Unit - 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:** → To find the depth, (t) & composition of each soil Strata. → To locate the boundaries of different Strata.

- Test pits & Trenches.
- Soundings or Probings.
- Geophysical investigations.

3) **Detailed exploration:** → To find engg. properties.

- Deep boring
- Sampling
- Field testing
- Laboratory testing

Methods of Exploration (or) Investigations.

1) Open excavation → Test Pits
→ Trenches.

2) Borings → Auger boring
→ Auger & Shell boring
→ Wash boring
→ Rotary Drilling
→ Percussion Drilling.

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 - 5 m
* 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:

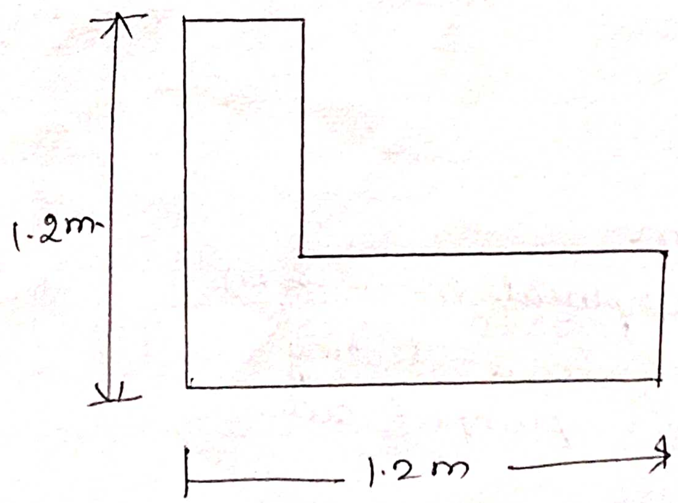
* Continuous length
* Useful for slope exploration

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).**

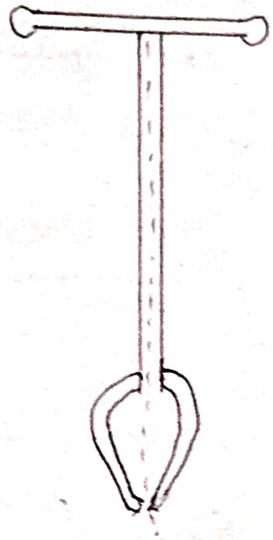
* Bore hole advanced by auger.
* Augers are used in cohesive & other soft soils above water table.
* Types of auger → Hand auger dia (15-20 cm) – upto 6m (dep)
  → Mechanical (or) Power – greater depth. (Gravel soil).
* Post hole auger & Helical auger.
* The soil samples are collected on the sides of augers & 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.



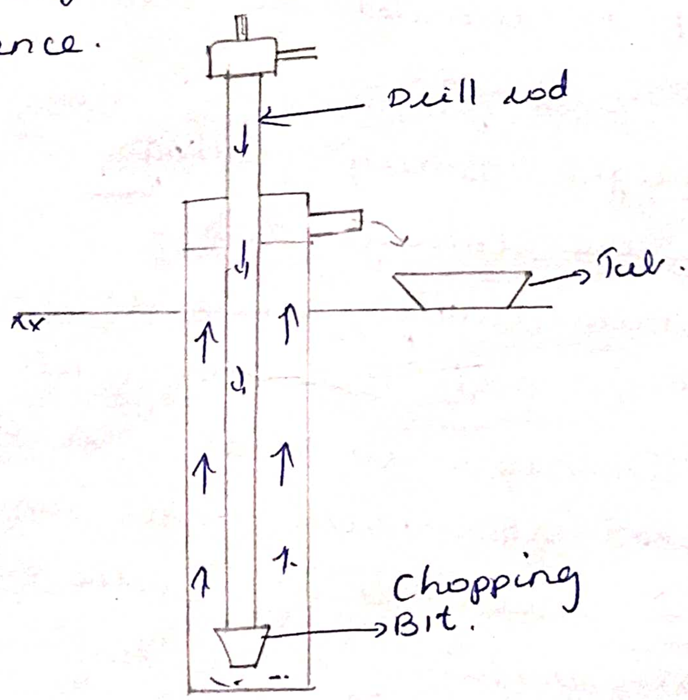
2) Auger & Shell boring (or) Sand bailer:

* 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 boring.

Advantages.	Limitations.
* Fast and inexpensive method	* Cannot be used in hard rock.
* Easy and simple operation	* Highly disturbed samples.
* Unskilled supervision	* Disintegration of soil particles
* Change in stratum can be seen	* 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 coring 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 ~~stt~~ 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) (ie) It is a rough measure of the degree of jointing (or) fracturing in rocks

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

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 pervious stratum due to high usage of drilling fluid
2) Highly disturbed samples
3) Skilled supervision required.

4) Percussion Boring:
* Borehole is advanced by raising and dropping action of the drill pit
* Cuttings are removed in the form of slurry by adding water.
* Sand pumps (or) bailers are used for removal of cuttings.

Advantages	Limitations.
1. Can be used for any types of soil	* Disturbance of soil due to impact.
2. Used for drilling tube wells	* Cannot used for loose sand
3. Rapid method	* Operations require casing
4. Suitable for glacial tills.	* More expensive.
	* Changes in stratum difficult to determine.

Sounding Methods : (or) Penetration Methods.

Sounding means pushing (or) driving by hammer, a steel rod or pipe into the ground, to determine the resistance to penetration (or) 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 methods (refraction, Reflection)
* 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.
- Bed rock profiling.

1. **Seismic Method:**

Principle:

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

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 $d_1, d_2, d_3 \ldots$ at time $t_1, t_2\ t_3 \ldots$

The arrival times are recorded in the recorders.

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.

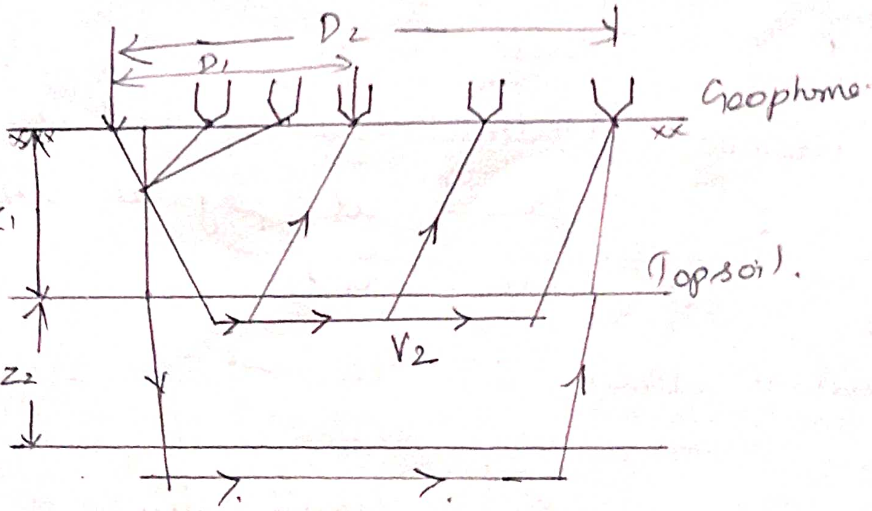
Depth of rock $H = \frac{D}{2}\left[\sqrt{\frac{(V_2 - V_1)}{V_2 + V_1}}\right]$.

Advantages:

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

Limitations

* Soil may not be homogeneous and isotropic
* Thickness of layer should be at least 1/4 th of the depth of occurrence
* Varying boundaries.
* Range of velocities.
* costly.



Refracted waves. (V_3)

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.

