

UNIT-V

DESIGN OF FOOTING AND STAIR CASE

The superstructure is placed on the top of the foundation structure, designated as substructure as they are placed below the ground level. The elements of the superstructure transfer the loads and moments to its adjacent element below it and finally all loads and moments come to the foundation structure, which in turn, transfers them to the underlying soil or rock. Thus, the foundation structure effectively supports the superstructure. However, all types of soil get compressed significantly and cause the structure to settle. Accordingly, the major requirements of the design of foundation structures are the two as given below (see cl.34.1 of IS 456)

:

1. Foundation structures should be able to sustain the applied loads, moments, forces and induced reactions without exceeding the safe bearing capacity of the soil.
2. The settlement of the structure should be as uniform as possible and it should be within the tolerable limits. It is well known from the structural analysis that differential settlement of supports causes additional moments in statically indeterminate structures. Therefore, avoiding the differential settlement is considered as more important than maintaining uniform overall settlement of the structure.

Types of Foundation Structures

1. Shallow Foundation

Shallow foundations are used when the soil has sufficient strength within a short depth below the ground level. They need sufficient plan area to transfer the heavy loads to the base soil. These heavy loads are sustained by the reinforced concrete columns or walls (either of bricks or reinforced concrete) of much less areas of cross-section due to high strength of bricks or reinforced concrete when compared to that of soil. The strength of the soil, expressed as the safe bearing capacity of the soil is normally supplied by the geotechnical experts to the structural engineer. Shallow foundations are also designated as footings. The different types of shallow foundations or footings are discussed below.

- (i) Plain concrete pedestal footings
- (ii) Isolated footings
- (iii) Combined footings
- (iv) Strap footings
- (v) Strip foundation or wall footings
- (vi) Raft or mat foundation

2. Deep foundations

As mentioned earlier, the shallow foundations need more plan areas due to the low strength of soil compared to that of masonry or reinforced concrete. However, shallow foundations are selected when the soil has moderately good strength, except the raft foundation which is good in poor condition of soil also. Raft foundations are under the category of shallow foundation as they have comparatively shallow depth than that of deep foundation. It is worth mentioning that the depth of raft foundation is much larger than those of other types of shallow foundations.

However, for poor condition of soil near to the surface, the bearing capacity is very less and foundation needed in such situation is the pile foundation. Piles are, in fact, small diameter columns which are driven or cast into the ground by suitable means. Precast piles are driven and cast-in-situ are cast. These piles support the structure by the skin friction between the pile surface and the surrounding soil and end bearing force, if such resistance is available to provide the bearing force. Accordingly, they are designated as frictional and end bearing piles. They are normally provided in a group with a pile cap at the top through which the loads of the superstructure are transferred to the piles.

Piles are very useful in marshy land where other types of foundation are impossible to construct. The length of the pile which is driven into the ground depends on the availability of hard soil/rock or the actual load test. Another advantage of the pile foundations is that they can resist uplift also in the same manner as they take the compression forces just by the skin friction in the opposite direction.

However, driving of pile is not an easy job and needs equipment and specially trained persons or agencies. Moreover, one has to select pile foundation in such a situation where the adjacent buildings are not likely to be damaged due to the driving of piles. The choice of driven or bored piles, in this regard, is critical.

Exhaustive designs of all types of foundations mentioned above are beyond the scope of this course. Accordingly, this module is restricted to the design of some of the shallow footings, frequently used for normal low rise buildings only.

