helical reinforcement to the volume of the core should not be less

than

$$0.36\left[\frac{A_g}{A_c}-1\right]\frac{f_{ck}}{f_y}$$

Where A_g = gross area of the section.

A_c = area of the core of the helically reinforced column measured to the outside diameter of the helix.

f_y = characteristic strength of the helical reinforcement, but not exceeding 415 N/mm²,

f_{ck} = characteristic compressive strength of the concrete.

Eccentrically Loaded Columns

As per IS 456 : 2000, to recapitulate, a member subjected to axial force and uniaxial bending shall be designed on the basis of the following assumptions:

(*a*) Maximum compressive strain is taken as 0.002.

(*b*) Maximum compressive strain at the highly compressed extreme fibre in concrete subject to axial compression and bending, when there is no tension on the section shall be 0.0035 minus 0.75 times the strain at the least compressed extreme fibre.

(*c*) When the calculated eccentricity is more than the minimum eccentricity, the minimum eccentricity should be ignored.

Design for Uniaxial Bending

(*a*) For known ultimate load, σ_{ck} and σ_y, assume 1 to 2 percentage of steel and find trial section using the equation, $P_u = 0.4\sigma_{ck}A_c + 0.67\sigma_y A_{ac}$.

(*b*) If there is no restriction in the column dimension, the column is designed as s short column by keeping $\frac{L_{eff}}{D \text{ or } b} \leq 12$ (using D or b, whichever is the least).

(*c*) Referring to the interaction diagram corresponding to the relevant $\frac{d'}{D}$ ratio, $\frac{P_u}{\sigma_{ck}.bd}$ and $\frac{M_u}{6_{ck}.6D^2}$, find the percentage of steel and provide reinforcement.

For biaxial bending, as per IS : 456 - 2000, the design is done using the equation

$$\left(\frac{M_{ux}}{M_{ux1}}\right)^{a_n} + \left(\frac{M_{uy}}{M_{uy1}}\right)^{a_n} \leq 1.0$$

Where M_{ux}, M_{uy} = moments about x and y axes, respectively, due to design loading

M_{ux1}, M_{uy1} = maximum uniaxial moment capacity of the column for an axial load P_u, bending about x and y axes, respectively.

For $\frac{P_u}{P_{uz}} < 0.2$, $\alpha_n = 1$

For $\frac{P_u}{P_{uz}} \geq 0.2$ and ≤ 0.8, α_n vary linearly between 1 and 2;

For $\frac{P_u}{P_{uz}} = 0.8$, $\alpha_n = 2$

where $P_{uz} = 0.45\sigma_{ck}A_c + 0.75\sigma_y A_{sc}$.

Slender Column

If the effective length to the lateral dimension ratio is greater than 12, the column is slender. Additional moments on the respective axis are to be considered in the design of the column.

$$M_{ax} = \frac{P_u D}{2000}\left(\frac{L_{ex}}{D}\right)^2 \text{ and } M_{ay} = \frac{P_u D}{2000}\left(\frac{L_{ey}}{b}\right)^2$$

These additional moment are to be reduced by a factor,

$$k = \frac{P_{uz} - P_u}{P_{uz} - P_b} \leq 1$$

where $P_{uz} = 0.45\sigma_{ck}A_c + 0.75\sigma_y A_{ac}$;

P_u = Axial load on the member.

l_{ex}, l_{ey} = effecgive length in respect of major axis and minor axis respectively.

D = Depth of the cross section at right angles to the major axis.

b = width of the member

P_b = axial load corresponding to the condition of maximum compressive strain of 0.0035 in concrete and tensile strain of 0.002 in outermost layer of tension steel.

Long Columns

The maximum permissible stress in a reinforced concrete column or part thereof having a ratio of effective column length to least lateral dimension above 12 shall not exceed the product of the appropriate maximum permissible stress by the coefficient C_r given by

$$C_r = 1.25 - \frac{L_{eff}}{48b}$$

where C_r = reduction coefficient;

I_{eff} = effective length of column, and

b = least lateral dimension of column; for column with helical reinforcement, b is the diameter of the core.

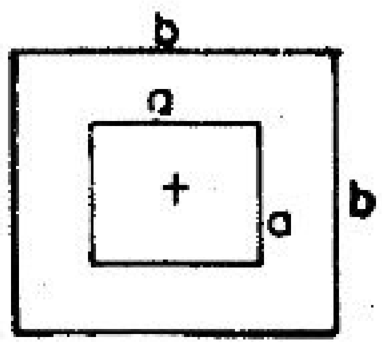
For more exact calculation, the maximum permissible stress in a reinforced concrete column or part thereof having ratio of effective column length to least lateral radius of gyration above 40 shall not exceed the product ofthe appropriate maximum permissible stresses by the coefficient C_r - given by

$$C_r = 1.25 - \frac{L_{eff}}{160 i_{min}},$$

where i_{min} is the least radius of gyration.

DESIGN OF SQUARE COLUMN FOOTING

Let the column size be "a" and the formation plan be "b". Let the bearing capacity of the soil be p' per unit area the weight of the column and the load on the column be W, and the weight of the footing be W_f, W_f is usually taken as 10% of the load on the column for preliminary calculations.



Area required for the footing = $a^2 = \frac{W + W_f}{P'}$

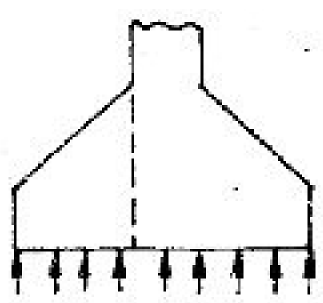
$\therefore$ Side of the square footing = $a = \frac{\sqrt{W + W_f}}{P'}$

Depth of the footing is determined from

(*i*) Bending Moment Considered, and

(*ii*) Punching Shear Consideration

(*i*) Depth of the footing bending moment consideration



Let p be the upward pressure.

$$\therefore \qquad p = p' \frac{b(b-a)^2}{8}$$

Equating the moment of resistance Qbd^2 to the maximum bending moment, the effective depth may be computed.

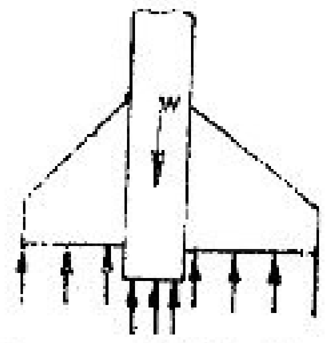
(*ii*) Depth of the footing from pumping shear consideration

Let D be the depth of the footing.

