Chapter 4

Foundations

4.1 Introductions

A foundation is that part of a structure which is in direct contact with the ground to which the loads are transmitted. It is the lowest part of a structure which transmits the weight of the structure, together with the effect of live loads and pressure, to the material on which the structure rests in such a manner that the underlying material is not stressed beyond its safe bearing capacity. Generally, the foundations are placed below the ground level, to increase the stability of a structure or building. Foundations are normally placed below the ground surface. The part of the building below the surface of the ground is called the sub-structure and that above the ground is called the super-structure. The soil or rock on which a building rests may also be called the foundation, and its surface the foundation bed.

4.2 Foundation of Foundation

The function of a foundation is to distribute the load over a larger area at a uniform rate so that the pressure on the soil below does not exceed its allowable bearing capacity. Foundations can be built from various types of materials. Generally bricks, stones, concrete, steel, etc. are used in different forms for constructing the foundation of a building. However, the type of building, which is supported on a particular foundation, and the nature of the underlying soil have a great bearing on the selection of a material.

Generally, foundations serve the following purposes:

1. Reduction of load intensity:
   Foundations distribute the loads of the super-structure, to a larger area, so that the intensity of the load at its base does not exceed the safe bearing capacity of the sub-soil.
2. Even distribution of load:
   For instance, two columns carrying unequal loads can have a combined footing that may transmit the load to sub-soil evenly with uniform soil pressure. Due to this, unequal or differential settlements are minimized.
3. Provision of level surfaces:
   Foundations provide leveled and hard surface over which the super-structure to be built.

4. Lateral stability:
   It anchors the super-structure to the ground, thus imparting lateral stability to the super-structure. The stability of the building, against sliding and overturning due to horizontal forces is increased due to foundations.
5. Safety against undermining:
   It provides structural safety against undermining or scouring due to burrow animals and floodwater.
6. Protection against soil movements:
   Special foundation measures prevent or minimize the distress (or cracks) in the super- structure, due to expansion or contraction of the sub-soil because of moisture movement in some problematic soil.

7. To prevent excessive settlement, and differential settlement of the structure.

4.3 Requirements for Foundation

The foundation of a structure has to be strong enough to transmit the load i.e. the load of the structure above as well as the side loads imposed through pressure of earth and wind. Because foundation is the part most liable to damage and the most difficult to get at after the completion of the building, the need for it to be satisfactorily designed and constructed, right from the beginning, should be strongly emphasized.

Foundations have to be strong enough to resist deformations. If, however, extensive and unequal settlement occurred, serious damage may result in the form of cracked walls, distorted door and window openings.

A foundation should therefore be sufficiently strong to prevent marked and unequal settlement, which may be caused by:

i. weak sub soils such as made-up ground,
ii. shrinkage of subsoil's (e.g. soft clay),
iii. movement of ground water,
iv. excessive vibration due to machinery, such as in pile driving,
v. slipping of strata on sloping sites, and
vi. Subsequent building operations involving deep excavations on an adjacent site.

The selection of foundation type depends on a number of factors, which include:

- ⇒ nature of soil,
- ⇒ size and weight of the structure,
- ⇒ climate (seasonal) variation of ground water level,
- ⇒ building laws and relationship of the floor to the grade line i.e. slope.

4.3.1 Sub-soil conditions

Certain sub-soils, for instance made ground from industrial waste products and ground water may contain chemicals, such as sulfates of calcium and sodium, and acids and may cause serious damage to foundations and foundation walls of normal Portland cement concrete. Chemical analysis of such soils and under-ground water is therefore necessary. Lean concrete especially is liable to chemical attack and dense concrete mixes are less vulnerable.

The foundation concrete should therefore be composed of special cement, such as sulfate resisting Portland cement if the concentration of sulfate is very high. Cement mixes of Portland blast furnace cement (GGBS cement) and high alumina cement concretes are more resistant to chemical attack than normal Portland cement concrete. In some cases it may be necessary to protect the concrete with asphalt or asphalt coat.

4.3.2 Foundation Material

All materials for foundation shall be water resistant, sufficiently strong, soil-acid resistant and immune from termite. As a result there are no many kinds of materials, which satisfy these requirements. The use of some typical materials for foundation purposes is summarized below.

a) **Basalt:** it is the best foundation material used for all types of foundation in different form.
b) **Trachyte:** they are of variable strength and durability. In general, they are good foundation materials.
c) **Granite:** it is good foundation material, but never used because of its high cost.
d) **Sandstone:** Generally of two kinds, strong and soft. The strong sandstone is good foundation material.
e) **Limestone:** It is of variable strength. The strong limestone is a good foundation material.
f) **Shale:** Generally weak and thus not used as a foundation material.
g) **Concrete:** It is a foundation material most commonly employed for small as well as large buildings. It has great strength but it ought to be protected against large scale attacks by water below the ground if not specially mixed. Sub-soil water sometimes contains aggressive carbonic acid. The carbonic acid in the coarse of time will attack, and destroy the concrete.

h) **Wood:** Wood is not recommendable for anything but relatively small buildings. In such cases, it must be a shard kind of wood that resists decay and attack by termites, e.g. Tid; olive (Weira). Zigba is never to be used underground and only red colored eucalyptus can be used.

i) **Iron:** Iron shall not be used uncovered as it rusts very rapidly when in contact with the soil. For this reason it is primarily used as reinforcement bars in concrete.

4.4 Types of Foundation

The various types of foundations commonly used in building construction are spread foundation /footings, pile and pier foundation.

4.4.1 Spread Foundation / footings

They include all the types designed to spread the building load over a sufficient area of soil to secure adequate bearing capacity. The total load coming at the base of the structure is spread over a larger area by such foundations. The intensity of load transmitted to the supporting soil is less than its allowable bearing capacity and thus the settlement of the building is prevented to reasonable extent. Spread footings are most widely used foundation types since they do not require special equipment and skill for construction and are usually economical.

The various types of spread footings include:

1. Wall footings
2. Isolate footings
3. Combined footings
4. Cantilever (strap) footings
5. Continuous footings
6. Raft or Mat foundation

Spread footings are also classified into three further groups based on the type of construction. They are simple footings, stepped footings and grillage foundation footings. Simple footings project only a few cm beyond the edges of the walls or other structures supported by them. They are used when only light loads come on to the wall. Stepped footings are necessary when a wider distribution of the load is to be ensured and also a uniform spreading from the top of the footing to the bottom is desired. Grillage foundation footings consist of steel or wooden joists arranged in a stepped manner.

4.4.1.1 Wall footings

A wall footing may have a base course of concrete or may be entirely built up of one material e.g. bricks or stones. They are provided under walls. See Fig 1.

For light loads, simple footings are constructed having projections beyond the width of the wall, on either side. These projections are generally not greater than 15cm on either side. As a thumb rule for small footings the base width of concrete bedding should be twice the width of the wall. The depth of the concrete bedding should be at least twice the projections. The base may be of concrete slab or completely built up of bricks or stones. In case no concrete base is provided, the wall is built up in steps to transmit the load safely. Rich mortar is used to join the bricks. This type of foundation is rarely used these days as it is not economical.

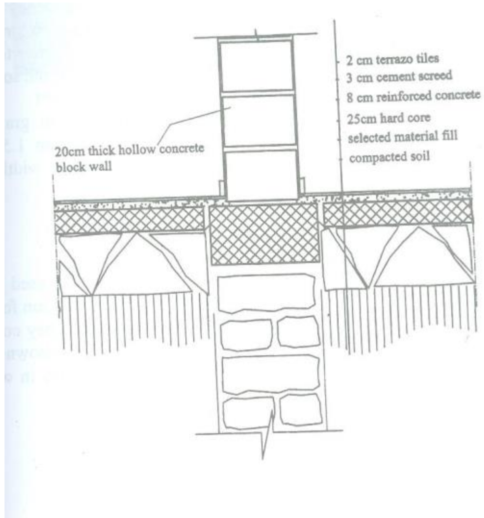


Figure 1: Typical wall footing on grade beam and masonry foundation

When the width of foundation is considerably more than the wall width, it is economical to make the brick footing stepped over a level concrete bed as shown in Fig 2. The footing should be designed properly otherwise the upward reaction from soil will have a tendency to break or crack the concrete bed. The concrete used in footings consists of ordinary Portland.

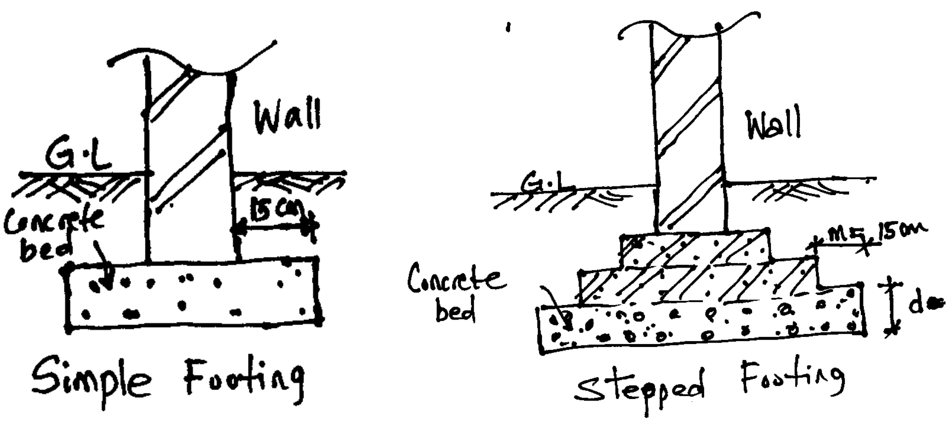


Figure 2: Simple and Stepped footing

It is usually desirable to provide light, longitudinal reinforcement in simple concrete footings in order to distribute shrinkage and temperature cracks.

Design of Wall Footing

(1) *Depth of Footing.* The minimum depth of footing is given by Rankine's formula as,

$$D = \frac{P}{w}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

Where, P = Safe bearing capacity of soil in kg/m^2

W = Unit weight of soil in $kg/m^{3.}$

Φ= Angle of repose of the soil in degrees.

D = Minimum depth of footing in meters.

The minimum depth of footing for the load bearing wall is limited to 90 cm for the stability. In case of clayey soils or black, cotton soils, the footing is taken down to a depth below where there is no danger of shrinkage cracks.

2. Width of Footing. It is obtained by dividing the total load including dead load, live load and wind load by the allowable bearing capacity of the soil.

$$B = \frac{T}{P}$$

Where B = Width of footing in meter.

T = Total load per meter run in kg.

P = Safe bearing capacity of soil in $kg.lm^2$•

3. Depth of Concrete Bed. The depth of concrete bed of the footing depends upon the projection of the concrete block beyond the footing over it, the upward soil pressure and the quality of the concrete. The concrete block may fail in bending, crushing, or shearing. It is a general practice to design the depth of concrete bed by the consideration of maximum bending moment. The following formula may be used to determine the depth of the concrete bed :

$$d = 0.775m$$

Where d = depth of concrete bed in cm,

m = offset of concrete bed in cm

Note: Considering $5kg/m^3$ as bending stress of concrete

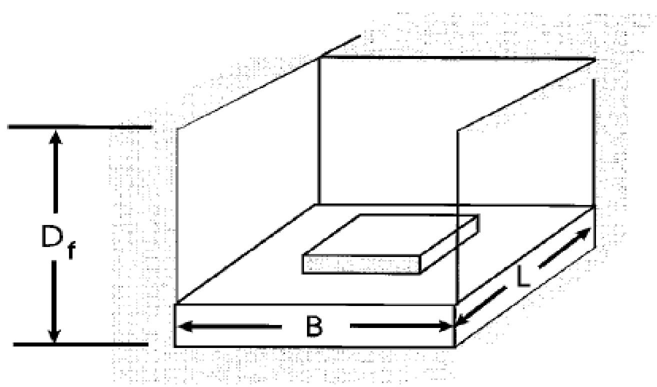
Problem

Design the foundation of a three storeyed residential building whose foundation will rest on sandy soil with angle of response of 30^0 *and safe bearing capacity of* 15 *tonnes per sq.* m. *The soil weighs of 1600 kg. per cubic metre. The walls are* 30 *cm. thick and 13.0 metre high above the ground level including parapet. The roof consists of 15cm. thick R.* C. C. *slab and* 10 *cm. thick average lime-terracing. The floors are made up of 10 cm. thick R.C.C. slab covered with* 25 *mm. of Indian Patent Stone (l.P.S.) flooring, the maximum span of* *the R.C.C. slab for the roof or floors between two main walls is 5 metres. The weight of R.C.C. may be assumed as 2200 kg 1m*^{3} *and that of lime concrete as 1800 kglm*^{3}.

