SHALLOW FOUNDATION

CONTENT

Introduction, significant depth, design criteria, modes of shear failures, Detail study of bearing capacity theories (Prandtl, Rankine, Terzaghi, Skempton), bearing capacity determination using IS Code, Settlement, components of settlement & its estimation, permissible settlement, Proportioning of footing for equal settlement, allowable bearing pressure. Bearing capacity from in-situ tests (SPT, SCPT, PLATE LOAD), Factors affecting bearing capacity including Water Table., Bearing capacity of raft/mat foundation as per codal provisions, Contact pressure under rigid and flexible footings. Floating foundation. T

DEFINATIONS

- **Footing:** It is the lowest portion of the foundation of a structure that transmit load directly to the soil.
- **Foundation:** A foundation is that part of structure which is in direct contact with contact with soil and transmit load of superstructure to the ground.
- **Bearing capacity:** It is defined as load carrying capacity of the foundation.

- **Gross bearing capacity**: It is defined as bearing capacity of a soil inclusive of pressure exerted by weight of the soil standing on the foundation.
- **Net bearing capacity**: It is defined as gross bearing capacity minus the original overburden pressure at the foundation level.
- **Ultimate bearing capacity**: It is defined as the gross pressure at the base of the foundation at which soil fails in shear.
- **Net ultimate bearing capacity**: It is the net pressure in excess of surcharge pressure at which soil fails in shear. It is equal to gross pressure minus surcharge pressure.

- **Net safe bearing capacity:** It is the maximum load carrying per unit area in excess of surcharge pressure which the foundation soil or bed can carry safely without risk of shear failure.

- **Safe bearing capacity**: It is the gross pressure at which soil can carry safely without shear failure.

- **Allowable pressure:** It is the loading intensity at which foundation soil neither fails in the shear nor in their settlement.

DESIGN CRITERIA

For a satisfactory performance, a foundation must satisfy the following criteria:

Location and depth criteria:

A foundation must be properly located and foundation at such a depth that its performance is not affected by factors such as:

- Volume change, presence of adjoining structure.

Shear failure criteria:

- Shear failure or bearing capacity failure of the foundation should not occur.
- This is associated with the expulsion of soil beneath the foundation and plastic flow of soil.

Settlement criteria:

- The settlement of the foundation especially differential settlement of the foundation should be in the permissible limit.

Modes of failure

- When a horizontal strip footing resting on the surface of homogenous soil is subjected to gradually increasing load, load settlement curves are obtained. The load settlement behaviour is found to be related to the soil characteristics.
- Three different types of failure mechanism, based on the pattern of the shearing zones have been identified.

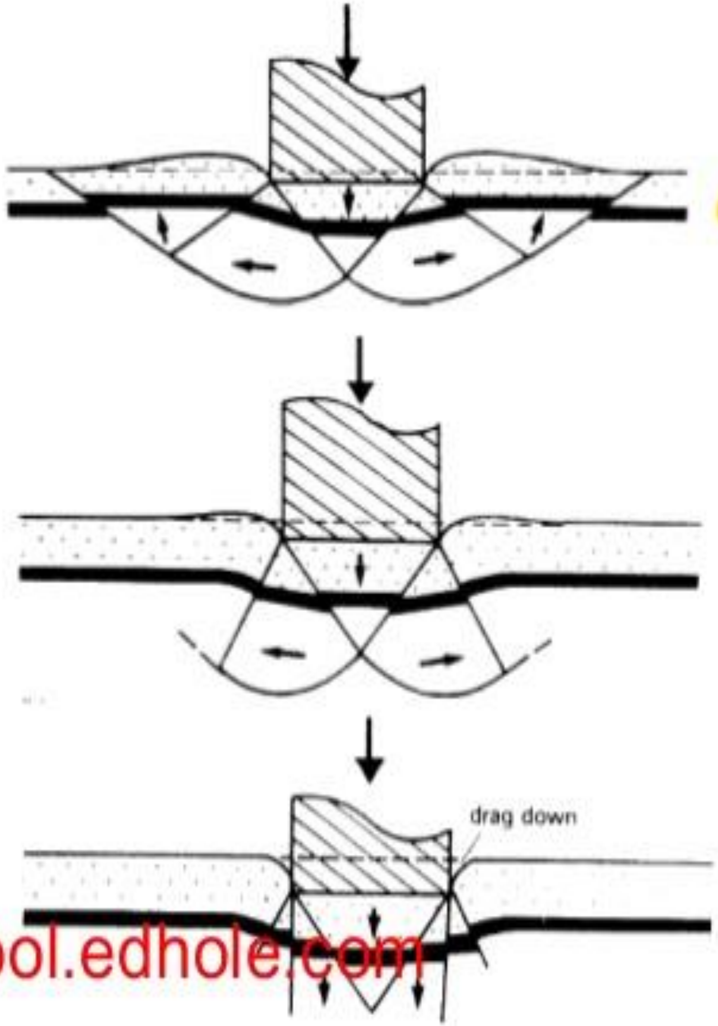
General shear failure

- If the soil properties are such that as the footing is loaded to the failure a slight downward movement of the footing develops fully plastic zones due to which the entire soil along a slip surface fails in shear and soil bulges out on the sides of the footing. This type of failure is known as general shear failure.