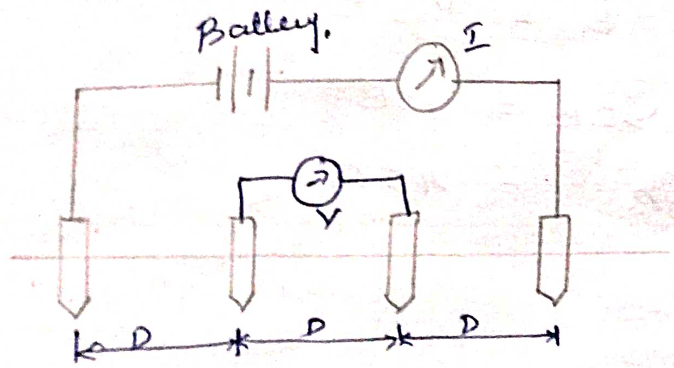
Equipments

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.
* Marked change in potential indicates presence of layers of different resistivity.



$$\rho = \frac{2\pi D E}{I}$$

$\rho \rightarrow$ Resistivity (ohm-cm)

D - Distance b/w electrodes

$E \rightarrow$ Potential drop. (v)

I - Current

Advantages	Limitations
1. Can detect sea water intrusion, organic deposits aquifers, ore bodies.	* Wide range and overlapping of resistances make interpretation difficult.
2. Can differentiate pervious aluvium from clay	* 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 :

$A >= 4B = 1.5B$

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

$A <= 2B = 4.5B.$

* 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 mixed 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.

Types
- Disturbed sample
  - Representative sample
  - Non-Representative sample.
- Non-Disturbed 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.

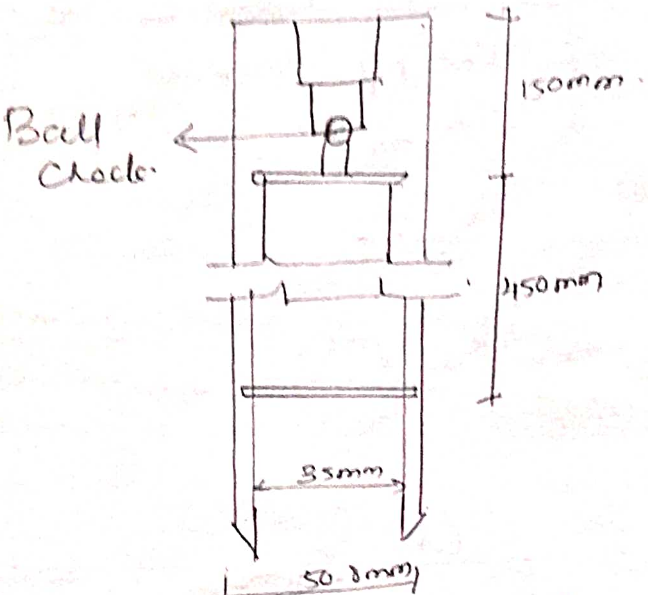
* Open drive sampler
* Stationary piston sampler.
* Rotary sampler.

1. Thick wall sampler (or) Split spoon sampler

* Thick walled tube, split length wise.
* A drive shoe attached to the lower end serves as the cutting edge.
* 35mm internal and 50.8 mm external dia & 600 mm 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 seperated 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 drilling a fluid (or water) into the soil.

Standard split spoon Sampler.



2) <u>Thin walled sampler:</u>

* 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.
* Procedure is the
* 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 engg. properties of soil.

Shell by tube:

* Outside dia varies b/w 40 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 values 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

4) <u>Rotary sampler:</u>

* 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 downward.
* When sufficient depth is drilled, the inner tube is raised to the ground level.
* Used for stiff clayey soils.

5) <u>Foil sampler:</u>

* 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 150mm dia. at the desired depth.
2) A hammer of 65 kg wt with a free fall of 300mm is used to drive the sampler.
3) The number of blows for a penetration of 300 mm is designated as the Standard penetration Value (or) 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 150mm drive
10. Driving is discontinued if N >= 100 for 30 cm penetration.

11. The top soaking 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,

16. or change in strata.

15. Base depth.

0 to 5 m	– 0.75 m
5 to 10 m	– 1 m
> 10 m	– 1.5 m.

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 over burden pressure
* Submergence (or) dilatancy correction.
* Gibbs corrections.

* **Submergance 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 recomenended.

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

N' - Observed SPT Value

$C_N \rightarrow$ Corrected SPT value.

* **Over burden pressure correction:**

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

σ' = Effective over burden pressure = γD (kN/m²)

* **Gibbs correction.**

$$C_N = \frac{50}{1.42\sigma' + 10}$$

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.

Equipment

1) Cone

Mechanical Cone → Dutch cone (3.57cm dia + 60° cone area $10cm^2$)
→ Packmann friction jacket cone

Electrical Cone → Piezo Cone.

2) Sounding rod - 1m long, 15mm dia.
3) Steel (or) Mantle tube - d_i = 16mm, d_o = 36mm, L=1m
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 50mm at the rate of 10-20mm/s by pushing the sounding rods.
5) The test is conducted in increments of not greater than 200mm
6) In case of friction jacket cone, cone resistance is obtained by pushing the cone by 50mm and then the friction jacket is pushed along with cone to get cone & friction resistance

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

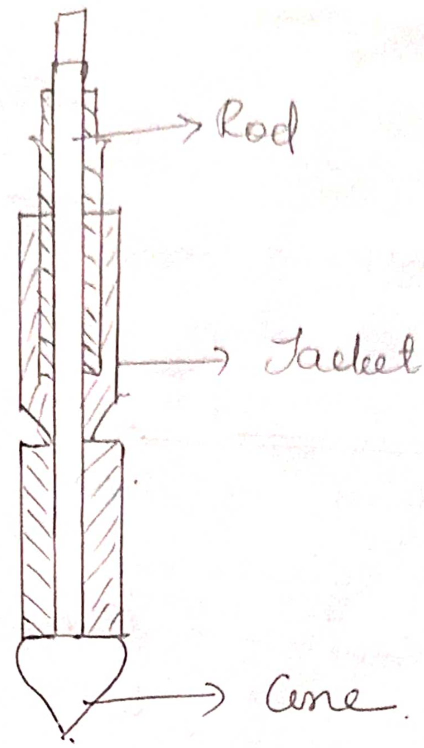
Unit friction (f_s) = $\dfrac{\text{Frictional resistance} \times \text{cone area}}{\text{Surface area of friction jacket.}}$

Friction ratio = $\dfrac{f_s}{q_c} \times 100.$

Applications of SCPT :

* classification of soils
* Strength parameters.
* Bearing capacity factors.
* Load capacity of pile foundation.
* Settlement of foundations.

Merits	Demerits.
1. Tests can be done on soil with low bearing capacity.	* Soil in which test is performed cannot be determined
2. Tests can be performed at smaller intervals	* Seperate rig is required for testing
3. Thin layers strength can be determined	* Cone penetration values are unreliable when particle size is beyond particular size.


Rod
Jacket
Cone

Bore 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 sub soil 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 technique based on soil condition.

Do you improve properties of soft soils.

- **Yes** → Can you led with ground water in soils
  - **Y** → Can you decrease water level
    - **Y** → Is there a risk of liquefaction
      - **Y** → Vibrofloating, Prefabricated vertical drain
      - **N** → Dewatering well point
    - **N** → Grouting method
  - **N** → Do you have plenty of time for improving
    - **Y** → Is it enough
      - **Y** → Preloading (or) Surcharging
      - **N** → Prefabricated vertical drain
    - **N** → Do you have admixture
      - **Y** → Jet grouting, Deep admixture method
      - **N** → Compacted Sand pile method (or) heavy tamping.
- **No** → Do you reinforce soil → Structural supporting Eg. Piles, Retaining wall
  - **Y** → Do you need permanent effects
    - **Y** → Anchor method (or) micropiling
    - **N** → Do you use grouting
      - **Y** → Grouting
      - **N** → Freezing

Data Interpretation :

Based on Liquifaction potential.

Penetration resistance	Unconfined Comp. Strength t/m²	Consistency.	Cohesion KN/m²
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	φ	Density Index	Description.
		0	-
0	25-30	15	very loose
4	27-32	35	Loose
10	30-35	65	Medium
30	35-40	85	dense
50	38-43	100	Very dense
>50	>43		

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. (Retaining earth.
6) Fender pile	Any type of soil. Protect water from impact of ships.

Unit - II Shallow Foundation.

Location and Depth Criterion.

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

* Lateral expulsion of soil from beneath the foundation.
* Seasonal volume change.

