UNIT V

LIMIT STATE DESIGN OF FOOTING AND MAQSONARY STRUCTURES

DESIGN OF CONCRETE WALLS CARRYING VERTICAL LOADS

INTRODUCTION

- ✓ A vertical load-bearing member whose breadth is more than four times its thickness is called a wall.
- ✓ In British practice a wall is considered to be a reinforced wall if the percentage of steel is not less than 0.4 so that the strength of reinforcement can also be taken into consideration when calculating its load carrying capacity.
- ✓ When the steel percentage is low (< 0.4 per cent), the wall is assumed to carry the whole load without the help of steel reinforcement, and it is called a plain concrete wall.
- ✓ In practice walls having less than one per cent steel are considered as plain walls, and all loads are to be carried by concrete only.
- ✓ Vertical as well as horizontal loads, as in earthquake or wind loads, may be arranged to be carried by properly designed reinforced and plain walls.
- ✓ IS 456, Clause 32 in Section 4 (Special Design Requirements for Structural Members and Systems) deals with the design of ordinary reinforced concrete walls.
- ✓ Special walls e.g. shear walls or cantilever retaining walls which have to carry horizontal loads, require more detailed analysis and are not considered as ordinary walls.
- ✓ According to Indian practice, ordinary plain walls are to be designed by 1S 1905 (1969) Code of Practice for Structural Safety of Buildings (Masonry walls) and R.C. walls should be designed by the theory of R.C. columns.
- ✓ Detailed rules for design of walls are laid down in BS 8110 where the design of R.C. walls and plain walls are dealt with separately.
- ✓ Wall elements of retaining walls, bunkers, and silos which act as slabs are designed mostly to resist bending.
- ✓ They are similar to reinforced slabs in their action.
- ✓ When considering ordinary walls, it should also be borne in mind that even though they are primarily designed for vertical loads, they should also have the capacity to transmit the usual horizontal loads like wind loads to their peripheral members.

SLENDERNESS RATIO OF WALLS

- ✓ The carrying capacity of walls depends on their slenderness.
- ✓ The slenderness of plain walls is to be calculated as in the case of masonry walls.
- ✓ Thus, according to the Indian Code of Masonry Walls, IS 1905 (1969), the slenderness ratio of a masonry wall is defined as the effective height divided by the effective thickness or its effective length divided by the effective thickness, whichever is less.
- ✓ It is important to note that the lesser of the two values is taken as the slenderness ratio. This slenderness controls the stress factors in the masonry.
- ✓ The effective height (along the vertical direction) is to be taken, for calculation depends, as in columns, on the 'free height' as well as the conditions of support of its base and top. Similarly, the effective length (along the horizontal direction) depends on the free length and conditions of support along its length such as cross walls.
- ✓ The slenderness of R.C. walls, on the other hand, is to be taken according to its method of construction.
- ✓ If it is constructed monolithically with the adjacent side constructions, it is considered as short or slender with reference to its height only, without reference to its length.
- ✓ When the ratio of the effective height to its thickness does not exceed 12, it is considered as short. If it is equal or more than 12, it is considered as slender.
- ✓ The slenderness effect in R.C. walls is thus similar to that already considered under R.C. columns.
- ✓ These walls are classified as braced or unbraced, similar to columns, according to the provisions made for carrying the lateral loads.
- ✓ However, where the construction of R.C. walls with adjacent construction is such that the loads can be assumed to be transmitted to the reinforced wall as in simply supported condition, the effective height is to be assessed as for plain walls with respect to both effective height and effective length measured horizontally. [8110: 1985 clause 3.9.3.2.1]

Braced and Un braced Walls

- ✓ IS 456, Clause 32.2.1 gives the conditions of lateral support for a wall to be considered as braced.
- ✓ The effect of cross walls in R.C. concrete walls is, sometimes, taken into account for considering it as braced or unbraced, depending on the capacity of the cross wall to resist lateral forces, as in R.C. columns.
- ✓ The wall can be considered as braced if all the lateral forces on it and also at least 2.5% of the vertical load on the wall can be borne by the walls constructed at right angles to the wall being considered.
- ✓ Otherwise, it is considered as unbraced. The overall stability of a multistory building should not depend on unbraced walls alone.
- ✓ Careful bracing of walls should be planned for these structures.
- ✓ Even when walls are considered as unbraced, it is recommended to design the columns and walls which are provided at right angles to it, to assist the unbraced wall to carry at least 25 per cent of the lateral loads to ensure a stable design.

Effective Height of Plain Walls in BS 8110

- ✓ Plain walls are classified as braced or unbraced, and their effective height should be calculated according to Tables 17.1 and 17.2, where L is the unsupported height of the wall.

TABLE 17.1 EFFECTIVE HEIGHT OF UNBRACED PLAIN CONCRETE WALLS (BS Practice)

Nature of wall	Unbraced
With a roof of floor spanning at right angles on top of the wall	$1.5L_0$
[illegible]	$2L_0$

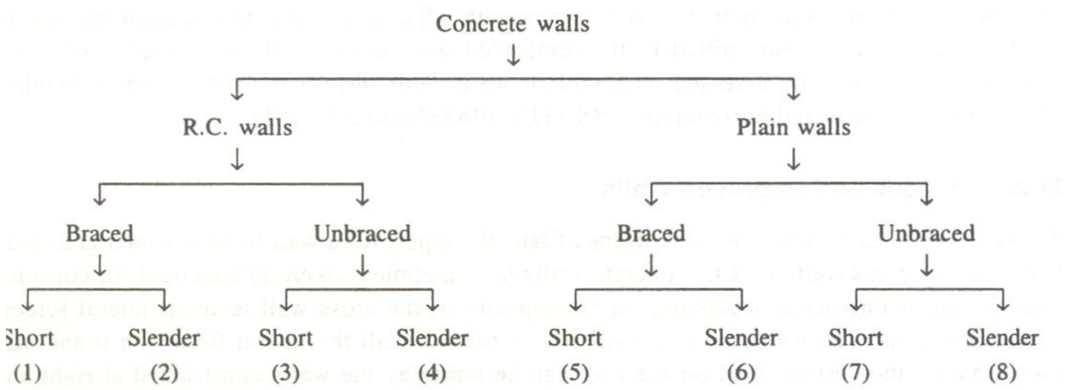
TABLE 17.2 EFFECTIVE HEIGHT OF BRACED PLAIN CONCRETE WALLS
(IS 456, Cl 32.2.4 and BS 8110 Cl 3.9.4.3)