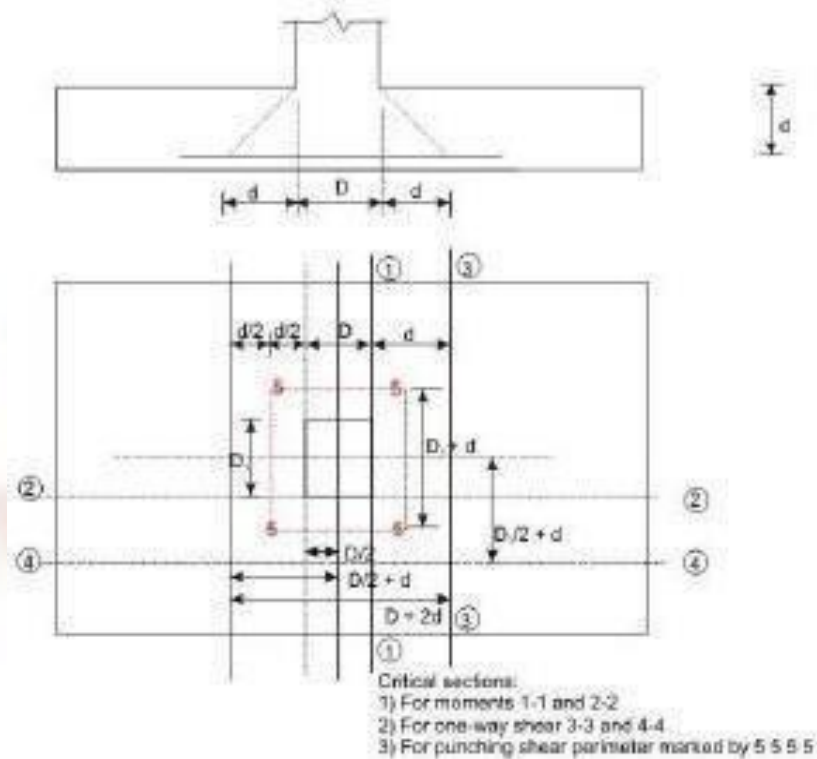


Figure 3.8: Uniform and rectangular footing

isolated Footing

Design Considerations

(a) Minimum nominal cover (cl. 26.4.2.2 of IS456)

The minimum nominal cover for the footings should be more than that of other structural elements of the superstructure as the footings are in direct contact with the soil. Clause 26.4.2.2 of IS 456 prescribes a minimum cover of 50 mm for footings. However, the actual cover may be even more depending on the presence of harmful chemicals or minerals, water table etc.

(b) Thickness at the edge of footings (cls. 34.1.2 and 34.1.3 of IS456)

The minimum thickness at the edge of reinforced and plain concrete footings shall be at least 150 mm for footings on soils and at least 300 mm above the top of piles for footings on piles, as per the stipulation in cl.34.1.2 of IS 456.

For plain concrete pedestals, the angle α (see Fig.11.28.1) 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 determined from the following

expression (cl.34.1.3 of IS 456)

$$0.5 \tan 0.9 \left\{ \left(\frac{100}{f_{ck}} \right)^{\frac{1}{3}} \right\} a \leq \frac{q_a}{f_{ck}}$$

where q_a = calculated maximum bearing pressure at the base of pedestal in N/mm², and
 f_{ck} = characteristic strength of concrete at 28 days in N/mm².

(c) Bending moments (cl. 34.2 of IS456)

1. It may be necessary to compute the bending moment at several sections of the footing depending on the type of footing, nature of loads and the distribution of pressure at the base of the footing. However, bending moment at any section shall be determined taking all forces acting over the entire area on one side of the section of the footing, which is obtained by passing a vertical plane at that section extending across the footing (cl.34.2.3.1 of IS456).

2. The critical section of maximum bending moment for the purpose of designing an isolated concrete footing which supports a column, pedestal or wall shall be:

- (i) at the face of the column, pedestal or wall for footing supporting a concrete column, pedestal or reinforced concrete wall, and
- (ii) halfway between the centre-line and the edge of the wall, for footing under masonry wall. This is stipulated in cl.34.2.3.2 of IS456.

The maximum moment at the critical section shall be determined as mentioned in 1 above. For round or octagonal concrete column or pedestal, the face of the column or pedestal shall be taken as the side of a square inscribed within the perimeter of the round or octagonal column or pedestal (see cl.34.2.2 of IS 456 and Figs.11.28.13a and b).

(d) Shear force (cl. 31.6 and 34.2.4 of IS456)

Footing slabs shall be checked in one-way or two-way shears depending on the nature of bending. If the slab bends primarily in one-way, the footing slab shall be checked in one-way vertical shear. On the other hand, when the bending is primarily two-way, the footing slab shall be checked in two-way shear or punching shear. The respective critical sections and design shear strengths are given below:

1. One-way shear (cl. 34.2.4 of IS456)

One-way shear has to be checked across the full width of the base slab on a vertical section located from the face of the column, pedestal or wall at a distance equal to

- (i) effective depth of the footing slab in case of footing slab on soil, and
- (ii) half the effective depth of the footing slab if the footing slab is on piles.

The design shear strength of concrete without shear reinforcement is given in Table 19 of cl.40.2 of IS 456.

2. Two-way or punching shear (cls.31.6 and 34.2.4)

Two-way or punching shear shall be checked around the column on a perimeter half the effective depth of the footing slab away from the face of the column or pedestal.

