

POSTAL Book Package

2023

CIVIL ENGINEERING

RCC & Prestressed Concrete

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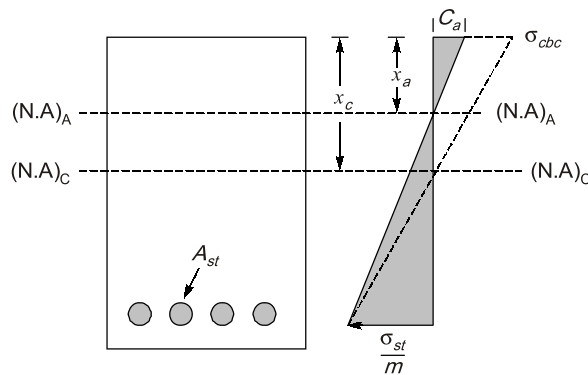
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Working Stress Method

Q1 Explain under reinforced and over reinforced failure of a reinforced concrete beam.

Solution:

Under reinforced failure: An 'under reinforced section' is one in which the area of tension steel (A_{st}) is such that the permissible stress is reached in the steel before the permissible stress is reached in the extreme fibre of the concrete.



In this case,

(i) $x_a < x_c$

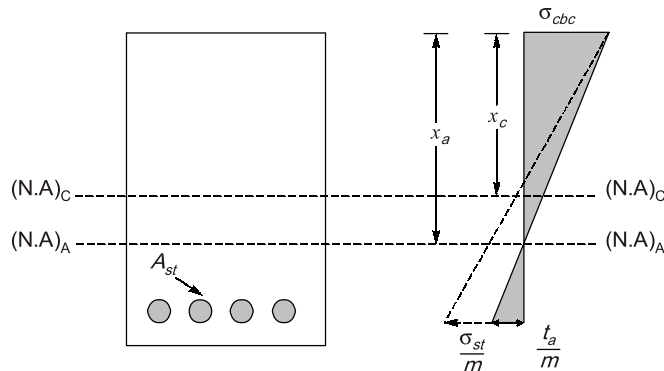
(ii) $C_a < \sigma_{cbc}$

(iii) $t_a = \sigma_{st}$

(iv) $A_{st \text{ provided}} < A_{st \text{ balanced}}$

A slight increase in the load, at this stage causes the beam to yield and elongate. In this case failure is due to failure of steel. It is known as tension failure or ductile failure. This gives sufficient warning before failure. Hence an under reinforced section is always preferred.

Over reinforced failure: An 'over reinforced' section is one in which the area of tension steel (A_{st}) is such that permissible stress in extreme fibre of concrete is reached before the permissible stress in the steel.



In this case,

(i) $x_a > x_c$

(ii) $C_a = \sigma_{cbc}$

(iii) $t_a < \sigma_{st}$

(iv) $A_{st \text{ provided}} > A_{st \text{ balanced}}$

The concrete fails in compression before the steel reaches its permissible stress. Hence this type of failure is known as compression failure or Brittle failure. The failure occurs without warning, hence an over reinforced section is always undesirable.

Q2 Analyze the balance concrete section:

- (i) When M20 concrete and Fe250 steel is used.
(ii) When M20 concrete and Fe415 steel is used.
Use W.S.M.

Solution:

(i)