Nature of wall	Lateral support resists rotation and movement	Lateral support resists movement only
With roof or floor on top at right angles	$0.75L_0$	L_0
With no roof or floor on top	$2L_0$	$2.5L_0$

Note: L_0 is the clear distance between lateral supports (unsupported height of wall)

Concrete walls can be classified into eight categories as per BS 8110: For design purposes A given wall is first classified into one of these categories and designed as indicated i Sections 17.4 and 17.5

CLASSIFICATION OF CONCRETE WALLS



LIMITS OF SLENDERNESS

- ✓ Is 456, Section 32.2.3 and the British Code give guidelines for the dimensions of R.C. walls.
- ✓ These may be summarised as follows:
- ✓ Normally, the thickness of an R.C. wall should not be less than 100 mm. If the slenderness ratio of the wall exceeds 12, slenderness effects should be considered for the
- ✓ walls as in the case of columns.
- ✓ The limits of slenderness allowed for walls are given in the classification in Section 17.2.2.

TABLE 17.3 SLENDERNESS LIMITS OF CONCRETE WALLS

Steel (percentage)	Type of wall	Braced or Unbraced	Max L_e/h
0.4 or less	Plain	Braced	30
0.4 or less	Plain	Unbraced	30
0.4 – 1.0	Reinforced	Braced	40
1 – 4	Reinforced	Braced	45
0.4 – 1.0	Reinforced	Unbraced	30
1 – 4	Reinforced	Unbraced	30

- ✓ to the
- ✓ The axial load in a wall is calculated by assuming that the beams and slabs
- ✓ transmit the load as in a simple hinged support.
- ✓ Moments are to be calculated by structural analysis, depending on the degree of fixity. However, a minimum eccentricity of load of 20 mm or 1/20th (0.5 per cent) the thickness of the wall is to be taken for the design for all walls also as in columns.

✓ An R.C. wall can be classified into one of the four types

Design of Short Braced R.C. Walls

Short braced R.C. walls not subjected to any moments may be designed by the formula (as in column). For Fe 415 steel Eq. (13.1) gives the following formula:

$$P = 0.4 f_{ck} A_c + 0.67 A_s f_y \quad ($$

where

A_c = area of concrete

A_s = area of compression reinforcement

Short braced R.C. walls supporting approximately symmetrical arrangement of slabs (spa either side not differing by more than 15 per cent) may be designed also by the formula

$$P = 0.35 f_{ck} A_c + 0.67 A_s f_y$$

With short R.C. walls, which have to resist moments in the plane of the wall as well as moments at right angles to it, special consideration should be given first to bending in the plane of the wall to establish a distribution of tension and compression along the length of the walls, and then to the bending at right angles to the plane of walls.

17.5.2 Case 2: Design of Slender Braced R.C. Walls

Let the thickness of wall be h. The slenderness ratio L_e/h should be limited to 40 to 45 as given in Table 17.3. The design is made as slender compression members, according to IS Code, Clause 39.7.1 with additional moment

$$M_{ax} = \frac{P_u h}{2000}\left(\frac{L_e}{h}\right)^2 \quad (17.3)$$

This is equivalent to taking the additional eccentricity e_a as in slender columns given by

$$e_a = \frac{h}{2000}\left(\frac{L_e}{h}\right)^2$$

A trial and error method may have to be used for the design. Where the wall is reinforced with only one central layer of steel, the additional moments are doubled.

17.5.3 Case 3: Design of Short Unbraced R.C. Wall

The section should be designed as columns to withstand the combination of P and M, the minimum moment being that due to an eccentricity of h/20 or 20 mm.

17.5.4 Case 4: Design of Slender Unbraced R.C. Wall

As mentioned in Table 17.3, the slenderness should not exceed 30. The design is as in case 2 above.

17.6 DESIGN OF PLAIN WALLS (ACCORDING TO BS 8110) (CASES 5 TO 8)

Plain walls are also classified into one of the four types (Cases 5 to 8) in Section 17.2.2 and are designed as follows according to BS 8110: Clause 3.9.4.

17.6.1 Case 5: Design of Short Braced Plain Concrete Walls

Plain short braced walls are designed by using the following formulae:

$$P = (h - 2e_x)\alpha f_{ck} \quad (17.4)$$

where

P = maximum axial load per unit length

h = thickness of wall

e_x = resultant eccentricity at right angles to the plane of the wall (minimum value $h/20$)

α = stress-reduction coefficient or factor depending on the type of concrete and dimension of walls as given in Table 17.5 (an average value of 0.3 may be used for all practical purposes as recommended in BS 8110).