The general shear failure is characterized by:

- A well defined failure surface, reaching up to the ground surface.
- A sudden, catastrophic failure accompanied by tilting of foundation.
- A bulging of ground surface adjacent to the foundation.
- The ultimate bearing capacity is well defined.

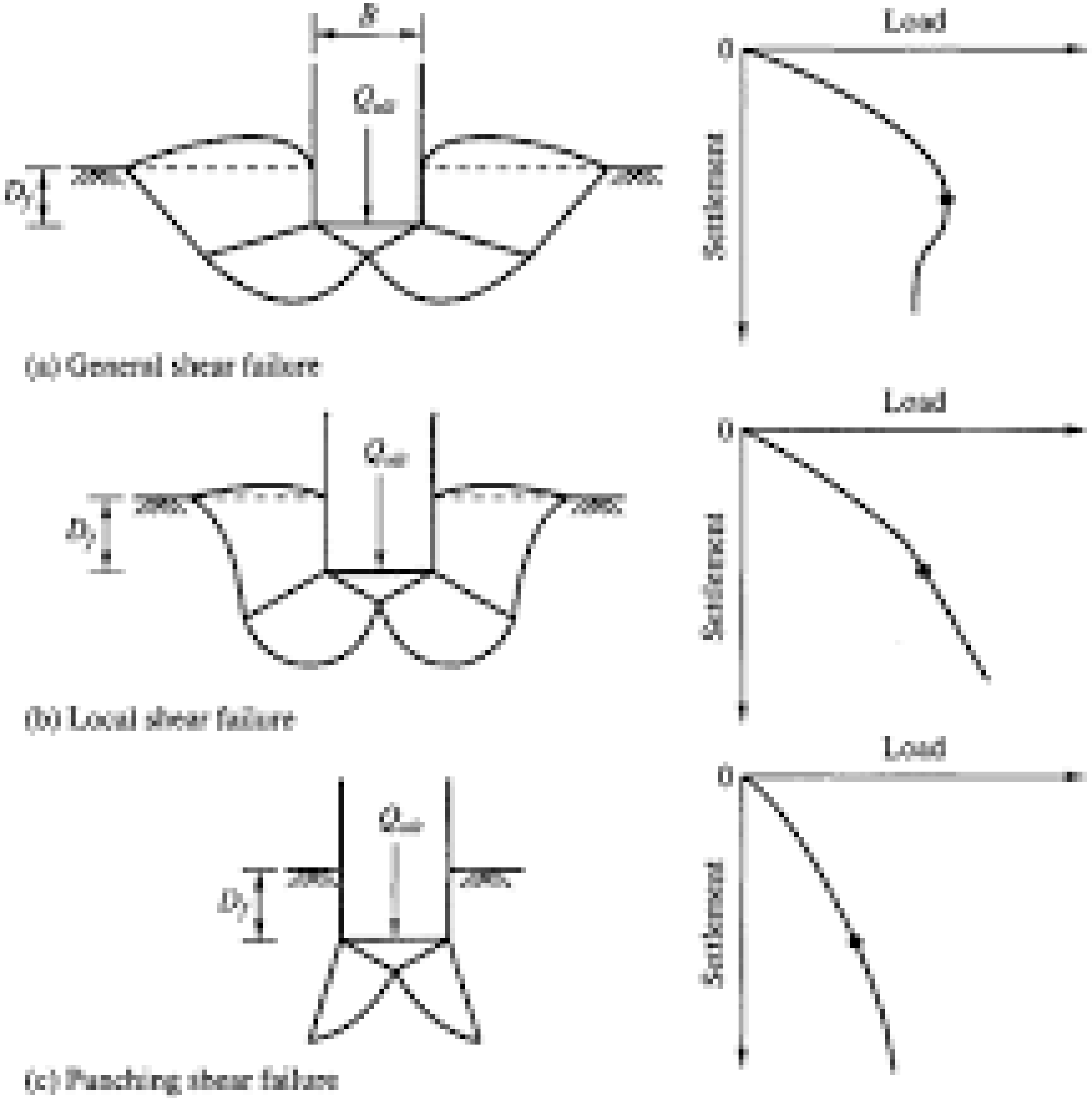
Bearing Capacity Failure



General shear failure

Local shear failure

Punching shear failure


B
Q_{ult}
D_f
Load
0
Settlement
(a) General shear failure
(b) Local shear failure
(c) Punching shear failure

Local shear failure

If the soil properties are such that before plastic zones are fully developed, large deformations occur immediately below the footing resulting in the failure of the soil in just portion below the footing is known as local shear failure.

Local shear failure associated with the considerable vertical movement of the footing before the failure surface extend to the ground surface, bulging takes places.

Following are the characteristic of local shear failure:

- Failure surface is well defined.
- The failure is not sudden and there is no tilting of foundation.
- Failure is defined by large settlements.
- Ultimate bearing capacity is not well defined.

Punching shear failure

- Punching shear failure occur when there is relatively high compression of soil under the footing, accompanied by shearing in vertical direction around the edges of the footing.
- The failure surface is vertical or slightly inclined.
- There is no heaving of ground surface and no tilting of the footing.

Following characteristic are observed:

No failure pattern is observed.

