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Program : **B.Tech**

Subject Name: **Construction Technology**

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Semester: **4th**

Unit: -1

Design features and construction of Foundations : - Introduction and essential requirements of foundations, footing types and depth of footings, contact pressure below footings such as strip footings, isolated footings, eccentrically loaded footings, Grillage foundations, , design features and construction detail of combined footing, strap footing, problem of frost heave, its causes and prevention, effect of ground water on footings. Purpose of pile foundation, classification based on different criterion and types, advantages and disadvantages, selection of pile type, pile action, behavior of pile and pile group under load, definition of load failure.

Foundation:-

Foundation is a structural part of a building on which a building stands. Foundation transmits and distributes its own load and imposed loads to the soil in such a way that the load bearing capacity of the "foundation bed" is not exceeded. The solid ground at which the foundation is rest called foundation bed. We use various types of footing as a foundation.

Foundations are mainly two categories.
1. Shallow foundation, and
2. Deep foundation.

Shallow Foundation

Shallow foundation is a type of foundation that transfers load to the very near the surface. Shallow foundations typically have a depth to width ratio of less than 1.

Following are the type's shallow foundations –

1. Pad footing or column footing
2. Cantilever or strap footings
3. Mat/Raft footings
4. Wall Footings

Pad footing or column footing

This type of footing can be two types - Isolated and Combined.

- Isolated footing

These are most economical. They are usually in square or rectangle size with the column sitting in the middle of the square. It's a kind of pad footing.

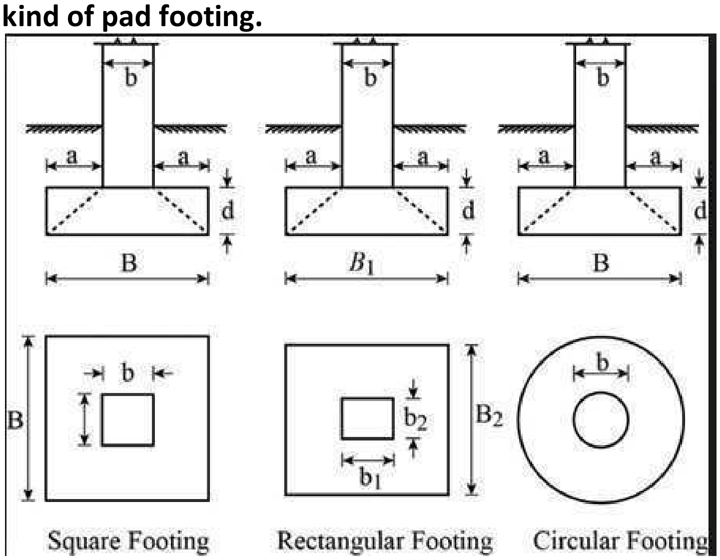

Fig 1 Isolated Footing

- **Combined footing**

A footing, either rectangular or trapezoidal, that supports two columns. It's also a pad footing.

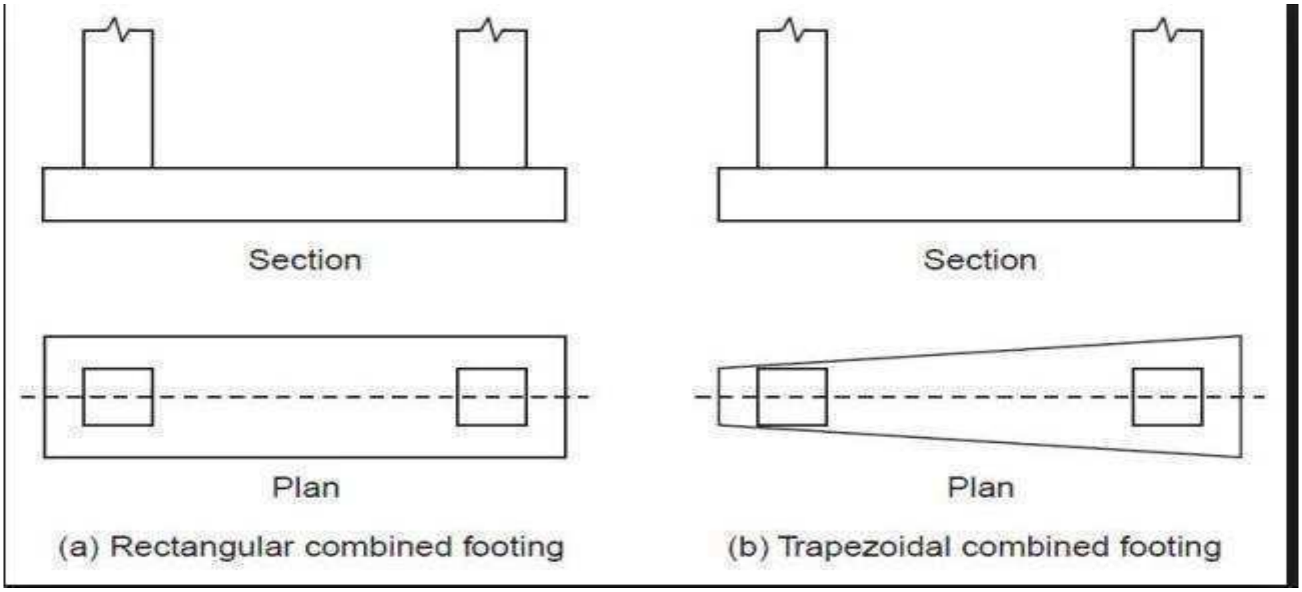

Fig 2 Combined Footing

- **Cantilever or strap footings**

Consist of two single footings connected with a beam or a strap and support two single columns.