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

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

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

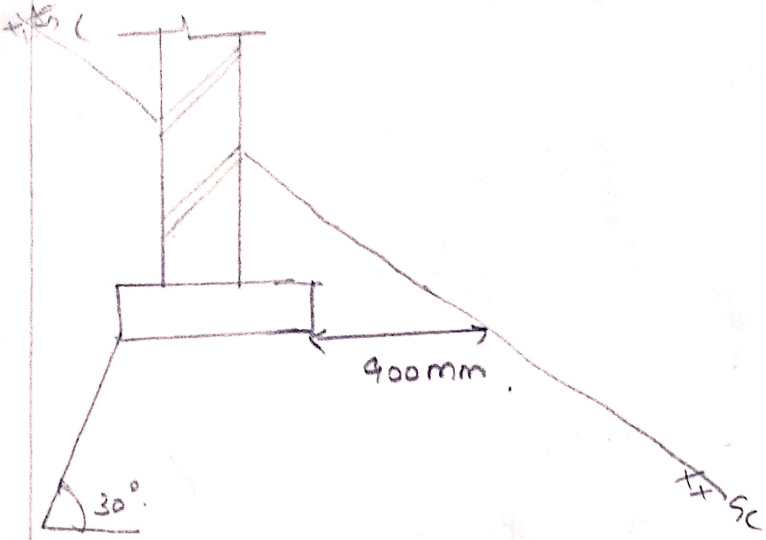
In expansive clay, foundation should be placed below the zone of volume change.

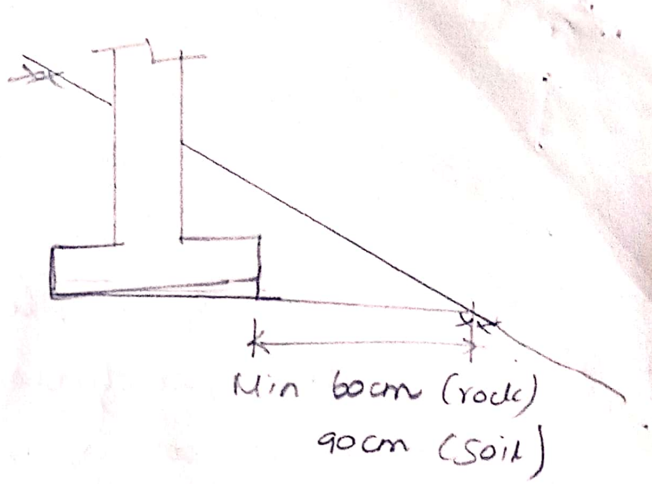
In case of fine sands and silts suceptible to freezing during winter, foundation should be taken below the zone of freezing & thawing.

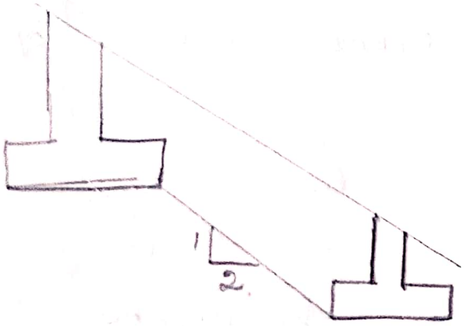
In case of foundations in rivers, the depth should be below the deepest scour level.

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° for rock and 30° for soil.


400mm
30°
GL


Min 60cm (rock)
90cm (soil)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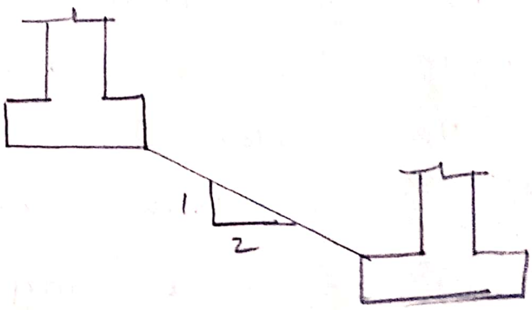
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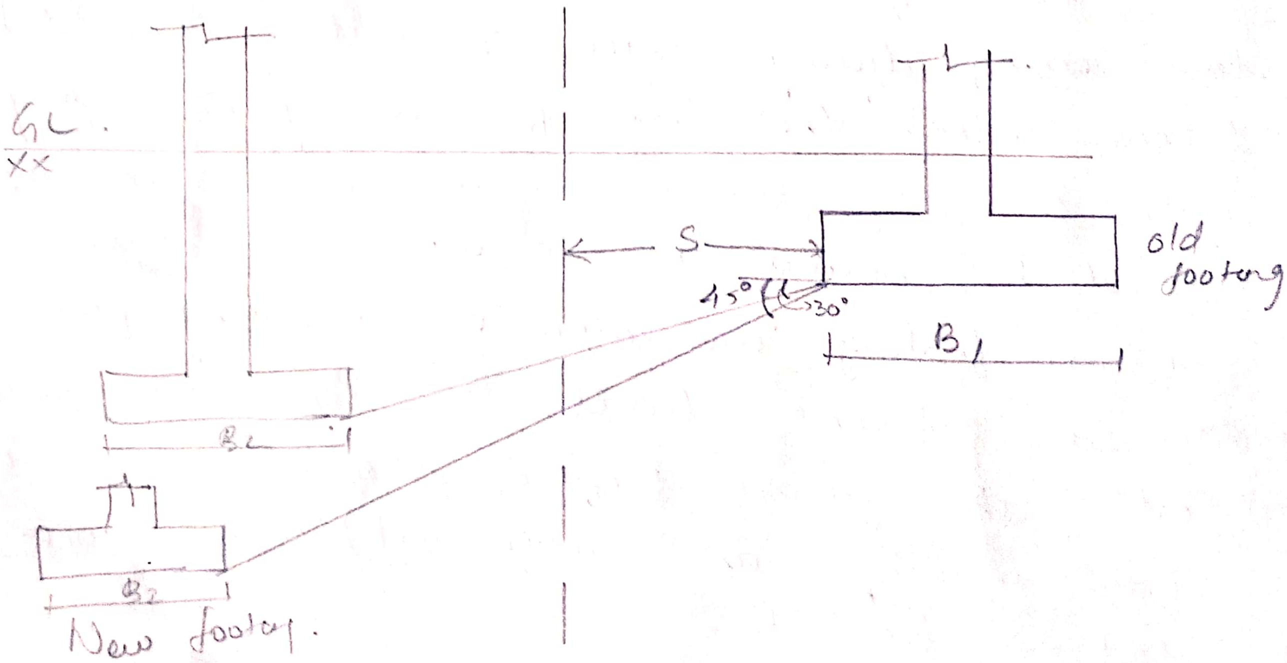

GL
XX
S
45°
30°
old footing
B1
B2
New footing

Total & Net bearing capacity.

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

q_{ns} → Net safe bearing capacity.

q_{nf} → Net ultimate bearing capacity.

Relation b/w q_s & q_{nf}.

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

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

For local shear failure:

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

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

N_c, N_q, N_γ are replaced by N_c', N_q', N_γ'.

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

$\phi > 36^\circ$ → 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

Eqns:

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

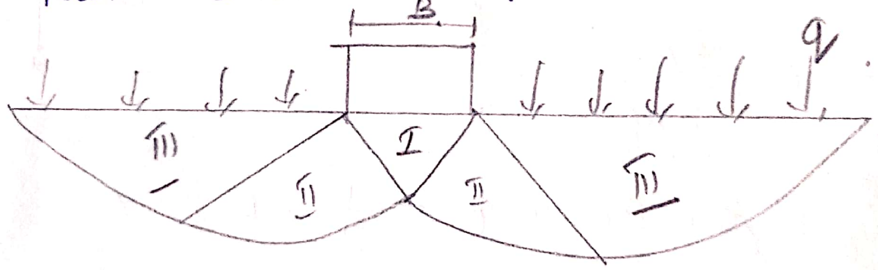
Scanned with OKEN Scanner

Terzaghi'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.

