MODULE 4

BEARING CAPACITY OF SHALLOW FOUNDATION:

4.1 TYPES OF FOUNDATIONS,

4.2 DETERMINATION OF BEARING CAPACITY BY TERZAGHI'S AND BIS METHOD (IS: 6403),

4.3 EFFECT OF WATER TABLE AND ECCENTRICITY,

4.4 FIELD METHODS - PLATE LOAD TEST AND SPT

4.5 PROPORTIONING OF SHALLOW FOUNDATIONS- ISOLATED AND COMBINED FOOTINGS (ONLY TWO COLUMNS)

PROPORTIONING SHALLOW FOUNDATIONS

4.11 Introductory concepts on foundations

The ultimate support for any structure is provided by the underlying earth or soil material and, therefore, the stability of the structure depends on it. Since soil is usually much weaker than other common materials of construction, such as steel and concrete, a greater area or volume of soil is necessarily involved in order to satisfactorily carry a given loading. Thus, in order to impart the loads carried by structural members of steel or concrete to soil, a load transfer device is necessary. The structural foundation serves the purpose of such a device. A foundation is supposed to transmit the structural loading to the supporting soil in such a way that the soil is not overstressed and that serious settlements of the structure are not caused. The type of foundation utilised is closely related to the properties of the supporting soil, since the performance of the foundation is based on that of the soil, in addition to its own. Thus, it is important to recognise that it is the soil-foundation system that provides support for the structure; the components of this system should not be viewed separately. The foundation is an element that is built and installed, while the soil is the natural earth material which exists at the site. Since the stability of structure is dependent upon the soil-foundation system, all forces that may act on the structure during its lifetime should be considered. In fact, it is the worst combination of these that must be considered for design. Typically, foundation design always includes the effect of dead loads plus the live loads on the structures. Other miscellaneous forces that may have to be considered result from the action of wind, water, heat ice, frost, earthquake and explosive blasts.

4.11.2 Choice of foundation type and preliminary selection

The type of foundation most appropriate for a given structure depends upon several factors:

(*i*) Function of the structure and the loads it must carry, (*ii*) the subsurface conditions, (*iii*) the cost of the foundation in comparison with the cost of the superstructure. These are the principal factors, although several other considerations may also enter into the picture. They are usually more than one acceptable solution to every foundation problem in view of the interplay of several factors. Judgment also plays an important part. Foundation design is enriched by scientific and engineering developments; however, a strictly scientific procedure may not be possible for practicing the art of foundation design and construction. The following are the essential steps involved in the final choice of the type of foundation:

1. Information regarding the nature of the superstructure and the probable loading is required, at least in a general way.

2. The approximate subsurface conditions or soil profile is to be ascertained.

3. Each of the customary types of foundation is considered briefly to judge whether it is suitable under the existing conditions from the point of view of the criteria for stability—bearing capacity and settlement. The obviously unsuitable types may be eliminated, thus narrowing down the choice.

4. More detailed studies, including tentative designs, of the more promising types are made in the next phase.

5. Final selection of the type of foundation is made based on the cost—the most acceptable compromise between cost and performance. The design engineer may sometimes be guided by

the successful foundations in the neighbourhood. Besides the two well known criteria for stability of foundations—bearing capacity and settlement—the depth at which the foundation is to be placed, is another important aspect. For small loading on good soils, spread footings could be selected. For columns, individual footings are chosen unless they come too close to one another, in which case, combined footings are used. For a series of closely spaced columns or walls, continuous footings are the obvious choice. When the footings for rows of columns come too close to one another, a raft foundation will be the obvious choice. In fact, when the area of all the footings appears to be more than 50 per cent of the area of the structure in plan, a raft should be considered. The total load it can take will be substantially greater than footings for the same permissible differential settlement. In case a shallow foundation does not answer the problem on hand, in spite of choosing a reasonable depth for the foundation, some type of deep foundation may be required. A pier foundation is justified in the case of very heavy loading as in bridges.

Piles, in effect, are slender piers, which are used to bypass weak strata and transmit loading to hard strata below. As an alternative to raft foundation, the economics of bored piles is considered. After the preliminary selection of the type of the foundation is made, the next step is to evaluate the distribution of pressure, settlement, and bearing capacity. Certain guidelines are given in **Table 15.1** with regard to the selection of the type of foundation based on soil conditions at a site. For the design comments it is assumed that a multistorey commercial structure, such as an office building, is to be constructed.

