Design of Foundations
Introduction/Classification of foundations.

A. Introduction

You have read about different structural elements viz. beams, slabs, staircases and columns, which are placed above the ground level and are known as superstructure. 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 (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 structures. Therefore, avoiding the differential settlement is considered as more important than maintaining uniform overall settlement of the structure. The permissible limits for absolute settlement/differential settlements as per IS:1904 are given in Table-1.

In addition to these two major requirements mentioned above, the foundation structure should provide adequate safety for maintaining the stability of structure due to either overturning and/or sliding (cl.20 of IS 456).

I. It is worth to mention here that the design of foundation structures is somewhat different from the design of other elements of superstructure due to the reasons given below. Therefore, foundation structures need special attention of the designers.
II. Foundation structures undergo soil-structure interaction. Therefore, the behaviour of foundation structures depends on the properties of structural materials and soil. Determination of properties of soil of different types itself is a specialized topic of geotechnical engineering. Understanding the interacting behaviour is also difficult. Hence, the different assumptions and simplifications adopted for the design need scrutiny. In fact, for the design of foundations of important structures and for difficult soil conditions, geotechnical experts should be consulted for the proper soil investigation to determine the properties of soil, strata wise and its settlement criteria.

TABLE 1 PERMISSIBLE DIFFERENTIAL SETTLEMENTS AND TILT (ANGULAR DISTORTION) FOR SHALLOW FOUNDATION IN SOILS

(*Clause* 16.3.4)

Sl No.	Type of Structure	Isolated Foundations						Raft Foundations					
		Sand and Hard Clay			Plastic Clay			Sand and Hard Clay			Plastic Clay		
		Maximum settlement	Differential settlement	Angular distortion	Maximum settlement	Differential settlement	Angular distortion	Maximum settlement	Differential settlement	Angular distortion	Maximum settlement	Differential settlement	Angular distortion
		mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	For steel structure	50	·003 3L	1/300	50	·003 3L	1/300	75	·003 3L	1/300	100	·003 3L	1/300
ii)	For reinforced concrete structures	50	·001 5L	1/666	75	·001 5L	1/666	75	·002 1L	1/500	100	·002L	1/500
iii)	For multistoreyed buildings												
	a) RC or steel framed buildings with panel walls	60	·002L	1/500	75	·002L	1/500	75	0·002 5L	1/400	125	0·003 3L	1/300
	b) For load bearing walls												
	1) L/H = 2⁺	60	·000 2L	1/5 000	60	·000 2L	1/5 000	Not likely to be encountered					
	2) L/H = 7⁺	60	·000 4L	1/2 500	60	·000 4L	1/2 500						
iv)	For water towers and silos	50	·001 5L	1/666	75	·001 5L	1/666	100	·002 5L	1/400	125	·002 5L	1/400

NOTE — The values given in the table may be taken only as a guide and the permissible total settlement/different settlement and tilt (angular distortion) in each case should be decided as per requirements of the designer.

L denotes the length of deflected part of wall/raft or centre-to-centre distance between columns.

H denotes the height of wall from foundation footing.

⁺For intermediate ratios of L/H, the values can be interpolated.

IS : 1904 - 1986

III. Since, foundation structure, once completed, is difficult to strengthen in future. Accurate estimations of all types of loads, moments and forces are needed for the present as well as for future expansion, if applicable.

IV. Foundation structures, though remain underground involving very little architectural aesthetics, have to be housed within the property line which may cause additional forces and moments due to the eccentricity of foundation.

V. Foundation structures are in direct contact with the soil and may be affected due to harmful chemicals and minerals present in the soil and fluctuations of water table when it is very near to the foundation. Moreover, periodic inspection and maintenance are practically impossible for the foundation structures.

VI. Foundation structures, while constructing, may affect the adjoining structure forming cracks to total collapse, particularly during the driving of piles etc.

VII. However, wide ranges of types of foundation structures are available. It is very important to select the appropriate type depending on the type of structure, condition of the soil at the location of construction, other surrounding structures and several other practical aspects as mentioned above.

B. Types of Foundation Structures

Foundations are mainly of two types: (i) shallow and (ii) deep foundations. The two different types are explained below:

(a) Shallow foundations

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, plain concrete or reinforced concrete) of much less areas of cross-section due to high strength of bricks, plain concrete or reinforced concrete when compared to that of soil. The strength of the soil, expressed as the bearing capacity of the soil is small as compared to the column or wall strength, thus require a larger area for transfer of column/wall loads safely into the ground below. The bearing capacity of 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.