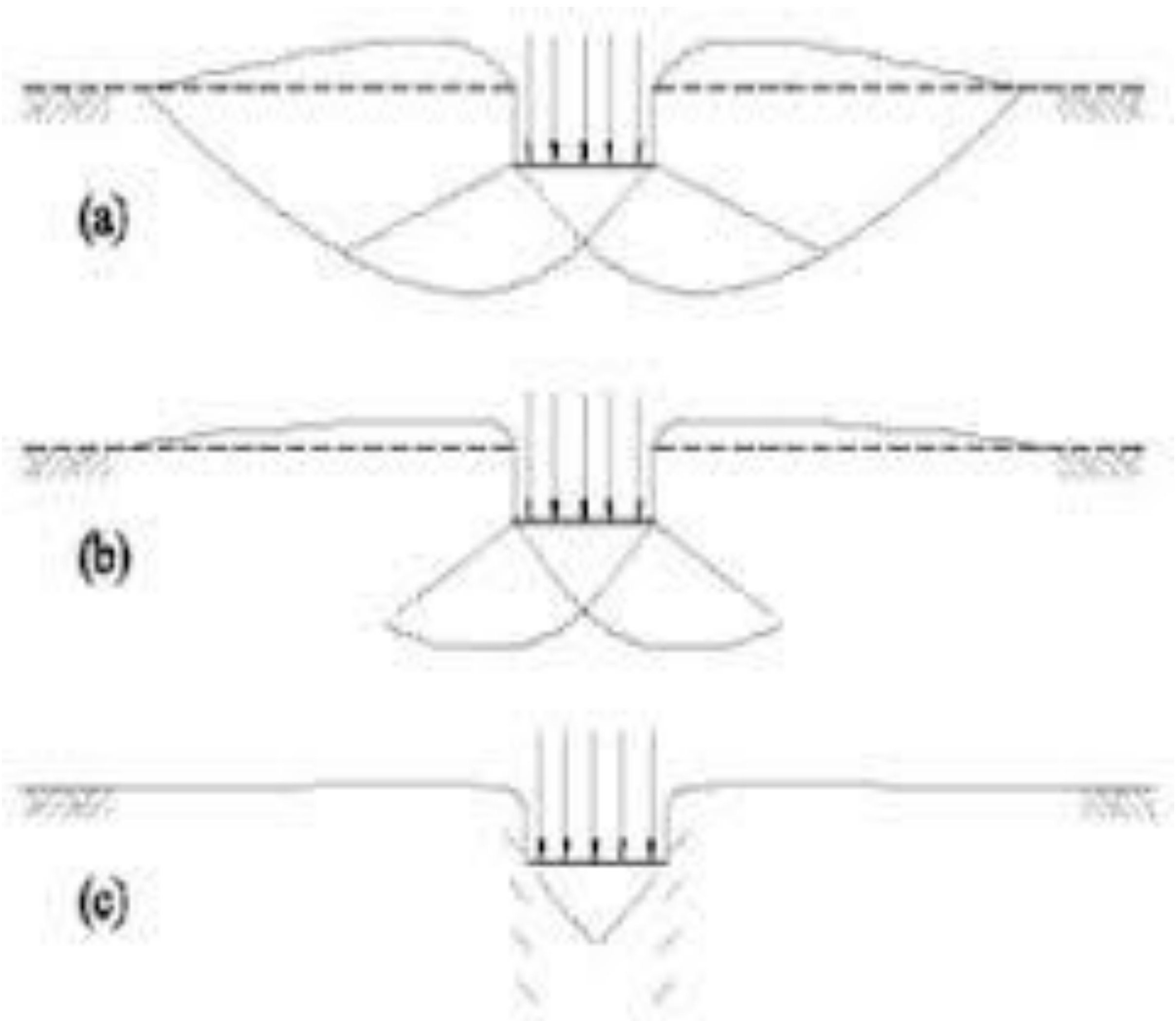
The failure surface is vertical or slightly inclined.

