2. FLEXURAL MEMBERS

2.1 ASSUMPTIONS

The basic assumptions in the design of flexural members for the limit state of collapse are given below (*see 37.1* of the Code):

a) Plane sections normal to the axis of the member remain plane after bending. This means that the strain at any point on the cross section is directly proportional to the distance from the neutral axis.

b) The maximum strain in concrete at the outermost compression fibre is 0·003 5.

c) The design stress-strain relationship for concrete is taken as indicated in Fig. 1.

d) The tensile strength of concrete is ignored.

e) The design stresses in reinforcement are derived from the strains using the stress-strain relationships given in Fig. 2 and 3.

f) The strain in the tension reinforcement is to be not less than

$$\frac{0{\cdot}87 f_y}{E_s} + 0{\cdot}002.$$

This assumption is intended to ensure ductile failure, that is, the tensile reinforcement has to undergo a certain degree of inelastic deformation before the concrete fails in compression.

2.2 MAXIMUM DEPTH OF NEUTRAL AXIS

Assumptions (b) and (f) govern the maximum depth of neutral axis in flexural members. The strain distribution across a member corresponding to those limiting conditions is shown in Fig. 4. The maximum depth of neutral axis $x_{u,\,max}$ is obtained directly from the strain diagram by considering similar triangles.

$$\frac{x_{u,max}}{d} = \frac{0{\cdot}003\,5}{(0{\cdot}005\,5 + 0{\cdot}87\,f_y/E_s)}$$

The values of $\frac{x_{u,max}}{d}$ for three grades of reinforcing steel are given in Table B.

TABLE B VALUES OF $\frac{x_{u,max}}{d}$ FOR DIFFERENT GRADES OF STEEL

(*Clause 2.2*)

f_y, N/mm²	250	415	500
$\frac{x_{u,max}}{d}$	0·531	0·479	0·456

2.3 RECTANGULAR SECTIONS

The compressive stress block for concrete is represented by the design stress-strain curve as in Fig. 1. It is seen from this stress block (*see* Fig. 4) that the centroid of compressive force in a rectangular section lies

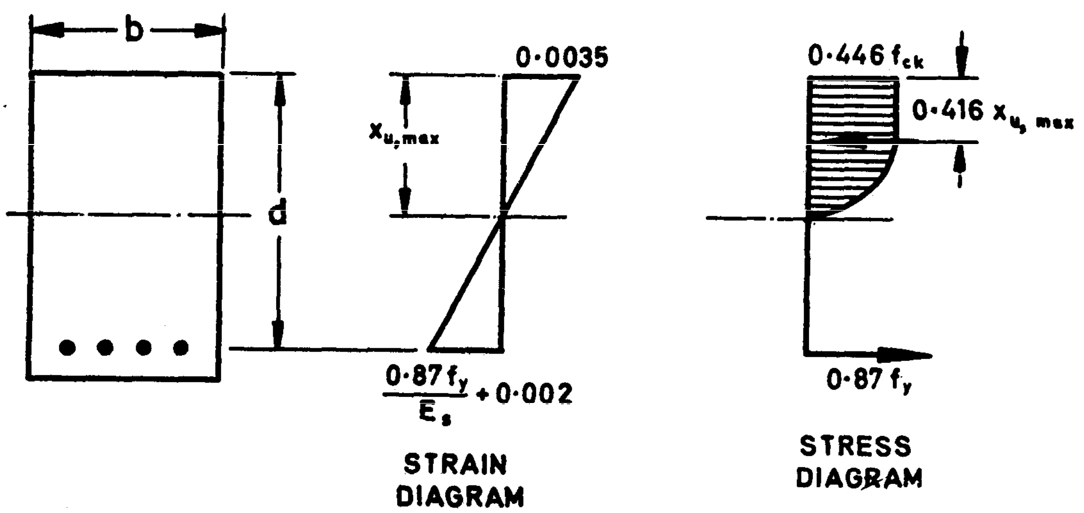

FIG. 4 SINGLY REINFORCED SECTION

at a distance of 0·416 x_u (which has been rounded off to 0·42 x_u in the code) from the extreme compression fibre; and the total force of compression is 0·36 $f_{ck}\, bx_u$. The lever arm, that is, the distance between the centroid of compressive force and centroid of tensile force is equal to $(d - 0{\cdot}416\, x_u)$. Hence the upper limit for the moment of resistance of a singly reinforced rectangular section is given by the following equation:

$$M_{u,lim} = 0{\cdot}36 f_{ck}\, bx_{u,max} \times (d - 0{\cdot}416\, x_{u,max})$$

