UNIT 9
FOUNDATIONS

Structure

9.0 INTRODUCTION

Foundations form an important part of building construction. The forces and moments acting on a structure have to be ultimately transmitted to the ground and this is achieved by means of foundations. The loads on a building are transmitted downwards, floor by floor by means of columns and/or walls. If these are directly set on the ground, the pressures under them would be so much that either the soil will give way or large and uneven settlements would take place. In order to prevent this, the load is spread over a wider area by means of foundations such as footings, strips, rafts etc. At the same time, we have to ensure that the stresses in the elements of foundation like concrete, steel masonry etc. are within the specified limits.

The crust of the earth over which the foundation rests, consists of various types of soils and rocks having widely different characteristics and properties. Further, the presence of suboil water affects some of these properties. Before foundations are designed, we should know the details of the soil characteristics.

Generally, one is confronted with a situation where the desired land has been acquired and the foundation for the proposed building has to be designed taking into consideration the soil characteristics at the site. For important and heavily loaded structures, it may be worthwhile to take into consideration the necessary soil properties and other features at the site, before acquiring the land.

In earlier days, the design of foundations was based more on experience and intuition, but modem developments in Soil Mechanics have enabled us to understand in greater detail, the properties of soil and the mechanism of load transfer from the building to the ground.

In this unit, you will learn about the various types of building foundations, where they are used and their constructional details.

9.1 OBJECTIVES

After studying this unit, you should be able to:

- classify the various types of building foundations,
- describe the tests used for site investigation,
- establish the criteria for selecting the type of foundations, and
- describe the constructional details of the commonly used foundations.

9.2 SITE INVESTIGATIONS

The surface crust of the earth consists broadly of rocks and soils. Their engineering properties are largely dependent on the particle size, shape, texture, the bedding, chemical composition etc. Rocks are classified as follows:

a. igneous (such as granite) formed by cooling and solidification of molten lava material,
b. sedimentary (like sand stone) formed by deposition of particles in layers, and
c. metamorphic (like slates) formed by re-crystallization of existing igneous or sedimentary rocks under the action of great pressure and for high temperature.

Generally, some rocky strata are a good base for foundation unless it is disintegrated or has faults, fissures etc.

Soil can be classified into the following categories:

Sands and Gravels: These are non-cohesive materials with good shear strength. The structural properties depend on density and particle size distribution. Size of particles of gravels range from 75 mm to 4.75 mm while that of sand from 4.75 mm to 75 microns.

Clays: These are cohesive with low shear strength and plastic in nature, prone to shrinkage and swelling depending on water content. Particle size is below 2 microns.

Silt: These are fine grained soil of particle size between 75 microns to 2 microns with little or no plasticity, and are compressible. In the presence of clay, it exhibits plasticity.

Sandy and gravely strata do not normally pose foundation problems while much more care is required in the case of clays and silts.

The first step in deciding about the foundation of a building is to have a site investigation carried out. Site investigation would cover all the techniques and enquiries to gather detailed information regarding the site, including study of maps, topographic surveys, reconnaissance surveys, soil investigations, climatic data etc. As a result of such investigations, following information should be available:

a) topography of site, contour maps, with details of streams, ditches, ponds, wells, trees, rock outcrops, high transmission electric lines etc.,
b) locations of underground sewers, waterlines and cables,
c) liability to flooding,
d) ground water details,
e) details of my structures existing at the site or nearby with details of their foundations, including information regarding failures, cracks etc.,
f) a detailed soil investigation report including bore charts, results of laboratory tests on soil samples and recommendations regarding depth and bearing capacity for foundation design, and
g) meteorological data.

The detailed soil report would form the basis for the choice design of foundation. While for small single storied buildings, it may be sufficient to have a few trial pits, for larger structures or where there are doubts regarding the substrata, borings at site taken to sufficient depth would be required to collect and analyze the soil samples. The depth and the number of borings would depend on the type of structure and the soil conditions.

9.2.1 Trial Pits and Borings

Trial pits consist of nuking excavation at site enabling examination of the subsoil and collection of samples. This method can be adopted for small depths of about 3 m. The depth of exploration required to be carried out is normally, one and a half times to twice the width of the foundation.

For deeper exploration, brings have to be carried out. These can be auger boring, percussion boring, rotary boring etc. From these brings, undisturbed/disturbed soil samples can be collected.

The samples collected from the pits/borings are listed in the laboratory to assess the various properties like grain size distribution, liquid and plastic limit, unit weight of soil, specific gravity, natural moisture content, compressive strength etc. From these investigations, a chart indicating the depths of various strata can also be prepared.

9.2.2 Field Tests

Plate load test and penetration tests are very useful field tests for site investigation. The set-up and other details of these tests are given in the following paragraphs.

Plate Load Test: It is one of the earliest tests to be performed to determine the bearing capacity of soil. The test consists of making a pit, usually at foundation level and measuring the settlements of a circular or square mild steel plate not less than 25 mm in thickness and 300 to 750 mm in size subject to gradual load increments. From the test results, load vs settlement curve is plotted and the ultimate bearing capacity of the soil is arrived at. This test has the following limitations:

a) The results are indicative of the character of boil within a depth of less than twice the width of the bearing plate which is usually 300 to 750 mm. Since the actual dimensions of foundations are larger, the settlements and shear resistance will depend on a much thicker stratum of the sub-soil.
b) It is a short duration test and does not give an idea about consolidation settlement particularly in cohesive soils. Thus, the results of the test could be misleading if the character of soil changes at shallow depths, which is not uncommon.
c) While for clayey soils, the bearing capacity (from shear consideration) for a larger foundation is almost the same as for the smaller test plate; while in the case of dense sandy soils, the bearing capacity increases with the size of foundation and hence, in such cases, the plate load test gives a conservative value.

Penetration Tests: These tests involve the measurement of the resistance to penetration of a sampling spoon, a cone or other shaped tools under dynamic or static loading. The commonly used tests are the standard penetration test and the static and dynamic cone penetration tests. From these tests, the soil strata at various depths along with their properties can be obtained. From these penetration values, bearing capacity can be assessed.

Soil exploration should be able to provide necessary data to evaluate the following parameters:
a) safe bearing capacity of the soil,
b) subsoil water level, and
c) probable settlement of the structure under the design load.
The test report generally gives recommendations regarding the depth of foundation and safe
hearing capacity.

9.3 BEARING CAPACITY OF SOIL

The purpose of the foundation being to transmit the load of the structure to the ground, it is necessary to know the capacity of the soil (bearing capacity) to withstand this pressure. The definitions of various terms used in connection with bearing capacity are given below:

Ultimate Bearing Capacity: The intensity of loading at the base of the foundation which would cause shear failure of the soil support.

Safe Bearing Capacity: Maximum intensity of loading the foundation will safely carry without the risk of shear failure.

Allowable Bearing Capacity: The net intensity of loading that the foundation will carry without undergoing settlement in excess of the permissible value for the structure under consideration but not exceeding the safe bearing capacity.

The ultimate bearing capacity can be determined
a) by plate load test,
b) theoretically, based on the characteristics of various types of soils, and
c) by making use of penetration and other test results.

The bearing capacity that can be adopted for the &sign of a foundation depends on the characteristics of the soil, the depth and dimensions of the foundation and the degree of settlement that can be allowed for the structure. There are two approaches to the determination of the bearing capacity.