Load causing the punching shear = $\frac{W}{b^2}(b^2 - a^2)$

If the punching shear resistance is 'q' per unit area, then

$$D = \frac{W(b^2 - a^2)}{4b^2 aq}$$



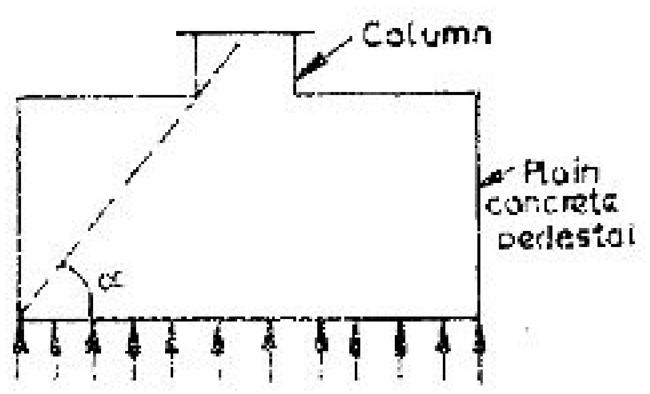
Relevant Provisions of I.S. Code 1S:456-2000

(1) Footing shall be designed to sustain the applied loads, moments and forces and the induced reactions and to ensure that any settlement which may occur shall be as nearly uniform as possible, and the safe bearing capacity of the soil is not exceeded.

(2) In sloped or stepped footings the effective cross-section in compression shall be limited by the area above the neutral plane, and the single of slope or depth and location of steps shall be such that the design requirements are satisfied at every section. Sloped and stepped footing that are designed as a unit shall be constructed to assure action as a unit.

Thickness at the edge of footing. In reinforced and plain concrete footing, the thickness at the edge shall be not less than 15 cm for footings on soils, nor less than 30 cm above the tops of piles for footing on plies.

(3) In the case of plain concrete pedestals, the angle α between the plane passing through the bottom edge of the pedestal and the corresponding junction edge of the column with pedestal and the horizontal plane shall be governed by the expression



$$\tan\alpha \nless 0.9\sqrt{\frac{100 q_0}{f_{ck}} + 1}$$

where q_0 = calculated maximum bearing pressure at the base of the pedestal in N/mm², and

f_{ck} = characteristic strength of concrete at 28 days in N/mm²

(4) In the case of footings on piles, computation for moments and shears may be based on the assumption that the reaction from any pile is concentrated at the centre of the pile. concrete column or pedestal, the face of the column or pedestal shall be taken as the side of square inscribed within the perimeter of the round or octagonal column or pedestal.

6. **Bending Moment:** The bending moment at any section shall be determined by passing through the section a vertical plane which extends completely across the footing, and computing the moment ofthe forces over the entire area ofthe footing on one side of the said plane.

The maximum bending moment to be used in the design of an isolated concrete footing which supports a column, pedestal or wall, shall be the moment computed at sections located as follows

(*a*) At the face of column, pedestal or wall, for footings supporting a concrete column, pedestal or wall.

(*b*) Half way between the centre line and the edge ofthe wall, for footing under masonry walls, and

(*c*) Halfway between the face of the column or pedestal and the edge of the gussetted base, for footing under gussetted base.

7. **Shear and Bond:** The shear strength of footing is governed by the more severe of the following two conditions :

(*a*) The footing acting essentially as a wide beam, with a potential diagonal crack extending in a plane across the entire width, the critical section for this condition shall be assumed as a vertical section located from the face of the column, pedestal or wall at a distance equal to the effective depth of the footing for footings on piles. In case of footing on soils, the distance equal to half the effective depth of footing.

(*b*) Two-way action of the footing, with potential diagonal cracking along the surface of truncated cone or pyramid around the concentrated load. The critical section for checking the development in length of a footing shall be assumed at the same planes as those described for bending moment and also at the over vertical planes where abrupt changes of section occur.

8. **Tensile Reinforcement:** The total tensile reinforcement at any section shall provide a moment or resistance at least equal to the bending moment on the section.

Total tensile reinforcement shall be distributed across the corresponding resisting section as given below -

(*a*) In one-way reinforced footing, the reinforcement shall be distributed uniformly across the full width of the footing.

(*b*) In two-way reinforced square footing, the reinforcement extending in each direction shall be distributed uniformly across the full width of the footing.

(*c*) In two-way reinforced rectangular footing, the reinforcement in the long direction shall be distributed uniformly across the width of the footing. For reinforcement in the short duration, a central band equal to the width of the footing shall be marked along the length ofthe footing and portion of the reinforcement determined in accordance with the equation given below shall be uniformly distributed across the central band:

$$\frac{\text{Reinforcement in central band width}}{\text{Total reinforcement in short duration}} = \frac{2}{\beta + 1}$$

Where β = ratio of the long side to the short side of the footing.

The remainder ofthe reinforcement shall be uniformly distributed in the outer portions of the footing.

Transfer of Load at the Base of Column

The compressive stress in concrete at the base of a column or pedestal shall be considered as being transferred by bearing to the top of supporting pedestal or footing. The bearing pressure on the loaded area shall not exceed the permissible bearing stress in direct compression multiplied by a value equal to $\sqrt{\frac{A_1}{A_2}}$,but not greater than 2,

where A_1 = supporting area for bearing of footing, which in sloped or stepped footing may be taken as the area of the lower base of the largest frustrum of a pyramid or cone contained wholly within the footing and having for its upper base, the area actually loaded and having side slope of one vertical to two horizontal; and A_2 = loaded area at the column base.

For working stress method of design the permissible bearing stress on full area of concrete shall be taken as $0.25\ f_{ck}$: for limit state method of design the permissible bearing stress shall be $0.45\ f_{ck}$.

INTRODUCTION TO IS : 456 : 2000

Make up of the revision:

Of the six sections into which IS : 456 : 1978 was divided, the first five sections have been retained in IS : 456 : 2000 also. The working stress method, which constituted the sixth section of the old version, has now been discontinued and is presented as Annex B. Accordingly, the status of working stress method as an alternate method for design of reinforced concrete has now been removed.

The revised code has incorporated many changes to give importance to durability of concrete structures, which of late has been neglected at the expense of much importance on strength.