Substituting for $x_{u,max}$ from Table B and transposing $f_{ck}\, bd^2$, we get the values of the limiting moment of resistance factors for singly reinforced rectangular beams and slabs. These values are given in Table C. The tensile reinforcement percentage, $p_{t,lim}$ corresponding to the limiting moment of resistance is obtained by equating the forces of tension and compression.

$$\frac{p_{t,lim}\, bd\,(0{\cdot}87 f_y)}{100} = 0{\cdot}36 f_{ck}\, bx_{u,max}$$

Substituting for $x_{u,max}$ from Table B, we get the values of $p_{t,lim}\ f_y/f_{ck}$ as given in Table C.

TABLE C LIMITING MOMENT OF RESISTANCE AND REINFORCEMENT INDEX FOR SINGLY REINFORCED RECTANGULAR SECTIONS

(Clause 2.3)

f_y, N/mm²	250	415	500
$\frac{M_{u,lim}}{f_{ck}\, bd^2}$	0·149	0·138	0·133
$\frac{p_{t,lim}\, f_y}{f_{ck}}$	21·97	19·82	18·87

The values of the limiting moment of resistance factor M_u/bd^2 for different grades of concrete and steel are given in Table D. The corresponding percentages of reinforcements are given in Table E. These are the maximum permissible percentages for singly reinforced sections.

TABLE D LIMITING MOMENT OF RESISTANCE FACTOR $M_{u,lim}/bd^2$, N/mm² FOR SINGLY REINFORCED RECTANGULAR SECTIONS

(Clause 2.3)

f_{ck}, N/mm²	f_y, N/mm²		
	250	415	500
15	2·24	2·07	2·00
20	2·98	2·76	2·66
25	3·73	3·45	3·33
30	4·47	4·14	3·99

TABLE E MAXIMUM PERCENTAGE OF TENSILE REINFORCEMENT $p_{t,lim}$ FOR SINGLY REINFORCED RECTANGULAR SECTIONS

(Clause 2.3)

f_{ck}, N/mm²	f_y, N/mm²		
	250	415	500
15	1·32	0·72	0·57
20	1·76	0·96	0·76
25	2·20	1·19	0·94
30	2·64	1·43	1·13

2.3.1 Under-Reinforced Sections

Under-reinforced section means a singly reinforced section with reinforcement percentage not exceeding the appropriate value given in Table E. For such sections, the depth of neutral axis x_u will be smaller than $x_{u,max}$. The strain in steel at the limit state of collapse will, therefore, be more than $\frac{0{\cdot}87 f_y}{E_s} + 0{\cdot}002$ and, the design stress in steel will be $0{\cdot}87 f_y$. The depth of neutral axis is obtained by equating the forces of tension and compression.

$$\frac{p_t\, bd}{100}(0{\cdot}87 f_y) = 0{\cdot}36 f_{ck}\, b\, x_u$$

$$\frac{x_u}{d} = \left(\frac{p_t}{100}\right)\frac{0{\cdot}87 f_y}{0{\cdot}36 f_{ck}}$$

The moment of resistance of the section is equal to the product of the tensile force and the lever arm.

$$M_u = \frac{p_t\, bd}{100}(0{\cdot}87 f_y)(d - 0{\cdot}416\, x_u)$$

$$= 0{\cdot}87 f_y\left(\frac{p_t}{100}\right)\left(1 - 0{\cdot}416\frac{x_u}{d}\right)bd^2$$

Substituting for $\frac{x_u}{d}$ we get

$$M_u = 0{\cdot}87 f_y\left(\frac{p_t}{100}\right) \times \left[1 - 1{\cdot}005\,\frac{f_y}{f_{ck}}\left(\frac{p_t}{100}\right)\right]bd^2$$

2.3.1.1 *Charts 1* to *18* have been prepared by assigning different values to M_u/b and plotting d *versus* p_t. The moment values in the charts are in units of kN.m per metre width. Charts are given for three grades of steel and two grades of concrete, namely M 15 and M 20, which are most commonly used for flexural members. Tables 1 to 4 cover a wider range, that is, five values of f_y and four grades of concrete up to M 30. In these tables, the values of percentage of reinforcement p_t have been tabulated against M_u/bd^2.