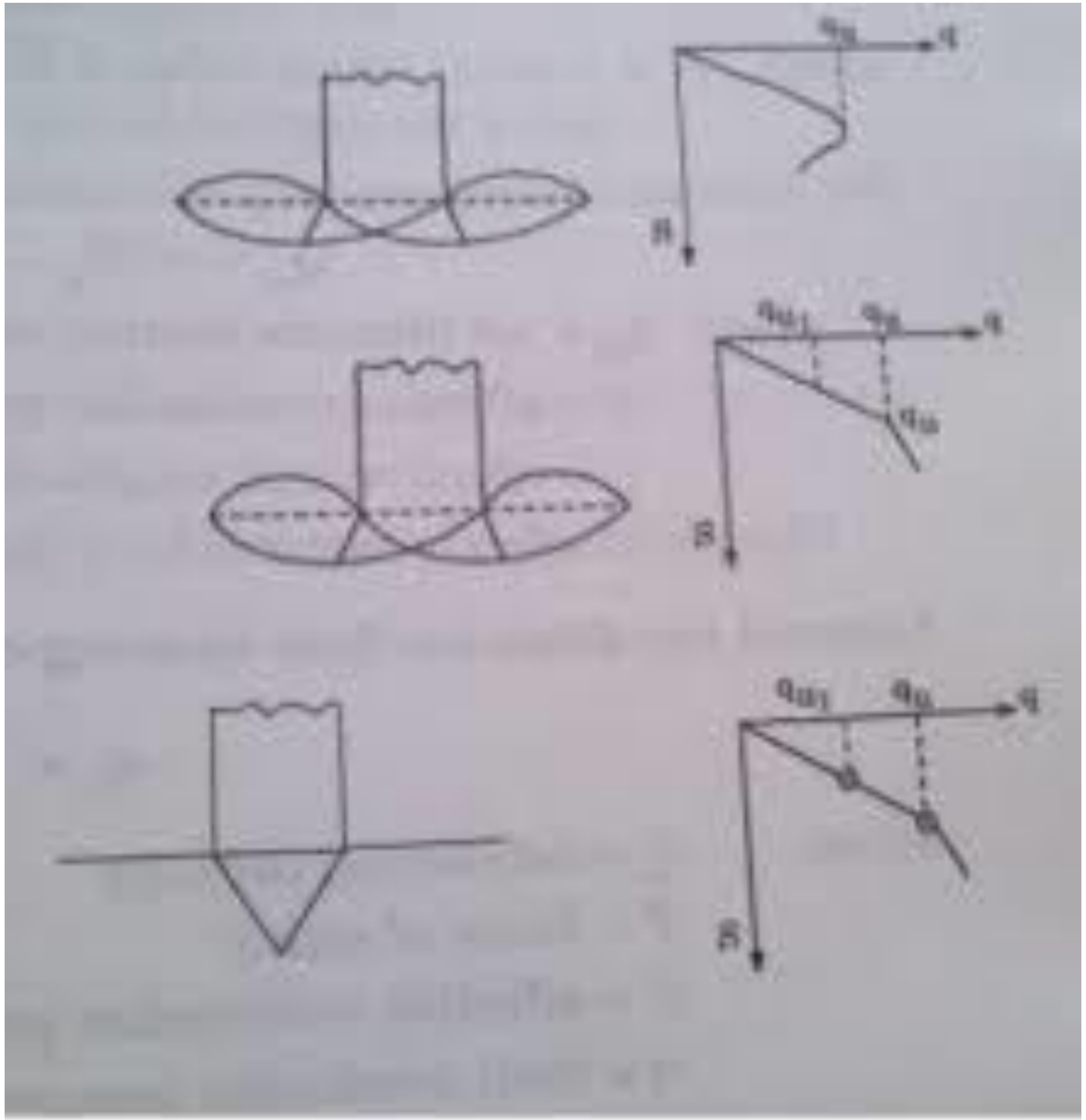
There is no bulging of foundation.

There is no tilting of foundation.

Failure is characterized in terms of large settlement.

The ultimate bearing capacity is not well defined.


(a)
(b)
(c)



General shear failure	**Local shear failure**
In such failure soil properties are such that slight downward movement of the footing develops fully plastic zones and soil budges out on the sides of footing.	In such failure soil properties are such that large deformation occur immediately below the footing, before plastic zone are fully developed.
Angle of shearing resistance greater than 36 degree.	Angle of shearing resistance less than 29 degree.

General shear failure	Local shear failure
SPT value, N>= 30	SPT value, N<=5
Density index ID> 70	Density index ID< 70
Form load vs settlement curve, failure point is well defined.	Form load vs settlement curve, failure point is not well defined.

General shear failure	**Local shear failure**
Void ratio $e < 0.55$	Void ratio $e > 0.75$
It is generally occur in dense sand or stiff clay.	Failure occurs in soft, loose or compressible soil.
Cohesion= C	Cohesion= C’, C’= 2/3 C
Angle of internal friction= ϕ	Angle of internal friction= ϕ' ϕ'= tan inv (2/3 tan ϕ')

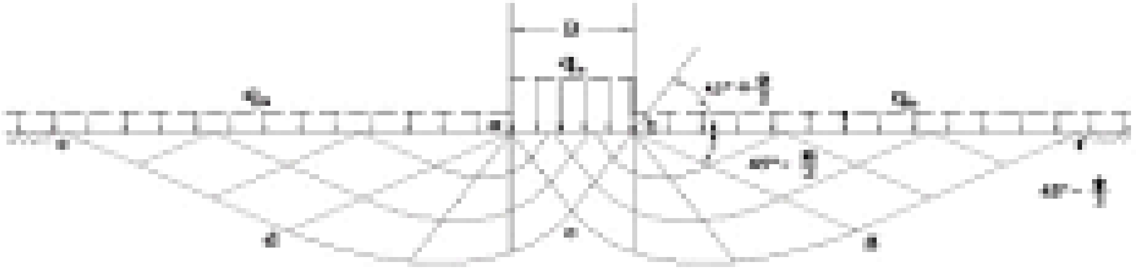
Prandtl's analysis

- Prandtl's gave theory of penetration of punches of metal.
- This theory is used to determine ultimate bearing capacity of soils.
- The analysis is based on the assumption that strip footing placed on the ground surface sinks vertically downward into the soil at failure, like a punch.

