6. WORKING STRESS DESIGN

6.1 FLEXURAL MEMBERS

Design of flexural members by working stress method is based on the well known assumptions given in *43.3* of the Code. The value of the modular ratio, m is given by

$$m = \frac{280}{3\,\sigma_{cbc}} = \frac{93{\cdot}33}{\sigma_{cbc}}$$

Therefore, for all values of σ_{cbc} we have

$$m\,\sigma_{cbc} = 93{\cdot}33$$

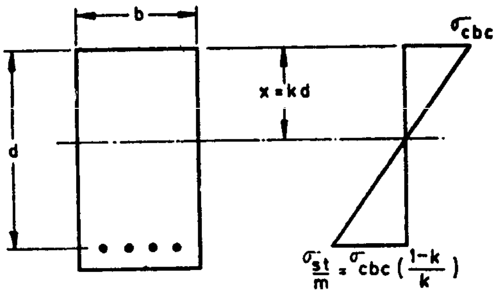

FIG. 9 BALANCED SECTION (WORKING STRESS DESIGN)

6.1.1 Balanced Section (*see* Fig. 9)

Stress in steel $= \sigma_{st} = m\sigma_{cbc}\left(\frac{1}{k} - 1\right)$

$$\left(\frac{1}{k} - 1\right) = \frac{\sigma_{st}}{m\sigma_{cbc}} = \frac{\sigma_{st}}{93{\cdot}33}$$

$$\frac{1}{k} = \frac{\sigma_{st}}{93{\cdot}33} + 1 = \frac{\sigma_{st} + 93{\cdot}33}{93{\cdot}33}$$

$$k = \frac{93{\cdot}33}{\sigma_{st} + 93{\cdot}33}$$

The value of k for balanced section depends only on σ_{st}. It is independent of σ_{cbc}. Moment of resistance of a balanced section is given by $M_{bal} = \frac{bd^2}{2}\sigma_{cbc}\,k\left(1 - \frac{k}{3}\right)$. The values of M_{bal}/bd^2 for different values of σ_{cbc} and σ_{st} are given in Table K.

TABLE K MOMENT OF RESISTANCE FACTOR M/bd^2, N/mm² FOR BALANCED RECTANGULAR SECTION

σ_{cbc} N/mm²	σ_{st}, N/mm² 140	230	275
5·0	0·87	0·65	0·58
7·0	1·21	0·91	0·81
8·5	1·47	1·11	0·99
10·0	1·73	1·30	1·16

Reinforcement percentage $p_{t,bal}$ for balanced section is determined by equating the compressive force and tensile force.

$$\frac{\sigma_{cbc}\,kdb}{2} = \frac{p_{t,bal}\,bd\,\sigma_{st}}{100}$$

$$p_{t,bal} = \frac{50\,k\cdot\sigma_{cbc}}{\sigma_{st}}$$

The value of $p_{t,bal}$ for different values of σ_{cbc} and σ_{st} are given in Table L.

TABLE L PERCENTAGE OF TENSILE REINFORCEMENT $p_{t,bal}$ FOR SINGLY REINFORCED BALANCED SECTION
(*Clause 6.1.1*)

σ_{cbc} N/mm²	σ_{st} N/mm² 140	230	275
5·0	0·71	0·31	0·23
7·0	1·00	0·44	0·32
8·5	1·21	0·53	0·39
10·0	1·43	0·63	0·46

6.1.2 Under Reinforced Section

The position of the neutral axis is found by equating the moments of the equivalent areas.

$$bkd\frac{kd}{2} = \frac{p_t\,bd}{100}\,m\,(d - kd)$$

$$bd^2\frac{k^2}{2} = bd^2\,\frac{p_t m}{100}(1 - k)$$

$$k^2 = \frac{p_t m}{50}(1 - k)$$

$$k^2 + \frac{p_t mk}{50} - \frac{p_t m}{50} = 0.$$

The positive root of this equation is given by

$$k = -\frac{p_t\,m}{100} + \sqrt{\frac{p^2_t\,m^2}{(100)^2} + \frac{p_t\,m}{50}}$$

This is the general expression for the depth of neutral axis of a singly reinforced section. Moment of resistance of an under-reinforced section is given by

$$M = bd^2\,\frac{p_t\,\sigma_{st}}{100}\left(1 - \frac{k}{3}\right)$$

Values of the moment of resistance factor M/bd^2 have been tabulated against p_t in

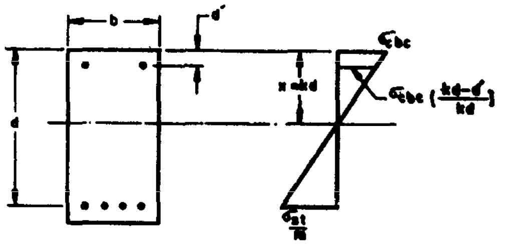

FIG. 10 DOUBLY REINFORCED SECTION (WORKING STRESS DESIGN)

Tables 68 to 71. The Tables cover four grades of concrete and five values of σ_{st}.

