Chapter 4

Slabs, Columns and Footings

CHAPTER HIGHLIGHTS

- *Introduction*
- *Slabs*
- *Types of slabs*
- *Columns*
- *Design of axially loaded short column*
- *Footings*

Introduction

The load transfer of reinforced concrete building takes place from slabs to beams and, then to columns. From columns, the load is transferred to footings to distribute load over a wide area and, then finally to soil. Hence, the present chapter outlines the design procedure and specifications of slabs, columns and footings.

Slabs

- These are plane structural elements whose thickness is very small in comparison to its length and breadth.
- Slabs mainly support transverse loads transferring to the beams or walls by bending action in one or more directions.

General Design Requirements for Slabs as per IS: 456–2000

The general design requirements for slabs as per IS:456–2000 are as follows:

Effective Span

1. For simply supported slabs: Minimum of
   (a) clear span plus effective depth of a slab.
   (b) centre-to-centre distance between the supports.
2. For cantilever slabs:
   (a) Length up to face of support + Half the effective depth.
   (b) Where it forms end of a continuous slab; the length to centre of support shall be taken.

Limiting Stiffness

For spans up to 10 m. The basic values of span to depth ratio are given below:

Cantilevers: 7
Simply supported: 20
Continuous: 26

Depending upon the type of steel and percentage of steel, the above values can be modified.

Minimum Reinforcement

As per clause 26.5.2.1 of IS: 456–2000, the minimum reinforcement shall not be less than 0.15% of gross sectional area if mild steel is used, and 0.12% of gross sectional area if high yielding deformed (HYSD) bars are used.

Maximum Diameter of Bars

The diameter of the bars shall not exceed 1/8 of the total thickness of slabs.

Spacing of Main Reinforcement

The spacing of main reinforcement in slabs shall not be more than three times the effective depth of the solid slabs or 300 mm, whichever is less.

Distribution Reinforcement

The area of distribution reinforcement shall not be less than 0.15% of the gross-cross sectional area if plain bars are used, and 0.12% if HYSD bars are used. The spacing of distribution reinforcement in slabs shall not be more than five times the effective depth of slabs or 450 mm whichever is less.

Cover to Reinforcement

The minimum nominal cover/clear cover provided to slabs is 20 mm. (If diameter of bar is <12 mm and mild exposure)

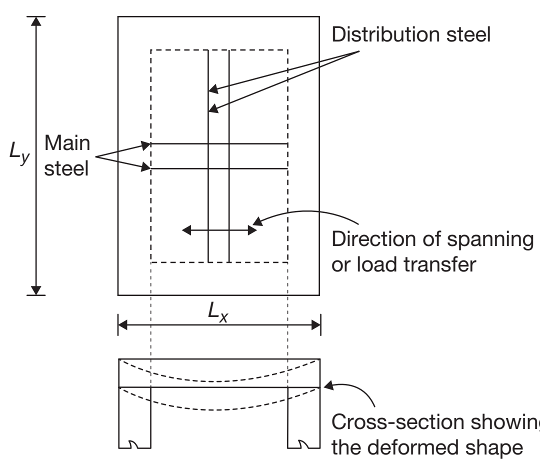
Types of Slabs

Based on the aspect ratio (i.e., longer span (l_y) to shorter span (l_x)), Slabs are classified into two types. These are:

1. One way slabs
2. Two way slabs

One Way Slab

- Slabs supported on two opposite edges is termed as one way slab.
- If aspect ratio is $(l_y/l_x) > 2$, then it is known as one way slab.
- One way slabs bends in single direction, i.e., along shorter span and, hence, main reinforcement is required in shorter direction only to resist bending.
- Distribution steel is provided in longer span to uniformly distribute loads, and to resist temperature and shrinkage stresses.



Design Procedure for One Way Slab

1. Based on stiffness requirement, assume suitable depth and calculate the effective span.
2. Calculate the loads acting on the slab.
3. Calculate the factored moment and shear force by considering one meter width of a slab.

   For a simply supported slab:

$$M_u = \frac{W_u l^2}{8}; V_u = \frac{w_u l}{2}$$

l = Lenght of shorter span

4. Determine the minimum depth required to resist the bending moment by equating:

$$M_u = M_{\text{Ulim}} = kf_{ck}\, bd^2$$

   $b = 1000$ mm; $k = 0.138$ for Fe415 steel, and 0.148 for mild steel.

   The depth provided should be more than this value.
5. Determine the area of steel considering meter width of slab.
6. Determine the spacing of bars by using:

$$S = \frac{a_{st}}{A_{st}} \times 1000$$

   Where

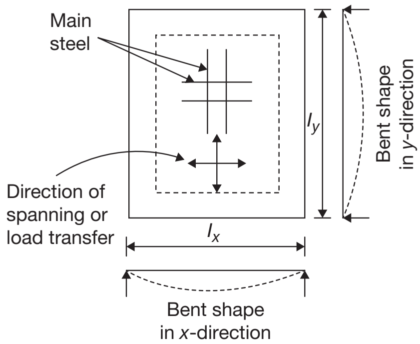
   a_{st} = Area of bar used
   A_{st} = Total area of steel required

   Spacing should not be more than $3d$ or 300 mm, or whichever is less.
7. Distribution steel: Provide minimum reinforcement as distribution steel at spacing of $5d$ or 450 mm, whichever is less.
8. Slab is checked for deflection, shear and development length. In case of slabs (thin members), no need of even minimum shear reinforcement. Shear due to loads always must be less than the shear strength of concrete.

Two Way Slabs

- Slabs supported on all the four edges and aspect ratio $(l_y/l_x) \le 2$, are termed as two way slabs.
- Slabs bend along the two spans and, hence, main reinforcement has to be designed in both the directions to resist two way bending.
- A slab behaves like a one way slab irrespective of aspect ratio when it is supported only on two opposite edges.