Based on the shear strength characteristics of the soil, the ultimate bearing capacity of the soil at a given depth for specific dimensions of the foundation can be calculated. A factor of safety can be applied to the ultimate bearing capacity to arrive at the safe bearing capacity. If calculation of settlements indicates that it is within the permissible limit then the safe bearing capacity would be the allowable bearing capacity. However, if the calculation of the settlements shows that it is beyond acceptable limit then a lower value has to be adopted for the allowable bearing capacity based on the permissible settlement. The second approach is to determine the bearing capacity on the basis of in-situ tests.

In the case of cohesion less soils, the main problem is to obtain satisfactory undisturbed soil samples for determination of shear strength. However, generally in such soils the allowable bearing pressures are governed by settlement consideration rather than ultimate bearing capacity due to shear failure. In cohesion less soils, therefore, the bearing capacity can be calculated on the basis of penetration tests and empirical methods relating allowable bearing pressure to permissible settlements for foundations of given dimensions.

The procedure of calculation of ultimate bearing capacity on the basis of shear strength characteristics is widely used in the case of silts and clays. For a foundation on rock, allowable bearing pressures are governed more by the stresses on the foundation elements.

For a preliminary estimation, the safe bearing capacities of various types of soil have been listed in National Building Code Group 2:1983.

9.4 SETTLEMENT OF FOUNDATION

By settlement we mean the vertical downward movements of the foundation. The effect of settlement on the structure depends on its magnitude, both absolute as well as relative with respect to the different parts of the foundation. Settlement may be caused by:

i. the weight of the structure and the superimposed loads,
ii. subsidence due to mining,
iii. shrinkage due to change in moisture content, and
iv. general earth movement.

Settlements that take place when the static load is within the range of the safe bearing capacity of the soil, consists of the following elements:

i. Elastic deformation which takes places immediately on application of load,
ii. Primary consolidation of foundation soil resulting from expulsion of pore water,
iii. Secondary compression of foundation soil, and
iv. Creep of the foundation soil.

If the structure settles uniformly, there will be no damage but if the settlement is excessive the underground service lines may be affected. In actual practice, as the soil is not a purely homogeneous material and superimposed loadings are not equal, settlements are non-uniform, inducing corresponding stress in the structure. Depending upon the extent of these stresses, the settlements have to be limited by appropriate designs.

Based on the loading pattern and the soil characteristics the settlements can be calculated and if it exceeds the desirable limits, the foundation has to be redesigned.

The permissible values of settlement for different types of structure are given in Table 1 on page 19 of IS:1904 - 1986.

9.5 DEPTH OF FOUNDATION

The depth to which foundation should be taken depends on the following principal factors:

a) Securing of adequate allowable bearing capacity,
b) In the case of clayey soils, penetration into the soil has to be below the zone where shrinkage and swelling due to seasonal weather changes and due to trees and shrubs are likely to cause appreciable movements,
c) In fine sands and silts penetration has to be below the zone in which trouble may be expected from frost,
d) The maximum depth of scour whenever relevant (say, in bridge piers) should also be considered and the foundation should be located sufficiently below this depth, and
e) It should be below the top soil, miscellaneous fill, tree roots etc.

All foundations should be taken down to a minimum depth of 0.5 m below natural ground level. In filled-up ground it may be necessary to go beyond the depth of fill or take special precautions. In such cases, it may be necessary for economic considerations to have the foundation at a higher level, and get the difference in level between the base of foundation and the level of excavation filled up with either : (a) concrete of allowable compressive strength not less than the allowable bearing pressure on the soil, or (b) incompressible fill material, for example sand, gravel etc. in which case the width of fill should be more than the width of foundation for dispersion of load on either side of the base of foundation.

In sloping grounds, the horizontal distance from the bottom edge of the footing to the ground surface shall be at least 60 cm for rock, and 90 cm for soil. A line drawn at an angle of 30" to the base from the outer edge should not intersect the sloping surface (Figure 9.1).

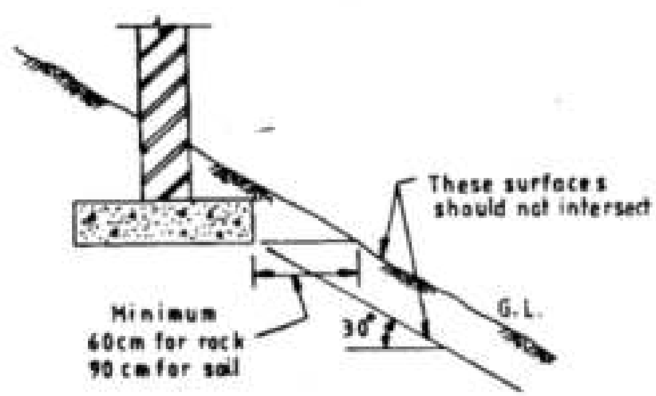


Figure 9.1: Footings on Sloping Ground

Foundation near Existing Building: The minimum horizontal distance between existing and new footings shall be at least equal to the width of the wider footing. In important cases, analysis of bearing capacity and settlement shall be carried out.

Foundation at Different Levels: In the case of footings on granular soil, the distance between the footings should be such that a line drawn between the lower adjacent edges of the footings shall not have a slope steeper than one vertical to two horizontals as shown in Figure 9.2.

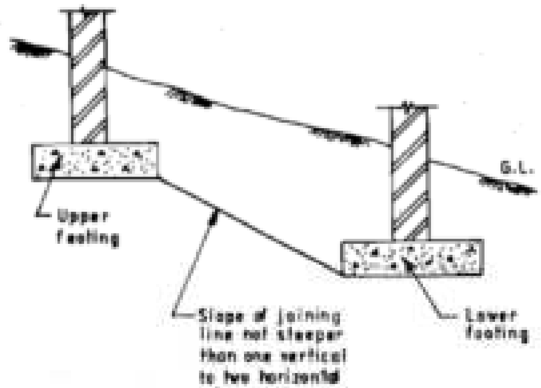


Figure 9.2: Footings on Granular Soil

In clayey soils, a line drawn between the lower adjacent edge of the upper footing and the upper adjacent edge of the lower footing shall not have a slope steeper than one vertical to two horizontals as shown in Figure 9.3.

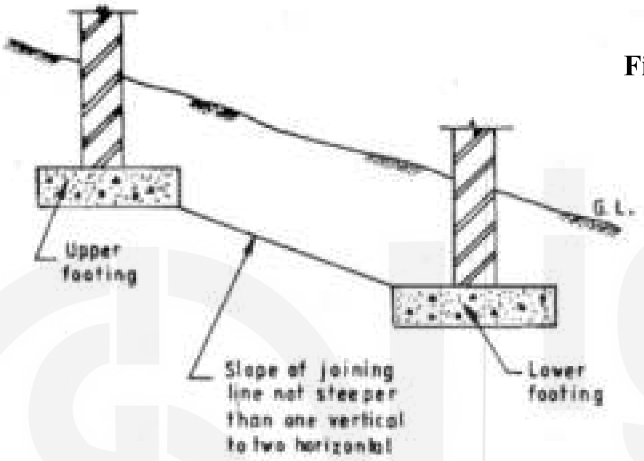


Figure 9.3: Footings on Clayey Soil

9.6 EXCAVATION FOR FOUNDATION

Site Clearance: Before the excavation for the proposed foundation is commenced, the site shall be cleared of vegetation, brushwood, stumps of trees etc. Roots of the trees shall be removed to at least 30 cm below the foundation level. The pits formed due to roots of trees, old foundations etc. shall be filled up with soil and compacted.

