INSTRUCTOR'S SOLUTIONS MANUAL

# REINFORCED CONCRETE

## A FUNDAMENTAL APPROACH

SIXTH EDITION

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**About the Cover:** Shown is the Milwaukee Art Museum, Milwaukee, Wisconsin. Construction in reinforced and prestressed concrete in various shapes that include cantilevered canopies and a unique cable-stayed bridge. Rows of exposed situ-cast concrete arches form a galleria that overlooks Lake Michigan. Designed by Architect Santiago Calatrava and opened in 2002. Photo courtesy Professor Tarun Naik, University of Wisconsin at Milwaukee.



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# CONTENTS

Please note that there are no solutions for Chapters 1 through 4. Solutions begin with Chapter 5.

**5.1.** For the beam cross-section shown in Fig. 5.33 determine whether the failure of the beam will be initiated by crushing of concrete or yielding of steel. Given:

$$f'_c = 4000 \text{ psi (27.6 MPa) for case (a)}, A_s = 10 \text{ in.}^2$$
$$f'_c = 7000 \text{ psi (48.3 MPa) for case (b)}, A_s = 5 \text{ in.}^2$$
$$f_y = 60{,}000 \text{ psi (414 MPa)}$$

Also determine whether the section satisfies ACI Code requirements.

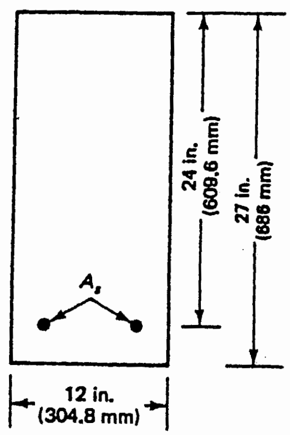


Figure 5.33

Solution:

a) $\beta_1 = 0.85$

$A_s = 10 \text{ in}^2$

$f_y = 60{,}000$ psi

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

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(10)(60{,}000)}{0.85(4{,}000)(12)} = 14.71 \text{ inches}$$

$$c = \frac{a}{\beta_1} = \frac{14.71}{0.85} = 17.31 \text{ inches}$$

$$\frac{c}{d_t} = \frac{17.31}{24} = 0.72 > 0.60$$

$\therefore$ Compression-controlled and concrete crushes before tension steel yields

b) $\beta_1 = 0.85 - 0.05\left(\dfrac{7{,}000-4{,}000}{1{,}000}\right) = 0.70$

$f'_c = 7{,}000$ psi

$A_s = 5\ \text{in}^2$

$a = \dfrac{A_s f_y}{0.85 f'_c b} = \dfrac{(5)(60{,}000)}{0.85(7{,}000)(12)} = 4.20$ inches

$c = \dfrac{a}{\beta_1} = \dfrac{4.2}{0.70} = 6.0$ inches

$\dfrac{c}{d_t} = \dfrac{6}{24} = 0.25 < 0.375$ $\therefore$ Tension - controlled and steel yields before concrete crushes

$\rho = \dfrac{A_s}{bd} = \dfrac{5}{(12)(24)} = 0.017$ in/in.

$\rho_{min} = \max\left\{\dfrac{3\sqrt{7{,}000}}{60{,}000} = 0.0042,\ \dfrac{200}{60{,}000} = 0.0033\right\} = 0.0042$ in/in.

$0.017 > 0.0042$ $\therefore$ O.K. satisfies ACI CODE

**5.2.** Calculate the nominal moment strength of the beam sections shown in Fig. 5.34. Given:

$f'_c$ = 5000 psi (20.7 MPa) for case (a)
$f'_c$ = 6000 psi (41.4 MPa) for case (b)

$f_y$ = 60,000 psi (414 MPa)

