

# Inet - I

## Site Investigation and Selection of foundation

The knowledge of subsoil conditions at a site is important for safe & economical design of substructure elements. The field & laboratory studies carried out for obtaining the necessary information about the subsoil characteristics including the position of ground water table are termed as soil exploration.

### Purpose and Scope:

- \* Provide information
- \* Reveals the need for further investigations.
- \* Indicates changes in design or confirms assumptions.
- \* Cost savings.
- \* Analysis of failure of existing structure.

### Objectives of Soil (or) Site exploration.

- 1) To select the type & depth of foundation.
- 2) To determine the bearing capacity of the soil.
- 3) To estimate the probable maximum and differential settlement.
- 4) To establish the groundwater level and to determine the properties of water.
- 5) To find soil and rock profile.
- 6) To select the suitable construction techniques.
- 7) To obtain Geological features.

## Site Investigation:

Three stages involved in exploration

- 1) Reconnaissance
- 2) Preliminary Exploration.
- 3) Detailed Exploration.

### 1) Reconnaissance

It includes,

- \* Site inspection → To visit the site.
- \* Library study:
  - Geological maps
  - Aerial photographs.
  - Toposheets.
  - Soil maps.

- ### 2) Preliminary investigation:
- \* Test pits & Trenches. → To find the depth, (t) & composition of each soil strata.
  - \* Soundings or Probing. → To locate the boundaries of different strata.
  - \* Geophysical investigations.

- ### 3) Detailed exploration:
- To find engg. properties.

- \* Deep boring
- \* Sampling
- \* Field testing
- \* Laboratory testing

# Methods of Exploration (or) Investigations.

1) Open excavation  $\left\{ \begin{array}{l} \rightarrow \text{Test Pits} \\ \rightarrow \text{Trenches.} \end{array} \right.$

2) Borings  $\left\{ \begin{array}{l} \rightarrow \text{Auger boring} \\ \rightarrow \text{Auger & Shell boring} \\ \rightarrow \text{Wash boring} \\ \rightarrow \text{Rotary Drilling} \\ \rightarrow \text{Percussion Drilling.} \end{array} \right.$

3) Subsurface soundings

4) Geophysical method (or) Averaging.

- (a) Seismic refraction method
- (b) Electrical resistivity method
- (c) Gravitational method.
- (d) Magnetic method.

1) Open excavation:

a) Test pits:

- \* Economical
- \* Size of 1.2 m x 1.2 m
- \* Max. depth of exploration - 5m
- \* Useful for plate load testing
- \* Water should be pumped out.

Data gathered:

- \* Physical & Engineering properties
- \* Stratification.

Limitations:

- \* Cost increases with depth.
- \* Unsuitable for pervious soils.
- \* Difficulty with water table.

## b) Trenches:

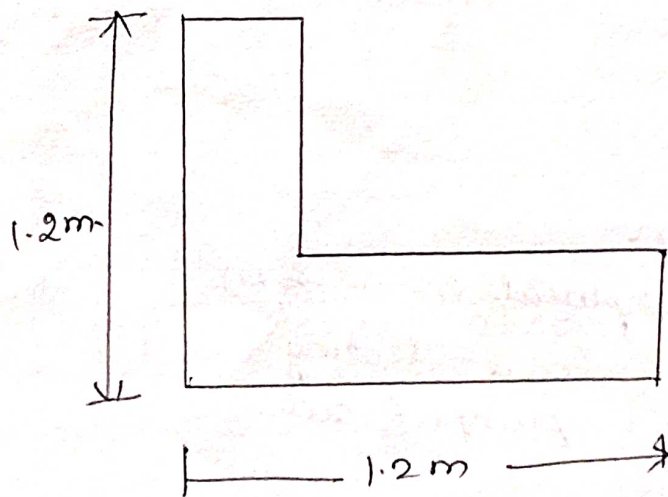
- \* Continuous length
- \* Useful for slope exploration

### Advantages:

- \* Stratification can be seen easily
- \* Fast and inexpensive method
- \* Reliable in field sampling & testing.

### Limitations:

- \* Limited depth of exploration
- \* Exploration difficult under water table
- \* Increased cost.
- \* Back filling may be non-uniform.



Test pit.

## Boring:

Boring may be defined as the process of advancing a horizontal, vertical (or) inclined hole in the soil to obtain samples and in the process determine its engineering properties.

### Methods of boring:

- (1) Auger boring (2) Auger and shell boring  
(3) Wash boring (4) Percussion boring (5) Rotary drilling

### (1) Auger Boring: (disturbed sample).

\* Bore hole advanced by auger.

\* Augers are used in cohesive & other soft soils above water table.

\* Types of auger  $\left\{ \begin{array}{l} \text{Hand auger} \text{ (dia (15-20 cm) - upto 6m (depth))} \\ \text{Mechanical (or) Power - greater depth.} \\ \text{(Gravel soil).} \end{array} \right.$

\* Post hole auger & Helical auger.

\* The soil samples are collected on the sides of auger & it is taken out.

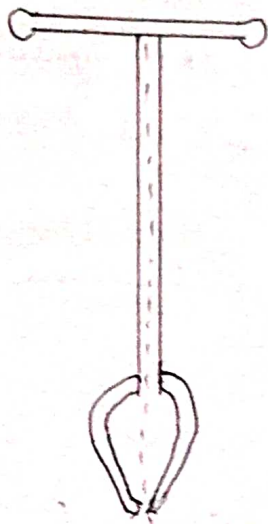
\* Used in Highway & railway construction.

### Advantages:

1. Useful for shallow exploration.
2. Inexpensive method
3. Useful in case of transportation projects.

### Limitations:

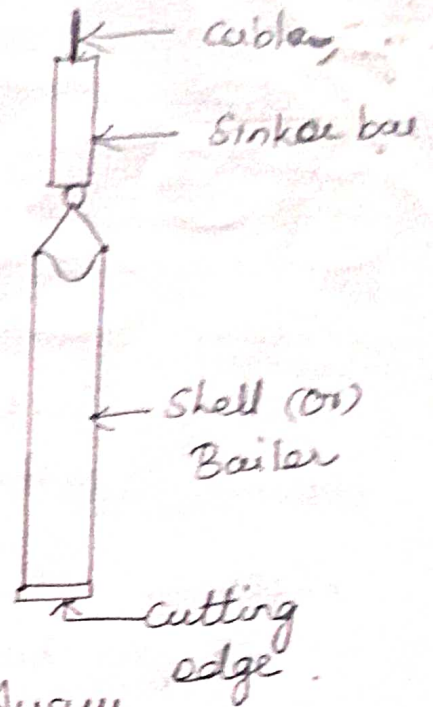
- \* cannot be used in gravel
- \* Difficulty with water table
- \* Change of stratum cannot be identified due to mixing of soil.



Auger Boring



Helical Auger



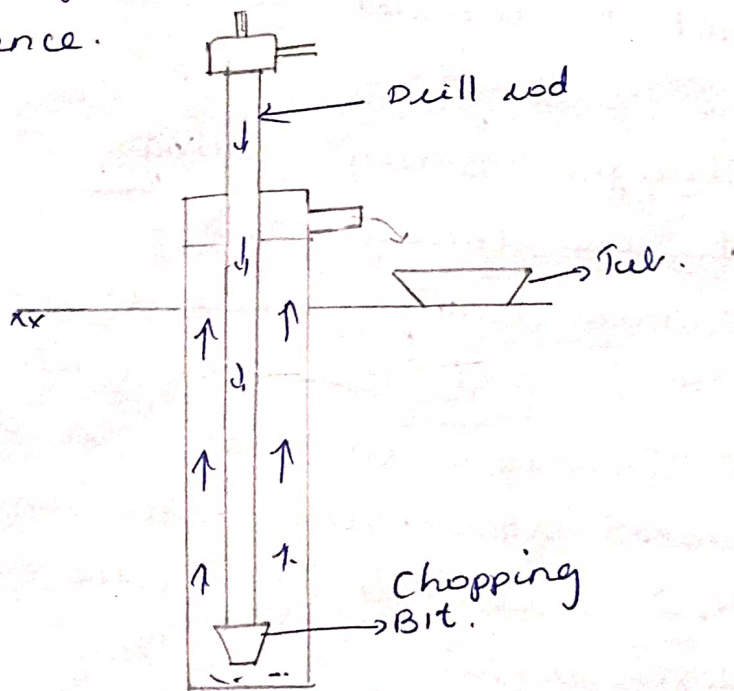
Auger & Shell boring.

- 2) Auger & Shell boring (or) Sand bailer:
- \* A shell also called bailer, is a heavy pipe with a cutting edge.
  - \* Sinker bars are used to add weight to the shell.
  - \* The shell is raised & let fall in a hole through the cable.
  - \* Depths upto 50 m can be achieved.

3) Wash Boring (or) Water Boring:

- \* It is used for exploration below water table.
- \* It is used for where the auger method is unsuitable.
- \* It is used for all types of soils except those mixed with gravel and boulders.

- \* Bore hole is advanced by chopping and jetting of water at high pressure.
- \* Soil is reduced to small fragments called cuttings.
- \* Water is pumped down through drill rod, water enters to the soil through the small openings in a chopping bit.
- \* Cuttings is brought to surface by wash water and collected in sump.
- \* Change in colour of water indicates change in stratum.
- \* Soil is extremely disturbed, so method is adopted only to advance the hole.
- \* Driving resistance gives an indication of soil resistance.



Wash being.

## Advantages.

- \* Fast and inexpensive method.
- \* Easy and simple operation
- \* Unskilled supervision
- \* Change in stratum can be seen

## Limitations.

- \* Cannot be used in hard rock
- \* Highly disturbed samples.
- \* Disintegration of soil particles
- \* High water content at bottom

### 3 Rotary Drilling:

- \* Hole is advanced by a rotating string consisting of hollow drill rods to which a cutting bit or cone or core barrel is attached.
- \* Downward pressure is applied for movement
- \* Drilling fluid is circulated to cool the bit and to remove the cuttings.

Types → Straight rotary drilling  
→ Reverse rotary drilling.

In reverse rotary drilling, there is faster removal of cuttings and minimum wall disturbance.

When drilling in rock ~~strata~~ strata, a diamond core barrel is used to obtain core samples of rock.

When obtaining rock samples, the quality of rock samples in terms of jointing and fracturing is designated by the term RQD

(Rock Quality Designation). (i) It is a rough measure of the degree of jointing (a) fracturing in rocks



$$RQD = \left( \frac{\text{sum of } 100}{\text{total core run}} \right) \times 100\%$$

RQD	Rock mass quality.
< 25%	Very poor.
25-50	poor
50-75	fair
75-90	Good
90-100	Excellent.

Advantages:

- 1) Used for all type of soil
- 2) Bore hole of dia 50mm-200mm can be achieved.

Limitations:

- 1) Not used in previous stratum due to high usage of drilling fluid
- 2) Highly disturbed samples
- 3) Skilled supervision required.

iv) Percussion Boring:

- \* Borehole is advanced by raising and dropping action of the drill bit
- \* Cuttings are removed in the form of slurry by adding water.
- \* Sand pumps (or) bailers are used for removal of cuttings.

## Advantages:

1. Can be used for any types of soil
2. Used for drilling tube wells
3. Rapid method
4. Suitable for glacial tills.

## Limitations:

- \* Disturbance of soil due to impact.
- \* Cannot used for loose sand
- \* Operations require casing
- \* More expensive.
- \* Changes in stratum difficult to determine.

## Soundings Methods: (or) Penetration Methods.

Soundings means pushing (or) driving by hammer, a steel rod or pipe into the ground, to determine the resistance to penetration at depth of hard stratum.

The devices are used to determine the penetration resistance called as 'penetrometer'.

### Tests (or) Methods:

1. Standard penetration tests (SPT)
2. Static Cone (or) Dutch cone penetration tests (SCPT)
3. Dynamic cone penetration tests (DCPT)

## Geophysical Method:

- \* Seismic <sup>refraction, Reflection</sup> methods
- \* Electrical Resistivity methods.
- \* Gravitational method
- \* Magnetic method.

## Objectives:

- Thickness of layers.
- Boundaries of layer
- Depth of water-table
- Location of gravel deposits.
- Location of organic deposits.
- Bedrock profiling.

## 1. Seismic Method:

### Principle:

It states that shear waves travel with different velocities in different types of material.

In this method, a shock waves are created into the soil at their ground level by striking a plate on the soil with a hammer.

Shock waves produced are picked up geophones 1, 2, 3 ... placed at regular intervals  $d_1, d_2, d_3 \dots$  at time  $t_1, t_2, t_3 \dots$ .

The arrival times are recorded in the recorder. As the distance b/w the shock point and geophone increases, the travel time of waves get reduced.

\* Time vs distance is plotted which gives the intersection of two straight lines at distance D.