2.3.1.2 The moment of resistance of slabs, with bars of different diameters and spacings are given in Tables 5 to 44. Tables are given for concrete grades M 15 and M 20, with two grades of steel. Ten different thicknesses ranging from 10 cm to 25 cm, are included. These tables take into account *25.5.2.2* of the Code, that is, the maximum bar diameter does not exceed one-eighth the thickness of the slab. Clear cover for reinforcement has been taken as 15 mm or the bar diameter, whichever is greater [*see 25.4.1*(d) of the Code]. In these tables, the zeros at the top right hand corner indicate the region where the reinforcement percentage would exceed $p_{t,lim}$; and the zeros at the lower left hand corner indicate the region where the reinforcement is less than the minimum according to *25.5.2.1* of the Code.

Example 1 Singly Reinforced Beam

Determine the main tension reinforcement required for a rectangular beam section with the following data:

Size of beam	30 × 60 cm
Concrete mix	M 15
Characteristic strength of reinforcement	415 N/mm²
*Factored moment	170 kN.m

Assuming 25 mm dia bars with 25 mm clear cover,

$$\text{Effective depth} = 60 - 2{\cdot}5 - \frac{2{\cdot}5}{2} = 56{\cdot}25 \text{ cm}$$

From Table D, for $f_y = 415$ N/mm² and $f_{ck} = 15$ N/mm²

$$\begin{aligned} M_{u,lim}/bd^2 &= 2{\cdot}07 \text{ N/mm}^2 \\ &= \frac{2{\cdot}07}{1\,000} \times (1\,000)^2 \\ &= 2{\cdot}07 \times 10^3 \text{ kN/m}^2 \\ \therefore \quad M_{u,lim} &= 2{\cdot}07 \times 10^3 bd^2 \\ &= 2{\cdot}07 \times 10^3 \times \frac{30}{100} \times \left(\frac{56{\cdot}25}{100}\right)^2 \\ &= 196{\cdot}5 \text{ kN.m} \end{aligned}$$

Actual moment of 170 kN.m is less than $M_{u,lim}$. The section is therefore to be designed as a singly reinforced (under-reinforced) rectangular section.

METHOD OF REFERRING TO FLEXURE CHART

For referring to Chart, we need the value of moment per metre width.

$$M_u/b = \frac{170}{0{\cdot}3} = 567 \text{ kN.m per metre width.}$$

*The term 'factored moment' means the moment due to characteristic loads multiplied by the appropriate value of partial safety factor γ_f.

Referring to *Chart 6*, corresponding to

$M_u/b = 567$ kN.m and $d = 56{\cdot}25$ cm,

$$\text{Percentage of steel } p_t = \frac{100 A_s}{bd} = 0{\cdot}6$$

$$\therefore \; A_s = \frac{0{\cdot}6\, bd}{100} = \frac{0{\cdot}6 \times 30 \times 56{\cdot}25}{100} = 10{\cdot}1 \text{ cm}^2$$

METHOD OF REFERRING TO TABLES

For referring to Tables, we need the value of $\frac{M_u}{bd^2}$

$$\frac{M_u}{bd^2} = \frac{170 \times 10^6}{30 \times 56{\cdot}25 \times 56{\cdot}25 \times 10^3} = 1{\cdot}79 \text{ N/mm}^2$$

From *Table 1*,

Percentage of reinforcement, $p_t = 0{\cdot}594$

$$\therefore \; A_s = \frac{0{\cdot}594 \times 30 \times 56{\cdot}25}{100} = 10{\cdot}02 \text{ cm}^2$$

Example 2 Slab

Determine the main reinforcement required for a slab with the following data:

Factored moment	9·60 kN.m per metre width
Depth of slab	10 cm
Concrete mix	M 15
Characteristic strength of reinforcement	a) 415 N/mm² b) 250 N/mm²

METHOD OF REFERRING TO TABLES FOR SLABS

Referring to *Table 15* (for $f_y = 415$ N/mm²), directly we get the following reinforcement for a moment of resistance of 9·6 kN.m per metre width:

8 mm dia at 13 cm spacing
or 10 mm dia at 20 cm spacing

Reinforcement given in the tables is based on a cover of 15 mm or bar diameter whichever is greater.

