Module 4

Site investigation and soil exploration

SOIL EXPLORATION

To, construct a Structure on soil → Should know the soil underneath

Knowing Subsurface Soil

- Finding Soil Type
- Finding Soil Structure
- Understanding the soil properties

- Assess site condition
- Sample Collection
- Sample Testing

SOIL EXPLORATION

Determination of surface and subsurface soil conditions of the proposed area of construction

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OBJECTIVES OF SITE EXPLORATIONS

Site investigations are done to obtain information useful for following purposes ;

- To select type and depth of foundations
- To determine the bearing capacity of soil
- To estimate maximum probable settlements of soil
- To establish ground water level and determine the properties of water

- To predict lateral earth pressure against retaining walls
- To select suitable construction technics
- To predict probable foundation problems and solve them
- To ascertain the suitability of soil as a construction material
- To investigate the safety of existing structures and suggest remedial measures

STAGES IN SITE EXPLORATIONS

1.RECONNAISSANCE

Includes

- Field visit
- Study of maps and Records

Helps to decide

- Method of exploration
- Types of samples to be taken
- Type of test to do (in-situ or lab)

2. PRILIMINARY EXPLORATION

Needed to determine

- Depth, thickness, extent and composition of soil stratum
- Location of ground water table.
- Depth of bed rock.

Done by

- Making test pits and few borings
- Geophysical Methods

3. DETAILED EXPLORATION

Needed to determine

- Engineering properties of soil in different strata.

Done by

- Extensive boring, sampling and lab testing of samples.
- Field tests like vane shear test, plate load test and permeability tests.

NEED OF SITE RECONNAISSANCE

Reconnaissance survey is required as it gives information about following features;

- Gives an idea about general topography of the site.
- Existence of settlement cracks in nearby structures.
- Evidence of landslides, slope failures and shrinkage cracks.
- Stratification of soil observed from deep cuts in the soil.

- The location of high flood marks on the nearby buildings and bridges. .
- Depth of ground water table as observed from the wells
- Existence of springs and swamps at the site
- The drainage pattern existing at the site.
- Type of vegetation at the site – Gives idea about soil.
- Existence of underground water mains, power conduits etc. at the site.

DEPTH OF EXPLORATION

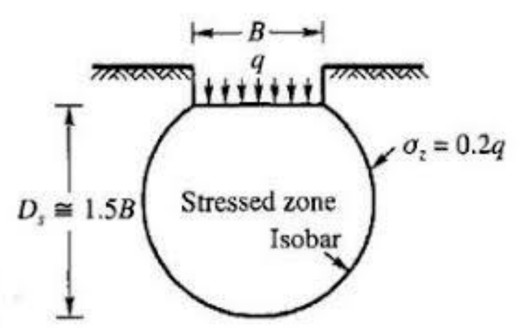
The depth up to which the soil properties are to be studied.

Depth of Exploration Depends on

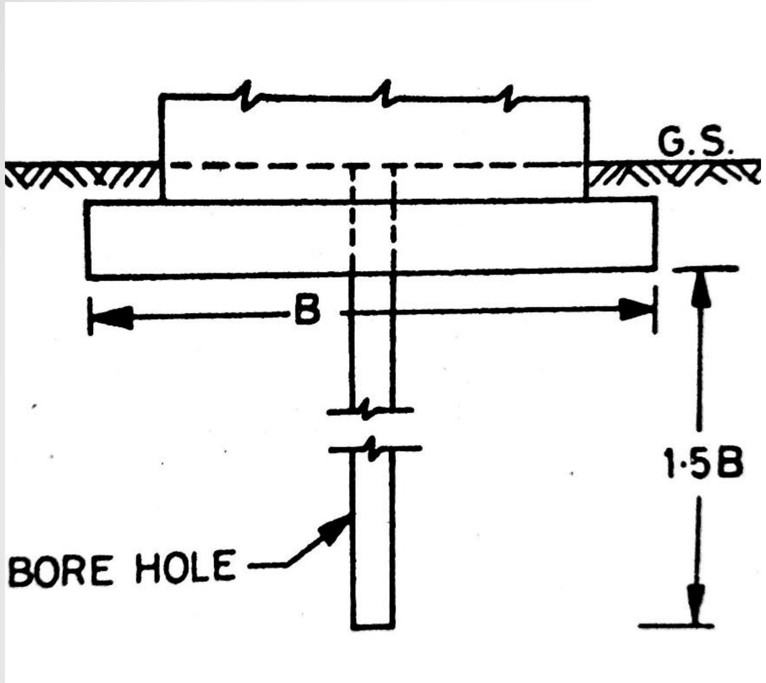
- Depth of Influence Zone
- Type of Structure
- Intensity of Loading
- Soil Profile
- Physical Characteristics of Soil

Depth of exploration should be at least equal to the significant depth.

- Depth up to which the imposed loads causes stress in soil is significant depth
- Generally taken as depth at which the vertical stress is 20% of load intensity.

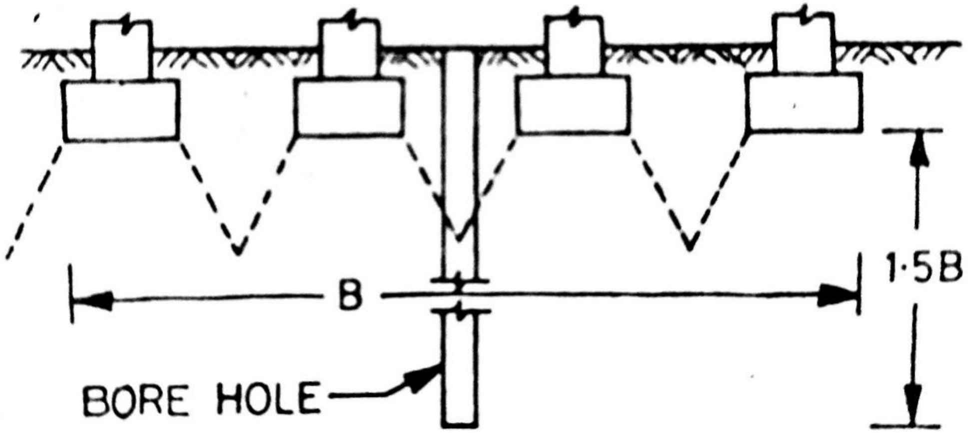


DEPTH OF EXPLORATION



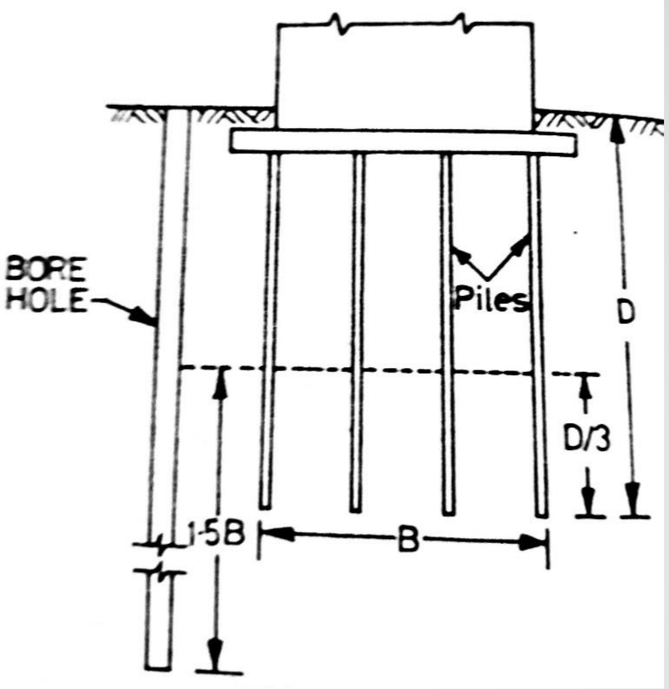
i) Isolated Footing

- 1.5 B – Square Footing
- 3.0 B- Strip Footing



ii) Closely Spaced Footing

- 1.5 x Width of entire loaded area



iii) Friction Piles

- 1.5 x Width of Pile Group
- Measured from lower third point.

DEPTH OF EXPLORATION FOR MULTI STORIED BUILDING

- Empirical Relationship for Multistoreyed Buildings

$$\boxed{D = C\,(S)^{0.7}}$$

where

D = Depth of exploration

C = Constant

= 3 for Light steel buildings & Narrow concrete bldgs

= 6 for Heavy Steel bldgs & Wide Concrete bldgs.

S = No. of storeys

LATERAL EXTENT OF EXPLORATION

POSITION AND SPACING OF BOREHOLES

For Small Buildings

- One bore hole at the centre

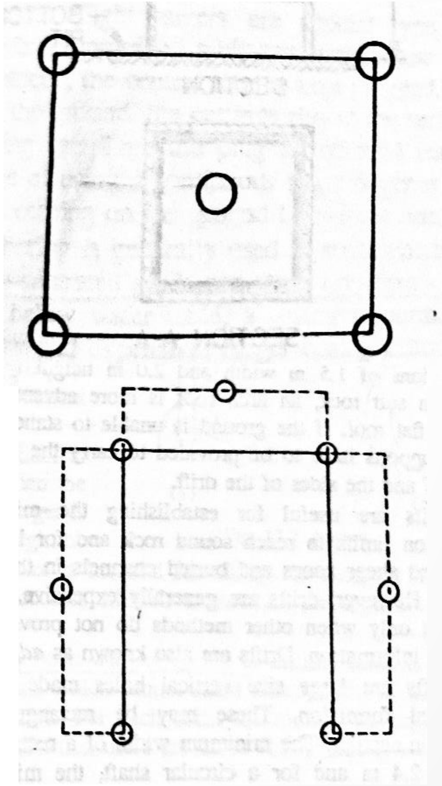
For Compact Buildings

(Covering area of 0.4hectres)

- One bore hole at the centre and four near the corners

For Large Multistoried Buildings

- Bore holes at all corners and all other important locations



Sl. No.	NATURE OF PROJECT	SPACING
1.	Multi-storied Buildings	10 to 30 m
2.	Highways	150 to 300m
3.	Earth Dams	30 to 60m
4.	Concrete Dams	40 to 80m
5.	Single-storied Factories	30 to 90m

METHODS OF EXPLORATION

SOIL EXPLORATION

OPEN EXCAVATION METHODS	PITS AND TRENCHES
	DRIFTS AND SHAFTS
BORING METHODS	AUGER BORING
	AUGER AND SHELL BORING
	WASH BORING
	ROTARY DRILLING
	PERCUSSION DRILLING
	CORE BORING
GEOPHYSICAL METHODS	SEISMIC METHOD
	ELECTRICAL RESISTIVITY METHOD

OPEN EXCAVATION METHODS

1. PITS AND TRENCHES

PITS

- Excavated at site to inspect strata.
- Size of pit is 1.2m x 1.2m as per IS:4453-1967.
- Not used for more than 6m depth.
- Visual inspection, collection of samples and personal feeling of soil is possible.

TRENCHES

- Long and shallow pits are called trenches.
- Continuous over a considerable length.
- Will aid visual inspection and collection of sample along a line.
- More useful than pits for exploration on slopes.

2. DRIFTS AND SHAFTS

DRIFTS/ADITS

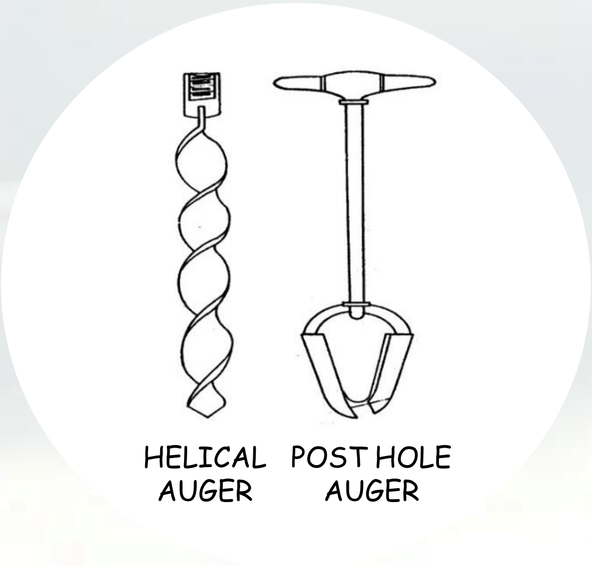
- Horizontal tunnels made in hill side.
- Helpful to determine the nature and structure of geological formation.
- Helpful to identify faults, shear zones and excavation limit to reach sound rock.
- Expensive.

SHAFTS

- Large size vertical holes made in geological formation.
- Can be rectangular or circular in cross section.
- Used to reach a particular strata at a depth of 4m or more.
- Used to extend exploration below the river bed.

BORINGS FOR EXPLORATION

1. AUGER BORING



Boring by using boring tools similar to that used for boring holes in wood.

HAND OPERATED

- Advanced by turning cross arm and at the same time applying thrust.
- Holes of 3m to 6m depth can be bored in soft soil.

MACHINE OPERATED

- Driven into the soil by power.
- Suitable for advancing holes up to a depth of 12m in hard strata.

Auger boring useful for subsurface investigations of highways, railways etc. (Depth of exploration is less).

Highly disturbed samples will be obtained by this method.

Image Source : Builder's Engineer

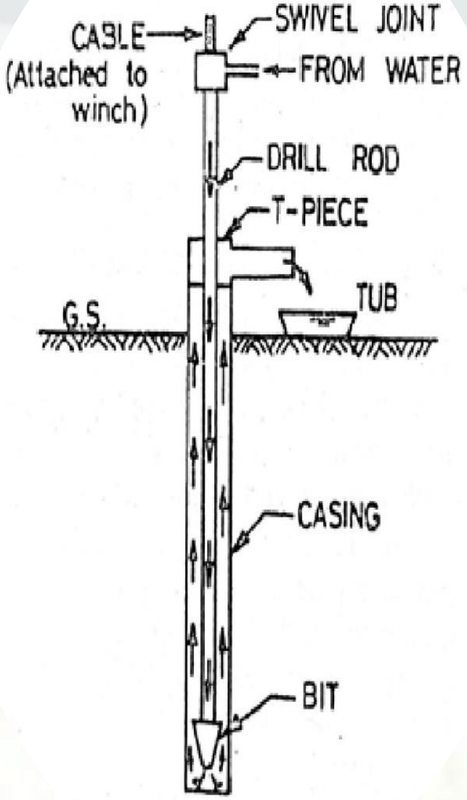
2. AUGER AND SHELL BORING

SHELL

- Used for boring holes up to higher depth.
- A cylindrical shell or casing is used along with the auger (boring rig).
- The shell with cutting edge will advance into soil as well as support the walls of bore hole in weak strata.
- Rig while hand operated can dig up to 25m. .
- Rig while machine operated can dig up to 50 m

Image Source : Archway-engineering

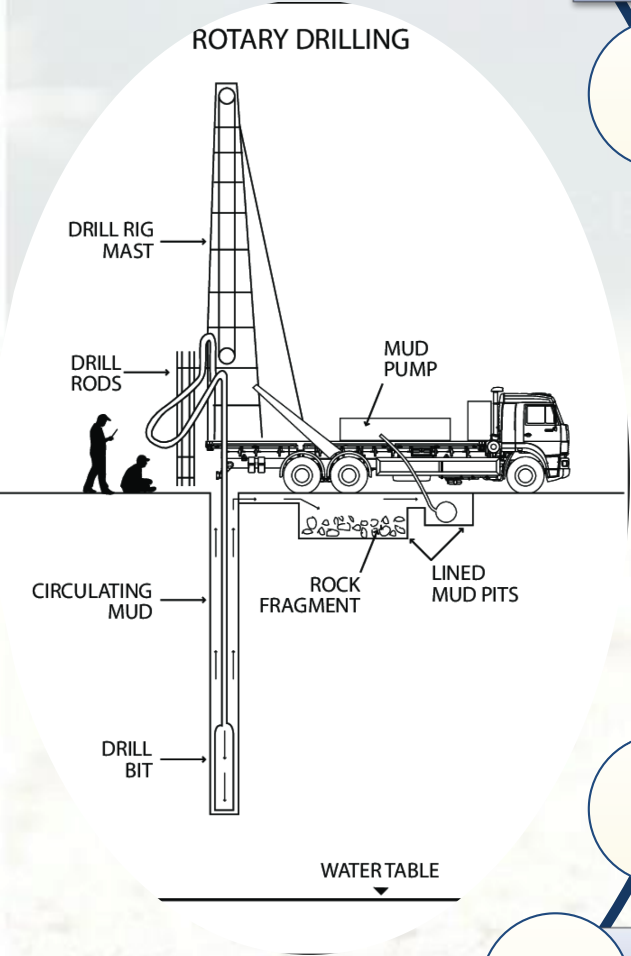
3. WASH BORING



- Hole is drilled by first driving a casing of 2 to 3 m into the soil.
- A drill pipe with chisel shaped chopping bit is then inserted.
- Water is pumped down through the hollow drill rod.
- Water jet as well as drilling bit advances hole in soil.
- Water and soil particles rising through the space between drill rod and casing is collected in a tub.
- After boring the hole good sample can be collected by using sampler.
- Not effective for stiff soil, rocks and soil containing boulders.

Image Source : Soil Mechanics by Dr.K.R. Arora

4. ROTARY DRILLING



- Bore holes is advanced by rotating a hollow drill rod which has cutting edge at its lower end.
- The drill head at top of rod is connected to a rotary mechanism which applies downward pressure.
- A drilling fluid (drilling mud) is circulated through the rod to the bottom of hole.
- The fluid brings the chipped of soil particles to the surface through the annular space.
- The drilling fluid also cools down the drilling bit and supports the vertical wall.
- After boring the hole good sample can be collected by using sampler.
- Used in clay, sand and rocks. Not useful for gravelly soil.

Image Source : Research Gate

5. PERCUSSION DRILLING

- Heavy chisel is alternatively lifted and dropped in a vertical hole.
- The falling chisel pulverizes the materials and thus the hole advances.
- Water is added to make a slurry of pulverized material.
- The slurry is lifted to the surface by using a sand pump.
- Percussion drilling can be used for any type of soil and is very useful in case of rocks or hard stratum.
- More expensive than the other methods and also the sample will be disturbed.

Image Source : Indiamart

6. CORE DRILLING

- Used for drilling holes and obtaining rock cores.
- A core barrel is fixed with a drilling bit fixed to a hollow drilling rod.
- As the drilling rod is rotated, the bit advances and cuts an annular hole around the core .
- The core is then removed from the bottom and is brought to the surface by a lifter.
- Core barrel gives a good quality sample.
- Core drilling with diamond bit is superior to other methods but expensive.

TYPES OF SOIL SAMPLES

DISTURBED SAMPLES

- Samples with natural structure of soil gets disturbed while sampling.
- Sample represent composition of mineral contents in soil.
- Can be used to determine index properties like grain size, plasticity characteristics and specific gravity.

UN DISTURBED SAMPLES

- Samples with natural structure of soil and water content are retained while sampling
- Can be used to determine engineering properties of soil.
- It is impossible to get 100% undisturbed sample.