4.4.1.2 Isolated footings

These footings are sometimes known as column footings and are used to support the individual columns, piers or other concentrated load. Most column footings are slab footings with two-way reinforcements and constant depth. They could either be stepped types or can have projections in the base concrete as shown typically in Fig. 3. Isolated footing is provided under column to transfer the load safely to the soil bed. An offset of at least 150 mm is provided in the concrete bed on all sides. When brick masonry columns are used, they are stepped down on all the four sides in regular layers with 50 mm offsets.

The use of concrete footings become essential when concrete columns are used. The footing may be a slab, stepped, or sloped ones. Steel reinforcement is provided in both directions with proper cover. Fig 2 illustrate various types of the isolated R.C.C. columns.



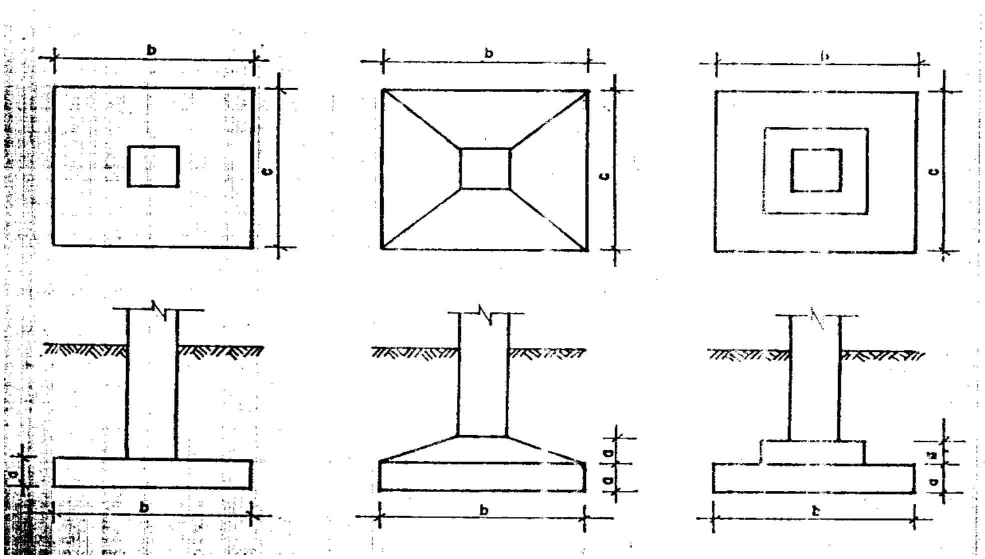


Figure 3: Isolated footings

4.4.1.3 Combined footing

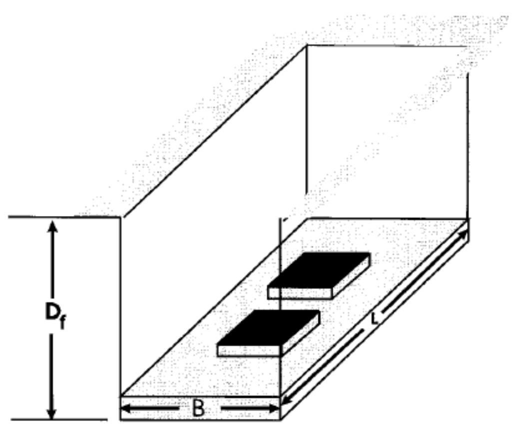
A combined footing is a long footing supporting two or more columns in one row. Footings of this type are most frequently used to support walls and columns, which are close to property line. Combined footings are essential whenever the projections of columns are not possible on one side due to limited available space and when the spacing of two consecutive columns are close for isolated footings. This means the construction of combined footing becomes essential when the external column is situated near the boundary line and it is not possible to project the footing symmetrically on both sides of the column.

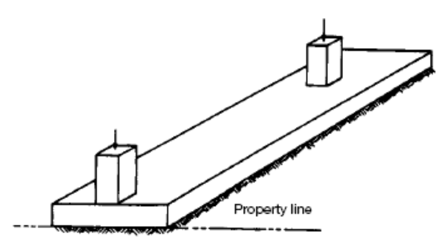
If such a column was centered on an isolated footing, the footing might project over property line. If it were placed near the edge of such a footing, the foundation pressure would not be symmetrically distributed and the footing would tend to settle unevenly. This condition can be overcome by combining the wall or column footing and the nearest interior footings i.e a single footing.

Combined footings are so proportioned that the centroid of the area which bears on the soil lies on the line of action of the resultant of the column loads, in order to avoid any tendency to rotate. The result is usually a trapezoidal footing. It is ordinarily assumed that arrangement also produces uniform pressure distribution under the footing.

Combined footings can also have rectangular shape if the load on the interior columns is heavier than the outer columns and the inward projection of the footing can be adjusted. Combined footings are usually built of reinforced concrete. However, steel grillage combined footings are also used. Typical reinforced concrete combined footing layouts are shown in Fig 4.

As described above the shape of the combined footing is proportioned in such a way that the centre of gravity of the resultant area is in the same vertical line in the centre of gravity of the loads. Generally, the shape of the footing is rectangular or trapezoidal.





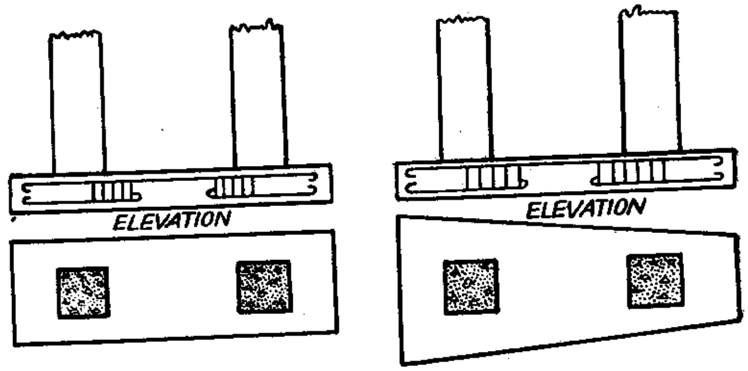


Figure 4: Combined footings

Design of Trapezoidal balanced foundations

The design is carried out by first of all calculating the area of the base required for a uniform pressure to resist the total applied load. The resultant load and its point of application are then calculated. By fixing the dimensions for the length of the base, the width on both sides can be calculated to give a centre of gravity which coincides with the location of the resultant load. The applied bending moments and shear forces are then calculated and the reinforced foundation designed to suit.

Design of Rectangular balanced foundations

The foundation base is designed by calculating the position of the resultant applied load and making the centre of gravity of the base coincide with that of the downward load. This is done by first calculating the area of the base required to resist the resultant load and then finding the most economic rectangular pad to achieve this. The pad is then located so that its centre of gravity is in the same position as the resultant load. The base is then designed to resist the bending moments and shear forces produced by the solution, and the depth and reinforcement are determined and detailed accordingly.

Problem 2. *Two columns* 50 *cm* x 50 cm *and* 60 cm x 60 cm *carry 80 tonnes and 120 tonnes of loads respectively. The centre to centre distance between the columns is 5.20 metres. The allowable bearing capacity of the soil is* 20 *tlm*^{2}. *Determine the dimensions of the combined footing if the footing is not to project more than* 25 cm *beyond the outside of the smaller column.*

4.4.1.4 Cantilever/ strap footing

Footings of this type are designed to serve the same function as combined footings by omitting a column load to be placed near the edge of the footing. A large spacing between two columns can create a situation where a continuous footing is uneconomical due to the use of a large quantity of concrete in the footing and because of the high negative bending moments between columns. Thus cantilever or strap footing is an alternative to the combined footing. Essentially this type of footing uses spread footings or pads beneath the columns and a rigid beam connecting the two pads to transmit the unbalanced shear and moment from the statically unbalanced footing to the second footing.

In other words, cantilever footing consists of an eccentric footing for the exterior column and a concentric footing for the interior column and they are connected by a strap or a cantilever beam. Such footings are used when it is not possible to place a footing directly below a column because of limitation of boundary or eccentric loading conditions. The load from the exterior column is balanced by the load of the interior column acting about a fulcrum.

The analytical solution for cantilever footing requires two simplified assumptions that uniform soil pressures are obtained beneath each footing pad, and the strap or beam connecting the two footings is perfectly rigid. Under this assumption, the resultant of the column loads would coincide with the center of gravity of the two footing areas. Cantilever footings can be built of steel as well. Typical strap or cantilever footings are shown in Fig. 5.

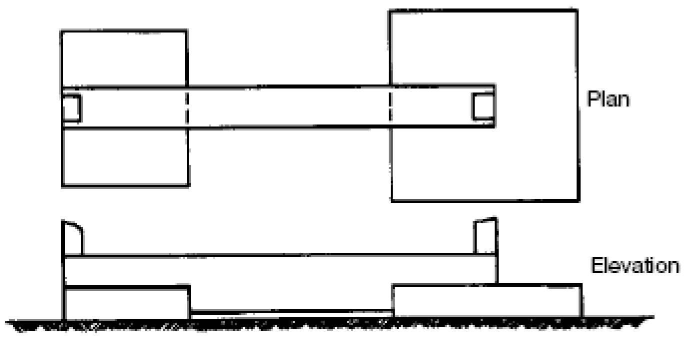


Figure 5: Strap or cantilever footing

4.4.1.5 Strip/Continuous footing

Strip footings are used under relatively uniform point loads or line loads. The main structural function of the strip is to disperse the concentration of load sideways into an increased width of sub-strata in order to reduce the bearing stress and settlement to an acceptable limit.

There are a number of different types of strips which include masonry strips; concrete strips – plain and reinforced; trench fill – concrete and stone; reinforced beam strips –rectangular and inverted T, and these are described in the following sections.

Strip footings are commonly used for the foundations to load-bearing walls. They are also used when the pad foundations for a number of columns in line are so closely spaced that the distance between the pads is approximately equal to the length of the side of the pads. (It is usually more economic and faster to excavate and cast concrete in one long strip, than as a series of closely spaced isolated pads.). They are also used on weak ground to increase the foundation bearing area, and thus reduce the bearing pressure – the weaker the ground then the wider the strip. When it is necessary to stiffen the strip to resist differential settlement, then *tee* or *inverted tee* strip footings can be adopted. Typical examples are shown in Fig.6.

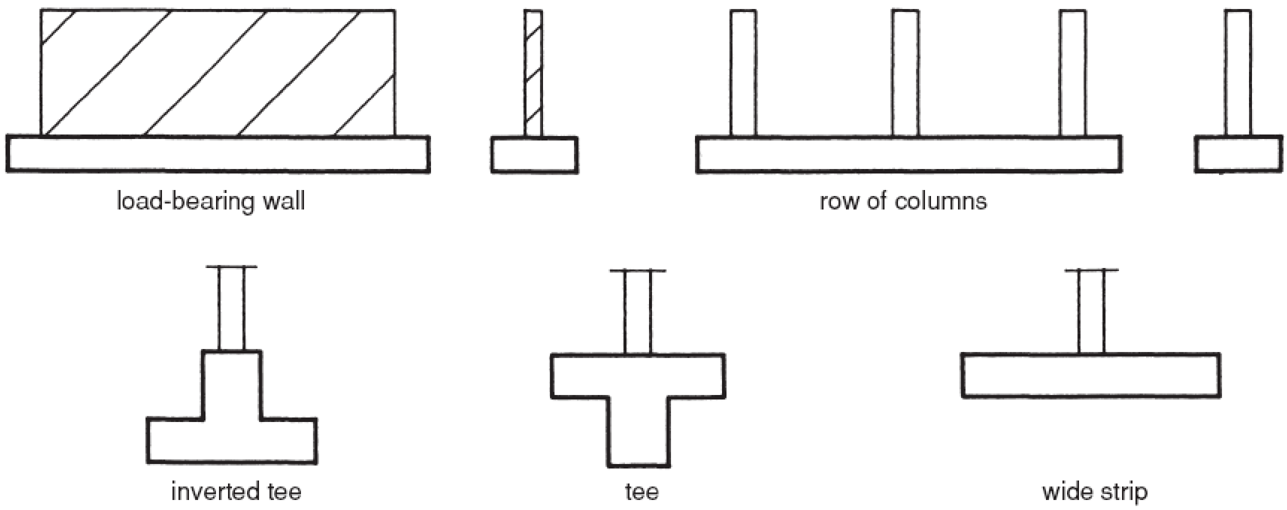


Figure 6: Strip/continuous footings.