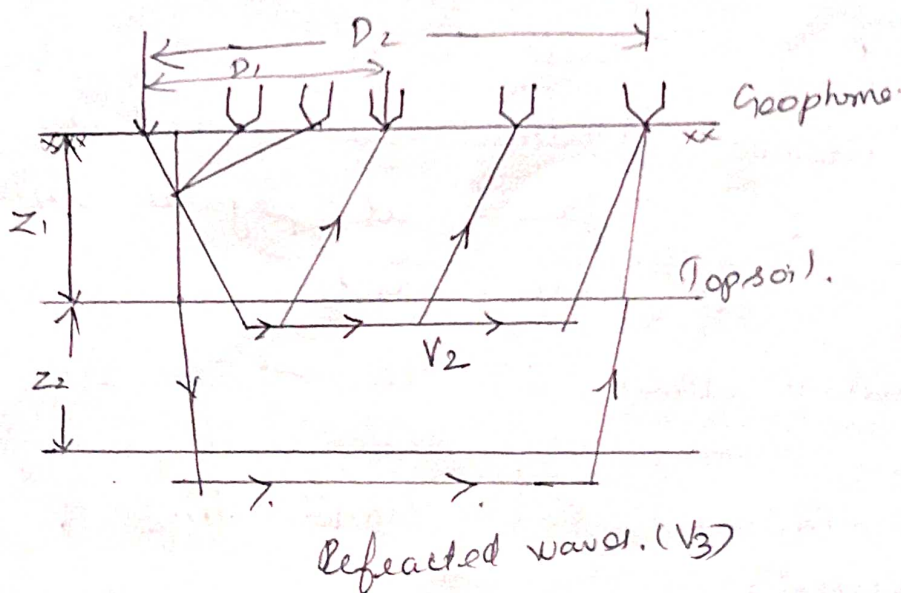
$$\text{Depth of rock } H = \frac{D}{2} \left[ \sqrt{\frac{(v_2 - v_1)^2}{v_2 + v_1}} \right]$$

### Advantages:

1. Rapid Method
2. Lots of additional information
3. Alternative alignments can be studied.
4. Borrow areas can be explored

### Limitations

- \* Soil may not be homogeneous and isotropic
- \* Thickness of layer should be at least  $\frac{1}{4}$  th of the depth of occurrence
- \* Varying boundaries.
- \* Range of velocities.
- \* costly.



# Electrical Resistivity method:

## Principle:

Based on the fact that different materials offer different resistances to the passage of electricity.

## Resistivity depends upon:

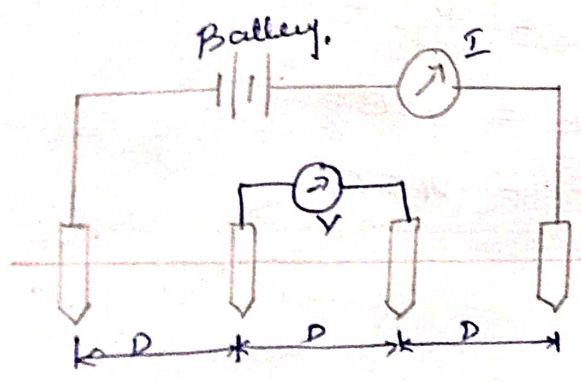
Water content, voids ratio, Particle size, Temperature, Stratification.

## Equipments

- ① 4 electrodes
- ② Potentiometer
- ③ Multimeter
- ④ Battery.

## Method:

- \* Electricity (I) is passed into the ground through the end electrodes
- \* The potential difference is measured between the inner electrodes.
- \* The spacing is changed and the procedure is repeated.
- \* Measured change in potential indicates presence of layers of different resistivity.



$$\rho = \frac{2\pi DE}{I}$$

D - Distance b/w electrodes  
I - Current

$\rho \rightarrow$  Resistivity (ohm-cm)  
 $E \rightarrow$  Potential drop (V)

## Advantages

1. Can detect sea water intrusion, organic deposits, aquifers, ore bodies.
2. Can differentiate pervious alluvium from clay

## Limitations

- \* Wide range and overlapping of resistances make interpretation difficult.
- \* Readings are easily affected by surface anomalies.

## Depth and spacing:

Isolated footing	- 1.5 to 2B
Strip footing	- 3 to 3.5 B
Dam	- greater of H (or) B/2
Narrow cuts	- H
Broad cuts	- B
Group of piles	- 1.5 to 2B

## Group of footing:

$$A \geq 4B = 1.5B$$

$$4B > A > 2B = 3B$$

$$A < 2B = 4.5B.$$

\* Used for grain size analysis, consistency and proctor tests.

### Non-representative samples:-

These samples are mixture of materials from various soil (or) rock strata from which some mineral constituents have been lost or got mined up.

### Undisturbed samples:

Samples which are more (or) less intact obtained from bore holes by means of tube sampling.

Used to obtain data on shear strength, permeability, consolidation & stress-strain behaviour.

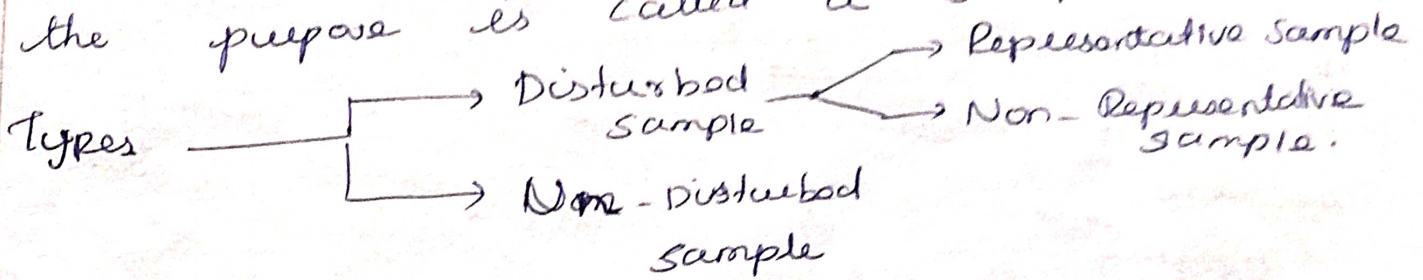
### Chunk samples:

- + Chunk samples are the least disturbed of all sampling methods.
- + Obtained by means of open excavation.
- + Samples are used for all types of tests.
- + They cannot be obtained below water table.

## Sampling:

The process of obtaining a small quantum of soil from a soil deposit in the field for the purpose of study (or) tests to know about the soil deposit in the field.

The quantum of soil obtained for the purpose is called a sample.



## Disturbed Sample:

These are the samples in which the natural structure of the soil gets disturbed during sampling. But these samples represent the composition and the mineral content of the soil.

\* These samples can be used to determine the index properties of the soil such as grain size, plasticity characteristics, specific gravity etc.

## Representative samples:

\* These are disturbed samples in which the structure of the soil is lost but water content and density parameters are preserved.

\* Obtained by direct excavation, augering (or) Split spoon sampling.



### Sampling methods:

#### Soil Sampler:

Depends on thickness.

- \* Thick wall sampler
  - Area ratio > 10 to 25%
  - Split spoon sampler
  - Thickness greater than 4mm
- \* Thin wall sampler
  - Area ratio < 10%
  - Shelby sampler
  - Thickness less than 4mm

Depends on mode of operation.

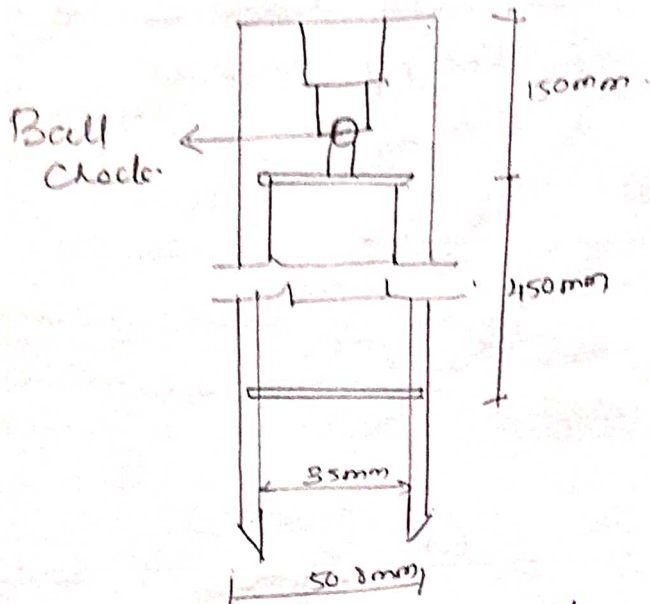
- \* Open drive sampler
- \* Stationary piston sampler.
- \* Rotary sampler.

#### 1. Thick wall sampler or Split spoon sampler

- \* Thick walled tube, split lengthwise.
- \* A drive shoe attached to the lower end serves as the cutting edge.
- \* 35mm internal and 50.8mm external dia & 100mm long.
- \* The sampler is lowered to the bottom of the bore hole
- \* The sampler is driven by forcing it into the soil by using hammer.
- \* The assembly of the sampler is then extracted from the hole.
- \* The two halves of the barrel are separated and the sample is exposed.
- The sample may be placed in a glass jar and sealed after visual examination.

\* The Ball check valve is provided for the purpose of allowing a fluid (or water) into the soil.

Standard Split spoon Sampler.



## 2) Thin walled sampler:

\* Smooth, thin seamless tubes provided with tapered cutting edges at the bottom and coupling at the top.

\* Area ratio is 13%.

\* Sample is retained by friction.

\* Made up of Steel or brass or Aluminium.

\* Procedure is same as that of split spoon.

\* The use of steel for the sampler is the danger of corrosion.

\* It can lead to the development of adhesion b/w the soil and the tube, making it difficult to remove the sample.

\* Chemicals change the orgg. properties of soil.

Shell by tube:

- \* Outside dia varies b/w 75 to 125 mm.
- \* The bottom of the tube is sharpened.
- \* Area ratio is less than 15%.
- \* Inside clearance is b/w 0.5 to 3%.
- \* Thickness 1.25 to 3.15 mm

3. Open drive sampler:

- \* Thick wall type as well as thin wall type.
- \* The tube may be split in two parts.
- \* The head of the sampler is provided with valves to permit water and air to escape during driving.

4. Piston sampler:

- \* It consists of a sampler with a piston attached to a long piston rod.
- \* It is used to prevent water and unwanted loose soil from entering into the sampler.
- \* The sampler is pushed to the desired depth with the piston closing the bottom end.
- \* Then piston is released and the sampler is pushed into the soil.
- \* The piston remains at the top while the sampler is driven.
- \* When sampler is fully driven, the piston is locked in its top position & the sampler is withdrawn.

\* Piston sampler with used in soft & sensitive clays.

## 1) Rotary sampler:

- \* Combined drilling and sampling operation.
- \* Consists of two concentric tubes, the inner one acting as sampler and outer one acting as cutter.
- \* After reaching the desired depth, the inner tube is pushed into the soil and the outer tube is rotated around it to advance it downwards.
- \* When sufficient depth is drilled, the inner tube is raised to the ground level.
- \* Used for stiff clayey soils.

## 5) Foil sampler:

- \* Provided with a thin lining of metal foil between sampler & soil to reduce the friction.
- \* Lining consists of thin vertical strips that enclose the sample.
- \* 20 m long sample can be obtained.

# 1. Standard Penetration Tests (SPT)

- \* SPT is used to determine the parameters of the in situ soil.
- \* SPT is suitable for cohesionless soils.

## Equipments used:

- \* Split spoon sampler
- \* Hammer (65 kg weight, free fall of 300 mm)
- \* Drive rods.
- \* Equipment for drilling and boring.
- \* Boring rig.

## Method:

- 1) The test consists of driving split spoon sampler into the soil through a bore hole of 55 to 150 mm dia. at the desired depth.
- 2) A hammer of 65 kg wt with a free fall of 300 mm is used to drive the sampler.
- 3) The number of blows for a penetration of 300 mm is designated as the Standard Penetration Value (SPV) number 'N'.
4. Drive the casing
5. Complete wash boring and clean bore hole.
6. Replace drill bit with split spoon sampler
7. Check whether the sampler penetrates under self weight.
8. If not, drive sampler using hammer.
9. Count the number of blows (N) for every 150 mm drive
10. Drilling is discontinued if  $N \geq 100$  for 30 cm penetration.

11. The top seating drive value of  $N$  is not considered for design purpose.

- \* Loose soil from the sides may have fallen on the bottom.
- \* The bottom soil may have been driven by driving.

12. The number of blows required for 300 mm of penetration is recorded as the SPT value.

13. Lift sampler and extract sample.

14. The spacing b/w subsequent sampling should not be  $< 0.5$  m. It is normally carried out every 0.75 m.

15. Base depth.

0 to 5 m	— 0.75 m
5 to 10 m	— 1 m
$> 10$ m	— 1.5 m.

(or) Change in stratum.

Problems with recorded  $N$ -Value:

- \* Hammer efficiency may vary.
- \* The height of drop may vary due to manual error.
- \* The bore hole dia may be different
- \* Sampler may or may not be lined.

Corrections:

The observed value of  $N$  is corrected for

- \* Correction for overburden pressure
- \* Submergence (or) dilatancy correction.
- \* Gibbs corrections.

\* Uplift correction:

In the case of fine sand (or) silt below water table, high value may be noted for  $N$ . In such cases, the following correction is recommended.

$$C_N = 15 + \frac{1}{2} (N' - 15)$$

$N'$  - Observed SPT Value

$C_N$  → Corrected SPT value.

\* Over burden pressure correction:

$$C_N = 0.77 \log_{10} \left( \frac{2000}{\sigma'} \right)$$

$\sigma'$  = Effective overburden pressure =  $\gamma D$  ( $\text{kN/m}^2$ )

\* Gibbs correction:

$$C_N = \frac{50}{1.425' + 10.}$$

- 2) Static cone penetration test (SCPT) (or) CPT  
Dutch cone test  
→ Used in place of SPT, particularly for soft clays + silts and fine to medium sand deposits.

1) Equipment  
Cone

Mechanical Cone → Dutch cone (3.57m dia + 60° cone area 10m<sup>2</sup>)  
→ Peckmann Friction jacket cone.

Electrical Cone → Piezo Cone.

- 2) Sounding rod - 1 m long, 15 mm dia.  
3) Steel (or) Mangle tube -  $d_i = 16 \text{ mm}$ ,  $d_o = 36 \text{ mm}$ ,  $L = 1 \text{ m}$ .  
4) Cone driving equipment.