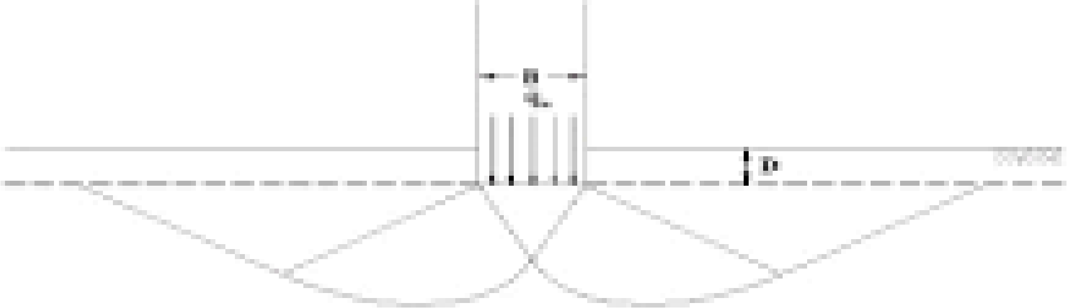
- The soil in the wedge shaped zone-I immediately under the footing is subjected to compressive stresses.
- As footing sinks zone-I exert pressure on zone-II, zone-III. The soil zone-II is assumed under plastic equilibrium. The zone-II pushes zone-II upward.
- Prandtl developed expression for ultimate bearing capacity for purely cohesive soil is given by:

$$Q_u = (\pi + 2) * c$$

$$Q_u = 5.14*c$$



Failure under a strip footing



Footing at depth *D* below the surface

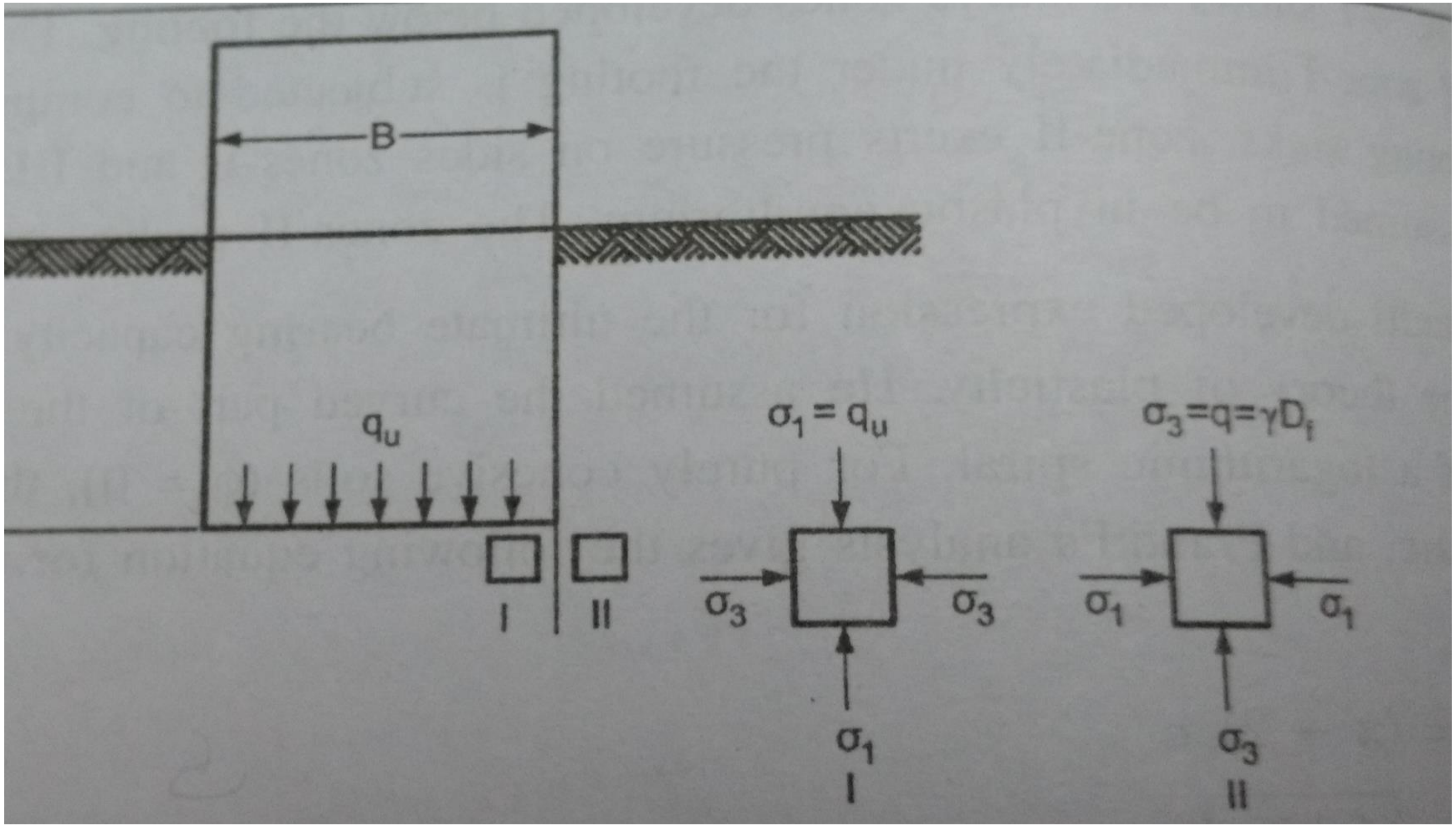
Fig. (1)

$$Q_u = 5.14 * c + \gamma * D$$

- Prandtl's theory is valid only for the footing with perfectly smooth base in contact with the soil. As the actual having the rough base, theory does not give accurate results.

Rankine's Analysis

- Rankine consider the plastic equilibrium of two soil elements, one just below the footing and other just outside the footing at the base level of the foundation.



