DAY 09

Soil exploration

- **Test pits (or) Trenches:** In these methods, soil can be inspected in their natural condition on pit of **size 1.2 m $\times$ 1.2 m [IS Code**]. Shallow **pits upto a depth of 3 m** can be made without providing any lateral support. For deeper pits, lateral support in the form of sheeting and bracing are provided. **For depths greater than 6 m, bore holes are more economical than test pits**.

- **Drifts and Shafts**: Drifts **are tunnels driven in horizontal direction** to find the nature of the soil strata. Drift should have the **minimum clear dimensions of 1.5 m width and 2.0 m height in hard rock. Shafts are large size vertical holes** driven into the ground to find the nature of the soil strata. Minimum diameter of such holes should be **2.4 m.**

Boring:

- **Auger Boring:** An auger is a device that is used for advancing a bore hole into the ground. Types are **hand augers [upto depth of 3-6m)** and **mechanical augers (upto depth 12 m).**

- **Auger and Shell Boring:** The sides of the bore hole cannot remain unsupported; the soil is prevented from falling with the help of casing (or) shell. Casings may be used for sandy soils (or) stiff clays.

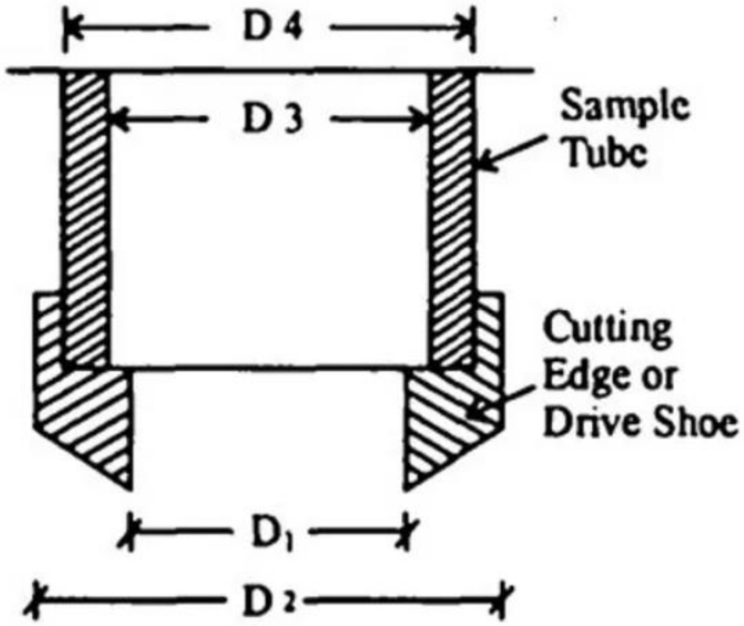
- **Wash Boring:** It is a simple method used for making holes in all types of soil **except** those which are mixed with **gravel and boulders**. This method used for exploration **below the ground water table**. This method is slow for stiff soils and coarse-grained soils.

- **Percussion Drilling:** This method is used for making **holes in rocks**, boulders and other hard strata. For this method, a **heavy drill bit is driven into the ground by repeated blows**.

- **Rotary Drilling:** In this method, the bore hole is advanced by a **rotating drill rod**. It is driven by a rotary drive mechanism by the application of downward pressure. This method is generally used to obtain the **rock core samples**.

Soil sampling and Samplers

- **Disturbed Samples:** Disturbed samples can be used to determine the index properties of the soil, such as grain size, plasticity characteristics, specific gravity.
- **Undisturbed Samples:** Undisturbed samples are used to determine the engineering properties of the soil, such as compressibility, shear strength, and permeability.



Inside Clearance (C_i)

$$C_i = \frac{D_3 - D_1}{D_1} \times 100$$

For undisturbed sample, inside clearance should be between 0.5 to 3 %

Outside Clearance (C_o)

$$C_i = \frac{D_2 - D_4}{D_4} \times 100$$

- For undisturbed sample, inside clearance should be between 0 to 2 %.

- **Area ratio (A_r)** $A_r = \frac{Maximum\ cross\ sectional\ area\ of\ the\ cutting\ edge}{Area\ of\ the\ soil\ sample} \times 100 = \frac{D_2^2 - D_1^2}{D_1^2} \times 100$

For obtaining good quality undisturbed samples, the area ratio should be 10% or less.

- **Recovery ratio (L_r)**

$L_r = \frac{Length\ of\ the\ sample\ within\ the\ tube}{Depth\ of\ the\ penetration\ of\ sampling\ tube}$ **L_r=1,** represents good recovery where **L_r>1** represents swelling of the soil.

- Split spoon sampler which is used for SPT test gives disturbed samples. Shelby tube are used for undisturbed sampling.
- Cutting angle should be within 20^0

Planning of soil exploration includes:

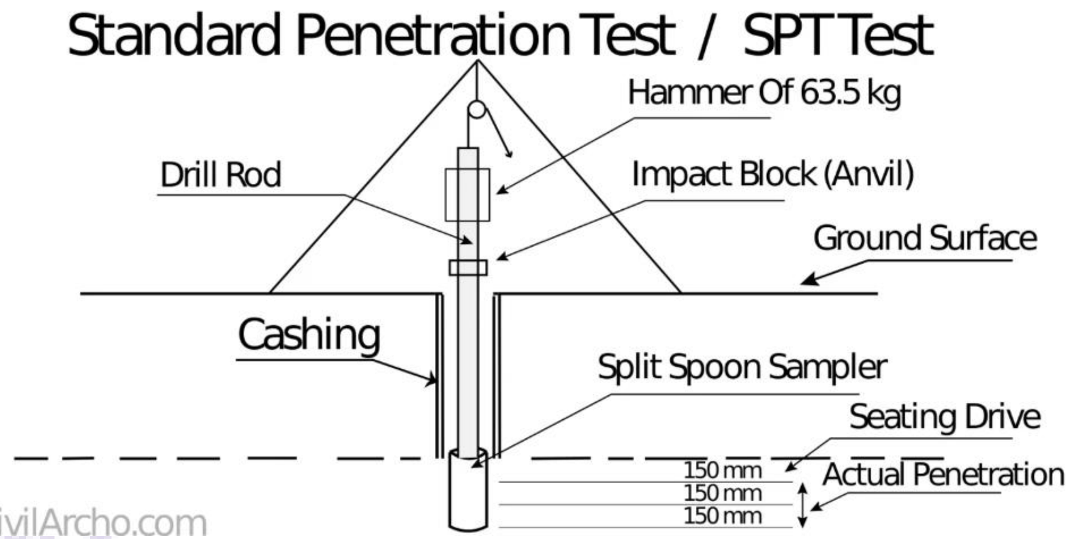
- The cost of the site investigation generally varies between **0.05 to 0.2% of the total cost** of the entire structure. In some unusual conditions, the cost may be even upto 1%.
- The depth of exploration required at a particular site depends upon the **degree of variation of the subsurface data** in the horizontal and vertical directions. The depth of exploration is governed by the depth of the **influence zone**.
- The depth upto which the stress increment due to superimposed loads **can produce significant settlement and shear stresses** is known as the **significant depth**.
- The depth of the exploration should be at least upto the significant depth. Significant depth is generally taken as the depth at which the **vertical stress is 20% of the load intensity**.
- According to this, the depth of exploration should be:
    - at about 1.5 times the width of square footing
    - 3.0 times the width of strip footing.
    - at least 1.5 times the width of the entire loaded area (raft).
    - at least 1.5 times the width of the pile group (below the tip of pile).
- In **case of multi-storeyed buildings**,
    - (Sowers and Sowers, 1970), $\boldsymbol{D = C(S^{0.7})}$ where D = depth of exploration (m), C = constant, which is equal to 3 for light steel buildings and narrow concrete buildings. It is equal to 6 for heavy steel buildings and wide concrete buildings, S = number of storeys.
- In case of road cuts, it is taken at least equal to the width of the cut.
- In case of road fills, the minimum depth of boring is **2 m below the ground surface** or equal to the height of the fill, whichever is greater.
- In case of gravity dams, the **minimum depth of boring is twice the height of the dam**.
- **Horizontal spacing:**
    - For small and less important buildings, even one bore hole or a trial pit in the centre may suffice. But for compact buildings, covering an area of about 0.4 hectares, there should be at least 5 bore holes, one at the center and four near the corners. For large, multi-storeyed buildings, the bore holes should be drilled at all the corners and also at important locations.

Standard Penetration Test (SPT):

The sampler is driven to the soil by drop hammer **63.5 kg** mass falling through **750 mm** and at a rate of **30 blows per minute**. The number of blows required to penetrate each 150 mm is counted for three penetrations. But the number of blows for first 150 mm is referred as **seating drive** and the number of **blows for last two 150 mm intervals** are recorded for standard penetration number (N). If the number of blows for 150mm **exceeds 50, it is taken as refusal** and the test is discontinued.

The obtained N value is further corrected for dilatancy and overburden to get corrected Standard penetration number (N_C)

- Used for cohesionless soil which can’t be easily sampled.
- Used for determining the relative density and the angle of shearing resistance for cohesionless soil.
- Used for determining compressive strength of cohesive soil.



Overburden Pressure Correction

- The overburden correction in SPT is mainly required in the **cohesionless soil** or **granular soil**.

As we all know that **effective overburden pressure** or **confining pressure** increases when the depth increases.

$$N_1 = N_0\left(\frac{350}{70+\bar{\sigma}}\right)$$

The dilatancy correction or water table correction:

- is applied in the **fine sand** and **silt** when the water table is present. when the **water table** is **at** or **above** the **test level**, then the dilatancy or water table correction shall be applied.

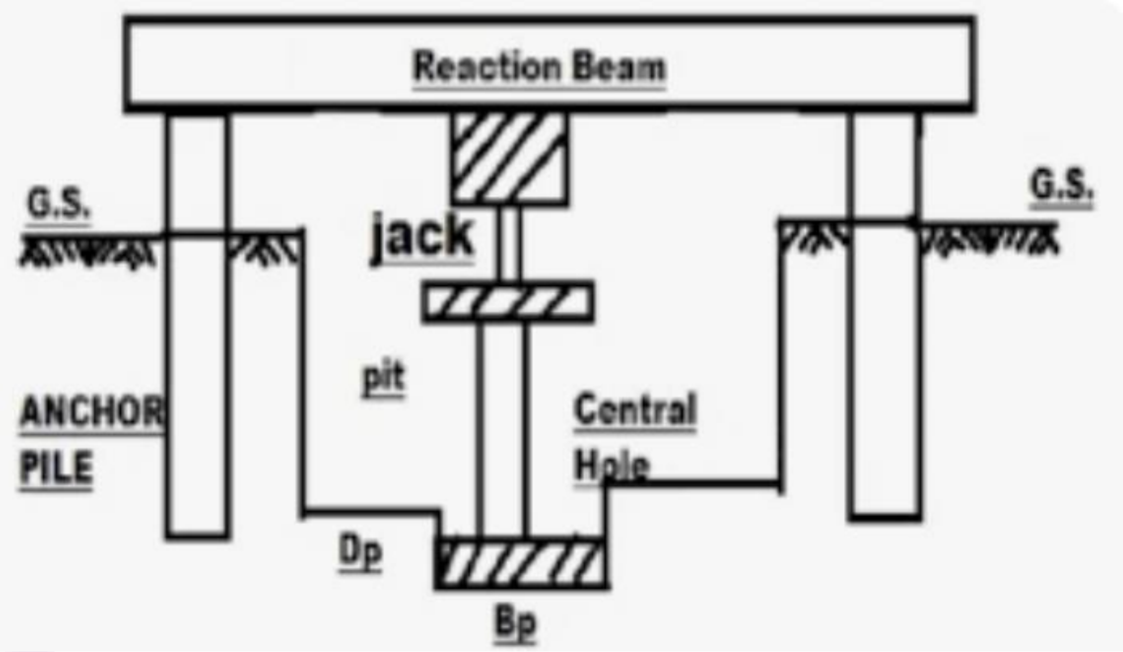
$$N_2 = 15 + 1/2\,(N_1 - 15)$$

Plate load Test:

- Size of pit 5 Bp * 5 Bp (Bp=size of plate, Usually 0.3 cm)
- The bearing plate is squared, of minimum size, 30 cm^2 and the maximum size is 75 cm^2. The thickness of the steel plate should not be less than 25 mm.
- Central hole: Bp* Bp with depth of central hole obtained by:

$$\frac{D_p}{B_P} = \frac{D_f}{B_F}$$

(p= plate, f=foundation)
- Seating load of 7 kN/m2 (released after sometime)
- Load applied at increment of 20% of estimated safe load or 10% of ultimate load.
- Settlement is recorded after 1, 5, 10, 20, 40, 60 minutes and further after an interval of 1 hour.
- The test is conducted until a failure or at least until the total settlement of about 25 mm has occurred (IS 888)



Load Settlement Curve:

- For the plate qu(p) the ultimate load denotes by a break on the log-log plot between the settlements and the load intensity (q).
- When the break does not well-defined, the ultimate load takes as that corresponding to a settlement of **one-fifth of the plate width (Bp).**
- On the natural plat, the ultimate load is obtained from the intersection of the tangents drawn.

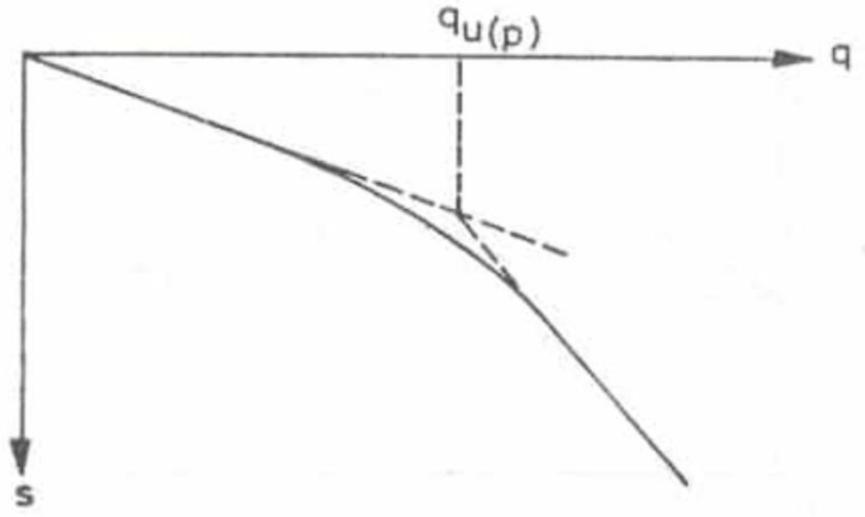


Figure: Load-settlement graph

For cohesioless soil → $\boxed{\dfrac{q_{uf}}{q_{up}} = \dfrac{B_f}{B_p}}$

For cohesive soil → $\boxed{q_{uf} = q_{up}}$

Terzaghi and Peck (1948):

$$\frac{S_f}{S_p} = \left[\frac{B_f\left(B_p + 30\right)}{B_p\left(B_f + 30\right)}\right]^2$$

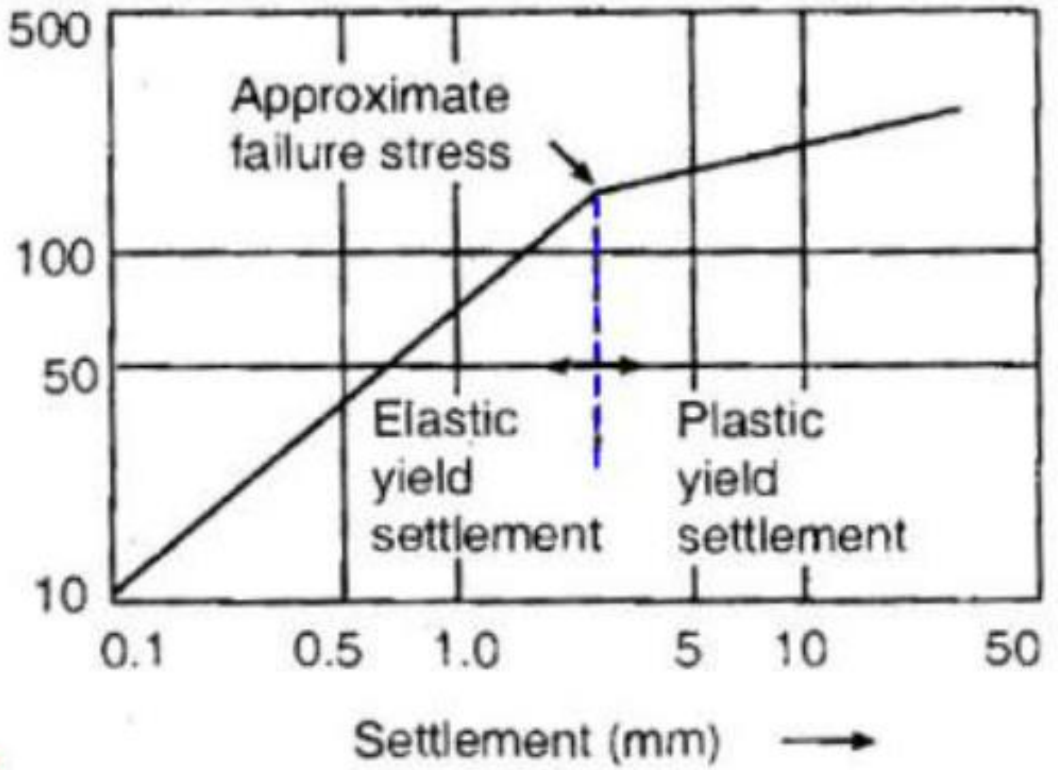
Bond (1961):