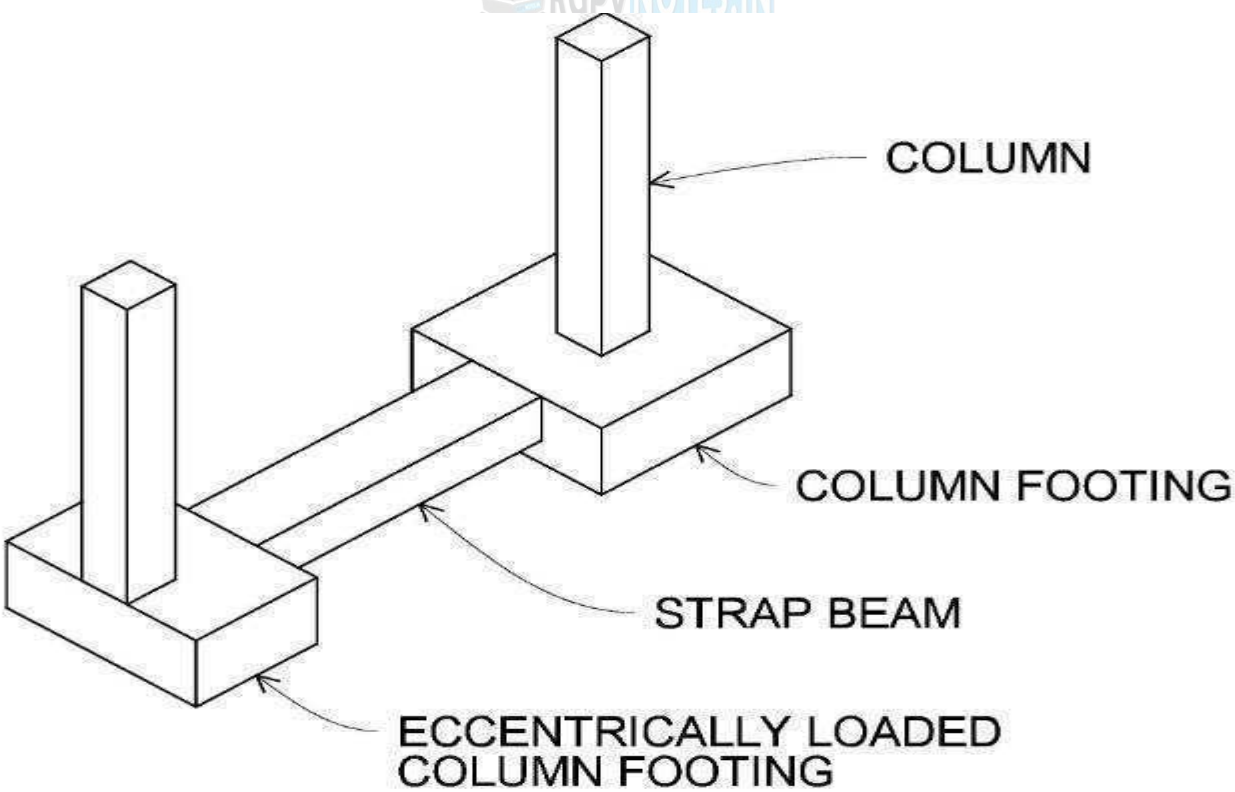

Fig 3 Cantilever or strap footings

- **Mat/Raft footings**

Consist of one footing usually placed under the entire building area. They are used when soil bearing capacity is low, column loads are heavy, single footing can't be used, piles are not used and differential settlement must be reduced.

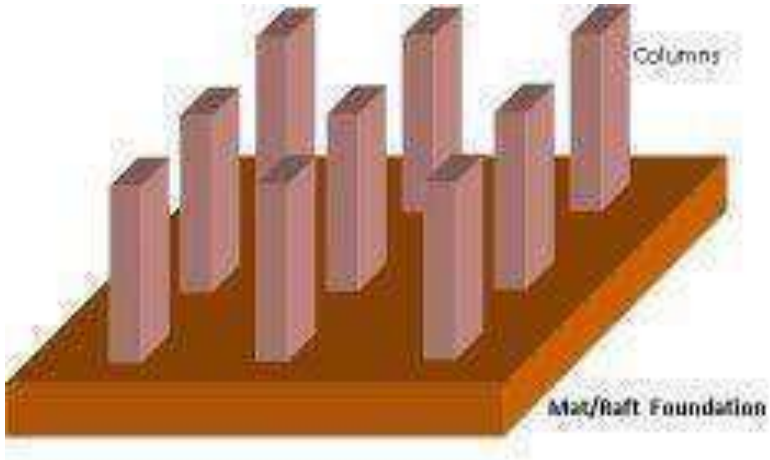

Fig 4 Mat/Raft footings

- **Wall Footings**

Wall footings are used to distribute the loads of structural load-bearing walls to the soil.

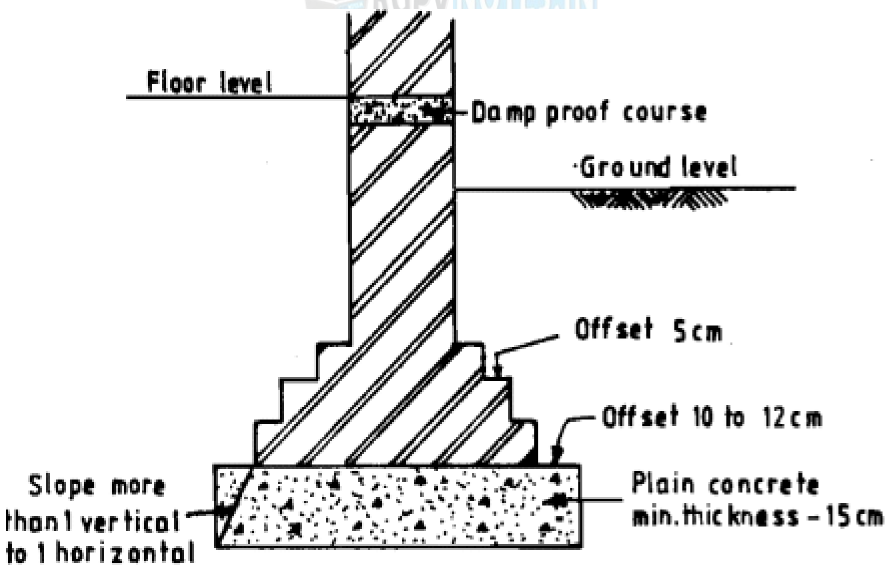

Fig 5 Wall Footings

2. Deep Foundations

Deep foundations are those founding too deeply below the finished ground surface for their base bearing capacity to be affected by surface conditions, this is usually at depths of 3 meter below finished ground level. Deep foundations can be used to transfer the load to deeper, more competent strata at depth if unsuitable soils are present near the surface.

Common Type of Deep Foundation:

Pile foundations are common type of deep foundation. These are relatively long, slender members that transmit foundation loads through soil strata of low bearing capacity to deeper soil or rock strata having a high bearing capacity. They are used when for economic, constructional or soil condition considerations it is desirable to transmit loads to strata beyond the practical reach of shallow foundations. In addition to supporting structures, piles are also used to anchor structures against uplift forces and to assist structures in resisting lateral and overturning forces. Thick slabs are used to tie a group of piles together to support and transmit column loads to the piles.

- **Pile foundations**
- **Caissons**
- **Cylinders**
- **Basements**
- **Hollow Box Foundations (Buoyancy Rafts)**
- **Shaft Foundations**

- **Pile foundations**

Pile foundations are constructed through driving preformed units into the required founding level or by drilling in, driving tubes filled with concrete to the desired depth. The tubes can be filled with concrete in different ways – they can be filled during or before withdrawal, or through drilling unlined, partly lined, or wholly lined boreholes before being filled with concrete.

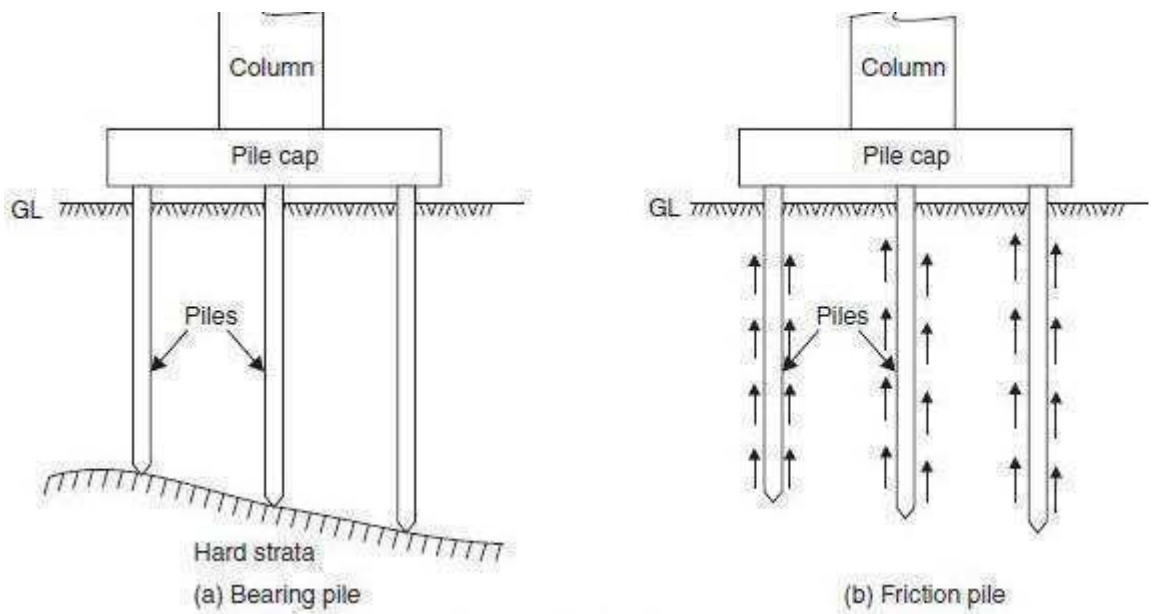

Fig 6 Pile foundation

- **Caissons**

These are hollow substructures that can be constructed near or on the ground surface and are sunk to the desired level as a single unit. They have an enormous load-carrying capacity and are commonly used for bridges.