The permissible shear stress, when shear reinforcement is not provided, shall not exceed k_s , where $k_s = (0.5 + c\beta)$, but not greater than one, $c\beta$ being the ratio of short side to long side of the column, and $= 0.25(f_{ck})^{1/2}$ in limit state method of design, as stipulated in cl.31.6.3 of IS 456. $k_s \leq c\beta$

Normally, the thickness of the base slab is governed by shear. Hence, the necessary thickness of the slab has to be provided to avoid shear reinforcement.

(e) Bond (cl.34.2.4.3 of IS 456)

The critical section for checking the development length in a footing slab shall be the same planes as those of bending moments in part (c) of this section. Moreover, development length shall be checked at all other sections where they change abruptly. The critical sections for checking the development length are given in cl.34.2.4.3 of IS 456, which further recommends to check the anchorage requirements if the reinforcement is curtailed, which shall be done in accordance with cl.26.2.3 of IS 456.

(f) Tensile reinforcement (cl.34.3 of IS456)

The distribution of the total tensile reinforcement, calculated in accordance with the moment at critical sections, as specified in part (c) of this section, shall be done as given below for one-way and two-way footing slabs separately.

(i) In one-way reinforced footing slabs like wall footings, the reinforcement shall be distributed uniformly across the full width of the footing i.e., perpendicular to the direction of wall. Nominal distribution reinforcement shall be provided as per cl. 34.5 of IS 456 along the length of the wall to take care of the secondary moment, differential settlement, shrinkage and temperature effects.

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

iii) In two-way reinforced rectangular footing slabs, the reinforcement in the long direction shall be distributed uniformly across the full width of the footing slab. In the short direction, a central band equal to the width of the footing shall be marked along the length of the footing, where the portion of the reinforcement shall be determined as given in the equation below. This portion of the reinforcement shall be distributed across the central band

Reinforcement in the central band = $\{2/(\beta+1)\}$ (Total reinforcement in the short direction)

Where β is the ratio of longer dimension to shorter dimension of the footing slab (Fig.3.10).

Each of the two end bands shall be provided with half of the remaining reinforcement, distributed

uniformly across the respective end band.

(g) Transfer of load at the base of column (cl.34.4 of IS456)

All forces and moments acting at the base of the column must be transferred to the pedestal,

if any, and then from the base of the pedestal to the footing, (or directly from the base of the column to the footing if there is no pedestal) by compression in concrete and steel and tension in steel. Compression forces are transferred through direct bearing while tension forces are transferred through developed reinforcement. The permissible bearing stresses on full area of concrete shall be taken as given below from cl.34.4 of IS 456:

□ $b_r = 0.25f_{ck}$, in working stress method, and

□ $b_r = 0.45f_{ck}$, in limit state method

The stress of concrete is taken as $0.45f_{ck}$

while designing the column. Since the area of footing is much larger, this bearing stress of concrete in column may be increased considering the dispersion of the concentrated load of column to footing. Accordingly, the permissible bearing stress of concrete in footing is given by (cl.34.4 of IS 456):

□ $b_r = 0.45f_{ck}(A_1/A_2)^{1/2}$

with a condition that

$(A_1/A_2)^{1/2} \leq 22.0$ (11.8)

where A_1 = maximum supporting area of footing for bearing which is geometrically similar to and concentric with the loaded area A_2

A_2 = loaded area at the base of the column.

The above clause further stipulates that in sloped or stepped footings, A_1 may be taken as the area of the lower base of the largest frustum 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.

If the permissible bearing stress on concrete in column or in footing is exceeded, reinforcement shall be provided for developing the excess force (cl.34.4.1 of IS 456), either by extending the longitudinal bars of columns into the footing (cl.34.4.2 of IS 456) or by providing dowels as stipulated in cl.34.4.3 of IS 456 and given below:

- (i) Sufficient development length of the reinforcement shall be provided to transfer the compression or tension to the supporting member in accordance with cl.26.2 of IS 456, when transfer of force is accomplished by reinforcement of column (cl.34.4.2 of IS456).
- (ii) Minimum area of extended longitudinal bars or dowels shall be 0.5 per cent of the cross-sectional area of the supported column or pedestal (cl.34.4.3 of IS456).
- (iii) A minimum of four bars shall be provided (cl.34.4.3 of IS456).
- (iv) The diameter of dowels shall not exceed the diameter of column bars by more than 3mm.
- (v) Column bars of diameter larger than 36 mm, in compression only can be doweled at the footings with bars of smaller size of the necessary area. The dowel shall extend into the column, a distance equal to the development length of the column bar and into the footing, a distance equal to the development length of the dowel, as stipulated in cl.34.4.4 of IS456.