$$\frac{S_f}{S_p} = \left[\frac{B_f}{B_p}\right]$$

Limitations of Plate load test

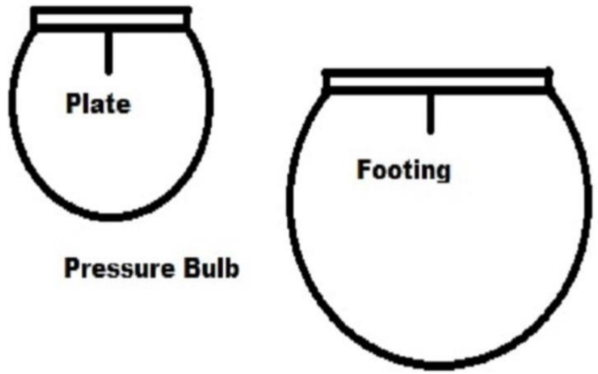
Limitations of plate load test

- •Size Effect
- •Scale Effect
- •Time Effect
- •Interpretation of Failure Load
- •Reaction load
- •Water-table



Log-Log plot

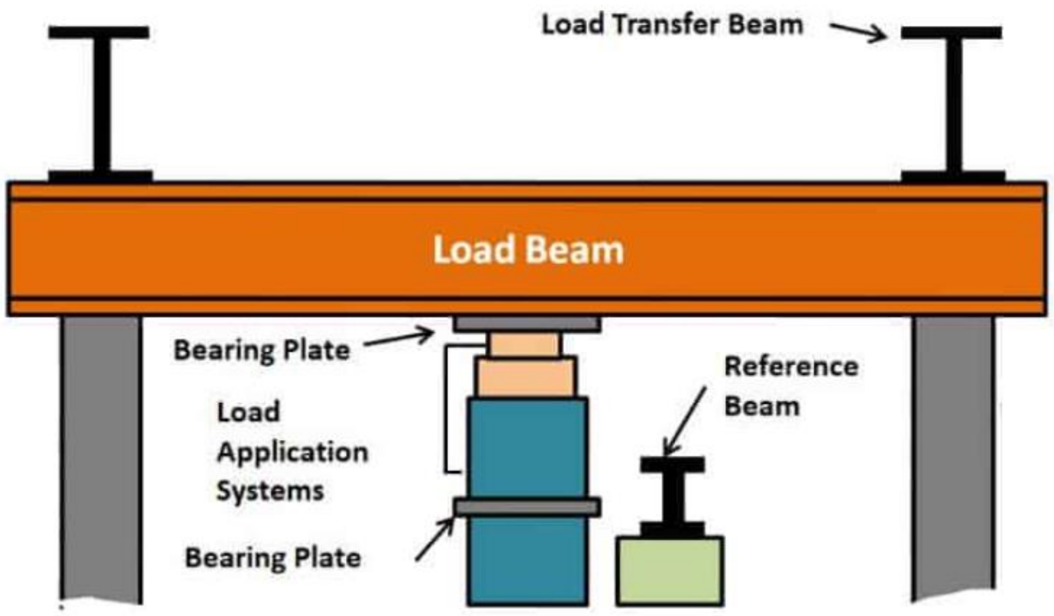
Size Effect

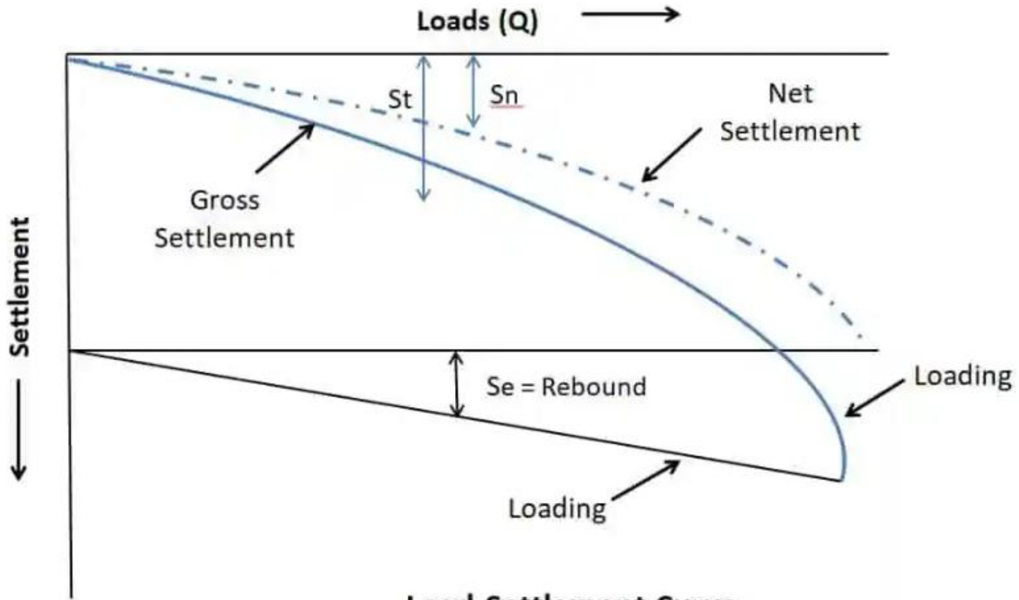


Pile load Test

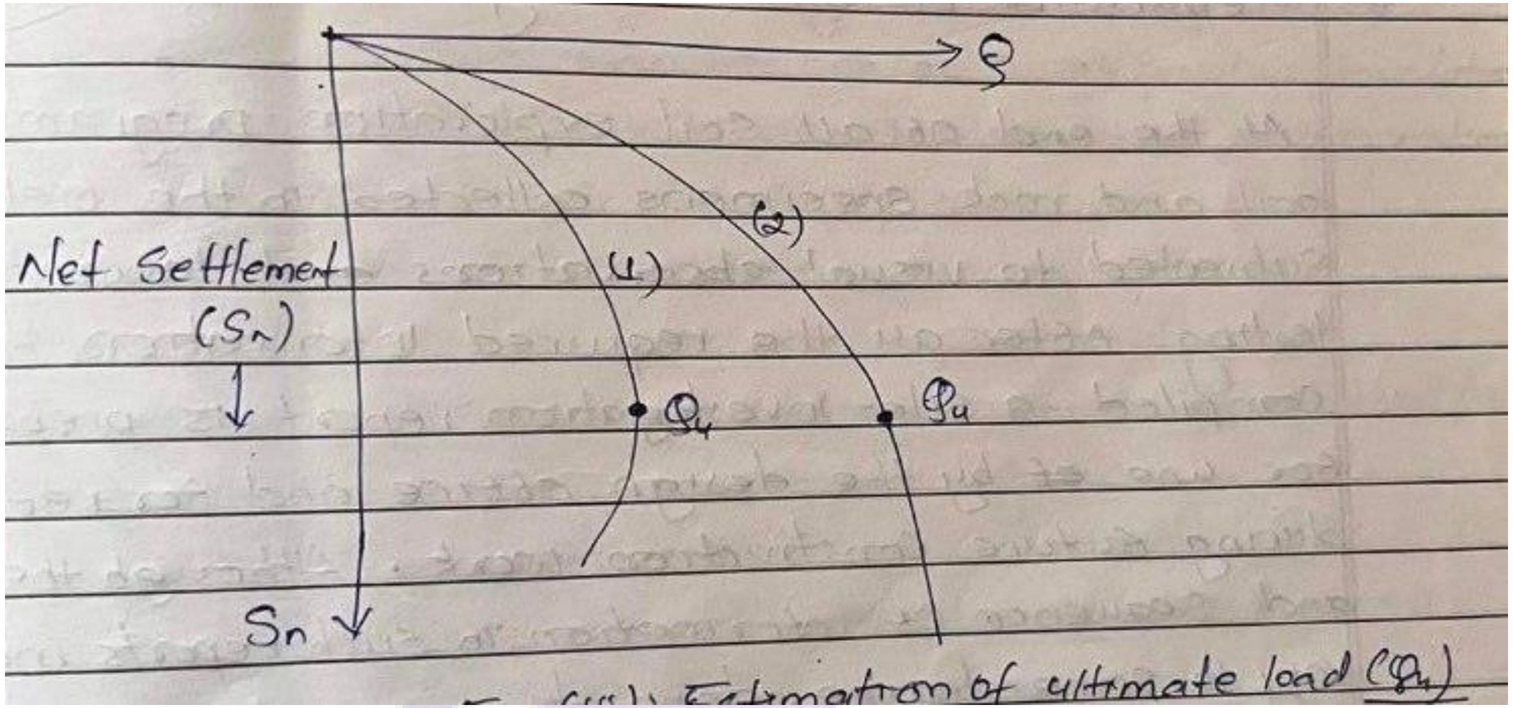
•The sets up for the load test on a pile consist of two anchor piles provided with an anchor girder or a **reaction girder** at their top as shown in Fig.
•The test pile is generally installed between two anchor piles in **such a manner in which the foundation piles are to be installed**.
•The Load is applied through a **hydraulic jack** resting on the reaction girder.
•The measurements of the settlement of the pile are recorded with the **help of three dial gauges**, with respect to a fixed reference mark.
•The test is conducted after a **rest period of 3 days** after installation of the test pile in **sandy soils**, and after a period of **one month** after the installation of the test pile in **silts and soft days**.
•The load is generally applied in an **equal amount of increment** and that is about **20 % of the allowable load**.
•Each load increment is maintained till the rate of movement of the pile is not more than **0.1 mm per hour in sandy soils and 0.02 mm per hour in clayey soils or a maximum of two hours** (IS: 2911 — 1979).
•For each load inclement settlements are observed at 0.5, 1, 2, 4, 8, 12, 16, 20, 60 minutes.
•The loading should he continued **up to twice the safe load** or the load at which the total settlement reaches a **specified value.**
•The load is removed in the **same decrements at 1 hour interval** and the final rebound is recorded after 24 hours after the entire load has been removed.

•Under the load twice the allowable load, the net settlement should not exceed 20 mm or the gross settlement should not exceed 25 mm.





Load-Settlement Curve



 # Site investigation report

It is the final document of whole exercise of soil exploration. A report should be clear, comprehensive and to the point. It should include:

- <u>Scope of the study</u> which Information regarding purposed structure
- Geological condition of site, Detailed field exploration program
- Description of subsoil condition, profile and water table conditions
- Related all types of field tests and lab tests, their procedures and outcomes
- Discussions of results with necessary recommendations (on allowable bearing pressure, type of foundation or structure) and conclusions

#Settlement has already been covered in Consolidation

Thank You !!!