$$\sigma_{cbc} = 7 \text{ N/mm}^2$$

$$\sigma_{st} = 140 \text{ N/mm}^2$$

$$m = \frac{280}{3\sigma_{cbc}}$$

From similarity condition in the stress diagram,

$$\frac{C}{T} = \frac{x_c}{d - x_c}$$

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7}$$

$$= 13.33$$

$$\therefore \frac{7}{140} = \frac{x_c}{d - x_c}$$

$$13.33$$

$$x_c = 0.4 d$$

Lever arm

$$LA = d - \frac{x_c}{3} = 0.87 d$$

$$\text{Moment of resistance} = \frac{1}{2} b x_c \cdot C_x \cdot L.A.$$

$$= \frac{b(0.4d)7}{2} \times 0.87 d = 1.213 b d^2$$

Equating total compression = Total tension

$$\frac{1}{2} b x_c \sigma_{cbc} = A_{st} \cdot \sigma_{st}$$

$$\frac{1}{2} b(0.4d) \times 7 = A_{st} \cdot 140$$

$$\frac{A_{st}}{bd} = 0.01$$

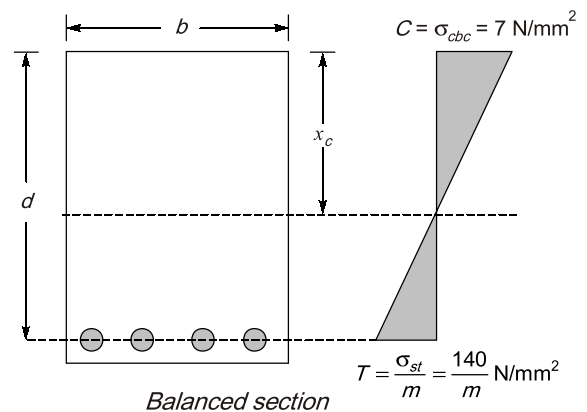
Hence, $A_{st} = 1\%$ of bd for balanced section
if $A_{st} < 1\%$ of $bd \Rightarrow$ underreinforced section
if $A_{st} > 1\%$ of $bd \Rightarrow$ overreinforced

(ii)

$$\sigma_{cbc} = 7 \text{ N/mm}^2$$

$$\sigma_{st} = 230 \text{ N/mm}^2$$

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$$



From similarity condition in stress diagram,

$$\frac{C}{T} = \frac{x_c}{d - x_c}$$

$$\frac{7}{230} = \frac{x_c}{d - x_c}$$

$$x_c = 0.289 d$$

$$\text{Lever arm L.A.} = d - \frac{x_c}{3} = 0.904 d$$

$$\begin{aligned} \text{Moment of resistance} &= \frac{1}{2} b x_c \cdot c \times \text{L.A.} \\ &= \frac{1}{2} \times b \times 0.289 d \times 7 \times 0.904 d \\ &= 0.914 b d^2 \end{aligned}$$

Equating total compression = Total tension

$$\frac{1}{2} b x_c \sigma_{cbc} = A_{st} \times \sigma_{st}$$

$$\frac{1}{2} b (0.289 d) \times 7 = A_{st} \times 230$$

$$\frac{A_{st}}{b d} = 0.0044$$

Hence, $A_{st} = 0.44\%$ of $b d$ for balanced section

if $A_{st} < 0.44\%$ of $b d \Rightarrow$ underreinforced section

if $A_{st} > 0.44\%$ of $b d \Rightarrow$ overreinforced

Q3 A rectangular RC section 25 cm wide and 50 cm overall deep is reinforced with 3-16 mm diameter HYSD bars at an effective cover of 4 cm from bottom face. If permissible stresses in concrete in bending compression and steel are 50 kg/cm² and 2300 kg/cm² respectively, modular ratio $m = 19$, calculate the moment of resistance of the section using WSM.

Solution:

Given data: $B = 25 \text{ cm} = 250 \text{ mm}$, $D = 50 \text{ cm} = 500 \text{ mm}$, $A_{st} = 3 \times \frac{\pi}{4} \times 16^2 = 603.19 \text{ mm}^2$, Effective cover = 4 cm = 40 mm, $\sigma_{cbc} = c = 50 \text{ kg/cm}^2 = 5 \text{ N/mm}^2$, $\sigma_{st} = t = 2300 \text{ kg/cm}^2 = 230 \text{ N/mm}^2$, $m = 19$, $d = D - 40 = 500 - 40 = 460 \text{ mm}$

(i) Calculating critical depth of NA:

$$\begin{aligned} x_c &= \left(\frac{mc}{t + mc} \right) d \\ &= \left(\frac{19 \times 5}{230 + (19 \times 5)} \right) 460 = 134.46 \text{ mm} \end{aligned}$$