Method:

- 1) The equipment is anchored firmly on the ground.
- 2) Cone with sounding rod is inserted into the required depth.
- 3) Apply pressure to take the cone to the required depth.
- 4) Obtain cone resistance by pushing the cone to a depth of 50 mm at the rate of 10-20 mm/s by pushing the sounding rods.
- 5) The test is conducted in increments of not greater than 200 mm.
- 6) In case of friction jacket cone, cone resistance is obtained by pushing the cone by 50 mm and then the friction jacket is pushed along with cone to get cone & friction resistance.



Cone resistance ( $q_c$ ) =  $\frac{\text{Load applied on cone}}{\text{Cone area}}$

Unit friction ( $f_s$ ) =  $\frac{\text{Frictional resistance} \times \text{Cone area}}{\text{Surface area of friction jacket}}$

Friction ratio =  $\frac{f_s}{q_c} \times 100$

### Applications of SPT:

- \* Classification of soils
- \* Strength parameters.
- \* Bearing capacity factors.
- \* Load capacity of pile foundation.
- \* Settlement of foundations.

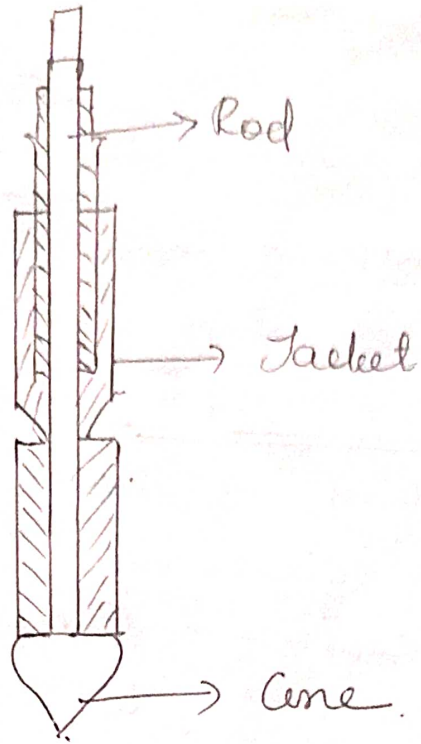


### Merits

1. Tests can be done on soil with low bearing capacity.
2. Tests can be performed at smaller intervals
3. Thin layers strength can be determined

### Demerits.

- \* Soil in which test is performed cannot be determined
- \* Separate rig is required for testing
- \* Cone penetration values are unreliable when particle size is beyond particulate size.



Soil log report (or) Subsoil investigation report :

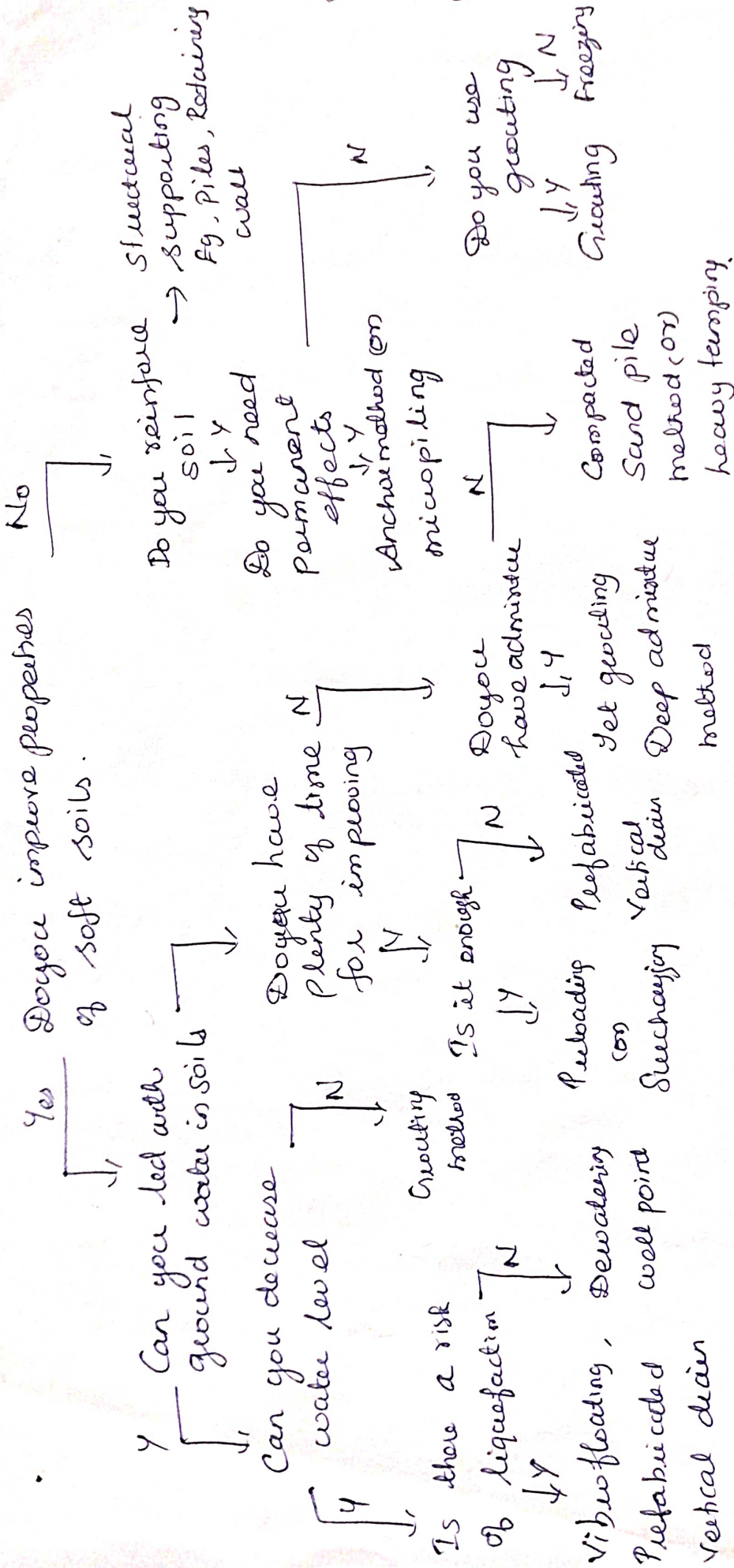
It is a report (or) record of the soil data that has been obtained from a particular bore hole :

Uses :

A soil exploration report generally consists of the following :

- 1) Introduction, which gives the scope of the investigation.
- 2) Description of the proposed structure, the location and the geological conditions at the site.
- 3) It indicates the number of borings, their location & depths.
- 4) Details of the method of exploration.
- 5) Bore hole logs.
- 6) General description of subsoil conditions as obtained from in-situ tests such as standard penetration test and CPT.
- 7) Details of laboratory test
- 8) Depth of ground water table and changes in water levels.
- 9) Discussion (or) Analysis of results.
- 10) Recommendation about the types of foundation.

Selection of ground improvement techniques based on soil conditions.



## Data Interpretation:

Based on Liquefaction potential.

Penetration resistance	Unconfined Comp. Strength $t/m^2$	Consistency.	Cohesion $kN/m^2$
0	0	Very soft.	< 12
2	2.5	Soft	12-25
4	5	Medium	50-100
8	10	Stiff	100-200
16	20	Very stiff	-
32	40	Hard.	> 200.

Based on Strength parameters:

N	$\phi$	Density Index	Description.
0	25-30	0	-
4	27-32	15	very loose
10	30-35	35	Loose
30	35-40	65	Medium
50	38-43	85	dense
> 50	> 43	100	Very dense

Selection of foundation based on soil.

1. Spread footing

Compact sand extending  
over greater depth  
clay or silty clay  
BC is good.

2) Mat foundation

Loose sand  
Highly compressible soil  
Very weak soil  
Non-homogeneous soil  
B.C. is poor.

3) Pile foundation

Soft clay  
Hard clay  
Medium dense sand  
Weak soil

4) Well foundation

Soil subjected to large  
uplift pressure as like  
transmission tower.

5) Sheet pile

Any type of soil.  
(Retains earth)

6) Tension pile

Any type of soil.  
Protect water from  
impact of ships.

Location and Depth Criteria

Foundation should be located at such a depth that their performance is not affected by factors like

- \* Lateral expansion of soil from beneath the foundation.
- \* Seasonal volume change.

IS 1904 - 1986 recommends a minimum depth of foundation as 50cm below natural ground surface.

The foundation should be taken below top organic soil, debris, muck.

If thickness of top soil is too large, two alternatives are available as shown below.

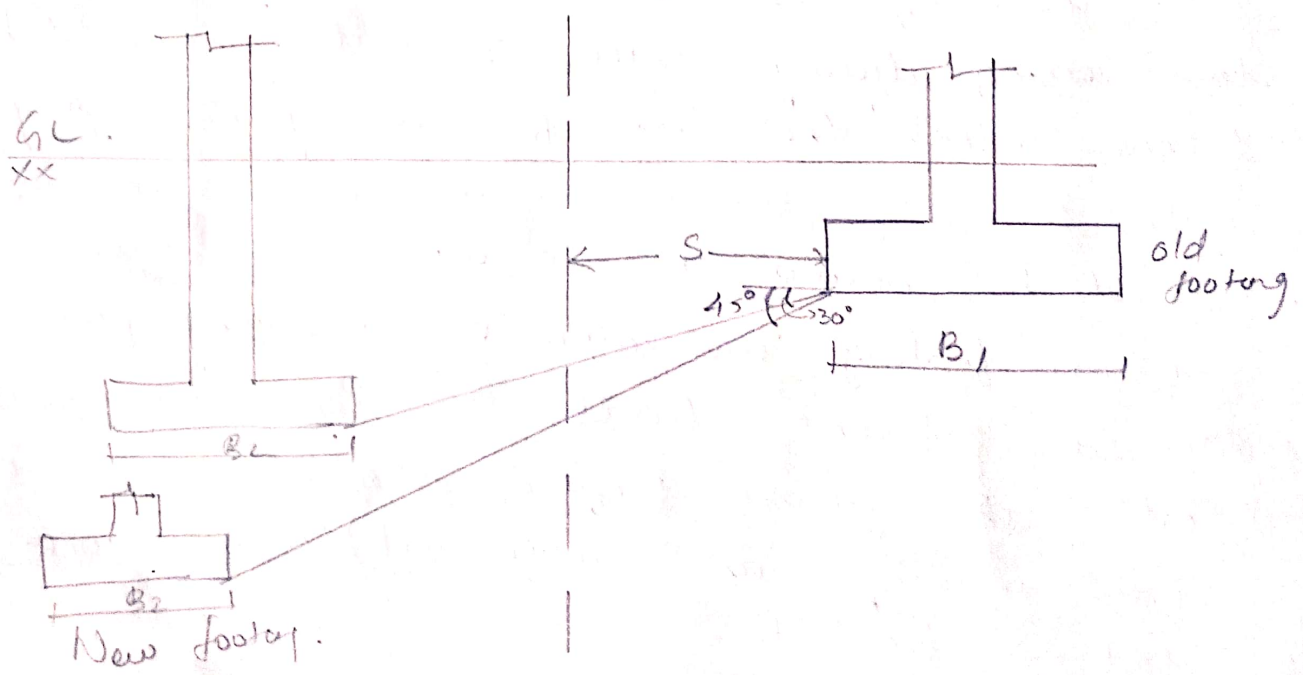
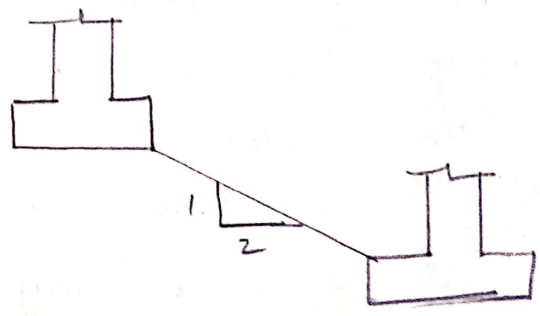
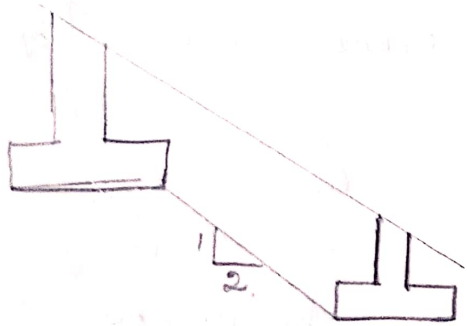
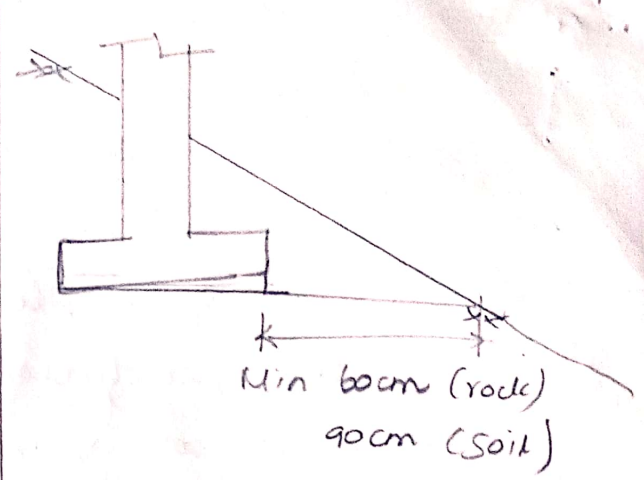
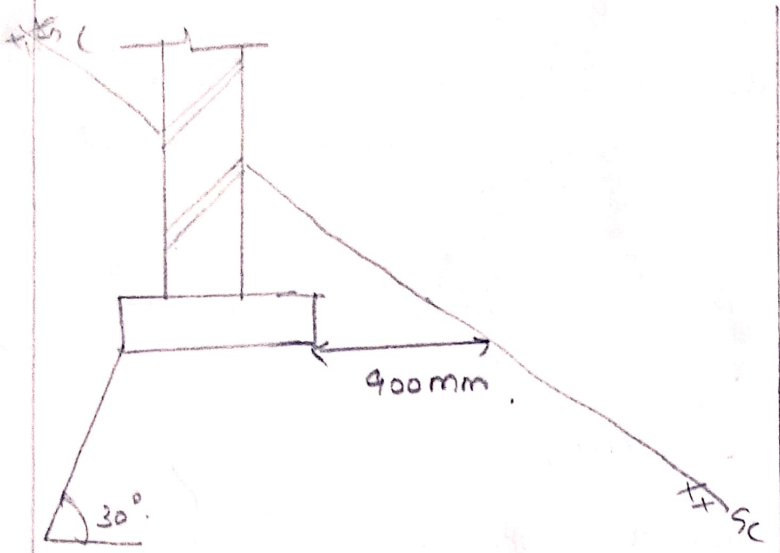
In expansive clay, foundation should be placed below the zone of volume change.