Indra Lal Subedi

Bearing capacity of soil

The load carrying capacity of the foundation soil, which enables it to bear the loads of the structure is called bearing capacity of the soil.

i. **Gross pressure intensity**: The total pressure at the base of footing due to the weight of the superstructure, self-weight of footing, and weight of earth fill, if any, is called gross pressure intensity.

ii. **Net pressure intensity**: The difference between gross pressure intensity minus overburden pressure (D_f) is called net pressure intensity.

iii. **Ultimate bearing capacity** $(\boldsymbol{q_u})$: The minimum gross pressure intensity at the foundation in which soil fails in shear, is called ultimate bearing capacity.

iv. **Net ultimate bearing capacity**$(\boldsymbol{q_{net}})$: It is the minimum net pressure intensity at the base of foundation in which soil fails in shear. $(q_{net} = q_u - D_f)$

v. **Net safe bearing capacity** $(\boldsymbol{q_{ns}})$**:** It is obtained by dividing net ultimate bearing capacity by factor of safety.

vi. **Gross safe bearing capacity**: It is equal to the net safe bearing capacity plus overburden pressure.

vii. **Net safe settlement pressure** $(\boldsymbol{q_{np}})$**:** Net pressure which the soil can carry without exceeding allowable settlement. It is also called unit soil pressure or safe bearing pressure.

viii. **Net allowable bearing pressure** $(\boldsymbol{q_{na}})$**:** At net allowable bearing pressure, No shear failure and settlement within allowable range. It is used for design and is taken minimum of q_{ns} and q_{np}::

Terzaghi's general bearing capacity theory

Assumptions of Terzaghi's general bearing capacity theory are as follow:

- The base of the footing is rough.
- Shallow footing (Strip footing) [Footing is long]
- The shear strength of the soil above the footing is neglected. The soil above the base is replaced by γD_f.
- Load on the footing is vertical and uniformly loaded.
- Mohr-Column equation of shear strength holds good.

According to Terzaghi, Ultimate bearing capacity (q) per unit area for **general shear failure** is given by,

$$q_u = cN_C + 0.5\gamma B N_\gamma + \ \gamma D_f N_q$$

$N_{c,}$ N_q and $N\gamma$ = bearing capacity factors which are functions **of internal friction angle.**

Net Ultimate bearing capacity will be given by:

$$q_{net\ ult} = q_u - D_f = cN_C + 0.5\gamma B N_\gamma + \ \gamma D_f (N_q - 1)$$

i. In case of square footing

$$q = 1.2\ cN_C + 0.4\gamma B N_\gamma + \ \gamma D_f N_q$$

ii. In case of circular footing

$$q = 1.2\ cN_C + 0.3\gamma B N_\gamma + \ \gamma D_f N_q$$

iii. In case of rectangular footing

$$q = cN_C\left[1 - 0.2\frac{B}{L}\right] + 0.5\gamma B N_\gamma \left[1 + 0.2\frac{B}{L}\right] + \ \gamma D_f N_q$$

For **clayey soils** (purely cohesive soils), q= 5.7 c + $\gamma D_f N_q$

For cohesion less soil $q = 0.5\gamma B N_\gamma + \ \gamma D_f N_q$

Variation of Bearing capacity on Fluctuation of Water Table:

Terzaghi Bearing capacity equation are based on the assumption that the water table is located at great depth. If the water table is near to the base of the foundation, the bearing capacity equation needs a small modification as shown below:

$$q_u = cN_C + \gamma D_f N_q R_{W1} + 0.5\gamma B N_\gamma R_{W2}$$

Where, R_{W1} and R_{W2} are water table correction factors which are given by:

$$R_{W1} = 0.5\left(1 + \frac{Z_{W1}}{D_f}\right) \;\&\; R_{W2} = 0.5\left(1 + \frac{Z_{W2}}{B}\right)$$

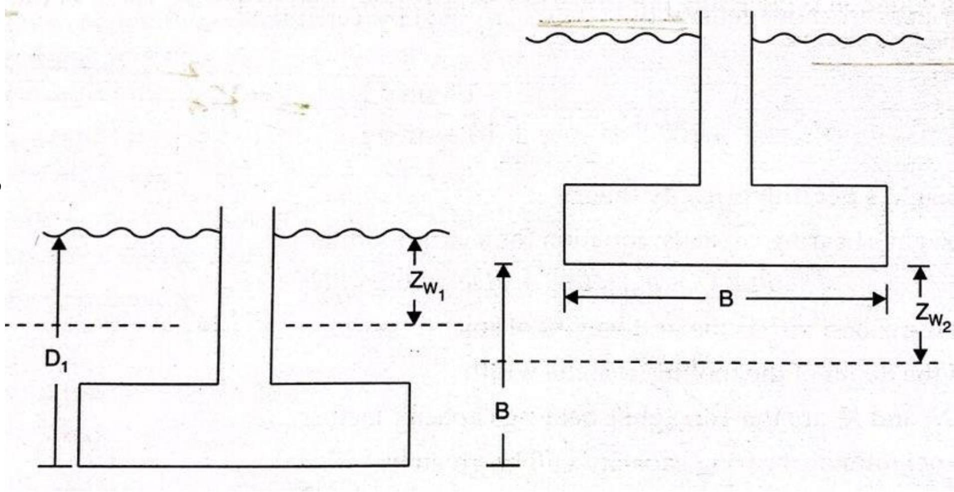
When the water table is at ground surface,

$$Z_{W1} = 0, \qquad Z_{W2} = 0\ Hence, R_{W1} = 0.5\ \&\ R_{W2} = 0.5$$

When the water table is at the base of the foundation,

$$Z_{W2} = 0\ \&\ R_{W2} = 0.5. [Z_{W1} = D_f\ \&\ R_{W1} = 1]$$

The maximum value of Z_{W1} is equal to the depth of the footing. The maximum value of Z_{W2} is the width of the foundation.