GEOPHYSICAL METHODS

1. SEISMIC REFRACTION METHOD

Locates Different Soil Strata

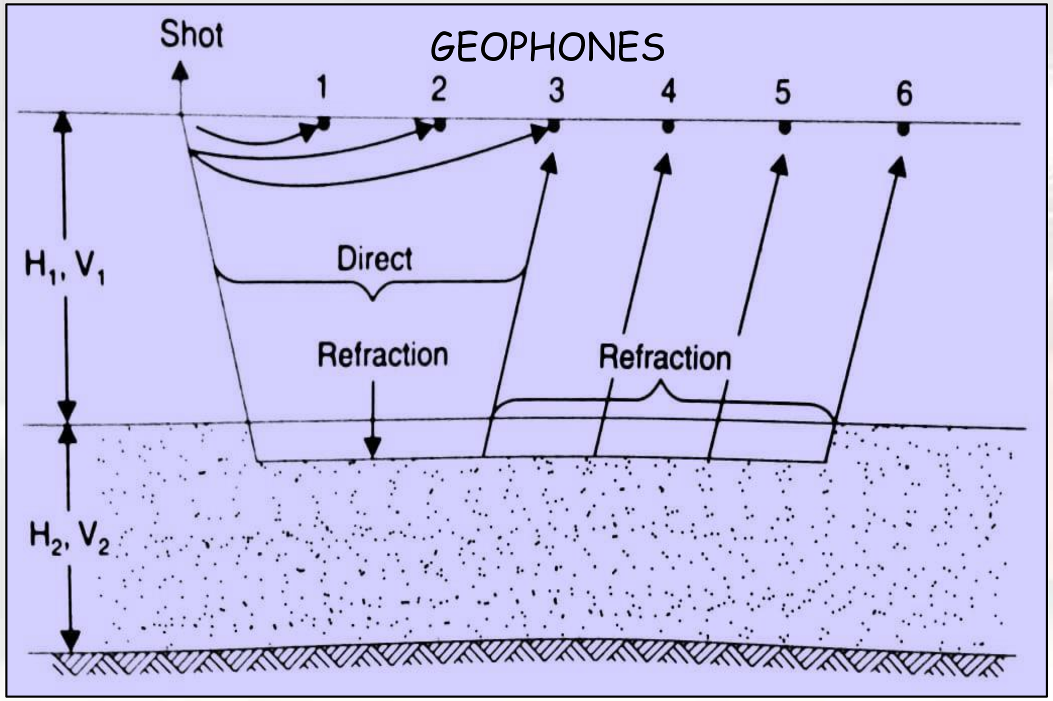
Based on reflection and refraction of elastic waves through soil

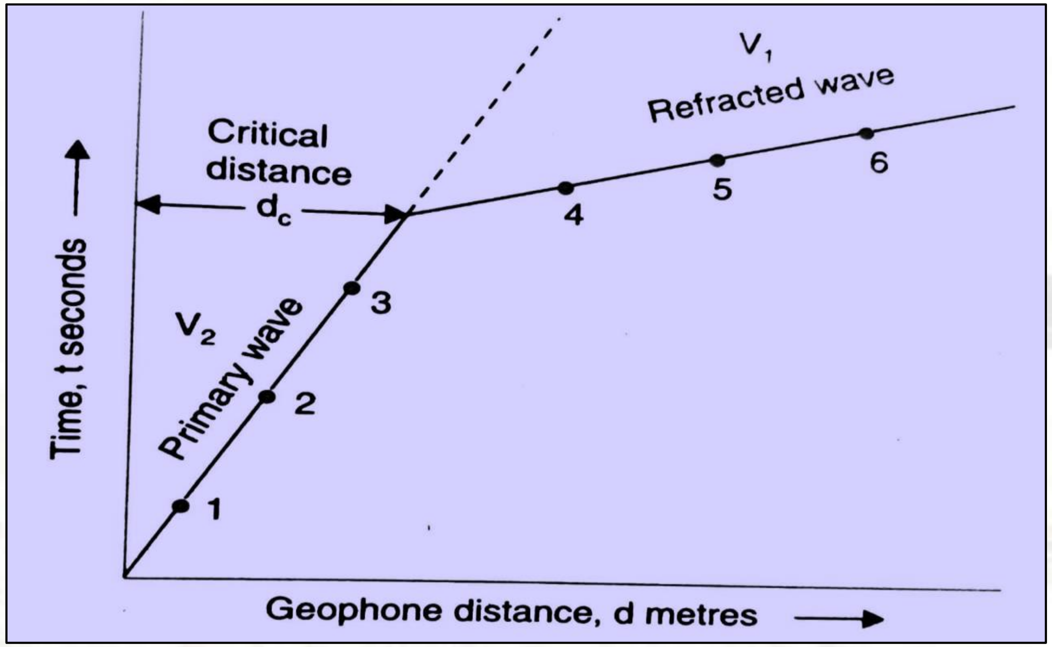
PRINCIPLE

- Elastic shock waves have different velocities in different materials.
- At the interface of two different materials, the waves get partially reflected and partially refracted

When elastic waves are transmitted through soil,

Knowing velocity	Know type of soil at different layers
Analyzing Refraction and Reflection	Locate depth of soil layers





At a surface point in the site shock waves are created by hammer blows.

Geophones (detectors) are located at different intervals on soil surface

Waves that travel directly through the surface or through upper stratum and picked up first by geophones- primary waves

The waves that travels down get refracted at the interface and picked up by geophones (refracted waves)

The time at which each geophone detects a signal is noted. Velocity is found from distance-time plot.

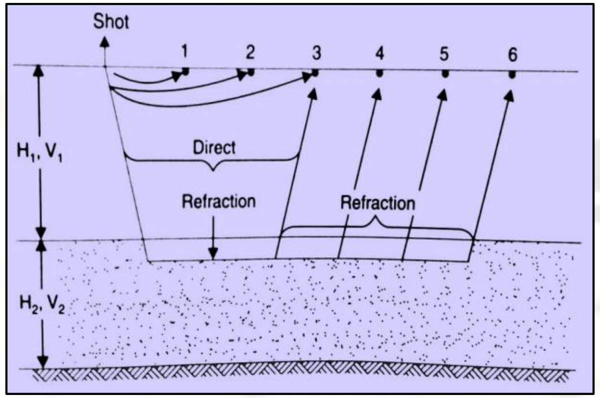
Image Source : Geotechnical Engineering by C.Venkataramaiah

Soil at different layers can be assessed by the velocity values

Material	Velocity (m/s)	Material	Velocity (m/s)
Sand and top soil	180 to 365	Water in loose materials	1400 to 1830
Sandy clay	365 to 580	Shale	790 to 3350
Gravel	490 to 790	Sandstone	915 to 2740
Glacial till	550 to 2135	Granite	3050 to 6100
Rock talus	400 to 760	Limestone	1830 to 6100

Source : Geotechnical Engineering by C.Venkataramaiah

Depth of each layer can be found by the equation,



$$H_1 = \frac{d_c}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

- H_1 : Depth of first layer
- d_c : Critical distance
- V_1 : Velocity in 1st layer
- V_2 : Velocity in 2nd layer

Equation is applicable only when 2nd layer is denser than the 1st

2. ELECTRICAL RESISTIVITY METHOD

Electrical resistivity of a conductor (ρ) is expressed as,

$$\rho = \frac{RA}{L}$$

- R : Electrical resistance in ohms
- A : Area of cross section of the conductor (cm^2)
- L : Length of the conductor (cm)

PRINCIPLE

- The resistivity of any material depends upon the **type of material, water content in it** and many other factors.
- So the value of resistivity gives an idea about the material

Table 17.4. Resistivity of Different Rocks and Soils

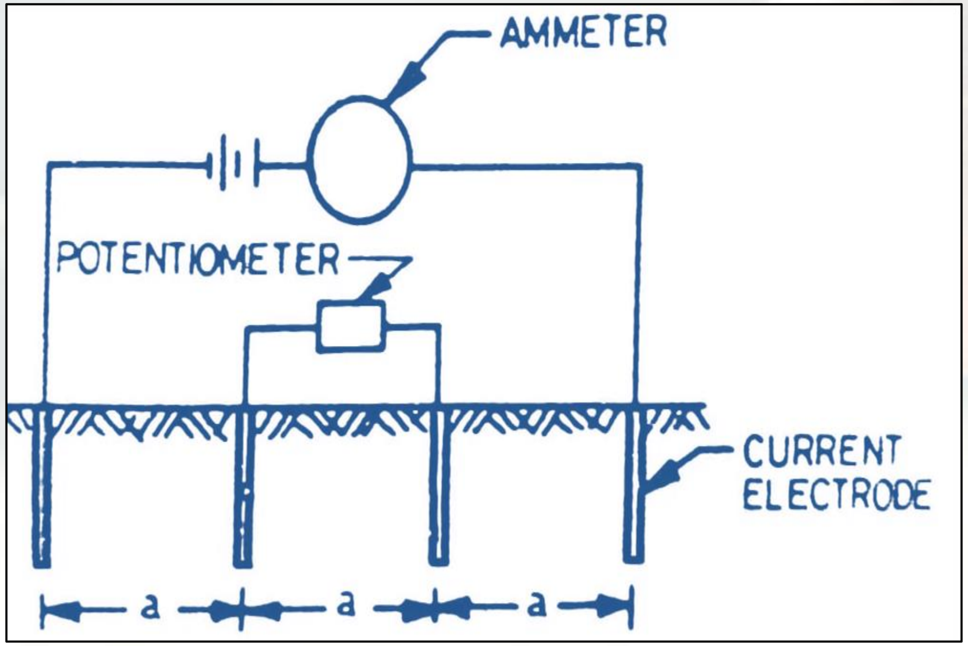
Type of rock/soil	*Sound rock*	*Weathered Rock*	*Gravel*	*Sand*	*Clayey sand*	*Saturated clay and silt*
Resistivity (Ohm-m)	> 5000	1500 ro 2500	1500 to 4500	500 to 1500	200 to 500	2 to 100

Source : Soil Mechanics by Dr.K.R. Arora

Resistivity is found by

- Electrical Profiling Method
- Electrical Sounding Method

i. ELECTRICAL PROFILING METHOD



Source : Soil Mechanics by Dr.K.R. Arora

$$\text{Resistivity}, \rho = \frac{2\pi a V}{I}$$

- I : Current supplied
- a : Electrode Spacing
- V : Voltage drop

Four electrodes are spaced at constant spacing and are driven into the ground.

Two outer electrodes : Current Electrodes
Two inner electrodes : Potential Electrodes

DC current is applied at the current electrodes.

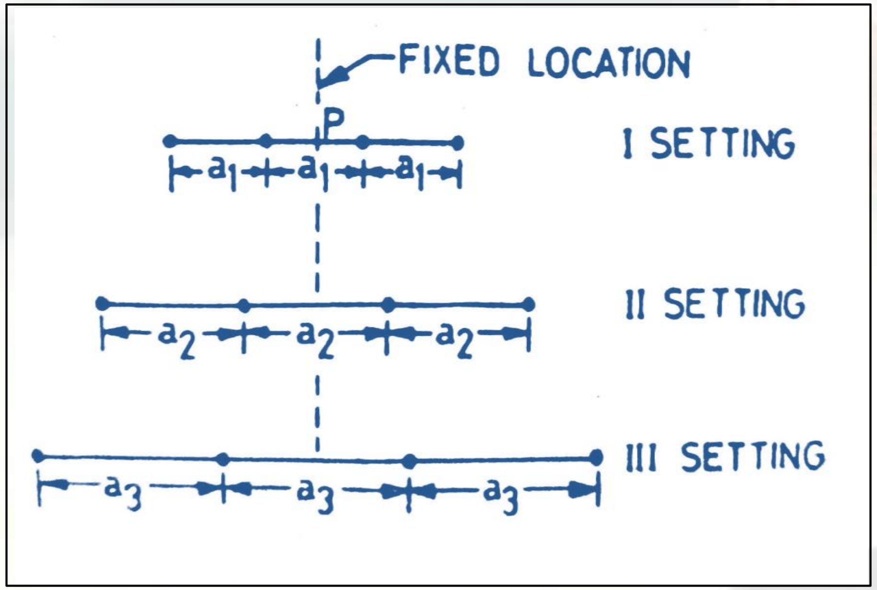
Voltage drop between inner electrodes is measured using voltmeter and resistivity is calculated

The depth at which the resistivity is measured is approximately equal to the spacing of electrodes.

The electrodes are then moved along a line and soil strata is identified.

The test is repeated for different spacing of electrodes to obtain soil strata at different depths.

ii. ELECTRICAL SOUNDING METHOD



Source : Soil Mechanics by Dr.K.R. Arora

- Electrodes used as same as that of profiling method.
- Here spacing between electrodes are increased about a fixed point (P) in different steps (settings).
- In each setting the spacing of electrode will be equal to the depth of soil at which the investigation is carried out.
- Resistivity at each of these depths is calculated by the method as described in the electrical profiling method.
- The resistivity values at different depths gives an idea about the variation of the soil strata at different depths.

When subjected to load, soil may fail by

SETTLEMENT FAILURE

SHEAR FAILURE

Foundations are designed in such a way that

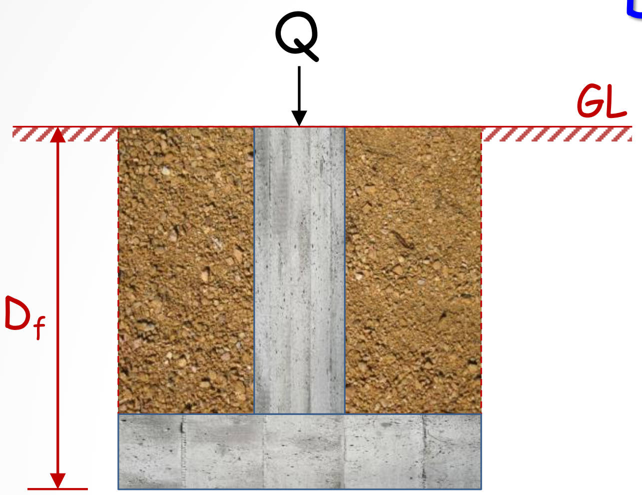
- Soil below does not fail in shear
- Settlement should be with in permissible limit

The load that can be transferred safely through foundation without causing failure in soil

BEARING CAPACITY

BEARING CAPACITY

DEFINITIONS



Pressure on soil just below the foundation is due to,

- Load from the foundation
- Load due to soil fill

1. ULTIMATE BEARING CAPACITY (q_u)

The minimum gross pressure at the base of foundation at which the soil fails in shear.

2. NET ULTIMATE BEARING CAPACITY (q_{nu})

The minimum net increase in pressure at the base of foundation at which the soil fails in shear.

$$q_{nu} = q_u - \gamma D_f$$

3. NET SAFE BEARING CAPACITY (q_{ns})

- It is the maximum net soil pressure which can be safely applied to the soil without shear failure.

$$q_{ns} = \frac{q_{nu}}{F}$$

F is the factor of safety usually taken as 3.

4. GROSS SAFE BEARING CAPACITY (q_s)

- It is the maximum gross pressure which the soil can carry safely without shear failure.

$$q_s = \frac{q_{nu}}{F} + \gamma D_f$$

5. NET SAFE SETTLEMENT PRESSURE (q_{np})

- The maximum net pressure which the soil can carry without exceeding the allowable settlement.
- The maximum allowable settlement generally varies between 25 mm and 40 mm for individual footings.

6. NET ALLOWABLE BEARING PRESSURE (q_{na})

- It is the net bearing pressure which can be used for the design of the foundations.

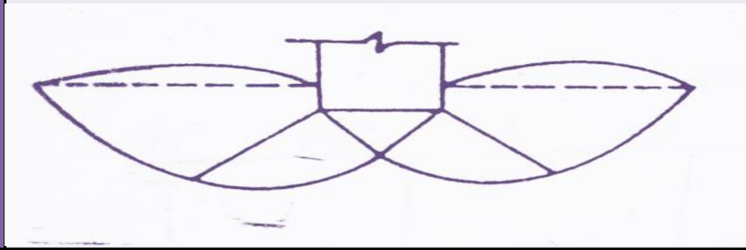
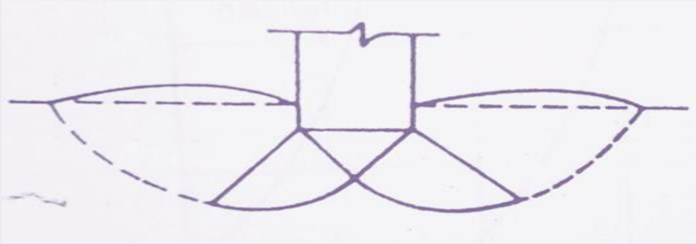
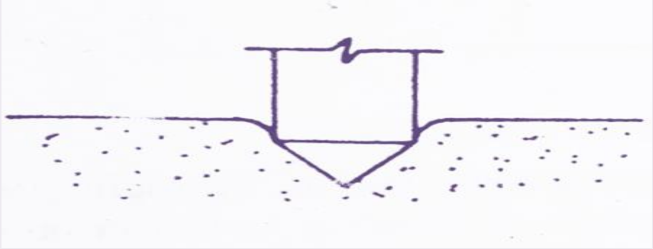
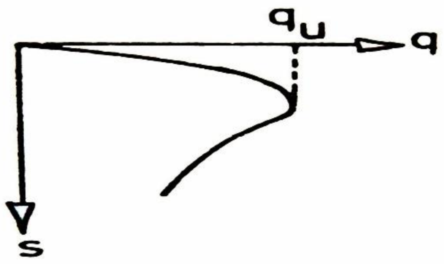
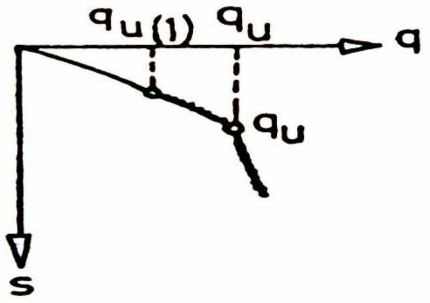
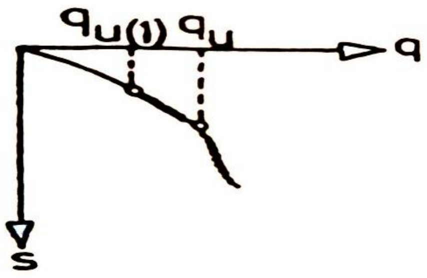
$$q_{na} = q_{ns}\,, \quad if\ q_{np} > q_{ns}$$

$$q_{na} = q_{np}\,, \quad if\ q_{np} < q_{ns}$$

- Net allowable bearing pressure is also known as allowable soil pressure or allowable bearing capacity.

FAILURE ANALYSIS

TYPES OF SHEAR FAILURE

ITEM	GENERAL SHEAR FAILURE	LOCAL SHEAR FAILURE	PUNCHING SHEAR FAILURE
Illustration			
Supporting Soil	Dense sand or stiff clay	Medium dense sand or Medium stiff clay	Loose sand or soft clay
Failure Nature	Heave on the sides	Small heaves occurs if there is substantial settlement	No heave. Only vertical movement of footing.
Load Settlement Curve			

Source : *Soil Mechanics by Dr.K.R. Arora*

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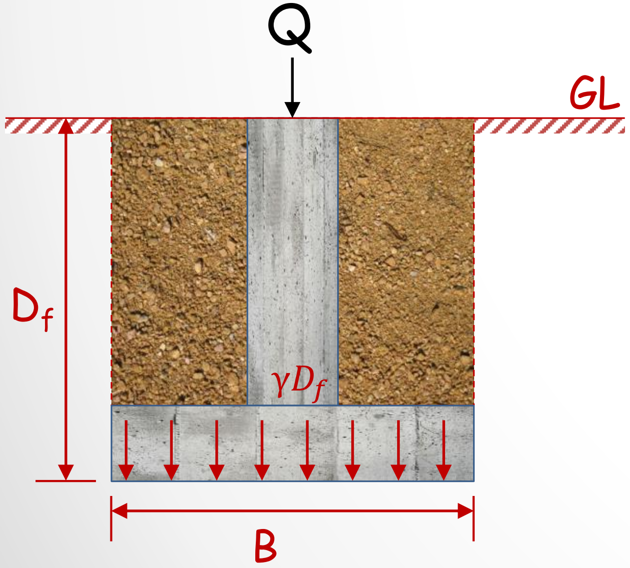
TERZAGHI'S BEARING CAPACITY THEORY

ASSUMPTIONS IN TERZAGHI'S THEORY

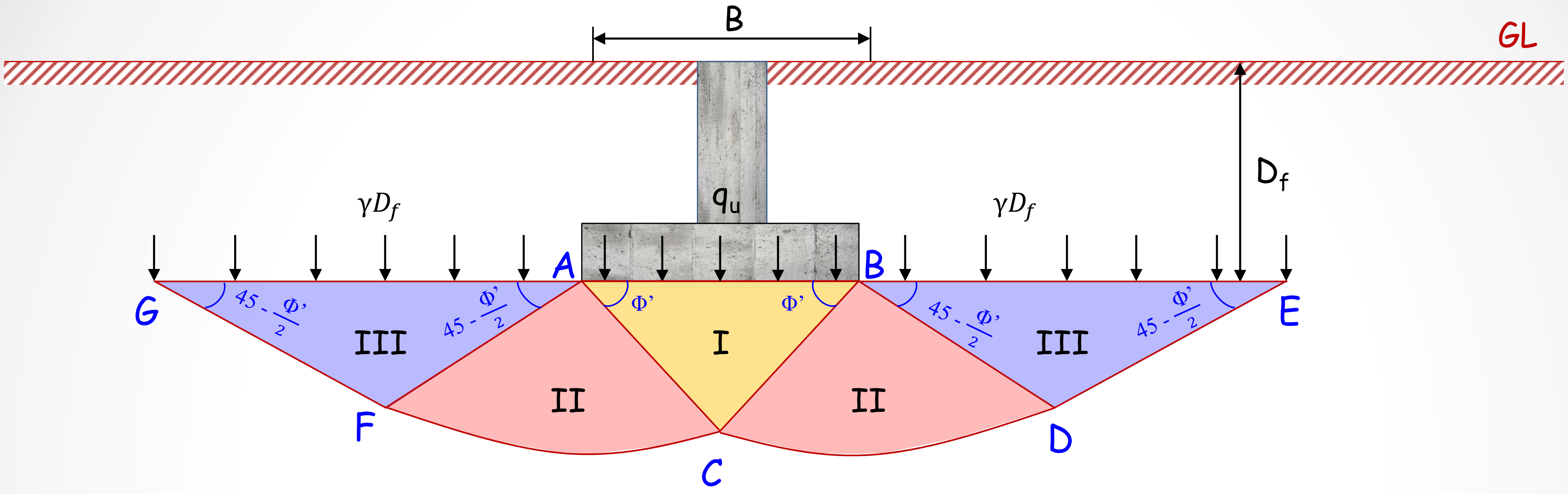
Father of Soil Mechanics

KARL VON TERZAGHI



1. The base of the strip footing considered is rough
2. The footing is laid at a shallow depth, i.e. $D_f <= B$
3. The soil above the base of footing is replaced by a surcharge γD_f and shear strength is neglected.
4. The load on the footing is uniformly distributed.
5. The footing is long (L/B is infinite, where L is length and B is the width of footing).
6. Shear strength of soil below the footing is governed by Mohr -Coulomb equation.