In case of fine sands and silts susceptible to freezing during winter, foundation should be taken below the zone of freezing & thawing.

In case of foundations in rivers, the depth should be below the deepest scum level.

When footing are adjacent to sloping ground

- (or) at different levels, IS code recommends
- 1) when the ground surface slopes downwards, sides making an angle of  $60^\circ$  for rock and  $30^\circ$  for soil.





Total + Net bearing Capacity.

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

$q_{ns} \rightarrow$  Net safe bearing capacity.

$q_{nt} \rightarrow$  Net ultimate bearing capacity.

Relation b/w  $q_s$  +  $q_{nt}$

$$q_s = q_{ns} + \gamma D$$

$$q_s = \frac{q_{nt}}{F} + \gamma D$$

For local shear failure:

In above all equations 'c' can be replaced by 'c'

$$c' = \frac{2}{3} c.$$

$N_c, N_q, N_\gamma$  are replaced by  $N_c', N_q', N_\gamma'$ .

$\phi < 28^\circ \Rightarrow$  Local shear failure.

$\phi > 36^\circ \rightarrow$  General shear failure.

## Factors affecting bearing capacity:

### Cohesionless soils.

- \* Relative density (or) angle of shearing resistance
- \* Width of footing
- \* Depth of footing
- \* Unit wt of the soil
- \* Position of ground water table.

### cohesive soil :

- \* Width of the footing
- \* Depth of footing
- \* Undrained cohesion.

### Allowable Pressure :

It is a maximum intensity of loading that can be allowed without shear failure (or) excessive settlement

### Eqs.:

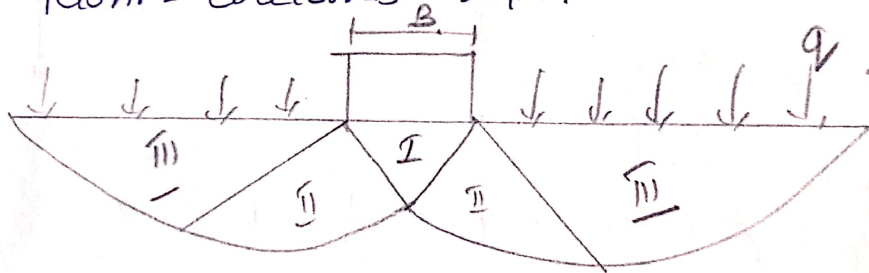
- 1) Terzaghi & Peck Method
- 2) Peck, Hanson & Thornburn Method
- 3) Teng's Correlation
- 4) Bowles Correlation.
- 5) Meyerhof's Correlation.

## Pezzani's Bearing Capacity theory:

He developed a general bearing capacity equation for a uniformly loaded strip footing.

### Assumptions:

- \*  $L/B$  ratio is large
- \* The base of the footing is laid at a shallow depth
- \* The shearing resistance of soil b/w the surface and depth of footing  $D_f$  is neglected.
- \* General shear failure takes place.
- \* The shear strength of the soil is governed by Mohr-Coulomb eqn.



### Zone I (Zone of elastic equilibrium)

When the footing sinks into the soil, a certain portion of the soil immediately below the footing

### Zone II (Zone of radial shear)

At failure the vertical downward movement of the soil wedge pushes the soil on either side of the wedge and transforms it into a state of plastic equilibrium.

Zone III (Rankine's zone of passive linear shear).

\* This zone has two sets of shear planes inclined at an angle of  $(45^\circ - \phi/2)$  to the h<sub>2</sub>l.

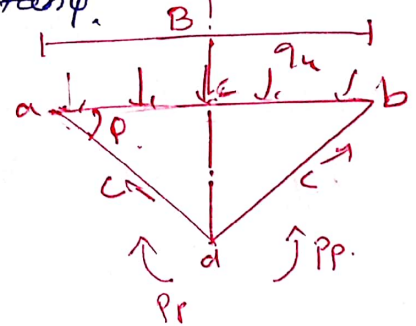
At equilibrium.

Downward forces due to self wt of wedge and load transmitted by footing } = Upward passive resistances of the soil

$$q_u B = 2P_p + 2C \sin \phi - \frac{1}{4} \gamma B^2 \tan \phi$$

$$C = c \times da \cos \phi$$

$$= c \frac{B/2}{\cos \phi}$$



$$q_u B = 2P_p + Bc \tan \phi - \frac{1}{4} \gamma B^2 \tan \phi$$

$$\cos \phi = \frac{B/2}{da}$$

$$da = \frac{B/2}{\cos \phi}$$

Total passive resistance  $P_p$

$$P_p = P_{p\gamma} + P_{pc} + P_{pq}$$

(Unit wt) + (Cohesion) + (surcharge)

$$q_u B = 2(P_{p\gamma} + P_{pc} + P_{pq}) + Bc \tan \phi - \frac{1}{4} \gamma B^2 \tan \phi$$

$$2P_{pq} = B \times q \times N_q$$

$$q_u = c N_c + q N_q + 0.5 \gamma B N_\gamma$$

Terzaghi's bearing equation.

Total + Net bearing capacity.

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

$q_{ns} \rightarrow$  Net safe bearing capacity.

$q_{nt} \rightarrow$  Net ultimate bearing capacity.

Relation b/w  $q_s$  &  $q_{nt}$

$$q_s = q_{ns} + \gamma D$$

$$q_s = \frac{q_{nt}}{F} + \gamma D$$

For local shear failure:

In above all equations 'c' can be replaced by 'c'

$$c' = \frac{2}{3} c.$$

$N_c, N_q, N_\gamma$  are replaced by  $N'_c, N'_q, N'_\gamma$ .

$\phi < 28^\circ \Rightarrow$  Local shear failure.

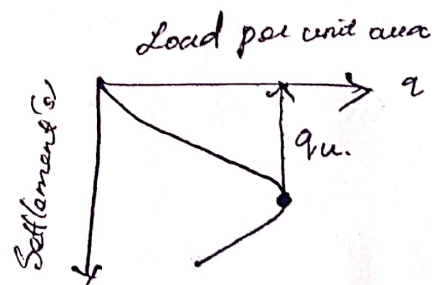
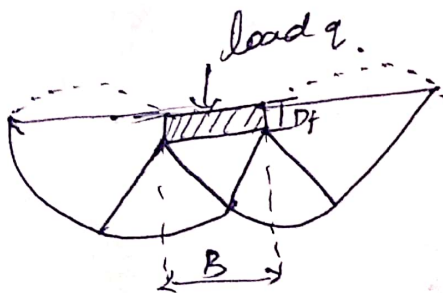
$\phi > 36^\circ \rightarrow$  General shear failure

## Types of Bearing capacity failure:

- \* General Shear Failure
- \* Local Shear Failure
- \* Punching Shear Failure.

### 1) General Shear Failure:

- \* It occurs in soils of low compressibility (i.e) dense or stiff soil.
- \* It has well defined failure surfaces, reaching upto the ground surface.
- \* There is considerable bulging of sheared mass of soil adjacent to the footing.
- \* Failure is accompanied by tilting of footing.
- \* Failure is sudden with pronounced peak resistance.
- \* The ultimate bearing capacity is well defined.



### 2) Local Shear Failure:

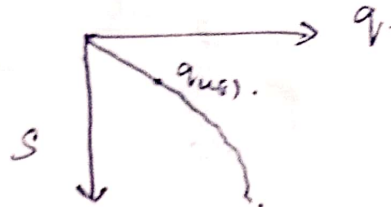
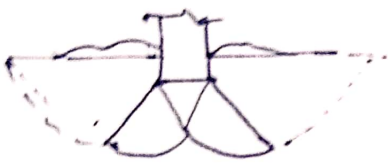
- \* It is associated with soils of high compressibility and in sands with medium relative density.
- \* Failure pattern is significant only immediately below the footing.

The failure surfaces do not reach the ground surface. There is only slight bulging of soil around footing.

Failure is not sudden & there is no tilting of footing.

Failure is characterised by large settlements.

UBC is not well defined.



### Punching shear failure:

It occurs when there is relatively high compression of soil below the footing along with vertical shearing around the edges of the footing.

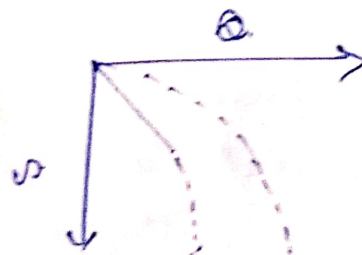
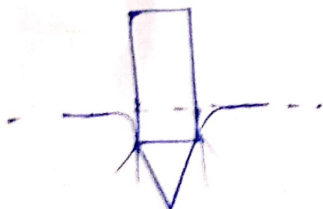
It occurs in relatively loose sand.

No failure pattern is observed.

Failure surface follows the perimeter of the base. There is no bulging of soil or tilting of footing.

Failure is characterised by very large settlements.

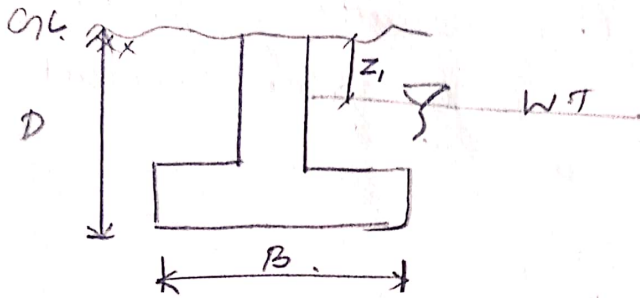
The UBC is not well defined.



Seismic consideration in bearing capacity.

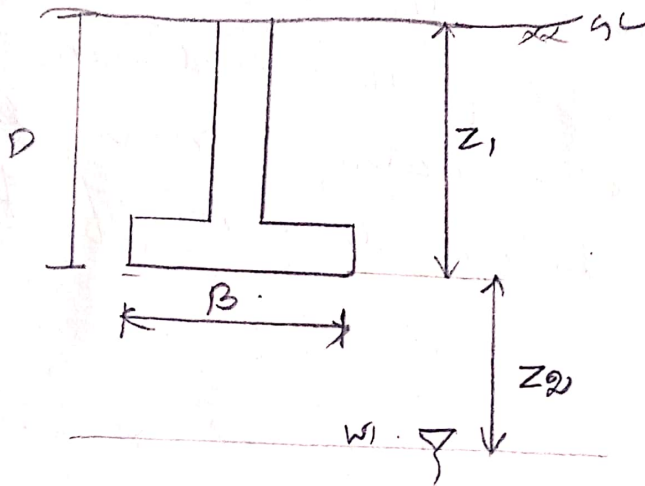
Effect of water table on bearing capacity.

Case (i) when WT is above the base of the footing.



$$\gamma = \gamma'$$

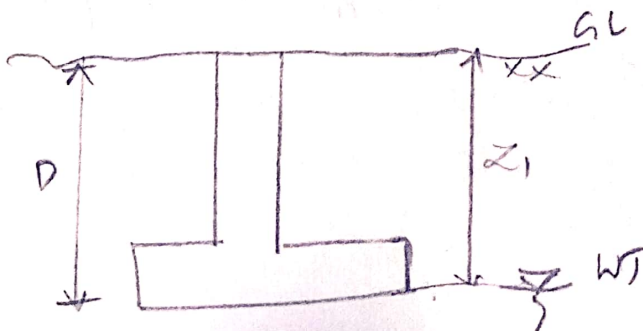
Case (ii) when the WT is below the base of the footing.



$$\gamma' = \frac{1}{2} \gamma_{sat}$$

Case (iii) when WT is just at the base of the footing.

No reduction of  $\gamma$  in this case.





For any position of water table,

$$q_s = CNc + \gamma_1 DNq R_{w1} + 0.5 B \gamma_2 N_2 R_{w2}$$

where,

$R_{w1}$  &  $R_{w2}$  are the reduction factor for the water table (or) water table reduction factor.

$$R_{w1} = 0.5 \left( 1 + \frac{z_1}{D} \right)$$

$$R_{w2} = 0.5 \left( 1 + \frac{z_2}{B} \right)$$

$\gamma_1$  → Avg unit wt of the surcharge soil situated above the water table.

$\gamma_2$  → Avg unit wt of the soil in the wedge zone situated within the depth 'B' below the base of the footing.

If  $z_1 = 0$  ;  $R_{w1} = 0.5$

$z_1 = D$  ;  $R_{w1} = 1$

$z_2 = 0$        $R_{w2} = 0.5$

$z_2 = B$        $R_{w2} = 1$

$$R_{w1} = 0.5 \left( 1 + \frac{z_1}{D} \right)$$

$$R_{w2} = 0.5 \left[ 1 + \frac{z_2}{B} \right]$$

## Bearing capacity by plate load test.

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

$D_p$  - Depth of plate

$D_f$  - Depth of footing

$B_p$  - Breadth of plate

$B_f$  - Breadth of footing

$$D = 2B_p$$

Effect of size of plate on bearing capacity & settlement.