4.11.3 Allowable bearing pressure

Allowable bearing capacity for a given foundation may be (a) to protect the foundation against a bearing capacity failure, or (b) to ensure that the foundation does not undergo undesirable settlement. There are three definitions for the allowable capacity with respect to a bearing capacity failure.

8.4 Factors influencing the selection of depth of footing

The important criteria for deciding upon the depth at which footings have to be installed may be set out as follows:

1. Footings should be taken below the top (organic) soil, miscellaneous fill, debris or muck. If

the thickness of the top soil is large, two alternatives are available: (*a*) Removing the top soil under the footing and replacing it with lean concrete; and (*b*) removing the top soil in an area larger than the footing and replacing it with compacted sand and gravel; the area of this compacted fill should be sufficiently large to distribute the loads from the footing on to a larger area. The choice between these two alternatives, which are shown in Fig. (*a*) and (*b*) will depend upon the time available and relative economy. Footings should be taken below the depth of frost penetration. Interior footings in heated buildings in cold countries will not be affected by frost. The minimum depths of footings from this criterion are usually specified in the load building codes of large cities in countries in which frost is a significant factor in foundation design. The damage due to frost action is caused by the volume change of water in the soil at freezing temperatures. Gravel and coarse sand above water level, containing less than 3% fines, cannot hold water and consequently are not subjected to frost action. Other soils are subjected to frost-heave within the depth of frost penetration. In tropical countries like India, frost is not a problem except in very few areas like the Himalayan region.

3. Footings should be taken below the possible depth of erosion due to natural causes like surface water run off. The minimum depth of footings on this count is usually taken as 30 cm for single and two-storey constructions, while it is taken as 60 cm for heavier construction.

4. Footings on sloping ground be constructed with a sufficient edge distance (minimum 60 cm to 90 cm) for protecting against erosion

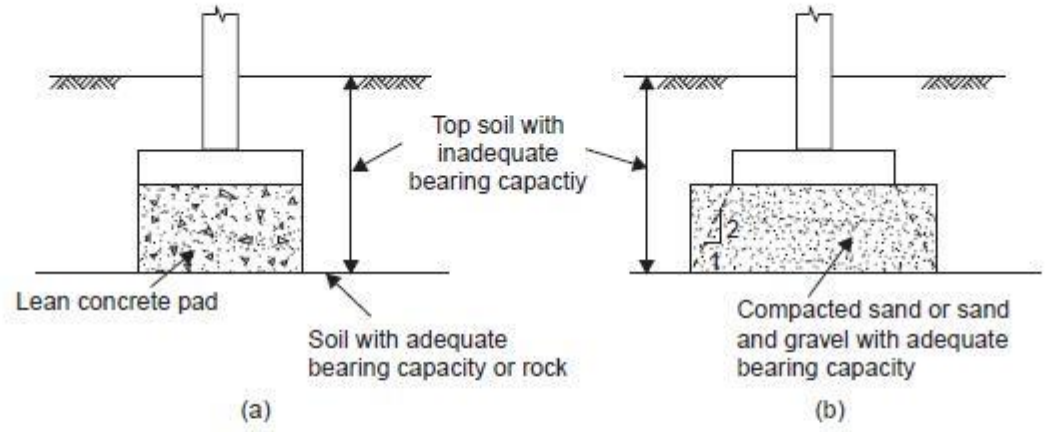

Fig. Alternatives when top soil is of large thickness

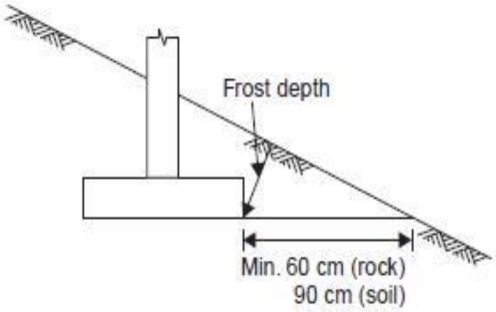

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Fig. Edge distance for floating on sloping ground

5. The difference in elevation between footings should not be so great as to introduce undesirable overlapping of stresses in soil. The guideline used for this is that the maximum difference in elevation should be maintained equal to the clear distance between two footings in the case of rock and equal to half the clear distance between two footings in the case of soil (Fig.). This is also necessary to prevent disturbance of soil under the higher footing due to the excavation for the lower footing.