Example: A square slab $\left(\frac{l_y}{l_x} = 1\right)$ also acts as an one way slab, if it is supported only on two opposite edges.



Two way slabs, depending on support conditions, are are divided into the follow two types:.

1. Simply supported slab with corners not held down
2. Restrained slabs.

Simply Supported Slabs

- Slabs supported on all four edges and corners are free to lift.
- Torsion reinforcement is not required as corners are free to lift up.
- The maximum moments per unit width are given by the following equations:

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

Where

M_x and M_y are design moments along the short and long spans.
w = Uniformly distributed load on the slab.
l_x and l_y = The lengths of short and long spans.
α_x and α_y = The moment coefficients.

BM coefficients for slabs spanning in two directions at right angle, simply supported on four sides (Table 27 of IS 456–2000)

ly/lx	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	2.5	3.0
α_x	0.062	0.074	0.084	0.093	0.099	0.104	0.113	0.118	0.122	0.124
α_y	0.062	0.061	0.059	0.055	0.051	0.046	0.057	0.029	0.020	0.014

Restrained Slabs

- Slab whose corners are prevented from lifting are called 'restrained slabs'.
- To prevent cracking of the corners, torsion reinforcement is provided.

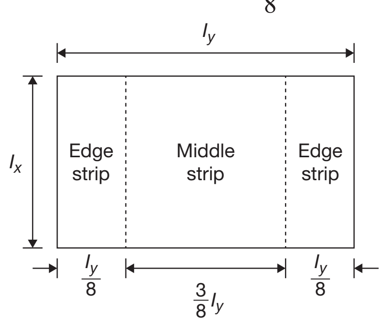
Recommendations of IS:456, for Design of Restrained Slabs

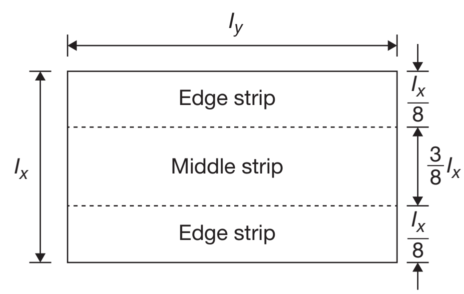
1. Maximum bending moments per unit width in a slab are given by the following equations:

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

α_x and α_y are moment coefficients which depends on $\frac{l_y}{l_x}$, and on the edge conditions (continuous or discontinuous).

2. Slabs are divided into middle strip and edge strip in each direction as considered. The middle strip being $\frac{3}{4}$ of width and edge strip is $\frac{1}{8}$ width of slab.





Division of slab into middle and edge strips

3. The maximum bending moments are applied to middle strips only.
4. Tension reinforcements provided at the mid-span in the middle strip shall extend into the lower part of slab to within $0.25l$ of a continuous edge or $0.15l$ of a discontinuous edge.
5. Over the continuous edges of a middle strip, the tension reinforcement shall extend in the upper part of the slab at a distance of $0.15l$ from the support and at least 50% shall extend a distance of $0.3l$.
6. At the discontinuous edge, negative moment may arise. They depend on the degree of fixity at the edge of slab, but, in general, tension reinforcement equal to 50% of that provided at mid-span extending $0.1l$ into the span will be sufficient.
7. Minimum reinforcement is provided in edge strip, parallel to that edge.
8. Area of torsion reinforcement required shall be $\frac{3}{4}$ of area required for the maximum mid-span moment in the slab. [when both edges are discontinuous]

9. Torsion reinforcement provided will be half of the torsion reinforcement described above, if one of edge is continuous.

10. There is no need of torsion reinforcement if the edges are continuous.

11. For two way slabs with shorter span $l_x < 3.5$ m and $LL < 3$ kN/m^2, the allowable (l_x/D) ratio is:

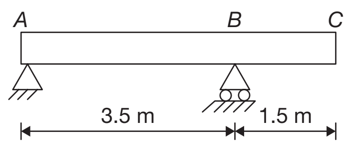
Type of Slab	Fe 250	Fe 415
Simply supported slabs	35	40
Fixed or continuous slabs	4	32

12. If $l_x > 3.5$ m and $LL > 3$ kN/m^2, the allowable $\frac{l_x}{d}$ ratio is same as that of one way slab.

SOLVED EXAMPLE

Example 1

The effective spans for a simple one-way slab system, with an overhang are indicated in the figure (below). The specified ultimate design loads on the slab are 6.0 kN/m^2 and 4.5 kN/m^2 for dead loads and live loads, respectively. Considering the possibility of live loads not occurring simultaneously on both spans, determine the maximum spacing (in mm) units of 8 mm diameter bars required as bottom reinforcement in the span AB, assuming an effective depth of 125 mm, assume M_{20} concrete and Fe415 steel. **[GATE, 2001]**



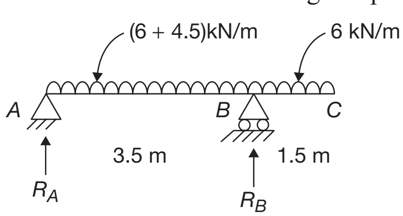
Solution

Given: $d = 125$ mm f_y: 415 Mpa

Live load: 4.5 kN/m^2 $f_{ck} = 20$ N/mm^2 $\phi = 8$ mm

Given that live load is not occurring simultaneously on spans AB and BC.

Hence, assume that live load is acting on span AB only.



Calculation of maximum bending moment in span AB.

