1. INTRODUCTION

CONCRETE

1. **Modulus of elasticity of concrete**

$$E_c = 5000\sqrt{f_{ck}}$$

where f_{ck} = characteristic strength of concrete

2. **Tensile strength of concrete in flexure**

$$f_{ckt} = 0.7\sqrt{f_{ck}}$$

> **Remember:** Characteristic strength of concrete is the value of strength of concrete below which not more than 5% of test results are expected to fail.

3. **Permissible value of strength in concrete**

Grade	Direct tensile strength (f_{ckt})	Compression: Direct (σ_{cc})	Compression: Bending (σ_{cbc})	Bondstress (τ_{bd}): WSM	Bondstress (τ_{bd}): LSM
M15	2	4	5	0.6	1
M20	2.8	5	7	0.8	1.2
M25	3.2	6	8.5	0.9	1.4
M30	3.6	8	10.0	1.0	1.5
M35	4.0	9	11.5	1.1	1.7
M40	4.4	10	13.0	1.2	1.9

- τ_{bd} given in table is only for plain mild steel bar in tension.
- τ_{bd} value should be increased by 60% for deformed bars both in LSM and WSM.
- For bars in compression the value should be increased by 25%.

- **Steel**
  1. Young's modulus of all type of steel is 2×10^5 N/mm^2.
- **Type of steel**
  1. Mild steel → Fe 250

     Here, 250 is the characteristic strength of mild steel bars.

     Also, $f_y = 250$ N/mm^2

  2. TMT bars

     Fe 415

     Fe 500

  3. Permissible stresses in steel

Table. Permissible Stresses in Steel Reinforcement

(Clauses B-2.2, B-2.2.1, B-2.3 *and* B-4.2)

Sl. No.	Type of Stress in Steel Reinforcement	Permissible stresses in N/mm^2: Mild steel bars conforming to grade 1 of IS 432 (part-1)	Medium tensile steel conforming to IS 432 (part-1)	High yield strength deformed bars conforming to IS 1786 (Grade Fe 415)
(1)	(2)	(3)	(4)	(5)
(i)	Tension (σ_{xt} or σ_{xv})			
	(a) Up to and including 20 mm	140	half the guaranteed yield stress subject to a maximum of 190	230
	(b) Over 20 mm	130		230
(ii)	Compression in column	130	130	190
(iii)	Compression in bars in a beam or slab when the compressive resistance of the concrete is taken into account	The calculated compressive stress in the surrounding concrete multiplied by 1.5 times the modular ratio or σ_{xc} whichever is lower		
(iv)	Compression in bars in a beam or slab where the compressive resistance of the concrete is not taken into account:			
	(a) Up to and including 20 mm	140	Half the guaranteed yield stress subject to a maximum of 190	190
	(b) Over 20 mm	130		190

> **NOTE**
> 1. For high yield strength deformed bars of Grade Fe 500 the permissible stress in direct tension and flexural tension shall be $0.55 f_y$. The permissible stresses for shear and compression reinforcement shall be as for Grade Fe 415.
> 2. For welded wire fabric conforming to IS 1566, the permissible value in tension σ_{yt}, is 230 N/mm^2.

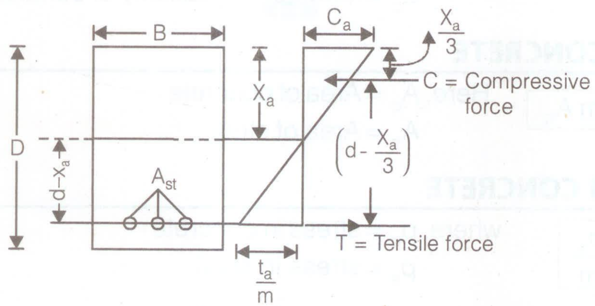
(ii) when $X_a > X_c$ → It is a over reinforced section.

(iii) when $X_a < X_c$ → It is a under reinforced section.