TERZAGHI'S ANALYSIS MODEL



ZONE I — • TRIANGULAR WEDGE ZONE — *Soil here acts as a part of footing itself*

ZONE II — • RADIAL SHEAR ZONE — *Zone where shear forces develops radially*

ZONE III — • RANKINE'S PASSIVE ZONE — *Zone where overburden pressure acts*

TERZAGHI'S EQUATION

$$q_u = C'N_c + \ q_0\, Nq + 0.5\, \gamma B N_\gamma$$

$$N_c = cot\Phi' \left[\frac{a^2}{2\, cos^2\left(45 + \frac{\Phi'}{2}\right)} - 1 \right]$$

$$N_q = \left[\frac{a^2}{2\, cos^2\left(45 + \frac{\Phi'}{2}\right)} \right]$$

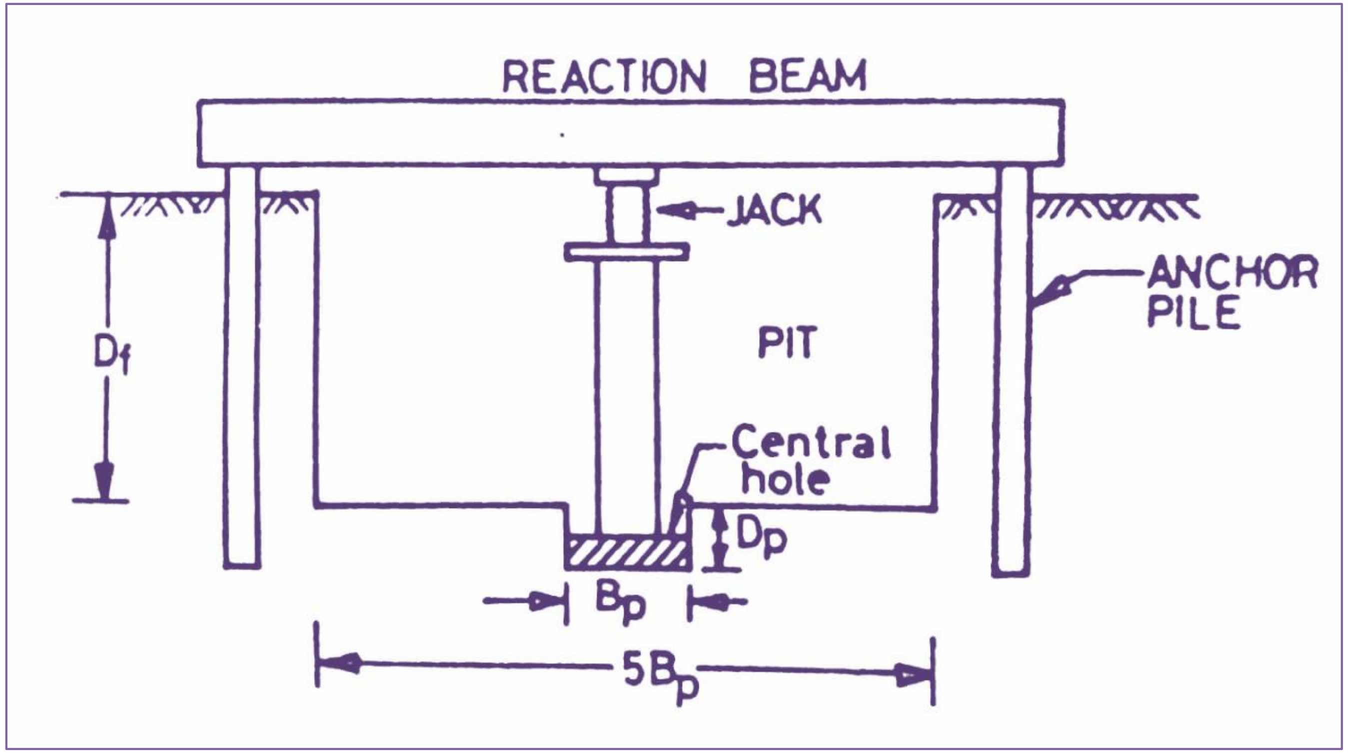
$$where, a = \ e^{\left(3\pi/_4 - \Phi'/_2\right) tan\Phi'}$$

$$N_\gamma = \frac{1}{2}\left[\frac{K_p}{cos^2(\Phi')} - 1 \right] tan\, \Phi'$$

q_u	:	*Ultimate Bearing Capacity*
N_c , N_q , N_γ	:	*Bearing Capacity Factors*
ϕ'	:	*Angle of Shearing Resistance.*
K_p	:	*Coefficient of passive earth pressure.*
C'	:	*Cohesion*
q_0	:	*Overburden pressure* (γD_f)
B	:	*Width of footing*

PLATE LOAD TEST

To determine the allowable bearing pressure of soil at the site



Source : Soil Mechanics by Dr.K.R. Arora

Steel Plate

- 0.3m x 0.3m
- 25 mm thick
- Circular and 0.6m x 0.6m large plates also can be used.

1

- In the soil a pit of size $5B_p \times 5B_p$ and depth equal to depth of foundation (D_f) is excavated.

2

- A central hole of size $B_p \times B_p$ is excavated in the pit with depth of pit taken as D_p

D_p is found by the relation,

$$\frac{D_p}{B_p} = \frac{D_f}{B_f} \longrightarrow D_p = \frac{D_f}{B_f} * B_p$$

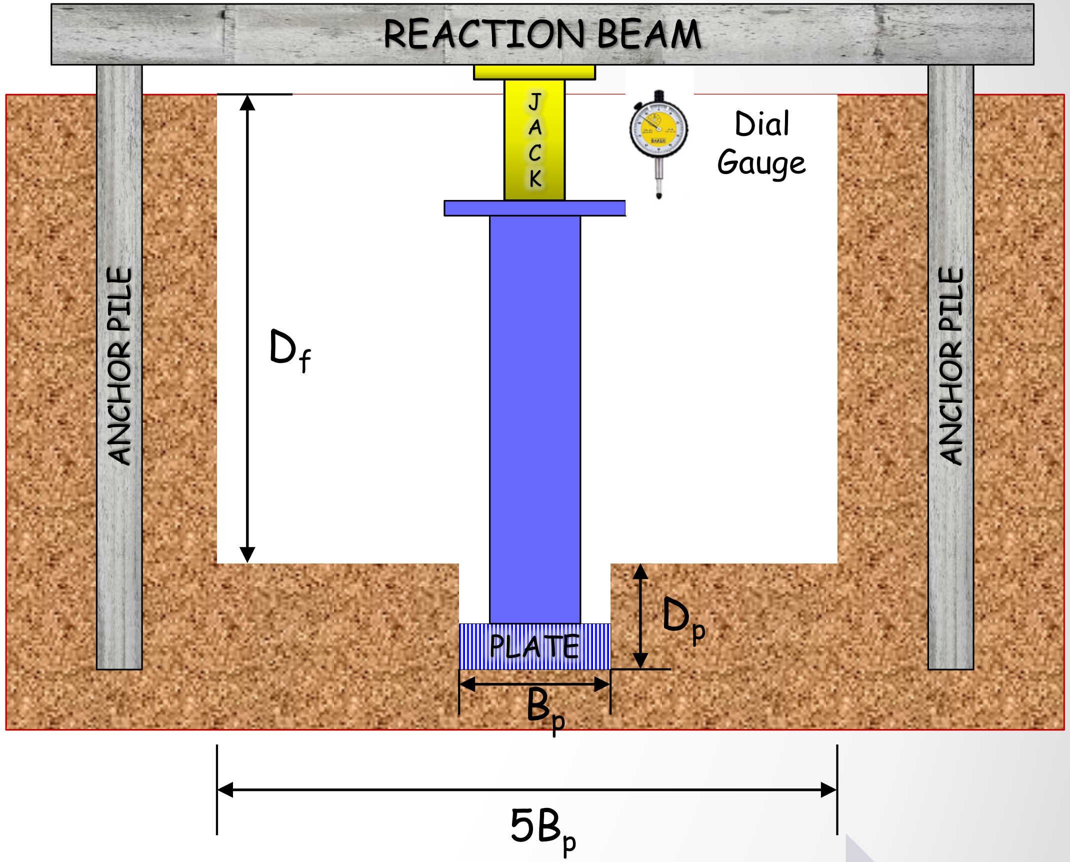
D_p : Depth of plate hole
B_p : Width of plate
D_f : Depth of pit
B_f : Width of pit

3

- The plate is placed in the hole and load is applied through a hydraulic jack.

4

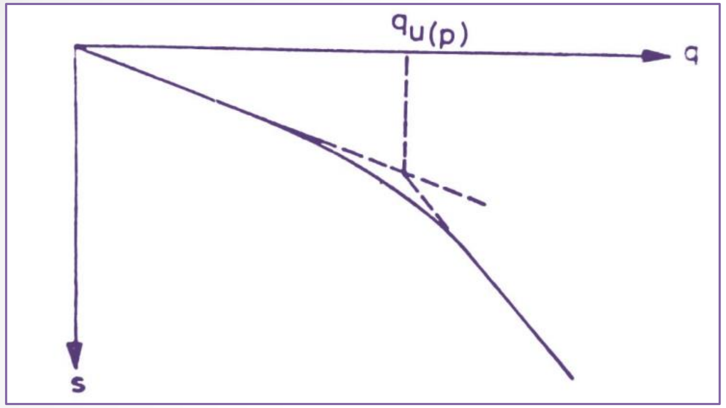
- The reaction to the jack is provided by a reaction beam. A loaded platform (kentledge) also can be used.



6

- A seating load of 7 kN/m² is first applied and then loads are applied at increments of 20% of estimated safe load or 1/10th of ultimate load.
- The settlements are recorded using a dial gauge after 1,5,10,20,40,60 minutes and at 1 hour intervals till failure or till a settlement of 25 mm has occurred.

7 • Load v/s settlement curve is plotted



Source : Soil Mechanics by Dr.K.R. Arora

Ultimate load for plate is indicated by

- Break in log-log plot
- Intersection of tangents in normal plot.

ULTIMATE BEARING CAPACITY

CLAYEY SOIL

$$q_u\,(f) = q_u\,(p)$$

SANDY SOILS

$$q_u\,(f) = q_u\,(p)\,\frac{B_f}{B_p}$$

SETTLEMENT

CLAYEY SOIL

$$s_f = s_p\,\frac{B_f}{B_p}$$

SANDY SOILS

$$s_f = s_p\left[\frac{B_f(B_p+0.3)}{B_p(B_f+0.3)}\right]^2$$

$q_u(p)$	:	*Ultimate bearing capacity of plate*
$q_u(f)$	:	*Ultimate bearing capacity of footing*
B_p	:	*Width of plate*
B_f	:	*Width of footing*
s_p	:	*Settlement of plate*
s_f	:	*Settlement of footing*

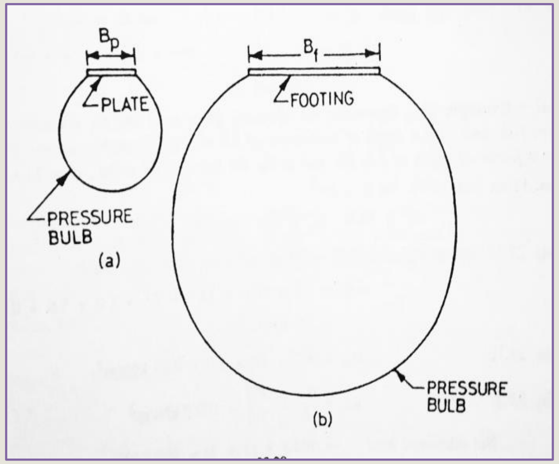
APPLICATIONS OF PLATE LOAD TEST

- To find the ultimate bearing capacity of a proposed foundation
- To find the settlement for a given load intensity
- For designing shallow foundation for an allowable settlement.
- To determine the influence factor (I).

LIMITATIONS OF PLATE LOAD TEST

1. SIZE EFFECT

- Size of pressure bulb depends on the loaded area.
- The actual pressure bulb will be deeper than the pressure bulb for the plate, as plate size is much smaller than the footing size.



Source : Soil Mechanics by Dr.K.R. Arora

2. SCALE EFFECT

- For cohesion less soil, the ultimate bearing capacity varies with the size of plates.
- Larger the size of plate, larger will be the bearing capacity .
- To avoid scale effect, test can be repeated for different sized plates and the ultimate bearing capacity for the footing can be extrapolated from those.

3. TIME EFFECT

- Plate load test is a smaller duration test, where as actual settlement takes longer time.
- So, the load-displacement curve may not exactly represent the actual case.

4. INTERPRETATION OF FAILURE LOAD

- Well defined failure load may not be obtained at all cases.
- Personal interpretation of results may cause errors.

5. REACTION LOAD

- It is not practical to provide reaction of more than 250 kN.
- Hence plate size larger than 0.6m can not be used for the test

6. WATER TABLE

- If water table is above footing level it has to be lowered by pumping before placing the plate.

STANDARD PENETRATION TEST

Conducted to determine

- Angle of shearing resistance (Φ)
- Unconfined compressive strength (q_u)

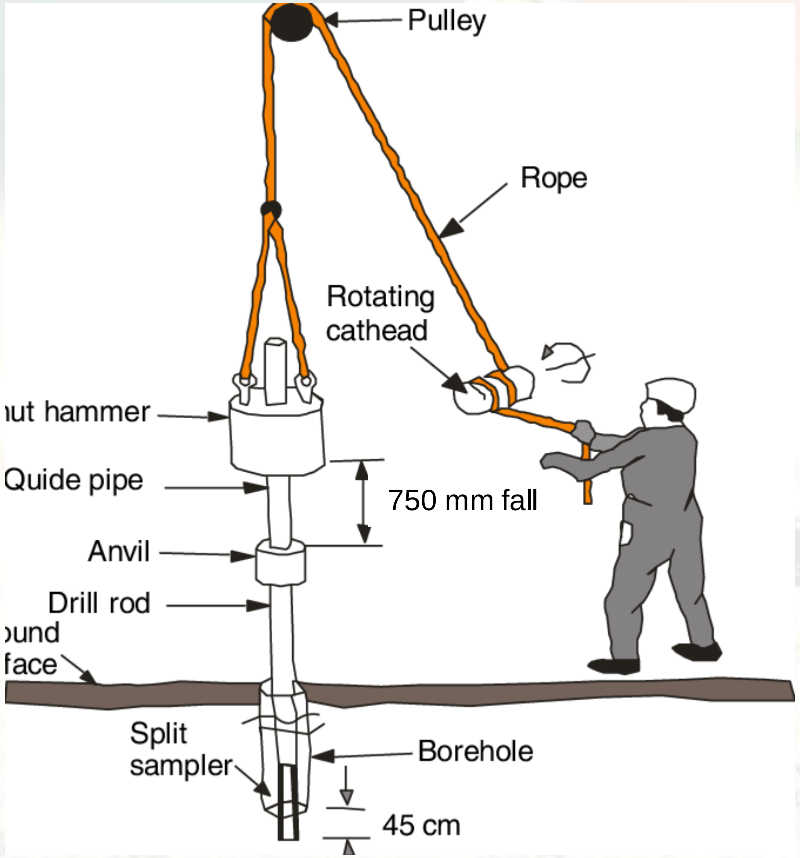


Image Source : Research Gate

Conducted in bore hole with a split spoon sampler.

The sampler is driven into the soil by a drop hammer applying impact force.

- Mass of hammer : 63.5 kg
- Drop height : 750 mm
- Rate of drop : 30 blows per minute

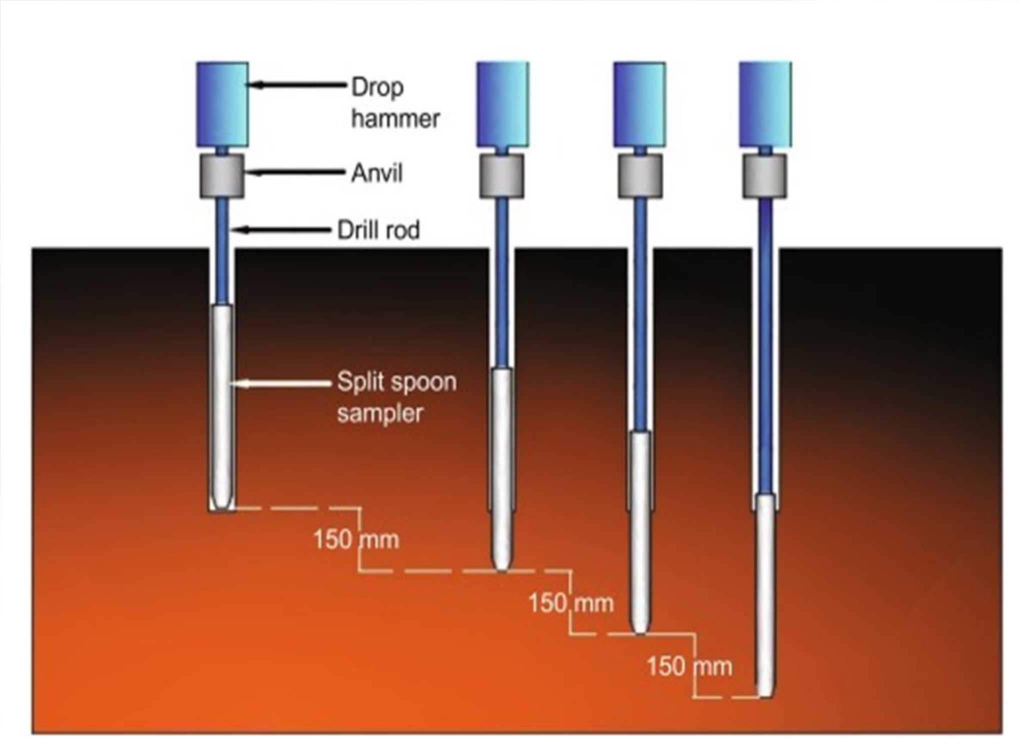


Image Source : easystudypoint.com

N_1
- No. of blows required for advancing the sampler to 150 mm is noted.

N_2
- No. of blows required for next 150 mm is noted

N_3
- Sampler is further blown and no. of blows required for the further 150 mm is noted

Standard Penetration number, $N = N_2 + N_3$

- N_1 is ignored considering it as the seating load.
- N is corrected for i) Dilatancy and ii) Overburden pressure

- From the N value obtained
  - Unconfined compressive strength (q_u) of cohesive soils is found using the relation;

$$q_u = 12.5\,N$$

  - For cohesion less soils, N value is used to find the angle of shearing resistance (Φ) and relative density.

Table 17.1. Correlation between N and ϕ

N	*Denseness*	ϕ
0—4	Very Loose	25°—32°
4—10	Loose	27°—35°
10—30	Medium	30°—40°
30—50	Dense	35°—45°
> 50	Very Dense	> 45°

Table 17.2. Correlation between N and q_u

N	*Consistency*	q_u (kN/m^2)
0—2	Very Soft	< 25
2—4	Soft	25—50
4—8	Medium	50—100
8—15	Stiff	100—200
15—30	Very Stiff	200—400
> 30	Hard	> 400

Source : Soil Mechanics by Dr.K.R. Arora

FOUNDATION ENGINEERING

MODULE 4

- *Loads from the structure has to be transferred to the soil in such a way*
  - *To ensure structural safety*
  - *Bearing capacity of the soil is not exceeded*
- *Foundation – helps in transferring the load from the structure above to the soil beneath the foundation*
- *Foundation is the bottom part of the structure which is in contact with the soil/ground and transmits the load to it*

4.2 OBJECTIVES OF A FOUNDATION :

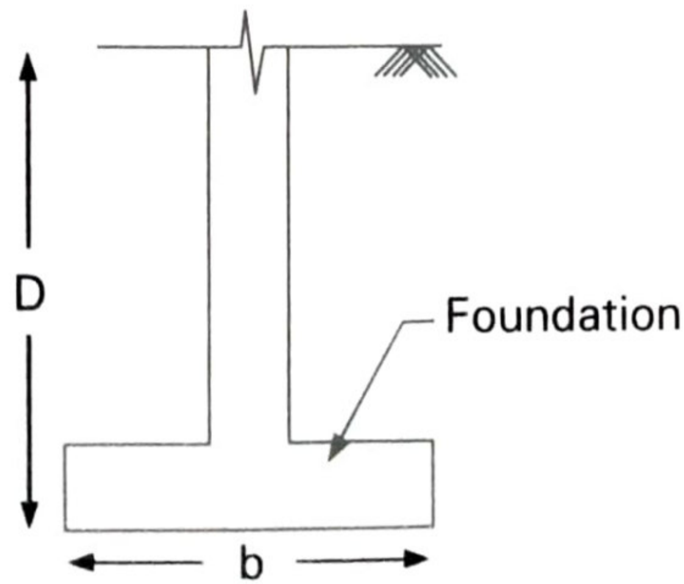
The objectives of a foundation are

1) To support the structure.
2) To transfer the structural loads safely to the soil below.
3) To ensure that the soil is never overtressed.
4) To avoid any settlements of the structure.