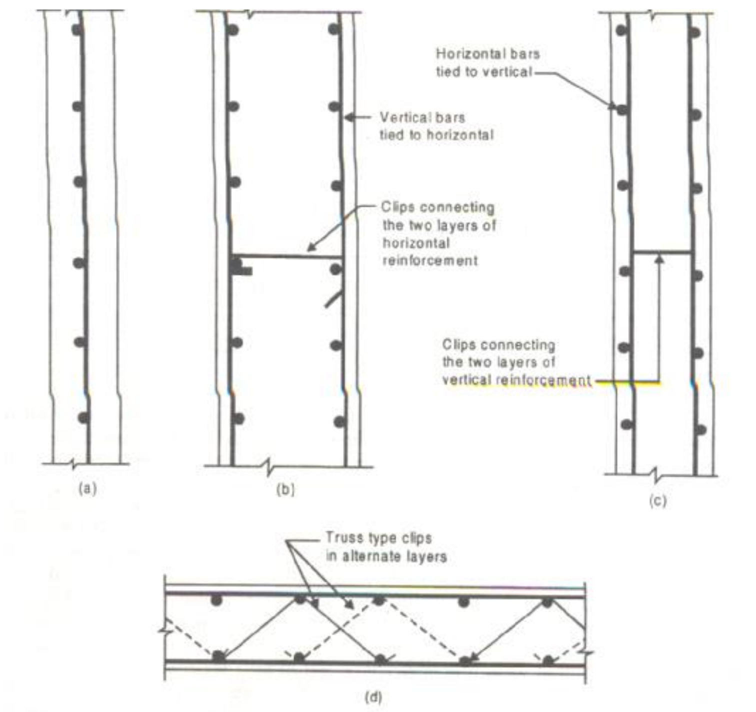
- ✓ Transverse reinforcement is provided by horizontal steel.
- ✓ The minimum amount of horizontal steel, needed is specified in various codes such as the IS and BS codes, and the rules in this respect are now given.

RULES FOR DETAILING OF STEEL IN CONCRETE WALLS

- ✓ The minimum steel to be provided in walls is expressed in terms of the gross area of concrete. The provisions for steel are as follows:
- ✓ **Indian Standards—IS 456, Clause 32.5**
- ✓ (a)Minimum vertical steel for plain walls should be 0.12% for high yield bars and welded fabric and 0.15% for mild steel bars.
- ✓ The maximum spacing should be 450 mm or three times the wall thickness, whichever is less.
- ✓ (Note: For R.C. walls the minimum vertical steel should not be less than 0.4 per cent, irrespective of the type and grade of steel.)
- ✓ (b) Minimum horizontal steel for all types of walls (plain or reinforced) should be 0.20% for high yield bars with diameter not larger than 16 mm and 0.25% for mild steel bars.

- ✓ The maximum spacing of bars should be 450 mm or three times the wall thickness, whichever is less.
- ✓ For walls more than 200mm thick the steel is to be provided as grids on each face of the wall.
- ✓ (It should be noted that the amount of minimum horizontal steel specified in IS 456 is higher than that for the vertical steel.)
- ✓ **British Standards**
  - Plain walls. Only nominal horizontal and vertical steel needs to be provided in plain walls. The function of steel is to control cracking due to shrinkage, temperature, etc. The minimum vertical and horizontal steel should be 0.25 per cent for high yield and 0.30 per cent for mild steel.
- ✓ All the steel should be placed at the exposed side for external walls. For internal walls, half the steel is placed near each side of these walls.
  - R.C. walls. Steel is provided in the form of vertical steel, horizontal steel, and links (if found necessary) as follows:
- ✓ Vertical steel. Minimum vertical steel should be 0.4 per cent in one or two layers and the maximum vertical steel should be 4 per cent.
- ✓ (ii) Horizontal steel Minimum steel should be as in the Indian code, but when the compression steel is more than 2 per cent of the area of the section, horizontal steel should be at least 0.25 per cent for high yield steel and 0.30 per cent for mild steel.
- ✓ The diameter should not be less than one-quarter that of vertical steel, and not less than 6 mm.
- ✓ (iii) Placing of steel in thick walls. In walls greater than 220 to 250mm thick, the steel is placed in two layers.
- ✓ Not less than one-half and not more than two-third steel is placed at the exterior face and the balance at the interior face.
- ✓ The vertical and horizontal steel are not placed further apart than three times the wall thickness or 450 mm.
- ✓ (iv)With large amount of vertical compression steel (more than 2 per cent), it is a good practice to provide horizontal steel through the thickness of walls, in the form of links.

- ✓ The diameter of the links should not be less than one-quarter the diameter of the main rods or 6 mm.
- ✓ The spacing of links too should be less than twice the thickness of wall in horizontal or vertical direction. In the vertical direction the spacing should not be more than 16 times the diameter of the main steel.
- ✓ No un-restrained vertical bar should be farther than 200 mm of a restrained bar Fig.



ig. 17.1 **Detailing of steel in reinforced concrete walls: (a) Wall thickness ≤ 170 m (b) Wall thickness > 220 mm; (c) Wall thickness > 170 mm but < 220 m (d) Truss type clips (links) in alternate layers in a wall.**

- ✓ It can be used as a ready reckoner for the selection of the necessary minimum steel for design of R.C. walls.

GENERAL CONSIDERATIONS IN DESIGN OF WALLS

- ✓ Overall stability of a multistoried building should never depend on its unbraced walls alone. In all cases of walls (even when wails are considered as unbraced) at least 25 per cent of the lateral load should be capable of being resisted by columns, cross walls, or both.

- ✓ A panel wall which is constructed as an infilling for a structural frame may be considered
- ✓ -as non-load bearing, but it should be sufficiently strong to resist the wind pressure to the frame.
- ✓ For this purpose the panels should be given enough bearing by setting them in rebates in the members of the frame or by means of steel dowels.