Shallow footings are further classified into the following based on their requirement and shape:

1. Isolated footing	**2. Combined footing**
• Square footing • Rectangular footing • Circular footing	• Rectangular footing • Trapezoidal footing • Strap footing and • Raft/Mat footing • Floating foundation

1. Isolated footings

These footings are for individual columns having the same plan forms of square, rectangular or circular as that of the column, preferably maintaining the proportions and symmetry so that the resultants of the applied forces and reactions coincide. However, the most common type of isolated footing is square type. Isolated footings, shown in Figs. 1 to 4, consist of a slab of uniform thickness, stepped or sloped. Though sloped footings are economical in respect of the material, the additional cost of formwork does not offset the cost of the saved material. Therefore, stepped footings are more economical than the sloped ones or very mild slope is provided, so that formwork is not required.

The adjoining soil below footings generates upward pressure which bends the slab about the faces of the column upwards somewhat into a saucer –like shape, like cantilever action. Hence, adequate tensile reinforcement should be provided at the bottom of the slab (tension face) in both the directions. The distribution of soil pressure at the base of the footing depends on the rigidity of the footing as well as properties of the footing. The distribution of soil pressure is generally non-uniform. However, for convenience, a linear or uniform distribution of soil pressure is assumed in normal practice.

Clause 34.1.1 of IS 456 stipulates that the sloped or stepped footings, designed as a unit, should be constructed to ensure the integrated action. Moreover, the effective cross-section in compression of sloped and stepped footings shall be limited by the area above the neutral plane. Though symmetrical footings are desirable, sometimes situation compels for unsymmetrical isolated footings (Eccentric footings) either about one or both the axes (Fig. 4).

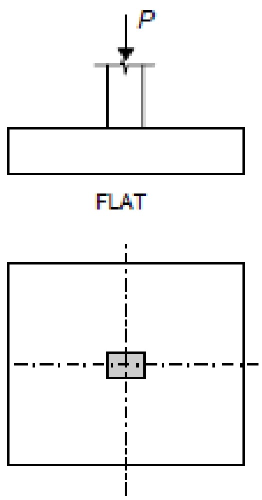

Fig. 1 Uniform and square footing

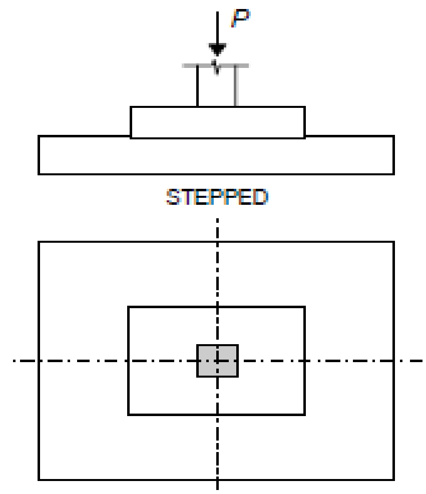

Fig. 2 : Stepped and rectangular footing

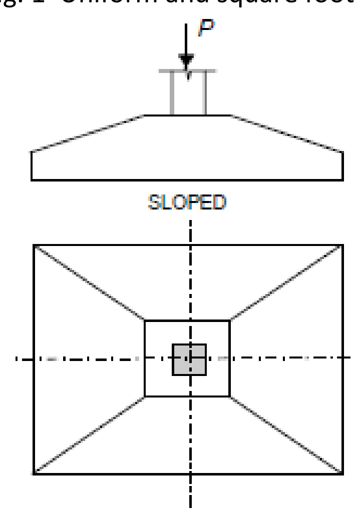

Fig. 3 Sloped footing

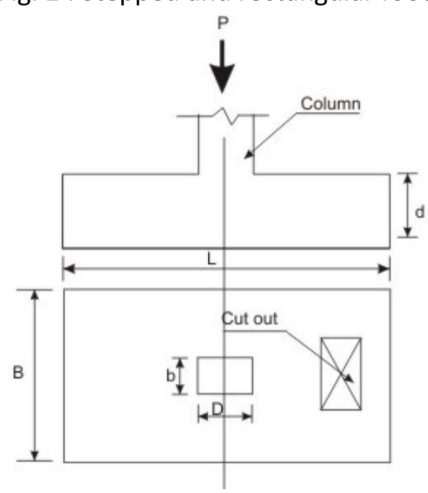

Fig. 4 Unsymmetrical footing about x-axis

3. Combined footings

When the spacing between the adjacent columns is so close that separate isolated footings are not possible due to the overlapping areas of the footings or inadequate clear space between the two areas of the footings, combined footings are the solution by combining the footing areas of two or more columns. Combined footing normally means a footing combining two or more columns. Such footings are either rectangular or trapezoidal in plan forms with or without a beam joining the two columns, as shown in Figs. 5 and 6.