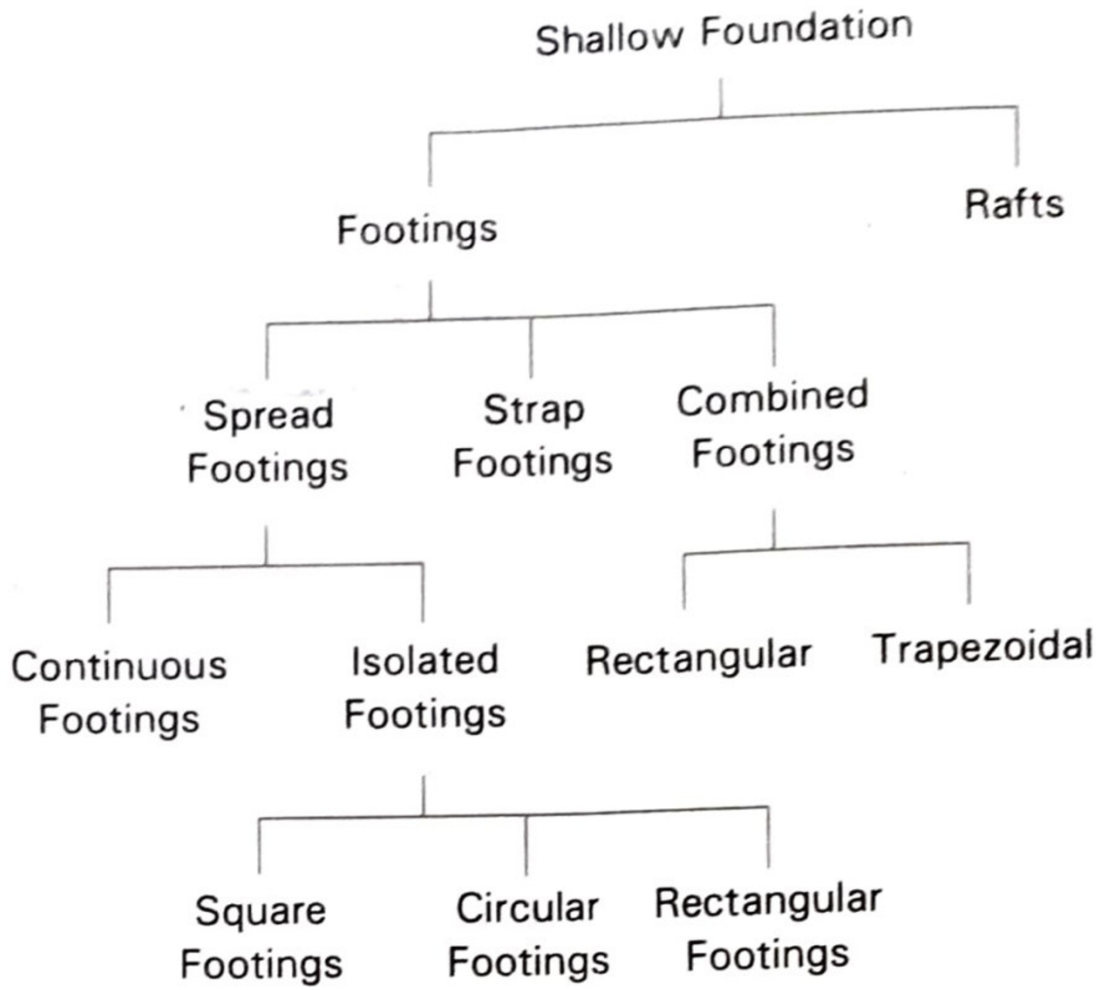
4.3 SHALLOW FOUNDATION :

Shallow foundation are these foundations whose depth is equal to or less than its width, as per Terzaghi.

$D < b$



4.3.1 Different Types of shallow foundation



Shallow foundation are classified as

1) Spread footings

2) Strap footings

3) Combined footings

SPREAD FOOTINGS

- *Isolated footing provided under each column*
- *Square, circular or rectangular in plan*
- *Area of footing depends upon the bearing capacity of soil*

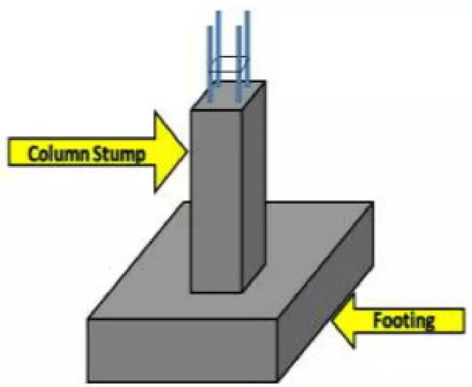
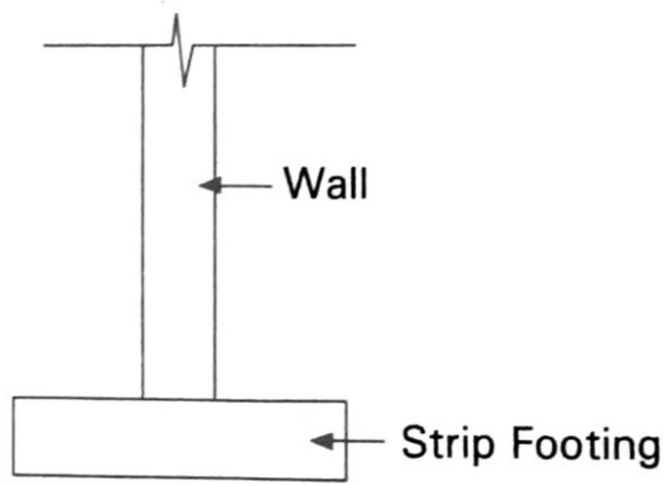
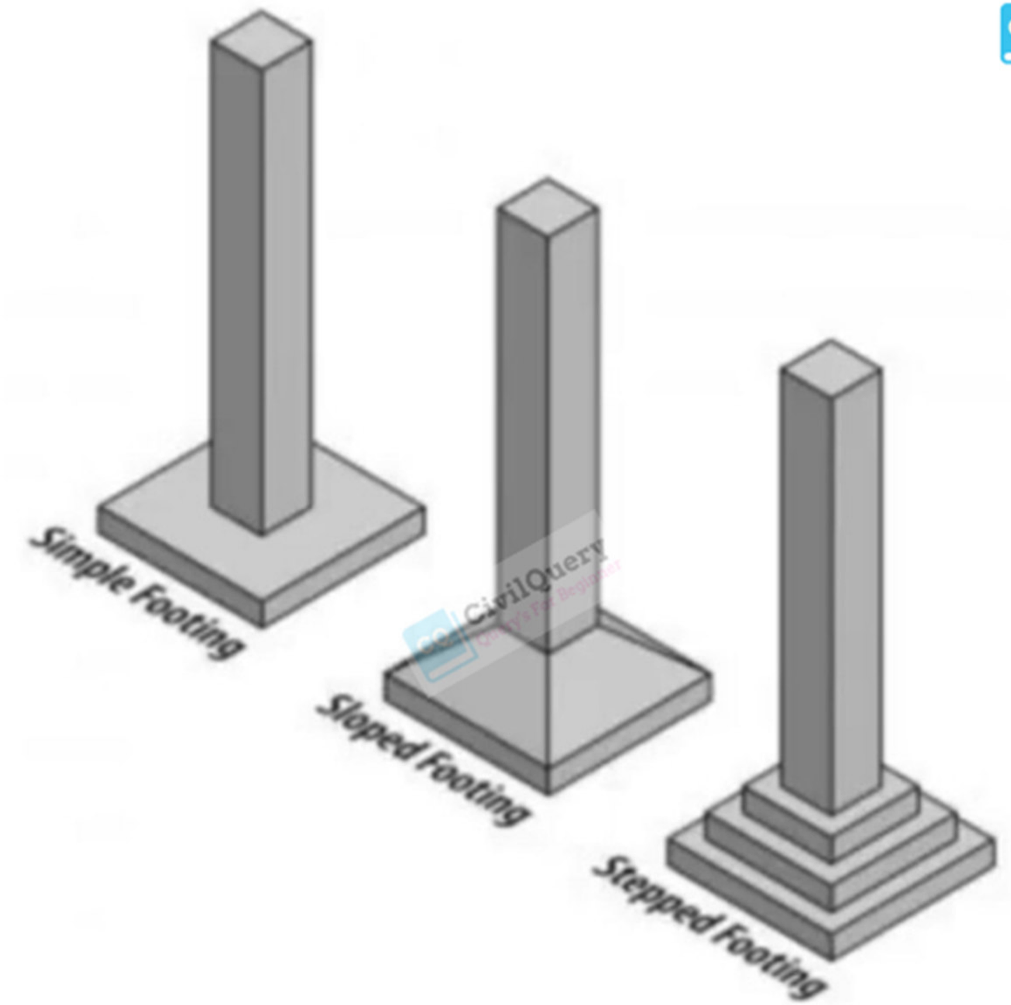
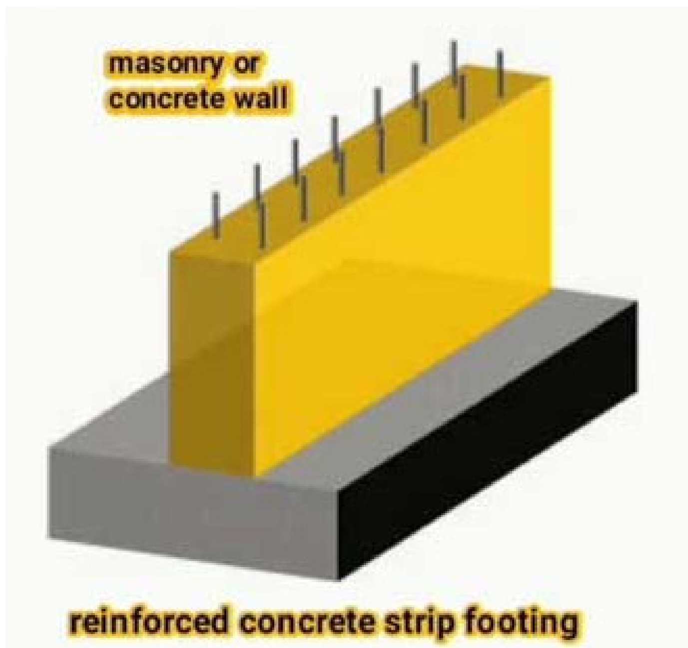


Fig: Spread footing



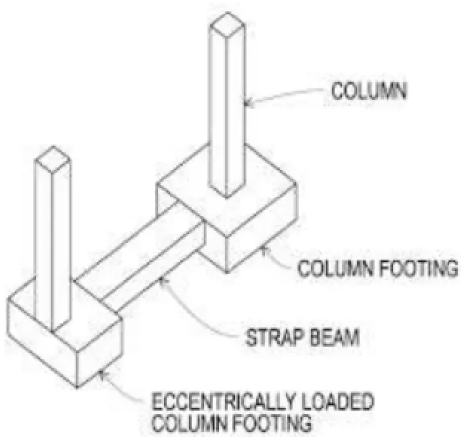

Simple Footing
Sloped Footing
Stepped Footing

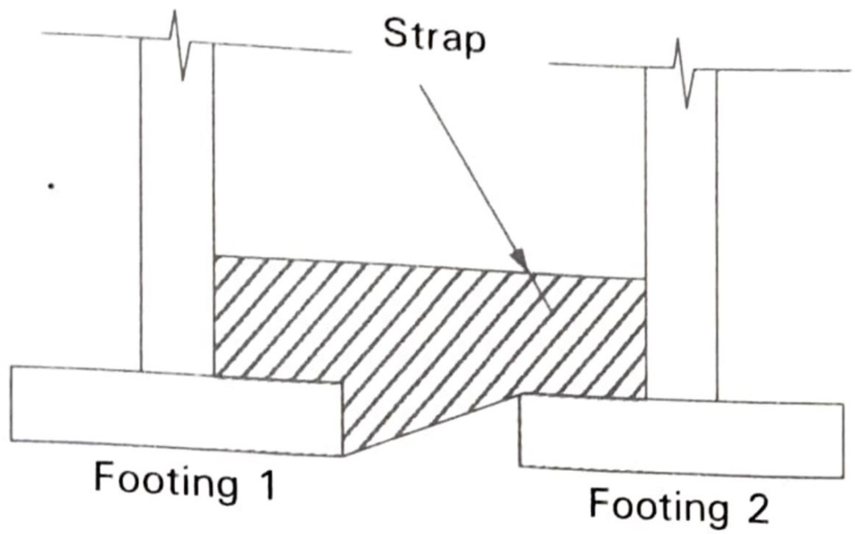
- *If spread footing is required to support a wall -> Strip or continuous footing*

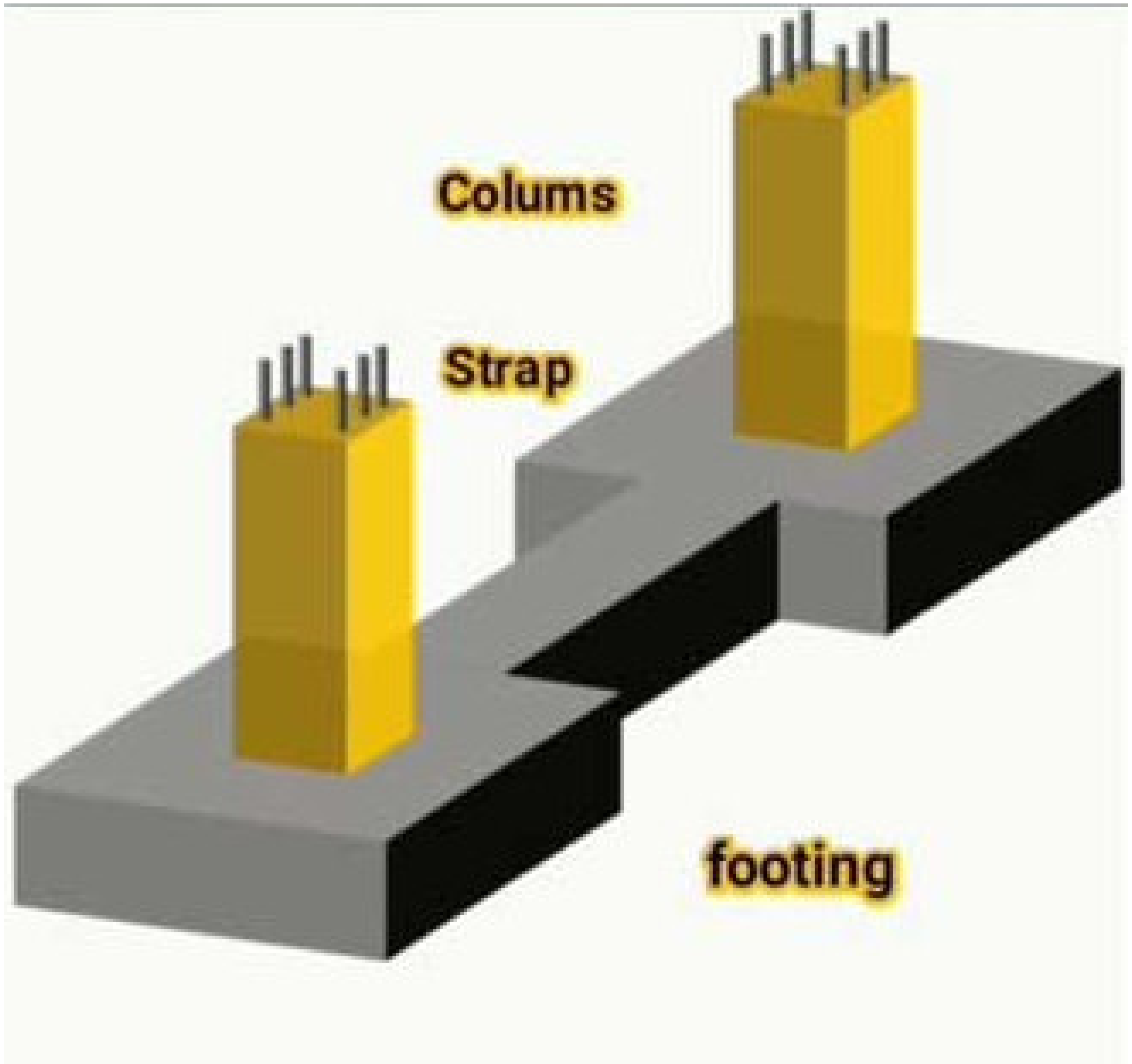


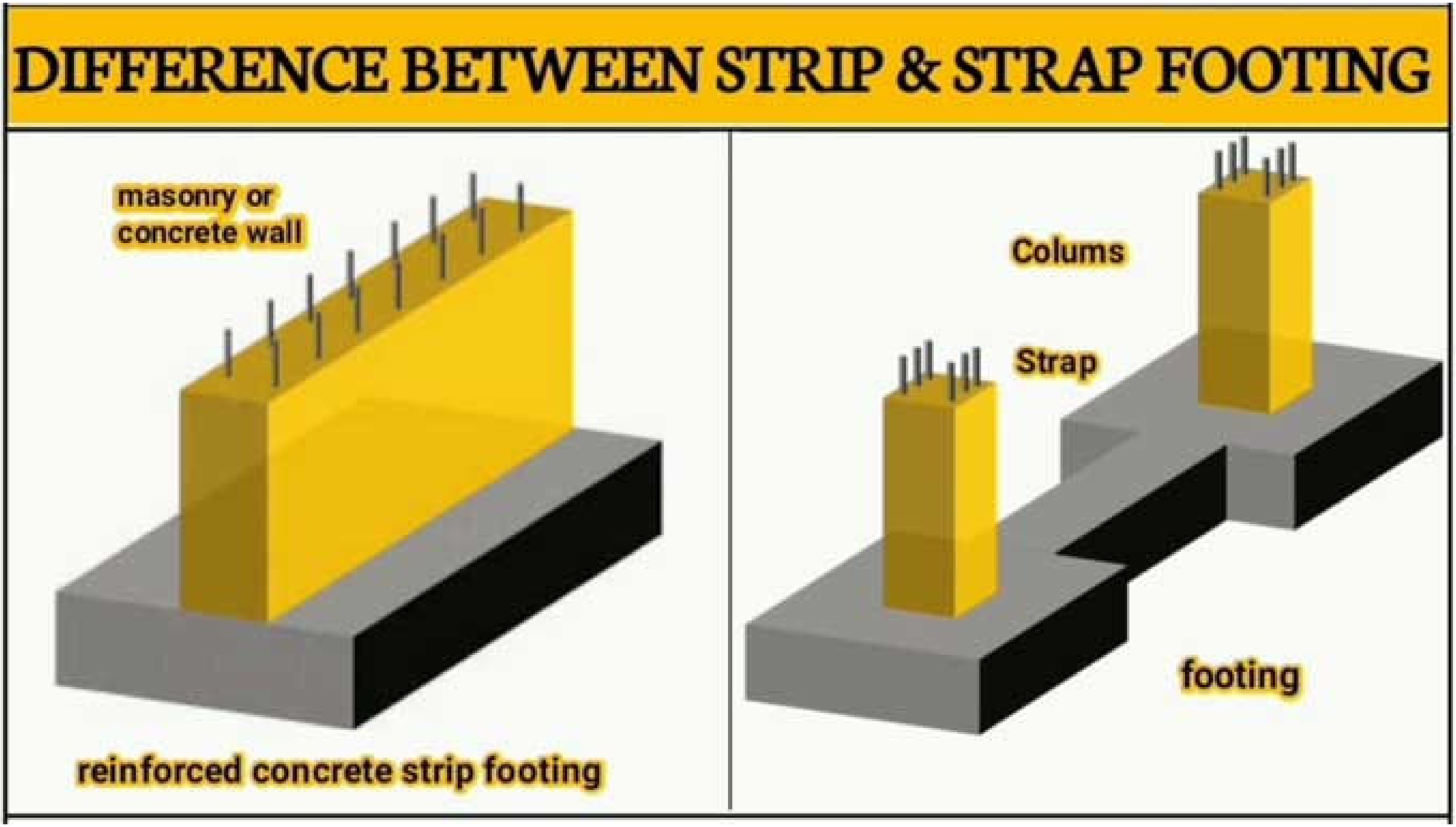
Strap footing

- *Two or more footings are connected by a beam called strap*
- *Also called cantilever footing*
- *Strap beam is not in contact with the soil*
- *CG of the two column loads shall pass through the CG of the two footings*