TABLE 17.6 MINIMUM REINFORCEMENT IN WALLS

Wall thickness (mm)	Steel spacings for given percentage of steel in two layers		
	0.20	0.25	0.4
100	6 mm at 280 mm	6 mm at 200 mm	8 mm at 250 mm
125	6 mm at 220 mm	6 mm at 175 mm	8 mm at 200 mm
150	6 mm at 175 mm	6 mm at 150 mm	10 mm at 250 mm
175	6 mm at 150 mm	8 mm at 225 mm	10 mm at 200 mm
200	6 mm at 140 mm	8 mm at 200 mm	12 mm at 275 mm
225	6 mm at 125 mm	10 mm at 275 mm	12 mm at 250 mm
250	8 mm at 200 mm	10 mm at 250 mm	12 mm at 225 mm
275	10 mm at 275 mm	10 mm at 225 mm	12 mm at 200 mm
300	10 mm at 250 mm	10 mm at 200 mm	12 mm at 175 mm

te: Steel should be provided on both faces at the given spacing; if a single layer is used, half the spacing

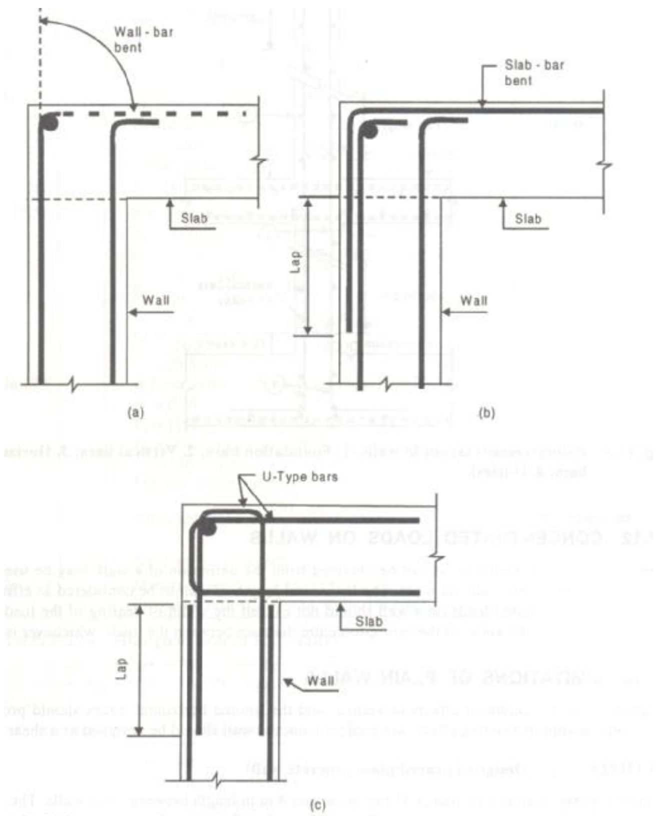
- ✓ Loads with small eccentricities can as well be carried by plain walls as this eccentricity can be taken into account in the design formula for plain walls also.
- ✓ It is essential that, while detailing steel, attention should be devoted to ease of construction.
- ✓ For economy in steel, it is preferable in R.C. walls to provide the maximum effective depth to steel in the direction of moments, but from the steel fabricator's point of view, it is more convenient to have horizontal bars placed on the side of the vertical steel.
- ✓ On the other hand, with smaller cover, horizontal bars next to the formwork may tend to segregate the concrete and make the aggregate to wedge in between the formwork and longitudinal bars.
- ✓ All these factors should be considered before finalizing the detailing of steel.

PROCEDURE FOR DESIGN OF CONCRETE WALLS

- ✓ Step I: Arrive at a layout of the wall and its dimensions.
- ✓ Step 2: Select type of wall—plain or R.C. (Plain walls are used when the factored load to be carried is light, and is of the order of 0.2 to 0.3 f h) per meter length of wall.)
- ✓ Step 3: Determine the effective length and slenderness ratio of the concrete wall and classify the wall into one of the eight types
- ✓ Step 4: Design the wall using the appropriate formulae
- ✓ Step 5: Detail the steel according to the rules

DETAILING OF STEEL

- ✓ Standard detailing of steel in walls is given in IS publication SP 34 Handbook on Concrete Reinforcement and Detailing.
- ✓ These recommendations for vertical steel and splices on top of wall are given in Figs.



7.2 Splices at top of walls: (a) Deformed bars < 10 mm; (b) Deformed bars > 10 mn (c) Deformed bars > 10 mm or mild steel of any diameter.

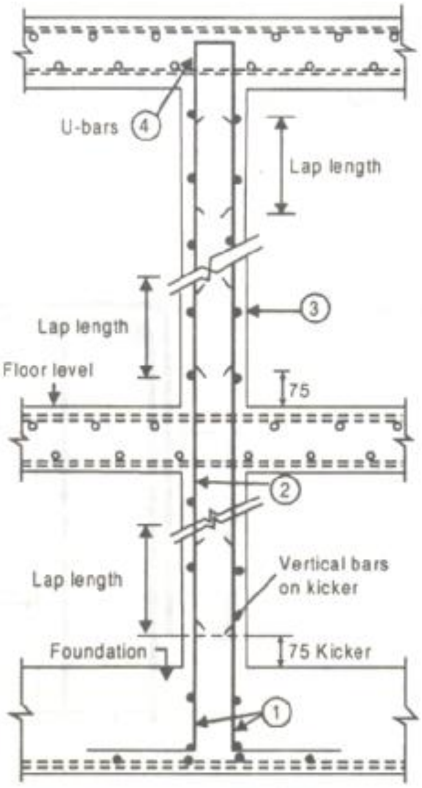


Fig. 17.3 Reinforcement layout in walls (1. Foundation bars; 2. Vertical bars; bars; 4. U-bars).

CONCENTRATED LOADS ON WALLS

- ✓ The following approximation, as can be obtained from the definition of a wall, may be used for design of concentrated loads on walls.
- ✓ The horizontal length of wall to be considered as effective in carrying concentrated loads on a wall should not exceed the width of bearing of the load plus four times the wall thickness or the centre-to-centre distance between the loads, whichever is less.