Continuous footings usually consist of reinforced concrete slabs (or beams) extending continuously under three or more columns. They tend to reduce the differential settlement between columns and for safety against earthquake. This action is more effective if the foundation wall is constructed as a reinforced concrete girder. Two-way continuous footings may be constructed, to reduce differential settlement more effectively than can the one-way continuous footing. Foundations tied together in this manner are desirable from the point of view of earthquake resistance.

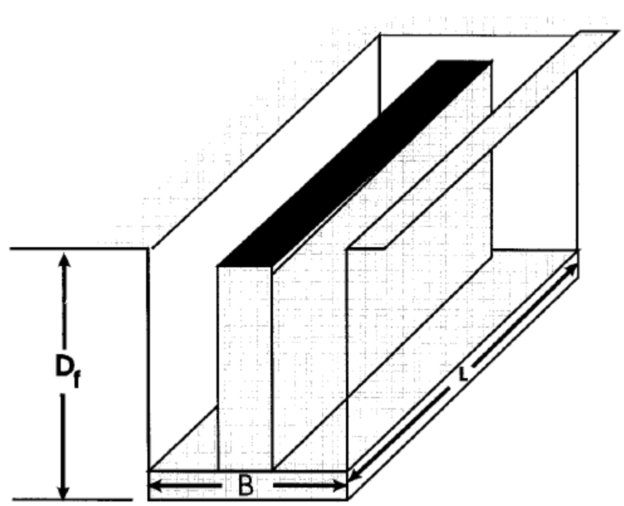


Fig 7: Continuous footings

4.4.1.6 Raft or Mat foundation

A mat foundation is a large footing, usually supporting several columns in two or more rows. This method is used when the soil is so loose that it cannot carry any appreciable load and where rock or other firm bedding cannot be reached within reasonable depth, either for piles or for pillars.

Raft is a type of foundation which transmits its load to the soil by means of a continuous slab that covers the entire area of the bottom of a structure similar to a floor. The raft is used in a situation in which the low bearing capacity of soil necessitates such large isolated footings that it is reasonable to joint them altogether. If the sum of the base areas of the footings required to support a structure exceeds about half the total building area then it is preferable to combine the footings into a single raft. Thus, raft can be assumed as a large footing.

In general raft foundations consist of reinforced concrete slabs covering the entire foundation area and constitute a form of foundation where the loads from load-bearing walls or columns are distributed over the whole area of the building or beyond it. They have a loading distribution similar to inverted floors, the upward pressure of the soil being fairly uniform under the whole raft. The concrete slab, being subjected to bending stresses, must be reinforced with layers of closely spaced reinforcing bars running at right angles to each other in both directions and may or may not need to incorporate beams, according to the structural arrangement, spans between load bearing walls or columns.

Rafts are used for the following purposes:

1. To give increased area of foundation due to poor bearing capacity of soil.
2. To span over small soft or loose pockets.
3. To counteract the effect of hydrostatic uplift.

Types of rafts: Flat plate type, flat plate with pedestal and two way beam and slab type. See figure 8.

Rafts should be used in the following situations.

1. When the load of the structure is very heavy but the bearing capacity of soil is so low that small individual footings cover more than half of the area under the structure, then use of raft foundation will be economical. This will develop the minimum contact pressure and in most cases the maximum safety factor against soil failure.

2. In highly compressible soils the settlements under individual footings are quite high. Provision of a raft foundation is the only solution in such circumstances. Sometimes the depth at which the raft is placed is so great that the unit load from the building becomes equal to the unit weight of the soil that has been excavated. Such type of raft is known as floating foundation. . .

3. Localised weak spots and loose pockets in soil mass can be bridged safely by a raft foundation but the size of the weak spot must be known so that it can be designed properly. Ordinarily a soft area smaller than one-third the column spacing does not pose any serious problem in bridgiag, Large weak area requires special treatment.

4. Raft is very useful for resisting large hydraulic uplift. Firstly, the weight of the raft and columns etc. resist the uplift. Secondly, it is easier to make structurally continuous foundation watertight than individual footing with separate floor slabs.

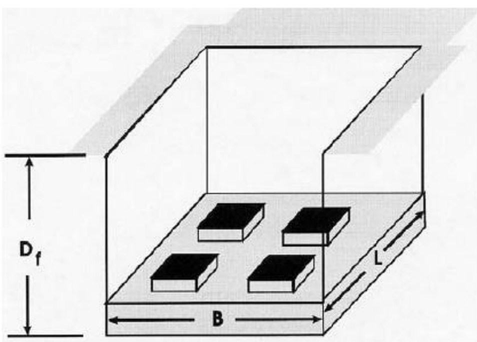
5. Sometimes people use pile foundation in place of raft foundation thinking that pile foundation is always good. Actually, sometimes pile foundation may be harmful whereas raft foundation will be economical. Following example will illustrate the point. There is a thick layer of fairly firm clay over a deep layer of soft clay. Soil investigations may show that the firm clay is having enough bearing capacity as a distributing raft

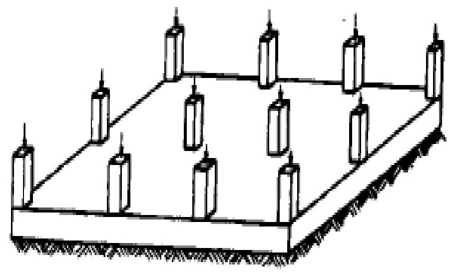
over the soft clay; If instead of raft, the pile is used then piles may destroy this advantage of spreading the load and thereby decreasing the unit pressure on the soft clay which will increase the settlement .

The advantage of raft over strip foundation is that the building becomes monolithic and any weak patches in bearing soil do not cause local subsidence. The foundation, if adequately reinforced, stands or sinks in one unit. Rafts are therefore especially suitable for soils of variable or unreliable bearing capacity, such as soft clay or other weak sub-soils.

The minimum foundation depth below ground level of 1.00 – 1.20m or more for strip foundations on clay soils is not applicable to raft foundations, which can be as shallow as consistent with complete coverage and floor level. The raft can have the dual function of foundation and site concrete.

If for some reasons beams have to be incorporated, a raft foundation can be given the form inverted T-beams of reinforced concrete with the slab covering the entire foundation. The beams run in both directions and intersect under the columns. These are poured at same time as the slab forming a monolithic structure, which will act as a unit. Before basement floor is placed, the space between these beams may be filled with cinders or other materials.





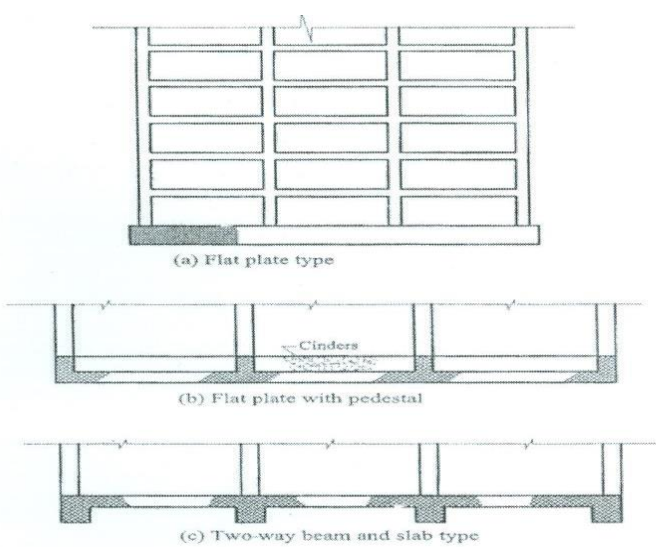


Figure 8: Mat or raft foundation.

If the slab is placed at the top of the beams and monolithic with the raft, the raft may serve the basement floor and save excavation and filling. This construction is suitable for a soil that will stand without casing so that the space occupied by the beams can be excavated and whole mat poured without the use of forms. Common types of mat or raft foundations sections are shown in Fig. 8.

When raft foundation is constructed it is preferable to pour the entire slab in one operation in order to avoid construction joints. To safeguard bearing soil under external walls from drying shrinkage, rafts should preferably extend 0.50m or more; beyond outside walls, alternatively the perimeter bearing soil may be protected by a concrete apron around the building, forming a path. Centers of gravity of structure and raft should approximately coincide; this is likely to occur in most cases, unless there is some heavy load, such as large chimney stock, near to perimeter of the building, in which case the raft projection may need to be increased near this edge to avoid eccentric loading on the raft.

Raft foundations are not suitable for steeply sloping sites, where excavation at upper end of the building would be excessive, nor are raft foundations generally suited to framed buildings with heavy concentrated (column) loads, where raft thickness and reinforcement would need to be excessive.

Determination of Bearing capacity of Raft foundation

For granular soils

$$Safe\,Bearing\,Capacity,\,q\,(in\,tones/sq.ft) = \frac{N-3}{5}$$

N value is obtained from standard penetration test.

The raft foundations are normally large and the bearing capacity of sand increases with the width of the foundation. Hence bearing capacity failue of raft foundation on sand deposits may be ruled out. For the same soil pressure the differential settlement is less for the raft foundation as compared to the individual footings. Hence the allowable soil bearing pressure in case of raft foundation can be increased.

For Clay soil

$$Ultimate\,Bearing\,Capacity,\,Q_{ult} = 2.85 * Q_u \left(1 + 0.3 * \frac{b}{L}\right)$$

Where, Q_u= Unconfined compressive strength of clay
L=Length
b=width

4.4.2 Pile foundation

This is an element of construction placed and driven into the ground either vertically or slightly inclined to increase the load carrying capacity of the soil and transfer the load of the superstructure to the selected strata safely. They are used to transfer the weight of the building on to the soil at a depth greater than would be economically feasible with spread foundations. In spread foundations, the loads are transmitted directly to the soil by the foundation. In pile foundations, the loads are transmitted first into the pile, which in-turn transmit then to the soil or rock.

Foundation structures rarely consists of a single pile. Generally, there will be a minimum of two or three piles under a foundation element or footing. Building codes may stipulate the minimum number and arrangement of piles under a building element.

Piles are structural numbers of timber, concrete, and/or steel that are used to transmit surface loads to lower levels in the soil mass. This transfer may be by vertical distribution of the load a long the pile shaft or direct application of load to a lower stratum through the pile point.

4.4.2.1 Types of piles

Piles are long and slender members which transfer the load to deeper soil or rock of high bearing capacity avoiding shallow soil of low bearing capacity. The main components of the foundation are the pile cap and the piles.

Bearing pile /*End bearing piles*

These piles transfer their load on to a firm stratum located at a considerable depth below the base of the structure and they derive most of their carrying capacity from the penetration resistance of the soil at the toe of the pile . It is used to transfer the superimposed load to a hard strata at a considerable depth. The pile behaves as an ordinary column and should be designed as such. Even in weak soil a pile will not fail by buckling and this effect need only be considered if part of the pile is unsupported, i.e. if it is in either air or water. Load is transmitted to the soil through friction or cohesion. But sometimes, the soil surrounding the pile may adhere to the surface of the pile and causes "Negative Skin Friction" on the pile. This, sometimes have considerable effect on the capacity of the pile. Negative skin friction is caused by the drainage of the ground water and consolidation of the soil. See Fig 9,11 and 12.