For clayey soil,

$$\frac{S_p}{S_f} = \frac{B_p}{B_f}$$

For sandy soil,

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

$S_p$  - Settlement of plate in mm.

$S_f$  - Settlement of foundation in mm.

$B_p$  - width of plate in m.

$B_f$  - width of foundation in m.

If  $A_p$  is the permissible settlement of the foundation. The maximum settlement

of the largest footing should be restricted from  $\frac{1}{3}$  of  $\Delta P$ .

The corresponding settlement of test plate ( $S_p$ ) on sandy soil is given by ~~sand~~ is.

$$\frac{S_f}{S_p} = \left[ \frac{B_f (B_p + 0.3)}{B_p (B_f + 0.3)} \right]^2 \quad S_f = \frac{1}{3} \Delta P$$

$$S_f = \frac{1}{3} \Delta P \left[ \frac{B_f (B_p + 0.3)}{B_p (B_f + 0.3)} \right]^2$$

By extrapolating the plate load test one may use the following equation for all practical purpose

$$q_f = q_p \frac{B_f}{B_p}$$

$q_f$  = Ultimate bearing capacity of footing

$q_p$  = Ultimate bearing capacity of plate

For c- $\phi$  soil.

Housel suggested the following equation

$$Q = Aq + Ps$$

where  $Q$  is the total load on bearing area.

$a$  is the contact area of footing.

$P$  is the perimeter of footing.

$q$  is the bearing pressure beneath the area 'a'.

$S$  is the perimeter shear.

For clay,  $\Rightarrow$   $q_f = q_p$

$E_d$  is considered as 1.2 as the maximum value is 1.2

$$q_p = 35 [20 - 3] \left[ \frac{1.2 + 0.3}{2 \times 1.2} \right]^2 \times 0.708 \times 1.2$$

$$q_p = 197.47 \text{ kN/m}^2$$

Settlement:

Immediate settlement:

$$S_i = \frac{q_B (1 - \mu^2) I}{E_s}$$

where,

$q$  = uniformly distributed load

$B$  - width (or) length of footing

$E_s$  - Modulus of elasticity.

$\mu$  → poisson's ratio [0.5 for saturated clay]

$I$  → Influence factor

For normally consolidated clay:

$$E_s = 250c \text{ to } 500c$$

For overconsolidated clays

$$E_s = 750c \text{ to } 1000c$$

$c$  - Undrained cohesion.

## Problems on bearing capacity from the SPT & SCPT.

A strip footing 1.2 m wide is located at a depth of 1.5 m in a non-cohesive soil deposit for which the corrected  $N$  value of SPT is 20. Water table is located at a depth of 2 m below the ground surface. Find the allowable bearing pressure for the given soil.

Soln:

From Terzaghi's analysis

$$q_g = 35 [N-3] \left[ \frac{B+0.3}{2B} \right]^2 R_{w2} \cdot R_d$$

$$R_{w2} = 0.5 \left[ 1 + \frac{2z}{B} \right]$$

$$R_{w2} = 0.5 \left[ 1 + \frac{0.5}{1.2} \right]$$

$$R_{w2} = 0.708$$

$R_d \rightarrow$  depth reduction factor

$$R_d = \left[ 1 + \frac{0.2D}{B} \right] \leq 1.2$$

$$R_d = 1 + \frac{0.2(1.5)}{1.2}$$

$$R_d = 1.25$$

The value of Influence factor  $I_z$  is obtained from the following table.

	Flexible footing	Rigid footing
Circle	1.0	0.79
Square	1.12	0.82
Rectangle	1.36	1.06

For cohesionless soils

$$\text{Immediate settlement } S_i = C_1 C_2 (\bar{q} - q) \int_{z=0}^{2B} \frac{I_z}{E_s} dz$$

$C_1$  → Correction factor for the depth of foundation

$$C_1 = 1 - 0.5 \left[ \frac{q}{\bar{q} - q} \right]$$

$C_2$  → Correction factor for creep in soils.

$$C_2 = \left[ 1 + 0.2 \log_{10} \left( \frac{\text{time in years}}{0.1} \right) \right]$$

$\bar{q}$  - Pressure at the level of foundation.

$q = \gamma D = \text{surcharge}$

$I_z = \text{Influence factor}$

$E_s = \text{Modulus of Elasticity.}$

' $E_s$ ' from standard penetration Number (N)

By Schmertmann

$$E_s = 765 N \text{ (kN/m}^2\text{)}$$

$E_s$  from static cone penetration resistance

$$E_s = 2q_c$$

## Consolidation settlement:

$$S = \frac{C_c}{1+e_0} H \log \left( \frac{\sigma_0 + \Delta\sigma}{\sigma_0} \right)$$

$q_c$  = Static cone resistance

$H$  = Thickness of layer

$\Delta\sigma$  = Increase in pressure at the centre of the layer

$\bar{\sigma}_0$  = Mean effective initial overburden pressure ( $\frac{\sigma D}{2}$ ) due to soil overburden measured at the centre of the layer.

$C_c$  = Compression index

$e_0$  = Initial void ratio

$C_c = 0.007 (w_L - 10)$  (Undisturbed sample)

$C_c = 0.009 (w_L - 10)$  (Disturbed sample)

## Minimizing settlement:

- 1) Proper selection & design of foundation.
- 2) Proper site compaction
- 3) Ground water control
- 4) Soil treatment
- 5) Vegetation
- 6) Avoiding overloading
- 7) Avoiding loss of heavy.

## Problems:

1. A square footing  $2.5\text{m} \times 2.5\text{m}$  is built in a homogeneous bed of sand of unit weight  $20\text{ kN/m}^3$  having angle of shearing resistance  $36^\circ$  at a depth of footing is  $1.5\text{m}$  below the ground surface. Calculate the safe load that can be carried by a footing with FOS of 3 against shear failure. Use Terzaghi's analysis.

### Given:

- Type - Square footing.  
Soil type - Sandy soil (i) cohesionless soil  
 $c = 0$ .

$$L = 2.5\text{m}; \quad b = 2.5\text{m}; \quad D = 1.5\text{m}.$$

$$\gamma = 20\text{ kN/m}^3.$$

$$F = 3$$

$$\phi = 36^\circ.$$

### Soln:

$$q_s = \frac{q_f}{F}$$

$$q_s = \frac{q_{nf}}{F} + \gamma D.$$

$$q_s = \frac{Q_s}{\text{Area.}} \Rightarrow Q_s = \text{SBC.} \times \text{Area} \quad (q_s)$$

$$Q_s = q_s \times A.$$



For square footing.

Ultimate bearing capacity  $q_u$

$$q_u = 1.3 C N_c + \gamma D N_q + 0.4 B \gamma N_\gamma$$

$$\phi = 35^\circ \Rightarrow N_c = 57.8, \quad N_q = 41.1, \quad N_\gamma = 42.4$$

$$\phi = 40^\circ \Rightarrow N_c = 95.7, \quad N_q = 81.3, \quad N_\gamma = 100.4$$

By Interpolating

$$\phi = 36^\circ \Rightarrow N_q = 49.38 \quad N_\gamma = 54$$

$$q_u = \gamma D N_q + 0.4 B \gamma N_\gamma$$

$$= (20 \times 1.5 \times 49.38) + (0.4 \times 2.5 \times 20 \times 54)$$

$$q_u = 2561.4 \text{ kN/m}^2$$

$$q_{nf} = q_u - \gamma D = 2561.4 - (20 \times 1.5)$$

$$q_{nf} = 2531.4 \text{ kN/m}^2$$

$$q_s = \frac{q_u}{F} = \frac{2561.4}{3} = 853.8 \text{ kN/m}^2$$

$$q_s = 853.8 \text{ kN/m}^2$$

$$q_s = \frac{q_{nf}}{F} + \gamma D$$

$$= \frac{2531.4}{3} + (20 \times 1.5)$$

$$q_s = 873.8 \text{ kN/m}^2$$

Greatest of these two is  $873.8 \text{ kN/m}^2$

$$\text{Hence } q_s = 873.8 \text{ kN/m}^2$$

$$\text{Safe load } (Q_s) = q_s \times \text{Area}$$

$$Q_s = 873.8 \times (2.5 \times 2.5)$$

$$Q_s = 5461.25 \text{ kN.}$$

Total and differential settlement & Maximum allowable settlement:

If there is a large differential settlement b/w various parts of a structure, damage may occur due to additional moments developed.

The allowable settlement depends upon the type of soil, type of foundation and the structural framing system.

Max. settlement from 20 mm to 30 mm.

Exceeding 150 mm may cause trouble.

Diff. settlement b/w two columns spaced at a distance  $L$  is 3.

$$\uparrow = \frac{3}{L}$$

## Unit - III Shallow foundation.

### Footing & Rafts.

#### Foundation :

Foundation is an integral part of the structure which transfers the load of the superstructure to the soil.

A foundation is that member which provides support for the structure and its loading.

#### Types of foundation :

- \* Shallow Foundation
- \* Deep Foundation

#### Shallow Foundation :

If the depth of foundation is less than or equal to the breadth of the foundation, it is known as shallow foundation. Depth of foundation less than 3m is known as shallow foundation.

$$D \leq B$$

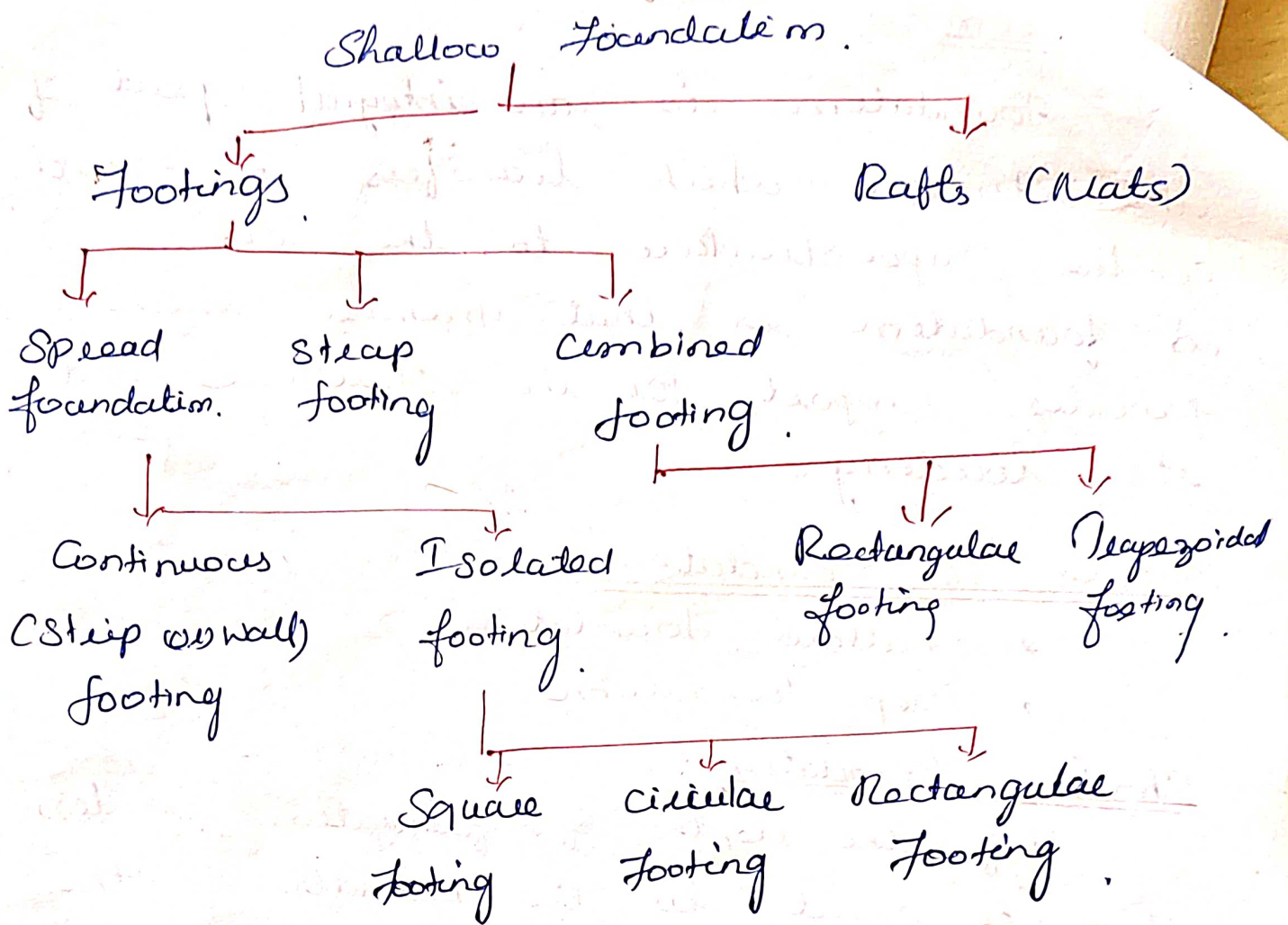
#### Deep foundation :

If the depth of the foundation is greater than breadth of the foundation, it is known as deep foundation.