Reactions:

$$\uparrow^{+ve} \Sigma Fy = 0$$

$$R_A + R_B - (10.5)(3.5) - 6(1.5) = 0$$

$$R_A + R_B = (10.5)(3.5) + 6(1.5)$$

$$\Sigma M_B = 0$$

$$R_A(3.5) + 6\,(1.5)\frac{(1.5)}{2} - 10.5 \times 3.5 \times \frac{3.5}{2}$$

$$\boxed{R_A = 16.45 \text{ kN}}$$

To obtain maximum bending moment in AB:

$$\frac{dM_x}{dx} = 0; M_x = R_A\, x - \frac{10.5x^2}{2}$$

$$\frac{dM_x}{dx} = R_A - \frac{(10.5)(2)(x)}{2}$$

$$R_A - 10.5\,(x) = 0$$

$$16.45 - 10.5\,(x) = 0$$

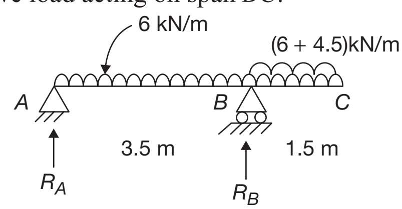
$$X = \frac{16.45}{10.5} = 1.6 \text{ m}$$

∴ Maximum bending moment in span

$$AB = (R_A)(1.6) - \frac{10.5(1.6)^2}{2}.$$

$$\boxed{M_{AB} = 12.88 \text{ kN/m}} \qquad (1)$$

Assume live load acting on span BC:



Taking moments about B:

$$\Sigma M_B = 0$$

$$R_A(3.5) - 6(3.5)\frac{(3.5)}{2} + \frac{(10.5)(1.5)^2}{2} = 0$$

$$R_A = 7.125 \text{ kN}$$

To obtain maximum bending moment in span AB:

$$\frac{dM_x}{dx} = 0$$

$$M_x = R_A(x) - 6\left(\frac{x^2}{2}\right)$$

$$\frac{dM_x}{dx} = R_A - \frac{12x}{2} = 0$$

$$R_A = 6x$$

$$X = \frac{R_A}{6} = 1.188 \text{ m}$$

Maximum bending moment in span

$$AB = (R_A)(1.188) - \frac{6 \times 1.188^2}{2}$$

$$\boxed{M_{AB} = 2.89 \text{ kN/m}} \qquad (2)$$

From Eqs. (1) and (2), maximum bending moment occurs when live load is over span AB only.

∴ $M = 12.88$ kN/m

Spacing:

$M = 0.87\, fy\, A_{st}\, (d - 0.42\, x_{umax})$

For Fe415 steel; x_{umax} 0.48 $d = 0.48 \times 125$

$12.88 \times 10^6 = (0.87)\,(415)\,(A_{st})\,(125 - 0.42 \times 0.48 \times 125)$

$A_{st} = 357.45\ \text{mm}^2$

Given diameter of steel as 8 mm:

$$A_{st} = \frac{\pi}{4} \times 8^2$$

$$= 50.2\ \text{mm}^2$$

∴ Spacing of reinforcement:

$$S_p = \frac{a_{st}}{A_{st}} \times 1000$$

$$= 140\ \text{mm c/c}$$

Spacing limits: Minimum of

1. $3d = 3(125)$
2. 300 mm
3. 140 mm

∴ Use spacing as 140 mm c/c.

Columns

- A vertical compression member whose effective length is greater than 3 times its least lateral dimension is known as a column.
- The compression member whose effective length is less than or equal to 3 times its least lateral dimension is known as a pedestal.

Necessity of Reinforcement in Columns

Longitudinal steel bars are placed in column:

1. To reduce the size of column.
2. To increase the load carrying capacity.
3. To resist any tension due to bending of column, horizontal loads, eccentric loads or moments.

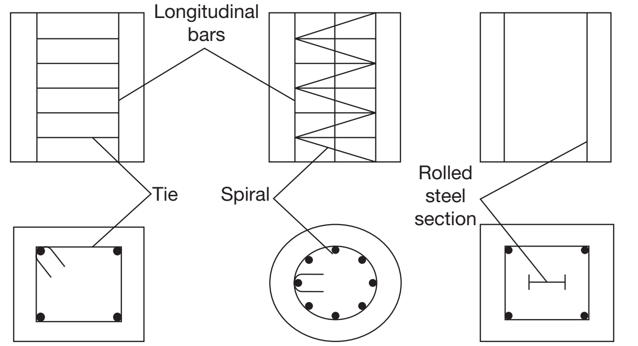
Transverse reinforcement in the form of lateral ties are provided to:

1. Resist longitudinal splitting of the column due to development of transverse tension.
2. Prevent buckling of longitudinal bars.

Types of Columns

Based on Type of Reinforcement

1. **Tied column:** Lateral ties are used to confine the longitudinal bars.
2. **Spiral column:** Spiral reinforcement is used continuously to confine the longitudinal bars.
3. **Composite column:** When the longitudinal reinforcement is in the form of structural steel or pipe with or without longitudinal bars is known as composite column.



Types of columns

Based on Type of Loading

Depending upon the type of loading columns may be classified into:

1. Axially loaded column
2. Eccentrically loaded columns (uniaxial or biaxial)

Based on Slenderness Ratio

Compression members are classified into three types based on slenderness ratio.

1. **Pedestal:** When the effective length of column is less than or equal to 3 times the least lateral dimension, the compression member is known as a pedestal.
2. **Short column:** When the effective length of a column is greater than 3, but less than 12 times the least lateral dimension, the column is known as a short column.

   Short column fails by direct crushing. (Pure compression failure)
3. **Long column:** If the slenderness ratio exceeds 12, the column is known as a long column.

   A long column fails by bending or buckling.

Effective Length of Column

Effective length of column is the distance between points of zero bending moments of a column.

Effective length of column is independent of load acting on column. It depends on end or boundary conditions only.