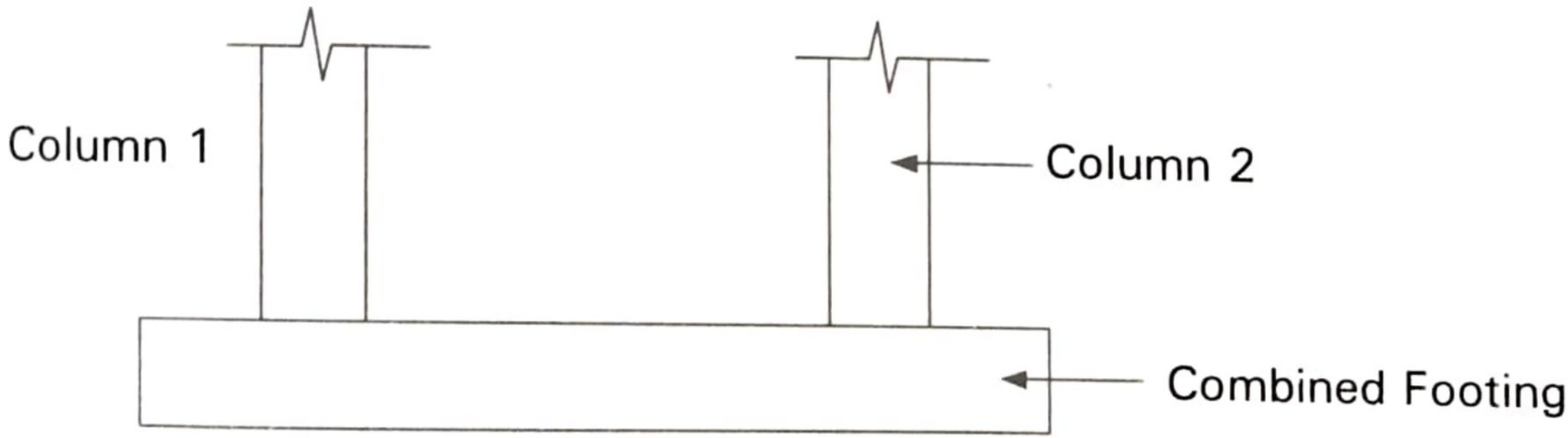


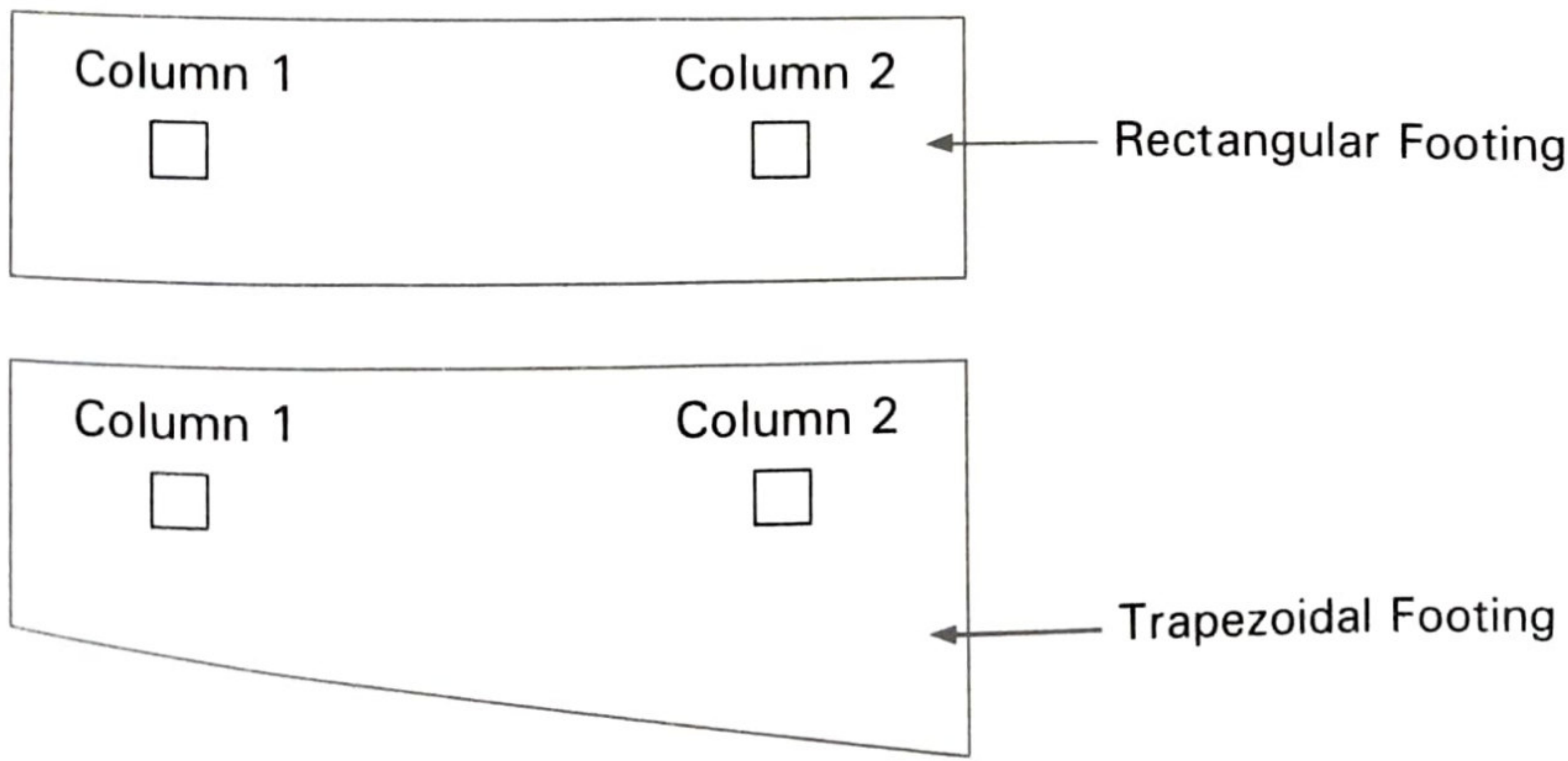

Colums
Strap
footing


DIFFERENCE BETWEEN STRIP & STRAP FOOTING
masonry or
concrete wall
reinforced concrete strip footing
Colums
Strap
footing

Combined footings

- *Sometimes the mat area required for adjacent footings are so large that the footings overlap.*
- *In such cases, single combined footing is provided for two or more columns*
- *Usually required where space is limited.*
- *Rectangular or trapezoidal in plan*
- *A combined footing supports two or more columns in a row.*
- *The combined footing can be rectangular in shape if both the columns carry equal loads or can be trapezoidal if both the loads are unequal.*
- *The location of the center of the gravity of the column loads and centroid of the footing should coincide.*


Column 1
Column 2
Combined Footing


Column 1
Column 2
Rectangular Footing
Column 1
Column 2
Trapezoidal Footing

Combined footing

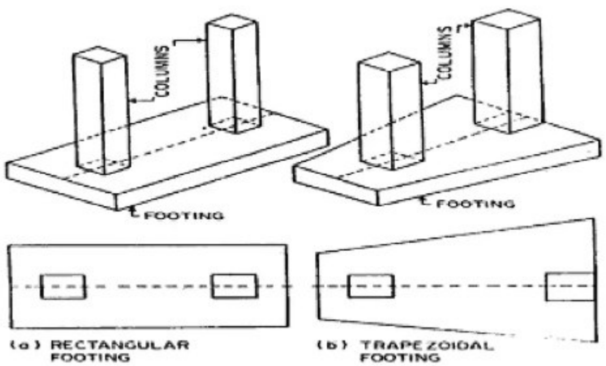
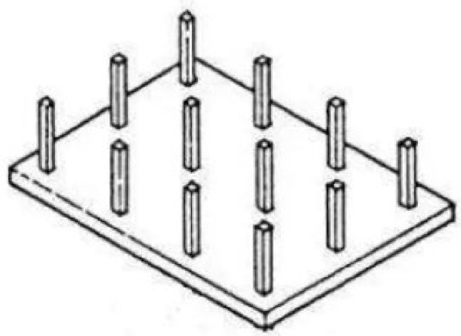
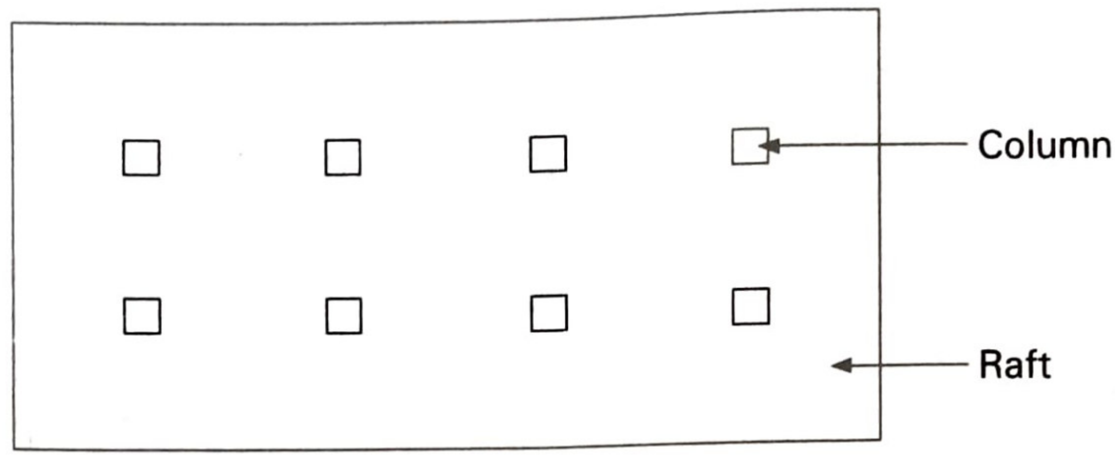


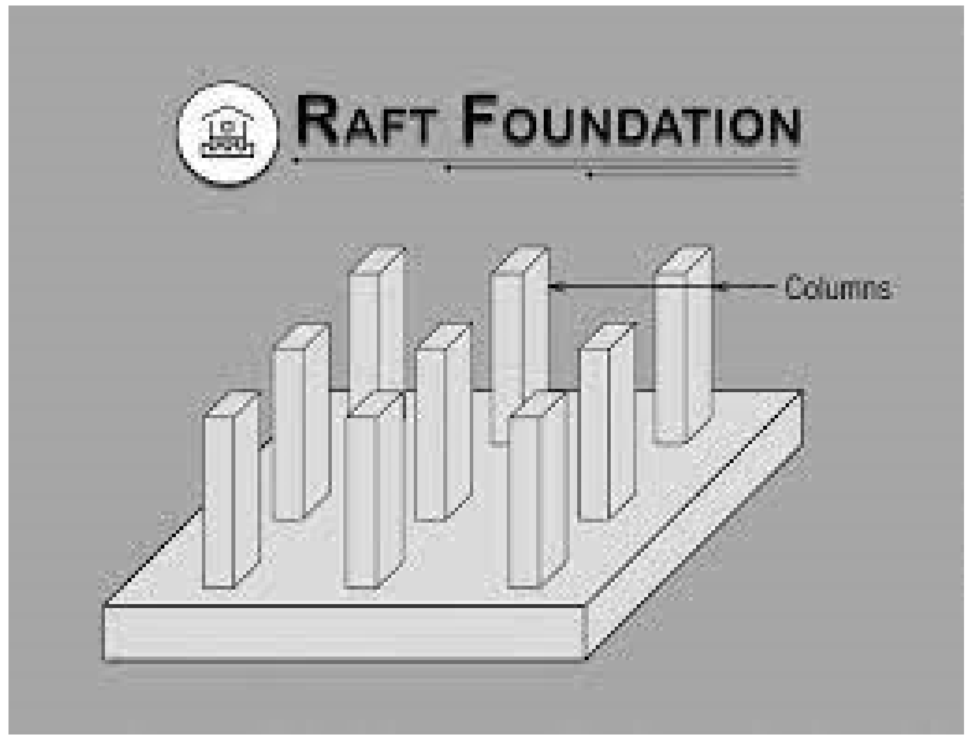
Fig: Combined footing

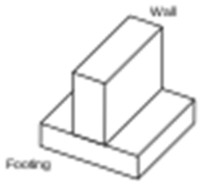
Mat / Raft footing

- *Bearing capacity of the soil is very low*
- *Then the mat area under the footings will exceed half the area*
- *In such conditions we provide mat footing*
- *Differential settlements can be avoided*
- *These footings can undergo large settlements*
- *Is like a concrete slab with uniform thickness throughout the area*
- *They are used where the soil mass contains compressible lenses so that the differential settlement would be difficult to control.*
- *Raft foundation is also used to reduce the settlement above highly compressible soils by making the weight of the structure and raft approximately equal to the weight of the soil excavated.*

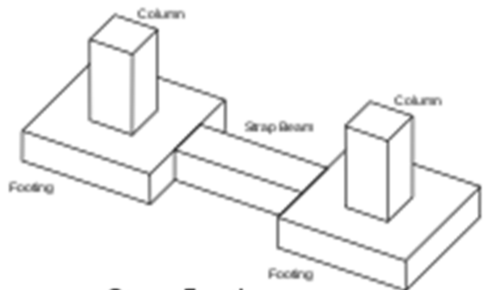



Column
Raft

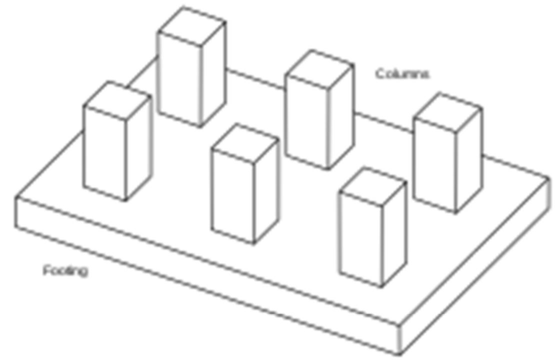

RAFT FOUNDATION
Columns



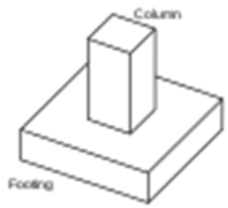
Wall Footing



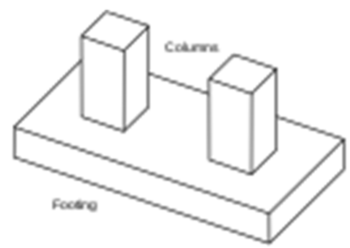
Strap Footing



Mat Foundation



Isolated Footing

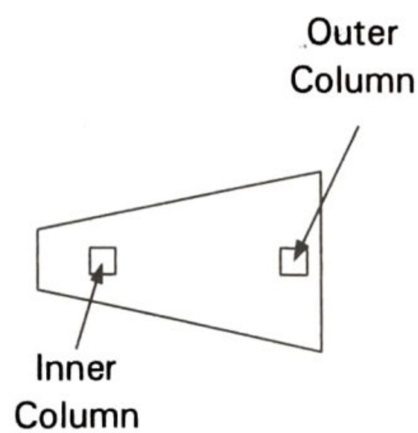


Combined Footing

PROPORTIONING OF A RECTANGULAR AND TRAPEZOIDAL COMBINED FOOTING

When two columns carry equal loads, the combined footing may be rectangular in shape and trapezoidal if the column carry unequal loads.

$$\text{Area of the footing} = \frac{\text{Load on the column}}{\text{S.B.C of the soil}}$$

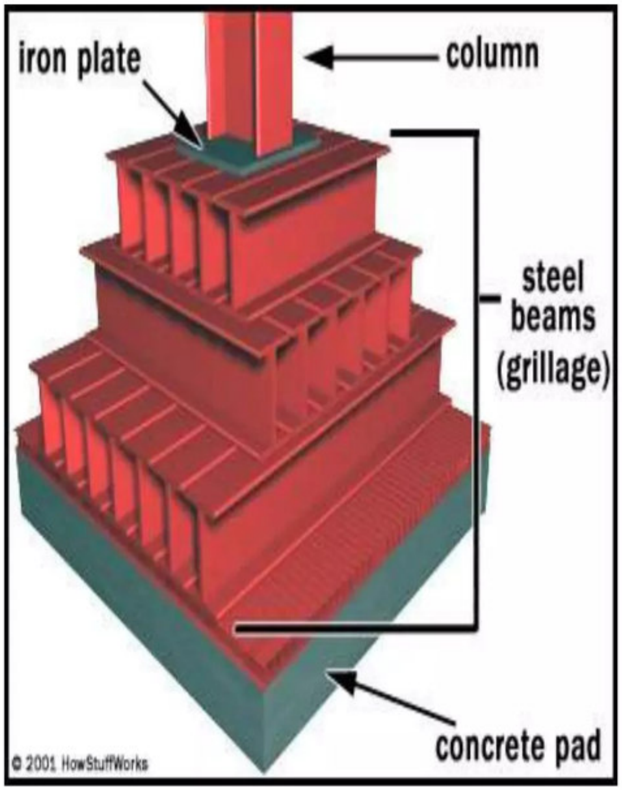


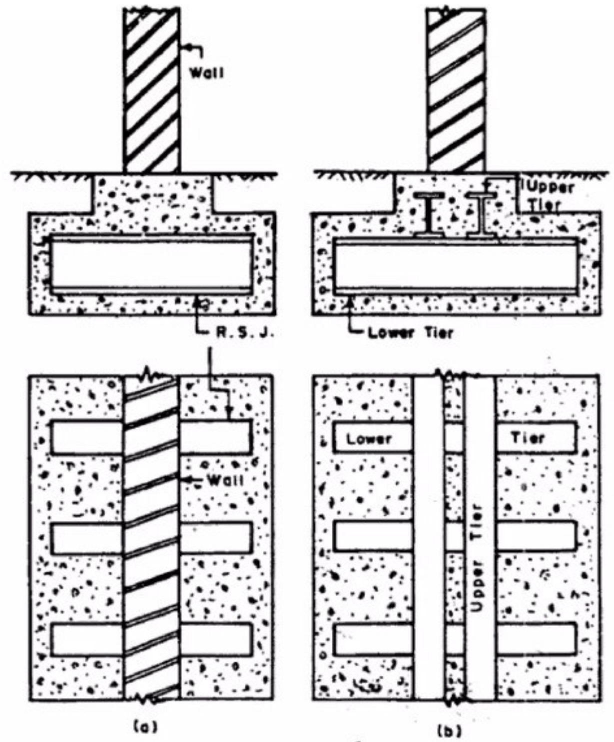
Therefore, when the column loads are unequal and the outer column near the boundary carries relatively heavy column load and when there is no space beyond the outer column for the footing, a trapezoidal combined footing is provided.

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 super imposed on a layer of concrete, adjacent tiers being placed at right angles to each other, while all tiers are encased in concrete.
- This is dependable foundation and is used in those place where the load of the structure is pretty high and bearing capacity of soil comparatively poor; extends to a depth of 1m to 1.5m

Grillage foundation





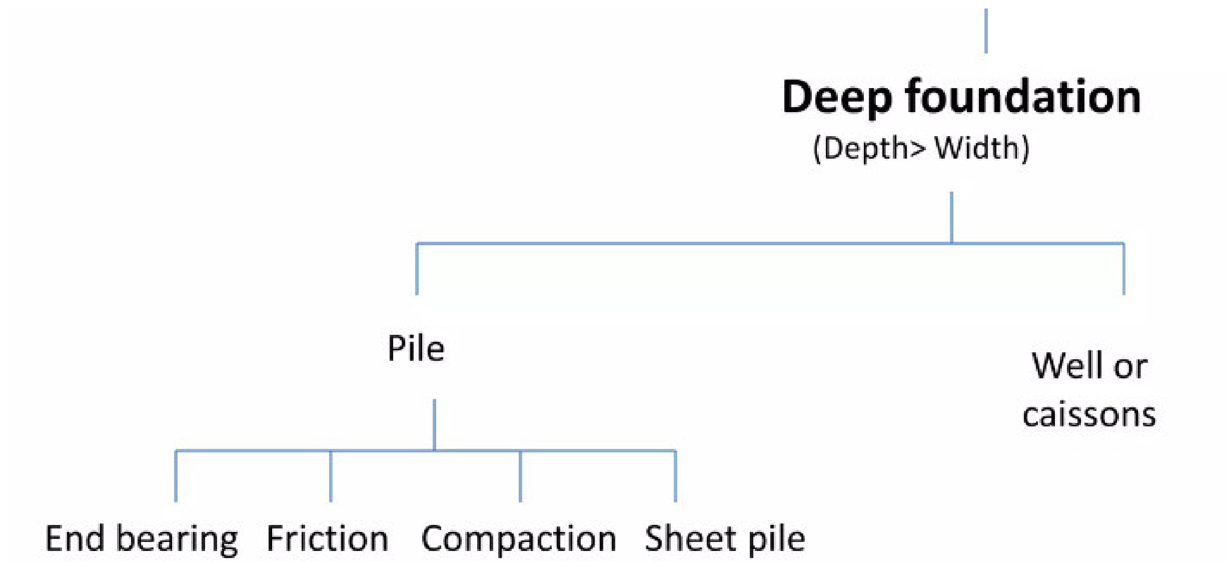
Grillage foundation

Grillage foundation

- The grillage foundation helps in distributing the load over a wider area of subsoil.
- The grillage foundation helps in avoiding deep excavations as the necessary base area is provided for the load of transmission.
- This type of foundation generally used for heavy structure columns piers and steel stanchions etc.

Deep foundations

- $\left(\frac{Depth\ of\ footing}{Breadth\ of\ footing}\right) \geq 1$



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 a deeper, more competent strata at depth if unsuitable soils are present near the surface.