(h) Nominal reinforcement (cl. 34.5 of IS456)

Clause 34.5.1 of IS 456 stipulates the minimum reinforcement and spacing of the bars in footing slabs as per the requirements of solid slab (cls.26.5.2.1 and 26.3.3b(2) of IS 456, respectively).

Design of Staircase

The staircase is an important component of a building, and often the only means of access between the various floors in the building. It consists of a flight of steps, usually with one or more intermediate landings (horizontal slab platforms) provided between the floor levels. The horizontal top portion of a step (where the foot rests) is termed tread and the vertical projection of the step (i.e., the vertical distance between two neighbouring steps) is called riser [Fig. 2.10]. Values of 300 mm and 150 mm are ideally assigned to the tread and riser respectively — particularly in public buildings. However, lower values of tread (up to 250 mm) combined with higher values of riser (up to 190 mm) are resorted to in residential and factory buildings. The width of the stair is generally around 1.1 – 1.6m, and in any case, should normally not be less than 850 mm; large stair widths are encountered in entrances to public buildings. The horizontal projection (plan) of an inclined flight of steps, between the first and last risers, is termed going. A typical flight of steps consists of two landings and one going, as depicted in Fig. 2.10(a). Generally, risers in a flight should not exceed about 12 in number. The steps in the flight can be designed in a number of ways: with waist slab, with tread-riser arrangement (without waist slab) or with isolated tread slabs — as shown in Fig. 2.10(b), (c), (d) respectively.

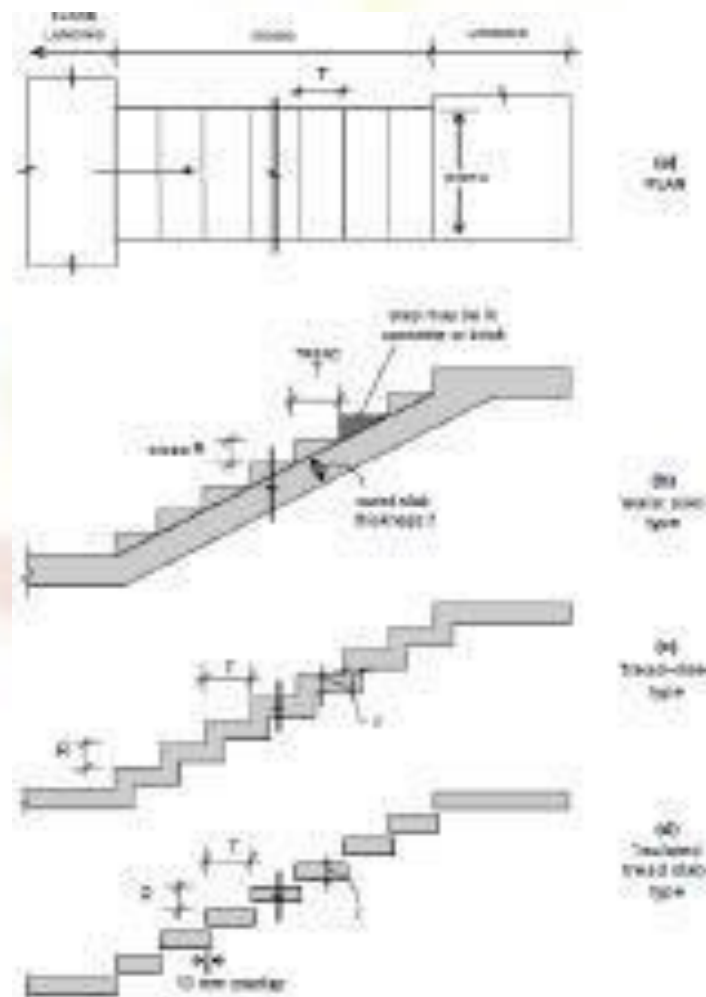


Figure 2.10 A typical flight in a staircase

TYPES OF STAIRCASES

Geometrical Configurations

A wide variety of staircases are met with in practice. Some of the more common geometrical configurations are depicted in Fig. 2.11. These include:

- straight stairs (with or without intermediate landing) [Fig. 2.11(a)]
- quarter-turn stairs [Fig. 2.11 (b)]
- dog-legged stairs [Fig. 2.11(c)]
- open well stairs [Fig. 2.11 (d)]
- spiral stairs [Fig. 2.11(e)]
- helicoidal stairs [Fig. 2.11(f)]

Structural Classification

Structurally, staircases may be classified largely into two categories, depending on the predominant direction in which the slab component of the stair undergoes flexure:

1. Stair slab spanning transversely (stair width wise);
2. Stair slab spanning longitudinally (along the incline).

Stair Slab Spanning Transversely

The slab component of the stair (whether comprising an isolated tread slab, a tread-riser unit or a waist slab) is supported on its side(s) or cantilevers laterally from a central support. The slab supports gravity loads by bending essentially in a transverse vertical plane, with the span along the width of the stair.