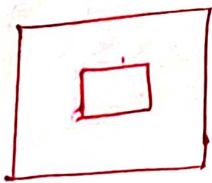
If the depth of foundation is greater than 3m is known as deep foundation.

$$B < D$$

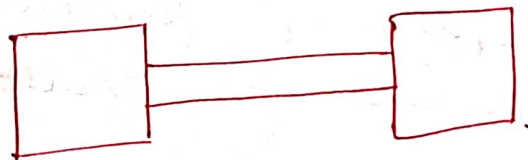
# Types of shallow foundations:



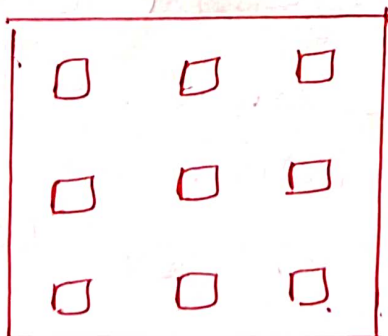
Isolated



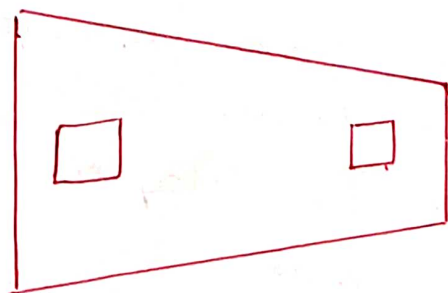
Strip



Mat

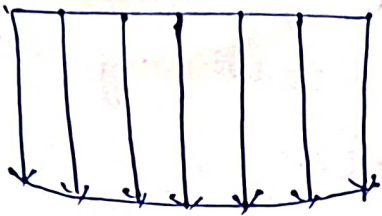


Trapezoidal



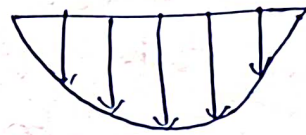
Contact pressure on sand (or) cohesionless soil.  
Flexible footing:

The edges of flexible footing undergo a large settlement than at the centre.  
The contact pressure is uniform.



Rigid footing

- \* The settlement is uniform.
- \* The contact pressure increases from zero at the edges to a maximum at the centre.



Note:

The contact pressure distribution for flexible footing is uniform for both clay and sand.

The contact pressure for rigid footing is maximum at the edges for footing on clay, but for rigid footings on sand, it is minimum at the edges.

## Contact Pressure

Contact pressure is the pressure exerted by soil in response to the applied load transferred by the foundation at the interface between the foundation & the soil.

Factors influencing contact pressure

It depends on the following factors.

\* Elastic properties of footing

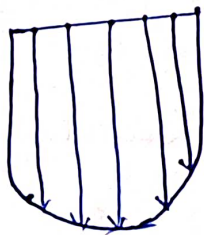
\* Elastic properties of soil

\* Thickness of footing.

Contact pressure on clay:

Flexible footing:

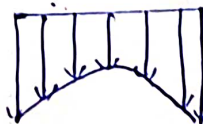
When the footing is flexible, it deforms into shape of bowl, with the maximum deflection at the centre. The contact pressure distribution is uniform.



Rigid footing:

When a footing is rigid, the settlement is uniform.

The pressure distribution is minimum at the centre and maximum at the edges.



## Design of Isolated Footings :

Design a reinforced cement concrete footing for a 1 m wide concrete wall carrying a load of 800 kN/m. The allowable soil pressure is 200 kN/m<sup>2</sup>.

Given :

$$L = 1 \text{ m}$$

$$Q = 800 \text{ kN/m}$$

$$q_a = 200 \text{ kN/m}^2$$

Soln :

Step : 1 Determination of width of footing, (B)

$$q_a = \frac{Q}{A} = \frac{Q}{B \times L}$$

$$q_a = \frac{800}{200 \times 1}$$

$$B = \frac{Q}{q_a} = \frac{800}{200} = 4 \text{ m}$$

$$\boxed{B = 4 \text{ m}}$$

$$\text{Actual pressure (q)} = \frac{Q}{A} = \frac{800}{4 \times 1} = 200 \text{ kN/m}^2$$

$$q = 200 \text{ kN/m}^2$$

Step : 2 Determination of overall depth of footing.

$$D = \frac{q [B^2 - (b+d)^2]}{4 (b+d) \sigma_{sp}}$$

$\sigma_{sp}$  = safe punching shear.

Assume  $\sigma_{sp} = 1000 \text{ kN/m}^2$ .

$$D = \frac{200 [4^2 - (1+d)^2]}{4(1+d) \cdot 10000} \quad \text{--- (1)}$$

Assume effective cover 60 mm.

$$D = d + d' = d + 0.06 \Rightarrow \text{sub in (1)}$$

$$d + 0.06 = \frac{200 (16 - (1+d)^2)}{4(1+d) \cdot 10000}$$

$$d + 0.06 = \frac{200 [16 - 1 - d^2 - 2d]}{4000 + 4000d}$$

$$d = 0.43 \text{ m}$$

$$\boxed{d = 430 \text{ mm}}$$

$$D = d + d' = 430 + 60 = 490 \text{ mm}$$

$$\boxed{D = 490 \text{ mm}}$$

$$\boxed{D = 500 \text{ mm}}$$

Step: iii Determination of Max BM.

$$\text{Max BM per m run} = \frac{q (B-b)^2}{8}$$

$$= \frac{200 (4-1)^2}{8}$$

$$= 225 \frac{\text{KN.m}}{\text{m}}$$

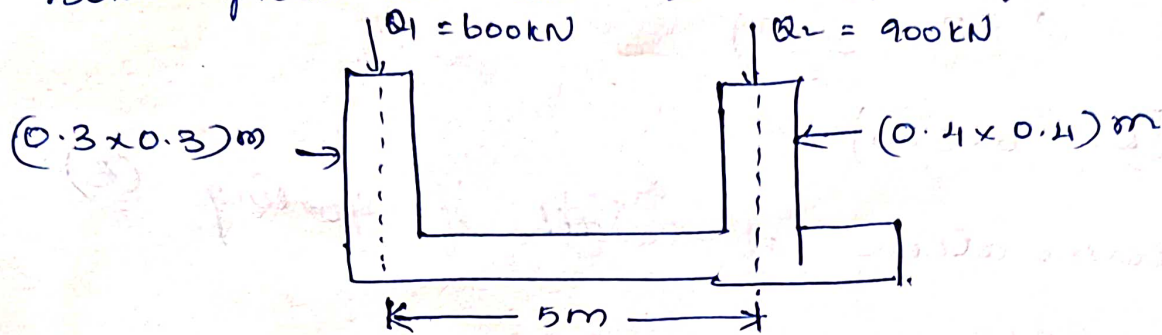
Step 4: Determination of diagonal shear.

$$F = q \left[ \left( \frac{B-b}{2} \right) - d \right] = 200 \left[ \left( \frac{4-1}{2} \right) - 0.43 \right]$$

$$\boxed{F = 214 \text{ kN}}$$



Design a rectangular combined footing for two columns shown in fig. Take allowable soil pressure as  $100 \text{ kN/m}^2$ .



Soln:

Step 1: Determination of total load acting on the footing ( $Q$ )

$$\text{Total load } (Q) = Q_1 + Q_2 \\ = 600 + 900$$

$$\boxed{Q = 1500 \text{ kN}}$$

Step 2: Determination of Area of footing.

$$q_a = \frac{Q}{A} \Rightarrow A = \frac{Q}{q_a} = \frac{1500}{100}$$

$$\boxed{A = 15 \text{ m}^2}$$

Step 3: Determination of line of action of resultant of column loads ( $\bar{x}$ )

Moment about the column ①.

$$R \times \bar{x} - Q_2 \times 5 = 0$$

$$\bar{x} = \frac{5Q_2}{R}$$

$$\bar{x} = \frac{5 \times 900}{1500} \Rightarrow \boxed{\bar{x} = 3 \text{ m}}$$

Step IV Determination of length of footing

$$L = 2 \left( \bar{x} + \frac{B_1}{2} \right)$$

$$L = 2 \left( 3 + \frac{0.3}{2} \right)$$

$$\boxed{L = 6.3 \text{ m}}$$

Step V Determination of width of footing (B)

$$A = B \times L$$

$$B = \frac{A}{L}$$

$$B = \frac{15}{6.3}$$

$$\boxed{B = 2.4 \text{ m}}$$

Step VI Determination of actual pressure

$$q_0 = \frac{Q}{A} = \frac{1500}{6.3 \times 2.4}$$

$$q_0 = 99.21 \text{ kN/m}^2 < 100 \text{ kN/m}^2$$

Hence it is safe.

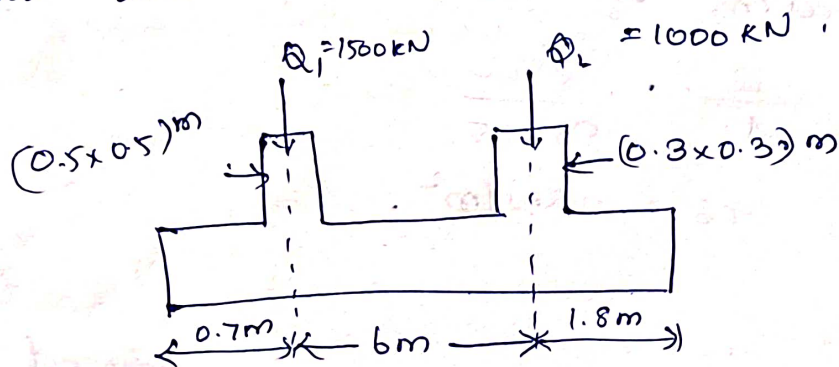
Actual pressure per m run

$$Q_0 = q_0 \times B$$

$$= 99.2 \times 2.4$$

$$Q_0 = 238.104 \text{ kN/m}^2 / \text{m}$$

Design a rectangular combined footing for two columns 6m c/c apart. The exterior column size is  $0.5\text{ m} \times 0.5\text{ m}$  and it carries 1500 kN load. The interior column is of size  $(0.3 \times 0.3)\text{ m}$  and it carries a load of 1000 kN. The projection of footing beyond left column is 0.5 m from centre of 6m beyond right side column centre. Take allowable soil pressure as  $200\text{ kN/m}^2$ .



Soln:

Step 1: Determination of total load. ( $Q$ )

$$Q = Q_1 + Q_2 = 1500 + 1000$$

$$Q = 2500\text{ kN}$$

Step 2: Determination of area of footing

$$q_a = \frac{Q}{A}$$

$$200 = \frac{2500}{A}$$

$$A = 12.5\text{ m}^2$$

Step 3: Determination of line of action of resultant of column loads ( $\bar{x}$ )

$$R \times \bar{x} = 1000 \times 6$$

$$Q \bar{x} = 6000$$

$$Q = R$$

$$\bar{x} = 2.4 \text{ m.}$$

Step 4: Determination of width of footing.

$$A = 12.5 \text{ m}^2$$

$$B \times L = 12.5$$

$$B = \frac{12.5}{8.5}$$

$$B = 1.5 \text{ m.}$$

Size of the footing  $8.5 \text{ m} \times 1.5 \text{ m}$ .

Step 5: Determination of actual pressure.

$$q_a = \frac{Q}{A} = \frac{2500}{8.5 \times 1.5}$$

$$q_a = 196.1 \text{ kN/m}^2.$$

A trapezoidal footing is to be produced to support two square columns of 30 cm and 50 cm size respectively. Columns are 6 m apart and safe bearing capacity of the soil is  $400 \text{ kN/m}^2$ . The bigger column carries 5000 kN and the smaller 3000 kN. Design a suitable size of the footing so that it does not extend beyond the faces of the column.

Given :

$$\text{Column ① size} = 30 \text{ cm} = (0.3 \times 0.3) \text{ m.}$$

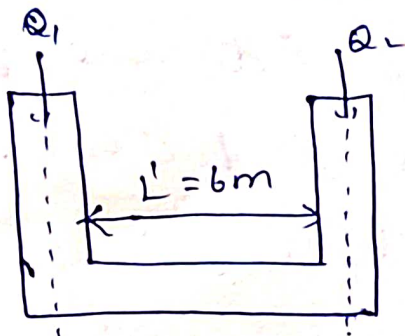
$$\text{Column ② size} = 50 \text{ cm} = (0.5 \times 0.5) \text{ m.}$$

$$L = 6 \text{ m}$$

Load on column ① = 3000 kN

Load on column ② = 5000 kN

$$\text{SBC} = 400 \text{ kN/m}^2$$



Soln:

Step 1: Determination of total load.

$$Q = Q_1 + Q_2 = 3000 + 5000$$

$$Q = 8000 \text{ kN}$$

Step 2: Determination of area of footing.

$$q_s = \frac{Q}{A}$$

$$A = \frac{Q}{q_s} = \frac{8000}{400}$$

$$A = 20 \text{ m}^2$$

$$A = \frac{1}{2} (a+b) L$$

$$20 = \frac{1}{2} (a+b) \times 6$$

$$a+b = 5.882 \text{ m} \quad \text{--- ①}$$

Step 3: Determination of line of action of resultant ( $\bar{x}$ ).

Taking moment about the centre of the column ①

$$Q \times \bar{x} = Q_2 \times L_1$$

$$\bar{x} = \frac{Q_2 \times L_1}{Q} = \frac{5000 \times 6.4}{8000}$$

$$\boxed{\bar{x} = 4 \text{ m}}$$

Step 4: Determination of  $x'$  (distance from external face of column ① + C.G.).

$$x' = \frac{L}{3} \left[ \frac{2a+b}{a+b} \right]$$

From diagram.

$$x' = \bar{x} + \frac{0.3}{2} = 4 + 0.15$$

$$\boxed{x' = 4.15 \text{ m}}$$

From ①

$$a+b = 5.882$$

$$a = 5.882 - b$$

$$x' = \frac{L}{3} \left[ \frac{2a+b}{a+b} \right]$$

$$4.15 = \frac{6.8}{3} \left[ \frac{2 \times (5.882 - b) + b}{5.882 - b + b} \right]$$

$$4.15 = \frac{6.8}{3} \left[ \frac{11.764 - 2b + b}{5.882} \right]$$

$$10.769 = 11.764 - b$$

$$\boxed{b = 0.995}$$

$$a = 5.882 - b = 5.882 - 0.995$$

$$\boxed{a = 4.887}$$

to the footing

$$a = 4.887 \text{ m}$$

$$b = 0.99 \text{ m}$$

$$L = 6.8 \text{ m}$$

Step 5: Check for area of the footing

$$\text{Area} = \frac{L}{2} [a+b] = \frac{6.8}{2} [4.887+1]$$

$$A = 20 \text{ m}^2$$

Step 6: Check for safe bearing capacity.

$$q_s = \frac{Q}{A} = \frac{800}{20}$$

$$q_s = 400 \text{ kN/m}^2$$

Safe.