Types of deep foundation

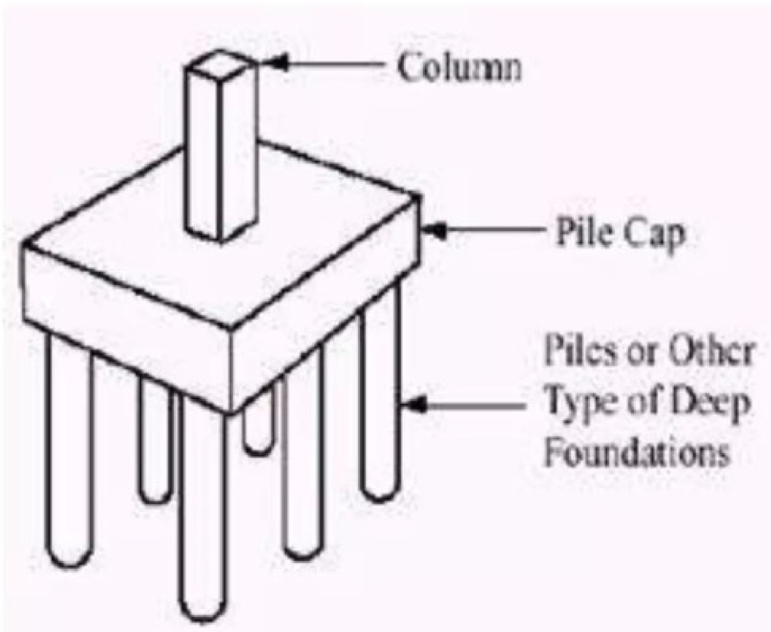
1. *Pile foundation*
2. *Caisson foundation*
3. *Well foundation*

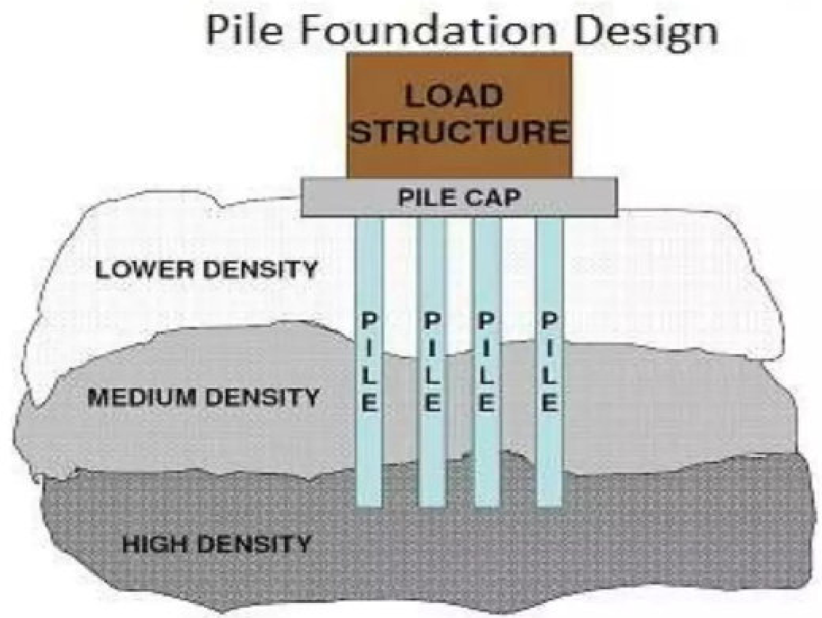
Pile foundations

- *Deep foundations*
- *Similar to columns driven on ground*
- *In some soils, sufficient hard strata is available only at considerable depth – loads are to be transmitted through strata of poor bearing capacity to a depth where soil has sufficient bearing capacity*

Pile foundations are used in the following situations:

- The load of the super structure is heavy and its distribution is uneven
- The top soil has poor bearing capacity
- The subsoil water level is high
- There is large fluctuations in subsoil water level
- Canal or deep drainage lines exist near the foundation
- The structure is situated on the sea shore or river bed


Column
Pile Cap
Piles or Other
Type of Deep
Foundations


Pile Foundation Design
LOAD
STRUCTURE
PILE CAP
LOWER DENSITY
MEDIUM DENSITY
HIGH DENSITY
PILE
PILE
PILE
PILE

Pile cap


Front
Structural Load
Pile cap
Soft
Medium
Hard ideal conditions

Classification of pile foundation

- *Based on*
  1. *Method of load transfer*
  2. *Function*
  3. *Method of construction*
  4. *Materials and composition*

Classification based on the method of load transfer

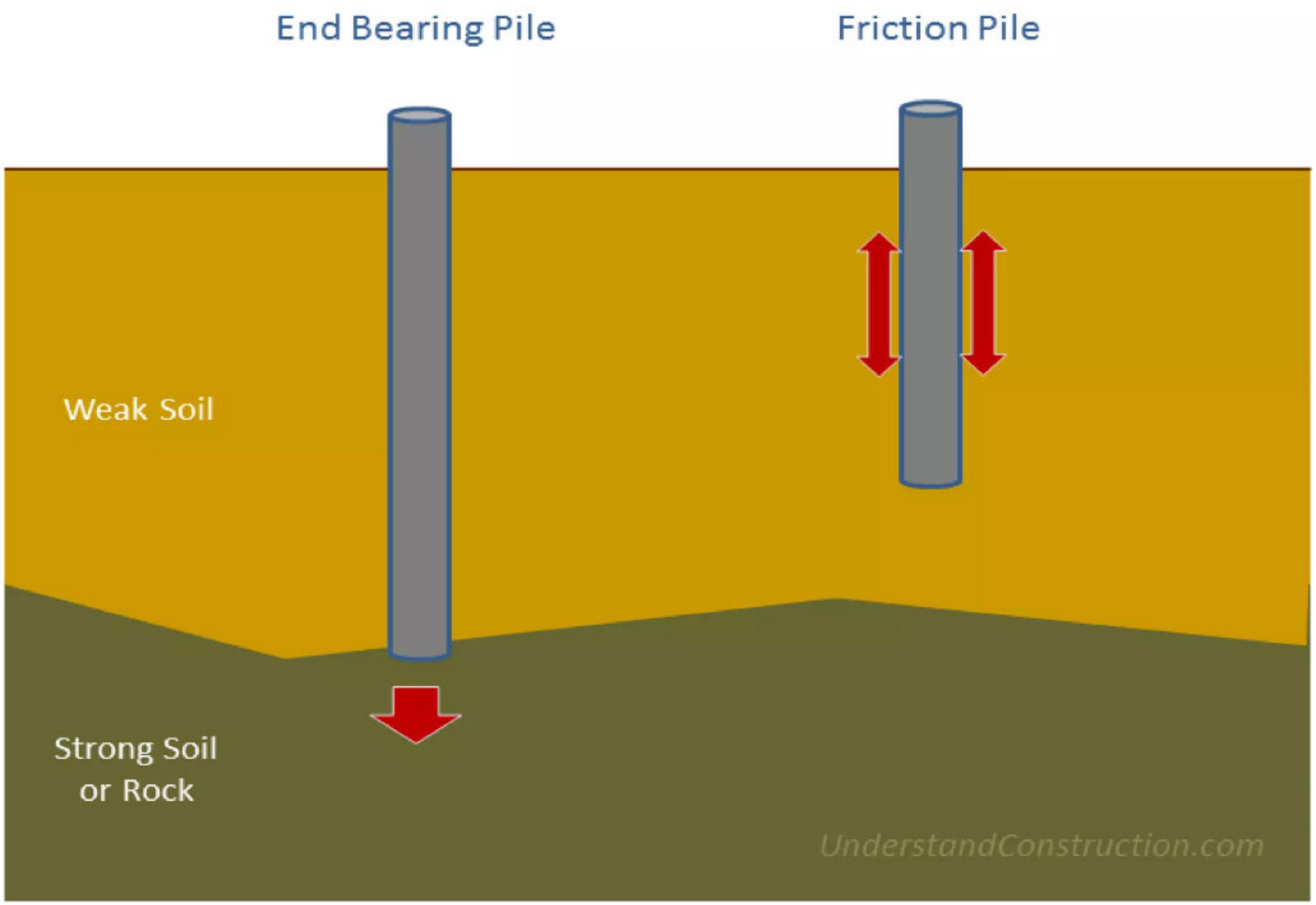
1. *End bearing piles*
2. *Friction piles*
3. *Combined end bearing and friction piles*

End bearing piles

- *Bottom end of the pile rests on a layer of especially strong soil or rock*
- *Load of the building is transferred through a pile onto a strong layer*
- *Pile acts like a column*
- *Load bypasses the weak layer and is safely transferred to the strong layer*

Friction piles

- *The pile transfers the load of the building to the soil across the full height of the pile, by friction*
- *Entire surface of the pile works to transfer the forces to the soil*


End Bearing Pile
Friction Pile
Weak Soil
Strong Soil
or Rock
UnderstandConstruction.com

a) Classification of Piles Based on the Function or Use

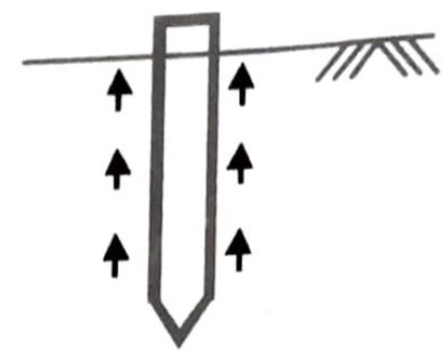
- Sheet piles
- Friction Piles
- Batter Piles
- End bearing Piles
- Compaction Piles
- Tension Piles
- Anchor Piles
- Fender Piles

1) **Sheet piles :**

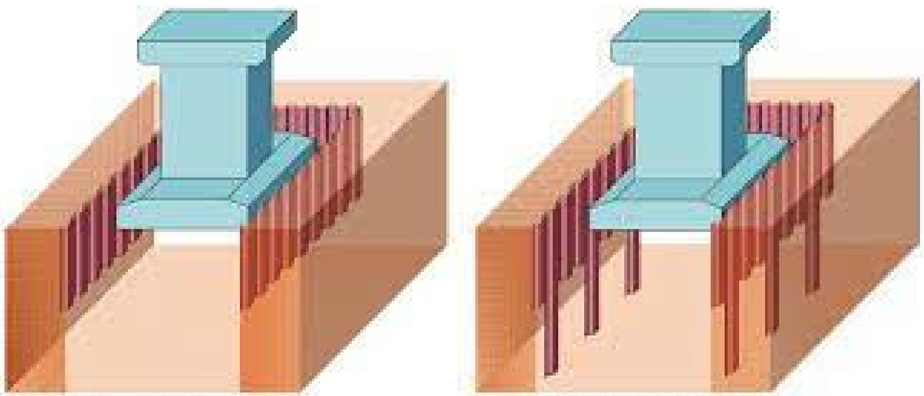
Sheet piles are sheets driven into the ground to reduce seepage and uplift under hydraulic structures.

2) **Friction piles** :

In friction piles, load is transfered to a depth by means of skin friction along the length of piles.



Sheet pile

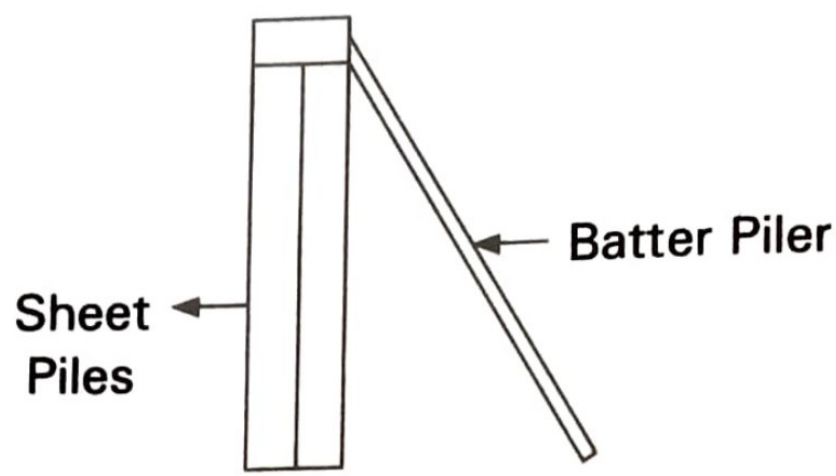


(a) Sheet pile foundation

(b) Sheet pile foundation by sheet pile with closed section

3) Batter piles :

Batter piles are used to resist large horizontal or inclined forces.

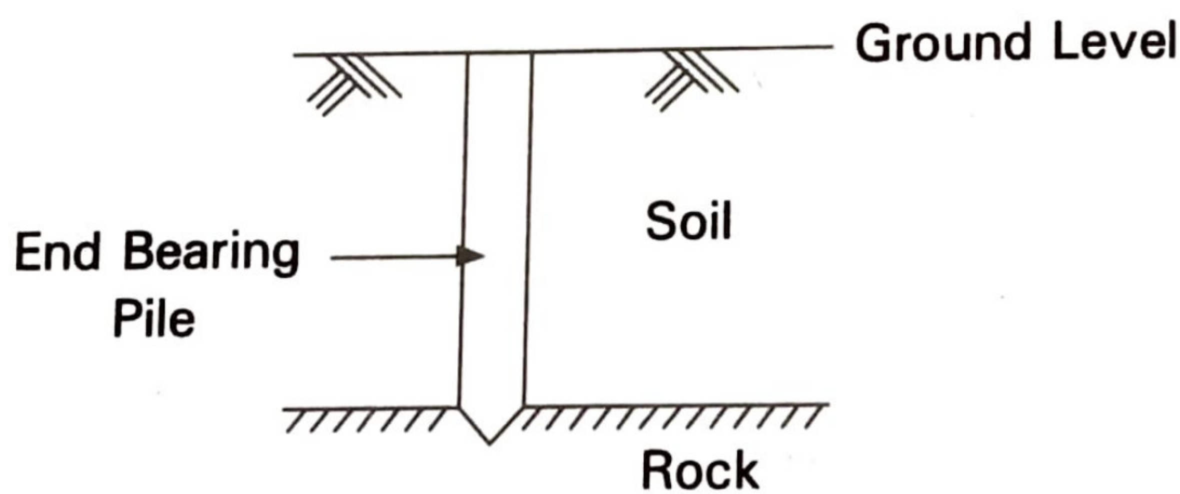


Batter piles along the protected side of the IHNC-Lake Bor... | Flickr

Visit

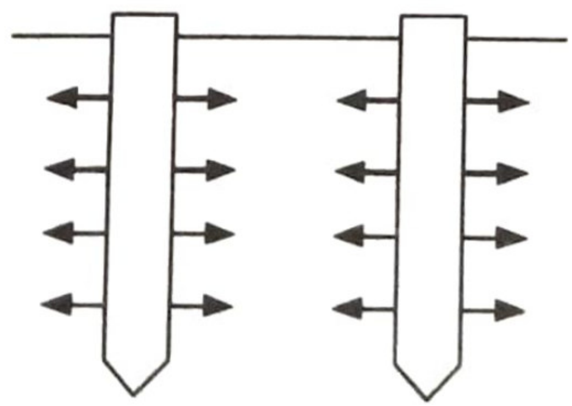
4) **End bearing piles :**

The end bearing pile is used to transfer load to a suitable soil structures.

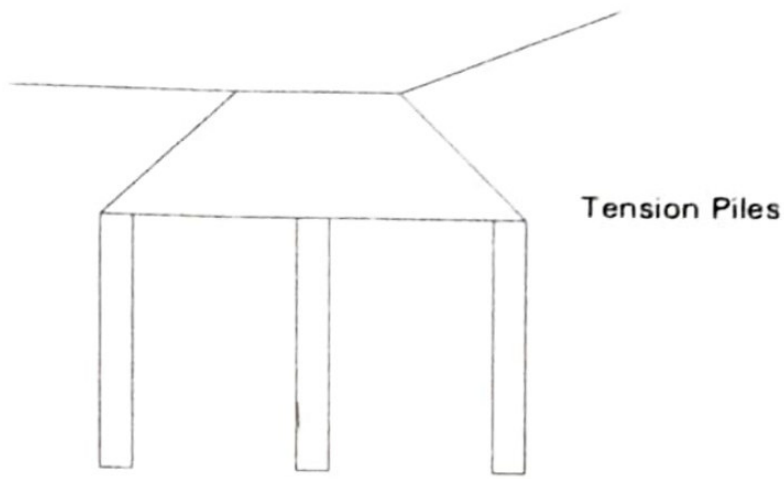


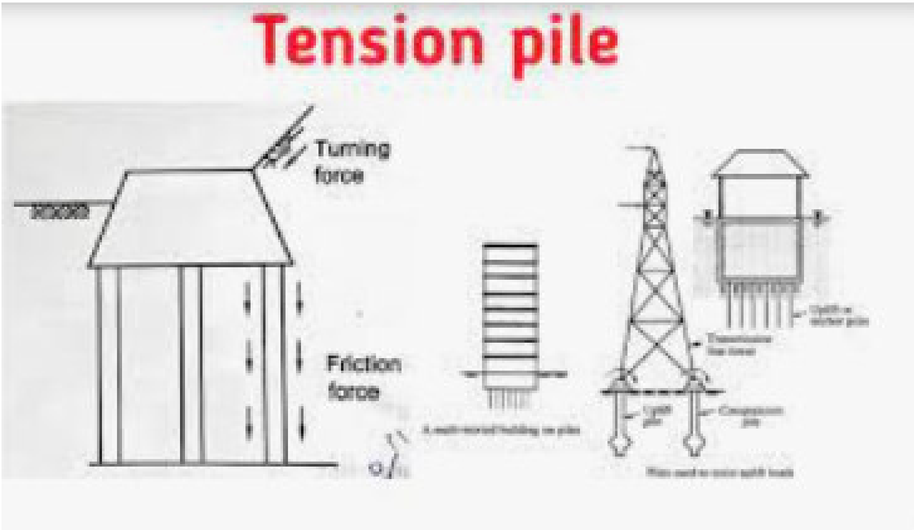
5) Compaction piles :

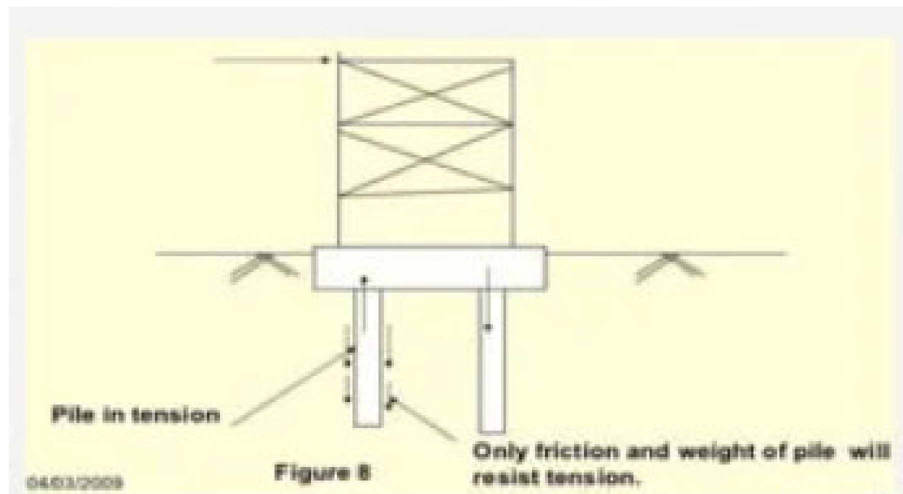
Compaction piles do not carry any load. They are used to compact loose granular coil.



6) Tension or uplift piles are used to anchor the structures subjected to uplift.




Tension pile
Turning force
Friction force

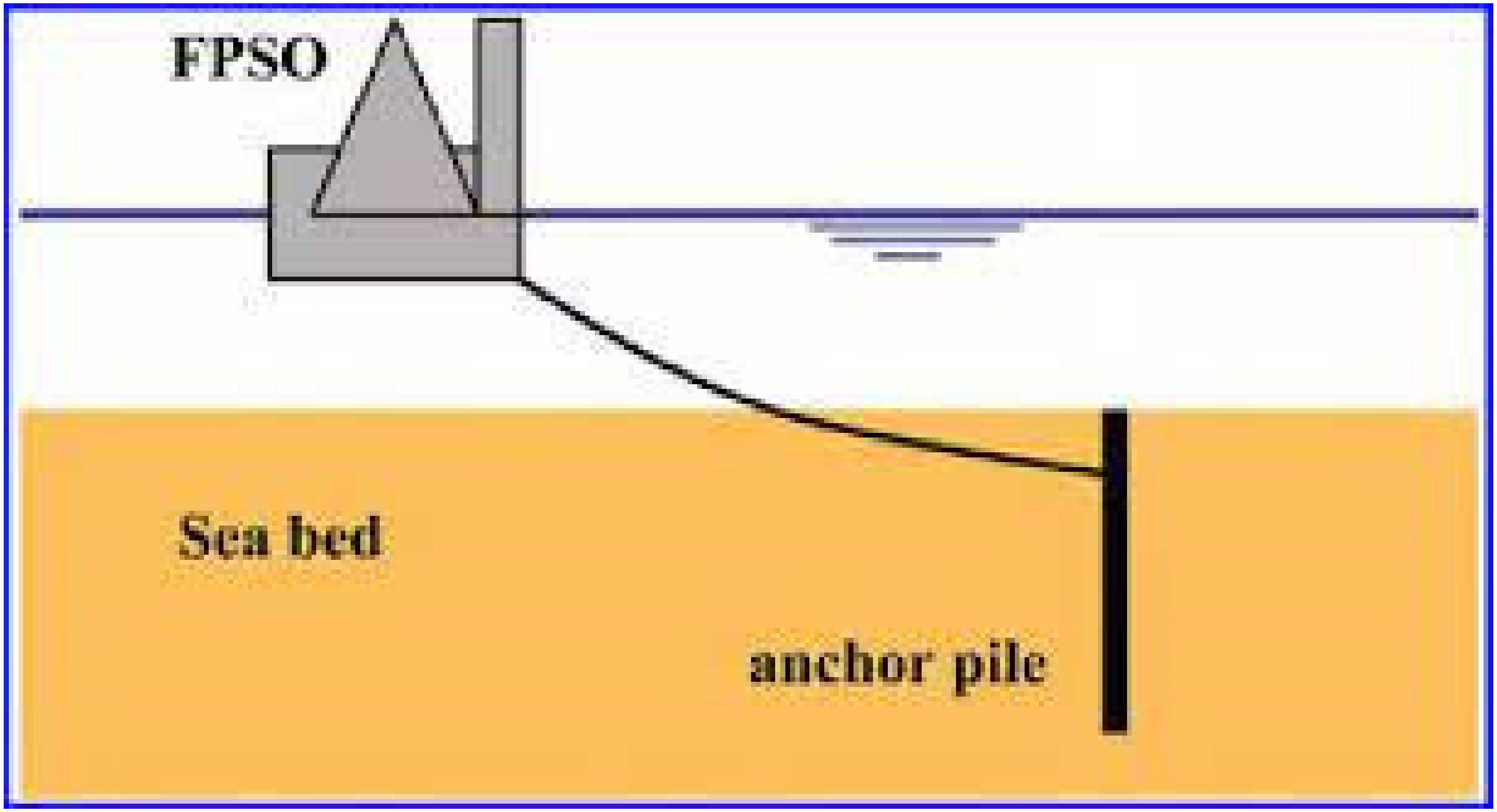

Pile in tension
Only friction and weight of pile will resist tension.
Figure 8
04/03/2009