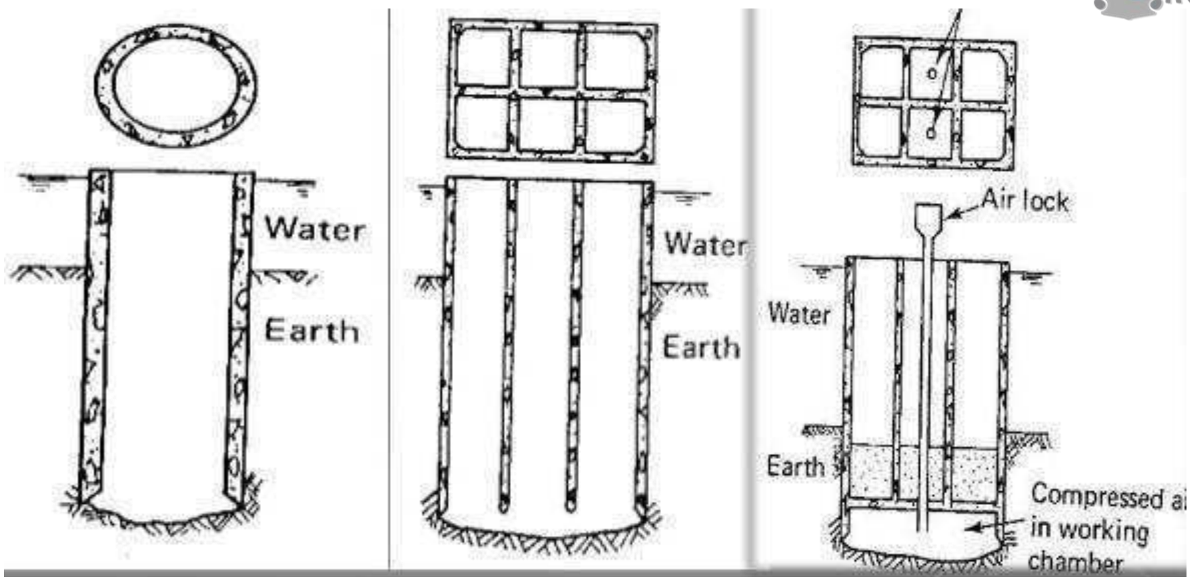

Fig 7 Caissons Foundation

- **Shaft Foundations**

These foundations are constructed by drilling a cylindrical hole within a deep excavation and subsequently placing concrete or another prefabricated load-bearing unit in it. Their length and size can be easily tailored. Drilled shafts can be constructed near existing structures and under low overhead conditions, making them suitable for use in numerous seismic retrofit projects. It may, however, be difficult to install them under certain conditions such as soils with boulders, soft soil, loose sand, and sand under water.

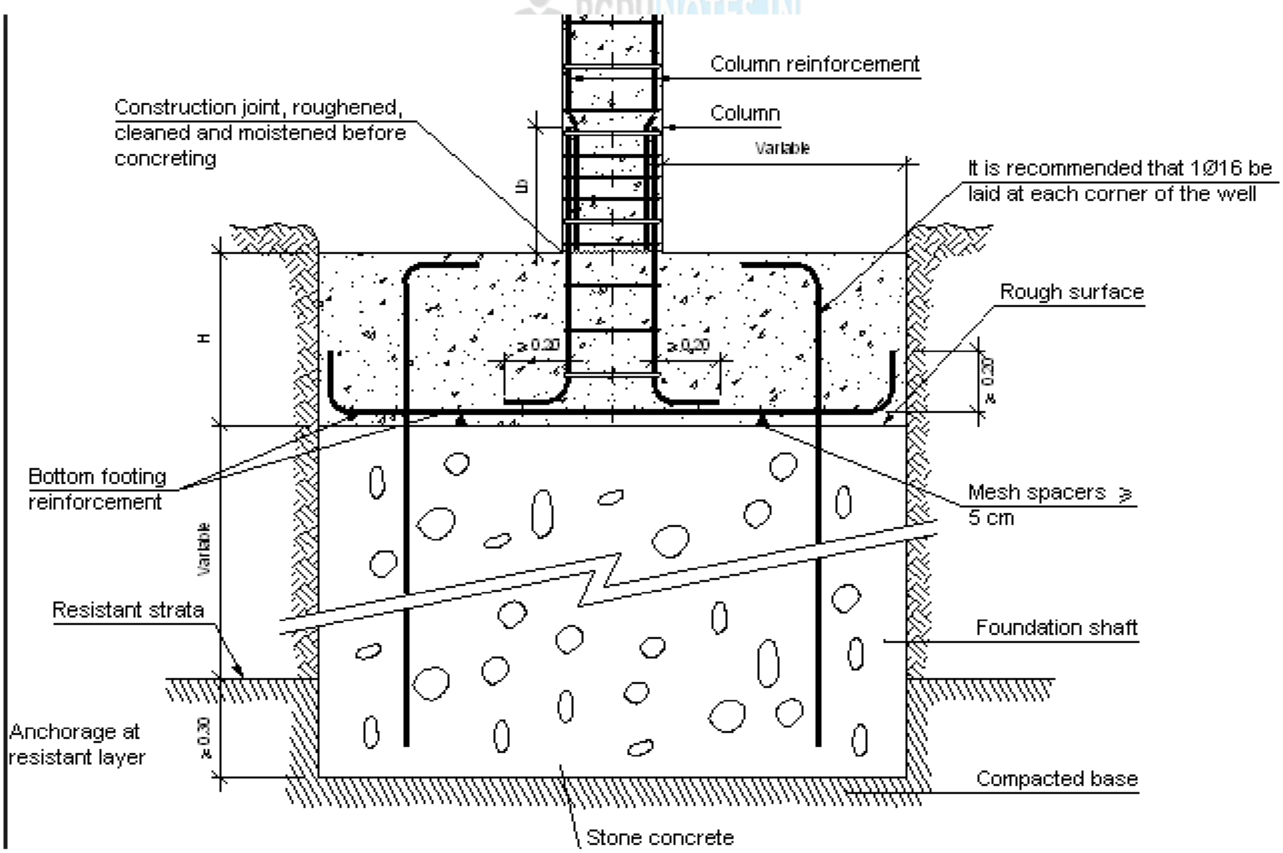

Fig 7 Shaft Foundation

Bearing capacity

In geotechnical engineering, bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil.

Ultimate bearing capacity is the theoretical maximum pressure which can be supported without failure; allowable bearing capacity is the ultimate bearing capacity divided by a factor of safety.

TECHNIQUES USED FOR IMPROVING BEARING CAPACITY OF SOIL

The following techniques can be used for improving bearing capacity of soil as per the site condition.

1. Increasing depth of foundation
2. Draining the soil
3. Compacting the soil
4. Confining the soil
5. Replacing the poor soil
6. Using grouting material
7. Stabilizing the soil with chemicals
8. How to improve bearing capacity of soil

1. INCREASING DEPTH OF FOUNDATION

At deeper depths, the over burden pressure on soil is higher; hence the soil is more compacted at deeper depth. As a result it shows higher bearing capacity. This is applicable only for cohesion less soils such as sandy and gravelly soils. This method of improving bearing capacity of soil is not applicable if the subsoil material grows wetter as depth increase. This method has a limited use because with increase in depth, the weight and cost of foundation also increases.