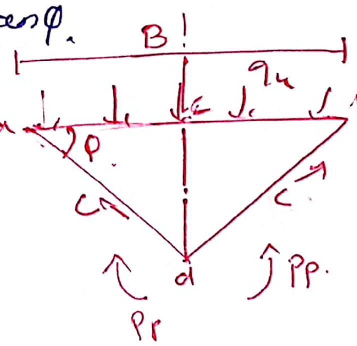
Zone III (Rankine's zone of passive linear shear).

* This zone has two sets of shear planes inclined at an angle of $(45° - \phi/2)$ to the hzl.

At equilibrium.

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

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



$$C = c \times da \text{ (or) } c \times db$$

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

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

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

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

Total passive resistance P_p

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

(Unit wt) + (cohesion) + (surcharge)

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

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

$$\boxed{q_u = cN_c + qN_q + 0.5\gamma B N_\gamma}$$

Terzaghi's bearing equation.

Total + Net bearing capacity.

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

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

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

Relation b/w q_s + q_{nf}

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

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

For local shear failure:

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

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

N_c, N_q, N_γ are replaced by N_c', N_q', N_γ'.

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

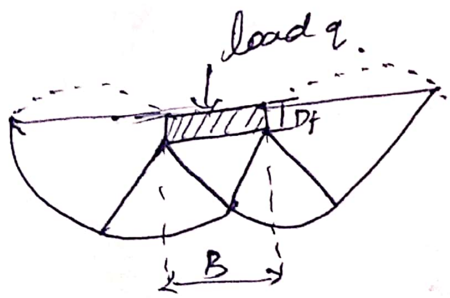
$\phi > 36^\circ \rightarrow$ General shear failure

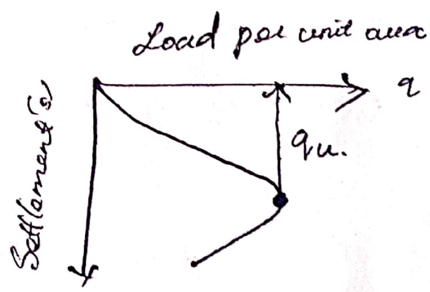
Types of Bearing capacity failure :

* 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.

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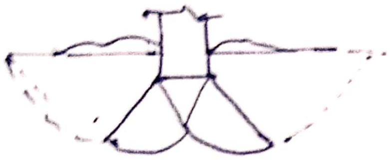
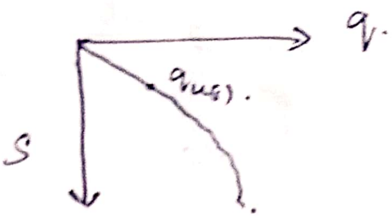
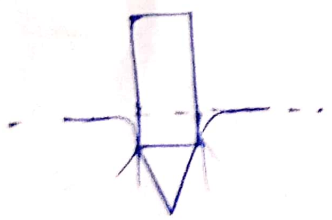
The failure surfaces do not reach the ground surface.
There is only slight bulging of soil around footing.
Failure is not sudden & there is no tilting of footing.
Failure is characterised by large settlements.
UBC is not well defined.

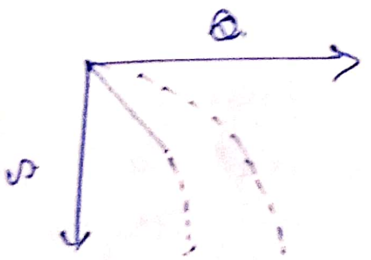




Punching Shear Failure:

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.

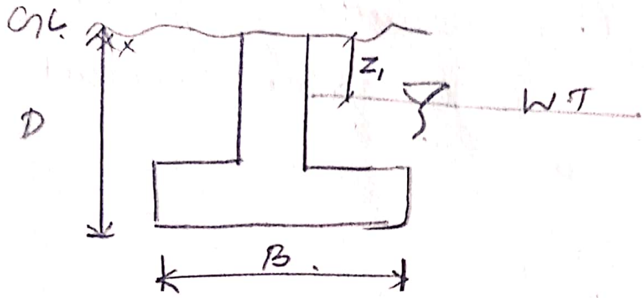




Seismic consideration in bearing capacity.

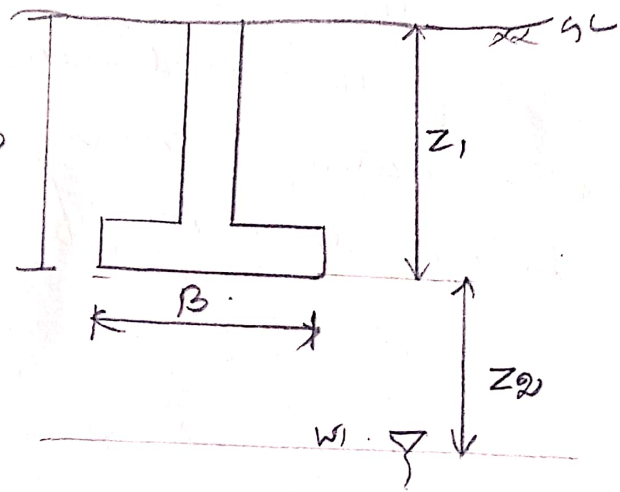
Effect of water table on bearing capacity.

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



$$\boxed{\gamma = \gamma'}$$

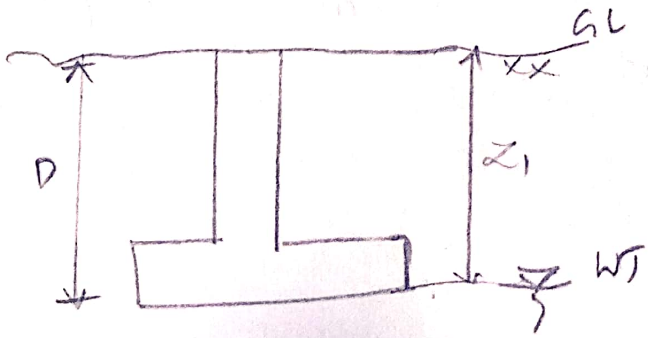
Case (ii) when the WT is below the base of the footing.



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

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

No reduction of γ in this case.



For any position of water table.

$$q_s = CN_c + \gamma_1 D N_q R_{w_1} + 0.5 B \gamma_2 N_\gamma R_{w_2}$$

where,

R_{w_1} & R_{w_2} are the reduction factor for the water table (or) Water table reduction factor.

$$R_{w_1} = 0.5\left(1 + \frac{z_1}{D}\right)$$

$$R_{w_2} = 0.5\left(1 + \frac{z_2}{B}\right)$$

$\gamma_1 \rightarrow$ dry unit wt of the surcharge soil situated above the water table.

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

If $z_1 = 0$; $R_{w_1} = 0.5$

$z_1 = D$; $R_{w_1} = 1$

$z_2 = 0$ $R_{w_2} = 0.5$

$z_2 = B$ $R_{w_2} = 1$

$$R_{w_1} = 0.5\left(1 + \frac{z_1}{D}\right)$$

$$R_{w_2} = 0.5\left[1 + \frac{z_2}{B}\right]$$

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 $\qquad D = 2B_p$

B_p - Breadth of plate

B_f - Breadth of footing

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 Δp is the permissible settlement of the foundation. The maximum settlement of the largest footing should be restricted from $\frac{4}{3}$ of ΔP.

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

$$\frac{\delta_f}{\delta_p} = \left[\frac{B_f\,(B_p + 0.3)}{B_p\,(B_f + 0.3)}\right]^2 \qquad \delta_f = \frac{4}{3}\Delta p$$

$$\delta_f = \frac{4}{3}\Delta P\left[\frac{B_f\,(B_p + 0.3)}{B_p\,(B_f + 0.3)}\right]^2$$

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-φ 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, $\Rightarrow \boxed{q_f = q_p}$

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Rd is consider as 1.2 as the maximum value is 1.2

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

$$q_p = 197.47\ kN/m^2.$$

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.

μ → poisson's ratio [0.5 for saturated clay)

I → Influence factor

For normally consolidated clay

$E_s = 250\,c$ to $500\,c$

For overconsolidated clays

$E_s = 750\,c$ to $1000\,c$

c - undrained cohesion.

Problems on bearing capacity from the SPT & SCPT.