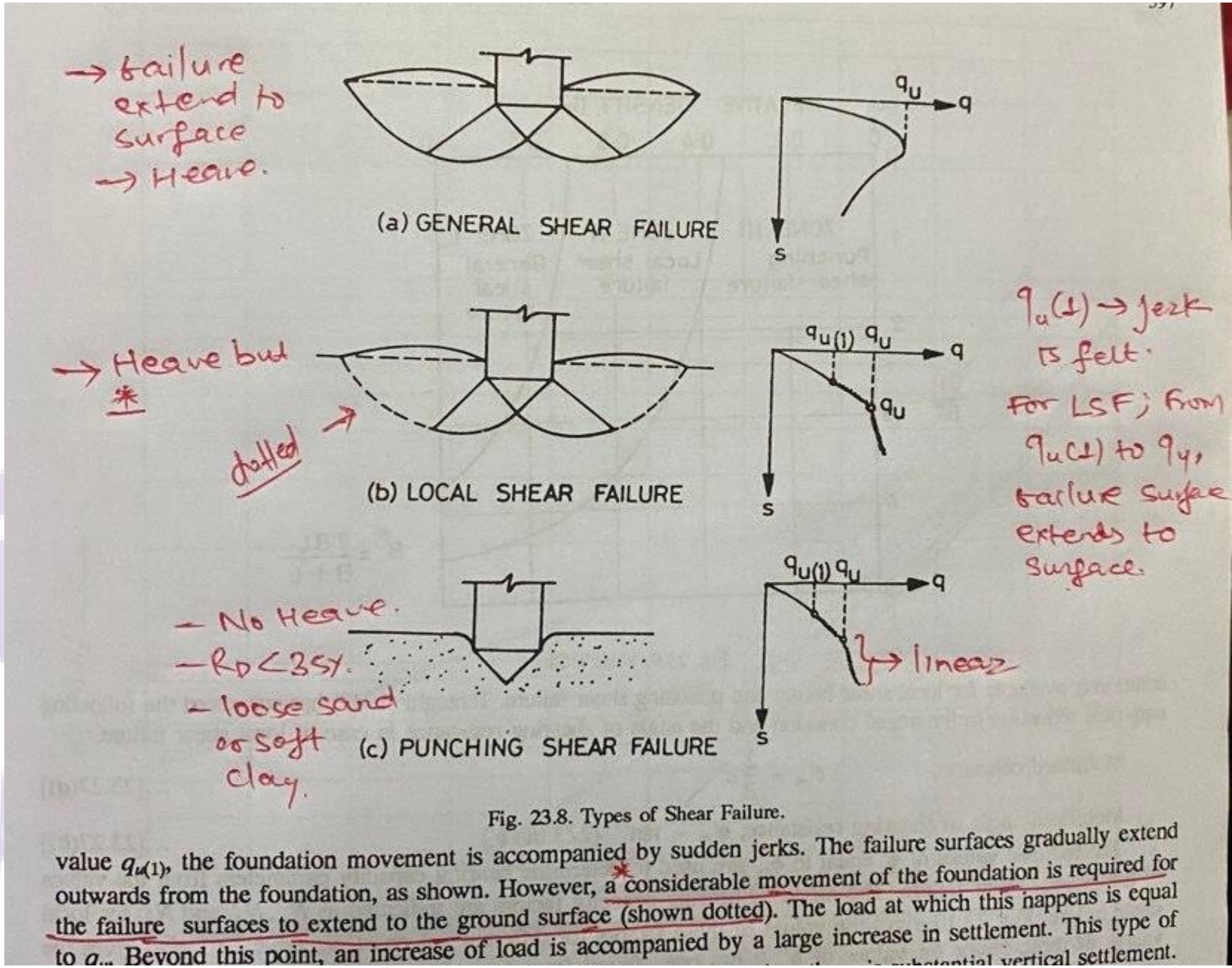
Factors affecting bearing capacity of soil:

- Types of soils (Coarse grained soils have higher bearing capacity than fine grained soil)
- Physical properties and structural arrangement of soils (c', ϕ, γ)
- Physical features of foundation (**type, size, depth, shape, inclination,** etc.)
- Types of failure anticipated
- The amount of total and differential settlement.
- Position of water level and fluctuations in GWT

i. **General shear failure**: Such failure occurs in dense sand or stiff clay; failure takes place at very small strain; load settlement curve shows well defined peak; entire soil mass within failure wedge participates; well defined rupture surface developed; considerable bulging of sheared mass of soil

ii. **Local shear failure**: Such failure occurs in medium dense sand or clay of medium consistency; failure takes place at very large strain; load settlement curve doesn't show well defined peak; only small portion of soil underneath the footing participates; well defined rupture surface develops on at a point directly below footing

iii. **Punching shear failure:** Such failure occurs in loose sand or weak clay; in this footing penetrates into the soil without any bulging of soil



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1. Terzaghi's equation for ultimate bearing capacity of a circular footing of diameter B is
   a. $q_u = 1.2cN_c + \gamma DN_q + 0.3\gamma BN_\gamma$
   b. $q_u = 1.2cN_c + \gamma DN_q + 0.4\gamma BN_\gamma$
   c. $q_u = 1.2cN_c + \gamma DN_q + 0.5\gamma BN_\gamma$
   d. $q_u = cN_c + \gamma DN_q + 0.5\gamma BN_\gamma$
2. Terzaghi's equation for ultimate bearing capacity of a square footing of size B is
   a. $q_u = 1.2cN_c + \gamma DN_q + 0.3\gamma BN_\gamma$
   b. $q_u = 1.2cN_c + \gamma DN_q + 0.4\gamma BN_\gamma$
   c. $q_u = 1.2cN_c + \gamma DN_q + 0.5\gamma BN_\gamma$
   d. $q_u = cN_c + \gamma DN_q + 0.5\gamma BN_\gamma$
3. Terzaghi's equation for ultimate bearing capacity of a strip footing of width B and infinite length
   a. $q_u = 1.2cN_c + \gamma DN_q + 0.3\gamma BN_\gamma$
   b. $q_u = 1.2cN_c + \gamma DN_q + 0.4\gamma BN_\gamma$
   c. $q_u = 1.2cN_c + \gamma DN_q + 0.5\gamma BN_\gamma$
   d. $q_u = cN_c + \gamma DN_q + 0.5\gamma BN_\gamma$
4. According to Terzaghi, in case of presence of water table the ultimate bearing capacity equation has to be modified as:
   a. $q_{ult} = cN_c + \gamma DN_q + 0.5\gamma BN_\gamma$
   b. $q_{ult} = cN_c - \gamma DN_q - 0.5\gamma BN_\gamma$
   c. $q_{ult} = cN_c - \gamma DN_q R_{w1} - 0.5\gamma BN_\gamma R_{w2}$
   d. $q_{ult} = cN_c + \gamma DN_q R_{w1} + 0.5\gamma BN_\gamma R_{w2}$
5. Any Foundation must satisfy that:
   a. The soil below does not fail in shear
   b. The settlement of footing is within safe limits
   c. The pressure exerted by footing should not exceed the allowable bearing pressure
   d. All of the above