2. DRAINING THE SOIL

With increase in percentage of water content in soil, the bearing capacity decreases. In case of sandy soil, the bearing capacity may reduce as much as 50% due to presence of water content. Cohesion less soils (i.e. sandy & gravelly soils) can be drained by laying the porous pipes to a gentle slope, over a bed of sand and filling the trenches above the pipes with loose boulders. These trenches subsequently should lead to the nearest well or any water body.

3. COMPACTING THE SOIL

If we compact soil using appropriate method, then there will be increase in its density and shear strength. As a result the bearing capacity of soil also increases. There are many methods of compacting soils on site. Few of them are mentioned below.
By spreading broken stones, gravel or sand and thereafter ramming well in the bed of trenches, using an appropriate roller as per the soil type to move at a specified speed.

4. CONFINING THE SOIL

In this method, the soils are enclosed with the help of sheet piles. This confined soil is further compacted to get more strength. This method is applicable for shallow foundations.

5. REPLACING THE POOR SOIL

In this method the poor soil is first removed and then the gap is filled up by superior material such as sand, stone, gravel or any other hard material. In order to do this, first excavate a foundation trench of about 1.5 m deep, and then fill the hard material is stages of 30 cm. Then compact the hard material at every stage. This method is useful for foundations in black cotton soils.

6. USING GROUTING MATERIAL

This method is applicable for soils where there is presence of pores, fissures or cracks etc. underneath the foundation. In this method, poor soil bearing strata is hardened by injecting the cement grout under pressure, because it scales off any cracks or pores or fissures etc. For proper distribution of the cement grout, the ground is bored and perforated pipes are introduced to force the grout.

7. STABILIZING THE SOIL WITH CHEMICALS

This method of improving bearing capacity of soil is costly and applied in exceptional cases. In this method, chemical solutions, like silicates of soda and calcium chloride is injected with pressure into the soil. These chemical along with the soil particles form a gel like structure and develop a compact mass. This is called chemical stabilization of soil and used to give additional strength to soft soils at deeper depths.

Soil stabilization

The prime objective of soil stabilization is to improve the California Bearing Ratio of in-situ soils by 4 to 6 times. The other prime objective of soil stabilization is to improve on-site materials to create a solid and strong sub-base and base courses. In certain regions of the world, typically developing countries and now more frequently in developed countries, soil stabilization is being used to construct the entire road.

In the past, soil stabilization was done by utilizing the binding properties of clay soils, cement-based products such as soil cement, and/or utilizing the "rammed earth" technique (compaction) and lime.

Some of the renewable technologies are: enzymes, surfactants, biopolymers, and synthetic polymers, co-polymer based products, cross-linking styrene acrylic polymers, tree resins, ionic stabilizers, fiber reinforcement, calcium chloride, calcite, sodium chloride, magnesium chloride and more. Some of these new stabilizing techniques create hydrophobic surfaces and mass that prevent road failure from water penetration or heavy frosts by inhibiting the ingress of water into the treated layer.

However, recent technology has increased the number of traditional additives used for soil stabilization purposes. Such non-traditional stabilizers include: Polymer based products (e.g. cross-linking water-based styrene acrylic polymers that significantly improves the load-bearing capacity and tensile strength of treated soils), Copolymer Based Products, fiber reinforcement, calcium chloride, and Sodium Chloride.

Grillage Foundation

A type of foundation often used at the base of a column. It consists of one, two or more tiers of steel beams superimposed on a layer of concrete, adjacent tiers being placed at right angles to each other, while all tiers are encased in concrete. Grillage foundation is the most economical foundation in case of transferring heavy loads from columns to soil of low bearing capacity.

Definition

Grillage foundations consist of a number of layers of beams usually laid at right angles to each other and used to disperse heavy point loads from the superstructure to an acceptable ground bearing pressure.

The grillage beam can be in any material, the most usual being either steel, precast concrete or timber. In some permanent situations, however, where unusual circumstances exist, such as an abundance of durable timber or the possible re-use of existing rolled steel sections, the grillage can prove both successful and economic. In permanent conditions durability becomes an important design factor and protection and/or the selection of suitable materials is a major part of the design.

The design of the grillage is carried out by calculating the loads and moments applied from the superstructure and determining the required base area using a suitable allowable ground bearing pressure for the condition involved.

From this area, the number and size of each grillage layer can be decided. The layers are then designed to cantilever from the edge of the layer above, which determines the beam sizes required to resist the applied bending moments and shear forces.

If the grillage is encased in concrete and the sequence and method of construction and loading is compatible with the design requirements, the composite action of the beam and concrete can be exploited.

Types of Grillage Foundation
Mostly there are two types of grillage foundation based on type of material used;
a) Steel grillage foundation
b) Timber grillage foundation
Mostly out of these two types the decision is made on the basis of availability of material and overall cost is the deciding factor

Under Reamed Pile
Under reamed piles are bored cast-in-situ concrete piles having one or more number of bulbs formed by enlarging the pile stem. These piles are best suited in soils where considerable ground movements occur due to seasonal variations, filled up grounds or in soft soil strata. Provision of under reamed bulbs has the advantage of increasing the bearing and uplift capacities. It also provides better anchorage at greater depths. These piles are efficiently used in machine foundations, over bridges, electrical transmission tower foundation sand water tanks. Indian Standard IS 2911 (Part III) - 1980 covers the design and construction of under reamed piles having one or more bulbs. According to the code the diameter of under reamed bulbs may vary from 2 to 3 times the stem diameter depending upon the feasibility of construction and design requirements. The code suggests a spacing of 1.25 to 1.5 times the bulb diameter for the bulbs. An angle of 45 0 with horizontal is recommended for all under reamed bulbs. This code also gives Mathematical expressions for calculating the bearing and uplift capacities.

Foundation on Black Cotton Soil

Black cotton soils and other expansive soils have typical characteristics of shrinkage and swelling due to moisture movement through them. During rainy season, moisture penetrates into these soils, due to which they swell. Most of the fine grained clays, including black cotton soils have their grains which are more or less in the form of platelets or sheets (just like leafs of a book), and their grains are not round. When moisture enters between the platelets under some hydrostatic pressure, the particles separate out, resulting in increase in the volume. This increase in volume is commonly known as swelling. If this swelling is checked or restricted (due to the construction of footings over it), high swelling pressure, acting in the upward direction, will be induced. This would result in severe cracks in the walls etc. and may sometimes damage the structural units, such as lintels, beams slabs etc. During summer season, moisture moves out of the soil and consequently, the soil shrinks. Shrinkage cracks are formed on the ground surface. These

shrinkage cracks sometimes also known as tension cracks, may be 10 to 15 cm wide on the ground surface and may be ½ to 2 m deep

In fat clays, having angle of internal friction Ø = 0, the depth z of tension cracks is found to be equal 2c/y, where c is the unit cohesion an y is the unit weight of the soil. These cracks result in loss of support beneath the footings, resulting in high settlements. Some expansive and shrinkable soils stick to the footing base and

Pull the footing down when they shrink. This results in horizontal cracks in the walls and other flexible units of the structure.

Black cotton soils and other expansive soils are dangerous due to their shrinkage and swelling characteristics. In addition to this, these soils have very poor bearing capacity, ranging from 5 t/m2 to 10 t/m2. In designing footings on these soils, the following points should be kept in mind:

1. The safe bearing capacity should be properly determined, taking into account the effect of sustained loading. In absence of tests, the bearing capacity of these soils may be limited to 5 to 10 t/m2.

2. The foundation should be taken at Least 50 cm lower than the depth of moisture movement. This depth should also be much more than depth of tension cracks.

