

INSTRUCTOR'S SOLUTIONS MANUAL

PRESTRESSED CONCRETE

A Fundamental Approach

*Fifth Edition Update
ACI, AASHTO, IBC 2009 Codes Version*

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About the Cover: The new I-35W bridge, Minneapolis, Minnesota. Designed for the Minnesota Department of Transportation by FIGG, this new bridge incorporates aesthetics selected by the community using a theme of “Arches–Water–Reflection” to complement the site across the Mississippi River. Curved, 70’ tall concrete piers meet the sweeping parabolic arch of the 504’ precast, prestressed concrete main span over the river to create a modern bridge. The new 10-lane interstate bridge was constructed by Flatiron-Manson, JV and opened to traffic on September 18, 2008. The bridge was designed and built in 11 months. The bridge incorporates the first use of LED highway lighting, the first major use in the United States of nanotechnology cement that cleans the air (gateway sculptures) and “smart bridge” technology with 323 sensors embedded throughout the concrete to provide valuable data for the future. The photograph of the new I-35W bridge is courtesy of FIGG.

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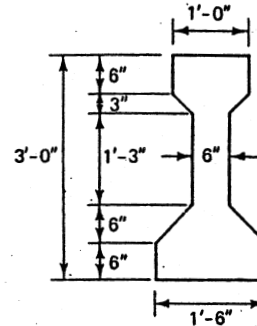
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- 1.1. An AASHTO prestressed simply supported I beam has a span of 34 ft (10.4 m) and is 36 in. (91.4 cm) deep. Its cross section is shown in Figure 14.18. It is subjected to a live-load intensity $W_L = 3600$ plf (52.6 kN/m). Determine the required $\frac{1}{2}$ -in.-diameter, stress-relieved, seven-wire strands to resist the applied gravity load and the self-weight of the beam, assuming that the tendon eccentricity at midspan is $e_c = 13.12$ in. (333 mm). Maximum permissible stresses are as follows:

$$\begin{aligned} f'_c &= 6000 \text{ psi (41.4 MPa)} \\ f_c &= 0.45f'_c \\ &= 2700 \text{ psi (26.7 MPa)} \\ f_t &= 12\sqrt{f'_c} = 930 \text{ psi (6.4 MPa)} \\ f_{pu} &= 270,000 \text{ psi (1862 MPa)} \\ f_{pi} &= 189,000 \text{ psi (1303 MPa)} \\ f_{pe} &= 145,000 \text{ psi (1000 MPa)} \end{aligned}$$

The section properties, given these stresses, are

$$\begin{aligned} A_c &= 369 \text{ in.}^2 \\ I_g &= 50,979 \text{ in.}^4 \\ r^2 &= \frac{I_g}{A_c} = 138 \text{ in.}^2 \\ c_b &= 15.83 \text{ in.} \\ S_b &= 3220 \text{ in.}^3 \\ S' &= 2527 \text{ in.}^3 \\ W_D &= 384 \text{ plf} \\ W_L &= 3600 \text{ plf} \end{aligned}$$



Solve the problem by each of the following methods:

- (a) Basic concept
- (b) C-line
- (c) Load balancing

SOLUTION:-

1. SOLUTION USING THE P-I METHOD:-

STRESS DATA:

$$\begin{aligned} \text{Span} &= 34 \text{ ft} \\ W_L &= 3600 \text{ plf} \\ f'_c &= 6000 \text{ psi.} \\ f_c &= 0.45f'_c = 2700 \text{ psi.} \\ f_t &= 12\sqrt{f'_c} = 930 \text{ psi} \\ f_{pu} &= 270,000 \text{ psi} \\ f_{pi} &= 189,000 \text{ psi} \\ f_{pe} &= 145,000 \text{ psi} \end{aligned}$$