A list of the changes in the various sections is given below :

- Recognition of all the three grades of OPC cements alongwith other types of cement (clause 5.1 of IS : 456 : 2000).
- Enumeration of allowable mineral admixtures (clause 5.2) and the approval of the practice of chemical admixtures (clause 5.5).
- The method of testing water for converting has been described and permissible limits of chlorides and sulphates given (clause 5.4 and Table 1).
- Characteristics strength of steel has been defined as the minimum yield on 0.2% proof stress (clause 5.6.3).
- The value of modulus of elasticity of concrete is to be taken as

  $E_c = 5000\sqrt{f_{ck}}$ (in N/mm^2) (Clause 6.2.3).
- The minimum strength of concrete for structural purposes is specified as M20, with minimum cement content including admixture of 300 kg/m^3 and maximum water cement ratio of 0.55. Grades up to M80 has been included in the code. The maximum cement content not including mineral admixtures has been specified as of 450 kg/m^3.
- Workability has been tabulated in terms of slump (clause 7).
- The factors affecting durability have been fully explained. The new five environmental classification has been described. The requirements to withstand sulphate attack of concrete has been expanded.
- Recommendation for using a minimum grade of M30 in seawater construction as well as other precautions to be taken to protect steel in saline atmosphere have been laid down.
- The recommended value to be used for standard deviation for concrete mix design under Indian conditions remains constant at 5N/mm^2 from M30 to M50.
- Quality assurance factors have been clearly defined.
- The accuracy of measuring equipment for weighing cement aggregate and water for batching has been laid down.
- Tolerance limits for steel fabrication has been specified.
- The clause on construction and cold joints has been modified.
- Recommendation for curing of concrete have been made. Whereas, ordinary portland cement (OPC) concrete requires seven days of good moist curing, portland pozzolane cement (PPC) concrete requires at least 10 days of good curing to atain frill strength.

  For concrete exposed to dry and hot weathered conditions, the corresponding curing periods are 10 and 14 days.
- Requirements of concrete for underwater placement has been described and placing concrete by pumps has been included.
- Simple acceptance criteria have been introduced for acceptance and quality control of small batches of concrete production.
- The status of working stress method without using load factor as an alternate method has been discontinued. Design should be normally made by limit state method and working state method is to be used only when the former method is not applicable like carrying out serviceability limit state of deflection, cracking etc.
- Factor for stability against overturning against dead load should be 1.2 to 0.9 depending on its action and that for imposed load 1.4. The lateral sway due to transient loads should be limited to $\frac{H}{500}$
- Fire resistance requirements are important additions to the code. Minimum dimensional requirements for slabs, beams, columns and walls as well as minimum cover requirements for different fire rating have been specified.
- Effective length of cantilevers has been defind.
- Bending moment coefficient at mid point of interior spans has been increased from $\frac{1}{24}$ to $\frac{1}{16}$ to bring its value to 3/4th value at the support. (table 12).
- The curves for the modification factor for tension reinforcment for checking deflection requirement of beams and slabs have been changed to represent the actual steel stress at service loads instead of the old curves based on types of steel and allowable stresses.
- The concept of determining effective length of columns by "stability index" defined in Annexe E has been introduced.

- When considering biaxial bending it has been specified that it is sufficient to ensure that eccentricity exceeds the minimum about only one axis at a time.
- Strength of welds has been modified so that for joints in tension values of 100% strength can be taken if there is strict supervision and not more than 20% of the bars are welded.
- The maximum spacing of main steel in slabs has been limited to 300 mm.
- Maximum spacing of vertical stirrups for shear reinforcement has been limited to 0.75 d or 300 mm instead of 450 of old code.
- The formula for nomial shear reinforcement has been changed as follows with 0.87 f_y

$$\frac{A_{sv}}{b_{sv}} \geq \frac{0.4}{0.87 f_y}$$

- The condition that the pitch of lateral ties in columns should not exceed 48 dia (laterals) has been replaced by 300 mm.
- The clauses regarding design of plain concrete walls have been modified to include design of walls in horizontal shear also.
- The concept of minimum reinforcement and nominal reinforcement for concrete sections of thickness greater than 1m has been added.
- For limit state of cracking guidance regarding width of cracks allowed in different environmnts have been specified.
- The design shear reinforcement for tension reinforcement values equal or less than 0.15% has been added.
- A new clause on cracking of flexural member has been added. (flexural member is defined as one subjected to axial loads lesser than 0.2 $f_{ck}A_c$).
- The general approach to design of reinforced concrete members in torsion has been explained in details.

Thus, the importance of ductility has been fully dealt with IS : 456 : 2000. It has also been enriched with additional clouses regarding design or fire resistance, design of cabels, design of plain concrete walls. It also gives guidance for calculations ofdeflection and crack width in members under bending.

SECTION WITH COMPRESSION REINFORCEMENT (DOUBLY REINFORCED BEAM)

The moment of resistance of a doubly reinforced section is the sum of the limiting moment of resistance $M_{u.lim}$ of a singly reinforced section and the additional moment of resistance, M_{u2}. This additional moment of resistance is obtained by providing compression reinforcement and additional tensile reinforcement.

$$M_{u2} = M_u - M_{u.lim}$$
$$= 0.87 f_y A_{st2}(d - d')$$

where, d = distance from the compression fibre to the centroid of compression steel.

Also,

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

where, f_{sc} = design stress in compression reinforcement corresponding to a strain of

$$\frac{0.0035(x_{u.max} - d')}{x_{u.max}}$$

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

FLANGED SECTION (T-BEAM)

(*i*) When depth of neutral axis, x_u is less that thickness of flange, D_f, then it can be designed as rectangular section.

(*ii*) When, $x_{u'max} > D_f$ and $\frac{D_f}{d} < 0.2$, then limiting moment of resistance can be calculated as

$$M_{u,lim} = \frac{0.36 x_{u,max}}{d}\left(1 - \frac{0.42 x_{u,max}}{d}\right) f_{ck} b_w d^2$$
$$+ 0.45 f_{cl}(b_f - b_w) D_f\left(d - \frac{y_f}{2}\right)$$

(*iii*) When $x_{u.max} > D_f$ and $\frac{D_f}{d} > 0.2$, then limiting moment of resistance can be calculated as

$$M_{u,lim} = \frac{0.36 x_{u,max}}{d}\left(1 - \frac{0.42 x_{u,max}}{d}\right) f_{ck} b_w d^2$$
$$+ 0.45 f_{ck}(b_f - b_w) y_f\left(d - \frac{D_f}{2}\right)$$

where, $y_f = (0.15\, x_u + 0.65\, D_f)$ subject to maximum of D_f

b_f = breadth of the compression face/ flange.

b_w = breadth of web.

As per IS: 456, a compression member is considered as.

(1) Pedestal if $\frac{I_{ex}}{D} \leq 3$ and also $\frac{I_{ey}}{b} \leq 3$

(2) Short if $3 < \frac{I_{ex}}{D} < 12$ and $3 < \frac{I_{ey}}{b} < 12$

(3) Long if $\frac{I_{ex}}{D} \geq 12$, or $\frac{I_{ey}}{b} \geq 12$

where D = larger lateral dimension

b = smaller lateral dimension

l_{cx} = effective length in respect of buckling about X-axis

l_{cy} = effective length in respect of buckling about Y axis.