Setting out: A bench mark shall be established at the site by a masonry pillar and connected to the nearest standard bench mark. Levels of the site should be taken at 5 to 10 m intervals depending on the terrain and the importance of the building. The center lines of the walls are marked by stretching strings across wooden pegs driven at the ends. The center lines of the perpendicular walls are marked by setting out the right angle with steel tapes or preferably with a theodolite. The setting out of walls shall be facilitated by having a permanent row of pillars (not less than 25 cm side) parallel Lo aid at a suitable distance beyond the periphery of the building so that they do 11ot foul with the excavation. The pillars shall be located at the junctions of the cross walls and external wall and shall be bedded sufficiently deep so that they are not disturbed during excavation for foundation. The center lines of the walls shall be extended and marked on the plastered tops of the pillars. The tops of the pillars may be kept at the same level, preferably the plinth level. In rectangular or square settings, the diagonals shall be checked to ensure accuracy of setting out.

Excavation: For small buildings, excavation is carried out manually by means of pick axes, crow bars. spades etc. In case of large buildings and deep excavation, mechanical earth cutting equipment can be used.

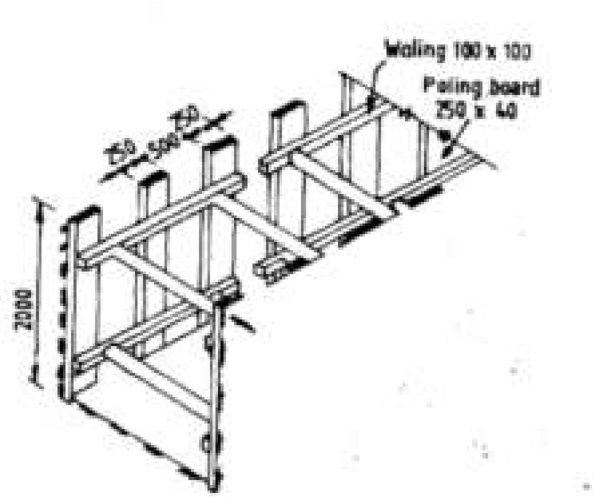


Figure 9.: Open Planking

For hard soils when the depth of excavation is less than 1.5 m, the sides of the trench do not need any external support. If the soil is loose or the excavation is deeper, some sort of shoring is required to support the sides from falling. Planking and strutting can be intermittent or continuous depending on the nature of soil and the depth of excavation. In the case of intermittent or "open" planking and strutting the entire sides of trenches are not covered. Vertical boards (known as poling boards) of size 250 x 40 mm of the required length can be placed with gaps of about 50 cm (Figure 4.4). These shall be kept apart by horizontal waling of strong timber of section 100 x 100 nun at a minimum spacing of 1.2 m and strutted by a cross piece of 100 x 100 square or 100 nun diameter. In the case of soft soils b continuous or "close" planking is adopted and the vertical boards are kept touching each other without any gap as shown in Figure 9.5 (a). If the soil is very soft and loose. the boards shall be placed horizontally against the sides of the excavation and supported by vertical waling boards which shall be strutted to similar timber pieces on the opposite side of the trench [Figure 9.5 (b)]. Care has to be taken while withdrawing the timber members after completion of the foundation work. So that there is no collapse of the trench.

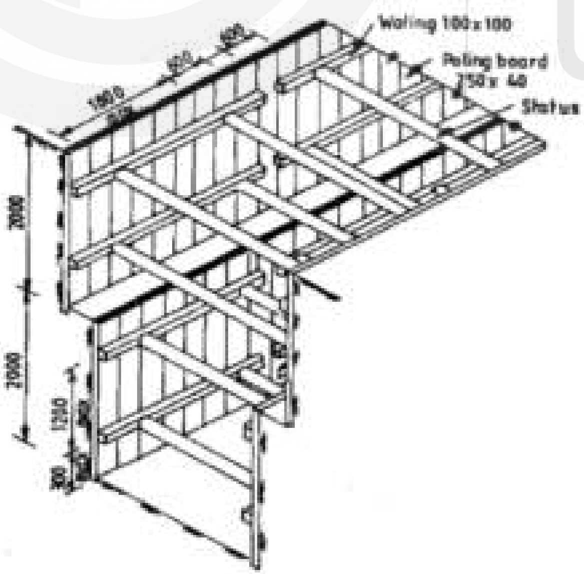


Figure 9.5 (a): Close Planking

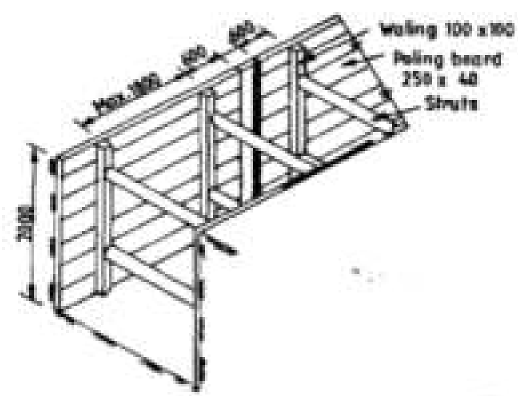


Fig. 9.5 (b): Planking in Very Soft and Loose Soil

Construction of foundation below the subsoil water level poses problems of waterlogging. It is therefore very often necessary to dewater the area of excavation. Several operations have to be carried out within the excavation, like laying bed concrete, laying of RCC raft slab and construction of masonry etc. Therefore, work can be carried out more efficiently if the excavation area is kept dry. To keep the area of excavation dry, water table should be maintained at least 0.5 m below the bottom of the excavation. There are several methods available for lowering the water table. Information obtained from site and soil investigation would be useful in deciding the most suitable and economical method of dewatering. For fairly dense soil and shallow excavations, the simplest method is to have drains along the edges of the excavation and collect water in sumps and remove it by bailing or pumping. This is the most economical method and is feasible of being executed with unskilled labor and very simple equipment.

Where large excavations such as for rafts are to be dewatered, well point system can he employed. Well point consists of a perforated pipe, 120 cm long and 4 cm in diameter with a valve to regulate flow and a screen to prevent entry of mud etc. These well points are installed along the periphery of the excavation at the required depth and spaced at about 1 m. The exact spacing can be decided on the basis of the type of soil. Well points are surrounded by sand gravel filter and have riser pipes of 5 to 7.5 cm diameter. These pipes are connected to a header pipe which is attached to a high capacity suction pump. The ground water is drawn out by the pumping action and is discharged away from the site of excavation (Figure 9.6).