3. Where this soil occurs only in top layer, and where the thickness of this layer does fol exceed 1 to 1.5 m, the entire layer of black cotton soil (or other expansive soil) should be removed, and the foundation should be laid on non-shrinkable non- expansive soil.

4. Where the depth of clay layer is large, the foundation or footing should be prevented from coming in contact with the soil. This can be done by excavating wider and deeper foundation trench and interposing layer of sand around and beneath the footing.

5. Where the soil is highly expansive, it is very essential to have minimum contact between the soil and the footing. This can be best achieved by transmitting the loads through deep piles or piers and by supporting wall loads on capping beams which are kept some distance (5 to 15 cm) above the ground surface, to permit free expansion of the soil.

6. Where the bearing capacity of soil is poor, or soil is very soft, the bed of the foundation trench should be made firm or hard by ramming sand and ballast.

7. The foundations should be constructed during dry season. Also suitable plinth protection around the external wall should be made on the ground surface, with its slope away from the wall, so that moisture does not penetrate the foundation during rainy season.

Types of foundation in black cotton soils

Foundation in black cotton soils may be of the following types:

1. Strip or pad foundation. For medium loads, strip foundation (for walls) and pad foundation (for columns) may be provided, along with special design features discussed above. Fig. 3.31 shows some typical section of shallow footings suitable for black cotton and other expansive soils....

2. Pier foundation shows a typical pier foundation for a wall carrying heavy loads. Piers are dug at regular interval and filled with cement concrete. The piers may rest on good bearing strata. These piers are be connected by....

3. Under-reamed pile foundation. An under-reamed pile is a pile of shallow depth (1 to 6 m) having one bulb its lower end. If this bulb is taken or provided at a level lower than the critical depth of moisture movement in expansive soils.

Dewatering

Dewatering is the removal of water from solid material or soil by wet classification, centrifugation, filtration, or similar solid-liquid separation processes, such as removal of residual liquid from a filter cake by a filter press as part of various industrial processes.

Deep wells

A deep well typically consists of a boreholes fitted with a slotted liner and an electric submersible pump. As water is pumped from a deep well, a hydraulic gradient is formed and water flows into the well forming a cone of depression around the well in which there is little or no water remaining in the pore spaces of the surrounding soil. Deep wells work best in soils with a permeability of k = 10−3 m/s to 10−5 m/s; the amount of drawdown that a well can achieve is limited only by the size of the fish pump.

Deep wells can be installed in a ring around an excavation to lower the water level and maintain a safe, dry site. Several equations can be used to design deep well dewatering systems, however many of these are based on empirical data and occasionally fail. Practice and experience, along with a firm understanding of the underlying principles of dewatering, are the best tools for designing a successful system. Some dewatering situations "are so common that they can be designed almost by rule of thumb".

Deep wells are also used for aquifer testing and for groundwater drainage by wells.

Well points

Well points are small-diameter (about 50 mm) tubes with slots near the bottom that are inserted into the ground from which water is drawn by a vacuum generated by a dewatering pump. Well points are typically installed at close centers in a line along or around the edge of an excavation. As a vacuum is limited to 0 bar, the height to which water can be drawn is limited to about 6 meters (in practice). Well points can be installed in stages, with the first reducing the water level by up to five meters, and a second stage, installed at a lower level, lowering it further. The water trickling between the deep wells may be collected by a single row of well point at the toe. This method ensures a much thicker width free from seepage forces.

Well point spears are generally used to draw out groundwater in sandy soil conditions and are not as effective in clay or rock conditions. Open pumps are sometimes employed instead of spears if the ground conditions contain significant clay or rock content.

Horizontal drainage

The installation of horizontal dewatering systems is relatively easy. A trencher installs an un perforated pipe followed by a synthetic or organic wrapped perforated pipe. The drain length is determined by the drain diameter, soil conditions and the water table. In general drain lengths of 50 meters is common. After installation of the drainpipe a pump is connected to the drain. After the water table has been lowered, the intended construction can start. After the construction is finished the pumps are stopped, and the water table will rise again. Installation depths up to 6 meters are common.

Removal of water

Removal of surface and/or groundwater may be necessary for the performance of the specified work, especially where the construction is near or in a lake, stream, or area subjected to frequent or periodic inundation or flow of surface water. If removal of water is needed, it is generally required prior to any significant excavation and backfill operations and will likely be required when preparing the foundation. Removal of water includes impoundment or diversion of surface runoff, exclusion of groundwater or impounded.

Removal of water involves furnishing and installing temporary works, such as water containment facilities, channels, diversions, wells or well points, pumps, Piping, pollution control measures, and other facilities and equipment, that must be monitored and maintained until no longer required.

Methods for controlling water will vary with site condition and location. Unless otherwise specified, the contractor is responsible for designing and constructing the works needed for the removal of water. The contractor must provide and operate all equipment needed to keep foundations, structures, and borrow areas free of excess water. When required, the contractor must furnish, in writing, a plan for removal of water before beginning any construction activities. The plan should include an explanation of all permits required to be obtained by the contractor to conduct work in a stream or near a wetland, including permits to divert water as applicable. This plan is usually reviewed and approved by the responsible engineer who provides a copy and any approval documents to the inspector. The inspector must verify that the plan for removal of water is fully implemented, including the acquisition of permits prior to beginning work. Plan performance should be documented in the diary throughout the construction period. The inspector should discuss with the contractor any concerns of inadequate removal of water efforts. The responsible engineer should be consulted when contractor's efforts fail to adequately remove the water so that the work may be performed as specified or when the quality of work is jeopardized due to wet conditions at the site. The methods and equipment used to divert stream flow or to dewater the site can affect the stability of the foundation and excavated slopes. These methods can also result in surface erosion, which can lead to further instability of slopes or pollution of surface water or groundwater. The inspector should monitor the foundation and excavated slopes for signs of instability and monitor diversions and dewatering operations for signs of pollution of surface water and groundwater. Make the contractor aware of related concerns, and document these concerns and any conversations with the contractor concerning removal of water.

Allowable Settlement for different structures:

The allowable settlement is defined as the acceptable amount of settlement of the structure and it usually includes a factor of safety. The allowable settlement depends on many factors, including the following:

The Type of Construction – For example, wood-frame buildings with wood siding would be much more tolerant than unreinforced brick buildings.

The Use of the Structure – Even small cracks in a house might be considered unacceptable, whereas much larger cracks in an industrial building might not even be noticed.

The Presence of Sensitive Finishes – Tile or other sensitive finishes are much less tolerant of movements.

The Rigidity of the Structure – If a footing beneath part of a very rigid structure settles more than the others, the structure will transfer some of the load away from the footing. However, footings beneath flexible structures must settle much more before any significant load transfer occurs. Therefore, a rigid structure will have less differential settlement than a flexible one.

Aesthetic and Serviceability Requirements – The allowable settlement for most structures, especially buildings, will be governed by aesthetic and serviceability requirements, not structural requirements. Unsightly cracks, jamming doors and windows, and other similar problems will develop long before the integrity of the structure is in danger.

Table below shows the allowable foundation displacement into three categories: total settlement, tilting, and differential settlement. It indicates that those structures that are more flexible (such as simple steel frame buildings) or have more rigid foundations (such as mat foundations) can sustain larger values of total settlement and differential movement.