MOMENT OF RESISTANCE (M_r)

(i) For balanced section ($X_a = X_c$)

$$M_r = BX_a \cdot \frac{\sigma_{cbc}}{2}\left(d - \frac{X_a}{3}\right)$$



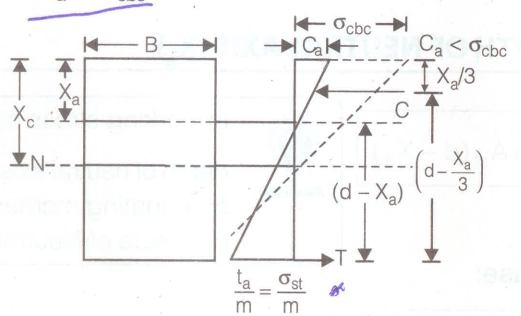
(Stress diagram)

and $$M_r = \sigma_{st} \cdot A_{st}\left(d - \frac{X_a}{3}\right), \quad \left(d - \frac{X_a}{3}\right) = \text{Lever Arm}$$

(ii) For under reinforced section ($X_a < X_c$)

$$M_r = BX_a \cdot \frac{C_a}{2}\left(d - \frac{X_a}{3}\right), \quad M_r = \sigma_{st} \cdot A_{st}\left(d - \frac{X_a}{3}\right)$$

Here, $C_a < \sigma_{cbc}$



(Stress diagram)

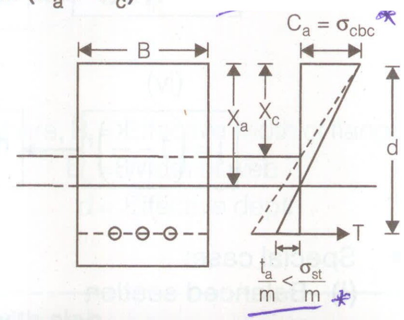
Here, $$C_a = \frac{\sigma_{st} \cdot X_a}{m(d - X_a)}$$

(iii) For over-reinforcement section ($X_a > X_c$)

$$\frac{\sigma_{cbc}}{X_a} = \frac{t_a/m}{d - X_a}$$

$$M_r = BX_a \cdot \frac{\sigma_{cbc}}{2}\left(d - \frac{X_a}{3}\right)$$

$$M = t_a A_{st}\left(d - \frac{X_a}{3}\right)$$



DOUBLY REINFORCED SECTION

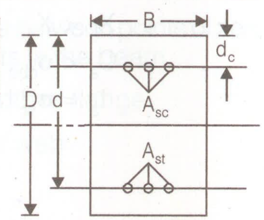
CRITICAL DEPTH OF NEUTRAL AXIS, (X_c)

$$X_c = \frac{mc}{t + mc} \cdot d$$

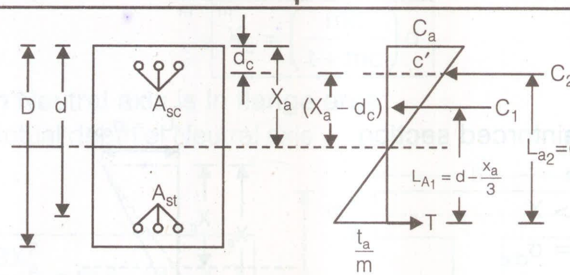
ACTUAL DEPTH OF NEUTRAL AXIS, (X_a)

$$\frac{BX_a^2}{2} + (1.5m - 1)\,A_{sc}\,(X_a - d_c) = m\,A_{st}(d - X_a)$$

Here, X_a = Actual depth of Neutral axis



MOMENT OF RESISTANCE (M_r)



$$M_r = C_1(LA_1) + C_2\,LA_2$$

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$$M_r = BX_a\,\frac{C_a}{2}\left(d - \frac{X_a}{3}\right) + (1.5\,m - 1)\,A_{sc} \cdot c'(d - d_c)$$

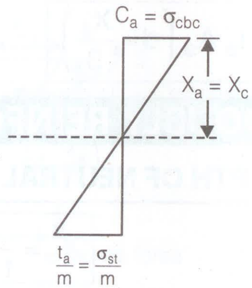
DESIGN STEPS

(i) $M_r = QBd^2$ → (ii) $Q = \frac{1}{2} c \cdot j \cdot k$ → (iii) $k = \frac{mc}{t + mc}$ $\approx \frac{280}{280+3t}$

(iv) $j = \left(1 - \frac{k}{3}\right)$ → (v) $m = \frac{280}{3\sigma_{cbc}}$ → (vi) $X_a = k \cdot d$