Friction pile
It transfers the superimposed load to the soft soil by frictional forces existing between the ground and the periphery of the pile. That is to mean its carrying capacity is derived mainly from the adhesion or friction of the soil in contact with the shaft of the pile. See Fig 10, 11 and 12.
Battered Pile: It is an inclined pile constructed to resist inclined forces. See Fig 12.
Sheet Pile: It is thin member of steel sheet or timber used as pile. See Fig 12.
Under–ream pile – It is a pile with one or more bulbs in its vertical shaft. These bulbs are known as under-reams and it increases the bearing capacity of the soil considerably.

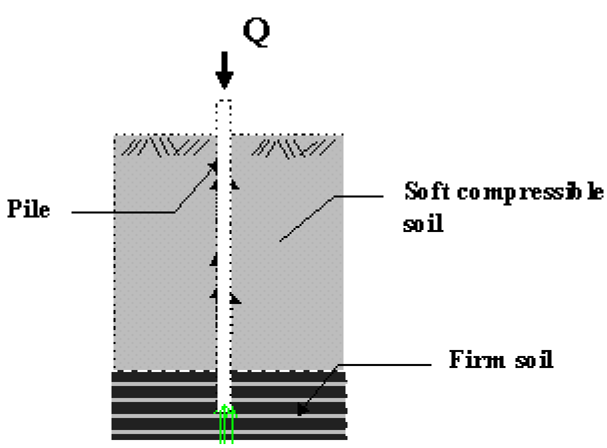


Figure 9: Bearing pile

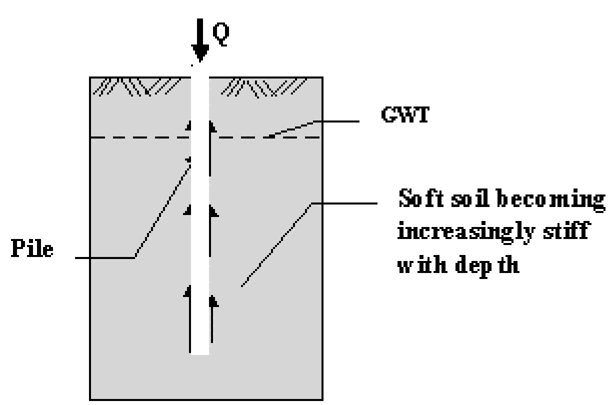


Figure 10: Friction pile

Depending on material and method of construction piles may be:

- ✓ Timber piles
- ✓ Concrete/reinforced concrete piles
- ✓ Steel piles
- ✓ Cast in situ piles
- ✓ Pre-stressed concrete piles
- ✓ Prefabricated piles

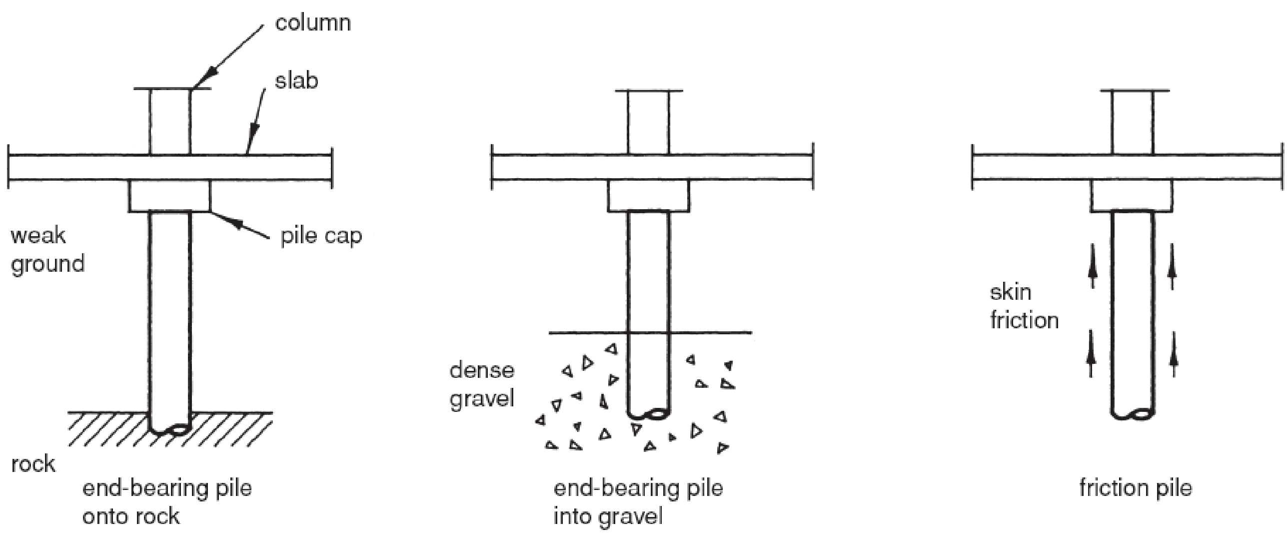


Fig. 11: Pile foundations.

4.4.2.2 Uses of piles

There are different types of piles and their uses can be summarized as:

- To transfer loads through water or soft soil to a suitable bearing stratum: ***end-bearing piles***.
- To transfer loads to a depth of a relatively weak soil by means of skin friction along the length of the piles: ***friction piles.***
- To compact granular soils, thus increasing their bearing capacity: ***compaction piles.***
- To anchor down the structure subjected to uplift due to hydrostatic pressure or overturning moment: ***tension piles or uplift piles.***
- To provide anchorage against horizontal pull from sheet piling walls or other putting forces: anchor piles.
- To protect water front structures against impact from ships or other floating object such as barges: ***fender piles***. Fender piles are ordinarily made of timber.
- To resist large horizontal or inclined forces: ***batter piles***

See figure 12.

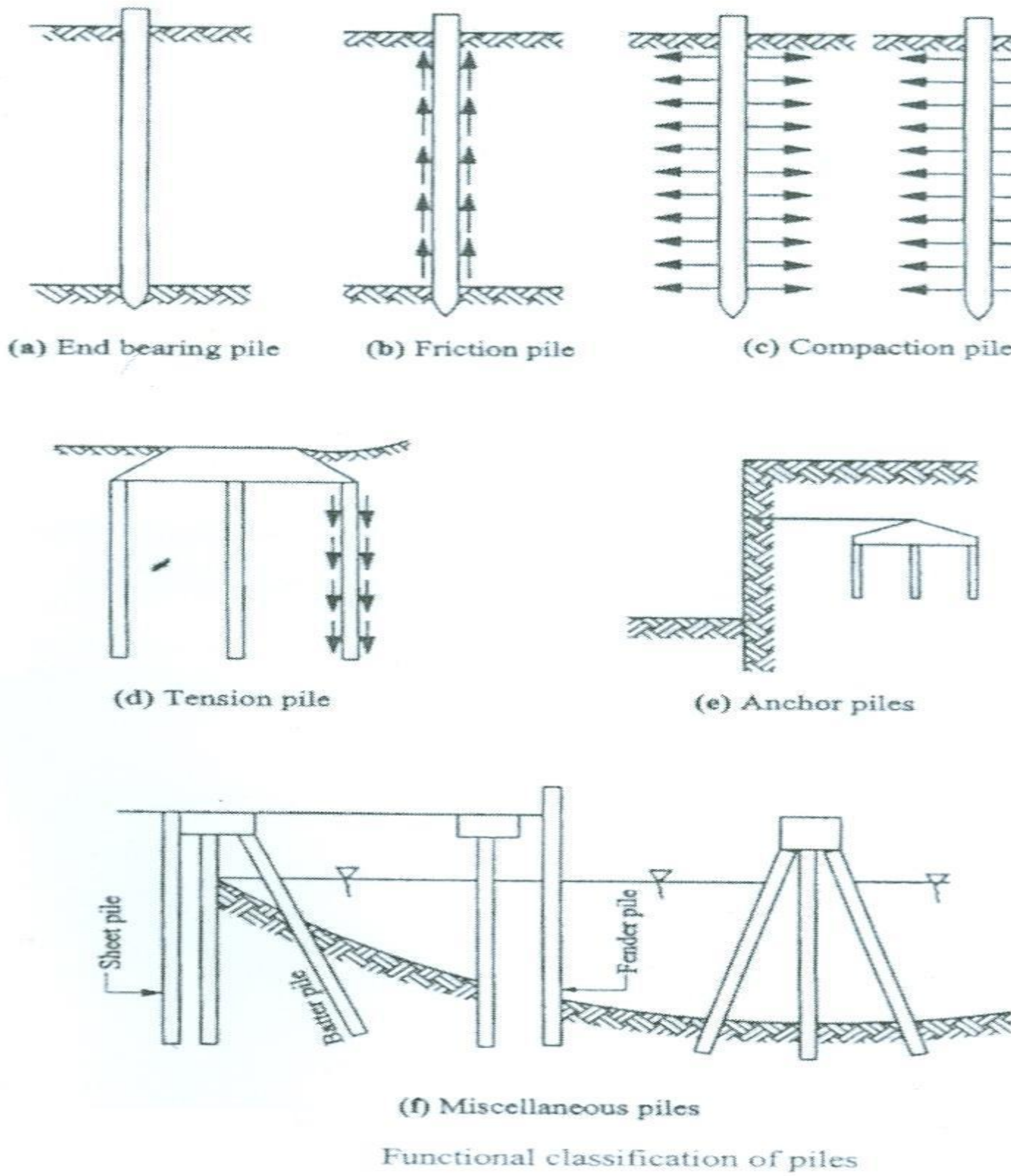


Figure 12 : The schematic classification of piles based on functions

4.4.2.3 Conditions where piles are used as foundations

Under the following circumstances the piles may be used as foundation:

1. The live and dead load coming from the structure is considerably large.
2. The construction of raft or grillage foundation is not economical.
3. The seasonal variation of groundwater table is considerable.
4. This type of foundation is suitable in the locality where canals deep sewers, etc are to be constructed at a latter date.
5. It is used in the construction of marine structures, e.g. docks, piers, etc. This protects embankment from scorning.
6. It may give lateral support to take care of an up ward pressure.

4.4.2.4 Bearing Capacity of Piles

Bearing capacity of pile may be defined as that load which can be sustained by a pile without producing excessive settlement or material movement resulting in the damage to the structure or interfering with its use.

Ultimate Bearing capacity of pile can be defined as the maximum load which can be carried by a pile and at which the pile continues to sink with out any further increase of load.

Safe Bearing capacity – Can be found by dividing the ultimate bearing capacity with a suitable factor of safety.

There are three important methods for the determination of bearing capacity of piles.

1. Determination of Bearing capacity by dynamic formula.
2. Determination of Bearing capacity by static formula.
3. Determination of Bearing capacity by pile load tests.

Determination of Bearing capacity by dynamic formula

Dynamic pile formula is based up on the theory that ultimate bearing capacity is the same as ultimate driving resistance. (i.e UBC=UDR).

All dynamic formula are based either on the Work- energy relationship or on the impact- moment theory.

Work-Energy relationship of dynamic formula

The pile penetrates into the soil by a succession of blows brought about by striking the pile on its head by a hammer. The kinetic energy of the hammer after striking the pile will be as follows.

W.h= Σ (Energy losses),

Where W= weight of falling hammer
h = height of fall

The energy losses take place due to friction, rebound of hammer, dissipation of heat in the system, and brooming of the head of pile.

The penetration of the pile in to the soil meets some resistance at the tip of the pile. To over come the soil resistance to penetration of the pile, mechanical work must be performed in driving the pile in to the soil, i.e R.S., where R= Resistance to penetration and S= Penetration of pile under one hammer blow.

The work energy relationship can be written as given below.

$$\frac{1}{2}Mv_o^2 = \int_0^s R.dS = R.S$$

Where M=Mass of hammer

$v_o = 2\sqrt{gh} = fall\,velocity$

g = acceleration due to gravity

We know, Mgh=1/2 mv^2=RS

This is synonymous with work done by friction.

It is assumed that hammer and pile are rigid bodies and hammer is a free falling body and that the final kinetic energy is zero. For the last few blows R is assumed to be constant.