METHOD OF REFERRING TO FLEXURE CHART

Assume 10 mm dia bars with 15 mm cover,

$$d = 10 - 1{\cdot}5 - \frac{1{\cdot}0}{2} = 8 \text{ cm}$$

a) For $f_y = 415$ N/mm²

From Table D, $M_{u,lim}/bd^2 = 2{\cdot}07$ N/mm²

$$\therefore \; M_{u,lim} = 2{\cdot}07 \times 10^3 \times \frac{100}{100} \times \left(\frac{8}{100}\right)^2 = 13{\cdot}25 \text{ kN.m}$$

Actual bending moment of 9·60 kN.m is less than the limiting bending moment.

Referring to *Chart 4,* reinforcement percentage, $p_t = 0{\cdot}475$

Referring to *Chart 90,* provide
8 mm dia at 13 cm spacing
or 10 mm dia at 20 cm spacing.

Alternately,

$$A_s = 0{\cdot}475 \times 100 \times \frac{8}{100} = 3{\cdot}8 \text{ cm}^2 \text{ per}$$

metre width.

From *Table 96,* we get the same reinforcement as before.

b) For $f_y = 250$ N/mm²

From Table D, $M_{u,lim}/bd^2 = 2{\cdot}24$ N/mm²

$$M_{u,lim} = 2{\cdot}24 \times 10^3 \times 1 \times \left(\frac{8}{100}\right)^2$$
$$= 14{\cdot}336 \text{ kN.m}$$

Actual bending moment of 9·6 kN.m is less than the limiting bending moment.

Referring to *Chart 1,* reinforcement percentage, $p_t = 0{\cdot}78$

Referring to *Chart 90,* provide 10 mm dia at 13 cm spacing.

2.3.2 Doubly Reinforced Sections — Doubly reinforced sections are generally adopted when the dimensions of the beam have been predetermined from other considerations and the design moment exceeds the moment of resistance of a singly reinforced section. The additional moment of resistance needed is obtained by providing compression reinforcement and additional tensile reinforcement. The moment of resistance of a doubly reinforced section is thus the sum of the limiting moment of resistance $M_{u,lim}$ of a singly reinforced section and the additional moment of resistance M_{u2}. Given the values of M_u which is greater than $M_{u,lim}$, the value of M_{u2} can be calculated.

$$M_{u2} = M_u - M_{u,lim}$$

The lever arm for the additional moment of resistance is equal to the distance between centroids of tension reinforcement and compression reinforcement, that is $(d-d')$ where d' is the distance from the extreme compression fibre to the centroid of compression reinforcement. Therefore, considering the moment of resistance due to the additional tensile reinforcement and the compression reinforcement we get the following:

$$M_{u2} = A_{st2}\,(0{\cdot}87\,f_y)\,(d - d')$$

also, $M_{u2} = A_{sc}\,(f_{sc} - f_{cc})\,(d - d')$

where

A_{st2} is the area of additional tensile reinforcement,

A_{sc} is the area of compression reinforcement,

f_{sc} is the stress in compression reinforcement, and

f_{cc} is the compressive stress in concrete at the level of the centroid of compression reinforcement.

Since the additional tensile force is balanced by the additional compressive force,

$$A_{sc}\,(f_{sc} - f_{cc}) = A_{st2}\,(0{\cdot}87\,f_y)$$

Any two of the above three equations may be used for finding A_{st2} and A_{sc}. The total tensile reinforcement A_{st} is given by,

$$A_{st} = p_{t,lim}\,\frac{bd}{100} + A_{st2}$$

It will be noticed that we need the values of f_{sc} and f_{cc} before we can calculate A_{sc}. The approach given here is meant for design of sections and not for analysing a given section. The depth of neutral axis is, therefore, taken as equal to $x_{u,max}$. As shown in Fig. 5, strain at the level of the compression reinforcement will be equal to $0{\cdot}003\,5\left(1 - \frac{d'}{x_{u,max}}\right)$