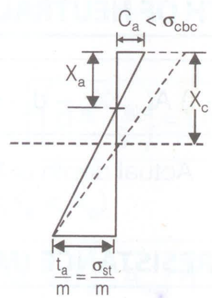
- Special case:
  (i) Balanced section

$X_a = X_c$
$\sigma_a = \sigma_{cbc}$
$t_a = \sigma_{st}$



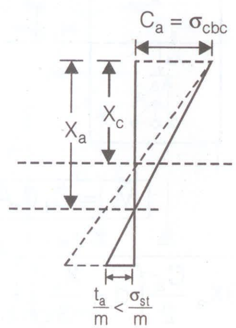
(ii) Under reinforced section

$X_a < X_c$
$C_a < \sigma_{cbc}$
$t_a = \sigma_{st}$

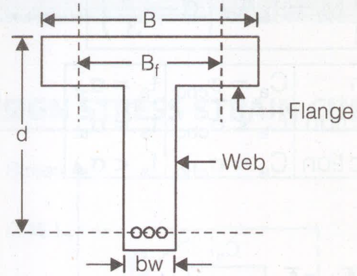


(iii) Over reinforced section

$X_a > X_c$
$C_a = \sigma_{cbc}$
$t_a < \sigma_{st}$



T-BEAM



where, B_f = Effective width of flange
b_w = Width of web
d = Effective depth

EFFECTIVE WIDTH OF FLANGE

(a) For beam casted monolithic with slab

$$B_f = \text{Minimum}\begin{cases}\left(\frac{l_0}{6} + b_w + 6d_f\right) \\ \text{or} \\ b_w + \frac{l_1}{2} + \frac{l_2}{2}\end{cases}$$

(b) For Isolated T-beam

$$B_f = \frac{l_0}{\left(\frac{l_0}{B} + 4\right)} + b_w$$

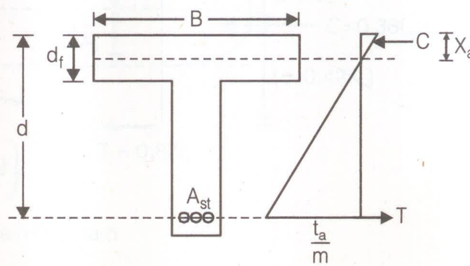
Here, l_0 = Distance between points of zero moments in the beam
B = Total width of flange
b_w = Width of web

CRITICAL DEPTH OF NEUTRAL AXIS (X_c)

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

- When Neutral axis is in flange area
  (i) Actual depth of Neutral axis

$$\frac{BX_a^2}{2} = m A_{st}(d - X_a)$$



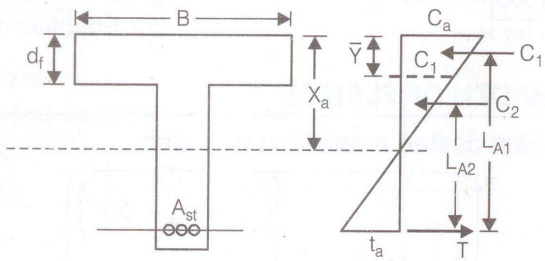
Here, X_a = Actual depth of Neutral axis

(ii) Moment of resistance (M_r)

$$M_r = BX_a \cdot \frac{C_a}{2}\left(d - \frac{X_a}{3}\right), \quad M_r = t_a A_{st}\left(d - \frac{X_a}{3}\right)$$

$X_a = X_c$	Balanced section	$C_a = \sigma_{cbc}$	$t_a = \sigma_{st}$
$X_a < X_c$	Underreinforced section	$C_a < \sigma_{cbc}$	$t_a = \sigma_{st}$
$X_a > X_c$	Over – reinforced section	$C_a = \sigma_{cbc}$	$t_a < \sigma_{st}$

- **When Neutral axis is in web area**



(Stress diagram)

(i) For actual depth of neutral axis

$$B_f d_f \cdot \left(X_a - \frac{d_f}{2}\right) = mA_{st}(d - X_a)$$ By neglecting web area

$$B_f d_f \cdot \left(X_a - \frac{d_f}{2}\right) + bw\frac{(X_a - d_f)^2}{2} = mA_{st}(d - X_a)$$ By considering web area

(ii) Moment of resistance (M_r)

$$M_r = B_f \cdot d_f\left(\frac{C_a + C_1}{2}\right)\left[d - \left(\frac{C_a + 2C_1}{C_a + C_1}\right)\frac{d_f}{3}\right] + b_w(X_a - d_f) \cdot \frac{C_1}{2}\left[d - d_f - \frac{(X_a - d_f)}{3}\right]$$

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