We know, $\frac{1}{2}mv_o^2 = W.h$

Hence, W.h=R,S

Some of the dynamic formulas are given below

1. Engineering News formula (1888)

A.M Wellington, editor of Engineering News proposed this formula based on his experience. Safe Bearing capacity of pile is given by:

$$Q = \frac{W.R}{F(S+C)}$$

Where: Q= allowable load
F= Factor of safety =6
S= penetration/below usually taken as average penetration cm per blow.
h= height of fall
W=weight of hammer
C= Constant.

If W is in kg, H in cm, and S in cm and C=2.5cm, per drop hammer and C= 0.25 for single and double acting steam hammer then the Engineering News Formula will be reduced to the following.

A) For drop hammer

$$Q \frac{W.\hbar}{6(S+2.5)}$$

B) For single acting steam hammer

$$Q \frac{W.\hbar}{6(S+0.25)}$$

C) For double acting steam hammer

$$Q \frac{(w+ap).\hbar}{6(S+2.5)}$$

, where a= Effective area of piston in cm^2

P= mean effective steam pressure in kg/cm^2

2. Brix Equation

Brix equation is widely used in continental Europe for sandy soils and applies to drop hammer only. It is not useful for dense soils or if the value of S and h is small. This equation is based on the impact theory. Safe bearing capacity Q is expressed in the following way.

$$Q = \frac{W^2.wh}{F(W+w)^2 S}$$

Where w=Weight of pile in kg

F= Factor of safety
W=Weight hammer in kg
H= height of drop of hammer in cm
S= Penetration in cm/b

Note that the value of F should be F>3.

Limitation of the use of Dynamic Formula

1. Dynamic formulae are most suitable for coarse grained soils because shear strength of such soil is independent of rate of loading. In such soils there is no development of excess pore pressure around the pile during driving even in saturated conditions.
2. Liquefaction of soil may occur in case of submerged uniform fine sands due to impact of driving thus showing much less resistance than that which will occur in static condition. Similarly, very dense saturated fine sand will show higher driving resistance which will get reduced with passage of time.

3. There is uncertainty about the relationship between the dynamic and static resistance of soil.

4. Dynamic formulae are ill-suited for clay because skin friction developed in clay during driving is very much less than which occurs after a period of time. In clayey soil, the point resistance is more

during driving because of development of pore pressure but later on the point resistance decreases after the dissipation of pore pressure. Hence it cannot be used for saturated clays.

5. In Engineering News' formula the weight of the pile and its inertia effect is not taken into account.

6. Dynamic formulae do not give any idea about probable settlement in future.

7. Group action of piles is not considered in the dynamic formulae

Determination of Bearing capacity by static formula.

Seeing the above limitations of dynamic formulae, a number of static formulae are also used for the determination of bearing capacity. The static bearing capacity formulae of piles are based on the assumption that the total resistance offered to a pile by system at a critical load is equal to the sum of the total ultimate skin friction R_f and the total end bearing resistance at the top of the pile, R_p.

The equation is as follows:

$$Q = A_p X_p + A_s Y_f$$

Where,

As= Surface area of pile up on which the skin friction acts which will be equal to the length of the pile multiplied by perimeter of pile.

A_p= Cross-sectional area of pile on which bearing resistance acts

Y_f= Average skin friction

X_p= Toe resistance

A factor of safety of 3 is taken for finding allowable load.

Vierendeel's Formula. Vierendeel's Pile static bearing capacity formula is based on the earth pressure theory. The formula assumes that at any depth there is a passive resistance on the pile and the total resistance is obtained by integrating the unit resistance over the total mantle surface area along the entire length o fthe pile.

$$Q_{ult} = \frac{1}{2} f \gamma \pi D L^2 \tan^2(45 + \phi/2)$$

Where,

f = Co-efficient of friction whose values for cast in situ piles and other rough surfaces like concrete or timber piles = 0.33 and for smooth piles or piles in wet and plastic soils = 0.25.

γ = Unit weight of soil

D = Diameter of pile

L = Embedded length of pile.

Determination of bearing capacity by pile load tests

The purpose of a pile load test may be either to determine the ultimate bearing capacity of a pile or to check whether a pile can safely carry its design load as obtained by any of the pile formulae. In the conventional pile load test the load is applied over the pile cap in equal increments of 1/4th of design load. Each load is maintained for 24 hours after which the next increment is given and the corresponding settlement is noted. The full design load should be maintained for a week. Loading is subsequently increased in steps and finally 1.5 times the design load is again maintained for a week. The load is then removed and the net settlement is noted. A load settlement curve drawn and the ultimate load is taken to be the value corresponding to a total settlement of 12 mm, It is also essential that net settlement should not exceed 6 mm. Fig. 13 shows the load settlement curve for a pile in sandy and clayey soil. The ultimate load can be determined in sandy soil when the curve begins (Point *A)* flattening. In clay the curve is practically straight up to failure. In Fig. 13 point *B* is the failure point. In some cases the point of failure is evident whereas in other cases the curve changes slope so gradually that picking the failure point is difficult and hence any of the following rules may be used for this purpose. See Fig 14 for pile load test.

(a) The test load should be twice the contemplated design load and should be maintained for at least 24 hours and until settlement does not exceed 5.6 mm in 24 hours. The design load shall not exceed one-half the maximum applied load provided the load settlement curve shows no signs of failure and provided the permanent settlement of the top of the pile, after removal of all load at completion of the test does not exceed 6.4 mm.

(b) Observe the load carried without exceeding a total permanent settlement of 6 mm in 48 hours and divide by a factor of safety of 2.

(c) Observe the point at which no settlement having occurred for 24 hours, the total settlement including elastic deformation of the pile is not more than 0.25 mm per tone to test load and apply a factor of safety of2.

(d) One-half or one third of the final load which causes settlement equal to 10% of pile diameter.

(e) Two-third of the final load which causes a total settlement of 12mm.

(j) Mark the point at which the plastic curve breaks sharply and divide by a factor of safety of 2.

(g) Draw tangent lines to the general slope of the upper and lower portion of the curve. Observe the load at their intersection and divide by a factor of safety of 1.5 or 2. See Fig 13.

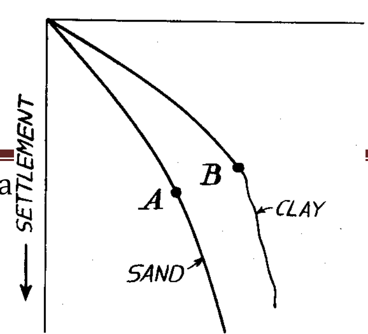


Fig 13: Curves

Limitation of this method is that pile load tests are generally done on one or two test piles after most of the piles are already driven. It generally provides an oversafe and costly design except in rare cases while the pile is unsafe. There are many other limitations also. Such as, it is not possible to arrive at the ultimate bearing capacity of the pile and separation of skin friction and point resistance is not possible. The latter is necessary while estimating the bearing capacity of piles used for formulations subjected to scour or vibration. The set up for the load test on pile has been shown in Fig. 14.

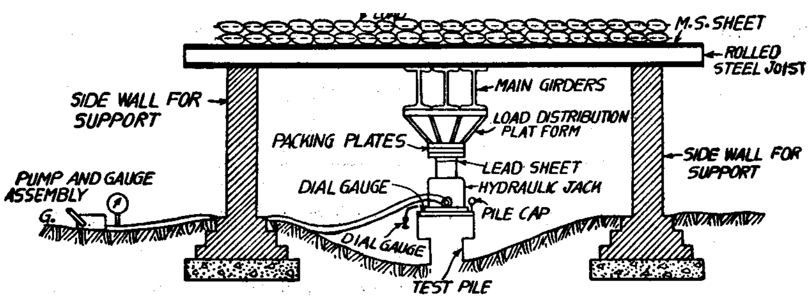


Figure 14: Pile load test

4.4.2.5 Types of piles

Piles can be made of timber, reinforced or prestressed concrete, steel and composite materials.

4.4.2.5.1 Timber piles

Usually timber tress is used as piles after the bark and the branches are removed and plained respectively. Timber piles could be circular 30-40 cm in diameter or rectangular in shape. The lower position of the piles is tapered to smaller areas to facilitate pile driving to 18 cm. the length of the piles is usually about 20 times the top width. Longer piles are liable to failure on account of buckling. For stiff clays the edge of the pile is pointed and provided with a metal point called a shoe in soft or silty ground it may not be necessary to sharpen the pile end. If such a pile comes across harder strata, it will have a wider bearing area over it and hence provide a stronger foundation.

Piles heads should be fitted with metal rings to prevent splitting. After driving timber piles, damaged heads of piles should be cut back to sound timber and ends treated with preservative. When capped with concrete, timber pile heads should be embedded in concrete, which surrounds the timberhead by at least 15cm.

Whenever it is necessary to use a longer pile than available in usual length, it is customary to splice the piles together with their ends abutting each other. Additional strength can be obtained by the use of steel plates bolted to the sides of the piles. In rare cases, small pieces of timber are bolted around the sides of the pile to increase the hold of the piles with the ground. this increase the surface area in contract with the soil.
Timber piles deteriorate due to decay or insect attack. Decay in timber piles is caused by the presence of a certain plant life called fungi, while insect attack is mainly due to termite or marine borers, which live on the cellulose present in the timber. Therefore adequate treatment of timber before driving is essential.

Timber fully below water throughout the year does not decay. It is desirable to ensure that the variations in the water level around the timber piles are least. Timber piles may be made mostly resistant to decay by preservative treatments. Some of the techniques include:

- ***Chemical preservation:*** e.g. treating timber with creosote oil under pressure is usually carried out. The amount to be applied depends up on the type of timber used and the degree of protection needed. Zinc chloride, copper sulphate, suphur chloride, etc. and used for the same purpose which are poisonous to the animal life but liable to be washed away by the water table fluctuation. Chemically treated piles should be handled very carefully so as to avoid the breaking of outer fibers, which act as protective coverings.
- ***Mechanical protection:*** Mechanical protection is afforded by various types of coverings like thin sheets of metal or a layer of felt soaked in various chemicals.

Advantage of timber piles:

- ✓ They are less expensive as most of the timber available can be used after suitable treatment.
- ✓ They can be made in longer lengths by joining the individual piles easily.
- ✓ Cutting of these piles is very easy.
- ✓ They can be driven quickly and with lighter machinery.

Disadvantages of timber piles:

- ✓ They deteriorate by the action of water or insects.
- ✓ They have a lesser load bearing capacity.
- ✓ Whenever long piles are to be driven, it is necessary to join a number of small individual units and this entails lot of joining work and the cost is high.
- ✓ One of the serious drawbacks of timber piles is the possibility of damage due to over driving. These may be damaged at the tips or above.

4.4.2.5.2 Concrete piles

Reinforced concrete is now used for piles more than any other material. Concrete piles may be classified as *precast concrete piles*, which are cast at a suitable place, cured and afterwards driven like a timber pile and Cast-in-situ piles, which are cast at the place where they have to rest finally.

4.4.2.5.2.1 Pre-cast concrete piles

Precast concrete piles are usually square or orthogonal in cross section, but they may be round, usually of uniform section except at the end point or sometimes tapered. Such piles must be designed for he stresses caused by handling and driving, as well as for those produced by the loads to which they are subjected to service. The stresses are usually compressive after the piles are in the ground, and do not necessary require much reinforcement.

Reinforcement for precast concrete piles consists of longitudinal bars with hops or spirals. The top end point of the pile should be provided with additional lateral reinforcement to withstand the driving stresses. Typical details of precast concrete piles are shown in Fig. 15.

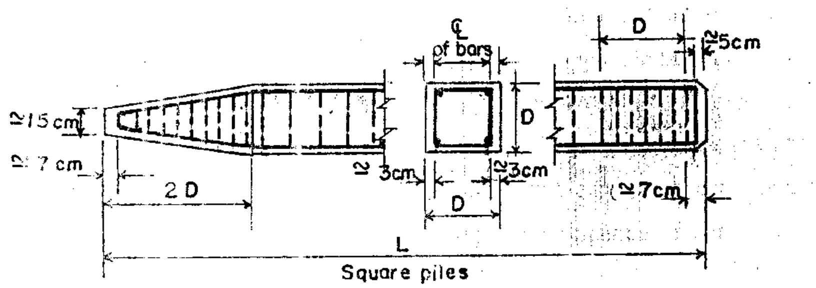


Figure 15: Typical details of precast concrete piles

The diameter of these piles varies from 25 to 60cm. for instance 30 cm for piles up to 10m in length and 40 cm for piles up to 15 m in length are usually employed. Precast concrete pile producers without even spending time for ordering.