- Minimum number of longitudinal reinforcement

  = 4 for rectangular section

  = 6 for circular section

- Quality of longitudinal reinforcement is given by

$$\frac{100A_x}{A_g} \nless 0.8\%$$

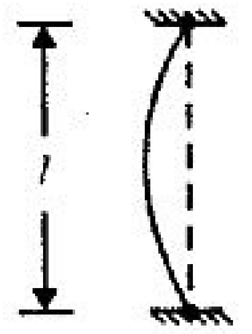
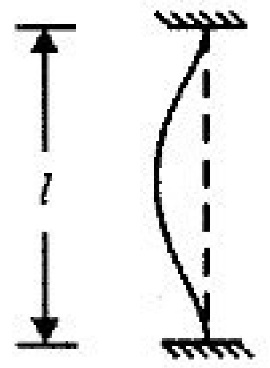
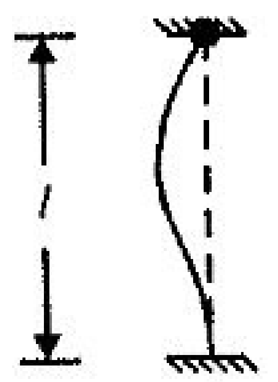
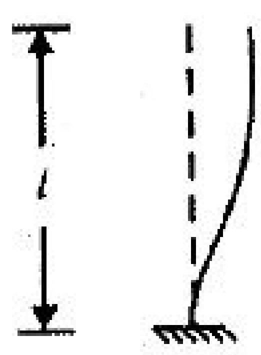
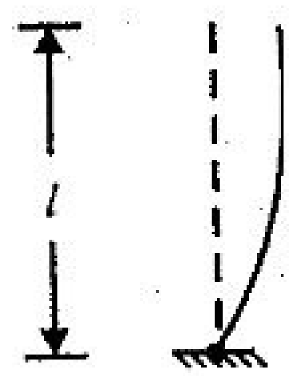
$$\ngtr 6\ \%$$

- Minimum eccentricity of load.

$$e_m = \frac{\text{Unsupported length}}{500} + \frac{\text{Lateral dimension}}{30}$$

$$e_m \nless 20 \text{ mm in any case}$$

TABLE- BASED ON TABLE 24 OF IS : 456

Case	***End conditions***	***Presentation***	***Recommended Effective length***
(1)	Both ends are Hinged		l
(2)	Both ends are fixed		$0.65\,l$
(3)	One end is fixed and other is hinged		$0.8\,l$
(4)	One end is fixed and other is free		$1.2\,l$
(5)	One end is hinged and other is free		$2\,l$

SHORT AXIALLY LOADED MEMBERS IN COMPRESSION

Capacity of member subjected to axial load and minimum eccentricity does not exceed 0.05 times the lateral dimension is given by

$$P_u = 0.4f_{ck}A_c + 0.67f_yA_{sc}$$

$$\text{Minimum eccentricity} = \frac{\text{Unsupported length}}{500} + \frac{\text{Lateral dimension}}{30}$$ subjected to minimum of 20 mm.

The strength of columns with helical reinforcement, such that volume of helical reinforcement to volume of core not less than $0.36\left(\frac{A_g}{A_c}-1\right)\frac{f_{ck}}{f_y}$, shall be taken as 1.05 times the strength of column with lateral ties.

where, A_g = gross area of section

A_{co} = area of the core of the reinforced column measured to outside diameter of helix

SLENDER COMPRESSION MEMBERS

The additional moments M_{ax} and M_{ay} due to effect to deflection can be calculated as :

$$M_{ax} = \frac{P_u D}{2000}\left(\frac{l_{ex}}{D}\right)^2$$

$$M_{ay} = \frac{P_u D}{2000}\left(\frac{l_{ey}}{b}\right)^2$$

where, P_u = axial load on the member

l_{ex} = effective length in respect of major axis

l_{ey} = effective length in respect of minor axis

D = depth of cross-section at right angle to the major axis

b = width of the member

LIMIT STATE OF COLLAPSE; SHEAR

Nominal shear stress in beams of uniform depth,

$$\tau_v = \frac{V_u}{bd}$$

where, V_u = design shear force

In beams with varying depth,

$$\tau_v = \frac{V_u \pm \frac{M_u}{d}\tan\beta}{bd}$$

Where M_u = bending moment at the section

β = angle between top and bottom edges of beam

Design shear strength of concrete can be calculated as,

$$\tau_c = \frac{0.85\sqrt{0.8f_{ck}}\left(\sqrt{1+5\beta}-1\right)}{6\beta}$$

where, $b = \frac{0.8f_{ck}}{6.89p_t}$ subject to minimum of 1

$$p_t = \frac{100A_s}{b_w d}$$

The strength of shear reinforcement V_{us} for various categories of stirrups can be calculated as :

(*a*) Vertical Stirrups

$$V_{us} = \frac{0.87f_yA_{sv}d}{S_v}$$

(*b*) Inclined stirrups or series of bars bent-up at different cross-sections:

$$V_{us} = \frac{0.87f_yA_{sv}d}{S_v}(\sin\alpha + \cos\alpha)$$

(*c*) Single bar or single group of parallel bars, all bent up at same cross-section

$$V_{us} = 0.87f_yA_{sv}\sin\alpha$$

where S_v = spacing of stirrups

A_{sv} = cross-sectional area of stirrups

α = angle between inclined stirrup or bent-up bar and the axis of the member, not less than 45.

WORKING STRESS METHOD

Short columns with Lateral ties:

Strength of column

$$P = \sigma_{cc}A_c + \sigma_{sc}A_{sc}$$

where σ_{cc} = permissible stress in concrete in direct compression

σ_{sc} = permissible compressive stress in steel

A_c = area of concrete

A_{sc} = cross-sectional area of longitudinal steel.