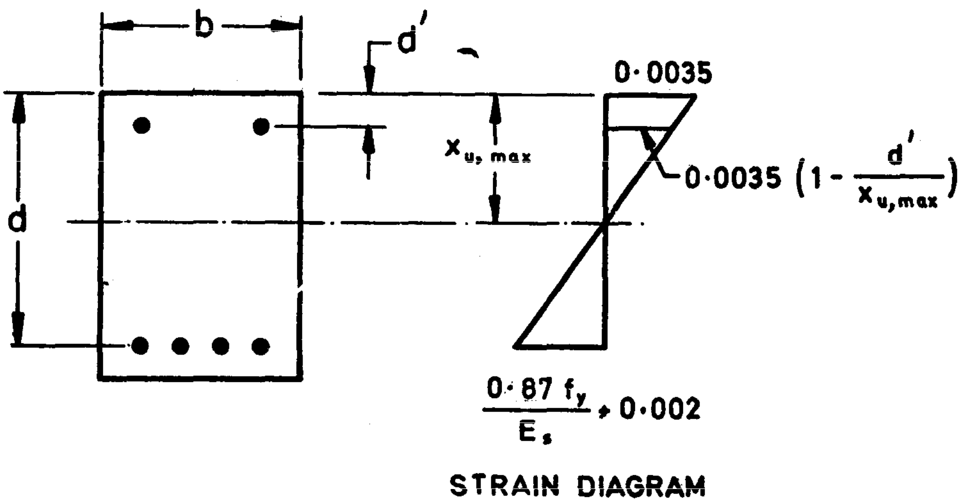

Fig. 5 Doubly Reinforced Section

For values of d'/d up to 0·2, f_{cc} is equal to 0·446 f_{ck}; and for mild steel reinforcement f_{sc} would be equal to the design yield stress of 0·87 f_y. When the reinforcement is cold-worked bars, the design stress in compression reinforcement f_{sc} for different values of d'/d up to 0·2 will be as given in Table F.

TABLE F STRESS IN COMPRESSION REINFORCEMENT f_{sc}, N/mm² IN DOUBLY REINFORCED BEAMS WITH COLD-WORKED BARS

(*Clause 2.3 2*)

f_y, N/mm²	d'/d			
	0·05	0·10	0·15	0·20
415	355	353	342	329
500	424	412	395	370

2.3.2.1 A_{st2} has been plotted against $(d-d')$ for different values of M_{u2} in *Charts 19* and *20*. These charts have been prepared for $f_s = 217·5$ N/mm² and it is directly applicable for mild steel reinforcement with yield stress of 250 N/mm². Values of A_{st2} for other grades of steel and also the values of A_{sc} can be obtained by multiplying the value read from the chart by the factors given in Table G. The multiplying factors for A_{sc}, given in this Table, are based on a value of f_{cc} corresponding to concrete grade M 20, but it can be used for all grades of concrete with little error.

TABLE G MULTIPLYING FACTORS FOR USE WITH CHARTS 19 AND 20

(*Clause 2.3.2.1*)

f_y, N/mm²	FACTOR FOR A_{st2}	FACTOR FOR A_{sc} FOR d'/d			
		0·05	0·10	0·15	0·20
250	1·00	1·04	1·04	1·04	1·04
415	0·60	0·63	0·63	0·65	0·68
500	0·50	0·52	0·54	0·56	0·60

2.3.2.2 The expression for the moment of resistance of a doubly reinforced section may also be written in the following manner:

$$M_u = M_{u,lim} + \frac{p_{t2}bd}{100}(0·87 f_y)(d-d')$$

$$\frac{M_u}{bd^2} = \frac{M_{u,lim}}{bd^2} + \frac{p_{t2}}{100}(0·87 f_y)\left(1-\frac{d'}{d}\right)$$

where

p_{t2} is the additional percentage of tensile reinforcement.

$$p_t = p_{t,lim} + p_{t2}$$

$$p_c = p_{t2}\left[\frac{0·87 f_y}{f_{sc} - f_{cc}}\right]$$

The values of p_t and p_c for four values of d'/d up to 0·2 have been tabulated against M_u/bd^2 in Tables 45 to 56. Tables are given for three grades of steel and four grades of concrete.

Example 3 Doubly Reinforced Beam

Determine the main reinforcements required for a rectangular beam section with the following data:

Size of beam	30 × 60 cm
Concrete mix	M 15
Characteristic strength of reinforcement	415 N/mm²
Factored moment	320 kN.m

Assuming 25 mm dia bars with 25 mm clear cover,

$$d = 60 - 2·5 - \frac{2·5}{2} = 56·25 \text{ cm}$$

From Table D, for $f_y = 415$ N/mm² and $f_{ck} = 15$ N/mm²

$M_{u,lim}/bd^2 = 2·07$ N/mm² $= 2·07 \times 10^3$ kN/m²

$\therefore$ $M_{u,lim} = 2·07 \times 10^3\, bd^2$

$$= 2·07 \times 10^3 \times \frac{30}{100} \times \frac{56·25}{100} \times \frac{56·25}{100}$$

$= 196·5$ kN.m

Actual moment of 320 kN.m is greater than $M_{u,lim}$

$\therefore$ The section is to be designed as a doubly reinforced section.