7) **Anchor piles :**

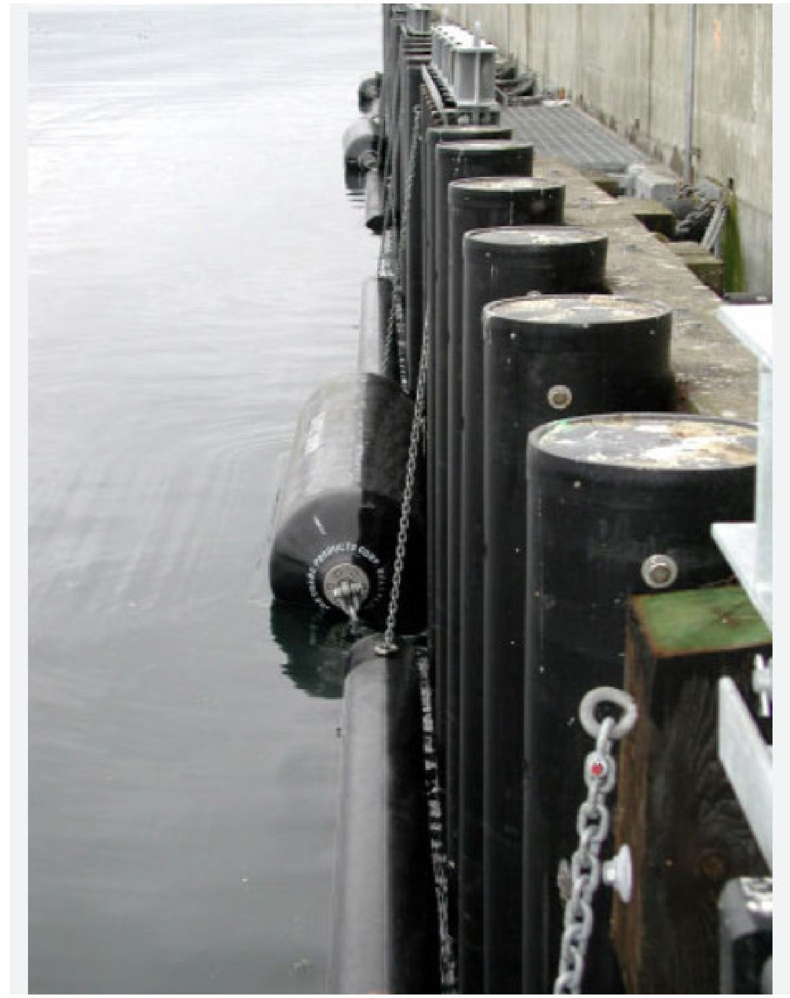
Anchor piles are used to provide incharge against horizontal pull.

8) **Fender piles :**

In water front structure usually the ships or other floating objects cause an impact. Fender piles are used to protect the water front structures from such impact.


FPSO
Sea bed
anchor pile

Fender pile



Classification based upon the material used

1. *Timber piles*
2. *Concrete piles*
3. *Composite piles*
4. *Steel piles*

Timber piles:

- *Transmission of load takes place by the frictional resistance of the ground and the pile surface.*
- *economical for supporting light structures to be located in compressive soils constantly saturated with water.*
- *driven with the help of pile – driving machine in which a drop hammer delivers blows on the pile head.*
- *the lower end of the pile is pointed and is provided with a cast iron conical shoe.*
- *Advantages:*
  - *They are economical*
  - *They can be driven rapidly*
  - *They do not need heavy machinery and elaborate technical supervision*
  - *Due to their elasticity, timber piles can be used where lateral forces are subjected*
- *Disadvantages:*
  - *They have low bearing capacity*
  - *They are liable to decay*
  - *They cannot be used where long piles are needed*

Concrete piles:

1. *Pre-cast piles*
2. *Cast-in-situ piles.*

Pre-cast piles:

- *are reinforced concrete piles which are cast and cured in casting yard and then transported to the site for driving.*
- *The function of reinforcement in pre-cast piles is to resist the stresses produced by its handling, driving and loading which the pile is finally expected to receive*
- *Advantages*
    - *Proper control in casting*
    - *Not affected by chemical action of ground soil*
    - *Can be subjected to load immediately after driving*
    - *Can be driven under water*
- *Disadvantages*
    - *Difficult for transport*
    - *Handling and driving stresses are high*
    - *Extra steel is requires at top and bottom*
    - *Length of pile is restricted*

Cast-in-situ piles:

- those piles which are cast in position inside the ground.
- piles are not subjected to handling or driving stresses it is not necessary to reinforce the pile in ordinary cases.
- Advantages
  - No handling & driving stresses, hence lighter reinforcement
  - Piles can be cast in required length
- Disadvantages
  - Position of reinforcement may get disturbed during installatiom
  - Difficult to be cast under water.

Steel Piles

- *suitable if the hard strata are available at greater depths.*
- *They have very small soil displacement owing to their small cross sections.*
- *Piles are welded during driving to achieve longer lengths.*
- *They are used in the form of H-Piles, Box-piles and tube piles.*
- *Advantages*
  - *Can be subjected to load immediately after driving*
  - *Suitable for deeper depths.*
- *Disadvantages*
  - *Requires heavy machinery for driving*
  - *Need skilled operators*
  - *Transportation to site is difficult*
  - *Subject to vibration during pile driving*

Caisson foundation

- *Also called pier foundation*
- *A watertight retaining structure used as a bridge pier, in the construction of a concrete dam, or for the repair of ships*
- *It is a prefabricated hollow box or cylinder sunk into the ground to some desired depth and then filled with concrete*
- *Adopted when the depth of water is great and foundations are to be laid under water*
- *Generally built on the shore and launched into the river floated to the site and sunk at proper position*

Caisson foundation - types

1. *Box caissons*
2. *Open caissons or well caissons*
3. *Pneumatic caissons*

Box caissons

- Watertight boxes – of timber / concrete / steel
- Open at top
- Floated to the appropriate location and sunk into place with a masonry pier within it
- Used where loads are not very heavy

Open caissons / Well foundations

- Box of concrete / steel / timber
- Open at top and bottom
- Placed and then pumped dry and filled with concrete
- Most common in Indian bridges

Pneumatic caissons

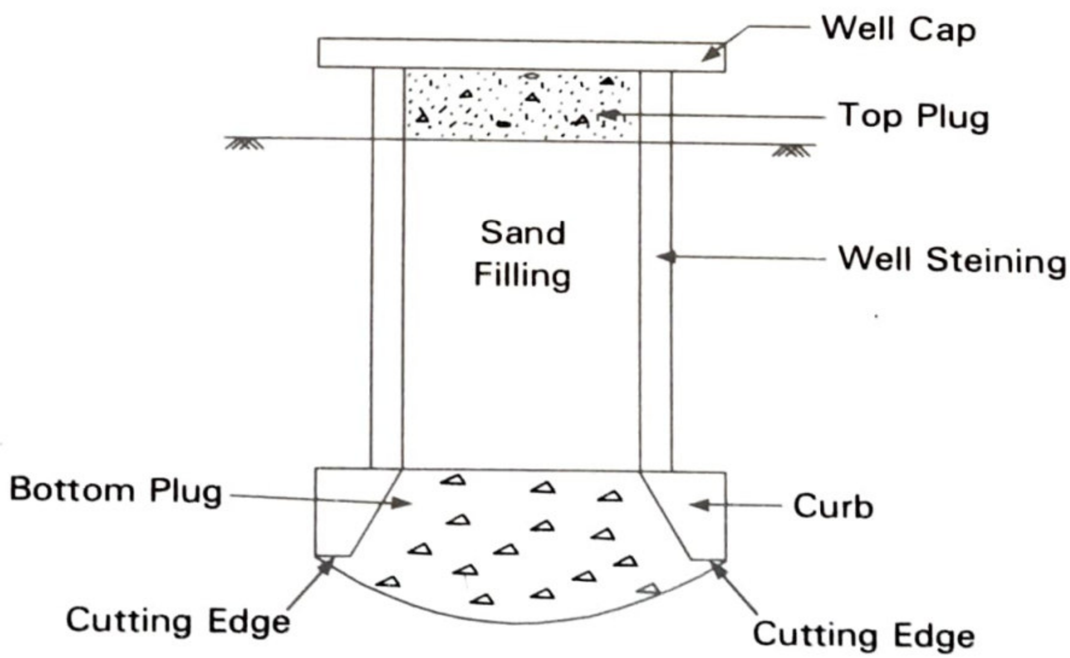
- *Large watertight boxes or cylinders*
- *Compressed air is used to exclude water from the working chamber*
- *Used only if head of water is more than 12m*

Well foundation

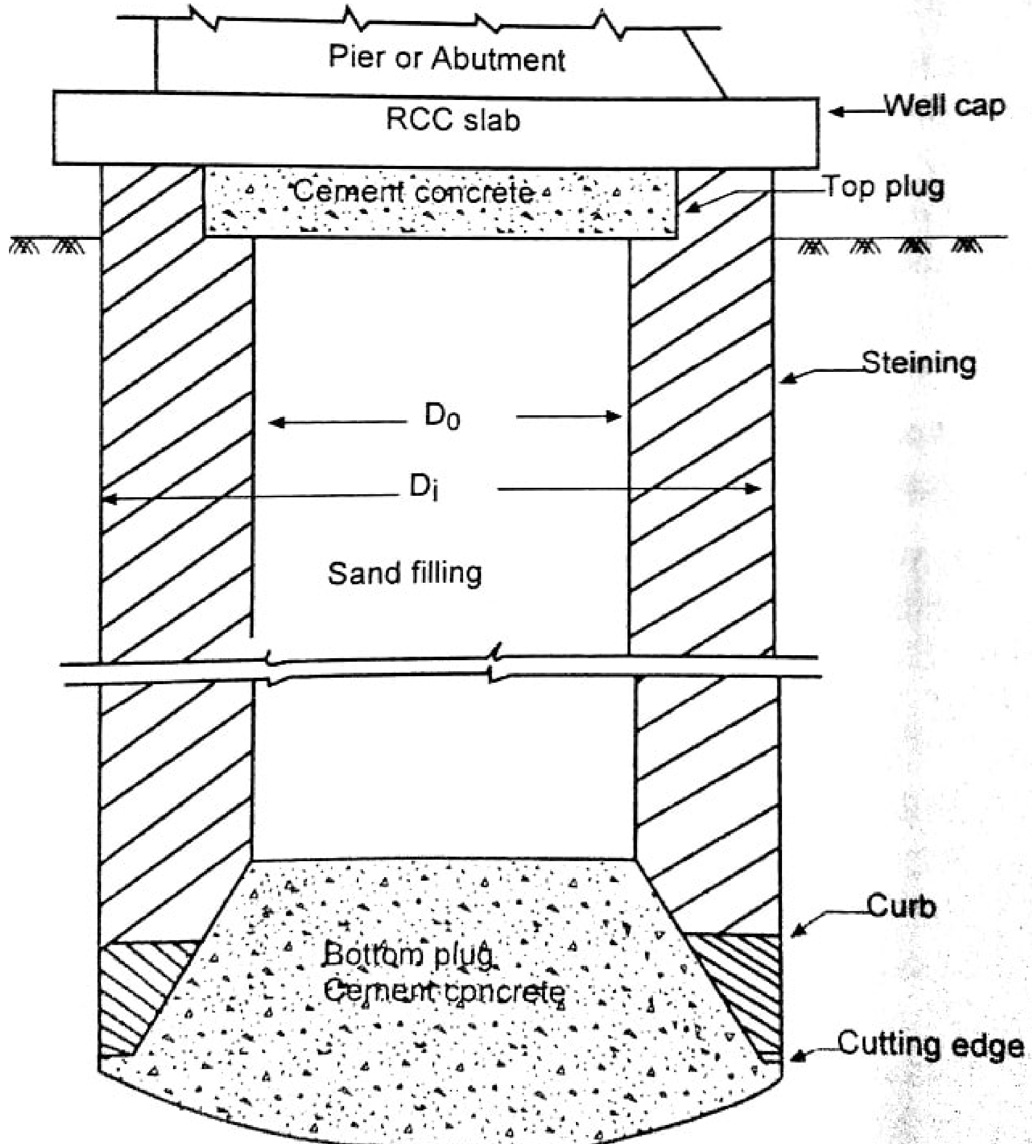
Open Caisson

4.6 SHAPES AND COMPONENTS OF WELL FOUNDATION

Well foundations are deep foundations and can be used below bridges, adequates etc.



Well Foundation



Pier or Abutment
RCC slab
Well cap
Cement concrete
Top plug
Steining
D_0
D_i
Sand filling
Curb
Bottom plug
Cement concrete
Cutting edge

The components parts of a well foundation are shown in the figure.

1. Well curb
2. Cutting edge
3. Well steining
4. Bottom plug
5. Top plug
6. Well cap

1) **Well curb** : The well curb is tapered in shape and in a member made up of R. Concrete in between the sharp cutting edge and the well staining.

2) **Cutting edge** : The cutting edge is a very sharp member usually made up of angle iron which helps in cutting through the soil and facilitates easy penetration of the well.

3) **Well steining** : The well steining forms the body of the well foundation and is usually made up of brick or stone masonry or with plain or reinforced concrete.

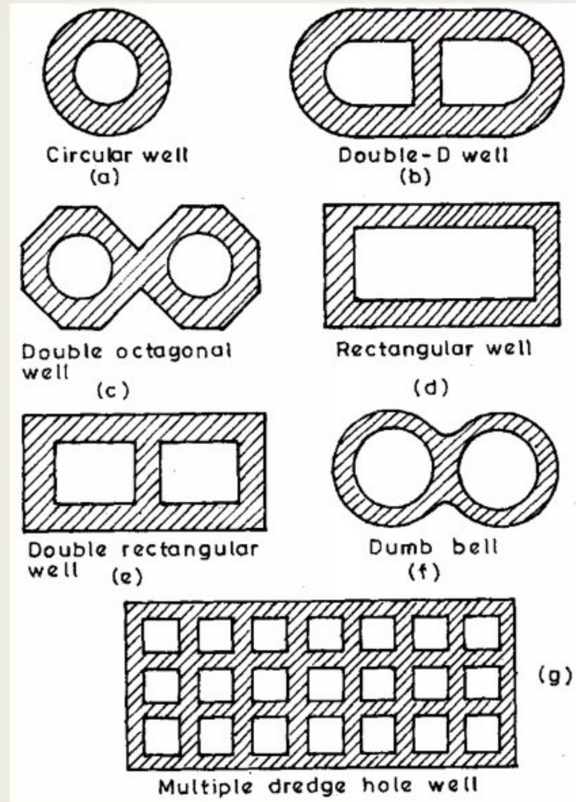
4) **Bottom plug** : The well foundation in carefully sunk to the required depth so that it rests on a hard stratum. Then, the bottom of the well is filled with concrete, called the bottom plug. The bottom plug forms the base of the well.

5) **Top plug** : On completion of the bottom plug, the well is filled with sand and a top layer of concrete is filled, which is known as the top plug.

6) **Well cap** : The well cap primarily provide a means of transfering the load from the super structure to the well steining. The piers or abutments may be constructed on the top of the well cap.

Types of well shapes:

- Circular well
- Rectangular well
- Double Rectangular well
- Double Octagonal well
- Double – D well
- Twin circular well



4.7 METHOD OF WELL SINKING

Well sinking is an interesting and challenging process and is explained in a step-wise procedure below.

1. If the river is with water during the progress of well sinking, an island is made which is big enough to provide space for men and machinery.

2. The centre point of the well is marked carefully.

3. The cutting edge is placed on a level plane.

4. Wooden sleepers are provided below the cutting edge at regular intervals to prevent uneven settlement of the cutting edge during concreting. However, they are subsequently removed.

5. The shuttering for the curb is carefuly positioned. The shuttering can be made of wood or steel.

6. The reinforcement for the curb and the vertical reinforcement for steining are placed in position.

7. Concreting of curb is done in a single operation.

8. Ensuring vertically of the well steining, the steining is raised by 1m at a time, to its complete height.

9. The well is cured for atleast 48 hours.
10. Subsequently, the well is either ready for loading or sinking.
11. The well is sunk by slowly excavating the material from inside the curb and throughout the well must be maintained to plumb.
12. Additional load known as kentledge is applied on the well to overcome the skin friction along the sides of the well and that due to buoyancy.

Correction of tilting and shifting

During sinking of a well, every care is taken to see that perfect verticality is maintained. However, sometimes there may be an angular movement in the well called 'tilt' or a 'shift' i.e., lateral movement of the well from its position. In order to avoid tilts and shifts in the well, the following precautions may be taken.

1. The body of the well i.e., the well steining must be smooth.
2. The cutting edge must be very sharp.

3. The radius of the curb must be larger than the radius of the well steining.
4. Uniform dredging must be done on all sides.
5. The tilt can be rectified by more on the higher side grabbing of the well.
6. Heavier kentledge may also be provided on the higher side of the well (with greater eccentricity) in order to control and reduce the tilt.
7. The well may also be brought to the required position by pulling with steel ropes.

8. The well may also be pushed by using a mechanical or hydraulic jack on the fitted side of the well.

9. A water jet may be forced on the outer faces of the well on the higher side.

10. In some conditions controlled dewatering may help in easing the situation.

Tilt and Shift

- The well should be sunk vertical & at the right position through all kinds of soils
- IS 3955 – 1967 suggests that tilt should be restricted to 1 in 60