Advantages

- ✓ Best concrete quality can be prepared by proper workmanship and any defect can be repaired immediately.
- ✓ The reinforcement bars remain in proper position and do not get displaced.
- ✓ The concrete has only to withstand loads after completer curing has taken place.
- ✓ They are convenient when driven through wet soil conditions.
- ✓ They are suitable when a part of their length is to remain exposed, and
- ✓ They are not affected by any other additional forces, which act on them while adjacent piles are driven.

Disadvantages of precast concrete piles:

- ✓ They are heavy and difficult to transport.
- ✓ The shocks of driving make them weaker, and
- ✓ Trimming is difficult.

4.4.2.5.2.2 Cast-in-situ concrete piles

Cast-in-situ concrete pile is a concrete pile built in its permanent location within a hole made by excavating with auger or by driving a suitable casing. In-situ-bored piles avoid vibration caused by driving and involve lighter equipment than that required for driven piles. Bored-piles may therefore be economical where there are only a few piles or when piles are of limited length. Moreover, underlying soil can be during the process of boring. Borings are usually made while sinking a metal tube; which may be in one piece or in sections. The reinforcement cage is placed within the tube; later or during the pouring of concrete the tube is withdrawn.

Steps in casting concrete in cast-in-situ concrete piles are summarized as:

- ✓ the pile hole is drilled;
- ✓ hollow cylindrical steel pipe is driven into the ground to the required depth;
- ✓ a cast iron or steel base is placed under the pipe to displace the soil;
- ✓ the reinforcement is placed into the pipe, if needed;

- ✓ concrete is poured to one meter into this pipe, the pipe is withdrawn; and continue pouring until the whole pile length

Typical sequence of concrete pouring in cast-in-situ concrete piles is shown in Fig. 16.

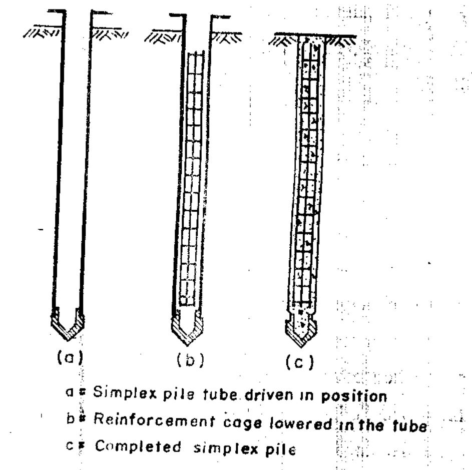


Figure 16: Sequence of concrete pouring in cast-in-situ concrete piles

Advantages of cast-in-situ piles:

- ✓ There is less wastage of material as exact length of pile is cast.
- ✓ The time spent on curing, etc. is saved.
- ✓ They can bear heavier loads by improving up on their cross-sectional profiles e.g. pedestal piles.

Where necessary, steel piles or H-Pipes can be attached to the lower end of cast-in-situ concrete piles in steel and concrete composite pile type. Such type of pile is recommended in cases where the required length of piles is greater than the possible cast-in-situ type.

Disadvantages of cast-in-situ piles:

- ✓ Good quality concrete cannot be easily obtained due to the unusual height of dumping.
- ✓ The reinforcements are liable to get displaced.
- ✓ They cannot be used under water.
- ✓ The green concrete loses strength after coming in contact with the soil.
- ✓ The shells are affected by casting additional piles adjacent to them.

4.4.2.5.2.3 Composite piles

A composite pile consists of two or more portions of different materials. The two common types of composite piles are "timber and concrete" and "steel and concrete". Wooden piles can advantageously be used below the ground water level as they are more durable under-water. Hence a pile consisting of wooden section for its up portion can be used. The joint between the wooden and the concrete section should be designed to withstand any forces coming on it when the adjacent piles are being driven. The joint should as well be adequate to resist a certain amount of tension and bending that could a rise from such as ground heaving or lateral movement resulted from pile deriving.

4.4.2.5.2.4 Steel piles

Steel piles may be of I-section or hollow pipe section. Because of a small sectional area, steel piles are easy to drive. The pipes are driven with open ends. Compressed air may be used to drive out the soil within the pipe and thus facilitate the driving. These piles are then filled civil concrete. Steel piles are mostly used as bearing piles because of their less available surface area to take the loads by frictional forces.

4.4.2.5.2.5 Under-reamed piles

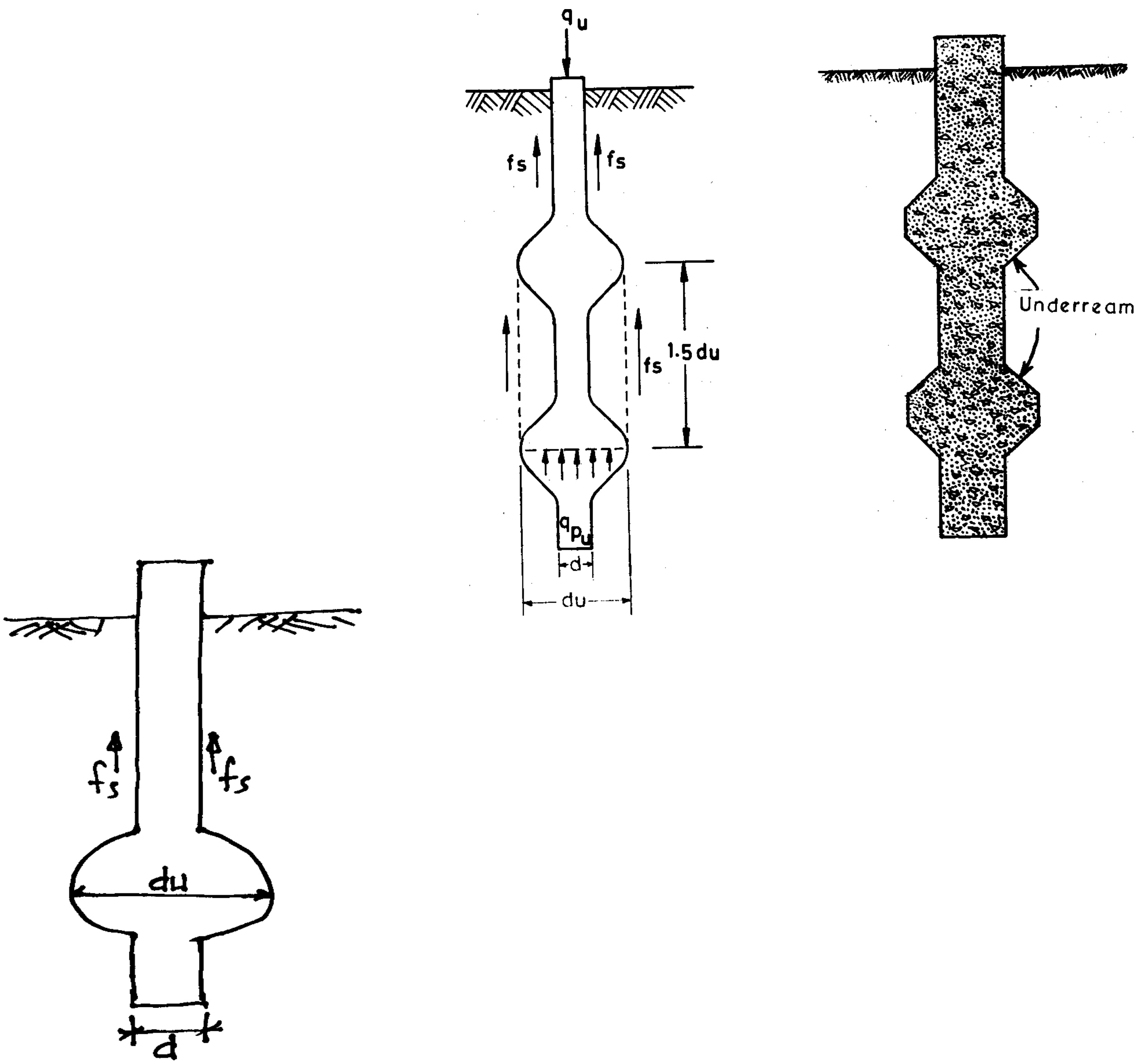
Structures built on black cotton soils and other expansive soils often crack due to the differential movement caused by the alternate swelling and shrinkage of the soil. The use of under-reamed pile foundation provides a satisfactory answer to such kind of problem. Under-reamed piles are bored and cast-in-situ concrete piles having bulb shaped enlargement near base.

The principle of this type of foundation is to anchor the structure at a depth where ground movements or volumetric change of soil due to changes in moisture content or consolidation of the poor strata are negligible. Under-reamed piles having one bulb are known as single-under-reamed piles and are used for light structures, whereas piles having two bulbs are known as double-under-reamed piles and are used for heavy structures. Typical single and double under-reamed piles are shown in Fig.17. Under-reamed piles may be provided for foundations of structures in poor soils overlying firm soil strata. In such soils for double under-reamed piles, however, both the under-reams rest shall within the firm soil strata. They have been found useful for machine foundations, factory building, transmission line towers, and other tall structures also.

Under-reamed piles can be constructed at a batter also for transferred heavy lateral loads. Hence, they are also suitable for tower footings, retaining walls and abutments. In sandy soils with high water-table, it is very difficult to build conventional footings suitable to resist large up thrusts but it is possible to provide these piles under such circumstances. This makes them more useful for transmission line and other tall structures where in addition to direct load, anchorage is also needed. Single under-reamed piles have been used successfully for one and two storey buildings. With one additional bulb the bearing capacity is increased by about 50%. Hence, by increasing the number of bulbs, very high capacity piles can be constructed for supporting multi-storeyed buildings and heavy structures.

Under-reamed piles are quite simple to construct. A vertical bore hole is prepared with an auger to the required depth. An under-reaming tool is used for enlarging the base. The tool consists of two sets of collapsible blades and a bucket at the bottom for collecting the soil. It is fixed to the extension rods and lowered down into the bore hole. As the tool is pressed down and rotated, blades try to widen out and cut the soil from the sides. The rotation is kept very slow with a steady downward pressure. When the collecting bucket is full, the under-reamer is withdrawn and the soil is removed by opening the bottom lid. The tool is again lowered and the process is repeated (Fig 17 C).

For single under-reamed piles the bore is taken down to the full depth by the auger and the base is enlarged by the under-reaming tool. In double and multi under-reamed piles, boring is first completed to the depth required for the first under-ream only and after completing the under-reaming, boring is extended further for the second underream and this process is repeated till completion. The concreting is done in the usual fashion. Under-reamed piles may be installed both in sandy or clayey soils. The sides may be stabilised if required by the bentonite slurry. The minimum distance between the centres of bulb in a multi under-reamed pile is 1.5 *du,* where *du* is the diameter of the bulb (Fig. 17 A and B).



A: Single under-ream pile   B:Double under-ream pile   C: Under-reamer

Fig 17: Under- reamed piles

The load carrying capacity of a single under-reamed pile is obtained by the equation:

$$Q_u = Q_{p'} + Q_f = A_b * q_{up} + A_s * f_s$$

where, Q_u = Ultimate load carrying capacity,

Q_p = Ultimate load carrying capacity by bearing,

Q_f = Ultimate load carrying capacity by friction,

A_b = Sectional area of bulb

Q_p = Base resistance per unit area of the bulb which may be calculated by any one of the methods explained earlier.

A_s = Surface area of the embedded shaft of the pile.

F_s = Unit skin resistance

The load carrying capacity of multi under-reamed pile increases with the increase in the number of bulbs. See Fig. 18. If the spacing between the centers of bulbs is not more than 1.5 *du,* the ultimate load carrying capacity of multi under-reamed piles may be determined by the following equation:

$$Q_u = A_b * q_{up} + A_s * f_s + A_s^{'} * f_s$$

Where, Ab = Sectional area of the lowest bulb;

As = Surface area of cylinder of the diameter du and height equal to the spacing between the centers of the extreme bulbs;

f_s = Unit frictional resistance between the pile to soil ;

As = Surface area of the embedded portion of pile shaft above the top bulb.