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

Soln:

From Terzaghi's analysis

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

$$R_{w2} = 0.5 \left[1 + \frac{Z_2}{B}\right]$$

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

$$R_{w2} = 0.708$$

$R_d \rightarrow$ depth reduction factor

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

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

$$R_d = 1.25$$

The value of Influence factor 'I' 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.

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

$C_1 \rightarrow$ Correction factor for the depth of foundation

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

$C_2 \rightarrow$ 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.

$q = \gamma D$ = surcharge

I_z = Influence factor

E_s = Modulus of Elasticity.

'E_s' from standard penetration Number (N)

By Schmertmann

$E_s = 765 N \ kN/m^2$.

E_s from static cone penetration resistance

$E_s = 2 q_c$

Consolidation settlement :

$$S = \frac{C_c}{1+e_o} H \log\left(\frac{\bar{\sigma}_o + \Delta\sigma}{\bar{\sigma}_o}\right)$$

q_c = Static cone resistance

H = Thickness of layer

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

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

C_c = Compression index

C_o = 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 bearing.

Problems :

1. A square footing 2.5m × 2.5m is built in a homogeneous bed of sand of unit weight 20 kN/m³ having angle of shearing resistance 36° is a depth of footing is 1.5m below the ground surface. Calculate the safe load that can carried by a footing with FOS of 3 against shear failure. Use Terzaghi's analysis.

Given :

Type - Square footing.

Soil type - Sandy soil (i.e) cohesionless soil

$c = 0$.

$L = 2.5m$; $b = 2.5m$; $D = 1.5m$.

$\gamma = 20 \ kN/m^3$.

$F = 3$

$\phi = 36°$.

Soln :

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

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

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

$$Q_s = q_s \times A.$$

For square footing.

Ultimate bearing capacity q_f

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

$\varphi = 35° \Rightarrow N_c = 57.8, \quad N_q = 41.4, \quad N_\gamma = 42.4$

$\varphi = 40° \Rightarrow N_c = 95.7, \quad N_q = 81.3, \quad N_\gamma = 100.4$

By Interpolating

$\varphi = 36° \Rightarrow N_q = 49.38 \qquad N_\gamma = 54$

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

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

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

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

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

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

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

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

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

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

Greatest of these two is 873.8 kN/m^2

Hence q_s = 873.8 kN/m^2.

Safe load (Q_s) = q_s × Area

Q_s = 873.8 × (2.5 × 2.5)

Q_s = 5461.25 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.

$T = \frac{3}{L}$.

Unit - III Shallow foundation.

Footing & Rafts

Foundation :

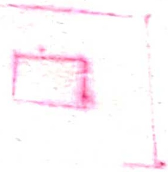
Foundation is an integral part of the structure which transfers the load of the superstructure to the soil. A foundation is that member which provides support for the structure and its loading.

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 3 m 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.

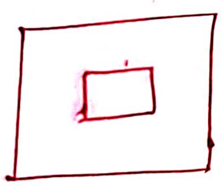
If the depth of foundation is greater than 3 m is known as depp foundation.

$$B < D$$

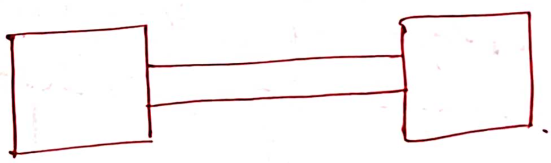
Types of shallow foundation:

- Shallow foundation.
  - Footings.
    - Spread foundation.
      - Continuous (Strip or wall) footing
      - Isolated footing.
        - Square footing
        - Circular footing
        - Rectangular footing.
    - Strap footing
    - Combined footing.
      - Rectangular footing
      - Trapezoidal footing.
  - Rafts (Mats)

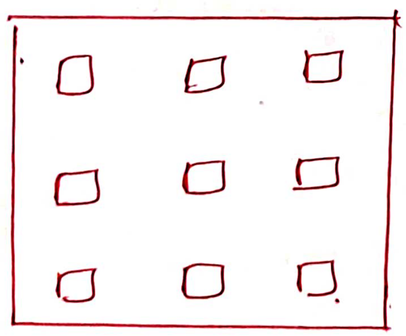
Isolated



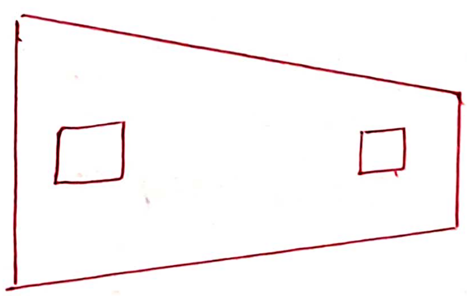
Strap.



Mat.



Trapezoidal.

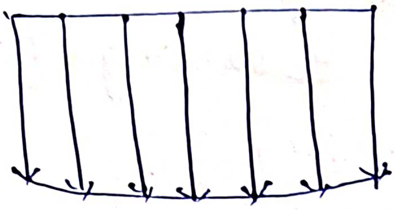


Contact pressure on sand (or) cohesionless soil.

Flexible footing :

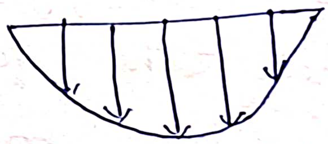
The edges of flexible footing undergo a large settlement than at the centre.

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

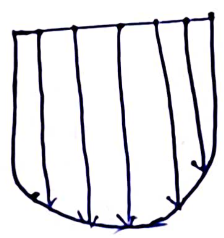
It depends on the following factors.

* Elastic properties of footing
* Elastic properties of soil
* Thickness of footing.

Contact pressure on clay :

Flexible footing :

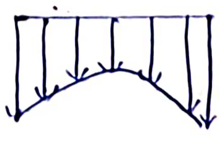
When the footing is flexible, it deforms into shape of bowl, with the maximum deflection at the centre. The contact pressure distribution is uniform.



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/m².

Given.

$L = 1\,m$

$Q = 800\ kN/m$

$q_a = 200\ kN/m^2$

Soln :

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

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

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

$$B = \frac{Q}{q_A} = \frac{800}{200} = 4\,m$$

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

$$\text{Actual pressure } (q) = \frac{Q}{A} = \frac{8}{4 \times 1} = 200\ kN/m^2$$

$$q = 200\ kN/m^2$$

Step : 2 Determination of overall depth of footing.

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

σ_{sp} = safe punching shear.

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

$$D = \frac{200\left[4^2 - (1+d)^2\right]}{4(1+d)\ 1000} \quad \text{—①}$$

Assume effective cover 60 mm.

$D = d + d' = d + 0.06 \rightarrow$ sub in ①

$$d + 0.06 = \frac{200\left(16 - (1+d)^2\right)}{4(1+d)\ 1000}$$

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

$d = 0.43\,m$

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

$D = d + d' = 430 + 60 = 490\,mm$

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

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

Step : iii Determination of Max BM.

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

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

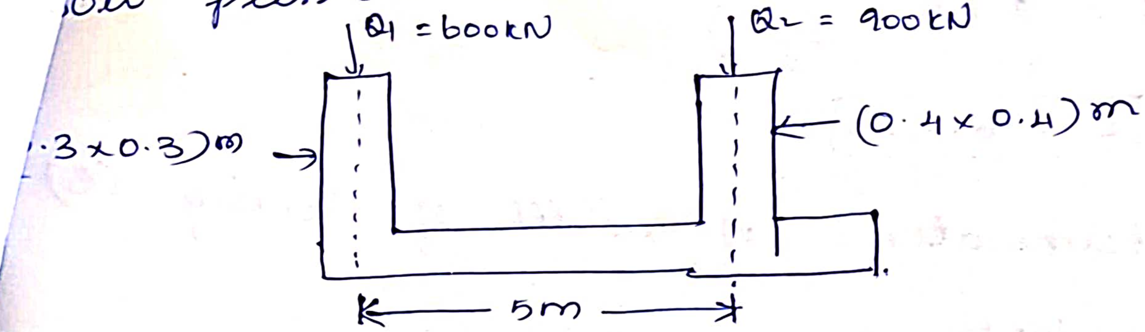
$= 225\ \dfrac{kN.m}{m}$

Step 4 : Determination of diagonal shear.