Effective length of compression members (Table 28 of IS:456–2000)

Degree of end Restraint of Compression Members	Symbol	Theoretical Value of Effective Length	Recommended Value of Effective Length
Effectively held in position and restrained against rotation in both ends.		0.50L	0.65L

(Continued)

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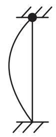
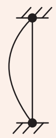
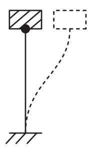
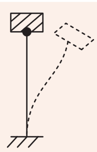
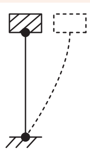
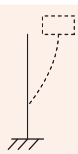
Degree of end Restraint of Compression Members	Symbol	Theoretical Value of Effective Length	Recommended Value of Effective Length
Effectively held in position at both ends, restrained against rotation at one end.		0.70*L*	0.80*L*
Effectively held in position at both ends, but not restrained against rotation.		1.00*L*	1.00*L*
Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position.		1.00*L*	1.50*L*
Effectively held in position and restrained against rotation at one end, and at the other partially restrained against rotation but not held in position.		-	1.50*L*
Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position.		2.00*L*	2.00*L*
Effectively held in position and restrained against rotation at one end, but not held in position or restrained against rotation at the other end.		2.00*L*	2.00*L*

Note: '*L*' is the unsupported length of column.

Slenderness Limits for Columns

To avoid the failure of column by buckling, IS:456 recommends the following slenderness limits for the column.

1. The unsupported length shall not exceed 60 times the least lateral dimension of column. $\boxed{L < 60\,b}$
2. If one end of column is unrestrained (unsupported).

$$\boxed{L < 100\frac{b}{D}}$$

Where
b = Width of cross-section
D = Overall depth of cross-section

Minimum Eccentricity

IS 456–2000 recommends that all columns shall be designed for minimum of eccentricity as given below.

$$\boxed{\begin{array}{l} e_{\min} = \dfrac{L}{500} + \dfrac{\text{Least lateral dimension}}{30} \\ \text{Subeject to a minimum of 20 mm} \end{array}}$$

Assumptions

In limit state of collapse–compression, following assumptions are made in addition to those made in limit state of collapse flexure.

1. The maximum compressive strain in concrete in axial compression is 0.002
2. The maximum compressive strain at the highly compressed extreme fiber in concrete subjected to axial compression and bending and when there is no tension shall be 0.0035 minus 0.75 times the strain at the least compressed extreme fiber.

Design of Axially Loaded Short Column

Short Column with Lateral Ties

As per IS:456, if minimum eccentricity does not exceed 0.05 times the lateral dimensions, the member shall be designed by the following equation.

$$\boxed{P_u = 0.4\, f_{ck}\, A_c + 0.67\, f_y\, A_{sc}}$$

Short Column with Helical Reinforcement

The strength of column with helical reinforcement shall be 1.05 times the strength of similar column with lateral ties provided the ratio of the volume of Helical reinforcement to the volume of the cone shall not be less than:

$$\boxed{0.36\left(\frac{A_g}{A_k} - 1\right)\frac{f_{ck}}{f_y}}$$

Where
P_u = Factored axial load on the column.
A_c = Area of concrete : gross area–area of steel.
A_{sc} = Area of longitudinal reinforcement.
f_{ck} = Characteristic compressive strength of concrete.
f_y = Characteristic strength of compressive steel.
A_g = Gross area of section.
A_k = Area of the core of helically reinforced column measured to the outside diameter of the helix.

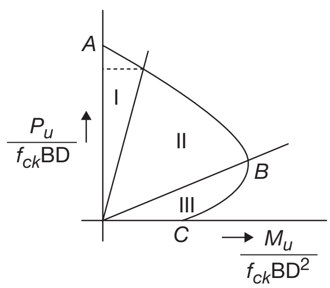
Design of Short Column Subjected to Axial Load and Uniaxial Moment

Procedure

1. Select a suitable interaction chart based on $\frac{d'}{d}$ and f_y values.
2. Calculate $\frac{P_u}{f_{ck}BD}$ and $\frac{M_u}{f_{ck}BD^2}$, i.e., Y-value and X-value of interaction chart.
3. Based on the above two values, read the value of (p/f_{ck}) form the chart.

$$\frac{P}{f_{ck}} = k(\text{say})$$
$$P = \%\text{ of steel} = k \because f_{ck}$$

Interaction Chart



Typical interaction chart

Where

A = Pure compression case
B = Balanced failure
C = Pure moment case
Region I: Minimum eccentricity region
Region II: Compression control region
Region III: Tension control region
A to B: Compression failure takes place.

Short Column Subjected to Axial Load and Biaxial Moments

The columns subjected to biaxial moment has to satisfy the following interaction formula given by IS:456.

$$\left[\frac{M_{ux}}{M_{ux1}}\right]^{\alpha_n} + \left[\frac{M_{ux}}{M_{uy1}}\right]^{\alpha_n} \le 1.0$$

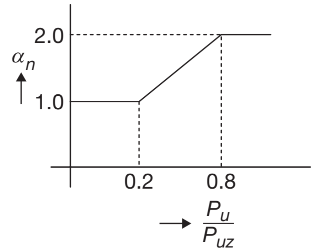
Where

M_{ux}, M_{uy} = Moment about X and Y axes due to design load
M_{ux1}, M_{uy1} = Moment capacity of column along X and Y axes

α_n is exponent which depends on $\left(\frac{P_u}{P_{uz}}\right)$ value

$$P_{uz} = 0.45 f_{ck}\ A_c + 0.75\ fy\ A_{sc}$$

Value of α_n



$\frac{P_u}{P_{uz}}$	α_n
≤0.2	1.0
0.2 – 0.8	1.0 – 2.0
≥0.8	2.0

Long Columns or Slender Columns

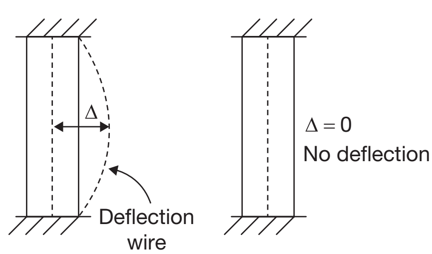
- In case of long columns, lateral deflection occurs due to the application of axial loads and is maximum at the centre.
- The long column is subjected to a bending moment ($P \times \Delta$) in addition to axial loads
- According to IS:456–2000, the additional moments M_{ax} and M_{ay} due to the lateral deflection shall be calculated by the following equations.