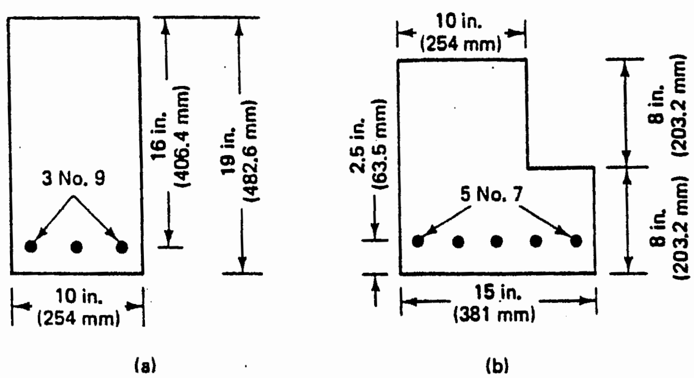


Figure 5.34

Solution:

a) $f'_c = 5{,}000$ psi
$\beta_1 = 0.80$
$A_s = 3$ No. 9 $= 3 \text{ in}^2$
$b = 10$ in.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(3)(60{,}000)}{0.85(5{,}000)(10)} = 4.24 \text{ inches}$$

$$c = \frac{a}{\beta_1} = \frac{4.24}{0.80} = 5.29 \text{ in.}$$

$$\frac{c}{d_t} = \frac{5.29}{16} = 0.33 < 0.375$$ ∴ Tension- Controlled
$\phi = 0.90$

$$\rho = \frac{A_s}{bd} = \frac{3}{(10)(16)} = 0.019$$

$$\rho_{min} = \max \left\{ \frac{3\sqrt{f'_c}}{f_y} , \frac{200}{f_y} \right\} = 0.0035 < 0.019 \qquad \underline{\underline{\text{O.K.}}}$$

$$M_n = A_s f_y (d - a/2) = (3)(60{,}000)\left(16 - \frac{4.24}{2}\right) = 2{,}498{,}824 \text{ in-lb}$$

$$M_u = \phi M_n = 0.90\,(2{,}498{,}824) = 2{,}248{,}941 \text{ in-lb.}$$

b) $f'_c = 6{,}000$ psi
$\beta_1 = 0.75$
$A_s = 5 \times 0.7 = 3 \text{ in}^2$
$b = 10$ in (assuming neutral axis is w/in top 8 inches)

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(3)(60{,}000)}{0.85(6{,}000)(10)} = 3.53 \text{ in.}$$

$$c = a/\beta_1 = 4.71 \text{ in} < 8 \text{ in.} \quad \therefore\ b = 10 \text{ in.} \quad \underline{\underline{\text{O.K}}}$$

$$\frac{c}{d_t} = \frac{4.71}{13.5} = 0.35 < 0.375 \quad \therefore \text{ Tension-Controlled}$$

$$\phi = 0.90$$

$$\rho = \frac{A_s}{bd} = 0.022 \qquad \rho_{min} = \max \left\{ \frac{3\sqrt{f'_c}}{f_y} , \frac{200}{f_y} \right\} = 0.0039 < 0.022 \quad \underline{\underline{\text{O.K}}}$$

$$M_n = A_s f_y (d - a/2) = (3)(60{,}000)\left(13.5 - \frac{3.53}{2}\right) = 2{,}112{,}353 \text{ in-lb}$$

$$M_u = \phi M_n = 0.9\, M_n = 1{,}901{,}118 \text{ in-lb.}$$

**5.3.** Calculate the safe distributed load intensity that the beam shown in Fig. 5.35 can carry. Given:

$$f'_c = 4000 \text{ psi (27.6 MPa), normal-weight concrete}$$
$$f_y = 60{,}000 \text{ psi (414 MPa)}$$

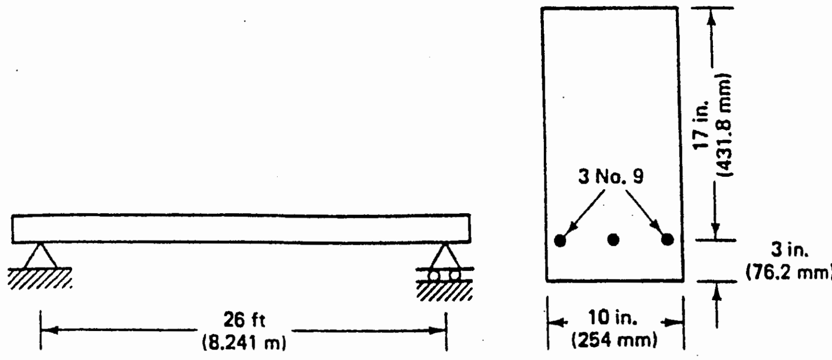


**Figure 5.35**

Solution:

Given

b= 10 in.

h= 20 in.