SECTION PROPERTIES:

$$\begin{aligned} A_c &= 369 \text{ in.}^2 \\ I_g &= 50,979 \text{ in.}^4 \\ r^2 &= I_g/A_c = 138 \text{ in.}^2 \\ C_b &= 15.83 \text{ in} \\ C^t &= 20.17 \text{ in} \\ e_c &= 13.12 \text{ in} \\ S_b &= 2527 \text{ in.}^3 \\ S_b &= 3,220 \text{ in.}^3 \\ W_d &= 384 \text{ plf.} \end{aligned}$$

a) BASIC CONCEPT:-

Assume that 10 $\frac{1}{2}$ " dia. seven wire strand tendons are used to prestress

i) Initial Conditions at Prestressing:-

$$A_{ps} = 10(0.153) = 1.53 \text{ in}^2$$

$$P_i = A_{ps} \cdot f_{pi} = 1.53(189,000) = 289,170 \text{ lb.}$$

$$P_e = 1.53(145,000) = 221,850 \text{ lb.}$$

The midspan self-weight dead-load moment is

$$M_D = \frac{W_D \cdot l^2}{8} = \frac{384(34)^2}{8} \times 12 = 665,856 \text{ in-lb.}$$

$$f_t^t = \frac{-P_i}{A_c} \left(1 - \frac{e \cdot c_t}{r^2} \right) - \frac{M_D}{S_t} = \frac{-289,170}{369} \left(1 - \frac{13.12(20)}{138} \right) - \frac{665,856}{2527}$$

$$\therefore f_t^t = 456 \text{ psi (C)}$$

$$f_b = \frac{-P_i}{A_c} \left(1 + \frac{e \cdot c_b}{r^2} \right) + \frac{M_D}{S_b} = \frac{-289,170}{369} \left(1 + \frac{13.12(25.83)}{138} \right) - \frac{665,856}{3220}$$

$$\therefore f_b = -1756 \text{ psi} < f_{ci} = -2880 \text{ psi allowed.}$$

ii) FINAL Conditions at Service Load:-

The midspan moment due to live load is:

$$M_L = \frac{W \cdot l^2}{8} = \frac{3600(34)^2}{8} \times 12 = 6,242,400 \text{ in-lb.}$$

$$M_T = 665,856 + 6,242,400 = 6,908,256 \text{ in-lb.}$$

$$f_t^t = \frac{-P_e}{A_c} \left(1 - \frac{e \cdot c_t}{r^2} \right) - \frac{M_T}{S_t} = \frac{-221,850}{369} \left(1 - \frac{13.12(20.17)}{138} \right) - \frac{6,908,256}{2527}$$

$$\boxed{f^t = -2,183 \text{ psi (C)}} < f_c = 2700 \text{ psi}$$

$$\begin{aligned} f_b &= -\frac{P_e}{A_c} \left(1 + \frac{e \cdot C_b}{r^2} \right) + \frac{M_T}{S_b} = - \\ &= -\frac{221,850}{369} \left(1 + \frac{13.12(15.83)}{138} \right) + \frac{6,908,256}{3220} \\ &= 639 \text{ psi (T)} < f_t = 930 \text{ psi} \therefore \underline{\text{O.K.}} \end{aligned}$$

b) C-LINE METHOD:

$$P_e = 221,850 \text{ lb.}$$

$$M_T = 6,908,256 \text{ in-lb.}$$

$$e = \frac{M_T}{P_e} = 31.1 \text{ in}$$

$$e' = a - e = 31.1 - 13.12 = 18.02 \text{ in}$$

$$\begin{aligned} f^t &= -\frac{P_e}{A_c} \left(1 + \frac{e' \cdot C_t}{r^2} \right) = -\frac{221,850}{369} \left(1 + \frac{18.02 \times 20.17}{138} \right) \\ &= -2,183 \text{ psi (C)} \end{aligned}$$

$$\begin{aligned} f_b &= -\frac{P_e}{A_c} \left(1 - \frac{e' \cdot C_b}{r^2} \right) = -\frac{221,850}{369} \left(1 - \frac{18.02 \times 20.17}{138} \right) \\ &= 639 \text{ psi (T)} \end{aligned}$$