These footings mainly deform about the longitudinal axis about the columns and design is generally governed about this axis. In the transverse direction the behaviour of the footing is like cantilever about two columns particularly in the vicinity of columns.

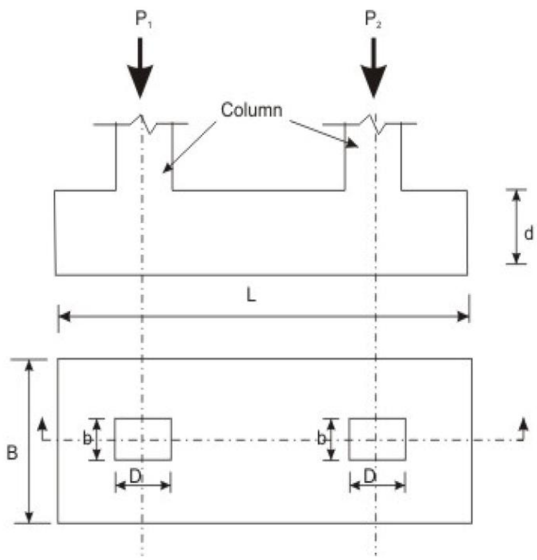

Fig. 5 Combined footing without a central beam

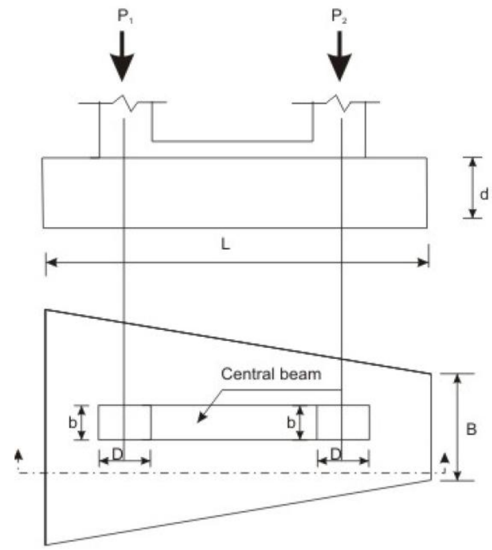

Fig. 6. Combined footing with a central beam

4. Strap footings

When two isolated footings are combined by a beam with a view to sharing the loads of both the columns by the footings, the footing is known as strap footing (Fig. 7). The connecting beam is designated as strap beam. These footings are required if the loads are heavy on columns and the areas of foundation are not overlapping with each other.

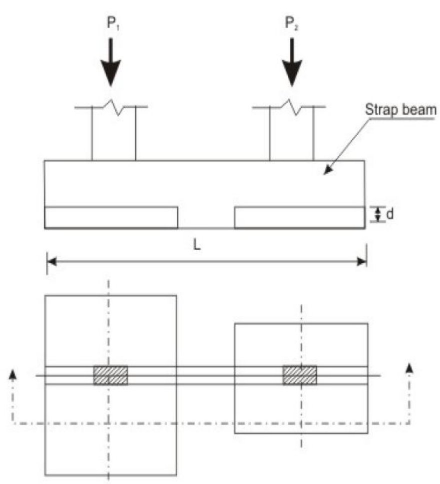

Fig. 7. Strap footing

5. Strip foundation or wall footings

These types of footings are provided in long strips especially for load bearing masonry walls or reinforced concrete walls (Fig. 8). However, for load bearing masonry walls, it is common to have stepped masonry foundations. The strip footings distribute the loads from the wall to a wider area and usually bend in transverse direction. Accordingly, these are mainly reinforced in the transverse direction, while nominal distribution steel is provided in the longitudinal direction.

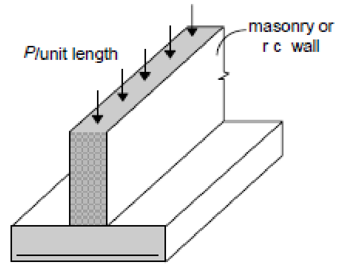

Fig. 8. Wall footing

6. Raft or mat foundation

These are special cases of combined footing where all the columns/walls of the building are having a common foundation (Fig..9). Normally, for buildings with heavy loads or when the soil condition is poor, raft foundations are very much useful to control differential settlement and transfer the loads not exceeding the bearing capacity of the soil due to integral action of the raft foundation. This is a threshold situation for shallow footing beyond which deep foundations have to be adopted.