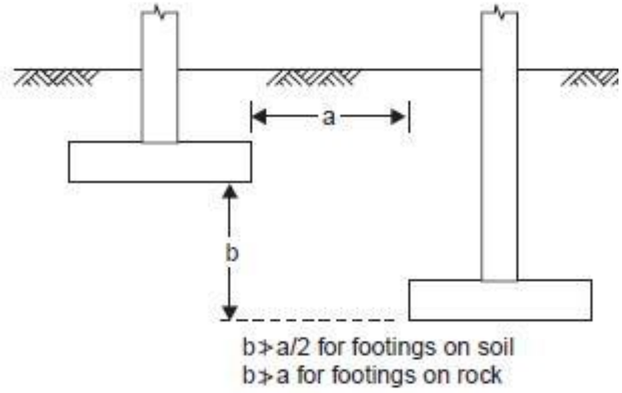

Fig. Footings at different elevations—restrictions

4.11.5 Proportioning of combined footings

The use of combined footings is appropriate either when two columns are spaced so closely that individual footings are not practicable or when a wall column is so close to the property line that it is impossible to center an individual footing under the column. A combined footing is so proportioned that the centroid of the area in contact with the soil lies on the line of action of the resultant of the loads applied to the footing; consequently, the distribution of soil pressure is reasonably uniform. In addition, the dimensions of the footing are chosen such that the allowable soil pressure is not exceeded. When these criteria are satisfied, the footing should neither settle nor rotate excessively. A combined footing may be of rectangular shape or of trapezoidal shape in plan. These are usually constructed using reinforced concrete.

4.11.5.1 Rectangular Combined Footing

A combined footing is usually given a rectangular shape if the rectangle can extend beyond each column the necessary distance to make the centroid of the rectangle coincide with the point at which the resultant of the column loads intersects the base. If the footing is to support an exterior column at the property line where the projection has to be limited, provided the interior column carries the greater load, the length of the combined footing is established by adjusting the projection of the footing beyond the interior column. The width is then obtained by dividing the sum of the vertical loads by the product of the length and the allowable soil pressure. A rectangular combined footing is shown in Fig.