LONG COLUMNS

Strength of column is reduced by a coefficient,

$$C_r = 1.25 - \frac{l_{ef}}{48b}$$

where, C_r = reduction coefficient

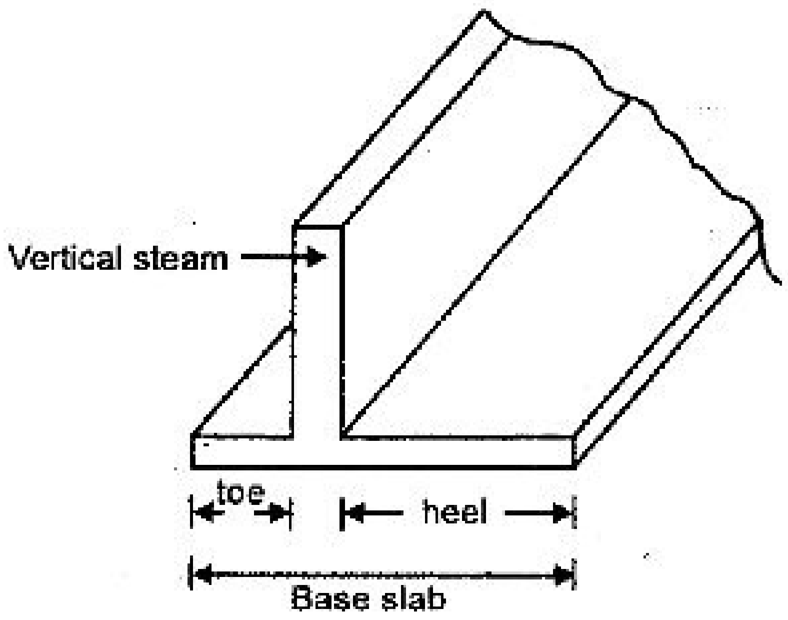
l_{ef} = effective length of column

b = least lateral dimension of column

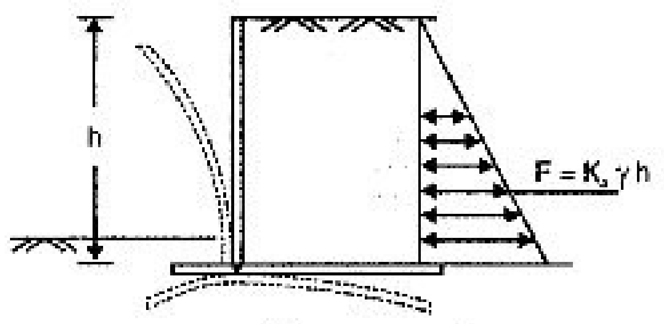
These are the structures to retain soil (or earth)

TYPES OF RETAINING WALL

(1) *Cantilever type:* These are designed up to height of 6 m. For more heights; generally counter fort type retaining walls are designed.

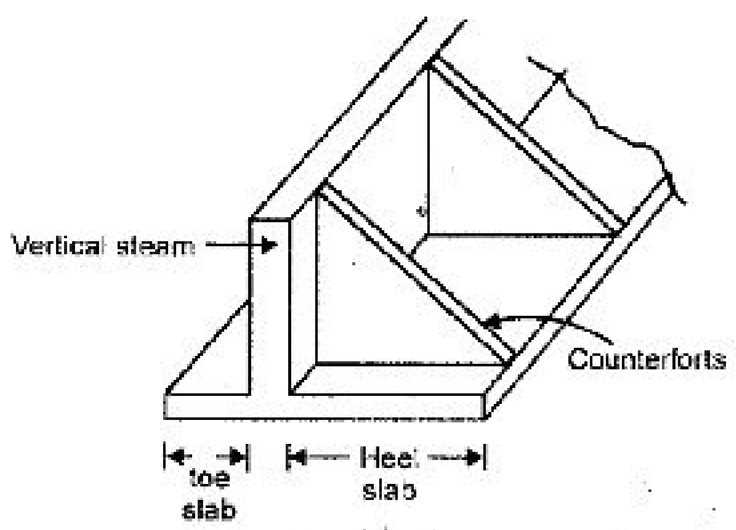


(a)

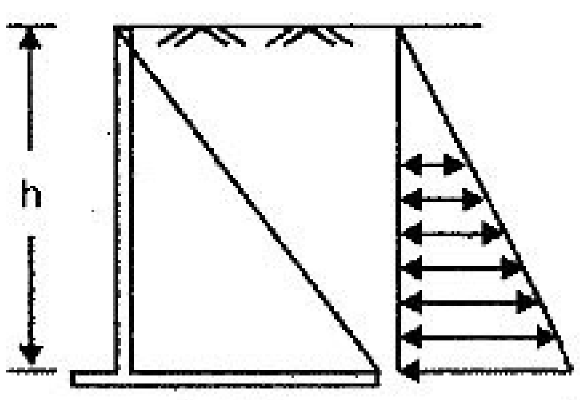


(b)

(2) *Counter fort type:* These are designed for height more than 6m

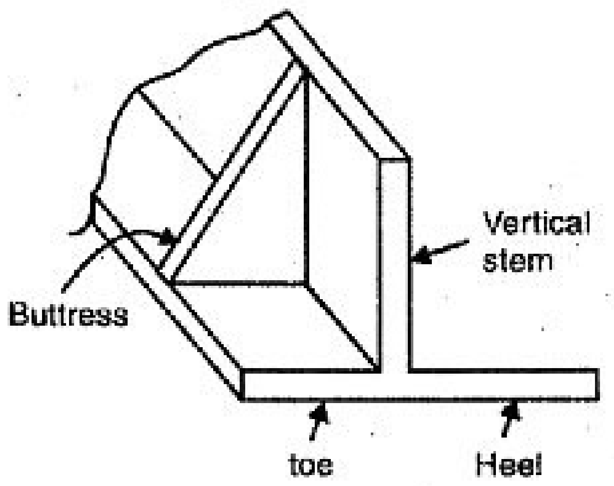


(a)

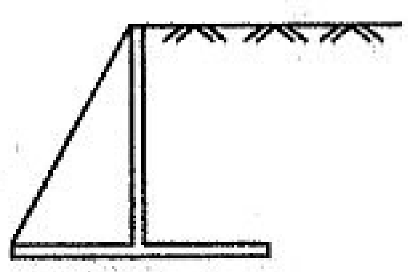


(b)

(3) *Buttress type wall :*



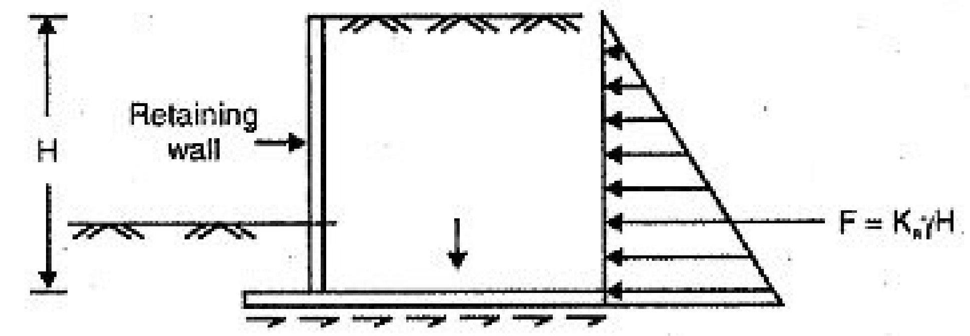
(a)



(b)

DESIGN CONSIDERATIONS

Case I. Cantilever type Retaining wall.



where K_a = coefficient of active earth pressure.

γ = unit weight of earth fill.

H = depth from top to bottom.

