times \left(36 - \frac{3.92}{2} \right) = 7,352.6 \text{ k-in} = 612.7 \text{ k-ft}$$

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

Repeating same steps as in part (a):

$$a = \frac{4.00 \times 60,000}{0.85 \times 4,000 \times 20} = 3.53''$$

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 4.00 \times 60 \times \left(36 - \frac{3.53}{2} \right) = 7,394.8 \text{ k-in} = 616.2 \text{ k-ft}$$

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.

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

Step 3.

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

(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.

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

Step 3.

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

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

Step 1.

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

Step 2.

$$\rho = 0.0062 \rightarrow \text{Table A2-6b} \rightarrow R = 316 \text{ psi}$$

Step 3.

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

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

Step 1.

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

Step 2.

$$\rho = 0.0056 \rightarrow \text{Table A2-6b} \rightarrow R = 287 \text{ psi}$$

Step 3.

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

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

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

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

$$d = 36''$$

$$b = 14''$$

Using Method I:

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

Use Method I. (Figure 2-39)

Step 1.

$$\rho = \frac{A_s}{bd} = \frac{1.76}{14 \times 36} = 0.0035$$

$$\rho_{min} = 0.0033 \text{ (from Table A2-4)}$$

$$\rho_{max} = 0.0207 \text{ (from Table A2-3)}$$

$$(\rho_{min} = 0.0033) < (\rho = 0.0035) < (\rho_{max} = 0.0207) \therefore O.K.$$

Step 2.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{1.76 \times 60,000}{0.85 \times 4,000 \times 14} = 2.22''$$

Step 3.

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

Step 4.

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

$$\phi = 0.90$$

Step 5.

$$M_R = \phi A_s f_y \left(d - \frac{a}{2} \right) = 0.90 \times 1.76 \times 60 \times \left(36 - \frac{2.22}{2} \right) = 3,316 \text{ k-in} = 276.3 \text{ k-ft}$$