LIMITATIONS OF PLAIN WALLS

- ✓ In plain walls the combined effects of vertical and the limited horizontal forces should produce only compression.
- ✓ If bending effects are predominant, the wall should be designed as a shear wall.

Design of Footings

INTRODUCTION

- ✓ The function of a foundation or substructure is to safely transfer the loads from the superstructure to the ground.
- ✓ Different types of foundation structures like isolated footings, continuous footings, combined footings, slab rafts, piles, piled rafts, caissons are used for this purpose.
- ✓ Design of foundation structure is a subject in its own right and only the design of elementary foundation structures, such as reinforced concrete individual footings, plain footings, pedestals and pile caps.
- ✓ The aim is to illustrate the method of approach of limit state design to foundation problems.
- ✓ IS 456 Clause 34 deals with design of footings.

DESIGN LOADS FOR FOUNDATION DESIGN

- ✓ The condition to be satisfied by the subsoil in design of foundations is that its safe bearing capacity (which is based on both strength and settlement) should not be exceeded by the loads from the structure.
- ✓ As the safe bearing capacity is obtained from principles of soil mechanics by dividing the ultimate capacity of the soil by a suitable factor of safety, its value represents the serviceability condition, and not the limit state condition.
- ✓ Accordingly, the loads to be used to determine the size of the foundation should be the service loads and not the factored loads.
- ✓ The loads to be used are

  1. Dead plus imposed 1.0 DL + 1.0 LL

  2. Dead plus wind 1.ODL+ 1.OWL

  3. Dead plus imposed + wind 1.0 DL + 0.8 LL + 0.8 WL (EL) (or earthquake)
- ✓ In multistoried buildings, one should take advantage of the allowable reduction in live load for residential and office buildings.

Effect of Horizontal Loads

- ✓ While considering the resistance of the structure to horizontal loads, it should be noted that horizontal loads are to be resisted by the friction and cohesion of the ground, together with the passive resistance of the soil in contact with the vertical faces of the foundation. Limit state design may conveniently be used for this purpose.
- ✓ However, for mobilizing friction, only 0.9 times the dead load should be considered as vertical loads.
- ✓ If the structure is to be planned to take the horizontal load by moments at its base, it should be properly fixed to the ground so that a fixing moment opposite to the applied moment will be produced by the reactions. Alternatively, the foundation pressure should be considered as non-uniform .

BASIS OF DESIGN OF FOOTINGS

- ✓ Footings under walls are called one-way footings and those under columns, two-way footings. The first step in design of footings is to calculate the necessary area from the formula
- ✓ Area of footings = $\dfrac{\text{Service load on column or wall above}}{\text{safe bearing capacity of soil below}}$
- ✓ Having thus determined the size of the footings, its structural design is carried out by using factored loads and principles of limit state design as already discussed in the case of other R.C. members.
- ✓ The main items to be designed are the thickness of the footings and its reinforcement. The thickness should be sufficient to resist the shear force without shear steel and the bending moment without compression steel;
- ✓ Give the structure the required structural rigidity so that the foundation reaction below can be assumed.
- ✓ Withstand the corrosion that can be caused from the ground.
- ✓ (This minimum cover required is not less than 75 mm when the concrete is cast against the ground, and not less than 40 mm when it is cast against a layer of blinding concrete of 75 to 80 mm thickness.)

- ✓ The minimum cover specified in IS 456 for footings is 50 mm (Clause 26.4.2.2).
- ✓ It is also important to remember that the percentage of steel provided should not be less than 0.15 for Fe 250 and 0.12 for Fe 415 steels as specified for slabs in IS 456, Clause 26.5.2.1.

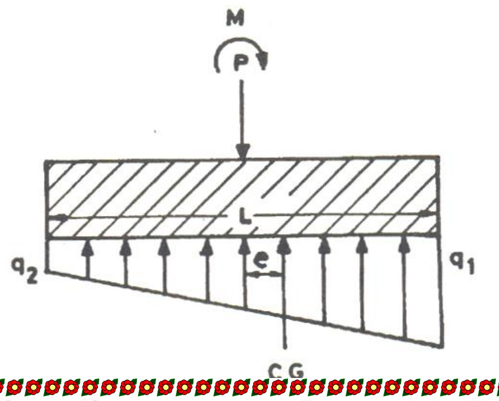
SOIL PRESSURE ON FOUNDATIONS

- ✓ In most designs of foundations and especially in individual footing design, the soil is considered as elastic and the R.C. foundation structure as infinitely rigid.
- ✓ Hence, if foundation pressures on these rigid structures are assumed as uniformly distributed on the base, it is necessary that the centre of gravity of the external load system always coincide with the C.G. of the loaded area.
- ✓ Otherwise, there will be a variation of pressure on the base of the foundation which, for rigid foundations, may be assumed as linearly varying.
- ✓ In all layout of foundations, this basic principle should always be borne in mind.

CONVENTIONAL ANALYSIS OF FOUNDATIONS SUBJECTED TO VERTICAL LOAD AND MOMENTS

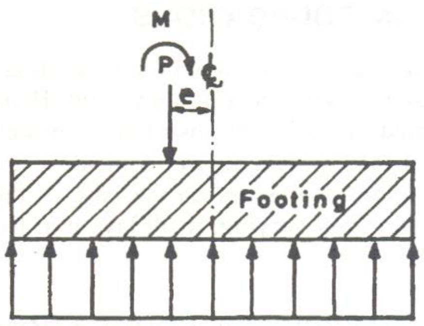
- ✓ With a vertical load P and a moment M acting on a column, the base pressure under the rigid footing will be non-uniform but will be linearly varying from a maximum value of q to minimum value of q as shown in Fig. 22.1.
- ✓ If the centre of gravity of the foundation and the line of application of P coincide, the values of q and q are given by Fig. 22.1 as

$$q_1 = \frac{P}{BL} + \frac{6M}{BL^2}, \qquad q_2 = \frac{P}{BL} - \frac{6M}{BL^2}$$



Non-uniform pressure under eccentrically loaded footings.