In the case of the cantilevered slabs, it is economical to provide isolated treads (without risers). However, the tread-riser type of arrangement and the waist slab type are also sometimes employed in practice, as cantilevers. The spandrel beam is subjected to torsion (equilibrium torsion), in addition to flexure and shear.

When the slab is supported at the two sides by means of __stringer beams__ or masonry walls, it may be designed as simply supported, but reinforcement at the top should be provided near the supports to resist the __negative__ moments that may arise on account of possible partial fixity.

Stair Slab Spanning Longitudinally

In this case, the supports to the stair slab are provided parallel to the riser at two or more locations, causing the slab to bend longitudinally between the supports. It may be noted that longitudinal bending can occur in configurations other than the straight stair configuration, such as quarter-turn stairs, dog-legged stairs, open well stairs and helicoidal stairs.

The slab arrangement may either be the conventional __waist slab__ type or the __tread-riser__ type. The slab thickness depends on the __effective span__, which should be taken as the centre-to-centre distance between the beam/wall supports, according to the Code (Cl. 33.1a, c). In certain situations, beam or wall supports may not be available parallel to the riser at the landing. Instead, the flight is supported between the landings, which span transversely, parallel to the risers. In such cases, the Code (Cl. 33.1b) specifies that the effective span for the flight (spanning longitudinally) should be taken as the going of the stairs plus at each end either half the width of the landing or one meter, whichever is smaller.

Numerical Problem

Design a (__waist slab__ type) dog-legged staircase for an office building, given the following data:

- Height between floor = 3.2m;
- Riser = 160 mm, tread = 270mm;
- Width of flight = landing width = 1.25m
- Live load = 5.0kN/m²
- Finishes load = 0.6kN/m²

Assume the stairs to be supported on 230 mm thick masonry walls at the outer edges of the landing, parallel to the risers [Fig. 12.13(a)]. Use M 20 concrete and Fe 415 steel. Assume mild exposure conditions.

Solution

Given: R = 160 mm, T = 270 mm $\Rightarrow$ +RT22

= 314 mm Effective span = c/c distance between supports = 5.16 m [Fig below].

- Assume a waist slab thickness $\approx 120 = 5160/20 = 258$
 $\rightarrow 260$ mm. Assuming 20 mm clear cover (mild exposure)
and 12 $\emptyset$ main bars, effective depth $d = 260 - 20 - 12/2 = 234$ mm.

The slab thickness in the landing regions may be taken as 200 mm, as the bending moments

are relatively low here.

Loads on going [fig. below] on projected plan area:

(1) self-weight of waist slab @ $25 \times 0.26 \times 314/270 = 7.56 \text{ kN/m}^2$

(2) self-weight of steps @ $25 \times (0.5 \times 0.16) = 2.00 \text{ kN/m}^2$

(3) finishes (given) = 0.60 kN/m^2

(4) live load (given)

= 5.00 kN/m^2 Total

= 15.16 kN/m^2

⇒ Factored load = $15.16 \times 1.5 = 22.74 \text{ kN/m}^2$

Loads on landing

(1) self-weight of slab @ $25 \times 0.20 = 5.00 \text{ kN/m}^2$

(2) finishes @ 0.6 kN/m^2

(3) live

loads @	5.0 kN/m^2	Total
		= 10.60 kN/m^2

⇒ Factored load = $10.60 \times 1.5 = 15.90 \text{ kN/m}^2$

• Design Moment [Fig. below]

Reaction $R = (15.90 \times 1.365) + (22.74 \times 2.43)/2 = 49.33 \text{ kN/m}$

Maximum moment at midspan:

$M_u = (49.33 \times 2.58) - (15.90 \times 1.365) \times (2.58 - 1.365/2)$

$- (22.74) \times (2.58 - 1.365)^2/2$

= 69.30 kNm/m

• Main reinforcement

Assuming $f_{ck} = 20 \text{ MPa}$, $f_y = 415$

⇒

Required spacing of 12 θ bars = 127 mm

Required spacing of 16 θ bars = 225 mm

Provide 16 θ @ 220 c/c

• Distributors

$2 (0.0012312 / \text{st req Abt mm m})$

□ spacing 10 θ bars = 251 mm

Provide 10 θ @ 250 c/c as distributors.