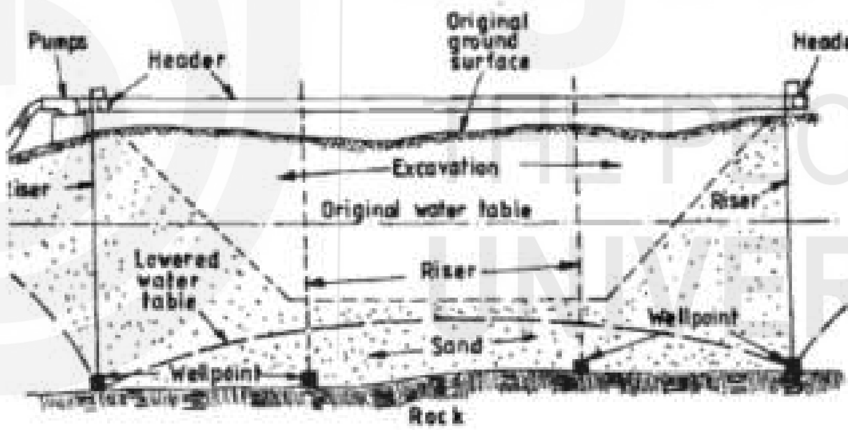


Figure 9.6: Lowering Water Table by Well Point

Foundation Concrete: In the case of a masonry wall, the footing is generally of cement concrete mix of ratio 1:4:8 or 1:5:10 (cement : sand : coarse aggregate). The size of coarse aggregate is limited to 40 mm. Lime concrete can also be used for this purpose. For important works. mixing of concrete should be done in a mechanical mixer. Concrete should be laid (not thrown) in layers not exceeding 15 cm and well compacted. The concrete should lie protected by moist gunny bags after about 1 or 2 hours of laying. Regular curing should be started after 24 hours and be continued for 10 days. The masonry work over the bed concrete can be started after 3 days of laying the concrete but curing along with that of masonry shall be continued.

For RCC column footings and raft foundations, a levelling course of lean concrete of 75 mm is laid in order to have an even and soil free surface for placing the reinforcement.

9.7 SELECTION AND TYPES OF FOUNDATION

The factors to be considered for the selection of the type of foundation for a given situation are as follows:

a) The characteristics of the superstructure and the superimposed loads,
b) Site conditions, type of soil and its allowable bearing capacity,
c) Materials and machinery/equipment available for construction, and
d) Relative costs.

Foundations can broadly be classified into following two categories:

a) Shallow foundations, and
b) Deep foundations.

9.8 SHALLOW FOUNDATIONS

These cover such types of foundation in which load transfer takes place primarily through shear resistance of the bearing strata; and, such foundations are normally up to a depth of 3 m. The various types of shallow foundations used in building construction are as follows:

a) Pad or spread and skip footing,
b) Grillage foundation, and
c) Raft foundation.

9.8.1 Pad or Spread and Strip Footings

The basic purpose of this foundation is to spread the load over a larger area so that the soil is able to withstand the stress, and the safe bearing pressure is not exceeded. In such types of foundations, if the resultant of the load deviates from the centre line by more than 116 of its least dimension at the base of the footing, it should be suitably reinforced.

Wall Footings: In the case of brick walls, the width of section is increased by 114 brick (5 cm) offset on either side. The base rests on a plain concrete footing which projects 10 to 15 cm beyond the last brick offset as shown in Figure 4.7. The width at the base shall not be less. than the width of the supported wall plus 30 cm.

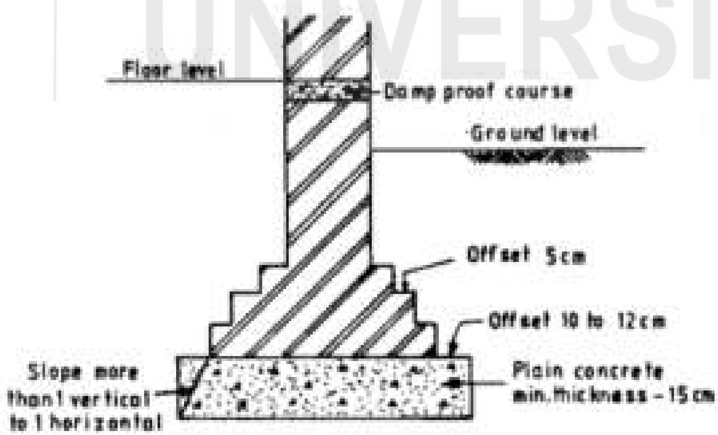


Figure 9.7: Wall Footing

The depth of each course can be one brick or multiples of brick thicknesses. In the case of stone masonry walls, the offsets could be 15 cm with the heights of the course as 30 cm. The depth of the concrete which is generally of 1 : 4 : 8 (1 Cement : 4 Fine aggregate : 8 Coarse aggregate) or 1 : 5 : 10 (1 Cement : 5 Fine aggregate : 10 Coarse aggregate) mix should not be less than 15 cm.

The angular spread of load from the wall should not be more than 1 vertical to 112 horizontals in masonry and 1 vertical to 1 horizontal for cement concrete. If the load on the wall is heavy or the soil is of low bearing capacity, reinforced concrete strip footing can be provided (Figure 4.8). The thickness of the strip can be reduced towards the edge to effect economy.

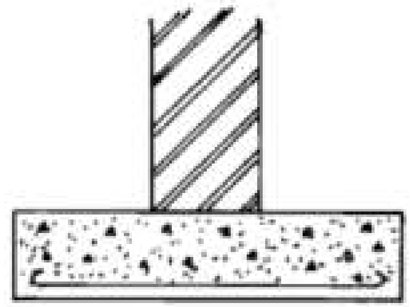


Figure 9.8: Strip Footing

RCC Column Footings: These are generally square or rectangular. They are reinforced in both directions and are designed to withstand the upwards soil pressure as shown in Figure 9.9. The reinforcement of the column is taken right up to the bottom of the footing. The RCC footings are laid over a bed of lean concrete of about 75 mm thickness.

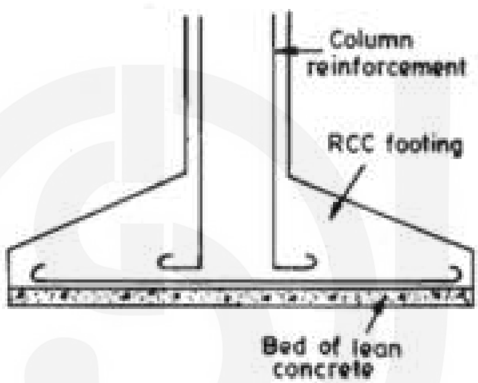


Figure 9.9: RCC Column Footing

As the bending moment decreases towards the edge, the thickness can also be reduced accordingly. The minimum thickness at the edge shall, however, be not less than 15 cm. Stepped footings should be avoided as sudden changes in stress conditions are likely to be produced. The top of the footings can be sloped towards the edge in the shape of a pyramid. Steep slopes exceeding 1 in 2 would require formwork and hence, normally the slope is of the order of 1 in 4. In a foundation, it is important to ensure that a minimum cover of 40 to 50 mm is provided to prevent corrosion of reinforcement.

When two column footings are near to each other or the foundations overlap, a combined footing can be provided. Such footings can be rectangular or trapezoidal in plan and its position is so adjusted that its center of gravity coincides with that of the loads from the columns.