(ii) Calculating actual depth of NA by equating moment of area of compression side and tension side about NA.

$$\Rightarrow \frac{B x_a^2}{2} = m A_{st} (d - x_a)$$

$$\Rightarrow \frac{250}{2} x_a^2 = 19 \times 603.19 \times (460 - x_a)$$

$$\Rightarrow x_a = 164.578 \text{ mm}$$

$\therefore x_a > x_c$, therefore section is over reinforced.

i.e. $C_a = \sigma_{cbc} = c$

$$t_a < \sigma_{st} = t$$

$$\therefore MR = B \cdot x_a \cdot \frac{C_a}{2} \left(d - \frac{x_a}{3} \right)$$

$$= 250 \times 164.578 \times \frac{5}{2} \times \left(460 - \frac{164.578}{3} \right)$$

$$MR = 41.67 \text{ kN-m}$$

Q4 A rectangular beam of overall cross-section $230 \times 600 \text{ mm}$ is provided. Imposed load = 50 kN/m over a span of 7 m . Check the adequacy of the section $m = 15$, $\sigma_{cbc} = 7 \text{ N/mm}^2$, $\sigma_{st} = 230 \text{ N/mm}^2$, $A_{bc} = 603.186 \text{ mm}^2$, $A_{st} = 2454.369 \text{ mm}^2$, clear cover = 50 mm .

Solution:

(i) Self-weight. = $0.23 \times 0.6 \times 25 = 3.45 \text{ kN/m}$
Total load = $3.45 + 50 = 53.45 \text{ kN/m}$

$$\text{Bending Moment (M)} = \frac{wl^2}{8} = \frac{53.45 \times 7^2}{8} = 327.381 \text{ kN-m}$$

(ii) Calculating actual depth for N.A.

$$B \cdot \frac{x_a^2}{2} + (1.5m - 1) A_{sc} (x_a - d_c) = m A_{st} (d - x_a)$$

Given, $A_{sc} = 603.186 \text{ mm}^2$
 $A_{st} = 2454.369 \text{ mm}^2$

$$\therefore 115x_a^2 + 21.5 \times 603.186 (x_a - 50) = 15 \times 2454.369 (550 - x_a)$$

$$\Rightarrow x_a = 261.632 \text{ mm}$$

Now, $\frac{C'}{x_a - d_c} = \frac{C_a}{x_a}$ $C' = 0.8088 C_a$

$$230 \times 261.632 \times \frac{C_a}{2} + (1.5 \times 15 - 1) A_{sc} C' = A_{st} \times \sigma_{st}$$

$$\Rightarrow C_a = 13.91 \text{ MPa} > 7 \text{ MPa} \quad (\text{Beam will fail})$$

Stress in compression concrete = $C' = 0.8088 \times 13.19 = 11.25 \text{ MPa}$
Stress in compression steel = $1.5 m C' = 253.125 \text{ MPa} > 190 \text{ MPa}$

Q5 Design a rectangular RCC beam for a simply supported span of 8 m subjected to a load of 45 kN/m (excluding the self wt.). Use M25 and Fe 500. Size of beam is restricted to $400 \times 850 \text{ mm}$

Solution:

$\sigma_{cbc} = 8.5 \text{ MPa}$ $\sigma_{st} = 275 \text{ MPa}$ $m = 11$

(i) Calculating Load and B.M.