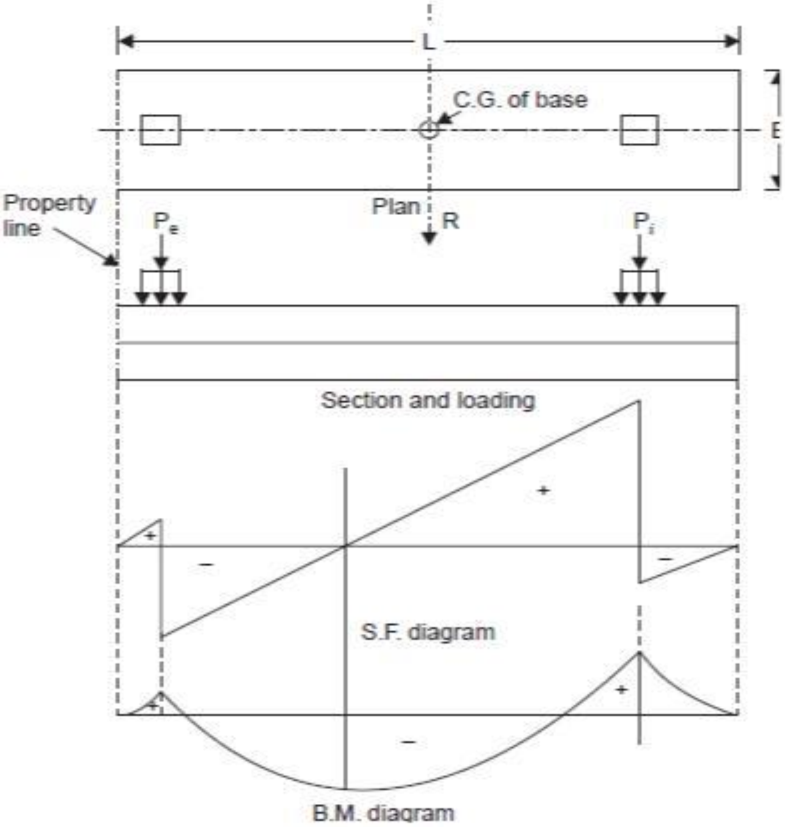

Fig. Rectangular combined footing

4.11.5.2 Trapezoidal Combined Footing

When the two column loads are unequal, the exterior column carrying higher load and when the property line is quite close to the exterior column, a trapezoidal combined footing is used. It may be used even when the interior column carries higher load; but the width of trapezoid will be higher in the inner side. The location of the resultant of the column loads establishes the position of the centroid of the trapezoid. The length is usually limited by the property line at one end and adjacent construction, if any, at the other. The width at either end of the trapezoid can be determined from the solution of two simultaneous equations—one expressing the location of the centroid of the trapezoid and the other equating the sum of the column loads to the product of the allowable soil pressure and the area of the footing. The resulting pressure distribution is linear or uniformly varying (and not uniform) as shown in Fig.

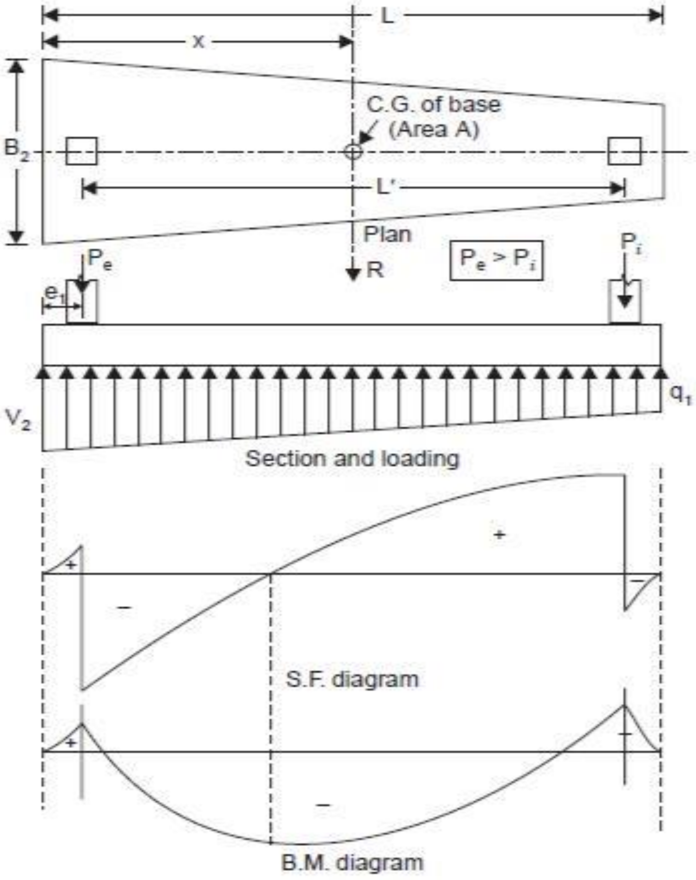

Fig. Trapezoidal combined footing

Problems

1. Compute the ultimate laod that an eccentrically loaded square footing of width 2.1 m with an eccentricity of 0.35 m can take at a depth of 0.5 m in a soil with γ = 18 kN/m^3, c = 9 kN/m^2 and φ = 36°, N_c = 52; N_q = 35; and N_γ = 42.
Conventional approach (Peck, Hanson and Thornburn, 1974): For φ = 36°, Nc= 52 Nq = 35 $N\gamma$ = 42 q_{ult} for axial loading = $1.3cN_c + \gamma D_f N_q + 0.4\gamma_b N_\gamma$ = 1.3 × 9 × 52 + 18 × 0.5 × 35 + 0.4 × 18 × 2.1 × 42 = 608.4 + 315 + 635.03 ≈ 1558 kN/m^2 Eccentricity ratio, e/b = 0.35/2.10 = 1/6. If the ultimate load is Q_{tul},

$$\text{maximum soil pressure} = 2\ .\ q_{av} = \frac{2 \times Q_{\text{ult}}}{\text{Area}} = \frac{2 \times Q_{\text{ult}}}{2.1 \times 2.1}$$

$$\text{Equating } q_{\text{ult}} \text{ to this value, } 1558 = \frac{2Q_{\text{ult}}}{4.41}$$

$$\therefore \qquad Q_{\text{ult}} = 1558 \times \frac{4.41}{2} \approx \mathbf{3435\ kN}$$