c) LOAD BALANCING METHOD: =

$$P' = P_e = 221,850 \text{ lb.}$$

$$a = 13.12 \text{ in} = e = 1.09 \text{ ft}$$

$$W_b = \frac{8 \cdot P' \cdot a}{l^2} = \frac{8 \times 221,850 \times 1.09}{(34)^2} = 1,678.59 \text{ plf}$$

$$W_T = 384 + 3600 = 3984 \text{ Plf}$$

$$W_{ub} = 3984 - 1678.59 = 2305.41 \text{ Plf}$$

$$M_{ub} = \frac{W_{ub} \cdot l^2}{8} = \frac{2305.41(34)^2}{8} \times 12 = 3,997,581 \text{ in-lb}$$

$$f^t = -\frac{P'}{A_c} - \frac{M_{ub}}{S^t} = -\frac{221,850}{369} - \frac{3,997,581}{2527} = -2183 \text{ psi (C)}$$

$$f_b = -\frac{P'}{A_c} + \frac{M_{ub}}{S_b} = -\frac{221,850}{369} + \frac{3,997,581}{3220} = 639 \text{ psi (T)}$$

$$< f_t = 930 \text{ psi} \therefore \underline{\underline{\text{OK}}}$$

2) S. I. SYSTEM:-

a) Basic Concept:-

Assume that ten 12.7 mm dia seven wire strand tendons are used to prestress.

i) Initial Conditions at Prestressing:-

$$A_{ps} = 10(99) = 990 \text{ mm}^2$$

$$P_i = A_{ps} \cdot f_{pi} = 990(1303) = 1290 \text{ kN}$$

$$P_e = 990(1000) = 990 \text{ kN}$$

The midspan self-weight dead load moment

$$M_D = \frac{W_D l^2}{8} = \frac{5.60(10.4)^2}{8} = 75.7 \text{ kN-m.}$$

$$f^t = -\frac{P_i}{A_c} \left(1 - \frac{e \cdot C^t}{r^2} \right) - \frac{M_D}{S^t}$$

$$= -\frac{1290}{2381} \left(1 - \frac{33.3(51.2)}{891} \right) - \frac{75.7 \times 10^2}{41410} = 3.1 \text{ MPa}$$

$$f_b = -\frac{P_i}{A_c} \left(1 + \frac{e \cdot C_b}{r^2} \right) + \frac{M_D}{S_b} = -\frac{1290}{2381} \left(1 + \frac{33.3(51.2)}{891} \right) + \frac{75.7 \times 10^2}{52766}$$

$$= -12.1 \text{ MPa} < -19.9 \text{ MPa} \quad \therefore \underline{\text{O.K.}}$$

Final Conditions at Service Load:-

The midspan moment due to live load is

$$M_L = \frac{52.6(10.4)^2}{8} = 711 \text{ kN-m.}$$

$$M_T = 75.7 + 711 = 787 \text{ kN-m.}$$

$$f^t = -\frac{P_e}{A_c} \left(1 - \frac{e \cdot C^t}{r^2} \right) - \frac{M_T}{S^t}$$

$$= -\frac{990}{2381} \left(1 - \frac{33.3 \times 51.2}{891} \right) - \frac{787 \times 10^2}{41410}$$

$$= -15.1 \text{ MPa (C)} < f_c = 18.6 \text{ MPa} \quad \underline{\text{2.0k.}}$$

$$f_b = -\frac{990}{2381} \left(1 + \frac{33.3 (40.2)}{891} \right) - \frac{787 \times 10^2}{52766}$$

$$= 4.5 \text{ MPa (T)} < f_t = 6.4 \text{ MPa (T)} \quad \therefore \underline{\text{0k.}}$$