D.L. = $0.4 \times 0.85 \times 25 = 8.5 \text{ kN/m}$
L.L. = 45 kN/m
Total load = 53.5 kN/m

$$\text{Bending Moment} = \frac{wl^2}{8} = 428 \text{ kN-m}$$

(ii) Calculating steel requirement

$$MR_1 = B \cdot x_c \cdot \frac{\sigma_{cbc}}{2} \left(d - \frac{x_c}{3} \right)$$

$$= \frac{1}{2} \times 8.5 \times 0.9154 \times 0.2537 \times 400 \times 800^2 = 252.98 \text{ kN-m}$$

For Balanced Section:

$$A_{st1} = \frac{MR_1}{\sigma_{st} \left(d - \frac{x_c}{3} \right)}$$

$$= \frac{252.98 \times 10^6}{275 \left(800 - \frac{202.96}{3} \right)} = 1256.13 \text{ mm}^2$$

$$MR_2 = 428 - 252.98 = 175.02 \text{ kN-m}$$

$$\Rightarrow \sigma_{st} \cdot A_{st2} (d - d_c) = 175.02 \times 10^6$$

$$\Rightarrow A_{st2} = 848.58 \text{ mm}^2$$

$$175.02 \times 10^6 = (1.5 \text{ m} - 1) A_{sc} (d - d_c)$$

$$\Rightarrow A_{sc} = \frac{15055.48}{C'}$$

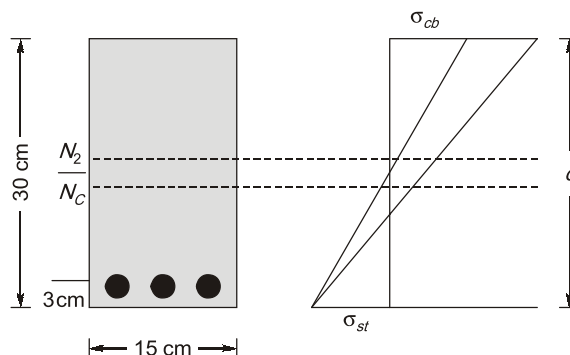
$$\frac{C'}{152.96} = \frac{C}{202.96}$$

$$C' = 6.406 \text{ MPa}$$

$$A_{sc} = 2350.2 \text{ mm}^2$$

$$A_{st} = A_{st1} + A_{st2} = 2104.61 \text{ mm}^2$$

Q6 A reinforced concrete beam of width 150 mm and over all depth 300 mm is reinforced with 3 numbers of 16 mm diameter bars. Effective cover to the reinforcement is 50 mm. Cube strength of concrete used is 200 kg/cm², yield stress of steel is 2100 kg/cm². Calculate its ultimate moment of resistance. By working stress method?

Solution:

Given:

 $\sigma_{cb} = 200 \text{ kg/cm}^2$, $\sigma_{st} = 2100 \text{ kg/cm}^2$; $b = 15 \text{ cm}$; effective depth, $d = 30 - 5 = 25 \text{ cm}$, $m = 18$

$$\text{Area of steel } A_{st} = 3 \times \frac{\pi}{4} (1.6)^2 = 6.032 \text{ cm}^2$$

(i) Critical Neutral Axis (x_c):

$$x_c = \frac{m\sigma_{cb}}{m\sigma_{cb} + \sigma_{st}} d$$

$$= \frac{18 \times 200}{18 \times 200 + 2100} = 0.63 d$$

(ii) Actual Neutral Axis (x_a):

By taking moment of area concrete + steel about N.A.

Let the distance of N.A. from top = x_a

Then,

$$bx_a \times \frac{n}{2} = A_{st} \times (d - x_a) \times m$$

$$\Rightarrow \frac{bx_a^2}{2} = A_{st} \times (d - x_a) \times m$$

$$\Rightarrow 15x_a^2 = 2 \times 6.032 (25 - x_a) \times 18$$

$$\Rightarrow 15x_a^2 + 217.152x_a - 5428.8 = 0$$

Divide the quadratic equation by 15

$$\therefore x_a^2 + 14.48x_a - 361.9 = 0$$

$$\therefore x_a = \frac{-14.48 \pm \sqrt{(14.48)^2 + 4 \times 361.9}}{2} = \frac{-14.48 + 40.70}{2}$$

$$\therefore x_a = 13.11 \text{ cm also } n = N_a d$$

$$\therefore N_a = \frac{x_a}{d}$$

$$\Rightarrow N_a = \frac{13.11}{25} = 0.52$$

Since $N_c > N_a$, hence the beam is under reinforced and steel will attain stress earlier to concrete.