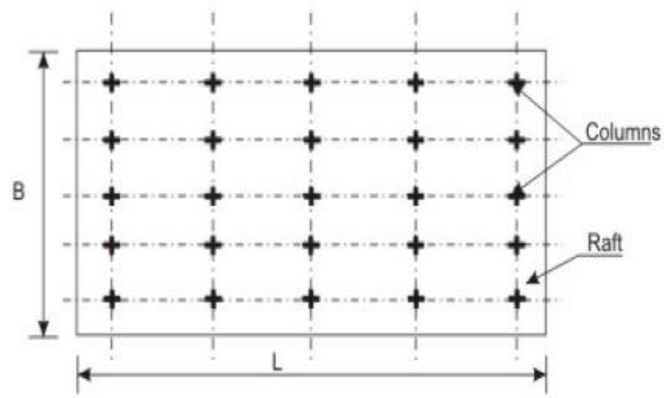

Fig. 9. Raft or Mat footing

7. Floating foundation

It is a special type of foundation in which, the weight of the building is approximately equal to the weight of the soil including water, removed from the site of the building (Fig. 10). It is useful when the soil is so soft that not even friction piles will support the building load. It is buoyed up by the weight of the earth displaced in creating the foundation.

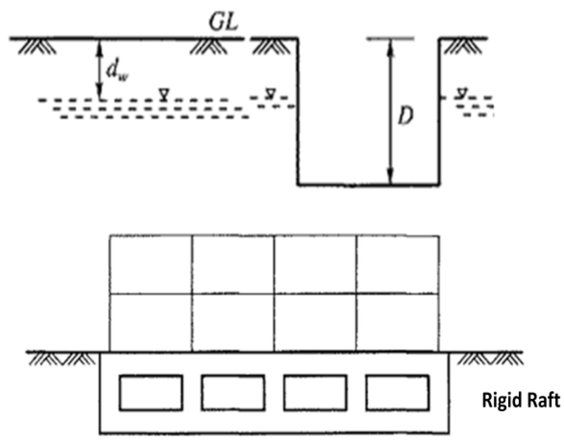

Fig. 10 **Floating Foundation**

(B) 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 (Fig. 11). 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.

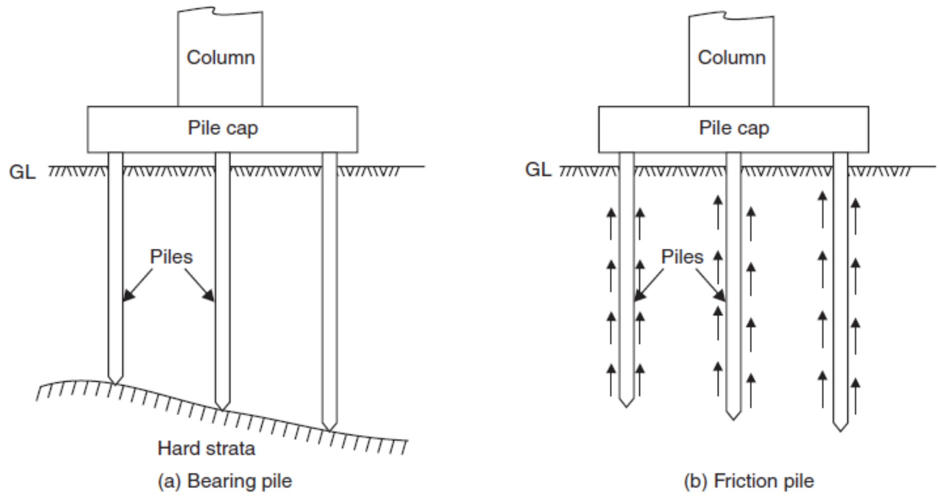

Fig. 11 Pile foundation a) End bearing piles; b) Friction piles

Assignment:

1. Revise fundamentals of Limit state design
2. Revise fundamentals of Working stress design
3. Use Limit state design methodology for design of following structural elements:
   a) Design a cantilever slab of span 2m carrying a uniformly distributed load of 100kN/m. Use M-20 grade concrete and Fe-415 grade steel.
   b) Design an overhang beam of span 4m (between supports) and has overhangs of 1m each on both sides of the support. The beam is carrying a udl of 160kN/m. the grade of concrete and steel is the same as given in Q. No. 3-a. Assume breadth of beam as 400mm.

References

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