Type of Settlement	Limiting factor	Maximum Settlement
Total settlement	Drainage	15 – 30 cm
	Access	30 – 60 cm
	Probability of non-uniform settlement:	
	1. Masonry walled structures	2.5 – 5 cm
	2. Framed structures	5 – 10 cm
	3. Chimneys, silos, mats	8 – 30 cm
Tilting	Stability against overturning	Depends on H and L
	Tilting of chimneys, towers	0.004L
	Rolling of trucks etc.	0.01L
	Stacking of goods	0.01L
	Crane rails	0.003L
	Drainage of floors	0.01 – 0.02 L
Differential settlement	High continuous brick walls	0.0005 – 0.001 L
	One-storey brick mill building, wall cracking	0.001 – 0.002 L
	Plaster cracking	0.001 L
	Reinforced concrete building frame	0.0025 – 0.004 L
	Reinforced concrete building curtain walls	0.003 L
	Steel frame, continuous	0.002 L
	Simple steel frame	0.005 L

Where, L = distance between adjacent columns that settle to different amounts, or between two points that settle differently. Higher values are for regular settlements and more tolerant structures. Lower values are for irregular settlement and critical structures. H = Height and W = width of structure.

Well Foundation: Meaning, Shapes, Forces and Description

Well foundation is a type of deep foundation which is generally provided below the water level for bridges. Cassions or well has been in use for foundations of bridges and other structures since Roman and Mughal periods.
The term 'Cassions' is derives from the French word Caisse which means box or chest. Hence Cassion means a box like structure, round or rectangular, which is sunk from the surface of either land or water to some desired depth.

The Cassions are of three types:
(i) Box Cassion: It is open at the top and closed at the bottom and is made of timber, reinforced concrete or steel. This type of Cassion is used where bearing stratum is available at shallow depth.

(ii) Open Cassion (wells): Open Cassion is a box opened both at top and bottom. It is made up to either timber, concrete or steel. The open Cassion is called well. Well foundation is the most common type of deep foundation used for bridges in India.

(iii) Pneumatic Cassions has its lower end designed as a working chamber in which compressed air is forced to prevent the entry of water and thus excavation can be done in dry conditions.
Shapes of Wells:

The common types of well shapes are:

- **Single circular**
- **Twin circular**
- **Dumb well**
- **Double-D**
- **Twin hexagonal**
- **Twin octagonal**
- **Rectangular.**

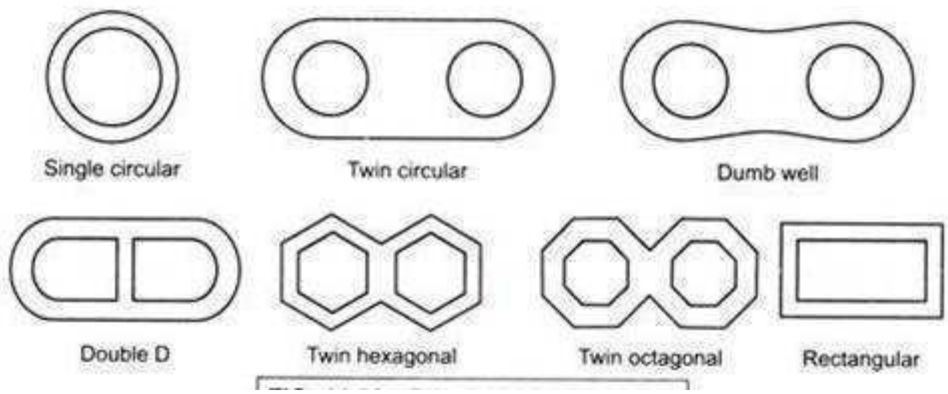

Fig 8 Different shapes of well

The choice of a particular shape of well depends upon the size of the pier, the care and cost of sinking, the considerations of tilt and shift during sinking and the vertical and horizontal forces to which well is subjected.

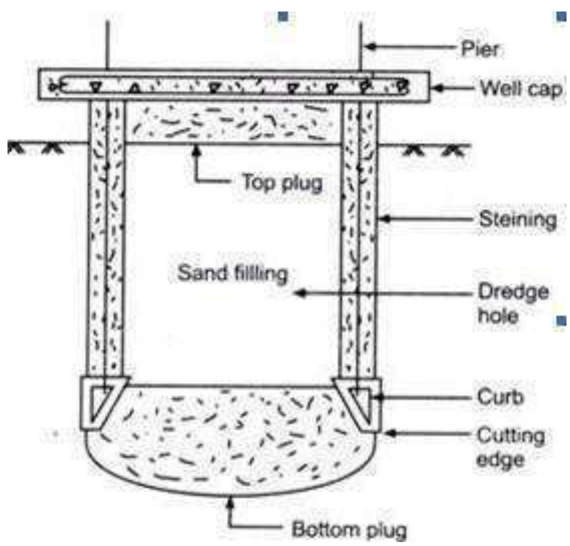

Fig 9 Sinking well foundation

A circular well has the minimum perimeter of a given dredge area. Since the perimeter is equidistant at the points from the centre of dredge hole, the sinking is more uniform than the other shapes. However, the circular well is that in the direction parallel to the span of bridge, the diameter of the well is much more than required to accommodate minimum size of pier and hence circular well obstruct water way much in comparison to other shapes.

Forces Acting On a Well Foundation:

In addition to the self weight and buoyancy, it carries the dead load of superstructure, bearing and piers and subjected to the following horizontal forces:

- **Braking effort of the moving vehicle.**
- **Force due to the resistance of bearings against movement due to temperature variations.**
- **Force of water current**
- **Seismic forces**
- **Wind force**
- **Earth pressure**

Description of Parts (Elements) of Well:

1. Staining: It is the wall or shall of the well, made of R.C.C. and which transfer the load to the curb. It acts as a enclosure for excavating the soil for the penetration of well.

2. Curb: It is a R.C.C. ring beam with steel cutting edge below. The cross- section of the curb is wedge shaped which facilitates the sinking of the well. The curb supports well stoning. The curb is kept slightly projected from the stoning to reduce the skin friction.

3. Cutting edge: It is the lowest part of the well curb which cuts the soil during sinking.

4. Bottom plug: After completion of well sinking the bottom of well is plugged with concrete. The bottom plug which is confined by the well curb acts as a raft against soil pressure from below.

5. Back fill: The well is dewatered after setting of the bottom plug and it is backfilled by sand or excavated material.

6. Top plug: It is a concrete plug provided over the filling inside the well.

7. Well cap: It is a R.C.C. slab provided at the top of stoniness to transmit the load of superstructure to the stoning and over which pier is laid. The minimum thickness of the slab is about 750 mm.

Causes of failures of foundations and remedial measures

The foundations may fail due to the following reasons:

1. Unequal settlement of sub-soil. Unequal settlement of the sub-soil may lead to cracks in the structural components and rotation thereof. Unequal settlement of sub-soil may be due to (i) non-uniform nature of sub-soil throughout the foundation, (ii) unequal load distribution of the soil strata, and (iii) eccentric loading. The failures of foundation due to unequal settlement can be checked by : (i)resting the foundation on rigid strata, such as rock or hard moor, (ii) proper design of the base of footing, so that it can resist cracking, (iii) limiting the pressure in the soil, and (iv)avoiding eccentric loading.

2. Unequal settlement of masonry. As stated earlier, foundation includes the portion of the structure which is below ground level. This portion of masonry, situated between the ground level and concrete footing (base) has mortar joints which may either shrink or compress, leading to unequal settlement of masonry. Due to this, the superstructure will also have cracks.

This could be checked by

(i) using mortar of proper strength

(ii) using thin mortar joints

(iii) restricting the height of masonry to 1 m per day if lime mortar is used and 1.5 m per day if cement mortar is used, and

(iv) Properly watering the masonry.

3. Sub-soil moisture movement. This is one of the major causes of failures of footings on cohesive soil, where the sub-soil water level fluctuates. When water table drops down, shrinkage of sub-soil takes place. Due to this, there is lack of sub-soil support to the footings which crack, resulting in the cracks in the building.

During upward movement of moisture, the soil (especially if it is expansive) swells resulting in high swelling pressure. If the foundation and superstructure is unable to resist the swelling pressure, cracks are induced.