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

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

[De]sign a rectangular combined footing for [tw]o columns shown in fig. Take allowable [s]oil pressure as 100 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.

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

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

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

Moment about the column ①.

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

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

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

Step IV. Determination of length of footing

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

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

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

Step V Determination of width of footing (B)

$$A = B \times L$$

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

$$B = \frac{1.5}{6.3}$$

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

Step VI Determination of actual pressure

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

$$q_0 = 99.21\ kN/m^2 < 100\ kN/m^2.$$

Hence it is safe.

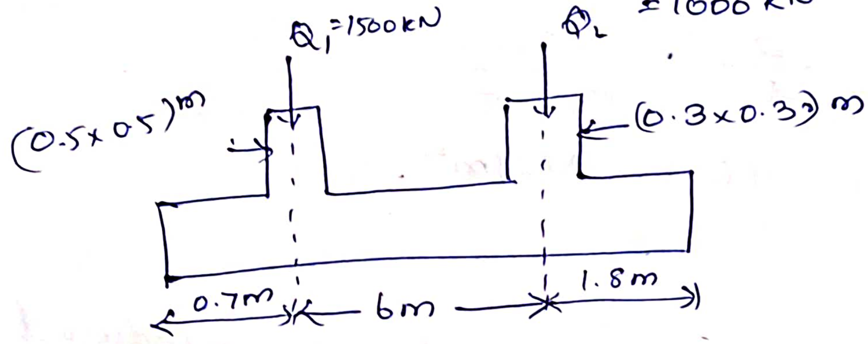
Actual pressure per m' run.

$$Q_0 = q_0 \times B$$

$$= 99.2 \times 2.4$$

$$Q_0 = 238.104\ kN/m^2/m.$$

ign a rectangular combined footing for two column 6m c/c apart. The exterior column size is 0.5m × 0.5m and it carries 1500 kN load. The interior column is of size (0.3×0.3)m and it carries a load of 1000 kN. The projection of footing beyond left column is 0.5m from centre & 1.8m beyond right side column centre. Take allowable soil pressure as 200 kN/m².



Soln:

Step I : Determination of total load. (Q)

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

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

Step 2 : Determination of area of footing

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

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

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

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

$$\boxed{Q = R}$$

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

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

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

Step 4: Determination of width of footing.

$A = 12.5\,m^2$

$B \times L = 12.5$

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

$B = 1.5\,m$.

Size of the footing $8.5\,m \times 1.5\,m$.

Step 5: Determination of actual pressure.

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

$q_a = 196.1\ kN/m^2$.

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 kN/m². 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 :

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

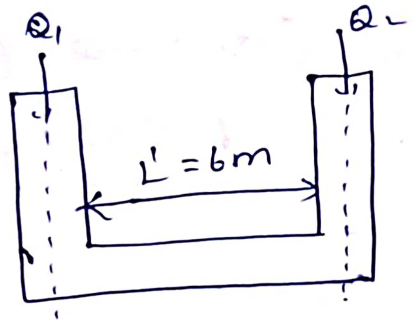
Column ① size $= 50\ cm = (0.5 \times 0.5)\ m$.

$L = 6\,m$

Load on column ① = 3000 kN

Load on column ② = 5000 kN.

SBC = 400 kN/m².



Soln:

Step 1: Determination of Total load.

$Q = Q_1 + Q_2 = 3000 + 5000$

$\boxed{Q = 8000\,kN}$

Step 2: Determination of area of footing.

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

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

$A = 20\,m^2$

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

$20 = \frac{1}{2}(a+b) \times 6.8$

$a+b = 5.882\,m$ ——— ①.

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

Taking moment about the centre of the column ①

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

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

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

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.

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

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

From ①

$$a+b = 5.882$$

$$a = 5.882 - b$$

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

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

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

$$10.769 = 11.764 - b$$

$$\boxed{b = 0.995}$$

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

$$\boxed{a = 4.887}$$

size of the footing

$a = 4.887 m$

$b = 0.99 m$

$L = 6.8 m$.

Step 5: Check for area of the footing

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

$$A = 20 m^2.$$

Step 6: Check for safe bearing capacity.

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

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

Safe.

Unit IV. 4

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
   - Anchors pile
   - Sheet pile.

4) Based on fabrication & installation, piles are classified into
   - Cast-insitu piles
     - Bored
     - Driven
       - Driven cased
       - Driven Uncased.
   - Precast piles.

② Based on extent of ground disturbance piles are classified into.
* Replacement piles
* Displacement piles.

ormally used deposits Comp

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

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

③

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 (Qu) 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: (4)

(*) Vertical support piles: To carry vertical loads coming on to them.

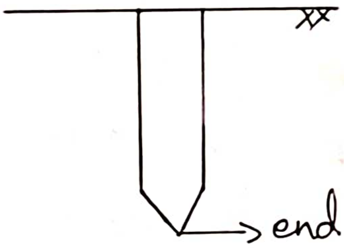
(*) Compaction pile: It is used to compact loose granular soil. They do not carry anyload themselves.

(*) Batter piles: Inclined piles used to resist lateral loads.

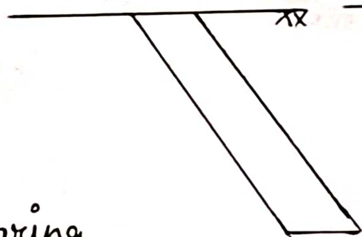
(*) Fender piles: It is used to protect offshore structures against impact from ships or floating objects.

(*) Anchor piles: It is used to anchor structures against uplift and resist tensile loads.

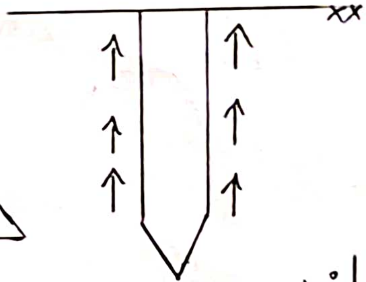
(*) Sheet piles: It is used for retaining earth and reduce seepage



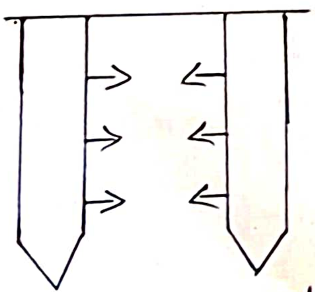
end bearing pile.



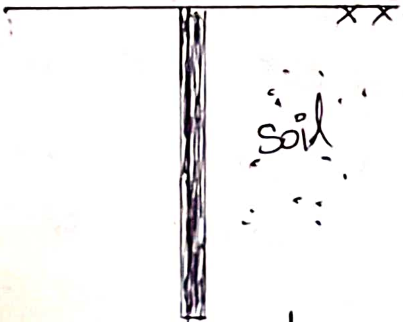
Batter pile



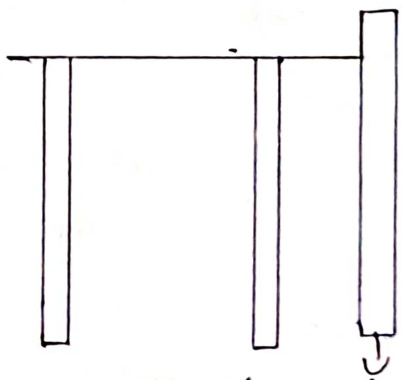
Friction pile



Compaction pile



Sheet pile



Fender pile.

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.

6) 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.

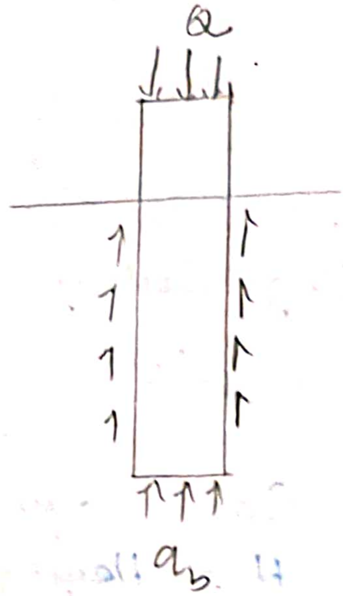
9) Economy:

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

Lime Pile:

Load carrying capacity in Granular & cohesive soils.