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

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

Where

P_u = Axial load on the member.
L_{ex} = Effective length in respect of the major axis.
L_{ey} = Effective length in respect of minor axis.
d = Depth of cross-section at right angles to the major axis.
b = Width of the cross-section.



(a) Long column (b) Short column

Behaviour of long and short column

Design Requirements for Columns (Clause 26.5.3 of IS456)

1. The cross-section area of longitudinal reinforcement shall not be less than 0.8% and not more than 6% of the gross cross-sectional area of the column.
2. In any column that has larger cross-sectional area than that required to support the load, the minimum percentage of steel shall be 0.8% of the required area and not the area actually provided.
3. Minimum number of longitudinal bars to be provided is 4 for rectangular columns and 6 for circular columns.
4. Minimum diameter of longitudinal bars is 12 mm.
5. Spacing of longitudinal bars measured along the periphery of the column shall not exceed 300 mm.
6. The nominal cover for longitudinal bars shall not be less than 40 mm, or less than the diameter of such bar.

Transverse Reinforcement

Lateral Ties

1. The diameter of lateral ties shall not be less than $\frac{1}{4}$ of the diameter of largest longitudinal bar and in no case less than 6 mm.
2. The pitch of the ties shall not be more than the least of the following:
   (a) Least lateral dimension of column
   (b) Sixteen times the smallest longitudinal bar
   (c) 300 mm

Helical Reinforcement

1. The diameter is same as that of lateral ties.
2. The pitch of helical reinforcement shall not be more than the least of the following:
   (a) 75 mm
   (b) $\frac{1}{6}$ of core diameter of column
3. The pitch of helical reinforcement shall not be less than the greatest of the following
   (a) 25 mm
   (b) Three times the diameter of helical bar.

Footings

Foundation increases the stability of structure by distributing the load of a superstructure over a larger area to the foundation soil, so that the pressure on soil does not exceed its allowable bearing capacity and restrict the settlement of structure with in the permissible limits.

General Design Requirements for Footings (As per IS:456–2000)

The general design requirements for footings (As per IS:456–2000) are as follows:

1. Minimum thickness at edges: In reinforced and plain concrete footings, the minimum thickness at the edges shall be taken as follows:
   For footings on soil: 150 mm
   For footings on piles: 300 mm
2. Minimum depth of foundation of 500 mm is to be provided (As per IS:1080–1962).
3. Rankin's formula is used to determine the minimum depth of foundation.

$$h = \frac{p}{\gamma}\left[\frac{1-\sin\phi}{1+\sin\phi}\right]^2$$

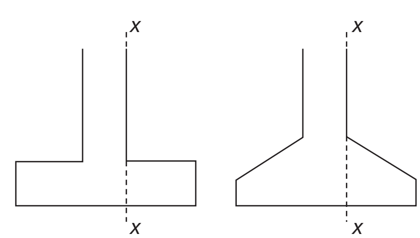
Where
h = Minimum depth of foundation below ground level.
p = Safe bearing capacity of soil.
γ = Unit weight of soil.
ϕ = Angle of friction of soil.

4. Minimum clear cover of 50 mm is to be provided for any type of exposure.
5. **Minimum reinforcement:** The minimum reinforcement described for slabs are applicable for footings also.

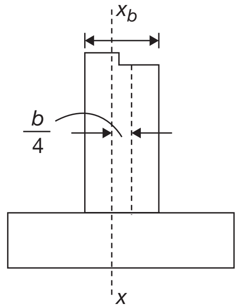
0.12% of gross area → If HYSD bars are used.
0.15% of gross area → If plain bars of mild steel are used.

Minimum diameter of bar to be used is 10 mm.

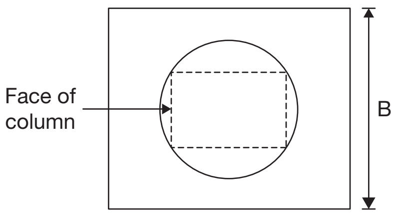
6. **Bending moments:** The critical section for determination of bending moment shall be as follows:
   (a) At the face of column, pedestal or wall, for footings supporting a concrete column, pedestal or wall.
   (b) Halfway between the centre line and edge of the wall, for footings under masonry walls.
   (c) Halfway between the face of the column or pedestal and the edge of the gusseted base, for footings under gusseted bases.
   (d) For footings under circular columns, the face of column shall be taken as the side of square inscribed within the perimeter of a circular column (clause 34.2.2 of IS:456–2000).



(a) Critical sections for footing under concrete column



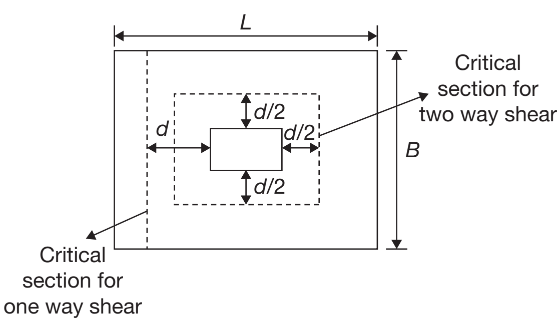
(b) Critical section for footing under masonry wall



(c) Face of column for footings under circular column

Critical sections for bending moment

7. **Shear:**
   (a) **For one way shear:** The critical for shear may be assumed as a vertical section located from the face of the column, pedestal or wall at a distance equal to the effective depth for footings on soil and a distance equal to half the effective depth in case of footings on piles.
   (b) **For two way shear:** The critical section for shear is at a distance '$d/2$' from the periphery of the column perpendicular to the plane of slab.