4. Lateral pressure on the walls. The walls transmitting the load to the foundation may be subjected to lateral pressure or thrust from a pitched roof or an arch or wind action. Due to this, the foundation will be subjected to a moment (or resultant eccentric load). If the foundation has not been designed for such a situation, it may fail by either overturning or by generation of tensile stresses on one side and high compressive stresses on the other side of the footing.

5. Lateral Movement of sub-soil This is applicable to very soft soil which are liable to move out or squeeze out laterally under vertical loads, specially at locations where the ground is sloping. Such a situation may also arise in granular soils where a big pit is excavated in the near vicinity of the foundation. Due to such movement, excessive settlements take place, or the structure may even collapse. If such a situation exists, sheet piles should be driven to prevent the lateral movement or escape of the soil.

6. Weathering of sub-soil due to trees and shrubs. Sometimes, small trees, shrubs or hedge is grown very near to the wall. The roots of these shrubs absorb moisture from the foundation soil, resulting in reduction of their voids and even weathering. Due to this the ground near the wall depresses down. If the roots penetrate below the level of footing, settlements may increase, resulting in foundation cracks.

7. Atmospheric action. The behavior of foundation may be adversely affected due to atmospheric agents such as sun, wind, and rains. If the depth of foundation is shallow, moisture movements due to rains or drought may cause trouble. If the building lies in a low lying area, foundation may even be scoured. If the water remains stagnant near the foundation, it will remain constantly damp, resulting in the decrease in the strength of footing or foundation wall. Hence it is always recommended to provide suitable plinth protection along the external walls by

(i) Filling back the foundation trenches with good soil and compacting it,

(ii) Providing gentle ground slope away from the wall

(iii) Providing a narrow, sloping strip of impervious material (such as of lime or lean cement concrete) along the exterior walls.

Timbering of trenches - soils

- When the depth of trench is large, or when the sub-soil is loose, the sides of the trench may cave in. The problem can be solved by adopting a suitable method of timbering. Timbering of trenches, sometimes also known as shoring consists of providing timber planks or boards and struts to give temporary support to the sides of the trench. Timbering of deep trenches can be done with the help of the following methods:

  1. Stay bracing.
  2. Box sheeting
  3. Vertical sheeting
  4. Runner system

5. **Sheet piling**

1. Stay bracing. This method is used for supporting the sides or a bench excavated in fairly firm soil, when the depth of excavation does not exceed about 2 meters. The method consists of placing vertical sheets (called sheathing) or polling boards opposite each other against the two walls of the trench and holding them in position by one or two rows of struts. The sheets are placed at an interval of 2 to 4 meters and generally, they extend to the full height of the trench. The polling boards may have width of about 200 mm and thickness of 44 to 50 mm. The struts may have size 1OO x 100 mm for trench up to 2 m width and 200 x 200 mm for trench up to 4 m width.

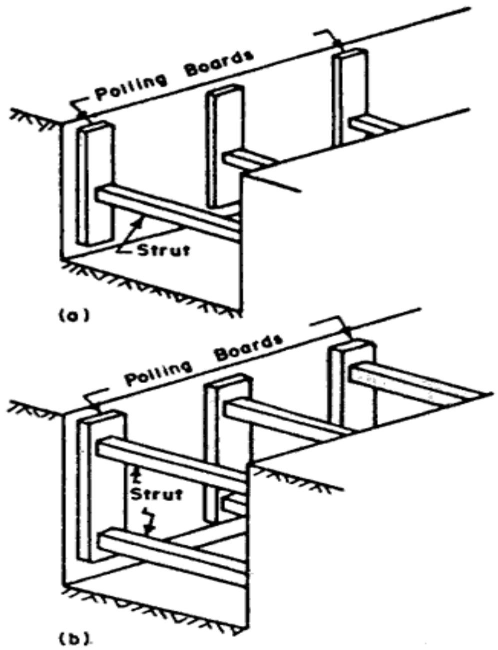

Fig 10 Stay Bracing

2. Box sheeting. This method is adopted in loose soils, when the depth of excavation does not exceed 4 meters. Shows the box like structure, consisting of vertical sheets placed very near to each other (sore times touching each other) and keeping them in position by longitudinal rows (usually two) of Wales. Struts are then provided across the Wales.

Another system of box sheeting is adopted for very loose soils. In this system, the sheeting is provided longitudinally, and they are supported by vertical Wales and horizontal struts [Fig. 2.32 (b)]. If the height is more, braces are also provided along with struts.

3. Vertical sheeting. This system is adopted for deep trenches (up to 10 m depth) in soft ground. The method is similar to the box sheeting [Fig. 2.32 (a)] except that the excavation is carried out in stages and at the end of each stage, an offset is provided, so that the width of the trench goes on decreasing as the depth increases. Each stage is limited to about 3 m in height and the offset may vary from 25 to 50 cm per stage. For each stage, separate vertical sheeting, supported by horizontal wailings and struts are provided.

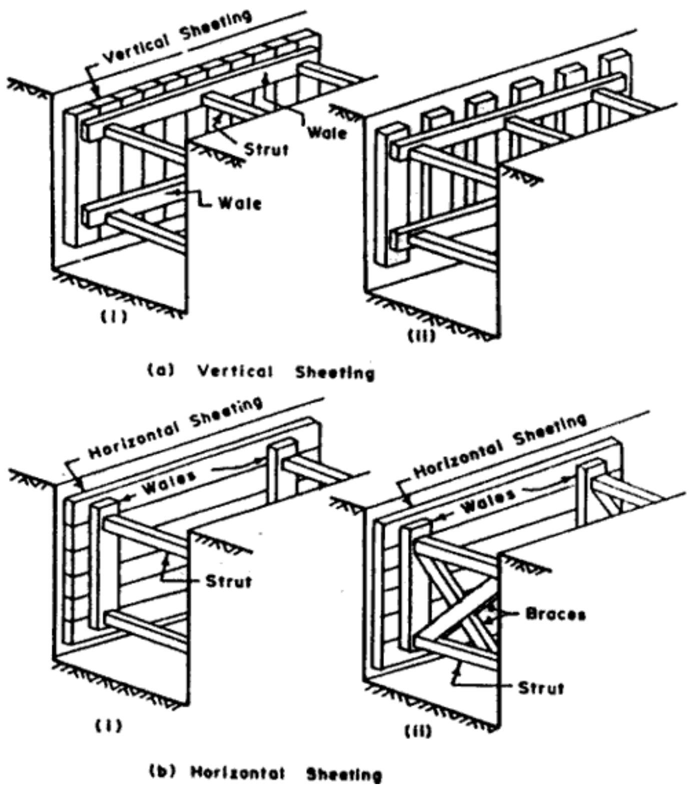

Fig 11 Box Sheeting

4. Runner system. This system is used in extremely loose and soft ground, which needs immediate support as excavation progresses. The system is similar to vertical sheeting of box system, except that in the place of vertical sheeting, runners, made of long thick wooden sheets or planks with iron shoe at the ends, are provided. Wales and struts are provided as usual. These runners are driven about 30 cm in advance of the progress of the work, by hammering