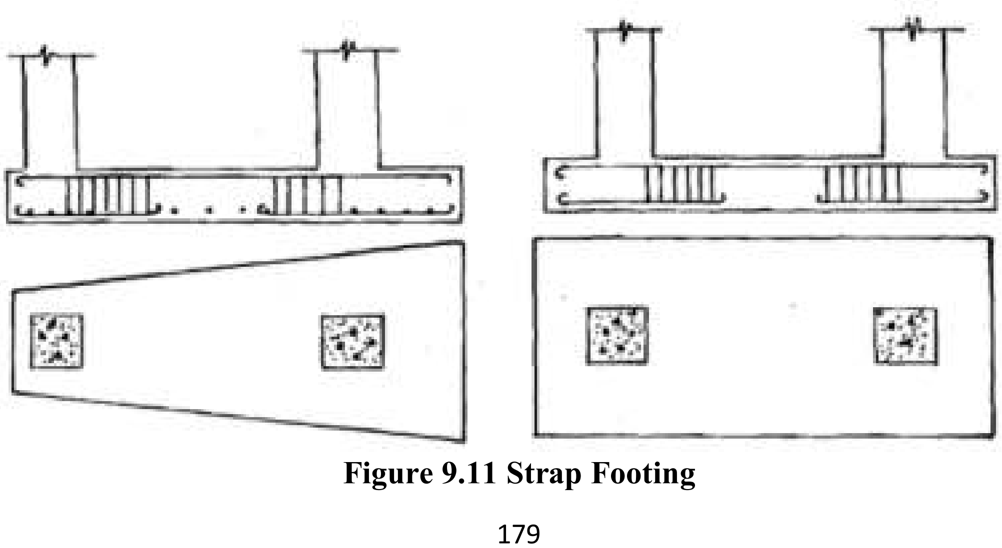


Figure 9.11 Strap Footing

Cantilever or Strap Footings: At times, there are restrictions in space for the external columns due to adjacent buildings etc., and it would not be possible to place the footings centrally with respect to the columns. In such cases, the column is connected with the interior column by a beam so that the loads are shared as shown in Figure 9.11.

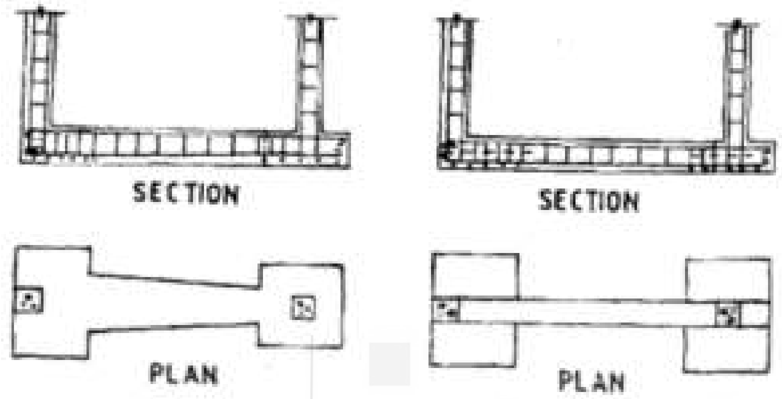


Figure 9.11: Strap Footing

9.8.2 Grillage Foundation

When there is heavy load on steel columns and the soil is of low bearing capacity, grillage foundations can be provided. These consist of rolled steel joists in one or two layers that are encased in concrete with the overall dimensions being such that the soil pressure is within the allowable bearing capacity. Adequate gap must be provided between the flanges of the girders to enable the concrete to flow and fill the gaps. However, it should not be more than 1.5 to 2 times the flange width in order that the concrete and steel should act together. Concrete is not intended as a structural element but is used to keep the beams in position and prevent its corrosion. To prevent movement during concreting, the joists are connected through the webs by bolts with spacers. This type of foundation is expensive on account of the large amount of steel and is now rarely used.

9.8.3 Raft Foundation

Where there are heavy loads on the columns and/or the soil has low bearing capacity, the individual footing or strips overlap or are too close to each other. In such cases raft foundations are adopted. If the footings cover more than half the area of the building, a raft foundation is likely to be economical. For buildings having basements particularly where subs011 water levels are high, it is advantageous to provide rafts. These can be designed to resist the water pressure and suitable water proofing treatment can be provided.

Basically a raft foundation consists of a thick reinforced cement concrete slab with reinforcement provided at the top and bottom in both directions. For fairly small and uniform column spacing and when the supporting soil is not very compressible, a slab of uniform thickness can be provided as shown in Figure 9.13.

If the loads are heavy, the slab can be thickened to take care of the shear and the negative moments. If the spacing between the columns is large, the loads are unequal and the soil is quite compressive, a beam and slab arrangement can be provided; raft slab in such a case acts as an inverted slab with T beams.

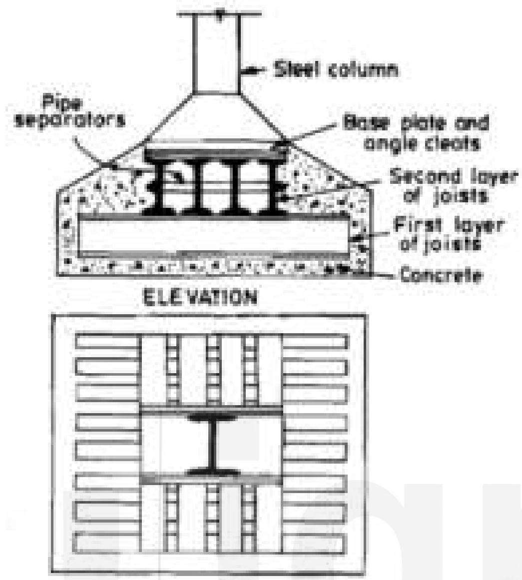
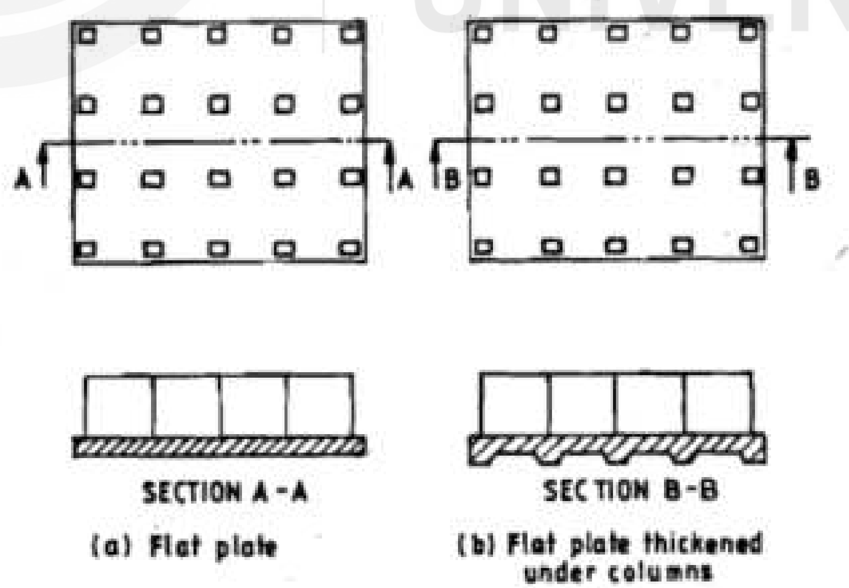


Figure 9.12: Grillage Foundation

The depth of foundation for a raft shall generally be not less than 1 m. A bed of lean concrete of 75 to 100 cm thickness is provided to facilitate laying of reinforcement and concreting. It is economical to project the raft slab by about 30 to 45 cm beyond the face of the peripheral columns.

Where possible, the raft is so proportioned that its center of gravity coincides with that of the column loads. If this is not possible, the eccentricity has to be taken into account in the structural design as well as in checking for the pressure on the soil.