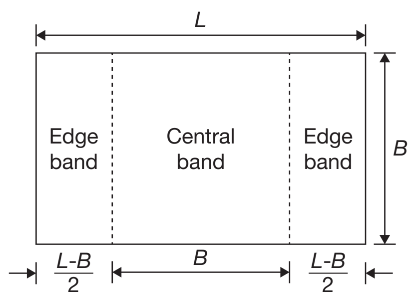
Critical section for shear in rectangular footing

8. **Bond:** The critical section for checking the development length in a footing shall be assumed.
   (a) As same planes described for bending moment.
   (b) The plane where abrupt changes of section occur.
9. **Tension reinforcement:** Distribution of total tensile reinforcement across the resisting section is as follows:
   (a) Reinforcement provided in one way reinforced footing shall be distributed uniformly across the full width of footing.
   (b) Reinforcement provided in two way reinforced footing shall be distributed uniformly in each direction across the full width of footing.
   (c) In two way reinforced rectangular footing, the reinforcement in long direction is uniformly placed across the full width of footings, whereas for reinforcement in shorter direction, a central band equal to the width of the footing shall be marked along the length of the footing and portion of reinforcement determined in accordance with the equation, given below, shall be uniformly distributed across the central band.

$$\frac{\text{Reinforcement in central band}}{\text{Toral reinforcement in shorter direction}} = \frac{2}{\beta + 1}$$

Where, β is ratio of longer side to shorter side of footing.

The remaining portion shall be provided uniformly in the outer portions of footing.



Bands for reinforcement in rectangular footing

10. **Transfer of load at base of column:**

The compressive stress in concrete at the base of column is transferred by bearing to the top of supporting footing.

Bearing pressure on loaded area $\ngtr$ [Permissible bearing stress in direct compression] $\times \sqrt{\frac{A_1}{A_2}} \ngtr 2$

Where

A_1 = Supporting area for bearing of footing.
A_2 = Loaded area at the column face.

- The permissible bearing stress on full area of concrete shall be taken as $0.45 f_{ck}$
- When the bearing stress is more than the allowable value, extended longitudinal bars or dowel bars are used to transfer the excess force.
- Such reinforcement should be a minimum of 0.5% of cross-sectional area of the column and minimum number of bars should be 4. The diameter of the dowel bar shall not exceed the diameter of column bars by more than 3 mm.

Exercises

1. According to IS:456–2000, Maximum slenderness ratio for a short concrete column is
(A) less than 12.
(B) between 12 and 18.
(C) between 12 and 18.
(D) more than 24.

2. A reinforced concrete slab is 75 mm thick. The maximum size of reinforcement bar that can be used is
(A) 12 mm dia
(B) 10 mm dia
(C) 8 mm dia
(D) 6 mm dia

3. The bending moment coefficients for continuous RC slabs is IS:456 is based on
(A) Pigeaud's method.
(B) Marcu's method.
(C) Yield line theory.
(D) Westergaard's mathematical analysis.

4. In case of two way slab the deflection of the slab is
(A) primary function of the long span.
(B) primary function of short span.
(C) independent of span, short or long.
(D) most long span but sometimes short span.

5. In case of continuous RC beam, in order to obtain the maximum positive span moment, where should the live load be placed?
(A) On all the spans.
(B) On alternate spans starting from left.
(C) On spans adjacent to the spans under consideration.
(D) On the span plus alternate spans.

6. Usually stiffness of a simply supported beam is satisfied if the ratio of its span to depth does not exceed which one of the following?
(A) 7 (B) 10
(C) 20 (D) 26

7. When is an RCC roof slab is designed as a two way slab?
(A) If the slab is continuous over two opposite edges only.
(B) If the slab is un-supported at one edge only.
(C) If the ratio of spans in two direction is > 2.
(D) If the ratio of spans in two directions is < 2.

8. What is the value of minimum reinforcement in case of Fe415 steel in slabs?
(A) 0.1%
(B) 0.12%
(C) 0.15%
(D) 0.2%

9. A square slab of 5 m × 5 m is a simply supported slab. If it is subjected to a design load of 15 kPa (including self weight) the moment capacity required as per IS: 456–2000 is: use $\alpha_x = \alpha_y = 0.0062$

10. The lateral ties in a reinforced concrete rectangular column under axial compression
(A) avoid the bucking of the longitudinal steel under compression.
(B) provide adequate shear capacity.
(C) provide adequate confinement to concrete.
(D) reduce the axial deformation of column.

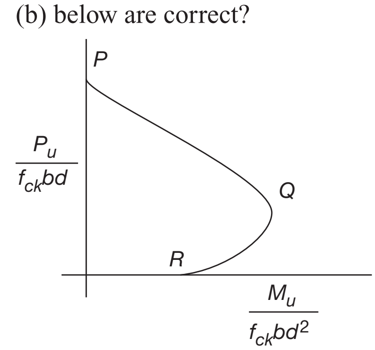
11. In a reinforced concreted beam-column, the increase in the flexural strength along with the increase in the axial strength occurs
(A) beyond the elastic limit of the material.
(B) when the yielding of tension reinforcement governs the strength.
(C) when the crushing of the concrete in compression zone governs the strength.
(D) never.