6.1.3 Doubly Reinforced Section — Doubly reinforced sections are adopted when the bending moment exceeds the moment of resistance of a balanced section.

$$M = M_{bal} + M'$$

The additional moment M' is resisted by providing compression reinforcement and additional tensile reinforcement. The stress in the compression reinforcement is taken as 1·5 m times the stress in the surrounding concrete.

Taking moment about the centroid of tensile reinforcement,

$$M' = \frac{p_c\, bd}{100} (1{\cdot}5\, m - 1)\ \sigma_{cbc} \times \left(\frac{kd - d'}{kd}\right)(d - d')$$

$$= \frac{p_c}{100} (1{\cdot}5\, m - 1)\ \sigma_{cbc} \times \left(1 - \frac{d'}{kd}\right)\left(1 - \frac{d'}{d}\right) bd^2$$

Equating the additional tensile force and additional compressive force,

$$bd\,\frac{(p_t - p_{t,bal})}{100}\ \sigma_{st}$$

$$= \frac{p_c\, bd}{100} (1{\cdot}5\, m - 1)\sigma_{cbc}\left(1 - \frac{d'}{kd}\right)$$

or $(p_t - p_{t,bal})\ \sigma_{st}$

$$= p_c\,(1{\cdot}5\, m - 1)\ \sigma_{cbc}\left(1 - \frac{d'}{kd}\right)$$

$$\therefore\quad M = M_{bal} + \frac{(p_t - p_{t,bal})}{100}\ \sigma_{st} \times \left(1 - \frac{d'}{d}\right) bd^2$$

Total tensile reinforcement A_{st} is given by

$$A_{st} = A_{st1} + A_{st2}$$

where $A_{ts1} = p_{t,bal}\ \frac{bd}{100}$

and $A_{st2} = \frac{M'}{\sigma_{st}\,(d - d')}$

The compression reinforcement can be expressed as a ratio of the additional tensile reinforcement area A_{st2}.

$$\frac{A_{sc}}{A_{st2}} = \frac{p_c}{(p_t - p_{t,bal})}$$

$$= \frac{\sigma_{st}}{\sigma_{cbc}}\ \frac{1}{(1{\cdot}5\, m - 1)\,(1 - d'/kd)}$$

Values of this ratio have been tabulated for different values of d'/d and σ_{cbc} in Table M. The table includes two values of σ_{st}. The values of p_t and p_c for four values of d'/d have been tabulated against M/bd^2 in *Tables 72 to 79.* Tables are given for four grades of concrete and two grades of steel.

TABLE M VALUES OF THE RATIO A_{sc}/A_{st2}
(*Clause 6.1.3*)

σ_{st} N/mm²	σ_{cbc} N/mm²	d'/d 0·05	0·10	0·15	0·20
140	5·0	1·19	1·38	1·66	2·07
	7·0	1·20	1·40	1·68	2·11
	8·5	1·22	1·42	1·70	2·13
	10·0	1·23	1·44	1·72	2·15
230	5·0	2·06	2·61	3·55	5·54
	7·0	2·09	2·65	3·60	5·63
	8·5	2·12	2·68	3·64	5·69
	10·0	2·14	2·71	3·68	5·76

6.2 COMPRESSION MEMBERS

Charts 86 and 87 are given for determining the permissible axial load on a pedestal or short column reinforced with longitudinal bars and lateral ties. Charts are given for two values of σ_{sc}. These charts have been made in accordance with *45.1* of the Code.

According to *46.3* of the Code, members subject to combined axial load and bending designed by methods based on elastic theory should be further checked for their strength under ultimate load conditions. Therefore it would be advisable to design such members directly by the limit state method. Hence, no design aids are given for designing such members by elastic theory.

6.3 SHEAR AND TORSION

The method of design for shear and torsion by working stress method are similar to the limit state method. The values of permissible shear stress in concrete are given in *Table 80*. *Tables 81 and 82* are given for design of shear reinforcement.

6.4 DEVELOPMENT LENGTH AND ANCHORAGE

The method of calculating development length is the same as given under limit state design. The difference is only in the values of bond stresses. Development lengths for plain bars and two grades of deformed bars are given in *Tables 83 to 85*.

Anchorage value of standard hooks and bends as given in *Table 67* are applicable to working stress method also.