\therefore Moment of resistance in steel

$$\boxed{\text{M.R.} = \sigma_{st} \times A_{st} \times j \times d}$$

where,

$$\boxed{j = 1 - \frac{N_a}{3}}$$

$$= 1 - \frac{0.52}{3} = 0.826$$

$$\therefore \text{M.R.} = 2100 \times 6.032 \times 0.826 \times 25$$

$$= 261577.68 \text{ kgcm}$$

Q7 A rectangular RC beam simply supported at ends over an effective span of 5.0 m carries a UDL of 2000 kg/m including its own weight. If $\sigma_{cbs} = 70 \text{ kg/cm}^2$, $\sigma_{st} = 1900 \text{ kg/cm}^2$ and $m = 13$, design the beam section for flexure only by WSM. The size of the beam is restricted to 40 cm wide \times 40 cm overall deep. Assume effective cover = 4.0 cm. Stress in compression reinforcement, if needed may be taken as 1.5 m times the stress in surrounding concrete.

Solution:

Given: $l_{\text{eff}} = 5 \text{ m}$, $w = 2000 \text{ kg/m} = 20 \text{ kN/m}$, $\sigma_{cbs} = c = 70 \text{ kg/cm}^2 = 7 \text{ N/mm}^2$, $t = \sigma_{st} = 1900 \text{ kg/cm}^2 = 190 \text{ N/mm}^2$, $m = 13$, $B = 40 \text{ cm} = 400 \text{ mm}$, $D = 40 \text{ cm} = 400 \text{ mm}$, Effective cover = 4.0 cm = 40 mm, $d = D - 40 = 400 - 40 = 360 \text{ mm}$

(i) Maximum $BM = \frac{w l_{\text{eff}}^2}{8} = \frac{20 \times 5 \times 5}{8} = 62.5 \text{ kN-m}$

(ii) Design constants:

$$k = \left(\frac{mc}{t + mc} \right)$$

$$= \frac{13 \times 7}{190 + (13 \times 7)} = 0.3238$$

$$j = 1 - \frac{k}{3}$$

$$= 0.8920$$

$$Q = \frac{1}{2} c j k$$

$$= \frac{1}{2} \times 7 \times 0.8920 \times 0.3238 = 1.011$$

(iii) M_R of the balanced section:

$$M_1 = Q B d^2$$

$$= 1.011 \times 400 \times 360 \times 360 = 52.41 \text{ kN-m}$$

(iv) $BM > M_1$, therefore a doubly reinforced section is required.

(v) Calculating area of steel for singly reinforced balanced section.

$$A_{st1} = \frac{M_1}{\sigma_{st} \left(d - \frac{x_a}{3} \right)}$$

$$= \frac{52.41 \times 10^6}{190 \left(360 - \frac{0.3238 \times 360}{3} \right)} \quad [\because x_a = x_c = kd]$$

$$A_{st1} = 858.94 \text{ mm}^2$$

(vi) A_{st2} , area of remaining tensile steel in the section with compression reinforcement

$$A_{st2} = \frac{M_2}{\sigma_{st} (d - d_c)}$$

$$= \frac{BM - M_1}{\sigma_{st} (d - d_c)} = \frac{(62.5 - 52.41) \times 10^6}{190 \times (360 - 40)}$$

$$A_{st2} = 165.95 \text{ mm}^2$$

(vii) Total tensile steel, $A_{st} = A_{st1} + A_{st2} = 858.94 + 165.95 = 1024.89 \text{ mm}^2$.

(viii) A_{sc} , area of compression reinforcement,

$$A_{sc} = \frac{m (d - x_a)}{(1.5 m - 1) (x_a - d_c)} \times A_{st2}$$

$$= \frac{13 \times (360 - 116.57)}{(1.5 \times 13 - 1) (116.57 - 40)} \times 165.95$$

$$A_{sc} = 370.74 \text{ mm}^2$$