- Static formula
- Dynamic formula
- Pile Load test
- Penetration test.



Static formula:

$$Q_f = Q_p + Q_s$$

Q_f - Ultimate capacity

Q_p - Point resistance

Q_s - Shaft resistance.

$$Q_f = Q_p + Q_s \quad (\text{or}) \quad R_f + R_p.$$

$$Q_f = q_p A_p + f_s A_s \quad \text{or} \quad A_s \tau_f + A_p \sigma_p.$$

σ_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 $\pi \delta^2$

τ_f (or f_s → Unit skin friction resistance $= \alpha c$ (or) mc

A_s → Surface area of the pile shaft. $= \pi DL$

For tapered piles. (1/3 l).

α (or m → adhesion coefficients (or) Reduction factor.

For $L < 20q$ ⇒ α (or m $= 0.4$

For deeper piles ⇒ α or m $= 0.4$ to 1 $\rightarrow c = 90\ kN/m^2$

$c = 170\ kN/m^2$

c - Avg undrained cohesion along the length of the pile.

C_p - Avg undrained cohesion of the soil at the pile tip $= q_u/2$

For cohesive soil, point or) and bearing is neglected.

Factor of safety = 2.5 to 3

$$Qa = \frac{Qup}{F}$$

2) Dynamic Formula:

a) Engineering News Formula:

$$Qa = \frac{WH}{F(S+C)}$$

Qa = 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

$$Qa = \frac{(W+ap)H}{6(S+0.25)}$$

a - effective area of piston in cm^2

p - Pressure in Kg/cm^2

For single acting Hammer.

$$Q_a = \frac{WH}{6(S+0.25)}$$

b) Hiley's Formula :

$$Q_f = \frac{\eta_H \, W H \eta_b}{S + C/2}$$

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.

η_H = Efficiency of hammer
(65% for double acting steam hammer
100% for drop hammer)

η_b = Efficiency of hammer blow.

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

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

P - wt of pile, helmet, follower

e → coeff. of restitution (0 to 0.5)

For timber pile (e = 0).

Effective fall = $\eta_H \cdot H$

Limitations:

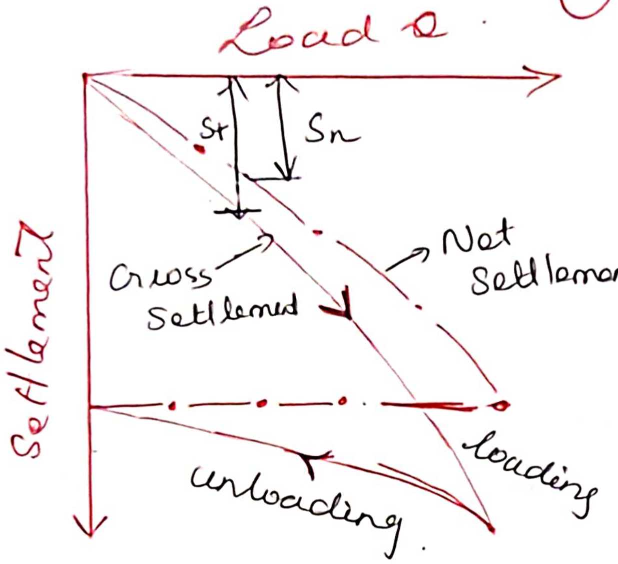
* Suited for coarse grained soil.
* Relation b/w static & dynamic resistance is uncertain
* Driving may cause liquefaction in loose sands.
* No indication of future changes in structure or settlement.
* Hiley's formula involves a lot of constants.
* Engineering News formula, wt of the pile & hence its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

Negative skin

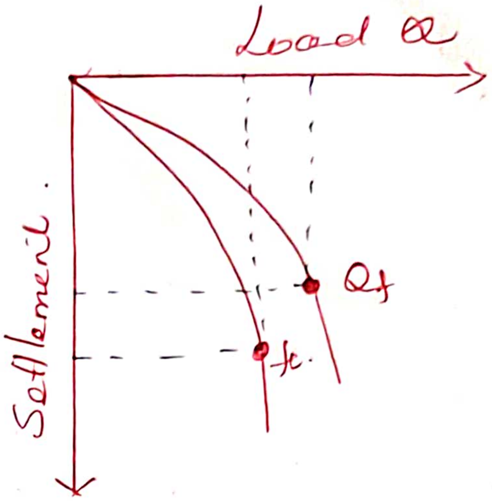
Pile load test:

∴ 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 gauges.
9) Settlement rate 0.1 mm per hour for sandy soil and 0.02 mm 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 safe load (or) the load at which the settlement reaches a specified value.
12) The load is removed in the same decrement at 1 hr interval & final rebound is recorded 24 hrs after the entire load has been removed.



Load- Settlement curve



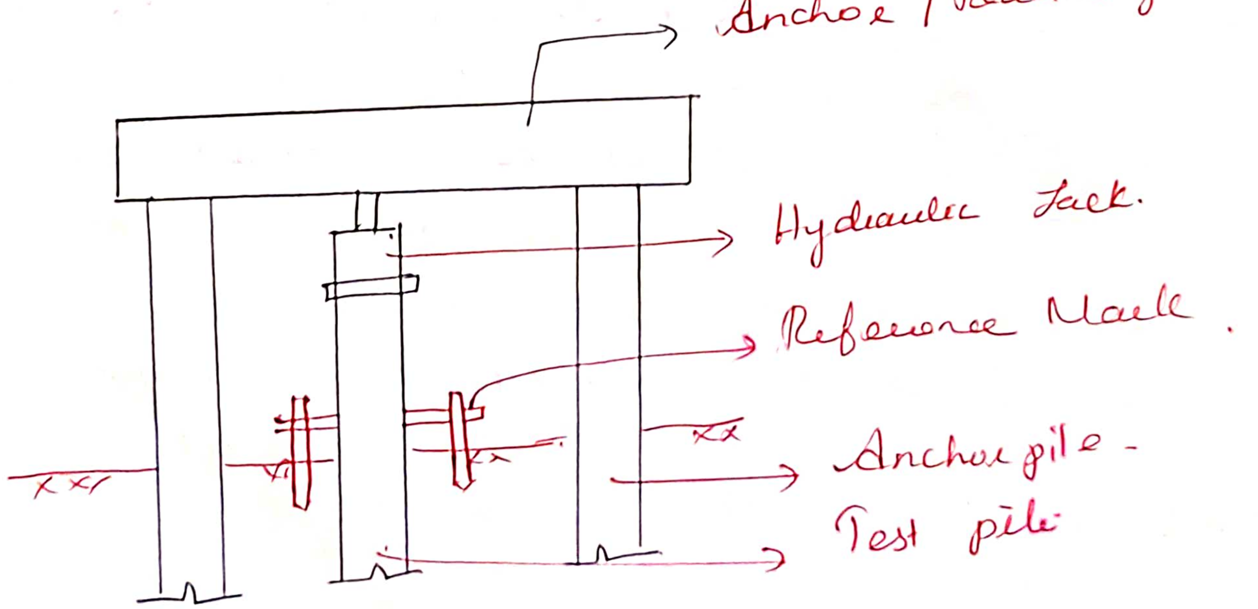
Load-settlement graph for two diff-soil.

$$\boxed{S_n = S_t - S_e}$$

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 or $\frac{2}{3}$ of final load at which total settlement is 12mm

14) Net settlement should not more than 20 mm
Gross 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_c – Length of compressible layer

C_a – Unit adhesion = αC_u

α – adhesion factor

C_u – 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.