$d_t$= 17 in

$A_s$ = 3 No.9 = 3.0 in$^2$

$f'_c$= 4,000 psi

$f_y$= 60,000 psi

$\beta_1$= 0.85

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(3)(60{,}000)}{(0.85)(4000)(10)} = 5.29 \text{ in.}$$

$$c = \frac{a}{\beta_1} = \frac{5.29}{0.85} = 6.23 \text{ in.}$$

$$\frac{c}{d_t} = \frac{6.23}{17} = 0.37 < 0.375$$

∴ Tension - controlled

$\phi = 0.90$

$$\rho = \frac{A_s}{bd} = \frac{(3)}{(10)(17)} = 0.018$$

$$\rho_{min} = \max\left\{\frac{3\sqrt{f'_c}}{f_y}, \frac{200}{f_y}\right\} = 0.0033 < 0.018$$

∴ Satisfies ACI CODE Requirement

$$M_n = A_s f_y (d - a/2) = (3)(60{,}000)\left(17 - \frac{5.29}{2}\right) = 2{,}583{,}529 \text{ in.-lb.}$$

$$\phi M_n = (0.9)(2{,}583{,}529) = 2{,}325{,}176 \text{ in-lb.}$$

<u>maximum applied moment</u>

$$M_u = \frac{w_u \ell^2}{8} = 2{,}325{,}176 \text{ in-lb}$$

$$w_u = \frac{(2{,}325{,}176)(8)}{(28 * 12)^2} = 191.1 \text{ lb/in} = 2293 \text{ lb/ft.}$$

$$w_u = 1.2\,DL + 1.6\,LL$$

$$DL = (150 \text{ lb/ft}^3)\frac{(10 * 20)}{144} = 208.3 \text{ lb/ft.}$$

$\therefore$

$$2293 = 1.2(208.3) + 1.6\,LL \quad \Rightarrow \quad LL = 1277 \text{ lb/ft.}$$

**5.4.** Design a one-way slab to carry a live load of 100 psf and an external dead load of 50 psf. The slab is simply supported over a span of 12 ft. Given:

$$f'_c = 4000 \text{ psi (27.6 MPa), normal-weight concrete}$$
$$f_y = 60{,}000 \text{ psi (414 MPa)}$$

Solution:

Design as a 1 ft. wide singly reinforced section.

Try, $\min h = \frac{L}{20} = \frac{(12)(12)}{20} = 7.2 \text{ in.}$

Try $h = 8$ in, $d_t = 7$ in. ; $b = 12$ in.

Self-weight $= (150)\frac{(8)(12)}{144} = 100$ lb/ft.

$DL = (50 \frac{lb}{ft^2})(1 ft) = 50$ lb/ft

$LL = (100 \frac{lb}{ft^2})(1 ft) = 100$ lb/ft.

$\therefore \quad w_u = 1.2(100 + 50) + 1.6(100) = 340$ lb/ft.

$$M_u = \frac{w_u \ell^2}{8} = \frac{(340 \text{ lb/ft})(12 \text{ ft})^2}{8} = 6{,}120 \text{ ft-lb} = 73{,}440 \text{ in.-lb.}$$

Required nominal moment strength:

$$M_n = \frac{73{,}440}{0.90} = 81{,}600 \text{ in-lb.}$$

Assume $(d - a/2) \simeq 0.9\,d = 0.9(7) = 6.3$ in.

$$M_n = A_s f_y (d - a/2)$$

$$81{,}600 = A_s (60{,}000)(6.3)$$

$$A_s = 0.22 \text{ in}^2/\text{12-in strip}$$

$$\rho_{min} = \max\left\{\frac{3\sqrt{f'_c}}{f_y}, \frac{200}{f_y}\right\} = 0.0033 \qquad \therefore \min A_s = (0.0033)(12)(7) = 0.27 \text{ in}^2/\text{12-in strip}$$