AAADA

6. Select the incorrect statement:
   The assumptions made by Terzaghi are
   a. The base of the footing is smooth
   b. Shear strength of the soil is governed by Mohr-Coulomb Equation
   c. The footing is a shallow foundation
   d. The shear strength of the soil above the base of the footing is neglected
7. The Terzaghi's bearing capacity factors are the function of
   a. Internal friction angle
   b. Cohesion
   c. Friction angle between footing and soil
   d. All of the above
8. The bearing capacity of soil doesn't depend upon:
   a. Applied load
   b. Size of the footing
   c. Shear Parameters of soil
   d. None
9. The net bearing pressure which can be used for the design of foundation is:
   a. Gross safe bearing pressure
   b. Ultimate bearing capacity
   c. Net safe settlement pressure
   d. Net allowable bearing pressure
10. The safe bearing capacity of soil can be defined as:
   a. Maximum pressure which the soil can carry safely without shear failure
   b. Ultimate load on the bearing area
   c. Pressure at which the settlement will not exceed the allowable settlement
   d. None

BCDACBC

11. Terzaghi has suggested mobilized cohesion and mobilized angle of friction for:
    a. General shear failure b. Local shear failure c. Punching shear failure d. All of the above
12. The value of mobilized cohesion will be:
    a. C b. C/3 c. 2C/3 d. 2C
13. The value of reduction factors R_{w1} and R_{w2} when the water table is at the ground surface are (where R_{w1}: correction for surcharge term and R_{w2}: Correction for weight term)
    a. 1.0 and 1.0
    b. 0.5 and 1.0
    c. 1.0 and 0.5
    d. 0.5 and 0.5
14. The value of reduction factors R_{w1} and R_{w2} when the water table is at a depth equal to or greater than the width of the footing is
    a. 1.0 and 1.0
    b. 0.5 and 1.0
    c. 1.0 and 0.5
    d. 0.5 and 0.5
15. The value of reduction factors R_{w1} and R_{w2} when the water table is at the base of the footing are
    a. 1.0 and 1.0
    b. 0.5 and 1.0
    c. 1.0 and 0.5
    d. 0.5 and 0.5
16. According to the Terzaghi's theory, the value of the ultimate bearing capacity for a strip footing which is at the ground surface on a purely cohesive soil is
    a. 5.7 C b. 5.14 C c. 7.5C d. 6.2C
17. Rise in water table upto the ground surface in case of a cohesionless soil will reduce the ultimate bearing capacity by (approximately)
    a. 10% b. 25% c. 50% d. 75%

Two footings, one circular and the other strip, are founded on the surface of a purely Cohesionless soil. Diameter of the circular footing and width of strip footing is same. Then, the ratio of ultimate bearing capacity of circular to strip footing is:

1. 0.75
2. 0.60
3. 1.20
4. 1.33

According to Tarzaghi,

Ultimate bearing capacity of **circular footing**,

$$q_u = 1.3CN_c + qN_q + 0.3D\gamma N_\gamma$$

Ultimate bearing capacity of **strip footing**,

$$q_u = CN_c + qN_q + 0.5B\gamma N_\gamma$$

For square footing, ultimate bearing capacity,

q_u = 1.3 CN_c + $\gamma D_f N_q$ + 0.4 $\gamma BN\gamma$

Calculation:

Given,

D = B

Surface footing ⇒ D_f = 0 ⇒ q = 0

Purely cohesionless ⇒ C = 0

$$Ratio = \frac{q_{u,circular}}{q_{u,strip}} = \frac{0.3D\gamma N_\gamma}{0.5B\gamma N_\gamma} = 0.60$$

Observed N-value of an SPT test is 21. The N-value after correcting for dilatancy is

1. 18
2. 21
3. 19
4. 15

Dilatancy correction:

It is to be applied when N_o obtained after overburden correction, exceeds 15 in saturated fine sands and silts. IS: 2131-1981 incorporates the Terzaghi and Peck recommended dilatancy correction (when $N_o > 15$) using the equation

$$N = 15 + \frac{1}{2}(N_0 - 15)$$

N_0 - SPT value after overburden correction

Calculation:

Given: $N_0 = 21$

$$N = 15 + \frac{1}{2}(21 - 15)$$

$\Rightarrow N =$ **18**

An embankment is to be constructed with granular soil (bulk unit weight = 20 kN/m^3) on a saturated clayey silt deposit (undrained shear strength = 25 kPa). Assuming undrained general shear failure and bearing capacity factor of 5.7, the maximum height (in m) of the embankment at the point of failure is

1. 7.1
2. 5.0
3. 4.5
4. 2.5

bulk unit weight (γ_b) = 20 kN/m^3

Undrained shear strength (S = C) = 25 kPa

Bearing Capacity N_c = 5.7, General Shear Failure

We know $q_u = CN_c$

$q_u = \gamma D_f = 25 \times (5.7)$

$20 \times D_f = 142.5$

D_f = 7.124 m