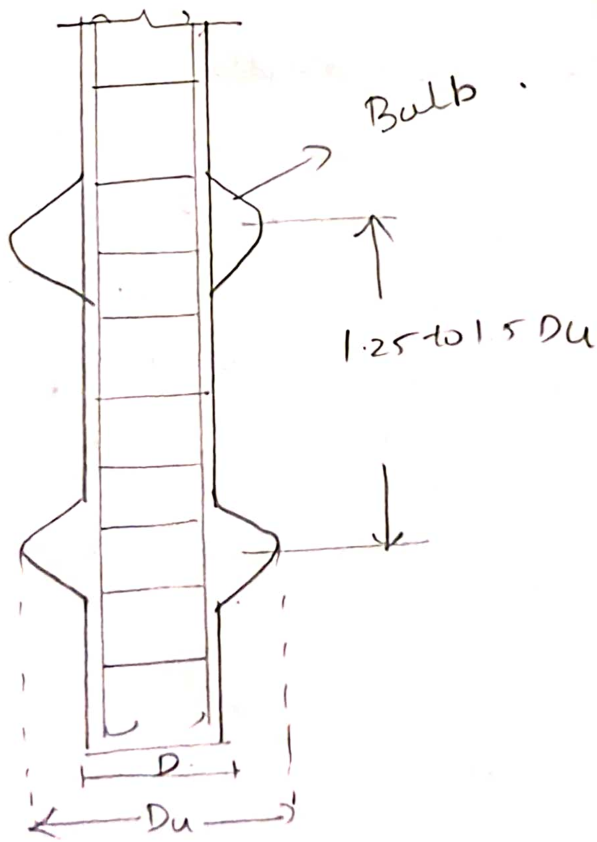
Under-reamed Pile foundation :

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

* Dia of the under ream D_u is kept 2.5 times the pile diameter D, But can vary b/w 2D to 3D

* Minimum length of the pile in expansive soils is 3.5 m.
* Centre to centre spacing should not be greater than 2 Du but can be reduced to 1.5 Du for 10% reduction in loads.
* The max spacing of under reamed piles should not exceed 2.5m.
* The centre to centre vertical bulb spacing may be kept equal to 1.5 Du in piles of diameter is less than 30 cm,

  1.25 Du in piles of dia > 30 cm in multi under reamed piles.
* The min depth of the uppermost bulb should be greater of 2Du (or) 1.75m



Uplift capacity of piles :

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

Piles in clay :

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

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.

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

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

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	0.7
Stiff	0.5
Stiff fissured clay	0.25

Piles in $c - \varphi$ soil.

For Shallow depth :

$$Q_{ut} = \pi c D_b L + \frac{1}{2} \pi S \gamma' D_b L^2 \tan\varphi + W_p \quad — ①$$

For deep depth.

$$Q_{ul} = \pi c D_b H + S \gamma' D_b (2L - H) H K_u \tan\varphi + W_p \quad — ②$$

$S \rightarrow$ Shape factor

$$S = 1 + \frac{mL}{D_b}$$

γ'. - Effective unit wt.

$K_u = (0.9 - 0.95)$.

$$Q_{ut} = \frac{1}{4} \pi (D_b^2 - D) (c N_c + \sigma_b' N_q) + f_s A_s + W_p \quad — ③$$

Q_{ut} is taken from the above least value of ③ eqn.

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}

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

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

C_u' - Avg undrained strength of clay along the length of the block

N_c = 9

A_b → C/S of block.

P_b → Perimeter of block.

L → 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.

$$\eta = \frac{Q_{ug}}{n Q_u}$$

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 or fills.

D → Pile shaft dia.

Converse - Labarre formula.

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

$\eta_g \rightarrow$ Group efficiency.

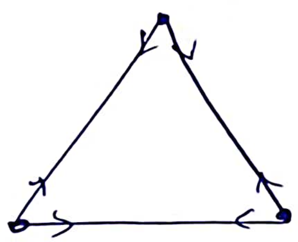
$\varphi = \tan^{-1}\frac{d}{s}$ in degrees. $\frac{\text{dia}}{\text{spacing}}$.

m = no. of rows of piles.

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

Feld's rule :

According to Felds 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.

$\eta_g = \frac{14}{16} = 97\%.$

Seiler-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.

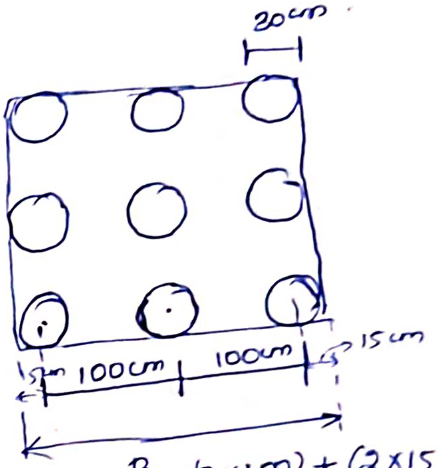
→ Equivalent raft approach.

→ 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.

A square group of 9 piles was driven into soft clay extending to a large depth. The dia & length of the piles were 30 cm & 9 m resply. If the unconfines compression strength of clay is 9 t/m^2 & the pile spacing is 100 cm c/c, what is the capacity of the group? F = 2.5 & adhesion factor 0.75.



$B = (2\times100) + (2\times15)$

$\boxed{B = 230\,cm}$

Soln: $q_u = 9\ t/m^2$

$B = 2\times100 + 30 = 230\,cm$

$B = 2.3\,m$

$C_u = \frac{q_u}{2} = \frac{9}{2} = 4.5\ t/m^2$

n = no of piles = 9 ;

case (i) Piles acting individually

$Q_{un} = (A_p \cdot r_p + A_s \cdot r_f)\,n$

$A_p = \frac{\pi}{4} \times 0.3^2 = 0.07069\,m^2$

$r_p = N_c\,C_u = 9 \times 4.5 = 40.5\ t/m^2$

$A_s = \pi d L = \pi \times 0.3 \times 9 = 8.4823\ m^2$

$r_f = m\,C_u = 0.75 \times 4.5 = 3.375\ t/m^2$.

$Q_{un} = [(0.07069 \times 40.5) + (8.4823 \times 3.375)]\,9$

$Q_{un} = 283.4\,t$.

case (ii) Piles acting in a group.

$Q_{ug} = A_{pg} \cdot r_p + A_{sg} \cdot r_f$

$A_{pg} = B^2 = (2.3)^2 = 5.29\, m^2$

$r_p = n\, C_u = 9 \times 4.5 = 40.5\, t/m^2$

$A_{sg} = 4BL = 4 \times 2.3 \times 9 = 82.8\, m^2$

$r_f = C_u = 4.5\, t/m^2$.

$Q_{ug} = 586.85\, t$.

Lesser of two $= 283.4t$.

Load capacity $= \frac{283.4}{2.5} = 113.36t$.

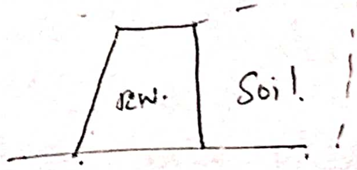
Retaining wall: (RW)

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:

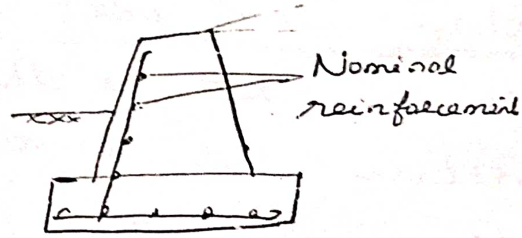
1. Gravity and Semi-gravity RW
2) Cantilever RW
3. Counterfort RW
4. Buttress RW
5. Sheet Pile Walls.
⑥ Crib walls
⑦ Gabion walls
⑧ Reinforced Earth walls.

1) **Gravity RW:**



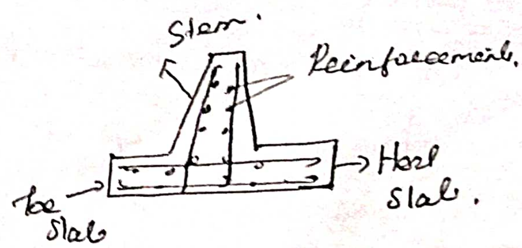
– To retain the soil by resisting the lateral thrust due to its immense size & weight.

) **Semi Gravity RW:**



→ To resist lateral earth pressure partly by it 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 6 m. The counterfort is provided at equal interval. It is similar to cantilever wall, retains the soil