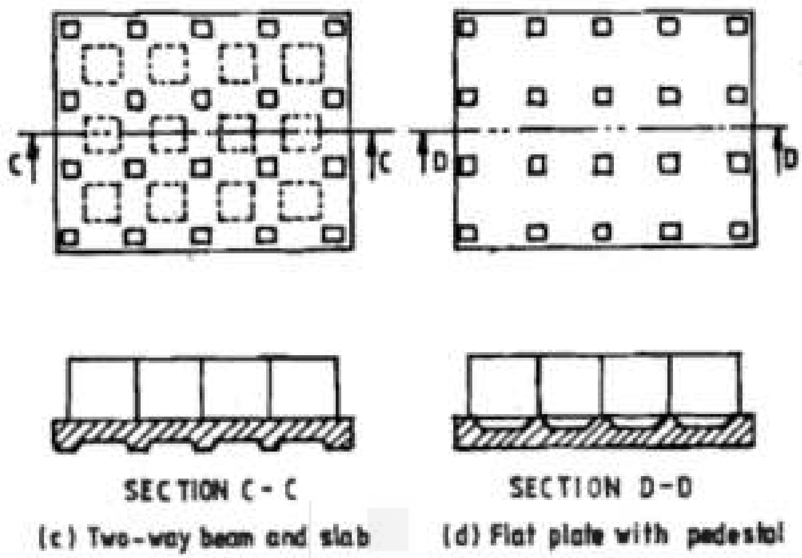


Figure 9.13 Types of Raft Foundation

9.9 DEEP FOUNDATIONS

If the soil in the top layers near the ground does not have adequate bearing capacity, it would be necessary to transfer the load to the lower strata. For buildings, this is achieved by means of piles.

Pile Foundation: Piles are long column-like members which transmit load of the structure through a weak material to an underlying hard strata. If the bearing stratum is hard and impenetrable like rock or hard dense gravel, a pile derives its strength mainly by bearing and is known as end bearing pile as shown in Figure 9.14 (a).

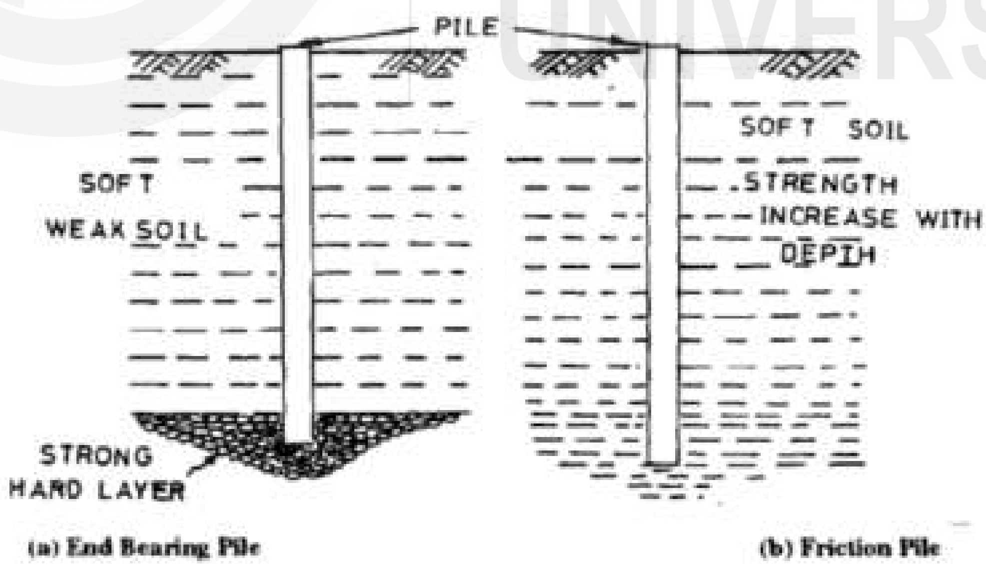


Figure 9.14: Different Types &Piles (Based on Mode of Load Transfer)

Piles driven in soil which increasingly becomes stiff with depth derive their bearing capacity from the friction along the surface of the pile and are known as friction piles as shown in Figure 4.14 (b). Normally, in a pile, part of the load is carried by friction and part by end bearing. Piles can also be used to resist uplift pressures on structures as also to withstand lateral forces. Such piles are called anchor piles. A pile which is installed at an angle to the vertical is known as a ***batter*** or ***raker*** pile.

Piles, particularly of timber have been use from ancient times and can be considered as one of the earliest innovations in foundation engineering. However, it is only in the past few decades that appropriate methods have been evolved to analyze and design piles.

Construction of pile foundation requires a careful choice of the type of pile and methodology of execution taking into consideration the soil strata, the level of subsoil water, the load characteristics of the structure, limitation of settlements and any other special requirements. The availability of materials and equipment and economic factors have also to be considered.

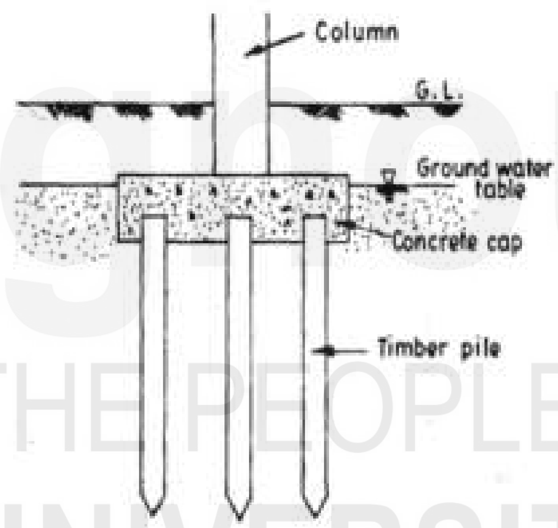


Figure 9.15 (a): Timber Pile with Concrete Cap

Materials for Piles: Piles can be of timber, steel or concrete. The earliest types of piles used were of timber while presently concrete piles are used to the maximum extent. Steel piles are expensive and rarely used.

9.9.1 Timber Piles

These can be used for relatively lightly loaded structures located in compressive types of soils with high ground water level has a high weight to strength ratio and can be cut, shaped and handled easily. If timber piles are wholly in a submerged condition they have a long life. If the subsoil water level is high, the piles can be cut off, at the top. below this level and a concrete pile cap be provided as shown in Figure 9.15 (a). Timber used for the piles has to be of good quality like teak, Sal, deodar etc. It should be straight grained and free from defects. The piles shall be treated with timber preservative. Shoe Timber piles can be of square or round section. Round section is preferable as cutting to square shape removes part of the outer sapwood which is absorptive to preservatives. Piles are driven into the soil by the drop hammer of a pile driving machine. For facilitating driving, the lower end is provided with a cast iron conical shoe and the head is prevented from splitting by means of a mild steel hoop [Figure 9.15 (b)]. Timber piles are relatively cheaper and easy to drive but get

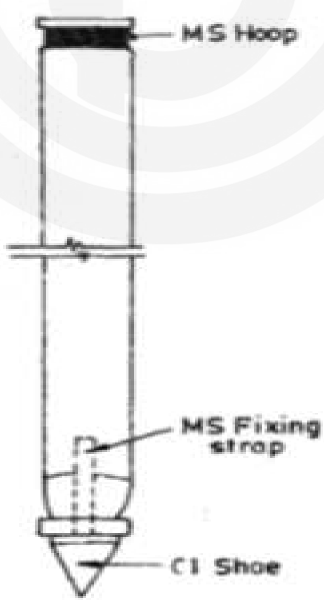


Figure 9.15(b): Timber Pile with MS Hoop and CI Shoe

deteriorated and decayed particularly when subject to alternative drying and wetting. They cannot be used for heavily loaded structures.