12. The effective length of a circular electric pole of length 'L' and constant diameter erected on ground is,
(A) $0.80L$ (B) $1.20L$
(C) $1.50L$ (D) $2.00L$

13. In reinforced concrete, pedestal is defined as a compression member, whose effective length does not exceed its dimension by,
(A) 12 times (B) 3 times
(C) 16 times (D) 8 times

14. The effective length of a column in a reinforced concrete building frame, as per IS:456–2000, is independent of the
(A) frame type i.e., braced (no sway) or unbraced (with sway).
(B) span of the beam.
(C) height of the column.
(D) loads acting on the frame.

15. Interaction diagram of a rectangular reinforced concrete beam-column is shown in Fig. with reference to this figure, which of the following statements in (a) and (b) below are correct?



I. (A) Point Q represents balanced failure.
(B) Point R represents balanced failure.

(C) Point R represents balanced failure.
(D) Point Q represents balanced failure under maximum eccentric compression.

II. (A) PQ corresponds to the primary tension failure range.
(B) QR corresponds to the primary tension failure range.
(C) QR corresponds to the primary compression failure range.
(D) PQ corresponds to the range of increase in axial force capacity with increase in bending moment capacity.

16. As RC short column with 300 mm × 300 mm square cross-section is made of M20 grade concrete and has 4 numbers, 20 mm diameter longitudinal bar of Fe415 steel. It is under the action of a concentric axial compressive load. Ignoring the reduction in the area of concrete due to steel bars, the ultimate load carrying capacity of the column is
(A) 1659 kN
(B) 1548 kN
(C) 1198 kN
(D) 1069 kN

17. An rectangular column section of 250 mm × 400 mm is reinforced with five steel bars of grade Fe500, each of 20 mm diameter. Concrete mix is M30. Axial load on the column section with minimum eccentricity as per IS:456–2000. Using limit state method can be applied up to:
(A) 1707.37 (B) 1805.30
(C) 1806.40 (D) 1903.7

18. A reinforced concrete member is subjected to combined action of compressive axial force and BM. If 'E_c' is the least compressive strain in the member, 'fy' is the yield stress of steel and 'E_s' is the modulus of elasticity of steel, the maximum permissible compressive strain in concrete member will be
(A) 0.002
(B) 0.002 ($fy/1.15\ E_s$)
(C) 0.0035-0.75 E_c
(D) 0.0035

19. In case of 2-way slab, the limiting deflection of the slab is
(A) primarily a function of the long span.
(B) primarily a function of the short span.
(C) independent of long or short spans.
(D) dependent on both long or short spans.

20. The bending moment coefficients for continuous RC slabs in IS:456–1978 code is based on
(A) Pigeaud's method
(B) Marcus's method
(C) Yield-line theory
(D) Westergaard's mathematical analysis

21. A reinforced concrete slab is 75 mm thick. The maximum size of reinforcement bar that can be used is
(A) 6 mm diameter
(B) 8 mm diameter
(C) 10 mm diameter
(D) 12 mm diameter

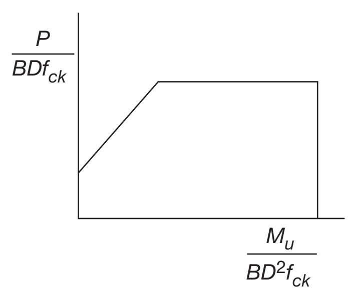
22. Minimum clear cover (in mm) to the main steel bars in slab, beam, column and footing respectively are
(A) 10, 15, 20, 25
(B) 15, 25, 40, 40
(C) 20, 25, 30, 40
(D) 20, 35, 40, 75

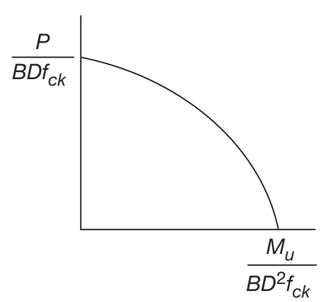
23. The limits of percentage 'p' of the longitudinal reinforcement in a column is
(A) 0.15% to 2%
(B) 0.8% to 4%
(C) 0.8% to 6%
(D) 0.8% to 8%

24. Lateral ties in RC columns are provided to resist
(A) bending moment
(B) shear
(C) buckling of longitudinal steel bars
(D) both bending moment and shear

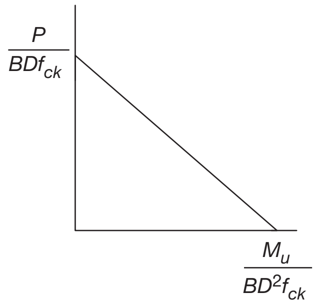
25. The critical section for two-way shear of footing is at the
(A) face of the column.
(B) distance d from the column face.
(C) distance $d/2$ from the column face.
(D) distance $2d$ from the column face.
(Where d is the effective depth of the footing)

26. A rectangular reinforced column ($B \times D$) has been subjected to uniaxial bending moment M and axial load P. Characteristic strength of concrete = f_{ck}. Which one among the following column design curves shows the relation between M and P qualitatively?

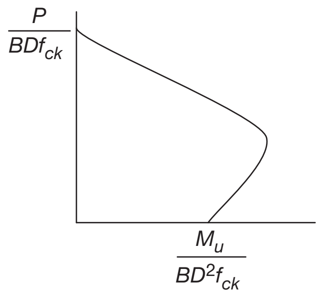
(A)


(B)


(C)



(D)



27. As per IS:456–2000, span/depth ratio of two way simply supported slabs is

(A) 40 (B) 30
(C) 20 (D) 35

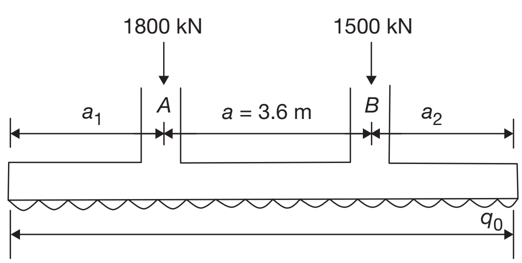
28. In a plain concrete pedestal of M35 Grade, the maximum bearing pressure at the base is found to be 40 N/mm^2. Find the depth of footing if the projection beyond the column is 300 mm