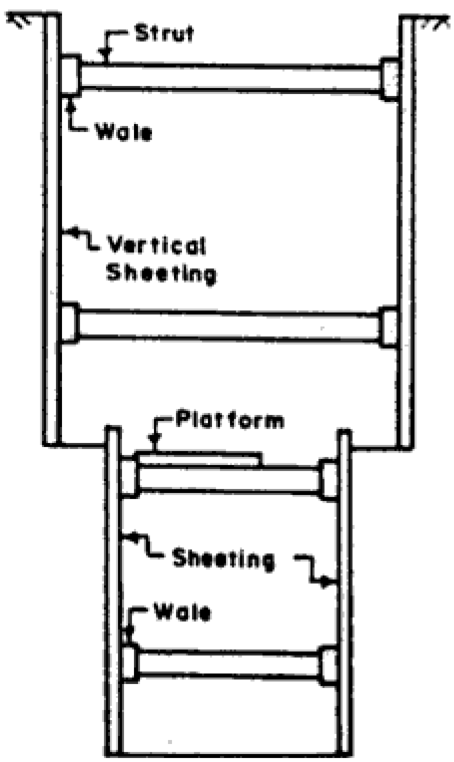

Fig 12.1 Vertical Sheeting

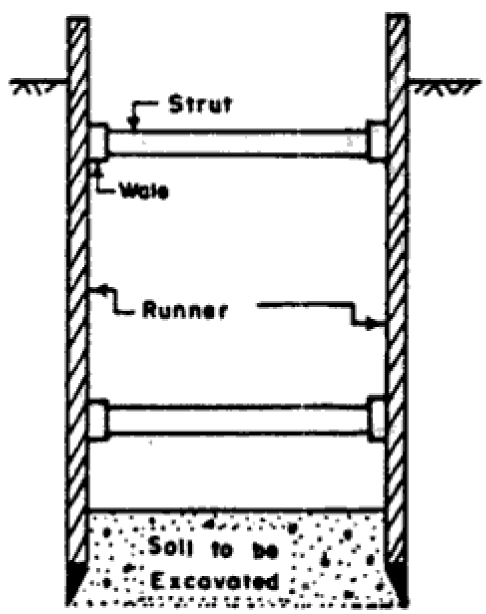

Fig 12.2 Runner System

5. Sheet piling. This method is adopted when

- **(i) Soil to be excavated is soft or loose**
- **(ii) Depth of excavation is large**
- **(iii) Width of trench is also large and**
- **(iv) There is sub-soil water. Sheet piles are designed to resist lateral earth pressure. These are driven in the ground by mechanical means (pile driving equipment). They can be used for excavating to a very large depth.**

Brick foundation and wall problems:

This article explains how to recognize, diagnose, & repair brick foundation & brick wall defects & failures such as cracks, spelling, movement, bulging, leaks, damage due to impact, settlement, frost or water damage, and other problems.

We describe types of brick foundation or wall cracks, crack patterns, differences in the meaning of cracks in different brick wall types (veneer vs. structural or solid brick walls), and where there is brick wall damage, the role of site conditions, building history, and other causes of building movement and damage.

We discuss the following: Examples & list of structural & other failures in brick walls & foundations. Damage caused to brick structures due to thermal expansion of long brick walls lacking expansion joints. Damage to brick veneer walls - cracks, bulges, loose brick. A catalog of types of brick foundation and brick wall damage and defects Types of foundation damage organized by foundation materials. Photographs of brick wall damage patterns and types.

This information helps in recognizing foundation defects and to help the building owner or inspector separate cosmetic or low-risk conditions from those likely to be important and potentially costly to repair.

Guide to Repair Methods for Foundation Cracks

Repair Methods for Foundation Shrinkage Cracks

Before repairing a foundation crack it is important to diagnose the cause of the crack and its effects on the building structure.

The significance of any foundation crack depends on the crack's cause, size, shape, pattern, location, foundation materials, extent of cracking, impact of the crack on the building, and possibly other factors as well. If there is an underlying ongoing problem causing foundation movement or damage, that problem needs to be corrected too.

Cracks in poured concrete walls that are larger than 1/4", cracks which are increasing in size, or cracks which are otherwise indicative of foundation movement should be evaluated by a professional.

At shrinkage cracks in slabs we discuss how we decide if a foundation crack needs repairing the first place.

Suggestions for Repairing Concrete Foundation Shrinkage Cracks

Repairs to foundation cracks which are not traced to building movement, structural problems, site problems, or other conditions which require site or structural repairs may be attempted for cracked foundations and other cracked concrete structural elements using a variety of products and materials such as masonry repair epoxy or sealant products.

These products, some of which include even structural repair epoxies, might be used to seal against water leakage as well, and may be used for repairing certain cracks in concrete foundations following evaluation and advice from a foundation professional. An evaluation of the presence, absence, or condition of reinforcing steel in cracked concrete foundations should be a part of such an inspection.

Shrinkage cracks, which are not normally a structural defect in a building, May nonetheless, need to be sealed against water entry. Common repair methods include chipping out the crack and applying a masonry patching compound to the surface, use of epoxies, or other sealants.

Water entry leaks at foundation cracks: Polyurethane foam sealant is used for foundation crack repairs to stop water entry. (Also find and correct outside water sources). See our article on Polyurethane Foam Injection for details on using this product to seal foundation cracks against leakage.

- **Pile group**

Piles are driven generally in groups in regular pattern to support the structural loads. The structural load is applied to the pile cap that distributes the load to individual piles. If piles are spaced sufficient distance apart, then the capacity of pile group is the sum of the individual capacities of piles. However, if the spacing between piles is too close, the zones of stress around the pile will overlap and the ultimate load of the group is less than the sum of the individual pile capacities specially in the case of friction piles, where the efficiency of pile group is much less.

Group action of piles is evaluated by considering the piles to fail as a unit around the perimeter of the group. Both end bearing and friction piles are considered in evaluating the group capacity. End bearing pile is evaluated by considering the area enclosed by the perimeter of piles as the area of footing located at a depth corresponding to the elevation of pile tips. The friction component of pile support is evaluated by considering the friction that can be mobilized around the perimeter of the pile group over the length of the piles as shown in figure below:

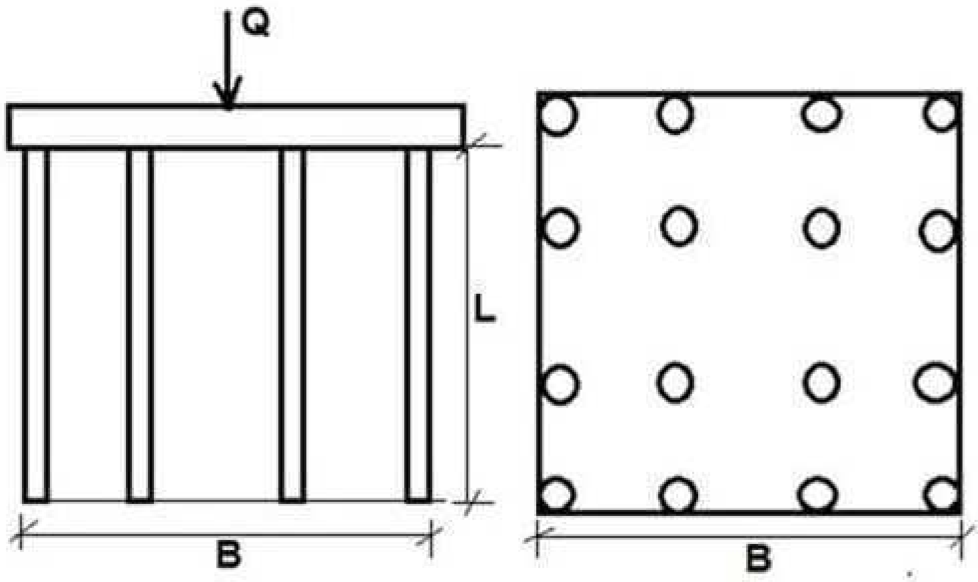

Fig 13 Group of Pile

The efficiency of pile group depends on the following factors:
1. Spacing of piles
2. Total number of piles in a row and number of rows in a group, and
3. Characteristics of pile (material, diameter and length)
The reduction in total bearing value of group of piles is more in case of friction piles, particularly in clayey soils. No reduction in grouping occurs in end bearing piles. The pile groups which are resisting the load by combined action of friction and end bearing, only the load carrying capacity of friction is reduced.