9.9.2 Steel Piles

High strength of steel makes it a good material for piles. Steel piles can be in the form of rolled steel H-sections or seamless/welded steel pipes. They can be directly driven into the ground for use as piles. The tubes can be open ended or close ended. In the case of open ended pipes, after the piles are driven, the earth inside is cleared out by water jetting and filled with concrete. The closed ended pipes are provided with a shoe to facilitate driving and these are also normally filled with concrete.

Because of its inherent strength, a steel pile can withstand the large impact of the pile driving hammers and can penetrate through relatively hard strata and boulders. The total length of pile can easily be extended by welding additional piece(s) or shortened by cutting. Steel piles cause little ground displacement and hence, can be driven at close intervals, or near existing buildings. They require less storage space and can be handled easily as compared to precast RCC piles. me disadvantages are the possibility of corrosion and lesser frictional resistance with reference to transfer of load. These piles are more expensive than other types of piles and hence, they are not used very widely. They can be used for very heavy loads and for foundations of bridges, trestles etc.

9.9.3 Concrete Piles

Concrete piles can be divided into following two categories:

a) precast concrete piles, and
b) cast in-situ concrete piles.

Precast Concrete Piles: These piles are usually cast near. the site of work in specially prepared casting yard with adequate supervision and control to produce good quality concrete. The casting yard should be a levelled firm area with proper drainage and located as close to the site as possible so that expenses on transporting are limited. The formwork of steel or timber should be of the required specifications and should be properly cleaned and oiled before placing the reinforcement cage. As far as possible, longitudinal reinforcement shall be in one length. In case this is not possible, overlaps shall be staggered and preferably joints butt welded. Necessary stirrups shall be provided and they shall be closely spaced near the top and bottom of the pile to avoid damage due to high impact stresses. The concreting of each pile has to be in one continuous operation and thoroughly compacted with vibrator. The exposed face must be trowel finished to provide a dense even surface. Side shuttering can be removed after a day and piles cured by wet gunny bags for a period of ten days. The piles should be carefully examined to see whether there are any defects, before they are taken to site for driving.

These piles are reinforced not only to carry the load on the foundation but also to withstand the stresses produced in lifting the piles and carrying them to the place of installation. In precast concrete piles, generally the reinforcement required to withstand the stresses during handling and driving are more than that required to take the load on the foundation. Piles can be lifted by hooks or clamps at a single point or at two points (Figure 9.16). Hooks can be embedded at the time of casting or proper markings made so that slinging is done correctly. The reinforcement has to be suitably designed according to the proposed mode of lifting. The high stresses produced while lifting and driving, necessitates proper structural design of the pile to take the bending and shear stresses. Once the pile is driven into the ground, much of the steel becomes redundant as the stresses are mainly compressive. Piles can also be manufactured in a factory but transportation of long piles to the site could pose problems.

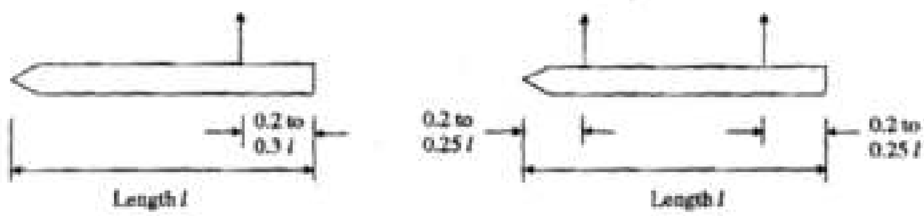


Figure 9.16: Lifting of Precast Piles

If it has been decided to adopt precast piles for the foundation, the length of piles has to be assessed fairly correctly, as cutting the piles or extending them cannot be done easily. They also require large casting yards and heavy equipment for handling and driving. However, in situations where soil is such that driving is easy or large number of piles of predetermined length are to be provided or where reinforcement is required from considerations of lateral pressure or tensile steel is required to resist uplift, precast piles are advantageous. The quality of concrete in precast piles is better as they are cast above ground under controlled conditions and hence, such piles are sometimes preferred in aggressive soil (e.g. sulphates) conditions.

Precast concrete piles for small loads and short lengths can be square in cross-section with chamfered comers, while for longer length and heavier loads they are generally of octagonal or circular section. Sometimes hollow sections are also used which are filled with concrete after driving. The tips are pointed to facilitate driving. As the reinforcement in the pile is mainly to resist the handling stresses, this objective can also be achieved by pre-stressing. It can be either pretension or post tensioned.

Pile Driving: Piles are commonly driven by means of a pile driver, basic elements of which are a frame and a hammer. The frame or trestle is generally of steel and has a pair of vertical guides, known as leaders within which the hammer is held. Mobile units are also available and are convenient when a large number of piles are to be driven.

The hammer could be a simple drop hammer or more efficient steam, air, diesel or hydraulic hammers. If the fall of hammer is due to gravity alone, it is known as single acting. If pressure is applied by steam etc., it is known as double acting.

Drop hammers weigh from 1000 to 5000 kg and fall through a distance of about 1 meter. As a rough rule, the weight of a drop or single acting hammer could be the same as the weight of the pile. For heavy piles, this would not be possible but for proper driving the hammer should weigh not less than a third of the weight of the pile. A cast steel helmet is placed over the top of the concrete pile with a resilient dolly on top to prevent the pile head from shattering under the impact of the hammer blow.

The resistance to pile driving is expressed in terms of number of blows per inch of penetration. Resistance of 6 to 8 blows per inch are specified for concrete piles. If piles have to be driven through dense layers, jetting around the pile is resorted to in order to loosen the soil and ease penetration. If piling is planned to be done by. jetting, it is preferable to insert an M.S. pipe of 50 to 75 mm in diameter at the center of the pile while casting.

In saturated plastic clays, displacement of soil on account of driving of pile may cause heaving of adjacent area, and in such cases piles can be placed in holes made by auguring.

Cast in-situ Concrete Piles
There are two types of concrete cast in-situ piles - driven or bored.

Driven Cast in-situ Piles: In this type of piles, a heavy sectioned metal tube, with a detachable metal shoe at the bottom, is driven into the ground by a drop hammer or any other type of hammer up to the required depth. Thereafter reinforcement is placed, if required, and concrete is filled into the tube and the tube simultaneously withdrawn leaving the shoe at the bottom. In another version, a thin steel shell is driven with the help of a mandrel, which is then withdrawn, reinforcement placed, if required, and concreting done, the shell being left permanently in the ground.

Raymond concrete pile company have developed a thin steel shell pile, known as Raymond Pile. The casing pipes consist of either uniformly tapered or step tapered light corrugated steel tubes. An internal mandrel is used to drive the casing, the mandrel is then withdrawn and the shell filled with concrete.

In Franki piles, a concrete plug is formed at the bottom of the steel casing and by repeated hammering the pipe is thrust downwards into the ground. When the bearing stratum is reached, additional concrete is poured and the plug hammered out of the tube to form a bulb end. Then the reinforcement cage is lowered into fie tube, concreted and the casing withdrawn.