Reinforcement from Tables

$$\frac{M_u}{bd^2} = \frac{320}{0·3 \times (0·5625)^2 \times 10^3} = 3·37 \text{ N/mm}^2$$

$$d'/d = \left(\frac{2·5 + 1·25}{56·25}\right) = 0·07$$

Next higher value of $d'/d = 0·1$ will be used for referring to Tables.

Referring to *Table 49* corresponding to

$$M_u/bd^2 = 3·37 \text{ and } \frac{d'}{d} = 0·1,$$

$p_t = 1·117, p_c = 0·418$

$\therefore$ $A_{st} = 18·85$ cm², $A_{sc} = 7·05$ cm²

REINFORCEMENT FROM CHARTS

$(d-d') = (56·25 - 3·75) = 52·5$ cm

$M_{u2} = (320 - 196·5) = 123·5$ kN.m

Chart is given only for $f_y = 250$ N/mm²; therefore use *Chart 20* and modification factors according to *Table G.*

Referring to *Chart 20*,

A_{st2} (for $f_y = 250$ N/mm²) $= 10·7$ cm²

Using modification factors given in *Table G* for $f_y = 415$ N/mm²,

$$A_{st_2} = 10{\cdot}7 \times 0{\cdot}60 = 6{\cdot}42 \text{ cm}^2$$
$$A_{sc} = 10{\cdot}7 \times 0{\cdot}63 = 6{\cdot}74 \text{ cm}^2$$

Referring to *Table E*,

$$p_{t,\text{lim}} = 0{\cdot}72$$
$$\therefore \quad A_{st,\text{lim}} = 0{\cdot}72 \times \frac{56{\cdot}25 \times 30}{100} = 12{\cdot}15 \text{ cm}^2$$
$$A_{st} = 12{\cdot}15 + 6{\cdot}42 = 18{\cdot}57 \text{ cm}^2$$

These values of A_{st} and A_{sc} are comparable to the values obtained from the table.

2.4 T-SECTIONS

The moment of resistance of a T-beam can be considered as the sum of the moment of resistance of the concrete in the web of width b_w and the contribution due to flanges of width b_f.

The maximum moment of resistance is obtained when the depth of neutral axis is $x_{u,\max}$. When the thickness of flange is small, that is, less than about 0·2 d, the stress in the flange will be uniform or nearly uniform (*see* Fig. 6) and the centroid of the compressive force in the flange can be taken at $D_f/2$ from the extreme compression fibre. Therefore, the following expression is obtained for the limiting moment of resistance of T-beams with small values of D_f/d.

$$M_{u,\text{lim},T} = M_{u,\text{lim,web}} + 0{\cdot}446 f_{ck} \times (b_f - b_w) D_f \left(d - \frac{d_f}{2} \right)$$

where $M_{u,\text{lim,web}}$

$$= 0{\cdot}36 f_{ck}\, b_w x_{u,\max} (d - 0{\cdot}416\, x_{u,\max}).$$

The equation given in *E-2.2* of the Code is the same as above, with the numericals rounded off to two decimals. When the flange thickness is greater than about 0·2 d, the above expression is not correct because the stress distribution in the flange would not be uniform. The expression given in *E-2.2.1* of the Code is an approximation which makes allowance for the variation of stress in the flange. This expression is obtained by substituting y_f for D_f in the equation of *E-2.2* of the Code; y_f being equal to $(0{\cdot}15 \ x_{u,\max} + 0{\cdot}65\ D_f)$ but not greater than D_f. With this modification,

$$M_{u,\text{lim},T} = M_{u,\text{lim,web}} + 0{\cdot}446 f_{ck} \times (b_f - b_w) y_f \left(d - \frac{y_f}{2} \right)$$

Dividing both sides by $f_{ck}\, b_w\, d^2$,

$$\frac{M_{u,\text{lim},T}}{f_{ck}\, b_w\, d^2} = \frac{M_{u,\text{lim,web}}}{f_{ck}\, b_w\, d^2} + 0{\cdot}446 \times \left(\frac{b_f}{b_w} - 1 \right) \frac{y_f}{d} \left(1 - \frac{y_f}{2d} \right)$$

where

$$\frac{y_f}{d} = 0{\cdot}15 \frac{x_{u,\max}}{d} + 0{\cdot}65 \frac{D_f}{d}$$

but $\frac{y_f}{d} \leqslant \frac{D_f}{d}$

Using the above expression, the values of the moment of resistance factor $M_{u,\text{lim},T}/f_{ck}\, b_w d^2$ for different values of b_f/b_w and D_f/d have been worked out and given in Tables 57 to 59 for three grades of steel.