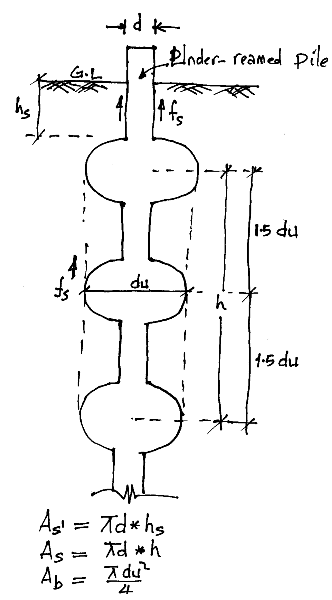


Figure 18: Multi under-ream piles

Group Action of Piles

A pile is not used singularly beneath a column or a wall, because it is extermily difficult to drive a pile absolutely vertical and to place the foundation exactly over its center line. If eccentric loading results, the connection between the pile and the column may break or the pile may fail structurally because of the bending stresses. In actual practice, structural loads are supported by several piles acting as a group.
For instance, for columns a minimum of three piles in triangular pattern are used. For walls piles are installed in staggered arrangement on both sides of its centre line.

Generally a number of piles are used as a foundation under any structure. The behavior of a group of piles is quite different from the behavior of a single pile. In case of a single pile, a small pressure bulb is formed which shows the effect of pressure bulb to a limited depth only. Whereas in case of a group of piles the pressure bulbs of individual piles overlap laterally and the effect of pressure bulbs reaches to a greater depth. See figure19 below. If the piles are closely spaced, the pressure in the overlapping area will cause movement of soil and hence the piles will settle down more. Therefore, some thumb rules adopted in code of practices are used to determine the spacing between piles. The piles may be arranged in any shape, depending upon the types of structure and nature of soil encountered.

All the piles of a group are driven into the ground to the desired depth and their top is kept at a uniform level. All the heads of the piles are joined by a concrete pile cap and over this cap the superstructure is built.

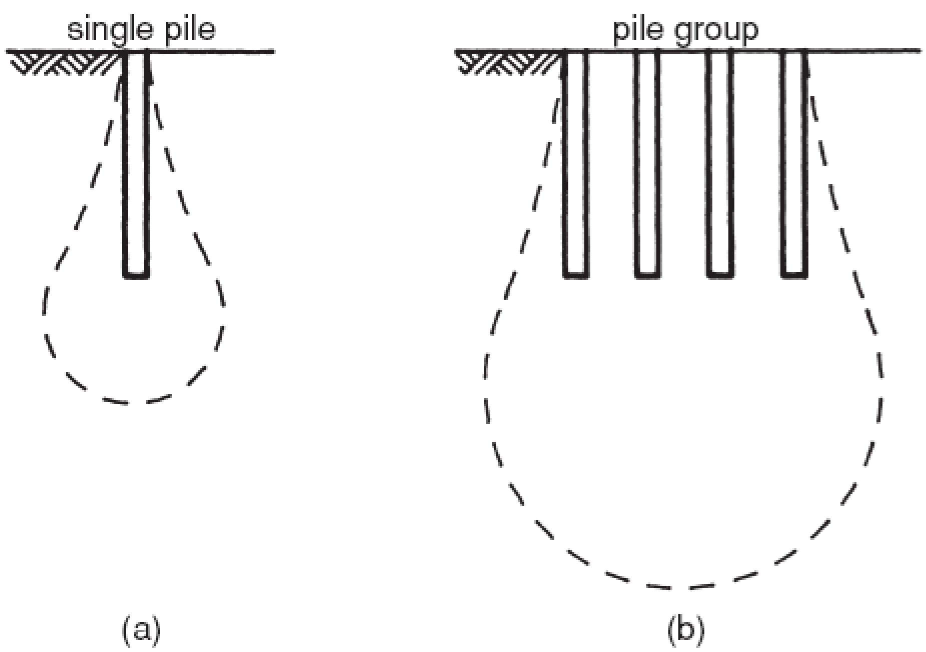


Figure 19: Pressure bulb under single and group of piles

The loads from the superstructure are transferred to the pile group through a reinforced concrete slab structurally tied to the pile tops such that the piles act as one unit. The slab is known as pile cup. The load acts on the pile cap which distributes the load to the piles. The load carrying capacity of a pile is not necessarily equal to the sum of the capacity of individual piles. Estimation of the load carrying capacity is a complicated problem. When the piles are closely spaced the stresses transmitted by piles to the soil may overlap and this may reduce the load carrying capacity of piles. For such case the capacity is limited by the group action. The bearing capacity od a group of piles depends on the spacing. When piles are spaced a sufficient distance apart, the group capacity may approach the sum of individual capacities.
The efficiency (η_a) of a group of piles is defined as the ratio of the ultimate load of the group to the sum of the individual ultimate loads.

$$\eta_g = \frac{Q_{u(g)}}{N * Q_u} * 100$$

Thus the group efficiency is equal to the ratio of the average load per pile in the group at which the failure occurs to the ultimate load of a comparable single pile.

$$\eta_g = \frac{Q_{u(g)}/N}{Q_u} * 100$$

Where $Q_{u(g)}/N$= Average load per pile in a group
$Q_{u(g)}$= ultimate load of the group
Q_u=Ultimate load of the individual pile
N= number of piles in a group

The group efficiency depends up on the spacing of the piles. Ideally, the spacing should be such that the efficiency is 100%. Generally the centre to centre spacing is kept between 2.5* d and 3.5*d where d is diameter of the pile. The methods for the determination of the ultimate load of the individual piles have been discussed earlier.

Methods of Estimation of Ultimate Load of the Group of Piles

Piles group in cohesion less soil

For piles driven in loose and medium to dense cohesionless soils, the group efficiency is high. The soil around and between the piles is compacted due to viberation caused during the driving operation. For better results it ios essential to start driving the piles at the center and then work outward. The piles and the soil between them move together as a unit when subjected to loads. The group acts as a pier foundation having a base equal to the gross plan area contained between the piles.

Driven piles

a) End bearing piles

For driven piles bearing on dense, compact sand with spacing equal to or greater than 3d, the group capacity is generally taken equal to the sum of individual capacity. Thus

$$Q_{u(g)} = N * Q_u$$

In this case, the load taken by the group capacity is much greater than (η_g>100%) the sum of individual capacities and the piles fail as individual piles.

b) Friction piles

The group efficiency of friction piles in sand is obtained from the following expression

$$\eta_g = \frac{Q_{U(g)}}{N8Q_u} * 100 = \frac{f_s(P_g * D)}{N * f_s(P * D)} * 100$$

Where P_g=perimeter of the block
P=perimeter of individual pile
D= length of pile
f_s= unit frictional resistance

If the centre to centre spacing is large, the group efficiency may be more than 100%. The piles will behave as individual piles and the group capacity is obtained from:

$$Q_{u(g)} = NQ_u$$

If group efficiency is less than 100%, then the group capacity is determined from:

$$Q_{u(g)} = \eta_g \frac{NQ_u}{100}$$

The group efficiency of friction driven piles on sandy soils can also be determined from the Converse-Labore equation given below.

$$\eta_g = 1 - \left[\frac{(n-1)m + (m-1)n}{mn}\right]\frac{\theta}{90}$$

Where m= number of rows of piles
N=number of piles in a row
$\theta = \tan^{-1}(\frac{B}{S})$
B= Diameter of pile
S=centre to centre spacing of pile

Bored Piles

The piles are formed by excavating a hole into the ground and then filling it with concrete. For bored piles in sand at conventional spacing of 3B, the group capacity is taken as 2/3 to ¾ times the sum of individual capacities for both the end bearing and friction piles. Thus

$$Q_{u(g)} = \left(\frac{2}{3} to \frac{3}{4}\right) * (NQ_u)$$

In bored piles, there is limited densification of the sand surrounding the pile group. Consequently their efficiency is lower.

Pile groups in clay

As the pile group acts as a block, its ultimate capacity is determined by adding the base resistance and the shaft resistance of the block. The capacity of the block having closely spaced piles (S<=3B) is often limited by the behaviour of the group acting as a block.

The group capacity of the block is given by

$Q_{u(g)} = q_p(A_g) + \alpha C(P_g D)$--Eq 1

Where q_p= unit point resistance

A_g=base area of the block

P_g=perimeter of the block

D=depth of the block

C=undrained cohesion

α=adhesion factor (α=1 for soft clays)

For individual pile capacity is given by

$Q_u = q_p(A_p) + \alpha C(PD)$ --Eq 2

The group capacity considering the piles as individual piles is given by

$Q_{u(g)} = NQ_u$--Eq 3

The lower of the two values obtained by the equations (1) and (2) is the actual capacity.

4.4.2.6 Pile Driving

Pile driving is an operation of forcing a pile into the ground without previous excavation. There are different methods of pile driving, among which drop hammer, steam hammer and water jets are most usually used. See Fig. 20.

4.4.2.7 Pile Caps

A group of piles is covered and connected together by a cap. Reinforced concrete piles have got reinforced concrete pile caps. The reinforcement of the piles continued into the cap to a distance of at least 8 cm, and further the cap projects around the piles by at least 10cm. The number of piles per cap should not be less than three so as to ensure stability of the group.

4.4.2.8 Bearing power of a pile

The number of piles required to support a given structure is to be determined by dividing the total load coming on the group of piles by the carrying capacity of one pile. In addition, settlement of pile group needs to be investigated. Load carrying capacity of each pile is determined conveniently by test piles.

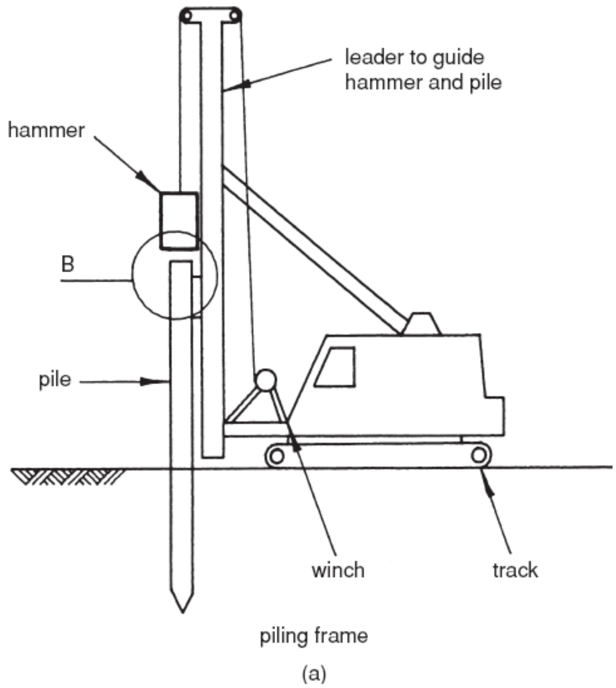


Figure 20: Pile driving machinery

The following points about pile foundation are worth considering:

1) reinforced concrete piles are not normally economical for depths less than 6m;
2) driving of piles is generally commenced at the center of the group of piles and continues driving outward;
3) when piles are driven in clay, displacement of the soil occurs which causes heave in the soil surface. Some type of clay get considerably disturbed and bearing capacity is decreased to a large extent. "H" section piles cause least displacement;
4) in the case of sandy soils, care should be taken that excessive vibrations are not impaired to the soil otherwise considerable settlement may occur;
5) not more than 4 cm deviation from the designed alignment of the pile should be accepted, the tolerance on the verticality of the pile being not greater than 1 in 50.

4.4.3 Pier Foundations

Piers are generally cylindrical columns used to support the loads like bearing piles. The difference between piers and piles lies in the method of construction.

- ✓ Piers are driven by excavation of the soil, which they occupy. Piles are may be driven with hammer or bored type.
- ✓ In the case of piers the excavation can be carried to the desired depth easily. In bearing piles when the pile refuses to be driven, it is discontinued.
- ✓ Piers are preferable when the structure is to be laid on decomposed rock overlying a stratum of sound rock as it becomes difficult to drive bearing piles through decomposed rock due to some rock fragments coming under the foot of the pile which prevent it from sinking further.