Useful width concept: $b' = b - 2e$ = 2.10 – 2 × 0.35 = 1.40 m Since the eccentricity is about only one axis, effective area = 1.40 × 2.10 = 2.94 m2

∴ $q$ult = 1.3 × 9 × 52 + 18 × 0.5 × 35 + 0.4 × 18 × 1.4 × 42 = 608.4 + 315 + 423.36 ≈ 1347 kN/m^2
∴ Qult = $q$ult × effective area = 1347 × 2.94 ≈ **3960 kN.**

There appears to be significant difference between the result obtained by the two methods. The conventional approach is more conservative.

2.Proportion a strap footing for the following data:

Allowable pressures:

150 kN/m2 for *DL* + reduced *LL*

225 kN/m2 for *DL* + *LL*

Column loads

	Column A	Column B
DL	540 kN	690 kN
LL	400 kN	810 kN

Proportion the footing for uniform pressure under DL + reduced LL. Distance c/c of columns = 5.4 m Projection beyond column A not to exceed 0.5 m.

DL + reduced *LL*:

for column A ... 740 kN

for column B ... 1095 kN

Footing A

Assume a width of 2.4 m. Eccentricity of column load with respect to the footing = (1.2 – 0.5) = 0.7 mc/c of footings (assuming footing B to be centrally placed with respect to column B) = 5.4 – 0.7 = 4.7 m

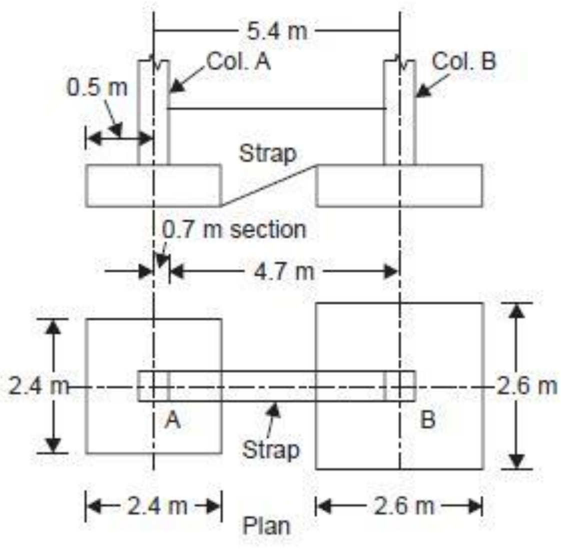

Fig. Strap footing

Enhanced load = 740 ×5 4/47kN = 850 kN

Area required = 850/150 = 5.67 m^2

Width: 5.67/2.40 = 2.36 m.

Use **2.4 m** × **2.4 m** footing (actual area 5.76 m^2).

Footing B

Load on Column B = 1095 kN

Net load = 1095 – 740 ×0 7/4 7 = 985 kN.

Area required = 950/150 = 6.57 m^2

Use **2.6 m** × **2.6 m** footing (actual area 6.76 m^2)

Soil pressure under *DL* + *LL*:

Footing A: Load = 940 ×54/ 4 7 = 1080 kN Pressure =1080/ 5.76 = 187.5 kN/m^2

Footing B: Load = 1500 kN – 940 ×0 7/ 4 7 = 1360 kN Pressure = 1360/ 6.76 ≈ 201 kN/m^2 These are less than 225 kN/m^2.

Hence O.K.

4.11 Assignment Questions

- What is bearing capacity of soil and define various types of bearing capacity
- Explain Terzaghis method of determination of bearing capacity of soils
- Explain proportioning of isolated footing and combined footing

4.12 Outcomes

Students should be able to

- Estimate bearing capacity of soils
- Understand types of foundations
- Design of Shallow foundations

4.13 Further reading

- https://theconstructor.org › Geotechnical Engineering