B
q_u
I
II
σ1 = q_u
σ3
σ3
σ1
I
σ3=q=γDf
σ1
σ1
σ3
II

Rankine's Analysis

$$\sigma_1 = \sigma_3 \tan^2\alpha + 2c\tan\alpha$$

But for cohesionless soil $c = 0$

$$\therefore \quad \sigma_1 = \sigma_3 \tan^2\alpha$$

For element-III :

$$\sigma_3 = \sigma_v = \gamma \cdot D$$

$$\sigma_1 = \sigma_h$$

$$\therefore \quad \sigma_1 = \sigma_h = \gamma \cdot D \tan^2\alpha \quad \text{.... (6.1)}$$

For element-I :

$$\sigma_1 = \sigma_h = \sigma_1 \text{ of element II}$$

$$= \gamma \cdot D \tan^2\alpha$$

$$\sigma_1 = \sigma_3 \tan^2\alpha$$

$$= \gamma \cdot D \tan^2\alpha\,(\tan^2\alpha)$$

$$= \gamma \cdot D \tan^4\alpha$$

But $\sigma_1 = q_u$

$$\alpha = 45^\circ - \frac{\phi}{2}$$

$$q_u = \gamma D \tan^4 \alpha$$

$$q_u = \gamma D \left[\frac{1 + \sin\phi}{1 - \sin\phi} \right]^2$$

Terzaghi’s bearing capacity theory

Terzaghi’s theory is based on the following assumptions:

- The footing is long, i.e L/B = infinite
- The base of footing is rough.
- The footing is laid at shallow depth.
- The load on footing is vertical and is uniformly distributed.

- The shear strength of the soil above the base is neglected. The soil above the base is replaced by equivalent surcharge.
- The shear strength of the soil is governed by Mohr-Coulomb equation.