- Force tending to slide the retaining wall,

$$P_a = K_a \gamma H . \frac{H}{2} = \frac{K_a \gamma H^2}{2}$$

- Passive force to resist sliding = $0.9\,\mu W$

  where μ = coefficient of friction and W = total load

- Factor of safety against sliding = $\dfrac{0.9\mu W}{P_a} \not< 1.4$

- Overturning moment, $M_0 = \dfrac{K_a \gamma H^2}{2} . \dfrac{H}{3} = \dfrac{K_a \gamma H^3}{6}$

- Restoring moment M_r (due to toe)

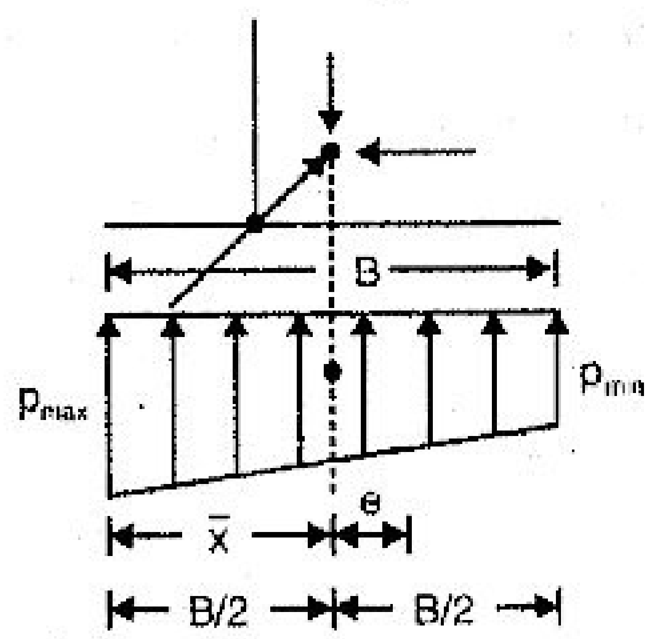
  Factor of safety = $\dfrac{0.9 M_r}{M_0} \not< 1.2$

  Safe bearing capacity will not be violated.

- Reaction from the foundation cuts the base line at

$$\bar{x} = \frac{M_r - M_0}{w}$$

Eccentricity, $e = \dfrac{B}{2} - \bar{x}$



where, B = Base width.

Then $p_{max}, p_{min} = \dfrac{W}{1 \times B} \pm \dfrac{W.e}{\left(1 \times \dfrac{B^2}{6}\right)}$

$P_{max} \not> $ safe bearing capacity

Stability Check

Remedial measure

(*i*) If not safe against sliding, provide a shear key

(*ii*) If not safe against overtunning, increase the toe width.

(*iii*) If safe bearing capacity is violated, increase both toe width and heel width.

DESIGN

Assume base width $B = \frac{2}{3}$ of H and heel width $= \frac{2}{3}$ of B.

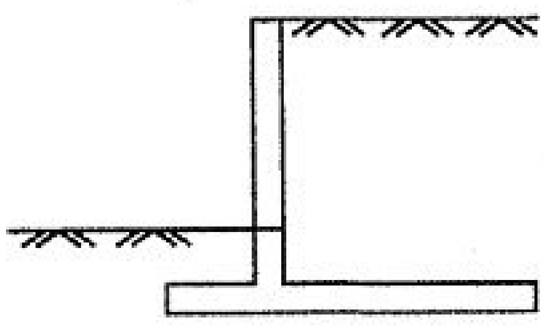
Design of vertical stem

(1) Calculate Bending moment, M from which calculate d.

Calculate Shear force, V from which calculate τ_u

From calculated d, calculate reinforcement

$A_{st} \rightarrow$ calculate τ_c



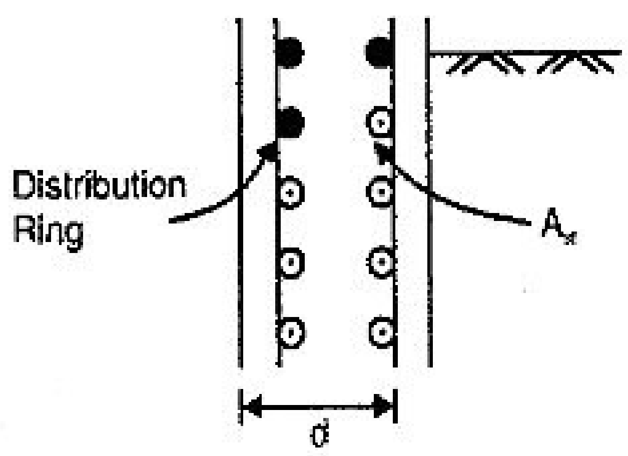
where d = effective thickness of vertical stem

If these conditions are not satisfied, increase d.

Provide A_{st} vertically on earth face.

Also provide, distribution reinforcement in front face

Provide $\frac{1}{2}$ minimum reinforcement horizontally, and $\frac{1}{2}$ minimum reinforcement vertically to resist the effect of shrinkage and temperature variations.



Main reinforcement is continued into the toe for the purpose of development length.

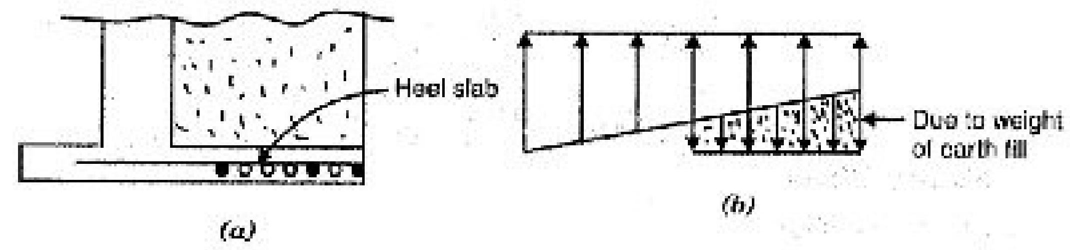
However it also serves as reinforcement required for toe.

Design of toe

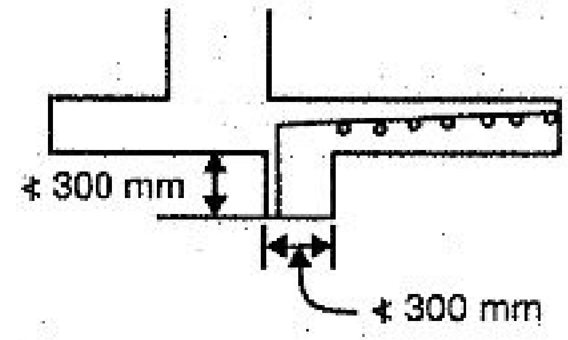
Calculate bending moment; thickness; reinforcement and verify that no extra reinforcement is required.