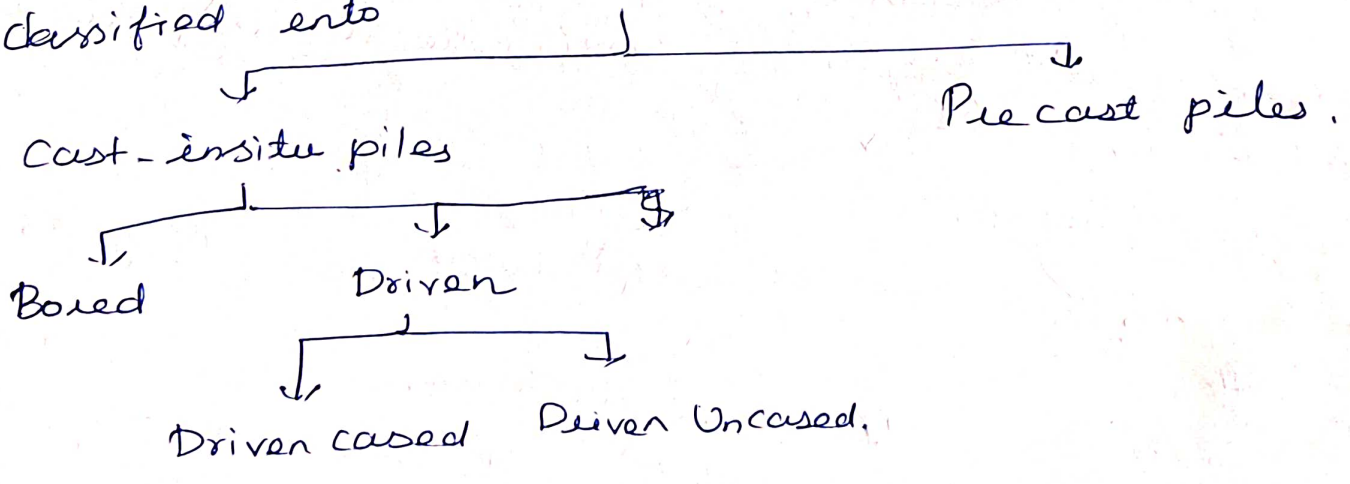
Pile Foundation:

Deep Compaction.

A pile is a pole or a slender column, usually made of concrete, steel or a composite material that transfers loads coming on to it from the superstructure to the soil in which it is installed.

Classification of pile:

- 1) Based on Material
  - Steel
  - Concrete
  - Timber
  - Composite.
- 2) Based on Load transfer mechanism
  - End bearing
  - Friction
  - Combination of both
- 3) Based on Function (or) use
  - Vertical support piles.
  - Compaction
  - Batter pile
  - Fender pile
  - Anchor pile
  - Sheet pile.
- 4) Based on fabrication + installation, piles are classified into





②

Based on extent of ground disturbance, piles are classified into.

- \* Replacement piles
- \* Displacement piles.

### 1. Based on Material:

#### Steel pile:

- \* Strong, lightweight and capable of handling heavy loads.
- \* Extension possible to any length.
- \* Suited for soft clays, silts.
- \* Must be protected for corrosion in under-water construction.
- \* Available in any shapes.

#### Concrete Pile:

- \* It can be cast in-site (or) precast.
- \* Load carrying capacity - 300 tons.
- \* Pile length ranges from 12-15m for reinforced piles and upto 40m for prestressed pile.
- \* Diameter - 500 to 1000 mm.
- \* They are designed for service loads. do not need splicing and pile lengths can be adjusted.

#### Timber piles:

- \* Can be cut to desired length and easy to handle.
- \* Diameter - 150mm - 400mm.
- \* Capacity upto 100 tons but usually restricted to 30 tons.

\* Normally it is tapered and is suited to be used as friction piles in granular deposits.

Composite pile:

- \* Made by joining two dissimilar material together
- \* Length 16 - 67 m.
- \* Design load - 30 - 200 tons.
- \* High capacity.
- \* Steel - concrete composite piles are most commonly adopted.

2) Based on load transfer:

End bearing piles:

It transmit the loads through their bottom tips. Such piles act as columns & transmit the load through a weak material to a firm stratum below.

Friction piles:

- \* Friction piles do not reach the hard stratum
- \* These piles transfer the load through skin friction b/w the embedded surface of the pile and the surrounding soil.
- \* The ultimate load ( $Q_u$ ) caused by the pile is equal to the load transferred by skin friction.
- Combination of both: These piles transfer loads by a combination of end bearing at the bottom of the pile and friction along the surface of the pile shaft.

### 3) Based on Function: <sup>(4)</sup>

- (\*) Vertical support piles: To carry vertical loads coming on to them.
- (\*) Compaction pile: It is used to compact loose granular soil. They do not carry any load themselves.
- (\*) Batter piles: Inclined piles used to resist lateral loads.
- (\*) Fender piles: It is used to protect offshore structures against impact from ships or floating objects.
- (\*) Anchor piles: It is used to anchor structures against uplift and resist tensile loads.
- (\*) Sheet piles: It is used for retaining earth and reduce seepage.

Factors affecting selection of pile:

1) Structural load:

Timber pile for lighter load

Steel & concrete piles for heavy load.

2) Location of site

Crowded location of site, small replacement piles rather than large displacement piles.

3) Soil condition:

Displacement piles are suitable in loose sand but may cause heaving in clays.

Driven piles are unaffected by water

table, where

care should be taken while casting pile below water table.

4) Required pile length and structural capability of pile:

Pile length have limitations.

Driven pile - 30 m

Bored pile - 45 m.

Steel - Indefinite.

5) Durability:

It depends on pile material.

Timber piles not used under wet & dry conditions.

Steel & concrete piles can corrode in adverse soil conditions.

b) Availability of materials.

7) Local experience:

Choice of piles in existing structures in the area also influences selection of pile.

8) Construction schedule.

Precast piles are used when piles are needed to be loaded quickly rather than cast in situ piles.

9) Economy:

When several pile types are suitable for a given site, the most economical one is selected.

Line Pile:

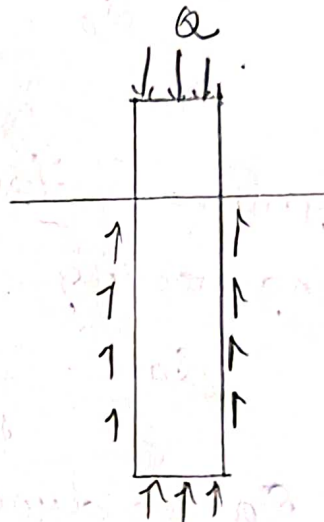
Load carrying capacity in Granular & cohesive soils

- \* Static Formula
- \* Dynamic Formula
- \* Pile Load test
- \* Penetration test.

Static formula:

$$Q_s = Q_p + Q_s$$

- $Q_s$  - Ultimate capacity
- $Q_p$  - Point resistance
- $Q_s$  - Shaft resistance.



$$Q_s = Q_p + Q_s \quad (\text{or}) \quad R_s + R_p$$

$$Q_s = q_p A_p + f_s A_s \quad (\text{or}) \quad A_s r_f + A_p r_p$$

- $q_p$  (or)  $q_p$  - Unit point resistance =  $C_p N_c$
- $A_p$  - C/s area of pile at the tip =  $\frac{\pi D^2}{4}$  (or)  $\pi d^2/4$
- $r_f$  (or)  $f_s$  - Unit skin friction resistance =  $\alpha c$  (or)  $m c$
- $A_s$  - Surface area of the pile shaft =  $\pi D L$

For tapered piles (1/3 L).

$\alpha$  (or)  $m$  - adhesion coefficients (or) reduction factor.

For  $L < 20q$   $\Rightarrow \alpha$  (or)  $m = 0.1$

For deeper piles  $\Rightarrow \alpha$  (or)  $m = 0.4$  to  $1$   
 $c = 170 \text{ kN/m}^2$   $c = 90 \text{ (or) } 100 \text{ kN/m}^2$

- $c$  - Avg undrained cohesion along the length of the pile.
- $C_p$  - Avg undrained cohesion at the pile tip =  $q_u/2$

(8)

For cohesive soil, point (e) and bearing is neglected.

Factor of safety = 2.5 to 3

$$Q_a = \frac{Q_{up}}{F}$$

2) Dynamic Formula:

a) Engineering News Formula:

$$Q_a = \frac{WH}{F(S+c)}$$

$Q_a$  = dynamic allowable load

$H$  = Height of fall

$W$  = wt of Hammer

$F$  = FOS ( $FOS = 6$ )

$S$  = Set per blow

$c$  = The empirical constant.

2.5 cm for drop hammer

0.25 cm for single & double acting hammer.

For double acting hammer

$$Q_a = \frac{(W + ap)H}{b(S + 0.25)}$$

$a$  - effective area of piston in  $\text{cm}^2$

$P$  - Pressure in  $\text{kg}/\text{cm}^2$

(9)

For single acting Hammer.

$$Q_a = \frac{WH}{b(S + 0.25)}$$

b) Hilary's Formula:

$$Q_f = \frac{\eta_H WH \eta_b}{S + C/2}$$

$Q_f$  = Ultimate load in pile

$H$  → Height of drop of hammer in cm

$S$  - set per blow in cm

$W$  - wt of Hammer in kg

$C$  → Total elastic compression

$$C = C_1 + C_2 + C_3$$

$C_1, C_2, C_3$  are temporary elastic compression of dolly & packing, pile & soil respectively.

$\eta_H$  = Efficiency of hammer

(65% for double acting steam hammer

100% for drop hammer)

$\eta_b$  = Efficiency of hammer blow.

$$\eta_b = \left( \frac{W + e^2 P}{W + P} \right) \quad \text{if } W > eP$$

$$\eta_b = \left( \frac{W + e^2 P}{W + P} \right) - \left( \frac{W - eP}{W + P} \right)^2 \quad \text{if } W < eP$$



(6)

$P$  - wt of pile, helmet, follower

$e \rightarrow$  coeff. of restitution (0 to 0.5)

For timber pile ( $e=0$ ).

$$\text{Effective fall} = h_H \cdot H$$

Limitations:

- \* Suited for coarse grained soil.
- \* Relation b/w static & dynamic resistance is uncertain
- \* Driving may cause liquefaction in loose sands.
- \* No indication of future changes in structure or settlement.
- \* Hiley's formula involves a lot of constants.
- \* Engineering News formula, wt of the pile & hence its inertia is neglected.

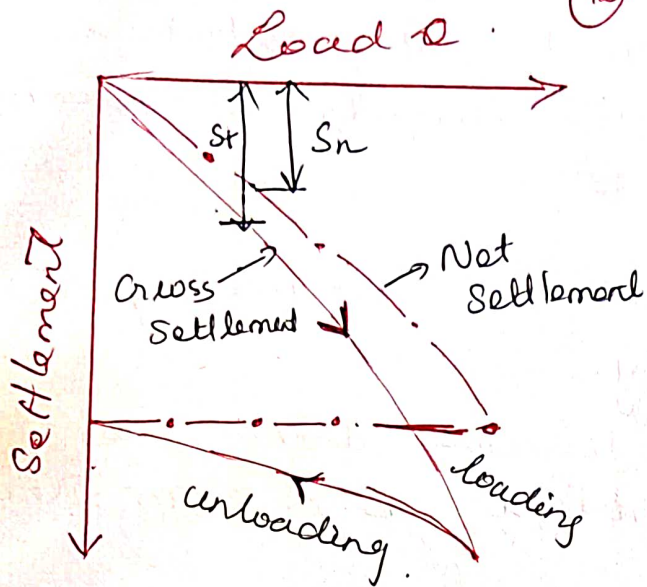
Negative skin

Pile load test:

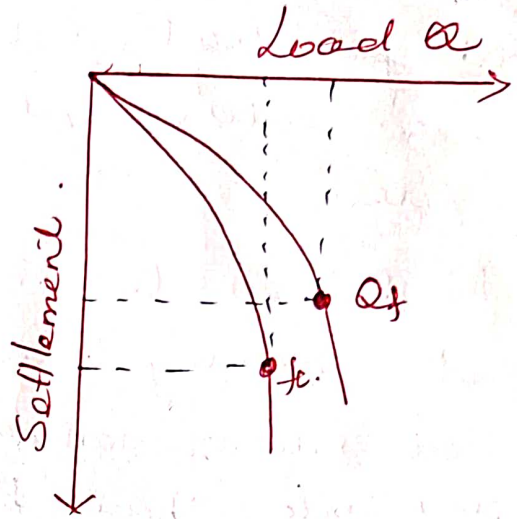
(1) A pile load test can be an initial test or a routine test. It depends on number of piles.

- 1) Most reliable method for determining the load carrying capacity.
- 2) Test pile installed in between anchor piles
- 3) Test pile should be at least 3B or 2.5m clear from anchor pile.
- 4) The load is applied through hydraulic jack resting on reaction girder.
- 5) Measurement of movement are taken with respect to fixed reference mark.
- 6) Test is conducted after a rest period of 3 days. (Sandy soil) & 1 month (Clay soil).
- 7) The load is applied in equal increment of about 20% of the allowable load.
- 8) Settlement recorded with 3 dial gages.
- 9) Settlement rate 0.1mm per hour for sandy soil and 0.02mm per hour for clayey soil.
- 10) Under each load increment, settlements are observed at 0.5, 1, 2, 4, 8, 12, 16, 20, 60 minutes.
- 11) The loading should be continued upto twice the <sup>safe</sup> load (or) the load at which the settlement reaches a specified value.
- 12) The load is removed in the same increment at 1hr interval & final rebound is recorded 24 hrs after the entire load has been removed.