Allowable bearing pressure for cohesionless soil

- Peck's equation
- Teng's equation
- Meyerhof's equation
- Bowel's equation

Plate load test

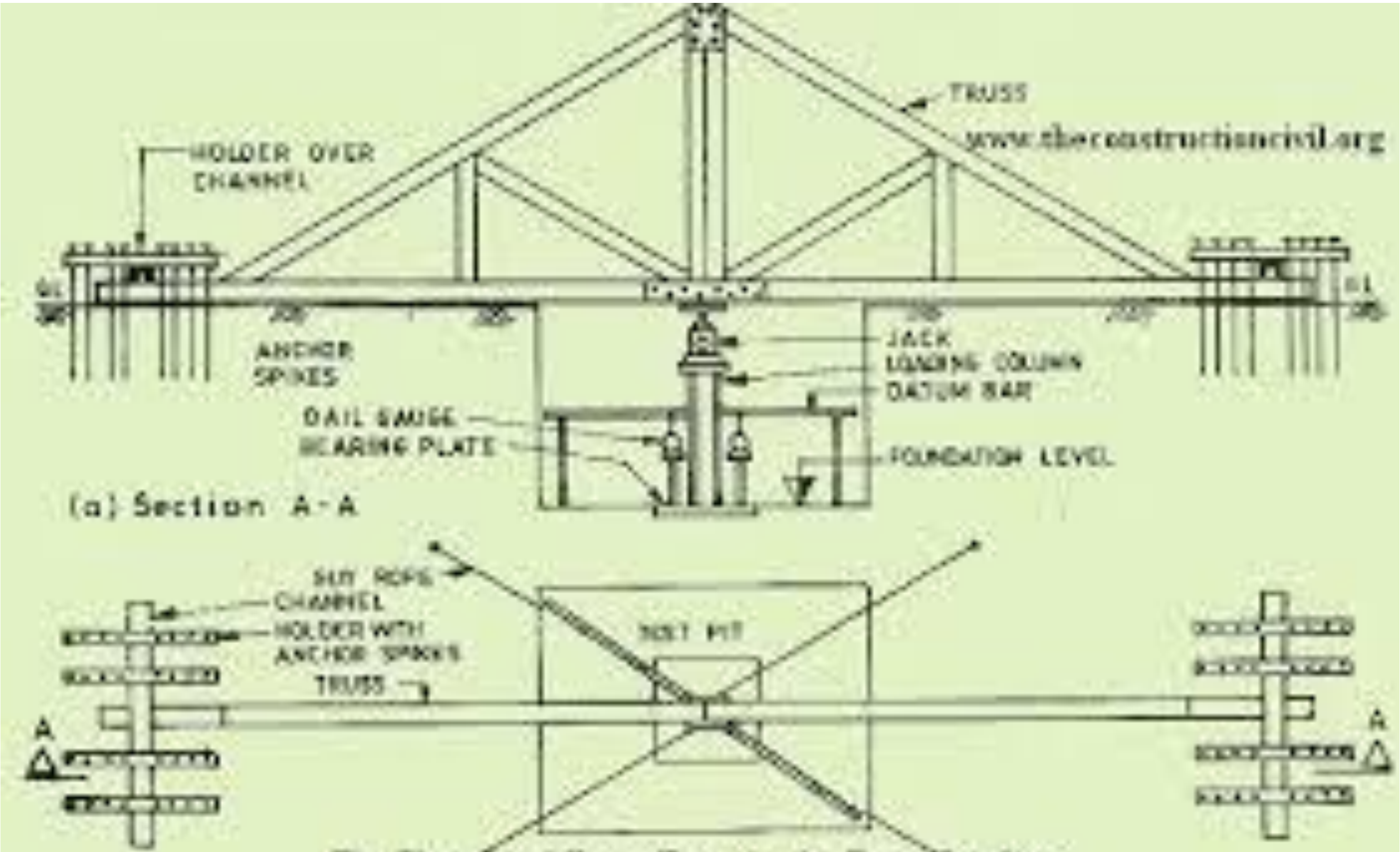
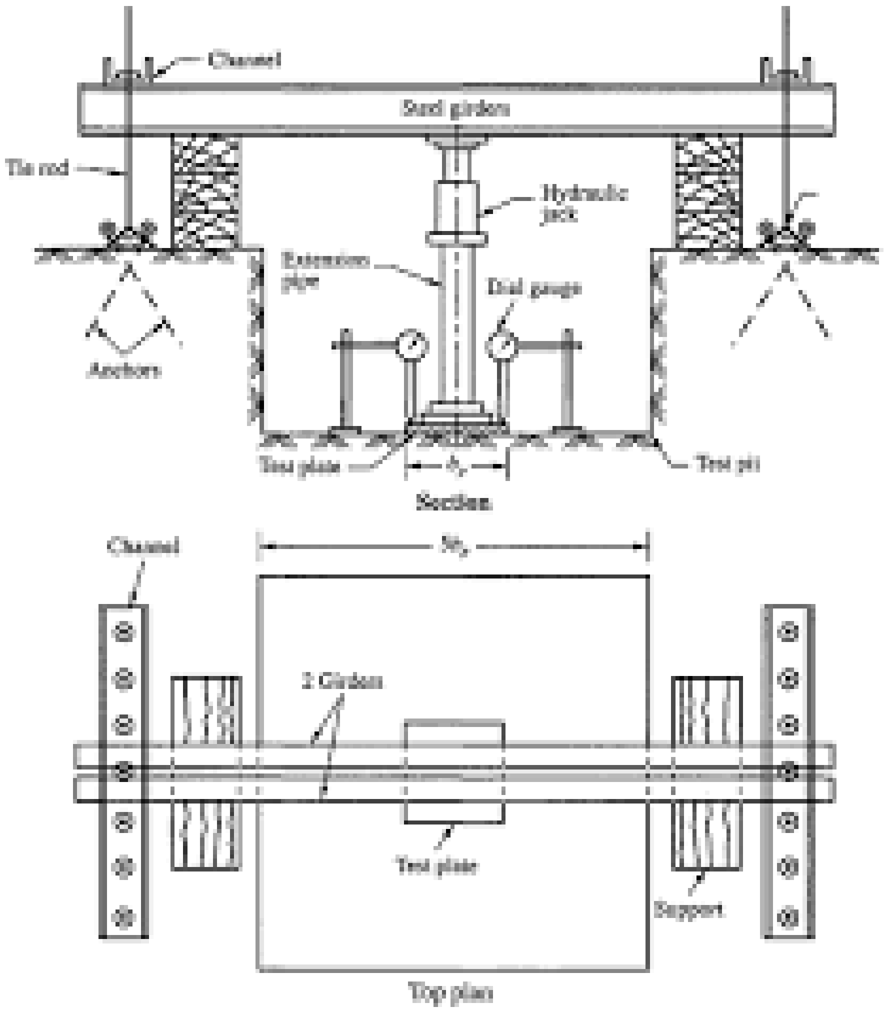
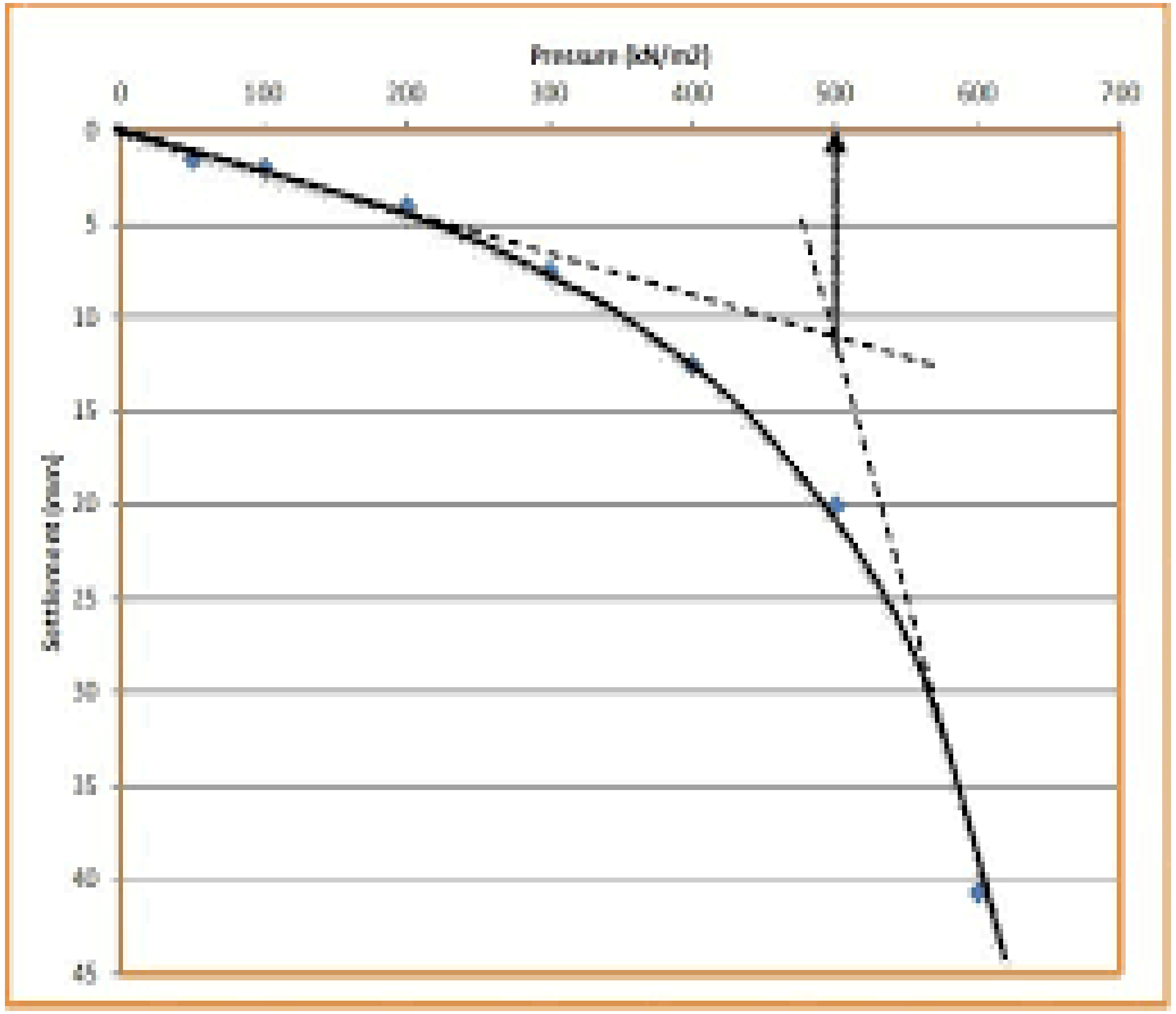