- where
  - L = the dimensions along the plane of action of the moment
  - B = the breadth
  - q and qu = the foundation pressures
- The eccentricity e produced by the resultant base reaction will produce the necessary moments to counteract the applied moment so that
  - e = MU
- In soils such as clays, large non-uniform base pressures can lead to differential settlements and consequent tilt in the column.
- Hence the ratio of (q should not exceed 2 to 4, depending on whether it is caused by permanent or transient loads.
- In the case of small eccentricities due to P and M, the centre of gravity of the foundation itself may be offset from the line of action of the load P to produce uniform resultant distribution on the base as shown in Fig.



Eccentric loading to produce uniform soil reaction.

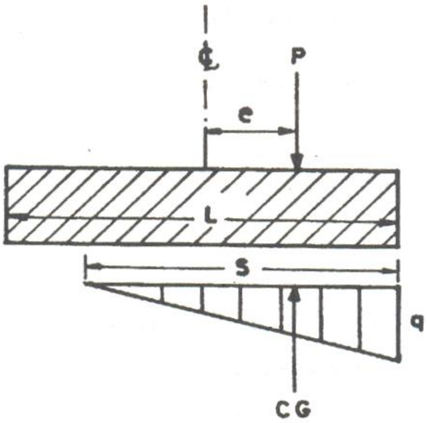
- The value of e = MIP gives indication of the probable variation of q and q If e = L/6, according to the middle third rule, q = 0 and q will be twice the average pressures.
- The eccentricity can be considered to be small.
- When e is greater than 116, part of the base will not be in contact.
- The maximum soil pressures q on the foundation can be calculated from the following equation (Fig. 22.3)

$$P = \frac{1}{2} qsB$$

- ✓ where B is the breadth of the footing s is the length of foundation in contact with the ground.
- ✓ The value of the eccentricity e is given by the equation

$$\frac{M}{P} = e = \left(\frac{L}{2} - \frac{s}{3}\right)$$

- ✓ In footings subjected to biaxial bending, the effect of variation of base pressures in both planes should be considered and combined to get the final values.



Effect of large eccentricity of load on foundation pressures

DESIGN OF INDEPENDENT FOOTINGS

- ✓ 15 456, Clause 34 deals with the design of independent footings.
- ✓ There can be three types of individual footings: rectangular, sloped or stepped. They may rest on soil, rock or on piles. The minimum thickness of edge of the footing on soil and rock should be 150 mm and that on top of piles should not be less than 300 mm. [Clause 34.1.23
- ✓ The column transfers the load to top of footing by bearing. In limit state design, the value of the pressure allowed under direct compression on an un reinforced loaded area of same size is to be limited as given by IS 456, Clause 34.4.
- ✓ However, when the supporting area is larger than the loading area on all sides, it may be increased by the factor A (where in the case of a footing A = area of

the footing and A = area of the column base), but the factor should not be greater than 2.

- ✓ If the above permissible stresses are exceeded, the transfer of forces should be with steel reinforcement, by extending the reinforcement into the footing or by providing dowel (starter) bars.
- ✓ According to IS 456, if dowel bars are provided, they should extend into the column a distance equal to the development length of the column bars (IS 456, Clause 34.4.4). However, this requirement for development length has been relaxed in BS 8110(1985): Clause 3.12.8.8.
- ✓ According to BS code, compression bond stress that develops on starter bars within bases need not be checked provided the starter bars extend down to the level of the bottom reinforcement.
- ✓ Application of this ck can reduce the depth required in footings and save on steel reinforcement.
- ✓ According to IS, the depth required for anchorage is given by

$$L_d = \frac{\phi f_s}{4\tau_{bd}}$$

where

ϕ = diameter of bar

f_s = stress in the bar

τ_{bd} = design bond stress (IS 456, Clause 25.2.1.1) and Cl

For grade 20 concrete and Fe 415, this works out to

$$L_d = \frac{\phi \times 0.87 \times 415}{4 \times 2.4} = 37.6\phi$$

usually it is rounded off as 40ϕ.

- ✓ When the depth required for the above development length or other causes is very large, it is more economical to adopt a stepped or sloped footing so as to reduce the amount of concrete that should go into the footing.
- ✓ According to IS 456, Clause 34.4.3, the extended longitudinal bars or dowels should be at least 0.5 per cent of the cross-sectional area of the supported columns or pedestal, and a minimum of four bars should be provided.
- ✓ The diameter of the dowels should not exceed the diameter of the column bars by 3 mm.
- ✓ As seen from the above discussions, the depth of the footings can be generally taken as that obtained from the point of shear and bending moment only.

- ✓ In all cases, the depth should be such that extra shear reinforcement or compression steel for bending should be avoided.
- ✓ Rectangular footings are generally used with rectangular columns. The most economical proportions of the footing are given if the rectangular base projects the same distance beyond all the column faces, so that the footing requires the minimum amount of materials.

Calculation of Shear for Design

- ✓ In many cases the thickness of the footing will be determined by requirements for shear. Both one- way shear (wide-beam shear) and two-way shear (punching shear) requirements are given below.

1. One-way shear (wide beam shear)

- ✓ One-way shear is similar to bending shear in slabs.
- ✓ Considering the footing as a wide beam, the shear is taken along a vertical plane extending the full width of the base located at a distance equal to the effective depth of t footing (i.e. a dispersion of 45°) in the case of footings on soil and a distance equal to half the effective depth of footings for footings on piles (Fig. 22.4a).
- ✓ The allowable shear stress is the same as in beams.
- ✓ The tension reinforcement to be considered for estimating the allowable shear should continue for a distance equal to full effective depth beyond the section. For routine design, the lowest value of allowable shear in Table 19 of IS 456, i.e. 0.28 N/mm (or B.S. value of 0.35 N/mm is recommended.
- ✓ In one-way shear, the shear distance equal to effective depth d (instead of d/2) from the column face.
- ✓ This will result in larger perimeter length and reduced requirement for shear strength.
- ✓ Both these approaches are found to give safe values for design, especially in footings.