Check for shear, provide distribution reinforcement also.

Design of Heel Slab



Shear key



Passive earth pressure

Calculate B.M., which will give d, so reinforcement can be calculated.

Calculate S.F. $\rightarrow \tau_u$ and τ_c

If $\quad \tau_u \ngtr \tau_c$ (satisfactory)

If $\quad \tau_u > \tau_c$, increase d

Minimum length of key = 300 mm.

Case II. Counterfort Type

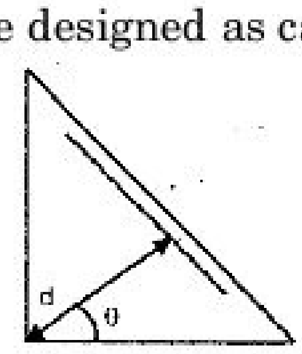
Vertical stem is designed as continuous slab. Spaning horizontally.

Check for shears $\tau_u \ngtr \tau_c$

Toe is designed as cantilever

Heel slab is designed as continuous slab supported by counterforts.

- Counterforts are designed as cantilever beam.



* Calculate B.M.

* Check for d.

* Calculate S.F.

* Provide stirrups, find spacing

Note: This calculated spacing is inclined. So multiply the spacing by cos θ; we get horizontal spacing.

Horizontal spacing = Calculated spacing $\cos\theta$

Separating force check for vertical stem.

Separating force check for heel slab.

Check weather design is safe or not.

TWO WAY SLAB

Bending Moment per unit width,

$M_x = \alpha_x w l_x^2$; $M_y = \alpha_y w l_x^2$

where $\alpha_x = \frac{1}{8} \cdot \frac{r^4}{(1+r^4)}, \alpha_y = \frac{1}{8} \cdot \frac{r^2}{(1+r^4)}$ and $r = \frac{l_y}{l_x}$

Footing

Area of square footing = $a^2 = \dfrac{W_f + W}{q}$

where a = size of column

q = Bearing capacity of soil

W_f = weight of footing

W = weight of column + load on column

- Maximum bending moment on beam

$$M_{max} = P\frac{b(b-a)^2}{8}$$

where b = size of foundation

p = net upward pressure

- Depth of footing $D = \dfrac{W(b^2 - a)^2}{4b^2 - as}$

where s = punching shear resistance.

SINGLY REINFORCED MEMBER

1. Design a singly reinforced rectangular section for beam to take up a bending moment at collapse of 65 kN-m. Keep b = 225mm. Concrete grade: M15 and steel grade: Fe 415. The design should be balanced.

Solution: Given, b = 225 mm, f_{ck} =15 N/mm^2 and f_y = 415 N/mm^2

For the balanced case, $\dfrac{X_u}{d} = 0.48$

Now, bending strength of balanced section is given by

$$M_u = 0.36 f_{ck}\frac{X_u}{d}\left(1 - 0.42\frac{X_u}{d}\right)bd^2$$

$$= 0.36 \times 15 \times 0.48(1 - 0.42 \times 0.48)\,225 \times d^2$$

$$= 465.63d^2$$

Equating, we get $465.63d^2 = 65 \times 10^6$

or d = 373.6 mm, say 375 mm.

Now $X_u = 0.48 \times 375 = 180$ mm

$\therefore$ Tension reinforcement,

$$A_{st} = \frac{M_u}{0.87 f_y (d - 0.42X_u)}$$

$$= \frac{65 \times 10^6}{0.87 \times 415(375 - 0.42 \times 180)}$$

$$= 601.3$$

Provide 16 mm 3 bars

Minimum clear cover required on bars = 25 mm.

Hence, keep the bar centre 35 mm away from the bottom face to satisfy this requirement.

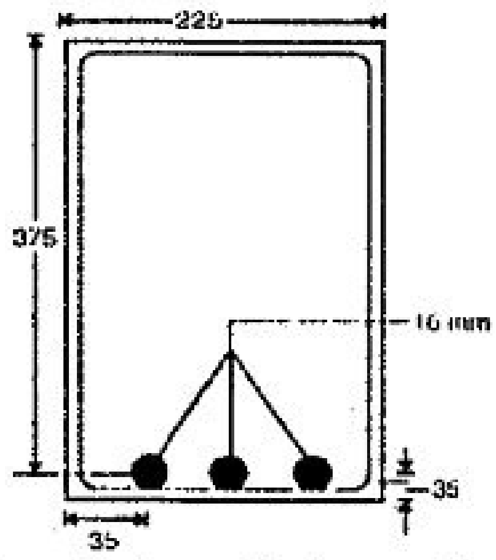
Similarly, for the bars near the side faces, the bar centre may be kept 35 mm away from the side faces. (See figure below)

The requirement for the clear distance between two parallel bars is as follows:

(*i*) $\nless$ diameter of bars, i.e. 16 mm.

(*ii*) $\nless$ maximum size of aggregate + 5 mm,

i.e. 20 + 5 = 25 mm.



Actual clear distance between the bars

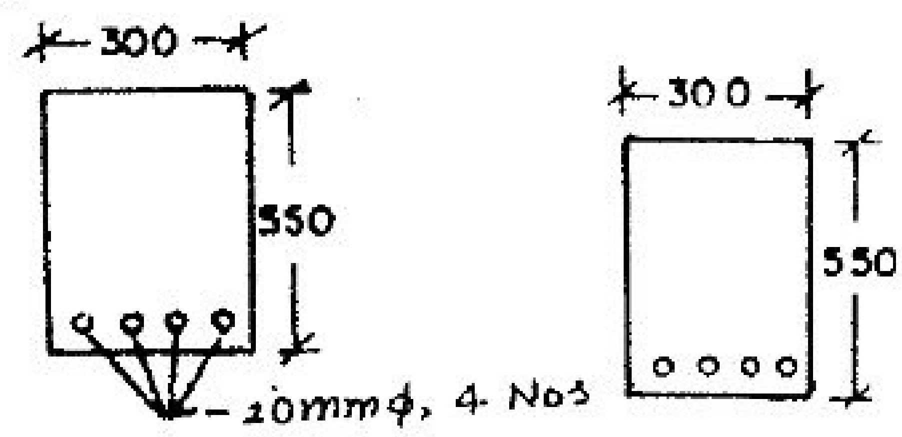
$$= \frac{1}{2}(255 - 2 \times 35 - 2 \times 16)$$

$$= 61.5 \text{ mm} > 25 \text{ mm O.K.}$$

Maximum permitted spacing between two parallel bars = 180 mm.

Actual clear distance is 61.5 mm, which is less than the maximum permitted, hence, it is O.K.