- ✓ Similarly whenever the top clayey layers offer larger resistance to the driving of a bearing pile, it is desirable to use piers. Piers can also be driven conveniently under water.
- ✓ Piers may be hollow or solid in section. They can be made of bricks, concrete, reinforced concrete, steel, cast iron, etc. The hollow space is plugged with concrete so as to form a solid section.

There are various methods of driving the piers:

- ✓ Open Caisson Method
- ✓ Compressed Air (Caisson Method): This type is used commonly when the soil is exceedingly soft and cave in as it is excavated, there by preventing proper working within the well. The well is reached at the top with the aid of special air-locks and compressed air pushed into the chamber. This prevents the inflow of soft soil. Men work within this chamber and excavated the soil as described above.
- ✓ Ordinary Excavation Method: For stiffer soils a sort of well is excavated and the pier is built within this well. This method is used only for smaller depths.
- ✓ Use of sheeting and Sheet Piles: Whenever the sides of the excavated pit are liable to fall vertical or horizontal wooden planks or suitably braced steel sheets are necessary. For still softer soils, thin piles know as sheet piles are driven adjacent to each other to form an enclosure. The soil is excavated within this area and the pier built as usual.

4.5 Excavation of Foundations

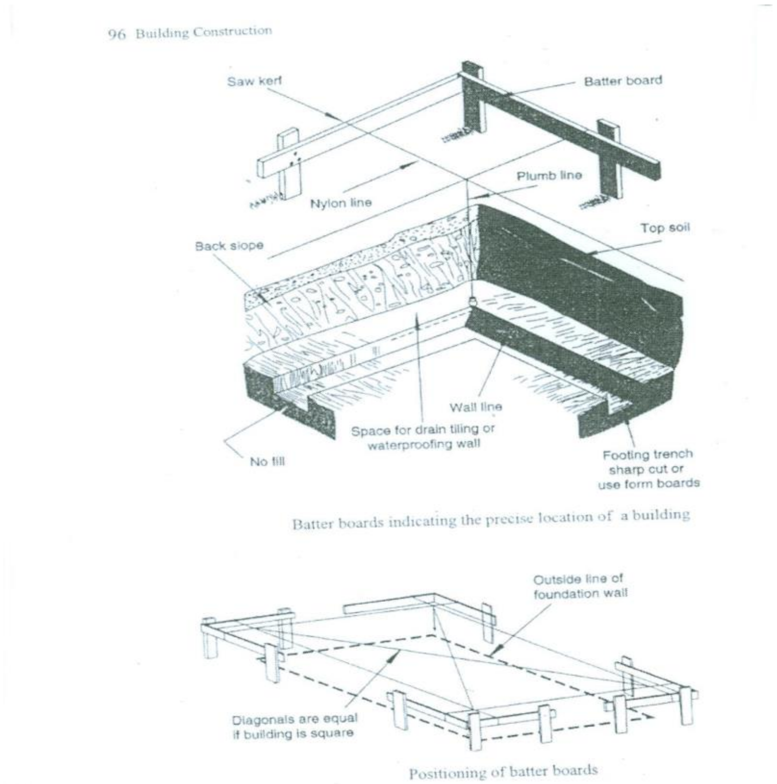
The first step in excavating the necessary volume of soil to be replaced by a suitable type of footing is to clear the site of all plants, debris etc. The site is then made somewhat level so as to remove large inequalities. Before commencement of the excavation of trenches for foundation, a setting out plan is prepared on paper. The setting out plan is a dimensioned ground floor plan, usually drawn to scale of 1:50. The steps in marking points of excavation can be summarized as follows:

- ✓ Establish reference points,
- ✓ Fix wooden pegs and batter-boards (poling boards) around the site to be excavate. Usually these boards shall not be closer than 2m from the excavation,
- ✓ Mark the center line of the walls,
- ✓ Mark the plinth lines: these are lines making the inside and the outside of walls.
- ✓ Mark the inside and outside line of excavation,
- ✓ By stretching strings, check right angles by forming triangles with sides 3,4 and 5 units long or by measuring the diagonals,
- ✓ If all dimensions are correct and all corners are right angle, the cutting lines are marked on the ground using lime powder.

It is essential to have permanent reference marks, which should not get disturbed as the excavation proceeds. These reference marks are useful until the sub-structure mark is completed. In larger buildings help of surveying equipment, such as theodolite, is required to mark the center line of the walls and to check the corner angles. Typical setting out plan is shown in the following Figure 21.

4.5.1 Excavation with the aid of timbering

Hard soils and small depth of excavation can be carried out without the aid of light support. The supports are spaced about 2m c/c and are fitted with the help of struts against each other For stiff soils and somewhat deeper excavation, medium supports in the form of wooden boards about 4cm thick and extending to the depth of excavation are usually used. The supports are spaced about 1m c/c and are fitted with the help of struts against each other. One strut in the middle of the board or one at top and one at bottom may be used. For soft soils the wall sheeting are placed close to each other to prevent the flow of soil in to the excavation. See Figures 22, 23, and 24.



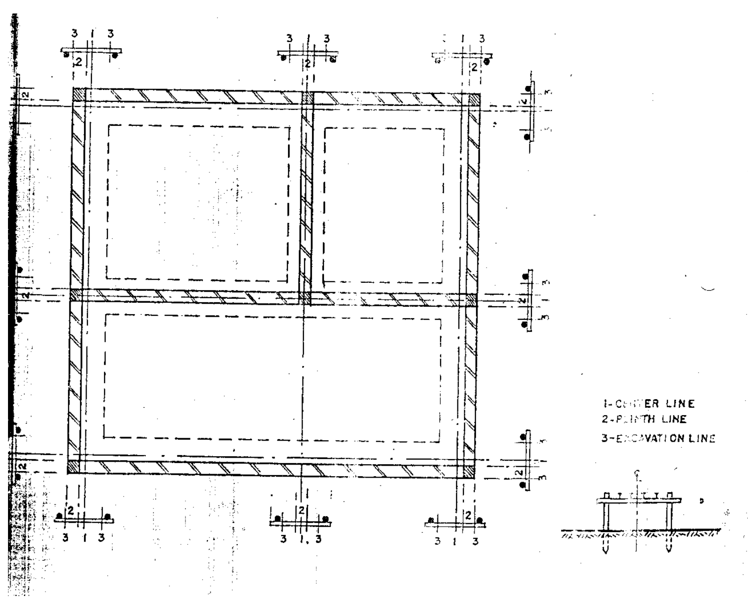


Figure 21: Typical setting out plan is shown in the following

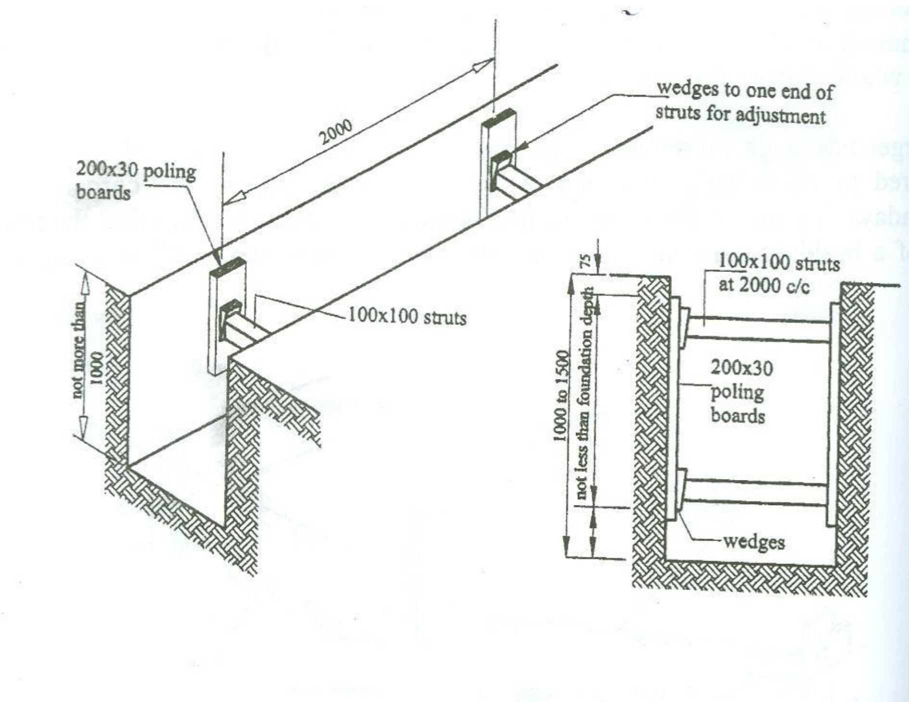


Fig.22: Typical timbering in hard soil

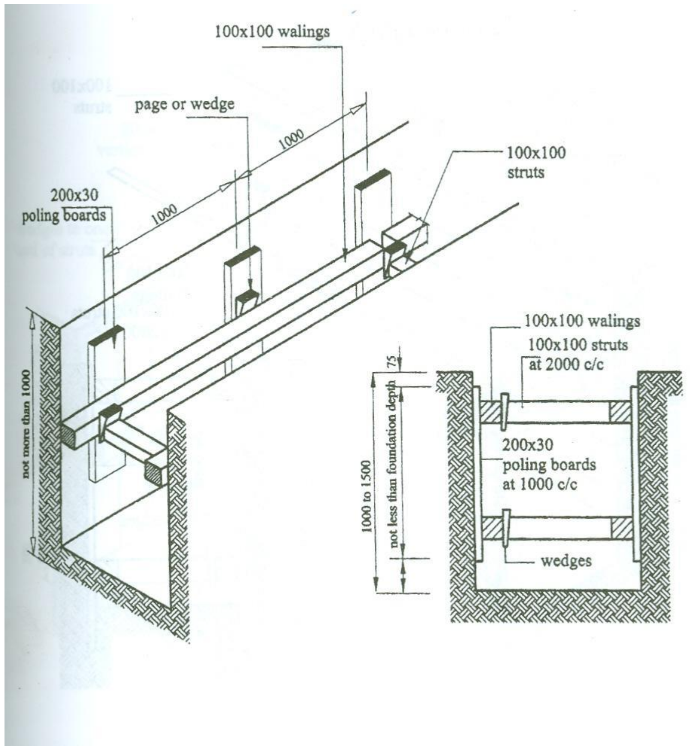


Fig. 23: Typical timbering for firm soil

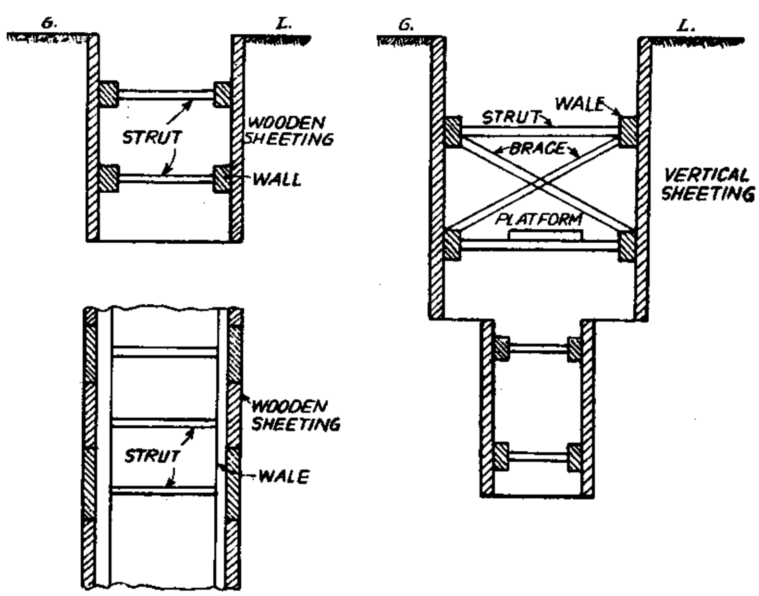


Fig. 24: Typical timbering for soft soil

Assignment 4

Describe different types of foundation with their character.