(12)



Load-settlement curve



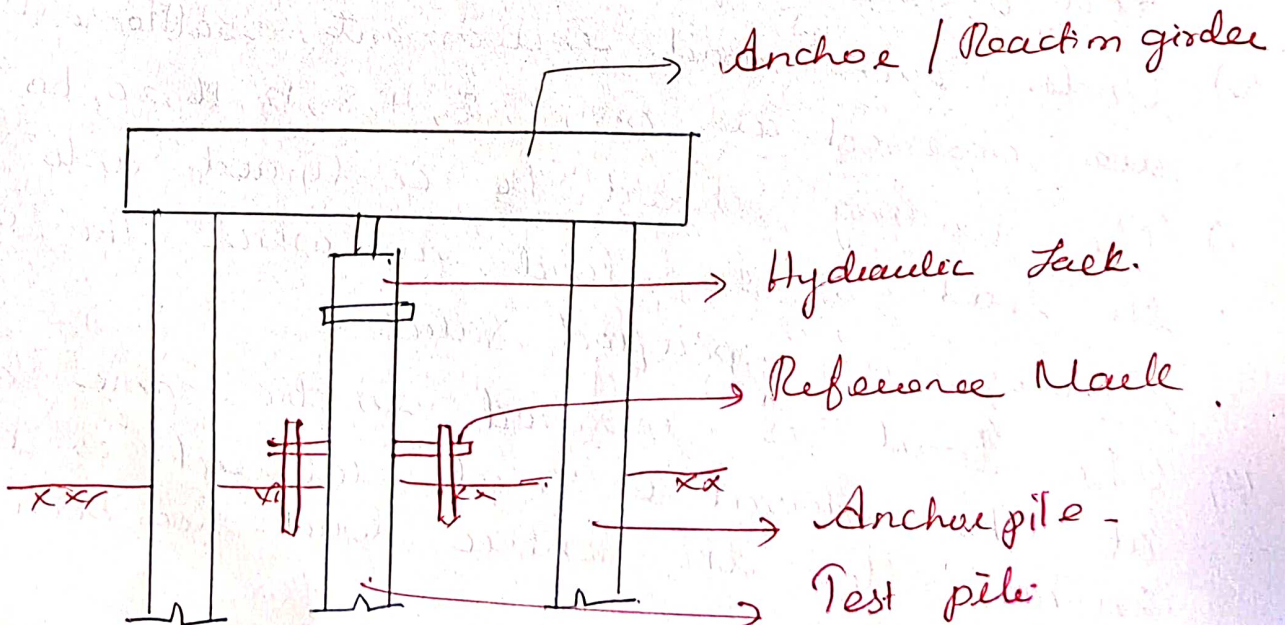
Load-settlement graph for two diff-soil.

$$S_n = S_t - S_e$$

$S_t$  → Total settlement

$S_e$  → Elastic settlement

- 13) The safe load is taken as one half of the load at which the total settlement is equal to 10% of pile diameter @  $\frac{2}{3}$  of final load at which total settlement is 12mm
- 14) Net settlement should not more than 20 mm  
Cross settlement should not more than 25 mm



Negative Skin Friction: (or) Downward drag force.

It is the downward drag acting on the pile due to downward movement of soil resulting from compression of recent fills, soft clay or loose sand layers in which the pile has been installed.

It results in the reduction of skin friction resistance of the pile.

Cohesive soil

$$F_n = P L_c C_a$$

P - Perimeter of pile

L<sub>c</sub> - Length of compressible layer

C<sub>a</sub> - Unit adhesion = α C<sub>u</sub>

α - adhesion factor

C<sub>u</sub> - Undrained cohesion.

Cohesionless soils.

$$F_n = \frac{1}{2} P L_c^2 \gamma K \tan \delta$$

K - Lateral earth pressure coefficient.

δ - Angle of Interface friction.

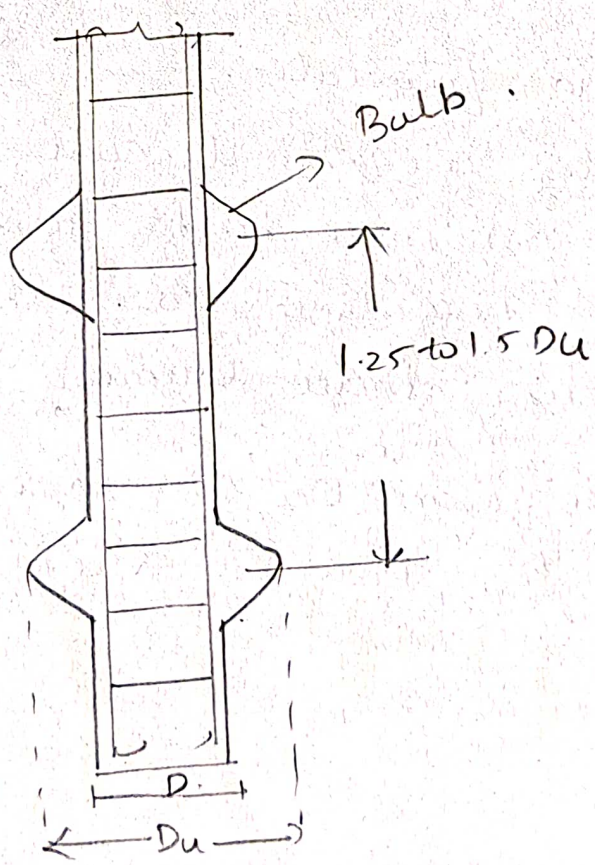
Under-reamed Pile Foundation:

\* Under-reamed piles are bored cast in situ piles having one or more bulbs formed by enlarging the bore hole fore the pile stem by using an under-reaming tool.

\* Dia of the under-ream D<sub>u</sub> is kept 2.5 times the pile diameter D, But can vary b/c 2D to 3D

(1c)

- \* Minimum length of the pile in expansive soils is  $\geq 3.5 \text{ m}$ .
- \* Centre to centre spacing should not be greater than  $2 D_u$  but can be reduced to  $1.5 D_u$  for 10% reduction in loads.
- \* The max spacing of under-reamed piles should not exceed  $2.5 \text{ m}$ .
- \* The centre to centre vertical bulb spacing may be kept equal to  $1.5 D_u$  in piles of diameter is less than  $30 \text{ cm}$ ,  
 $1.25 D_u$  in piles of dia  $> 30 \text{ cm}$  in multi under-reamed piles.
- \* The min depth of the uppermost bulb should be greater of  $2 D_u$  or  $1.75 \text{ m}$



### Uplift capacity of piles :

Tall structures like transmission towers, chimneys and silos as well as offshore platforms, deck docks are provided with piles that need to resist large uplift forces & overturning moments called as uplift or tension piles.

### Piles in clay :

$$Q_{ult} = f_{st} A_s + W_p$$

- $f_{st}$  → Unit skin friction
- $A_s$  → Embedded area of pile.
- $W_p$  - Weight of pile.

When the pile is provided with a bell bottom, the smaller of the two values is taken as the pull out capacity.

$$Q_{ult} = C_a A_s' K + W_s + W_p$$

$$Q_{ult} = 2.25 \pi (D_b^2 - D^2) C_a + W_p$$

- $A_s'$  → Surface area of the cylinder above base
- $D_b$  → Dia of base
- $D$  → Dia of shaft
- $K$  - Coefficient
- $W_s$  - Weight of soil in the annulus b/w pile shaft & vertical cylinder above the case

Type of soil	Value of k.
Soft clay	1 to 1.25
Medium stiff	0.7
Stiff	0.5
Stiff fissured clay	0.25

Piles in  $c-\phi$  soil. (16)

For shallow depth:

$$Q_{ult} = \pi c D_b L + \frac{1}{2} \pi S \sigma'_v D_b L^2 \tan \phi + W_p \quad \text{--- (1)}$$

For deep depth:

$$Q_{ult} = \pi c D_b H + S \sigma'_v D_b (2L - H) H K_a \tan \phi + W_p \quad \text{--- (2)}$$

$S \rightarrow$  Shape factor

$$S = 1 + \frac{\alpha L}{D_b}$$

$\sigma'_v$  - Effective unit wt.

$$K_a = (0.9 - 0.95)$$

$$Q_{ult} = \frac{1}{4} \pi (D_b^2 - D) (C N_c + \sigma'_v N_q) + f_s A_s + W_p \quad \text{--- (3)}$$

$Q_{ult}$  is taken from the above least value of (3) eqn.

## (17) Load capacity of pile group:

A pile group fails by either of the following two ways.

\* Individual Failure

\* Block Failure

A block failure occurs when the pile spacing is in the range of 2 to 3 diameters.

In block failures, the embedded length of the pile and soil within the perimeter of the pile group acts as a monolithic unit.

Block failure:

Ultimate load capacity.  $Q_{ug}$

$$Q_{ug} = C_{ub} N_c A_b + P_b L C_a'$$

$C_{ub}$  = Undrained strength of clay at the base of the pile group.

$C_a'$  - Avg undrained strength of clay along the length of the block

$$N_c = 9$$

$A_b$   $\rightarrow$  C/A of block.

$P_b$   $\rightarrow$  Perimeter of block.

$L$   $\rightarrow$  Embedded length of pile.

Individual failure:

$$Q_{ug} = n Q_u$$

$Q_{ug}$  is taken as the smaller value of two.



## Group action in piles. (18)

Piles when used as a foundation members are mostly used in groups.

### Pile cap:

Load is transferred to the piles through a rigid slab called as the pile cap which integrates the piles into a single unit.

### Pile Group efficiency:

It is defined as the ultimate load capacity of pile group  $Q_{ug}$  to the sum of the individual load capacities of the piles in the group is called as group efficiency.

$$\eta = \frac{Q_{ug}}{nQ_u}$$

It depends on

- \* Pile spacing
- \* Pile installation method.
- \* Soil type.

IS 2911,

Minimum spacing

2.5D for end bearing piles

3D for friction piles.

2D for piles in loose sands.  
corfills.

D  $\rightarrow$  Pile shaft dia.

(19)

Converse - Labarre formula .

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

$\eta_g \rightarrow$  Group efficiency .

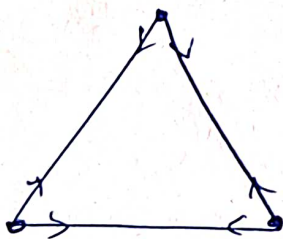
$\phi = \tan^{-1} \frac{d}{s}$  in degrees .  $\frac{\text{dia}}{\text{spacing}}$  .

$m =$  no. of rows of piles .

$n \rightarrow$  no. of piles in a row .

Feld's rule :

According to Feld's rule, the value of each pile is reduced by one-sixteenth owing to the effect of the nearest pile in each diagonal (or) straight row of which the particular pile is a member.



3 piles .

$$\eta_g = \frac{14}{16} = 87.5\%$$

Skillee - Keeney Formula .

$$\eta_g = \left[ 1 - 0.479 \left[ \frac{s}{s^2 - 0.093} \right] \left[ \frac{m+n-2}{m+n-1} \right] \right] + \frac{0.3}{(m+n)}$$

### Settlement of pile groups :

It is more than that of a single pile even though the load on the single pile and the individual piles of the group are the same.

→ Equivalent raft approach.

→ Single large raft placed at some arbitrary depth below the soil surface.

### Forces acting on pile cap :

- \* Compressive & shear forces due to structural loads
- \* Forces due to earth pressure (active & passive)
- \* Frictional & Inertial forces.



## Unit - V Retaining Walls.

①

### Retaining wall: (RW)

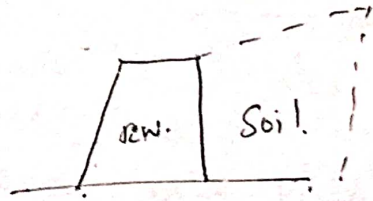
It can be defined as "A structure built to maintain soil at two different levels, designed to resist the lateral thrust coming on to it from the soil held at higher level".

### Types of Retaining wall:

1. Gravity and Semi-gravity RW
2. Cantilever RW
3. Counterfort RW
4. Buttress RW
5. Sheet Pile Walls.
6. Gab walls
7. Gabion walls
8. Reinforced Earth walls.

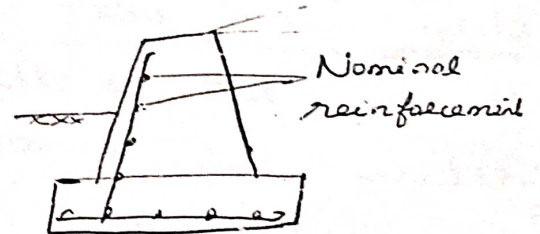
### Gravity RW:

- To retain the soil by resisting the lateral thrust due to its immense size & weight.



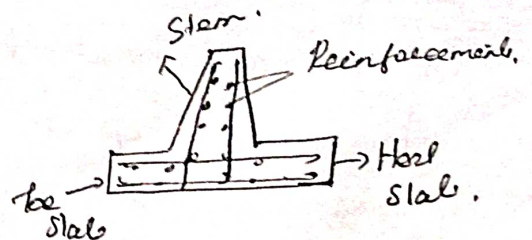
### Semi Gravity RW:

→ To resist lateral earth pressure partly by its weight and partly by nominal reinforcements provided.



### Cantilever RW:

→ To retain the soil by cantilever action.



### Counterfort RW:

When the length of wall is exceeding 6m, the counterfort is provided at equal interval. It is similar to cantilever wall, retains the soil