2. A rectangular RC beam of concrete grade M 20 is 300 mm wide and 550 mm deep (effective depth) as shown in figure below. It is provided with 4 numbers of 20 mm diameter mild steel roads as tension reinforcement. Determine the moment of resistance of the beam. Take σ_{cbe} = 7 N/mm^2 and σ_{st} = 140 N/mm^2 and m = 13.



Solution: Given, b = 300 mm d = 550 mm

$$A_{st} = 4 \times \frac{\pi}{4} \times (20)^2$$

$$= 1256.64 \text{ mm}^2$$

Balanced neutral axis,

$$x_{bal} = k.d. = \frac{1}{1 + \dfrac{\sigma_{st}}{m\sigma_{cbc}}}.d = \frac{1}{1 + \dfrac{140}{13 \times 7}} \times 550$$

$$= 0.4 \times 550 = 220 \text{ mm}$$

But actual neutral axis, x_a can be found out by,

$$\frac{1}{2}.b.x_a.\sigma_{cbe} = \sigma_{st}.A_{st}$$

$$x_a = \frac{2\times 140\times 1256.64}{300\times 7}$$

$$= 167.55 \text{ mm}$$

Since $x_a < x_{bal}$, so the given section is under reinforced; so the moment of resistance of beam will be given by,

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

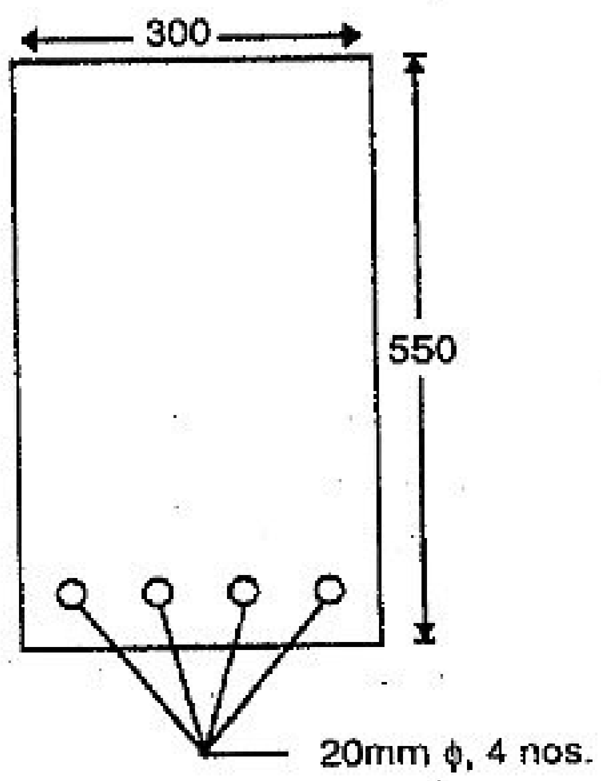
$$= 140 \times 1246.64\left(550 - \frac{167.55}{3}\right)$$

$$= 86935612 \text{ N.mm}$$

$$= 86.935 \times 10^6 \text{ N. mm.}$$

$$= 86.935 \text{ kNm.}$$

3. For the beam shown in the figure, determine the area of reinforcement required to have it as a balanced section. Determine also the moment of resistance of the balanced section.



Solution:

$$x_{bal.} = 0.4 \text{ d} = 0.4 \times 550 = 220 \text{ mm.}$$

$$\therefore \quad \frac{1}{2}.b.x_{bal.}\sigma_{cbc} = \sigma_{st}.A_{st}$$

∴ Area of steel required for balanced moment of resistance.

$$A_{st} = \frac{1}{2}bx_{bal.}\sigma_{cbc} = \frac{300\times 220\times 7}{2\times 140} = 1650 \text{ mm}^2$$

Moment of resistance of the balanced section,

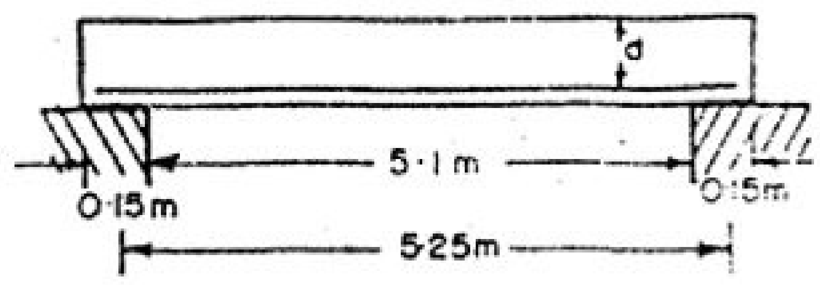
$$M = \frac{1}{2}bx_{bal.}\sigma_{cbc}\left(d - \frac{x_{bal.}}{3}\right)$$

$$= \frac{1}{2}\times 300\times 220\times 7\left(550 - \frac{220}{3}\right)$$

$$= 110.1 \times 10^6 \text{ N.mm}$$

$$= 110.1 \text{ kNm.}$$

4. A simple beam is to be designed for a clear span = 5.1 m. Length of bearing at each end = 150 mm. Superimposed dead load = 18 kN/m. Live load =12 kN/m. Concrete grade: M15 and steel grade: Fe 415. Calculate the sectional dimensions of the beam and the reinforcement area. Keep b/d = 0.5.



Solution: Beam loads are as given below:

Superimposed dead load = 18 kN/m

Estimated self weight = 4 kN/m

Total dead load is DL = 22 kN/m

Live load, L L = 12 kN/m

Design load at collapse,

$$w = 1.5DL + 1.5 \text{ LL}$$

$$= 1.5 \times 22 + 1.5 \times 12$$

$$= 51 \text{ kN/m}$$

Effective span of the beam,

$$1 = 5.1 + 0.15 \text{ m}$$

$$= 5.25 \text{ m}$$

Design bending moment,

$$M_u = \frac{wl^2}{8}$$

$$= \frac{51\times 5.25^2}{8}$$

$$= 175.71 \text{ kN/m}$$

Now

$$0.36f_{ck}\frac{X_u}{d}\left(1 - 0.42\frac{X_u}{d}\right)bd^2 = M_u$$

Taking $\frac{X_u}{d} = 0.48$ for the balanced design and substituting all the values in the above expression, we get $0.36\times 15\times 0.48(1 - 0.42\times 0.48)$ bd^2

$$= 175.71 \times 10^6$$

or $\quad bd^2 = 84.907 \times 10^6$

or $\quad d^2 = 169.81 \times 10^6$

∴ $\quad d = 553.76$ mm and $b = 276.88$ mm

Adopt $\quad b = 280$ mm and $d = 555$ mm.

∴ $\quad X_u = 0.48 \times 555$

$$= 266.4 \text{ mm}$$