b) C-LINE METHOD :=

$$P_e = 990 \text{ kN}$$

$$M_T = 787 \text{ kN-m}$$

$$a = \frac{787}{990} = 0.795 \text{ m}$$

$$e' = a - e = 79.49 - 33.3 = 46.19 \text{ cm.}$$

$$f^t = \frac{-990 \text{ kN}}{2381 \text{ cm}^2} \left(1 + \frac{46.19 \times 51.2}{891} \right) \approx 15.1 \text{ MPa (C)}$$

$$f_b = \frac{-990 \text{ kN}}{2381 \text{ cm}^2} \left(1 - \frac{46.19 \times 40.2}{891} \right) = 4.5 \text{ MPa (T)}$$

c) LOAD BALANCING METHOD :=

$$P' = P_e = 990 \text{ kN}$$

$$a = 33.3 \text{ cm} = e$$

$$W_b = \frac{8P'a}{l^2} = \frac{8(990) \times \frac{33.3}{100}}{(10.4)^2} = 24.38 \text{ kN/m}$$

$$W_{ub} = 52.6 + 5.6 - 24.38 = 33.82 \text{ kN/m.}$$

$$M_{ub} = \frac{W_{ub} \cdot l^2}{8} = \frac{33.82 \times (10.4)^2}{8} = 457.25 \text{ kN-m}$$

$$f^t = -\frac{P'}{A_c} - \frac{M_{yb}}{S^t} = \frac{-990}{2381} - \frac{457.25 \times 10^2}{41410} \approx 15.1 \text{ MPa (C)}$$

$$f_b = -\frac{P'}{A_c} + \frac{M_{yb}}{S_b} = \frac{-990}{2381} + \frac{457.25 \times 10^2}{52766} = 4.5 \text{ MPa (T)}$$

$$< f_t = 6.4 \text{ MPa}$$

$\therefore \text{O.K.}$

- 1.3 A simply supported pretensioned pretopped double T-beam for a floor has a span of 70 ft (21.3 m) and the geometrical dimensions shown in Figure P1.3. It is subjected to a gravity live-load intensity $W_L = 480$ plf (7 kN/m), and the prestressing tendon has an eccentricity at midspan of $e_c = 19.96$ in. (494 mm). Compute the concrete extreme fiber stresses in this beam at transfer and at service load, and verify whether they are within the permissible limits. Assume that all permissible stresses and materials used are the same as in example 1.1. The section properties are:

Section Properties

Untopped

A_c	=	1185 in. ²
I_g	=	109,621 in. ⁴
C_b	=	25.65 in.
C_t	=	8.35 in.
S_b	=	4274 in. ³
S_t	=	13,128 in. ³
W_D	=	1234 plf
		82 psf
V/S	=	2.45 in.

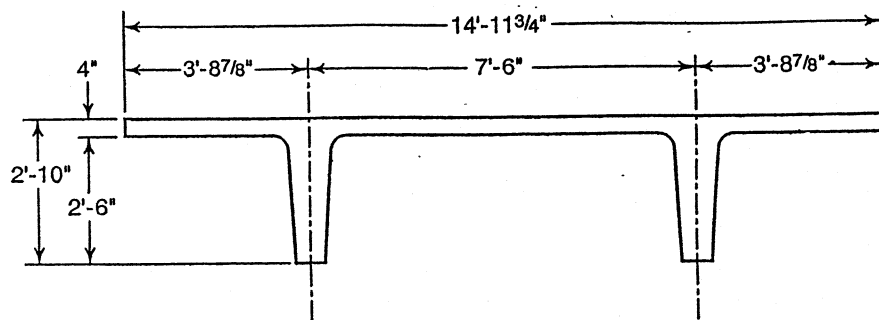


Figure P1.3.

Design the prestressing steel needed using $\frac{1}{2}$ -in. dia stress-relieved seven-wire strands. Use the three methods of analysis discussed in this chapter in your solution.