Shift

- IS 3955 – 1967 suggests that shift be limited to 1% of depth sunk

1.Regulation of grabbing

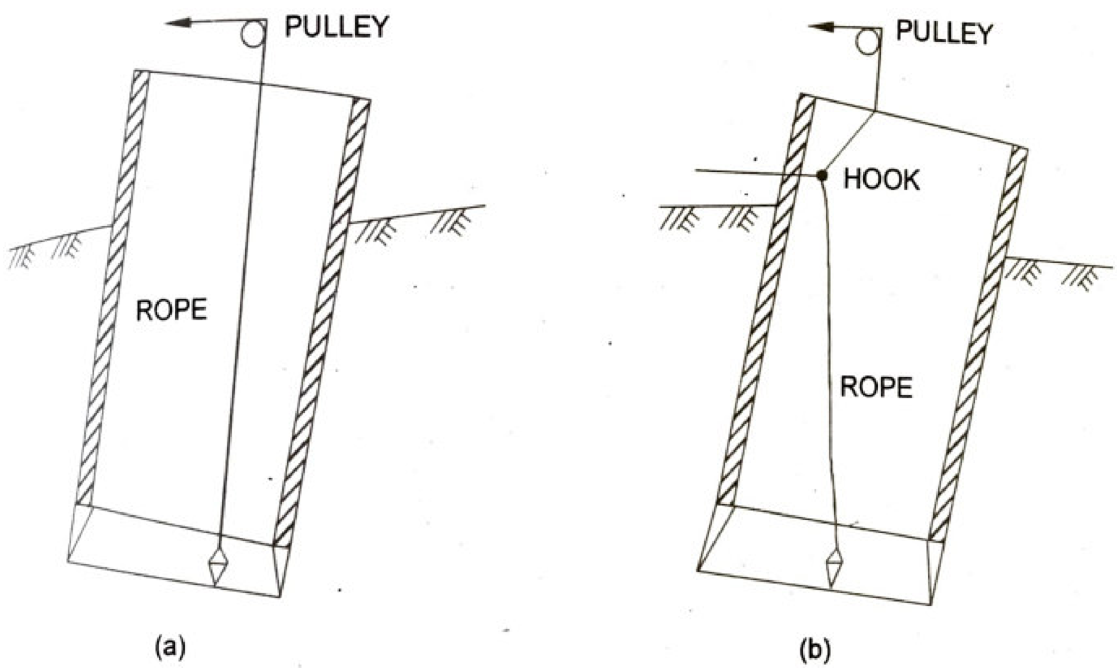


Fig. 4.13

Eccentric loading

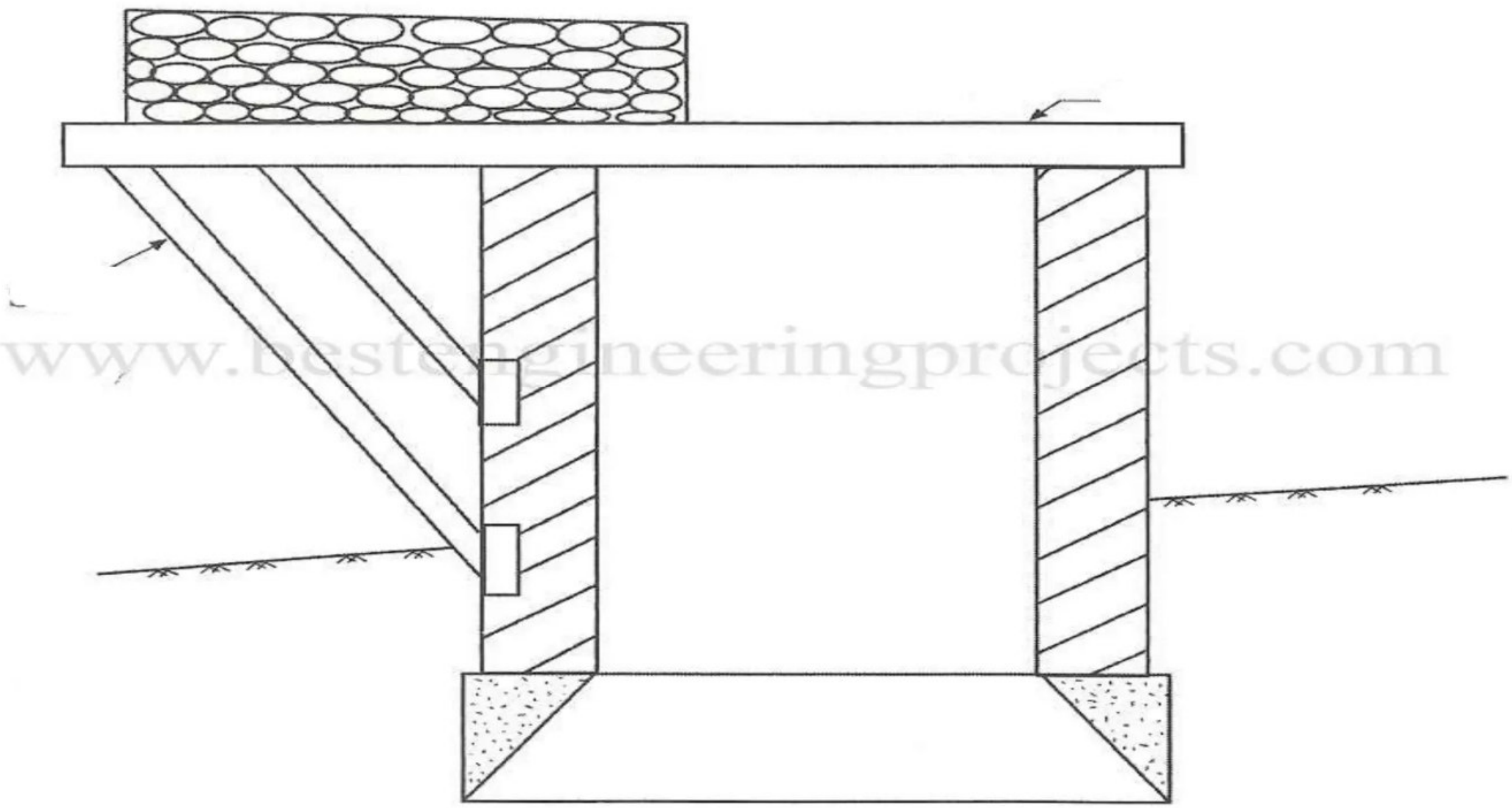


Fig 5 Eccentric Loading

Inserting wooden sleeper under the cutting edge

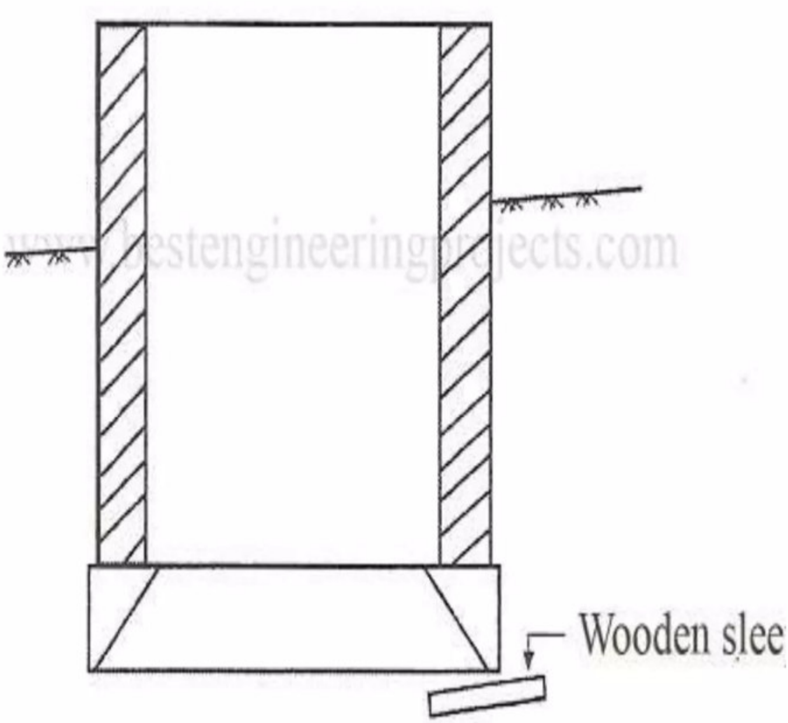


Fig 6 Provision of Wooden Slipper

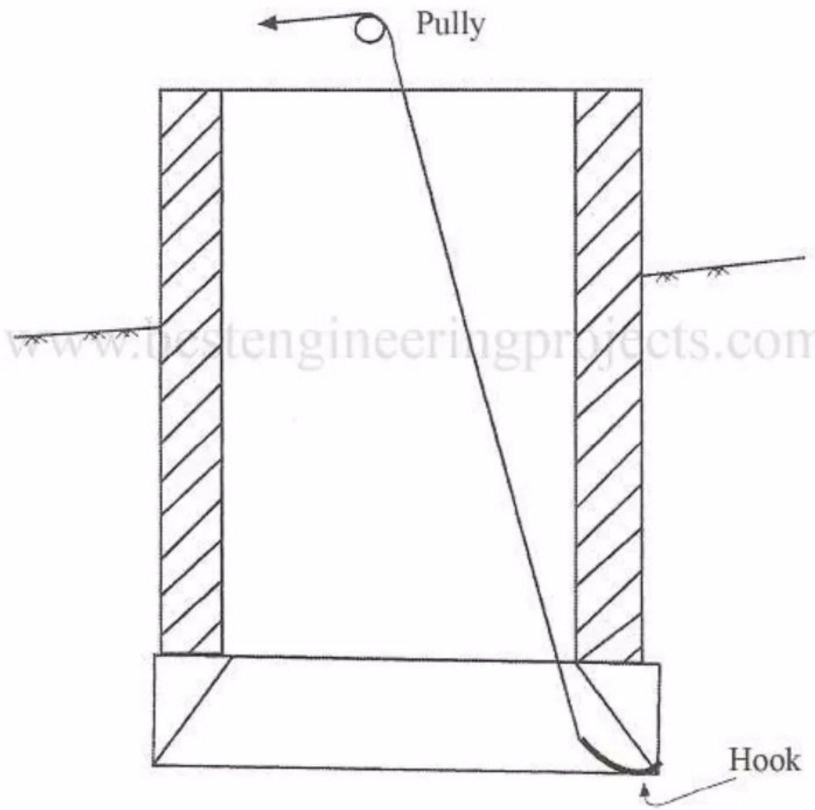


Fig 7 Hooking the Well

3. *Water Jetting :*

If the water jets are applied on the outer surface of the well on the higher side, the side friction is reduced & the tilt is rectified.

4. *Excavation under cutting edge :*

A tilted well in a hard clayey stratum does not straighten due to unbroken hard stratum on the higher side. if dewatering of the well is possible, open excavation is done under the cutting edge. In case dewatering is not possible, divers can be sent to loosen the strata.

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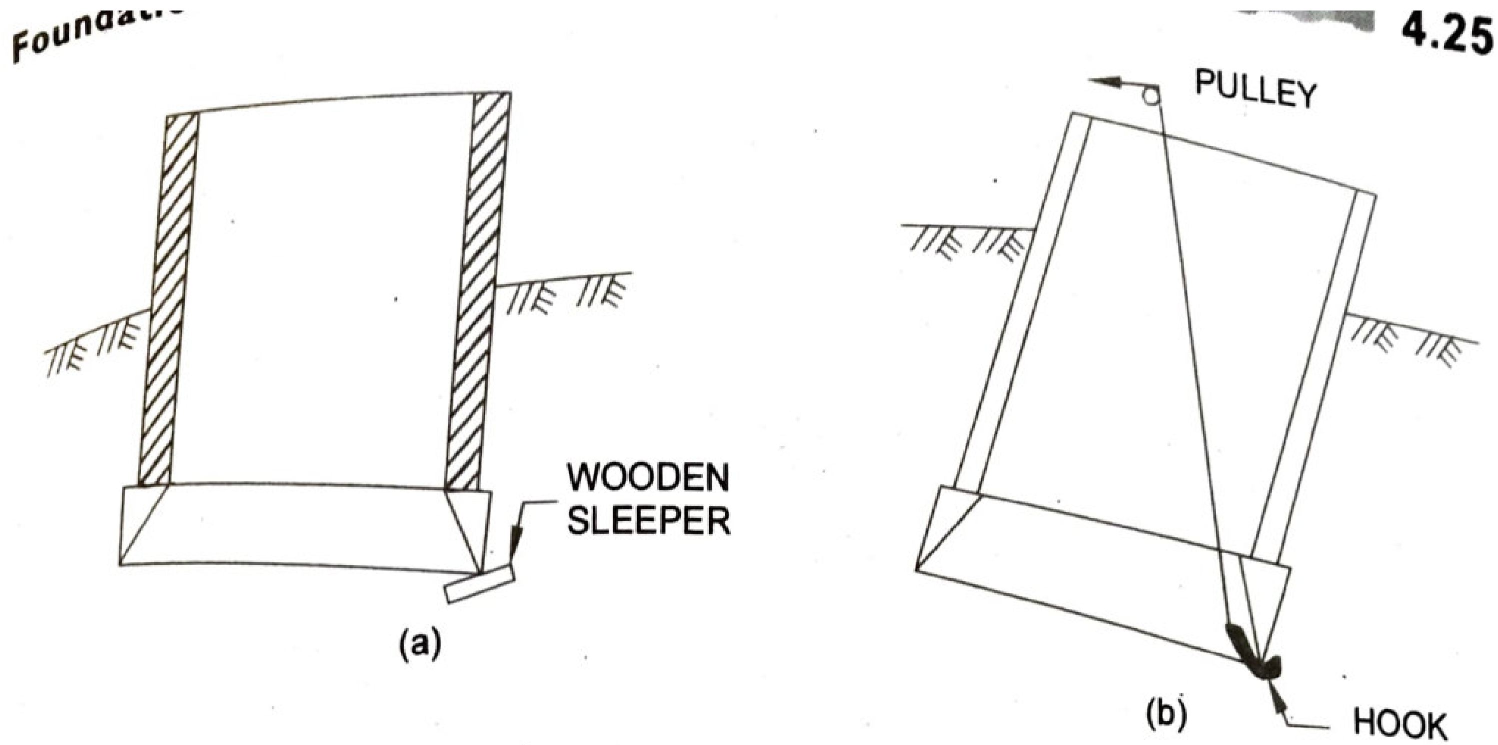
- *If dewatering of the well is possible, open excavation is done under the cutting edge.*
- *In case dewatering is not possible, divers can be sent to loosen the strata*

Inserting wooden sleeper under cutting edge



Pulling the well

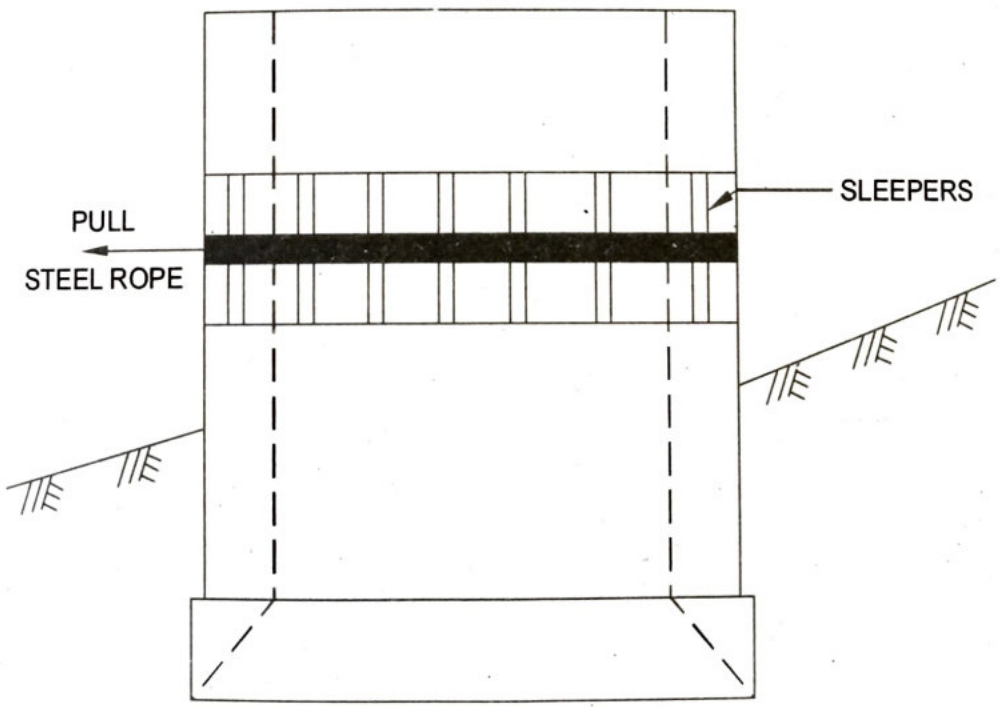
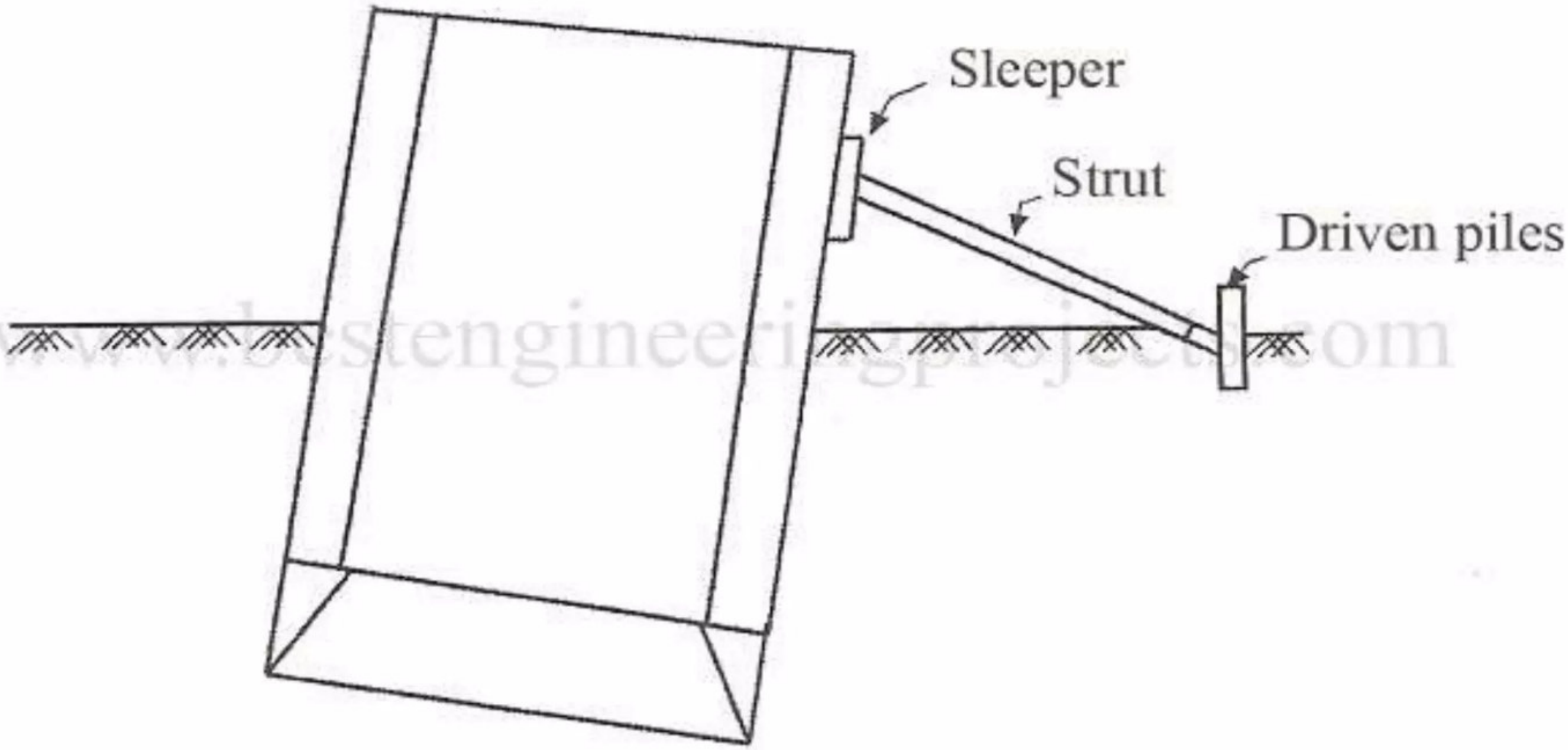


Fig. 4.16

Strutting the well



Fif 9 Strutting of the Well

Pushing the well by jacks

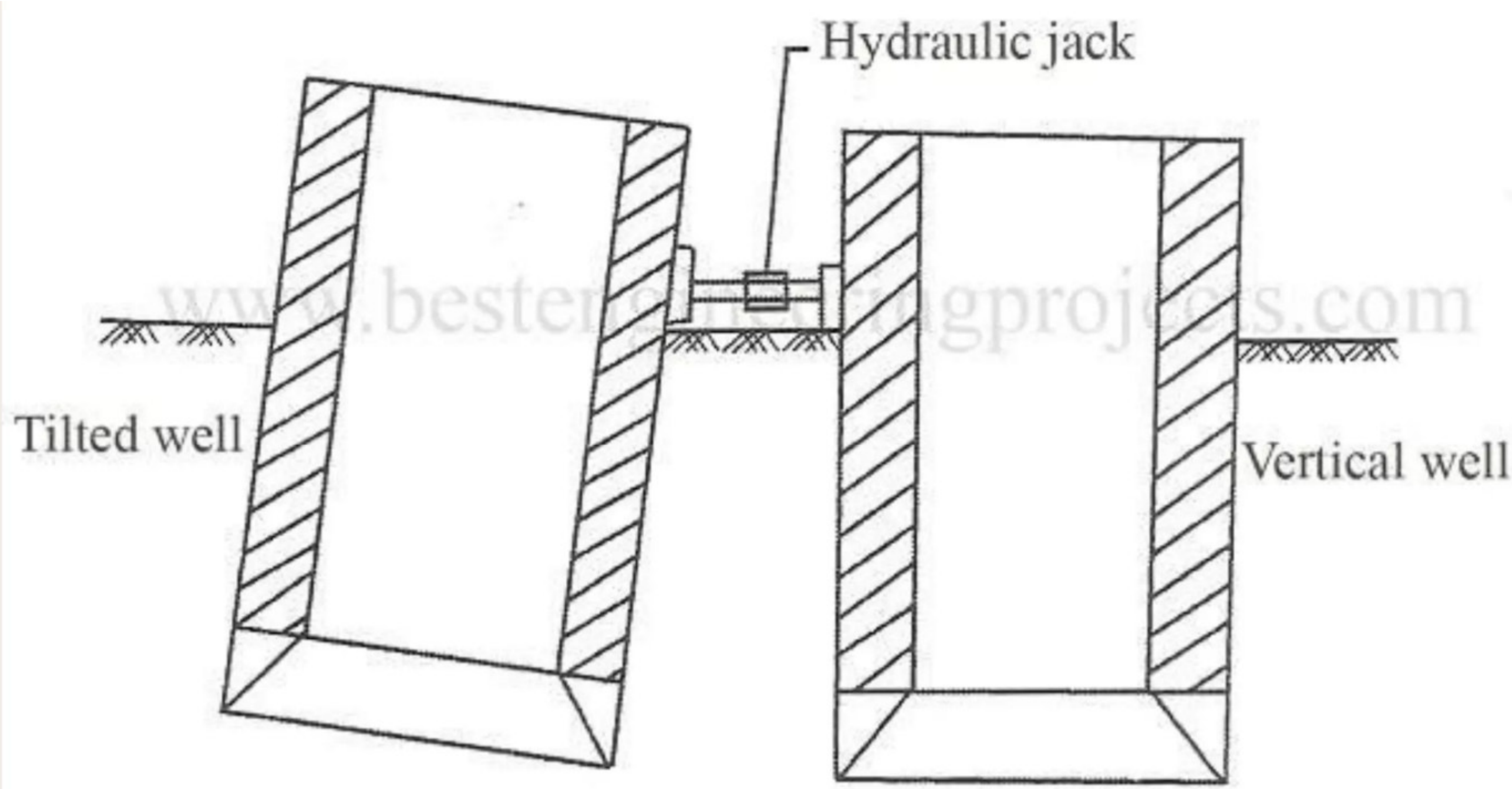


Fig 10 Pushing of the well

Requirements of a good foundation

- Following are the three basic requirements to be fulfilled by a foundation to be satisfactory
- **Location :** The foundation should be located that it is able to resist any unexpected future influence which may adversely affect its performance. This aspect requires careful engineering judgment.
- **Stability**: The foundation structure should be stable or safe against any possible failure
- **Settlement**: The foundation structure should not settle or deflect to such an extent so as to impair its usefulness.