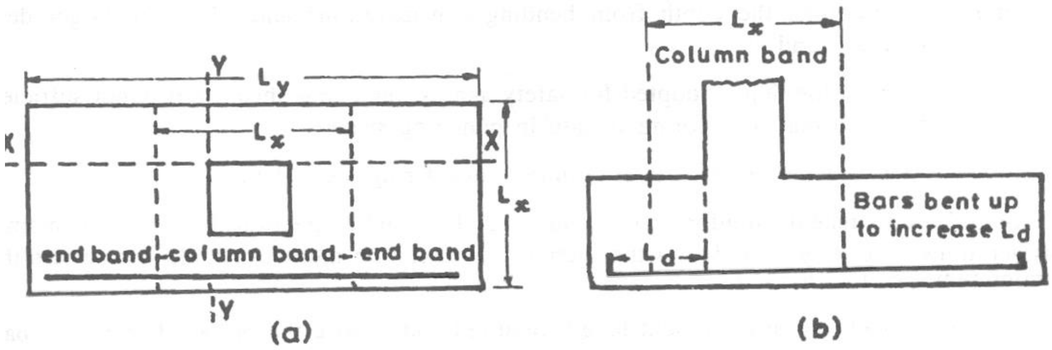
Bending Moment for Design

- ✓ IS 456, Clause 33.2.3 states that the bending moment to be taken for design of footings is the moment of the reaction forces due to the applied load (excluding the weight of the foundation itself) at the following sections:
- ✓ At the face of the column for footings supporting a reinforced concrete column as shown in Fig. 22.4a.
- ✓ Half-way between the centre line and edge of the wall for footings under masonry walls.
- ✓ Half-way between the face of the column and edge of the gusseted base for footings under gusseted bases.
- ✓ Moments should be considered both in X and Y directions and the necessary areas of steel provided in both directions.
- ✓ The steel for the above bending moment is placed as detailed under placement of reinforcement (section 22.7).
- ✓ The footing is to be considered as a slab and the rules for minimum reinforcement for solid slabs should apply to these slabs also (IS 456, Clause 34.5).
- ✓ This recommendation is very important as in many cases of design of footings the reinforcement calculated from bending moment consideration can be less than the minimum required as a slab by IS 456, Clause 26.5.2.1.

MINIMUM DEPTH AND STEEL REQUIREMENTS

- ✓ Depths of footings are governed by the following considerations:
- ✓ The depth should be safe in one-way and two-way shear without shear reinforcements.
- ✓ The depth should be safe for the bending moment without compression reinforcement.
- ✓ The depth, according to IS 456, should develop the necessary transfer bond length by the main bars or dowel bars. (This condition is relaxed in ES 8110).
- ✓ The minimum steel and maximum spacing should be as in slabs: 0.15 per cent for Fe 250 and 0.12 per cent for Fe 415.
- ✓ If the column bars are bent and properly extended into the footing such bars can also be considered to act with the footing.
- ✓ In a sloped footing, the check for minimum steel area then needs to be made only at the middle of the footing.

- ✓ The maximum spacing is 3d or 300 mm.
- ✓ The steel required in X and V directions should be distributed across the cross-section of the footing as follows (see also Fig. 22.5 also IS 456, Clause 34.5).
- ✓ In one-way reinforced footings as in wall footings, the main steel is distributed uniformly across the full width of the footing.
- ✓ In two-way square reinforced footings also, the steel is distributed uniformly across the full width of the footing.
- ✓ In two-way rectangular footings, the steel in the long direction is distributed uniformly over the width of the footing.
- ✓ But as regards the steel in the short direction, more of this steel is placed on the column portion than in the outer portion.
- ✓ For this purpose, a column band equal to the width of the footing is marked beside the column, along the length of the footing, as shown in Fig. 22.5.
- ✓ The portion of the reinforcement to be placed at equal spacing in this band is determined by the equation (IS Clause 34.3.1)



;. 22.5 **Placement of steel in isolated footings: (a) Central column (plan); (b) Non-central column (elevation).**

CHECKING FOR DEVELOPMENT LENGTHS OF REINFORCEMENTS IN FOOTINGS

$$\text{Reinforcement in column band} = \frac{2}{(y/x+1)} A_t$$

'here

A_t = total area of reinforcement in the short direction

y/x = ratio of the length to breadth of footing

'he remaining steel is placed at uniform spacing outside the column band.

- ✓ Individual footings are small sized members with heavy moments.
- ✓ The sizes of the bars selected should be small enough to develop the full development length in the available dimension of the footing.
- ✓ Thus, in Fig. 22.5(b), the anchorage length Ld required, for the sizes of the bars selected for the long and short direction, should be less than one-half of the lengths for the footing in the respective directions.
- ✓ One way of increasing the development of bars in footings is to bend them up at 90 as shown in Fig. 22.5(b), but this is not an economical solution.

PROCEDURE FOR DESIGN

- ✓ The major steps in the design of a footing square or rectangular can be summarized as follows:
    - o Step I: Determine the plan area from the allowable bearing capacity and service loads from the column, assuming a reasonable weight for the footing.
    - o Step 2: Taking the dead and live loads, determine the ultimate soil reaction for factored design load.
    - o Step 3: Determine the depth for one-way shear, assuming a design shear strength value q. Theoretically, this value depends on the percentage of steel in the slab, for preliminary design, a value of ç = 0.35 N/mm may be assumed. This saves the amount of concrete required. Sloped footings generally require more depth but less steel than block footings. Figure 22.7 (a) shows such a sloped footing.
- ✓ According to IS 456, Clause 34.1.2, the edge thickness should not be less than 150 mm.