SOLUTION:

$$l = 70 \text{ ft}$$

$$W_L = 480 \text{ lb/ft}$$

$$e_c = 19.96 \text{ in}$$

$$f_c' = 6000 \text{ psi}$$

$$f_c = 2700 \text{ psi}$$

$$f_t = 12\sqrt{f_c'} = 930 \text{ psi}$$

$$f_{pu} = 270,000 \text{ psi}$$

$$f_{pi} = 189,000 \text{ psi}$$

$$f_{pe} = 145,000 \text{ psi}$$

$$A_c = 1185 \text{ in}^2$$

$$I_g = 109,621 \text{ in}^4$$

$$C_b = 25.65 \text{ in}$$

$$C_t = 8.35 \text{ in}$$

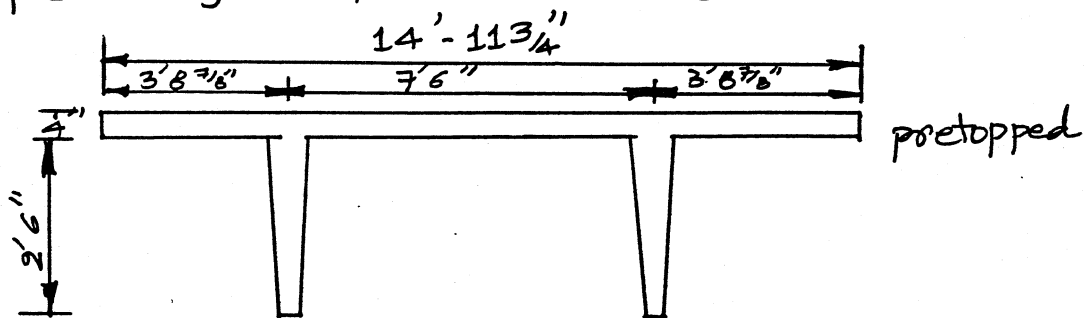
$$r^2 = I/A = 92.5 \text{ in}^2$$

$$S_b = 4274 \text{ in}^3$$

$$S_t = 13,128 \text{ in}^3$$

$$W_D = 1234 \text{ lb/ft}$$

$$V/S = 2.45 \text{ in}$$



Assume $16 - \frac{1}{2}$ " dia seven wire tendons are used.

Initial Conditions @ Prestressing:

$$A_{ps} = 16 \times 0.153 = 2.45 \text{ in}^2$$

$$P_i = A_{ps} \cdot f_{pi} = 2.45 \times 189,000 = 463,050 \text{ lb.}$$

$$P_e = A_{ps} \cdot f_{pe} = 2.45 \times 145,000 = 355,250 \text{ lb.}$$

Midspan self-wt. D.L. moment

$$= \frac{w l^2}{8} = \frac{1234(70)^2}{8} \times 12 = 9,069,900 \text{ in-lb}$$

$$f^t = -\frac{P_i}{A_c} \left(1 - \frac{e \cdot c}{r^2}\right) - \frac{M_D}{S^t} = -\frac{463,050}{1185} \left(1 - \frac{19.96 \times 8.35}{92.5}\right) - \frac{9,069,900}{13,128}$$

$$= 313.31 - 690.88 = -377.57 \text{ psi (C)}$$

$$F_b = -\frac{463,050}{1185} \left(1 + \frac{19.96 \times 25.65}{92.5}\right) + \frac{9,069,900}{4274}$$

$$= -431.4 \text{ psi (C)}$$

Assuming $f_{ci}' = 4800 \text{ psi}$

$$f_{ci} = 0.6 f_{ci}' = 2880 \text{ psi.}$$

$$\text{then } -431.4 < -377.57 < f_{ci} = 2880 \text{ psi}$$

∴ o.k.

FINAL Condition @ Service Load: =

$$M_L = \frac{480(70)^2}{8} \times 12 = 3,528,000 \text{ in-lb.}$$

$$M_T = 3,528,000 + 9,069,900 = 12,597,900 \text{ in-lb.}$$