2.5 CONTROL OF DEFLECTION

2.5.1 The deflection of beams and slabs would generally be within permissible limits if the ratio of span to effective depth of the member does not exceed the values obtained in accordance with *22.2.1* of the Code. The following basic values of span to effective depth are given:

Simply supported	20
Continuous	26
Cantilever	7

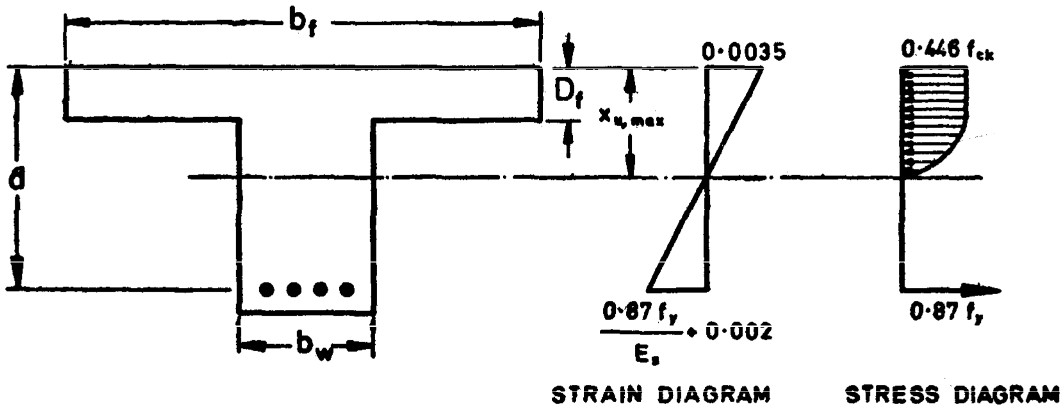

Fig. 6 T-Section

Further modifying factors are given in order to account for the effects of grade and percentage of tension reinforcement and percentage of compression reinforcement.

2.5.2 In normal designs where the reinforcement provided is equal to that required from strength considerations, the basic values of span to effective depth can be multiplied by the appropriate values of the modifying factors and given in a form suitable for direct reference. Such charts have been prepared as explained below:

a) The basic span to effective depth ratio for simply supported members is multiplied by the modifying factor for tension reinforcement (Fig. 3 of the Code) and plotted as the base curve in the chart. A separate chart is drawn for each grade of steel. In the chart, span to effective depth ratio is plotted on the vertical axis and the tensile reinforcement percentage is plotted on the horizontal axis.

b) When the tensile reinforcement exceeds $p_{t,lim}$ the section will be doubly reinforced. The percentage of compression reinforcement is proportional to the additional tensile reinforcement $(p_t - p_{t,lim})$ as explained in *2.3.2*. However, the value of $p_{t,lim}$ and p_c will depend on the grade of concrete also. Therefore, the values of span to effective depth ratio according to base curve is modified as follows for each grade of concrete:

   1) For values of p_t greater than the appropriate value of $p_{t,lim}$, the value of $(p_t - p_{t,lim})$ is calculated and then the percentage of compression reinforcement p_c required is calculated. Thus, the value of p_c corresponding to a value of p_t is obtained. (For this purpose d'/d has been assumed as 0·10 but the chart, thus obtained can generally be used for all values of d'/d in the normal range, without significant error in the value of maximum span to effective depth ratio.)

   2) The value of span to effective depth ratio of the base curve is multiplied by the modifying factor for compression reinforcement from Fig. 4 of the Code.

   3) The value obtained above is plotted on the same Chart in which the base curve was drawn earlier. Hence the span to effective depth ratio for doubly reinforced section is plotted against the tensile reinforcement percentage p_t without specifically indicating the value of p_c on the Chart.