If τ_c is the design shear strength, then

$$\tau_c L d = V$$

Substituting for V and simplifying the expression, we get

$$d = \frac{P(L-a)}{2(P + \tau_c L^2)} \qquad (22.4)$$

Assuming $\tau_c = 0.35\ \text{N/mm}^2$ and using metre and kN units

$$d = \frac{P(L-a)}{2P + 700L^2} \qquad (22.4a)$$

For calculation purposes, it is convenient to work in metres with τ_c expressed in N/m^2. As the actual value of τ_c will depend on the percentage of steel present at the section continued for a distance d on both sides of the section, it is sometimes recommended to adopt the lowest value of τ_c (namely, the one corresponding to a percentage of steel equal to 0.15 per cent) for routine calculations.

Step 4: The depth from bending moment consideration is obtained by taking moments at face of column XX.

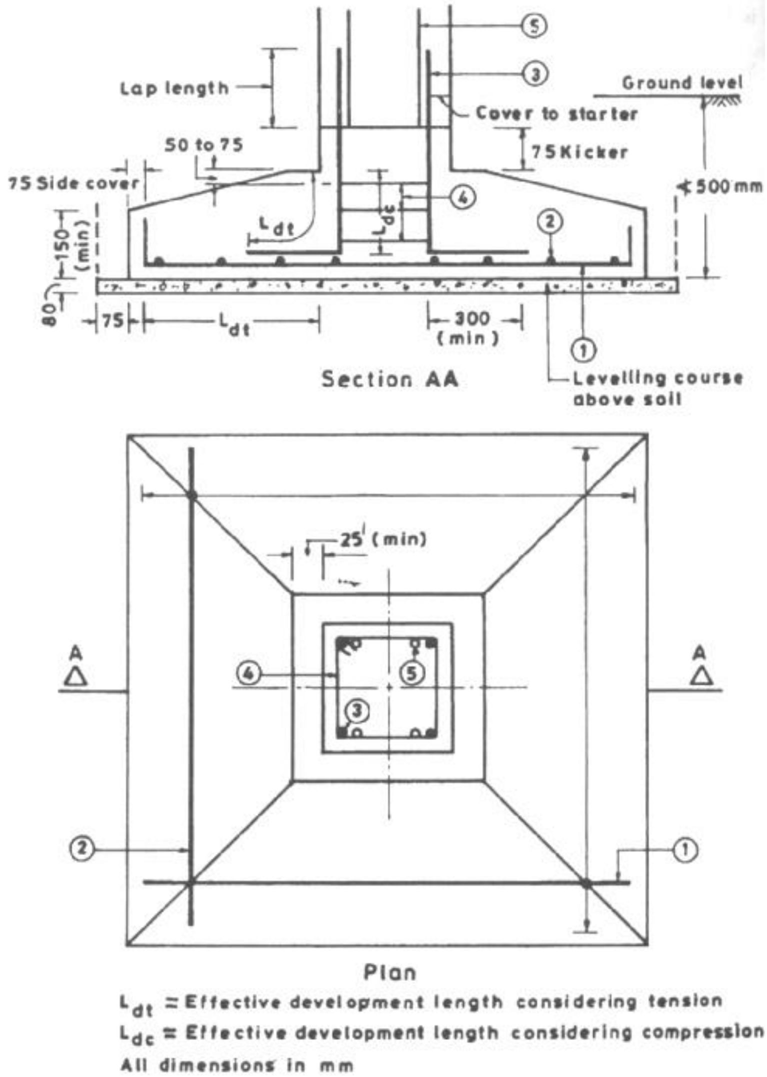
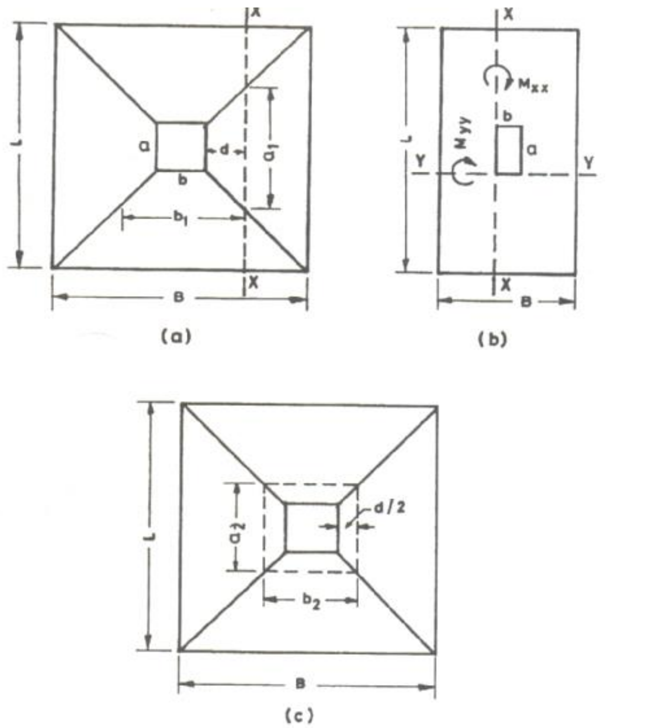


Fig. 22.6 Reinforcement drawing of a footing. (1–5: Bar marks. 1. Main reinforcement upwards if required; 2. Main reinforcement in other direction; 3. Starter
4. Stirrup, unless specified use T8 @ 300, minimum 3; 5. column bars.)



Design of footings: (a) Design of sloped footing; (b) Design of rectangular footings; (c) Checking of two-way shear in footings.