(A) 3.1 m (B) 2.6 m
(C) 2.4 m (D) 1.9 m

29. A hall of 10 m × 24 m consists of a number of beams 4 m centre to centre parallel to the shorter span of the hall. Width of web = 300 mm. Thickness of slab 120 mm, the beams are cast monolithic with the columns at their ends. The effective width of flange of an intermediate beam is

(A) 1.52 m (B) 0.94 m
(C) 2.01 m (D) 2.19 m

30. Two columns A and B carrying loads are shown in figure below with different notations. Soil bearing capacity of soil q_0 = 200 kN-m^2. Width of footing for both columns is 2.4 m. Find a_1 and a_2 shown in figure (assume footing weight as 10% of column load)



(A) a_1 = 1.82 m and a_2 = 2.14 m
(B) a_1 = 2.14 m and a_2 = 1.82 m
(C) a_1 = 1.24 m and a_2 = 2.72 m
(D) a_1 = 2.72 m and a_2 = 1.24 m

31. A column is of 500 × 300 mm and unsupported length of 3 m. The design criteria of the column as per IS: 456– 2000 will be.

(A) Short along long and short dimensions.
(B) Long along short and short along long dimension.
(C) Long along long and short dimensions.
(D) Long along long and short along short dimensions.

32. The factored load carrying capacity of a column of 300 mm × 500 mm size with minimum percentage of steel is (M20 and Fe415)

(A) 1234 kN (B) 1468 kN
(C) 1524 kN (D) 1632 kN

33. A concrete column carries an axial load of 500 kN and a bending moment of 50 kN-m at its base. An isolated footing of 2 m × 3 m, with 3 m side along the plane of bending moment is provided under column. The CG of column and footing coincides. The net maximum and minimum pressures in kN-m^2 on the soil under the footing are respectively

(A) 100 and 66.67 (B) 95 and 55.32
(C) 72 and 46.18 (D) 120 and 75

34. For a footing under 2-way (punching) shear, critical section would be ______.

(A) at face of the column
(B) at a distance 'd' from the face of column.
(C) at a distance $\frac{d}{2}$ from the periphery of column.
(D) at a distance 'd' from the periphery of column

35. For continuous slab of 3 m × 3.5 m size, the minimum overall depth of slab (in cm) to satisfy vertical deflection limit is _______.

(A) 8 cm (B) 10 cm
(C) 12 cm (D) 14 cm

36. A rectangular column section of 300 mm × 450 mm is reinforced with 5 steel bars of grade Fe415, each of 20 mm diameter. Given that concrete mix is M30. Then, axial load on the column section (with minimum eccentricity as per IS:456) can be applied up to ______.

(A) 1038 kN (B) 2038 kN
(C) 3038 kN (D) 4048 kN

37. Identify the incorrect statement from the following.

(A) Simply supported 2-way slab is analyzed using Rankine-Grasholf theory.
(B) Restrained 2-way slabs are analyzed using Jenson-Yield line theory.
(C) 2-way slab is designed as an indeterminate member.
(D) All of these

38. The critical section for finding maximum bending moment for footing under masonry wall is located.

(A) At the edge of the wall.
(B) At the middle of the wall.

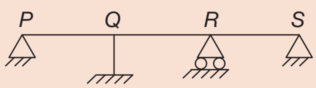
(C) At a distance equal to effective depth of footing from the edge of the wall.
(D) Halfway between the middle and edge of the wall.

39. In RC footing on soil, the thickness at the edge should not be less than
(A) 20 cm
(B) 15 cm
(C) 10 cm
(D) 25 cm

40. A column of size 500 mm × 550 mm has unsupported length of 3.0m and is braced against side sway in both directions. According to IS:456–2000, the minimum eccentricities (in mm) with respect to major and minor principal axes are:
(A) 22.6 mm, 24.3 mm
(B) 25 mm, 30 mm
(C) 20 mm, 20 mm
(D) 27.2 mm, 21.2 mm

Previous Years' Questions

1. The span(s) to be loaded uniformly for maximum positive (upward) reaction of support, *P* as shown in the figure below, is (are) **[GATE, 2008]**



(A) *PQ* only
(B) *PQ* and *QR*
(C) *QR* and *RS*
(D) *PQ* and *RS*

2. A column of size 450 mm × 600 mm has unsupported length of 3.0 m and is braced against side sway in both directions. According to IS:456–2000, the minimum eccentricities (in mm) with respect to major and minor principle axes are **[GATE, 2015]**
(A) 20.0 and 20.0
(B) 26.0 and 21.0
(C) 26.0 and 20.0
(D) 21.0 and 15.0

3. Net ultimate bearing capacity of a footing embedded in a clay stratum **[GATE, 2015]**
(A) increases with depth of footing only.
(B) increases with size of footing only.
(C) increases with depth and size of footing.
(D) is independent of depth and size of footing.

Answer Keys

Exercises

1. A	**2.** C	**3.** D	**4.** B	**5.** D	**6.** C	**7.** D	**8.** B	**9.** 23.25 kN-m	
10. A	**11.** C	**12.** D	**13.** B	**14.** D	**15.** (i) A (ii) B		**16.** D	**17.** A	**18.** C
19. B	**20.** B	**21.** B	**22.** B	**23.** C	**24.** C	**25.** C	**26.** D	**27.** D	**28.** A
29. D	**30.** B	**31.** A	**32.** C	**33.** A	**34.** C	**35.** C	**36.** B	**37.** D	**38.** D
39. B	**40.** A								

Previous Years' Questions

1. A	**2.** A	**3.** D