2.5.3 The values read from these Charts are directly applicable for simply supported members of rectangular cross section for spans up to 10 m. For simply supported or continuous spans larger than 10 m, the values should be further multiplied by the factor (10/span in metres). For continuous spans or cantilevers, the values read from the charts are to be modified in proportion to the basic values of span to effective depth ratio. The multiplying factors for this purpose are as follows:

Continuous spans	1·3
Cantilevers	0·35

In the case of cantilevers which are longer than 10 m the Code recommends that the deflections should be calculated in order to ensure that they do not exceed permissible limits.

2.5.4 For flanged beams, the Code recommends that the values of span to effective depth ratios may be determined as for rectangular sections, subject to the following modifications:

a) The reinforcement percentage should be based on the area $b_f d$ while referring the charts.

b) The value of span to effective depth ratio obtained as explained earlier should be reduced by multiplying by the following factors:

b_f/b_w	*Factor*
1·0	1·0
$\geqslant$3·33	0·8

For intermediate values, linear interpolation may be done.

NOTE — The above method for flanged beams may sometimes give anomalous results. If the flanges are ignored and the beam is considered as a rectangular section, the value of span to effective depth ratio thus obtained (percentage of reinforcement being based on the area $b_w d$) should always be on the safe side.

2.5.5 In the case of two way slabs supported on all four sides, the shorter span should be considered for the purpose of calculating the span to effective depth ratio (*see* Note 1 below *23.1* of the Code).

2.5.6 In the case of flat slabs the longer span should be considered (*30.2.1* of the Code). When drop panels conforming to *30.2.2* of the Code are not provided, the values of span to effective depth ratio obtained from the Charts should be multiplied by 0·9.

Example 4 Control of Deflection

Check whether the depth of the member in the following cases is adequate for controlling deflection:

a) Beam of Example 1, as a simply supported beam over a span of 7·5 m

b) Beam of Example 3, as a cantilever beam over a span of 4·0 m

c) Slab of Example 2, as a continuous slab spanning in two directions the shorter and longer spans being, 2·5 m and 3·5 m respectively. The moment given in Example 2 corresponds to shorter span.

a) Actual ratio of $\frac{\text{Span}}{\text{Effective depth}}$

$$= \frac{7\cdot5}{(56\cdot25/100)} = 13\cdot33$$

Percentage of tension reinforcement required,

$p_t = 0\cdot6$

Referring to *Chart 22*, value of Max $\left(\frac{\text{Span}}{d}\right)$ corresponding to $p_t = 0\cdot6$, is 22·2.

Actual ratio of span to effective depth is less than the allowable value. Hence the depth provided is adequate for controlling deflection.

b) Actual ratio of $\frac{\text{Span}}{\text{Effective depth}}$

$$= \left(\frac{4\cdot0}{56\cdot25/100}\right) = 7\cdot11$$

Percentage of tensile reinforcement, $p_t = 1\cdot117$

Referring to *Chart 22*,

Max value of $\left(\frac{\text{Span}}{d}\right) = 21\cdot0$

For cantilevers, values read from the Chart are to be multiplied by 0·35.

$\therefore$ Max value of l/d for cantilever $\} = 21\cdot0 \times 0\cdot35 = 7\cdot35$

$\therefore$ The section is satisfactory for control of deflection.

c) Actual ratio of $\frac{\text{Span}}{\text{Effective depth}}$

$$= \frac{2\cdot5}{0\cdot08} = 31\cdot25$$

(for slabs spanning in two directions, the shorter of the two is to be considered)

(i) For $f_y = 415$ N/mm²

$p_t = 0\cdot475$

Referring to *Chart 22*,

Max $\left(\frac{\text{Span}}{d}\right) = 23\cdot6$

For continuous slabs the factor obtained from the Chart should be multiplied by 1·3.

$\therefore$ Max $\frac{\text{Span}}{d}$ for continuous slab

$= 23\cdot6 \times 1\cdot3 = 30\cdot68$

Actual ratio of span to effective depth is slightly greater than the allowable. Therefore the section may be slightly modified or actual deflection calculations may be made to ascertain whether it is within permissible limits.

(ii) For $f_y = 250$ N/mm²

$p_t = 0\cdot78$

Referring to *Chart 21*,

Max $\left(\frac{\text{Span}}{d}\right) = 31\cdot3$

$\therefore$ For continuous slab,

Max $\frac{\text{Span}}{d} = 31\cdot3 \times 1\cdot3 = 40\cdot69$

Actual ratio of span to effective depth is less than the allowable value. Hence the section provided is adequate for controlling deflection.