Vibro pile uses a detachable steel or cast iron shoe with a steel tube casing. With the help of a hammer, the tube with the shoe on is driven to the required depth, reinforcement cage lowered. concreting done and the tube withdrawn leaving the shoe at the bottom of the pile. Simplex piles are also similar to this sort of arrangement.

Bored Cart in-situ Piles: In this system, a hole is bored into the ground, reinforcement (if required) lowered and concreting done. Boring is generally carried out by rotary or percussion type drilling rigs. Kelly mounted hydraulically operated grabs are also used.

If the soil is such that the walls of the bore would cave in. casing tubes have to be used which is subsequently extracted while concreting. Sometimes the casing is left in the ground and the concreting done within the casing. Such piles are known as cased piles. Another method to keep the sides of the hole in position is by pumping bentonite slurry into the borehole as the soil is removed. Bentonite is a clay of the montmorillonite group. Its slurry forms a membrane along the walls of the bore hole and also acts hydrostatically to retain the stability of the sides of the hole. After the required depth of the bore is reached a high slump concrete is placed by means of a tremie.

For piles of small diameter and depths up to 10 m, the minimum cement content of the concrete should be 350 kg/m3 while for larger diameter and deeper piles it should be 400 kg/m3. Slump of concrete shall range between 100 to 180 mm depending on the manner of concreting.

Where drilling mud is used before concreting, the bottom of the hole shall be flushed with fresh bentonite slurry. Throughout the boring operation it has to be ensured that the drilling mud suspension is of the required consistency.

9.9.4 Undreamed Piles

These are bored cast in situ concrete piles having one or more bulbs formed towards the bottom by enlarging the bore hole of the pile stem. The enlargements help in providing substantial bearing or anchorage. Such piles have been found to be useful in expansive soils like black cotton soil as the bulbs provide anchorage against uplift due to swelling pressures. The diameter of the undreamed bulbs may be of the order of 2 to 3 times the stem diameter. The spacing of the bulbs is 1.25 to 1.5 times the stem diameter. The top most bulb should be at a minimum depth of 2 times the bulb diameter. Borings for the piles are carried out in the usual way. Thereafter the bulbs are formed by means of an under reamer rotated by the drill rod. The excavated soil is removed by means of buckets. The reinforcement cage is then lowered and the pile concreted. The cement content and slumps shall be as indicated for bored cast in situ piles. Bored compaction pile is a modified form of under reamed pile where, after the concrete is poured, the reinforcement assembly, with a cone welded at the bottom is driven through the fresh concrete with the help of a driving pipe, thereby compacting the concrete.

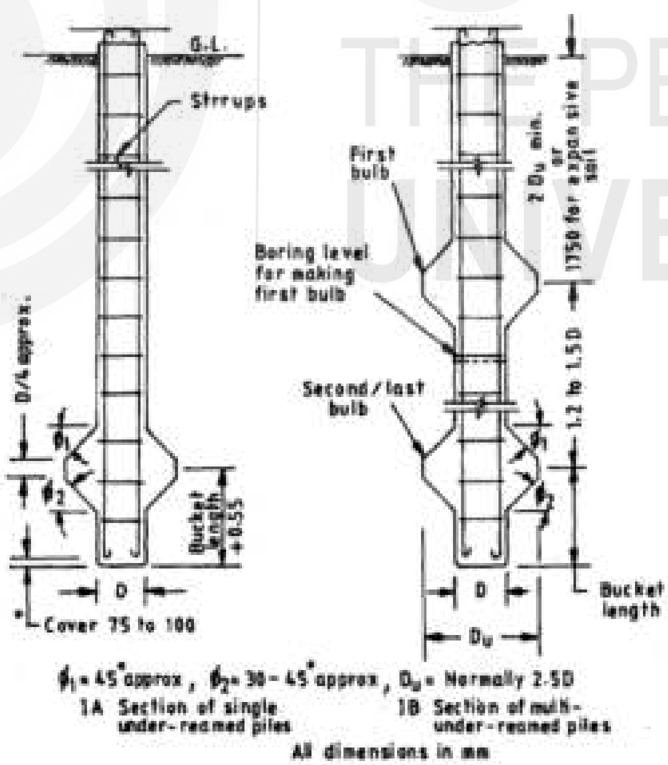


Figure 9.17: Undreamed Piles

Spacing of Piles: Spacing of piles has to be decided taking into consideration the practical aspects of installing the pile and the type of load transfer from the pile to the soil. For end bearing piles the minimum spacing is kept as 2.5 times the diameter of the shaft and if it is resting on rock it can be 2 times the diameter. The spacing between friction piles has to be such that the zones of soil from which the piles derive their support do not overlap and thereby reduce their bearing values. Generally, in such cases the minimum spacing is three times the diameter of the shaft.

Alignment of Piles: Piles shall be installed as accurately as possible. Generally, for vertical piles the permissible deviation is 1.5% and for raker piles 4%. The deviation from the designed position for a single pile should not be more than 50 mm (100 mm if diameter is more than 600 mm) and for each pile in a group not more than 75 mm or one tenth the diameter of the pile, whichever is more.

Load Testing of Piles: Load testing of piles consists of two types. Initial load test is done to determine the ultimate load carrying capacity and to arrive at the safe design load on the pile. It also helps to fix guide lines for routine tests, assess the suitability of the piling system, and to study the effect on existing adjacent structures etc. The second type of test is the routine test to check whether the pile is capable of carrying the designed load. Such tests are usually carried out on 112 to 2% of the total number of piles at the site, for a test load of one and a half times the working load, maximum settlement shall not be exceeding 12 mm.

Piles are loaded by jacking against a kentledge placed on a platform supported clear of the test pile or against a beam restrained by anchor piles. Settlements of the pile are recorded by dial gauges carried by supports clear of the pile and resting on arms fixed rigidly to the pile head.

There are two methods of applying test loads. In the Constant Rate of Penetration (CRP) test, the load is adjusted to give a constant rate of downward movement. In the maintained load (ML) method the load is applied in increments and deflections recorded. The CRP test is suitable for determining the ultimate load, while the ML method can be used for both initial test and routine tests.

Pile Caps: The depth of the pile cap should be sufficient for anchoring the column reinforcement as well as that of the pile. The pile should project 50 mm into the concrete of the cap. The cap should be rigid enough to distribute the load to the pile and to take care of differential settlements, if any. The overhang of the pile cap beyond the outer pile is of the order of 100 to 150 mm. The cap is generally cast over a 75 mm thick bed of levelling concrete. A clear cover of 60 mm is provided for the main reinforcement.

9.10 SUMMARY

The first step in deciding on the type of foundation is to carry out a detailed soil investigation to ascertain the characteristics of the subsoil. Field tests of soil can also be carried out for quicker results. On the basis of these tests and investigations, the depth of foundation can be arrived at and the safe bearing capacity of the soil can be estimated. Taking into consideration the properties of soil substrata and the load due to the proposed building, it should be possible to decide on the type of foundation that would be suitable.

The details of shallow foundations such as pad, strip, grillage and raft have been described in the unit. If the soil in the top layer, near the ground, does not have adequate bearing capacity to support the superimposed load, it would be necessary to adopt pile foundations. The details of various types of pile foundation have also been explained in this unit.