$\therefore$ try $A_s = 0.28 \text{ in}^2/\text{12-in strip}$ (#4 bars at 8.5 in c-c)

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.28)(60{,}000)}{0.85(4000)(12)} = 0.41 \text{ in.}$$

$$c = \frac{a}{\beta_1} = \frac{0.41}{0.85} = 0.48 \text{ in.}$$

$$\frac{c}{d_t} = \frac{0.48}{7} = 0.069 < 0.375$$ $\therefore$ Tension-controlled $\phi = 0.90$

Actual nominal moment strength.

$$M_n = A_s f_y (d - a/2) = (0.28)(60{,}000)\left(7 - \frac{0.41}{2}\right) = 114{,}156 \text{ in-lb}$$

114,156 in-lb > Req'd 81,600 in-lb <u>O.K.</u>

<u>Shrinkage and Temperature Reinforcement</u> :

Req'd steel area = $0.0018(12)(8) = 0.17 \text{ in}^2/\text{12-in strip}$

maximum spacing = $\min\{5(8) = 40 \text{ in}, 18 \text{ in}\} = 18$ in.

$\therefore$ use #4 bar @ 14 in. c-c ($A_s = 0.17 \text{ in}^2/\text{12-in strip}$)

**5.5.** Design the simply supported beams shown in Fig. 5.36 as rectangular sections. Given:

$f'_c$ = 5000 psi (34.5 MPa), normal-weight concrete
$f_y$ = 60,000 psi (414 MPa)

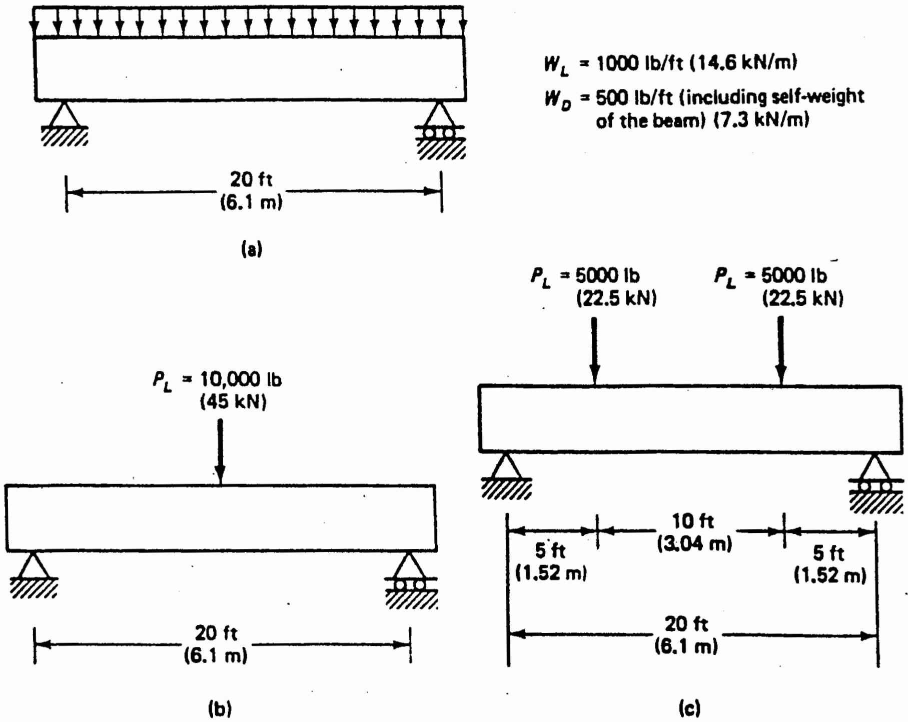


Figure 5.36

Solution:

a) $w_u = 1.2DL + 1.6LL = 1.2(500) + 1.6(1{,}000) = 2200$ lb/ft.

$$M_u = \frac{w_u \ell^2}{8} = \frac{(2200)(20)^2}{8} \times 12 = 1{,}320{,}000 \text{ in-lb}$$

Required nominal moment strength:

$$M_n = \frac{1{,}320{,}000}{0.90} = 1{,}466{,}667 \text{ in-lb}$$