Fig. Plate Load Test - Reaction by Truss Loading



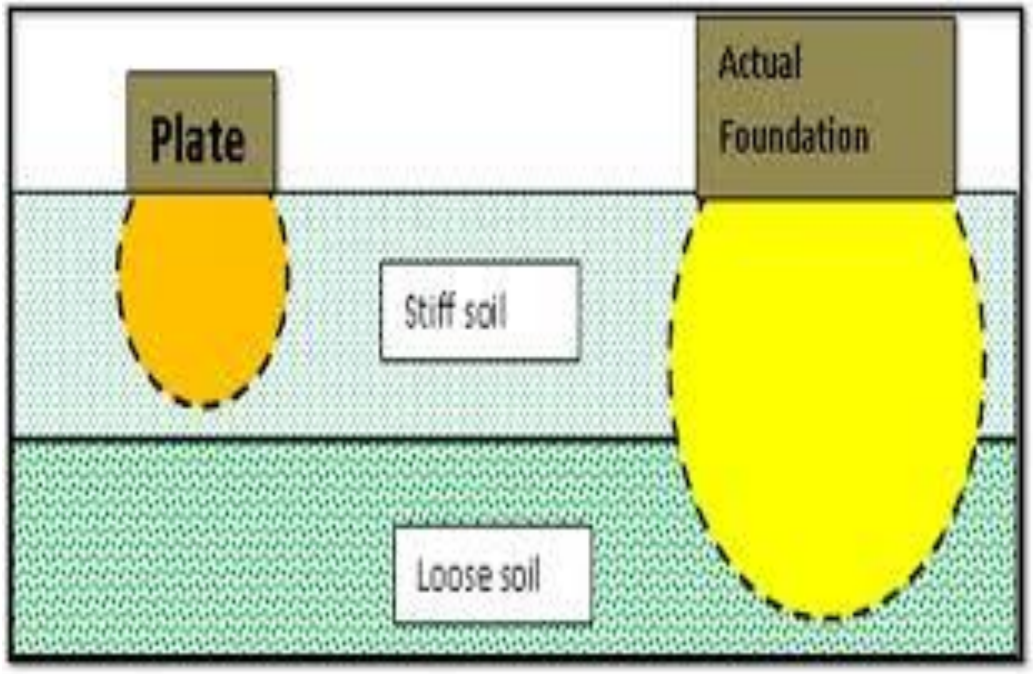
Channel
Steel girders
Tie rod
Hydraulic jack
Extension pipe
Dial gauge
Anchors
Test plate
Test pit
Section
Channel
2 Girders
Test plate
Support
Top plan



Pressure (kN/m2)
0
100
200
300
400
500
600
700
Settlement (mm)
0
5
10
15
20
25
30
35
40
45

Limitation of plate load test

- Size effect
- Scale effect
- Time effect
- Reaction load
- Water table
- Interpretation of failure load



Settlement of foundation

The total settlement of a saturated clay under excessive effective pressure may be consider as the sum of the:

- Immediate settlement(S_i)
- Primary or consolidation settlement(S_p)
- Secondary settlement(S_s)

The total settlement is given by

$$\mathbf{S = S_i + S_p + S_s}$$

Loads for settlement analysis

Immediate settlement of cohesive soil:

- The linear theory of elasticity is used to determine the elastic settlement of the footing saturated clay.

$$S_i = qB [1-\mu^2 / E_s] * I$$

Where, S_i = Immediate settlement of rectangular flexible foundation

q= load per unit area on foundation

B= width of the foundation

E_s = modulus of elasticity

μ = poisson's ratio

I= Influence factor

Immediate settlement of cohesionless soil:

- Settlement of foundation on cohesionless soil takes place very rapidly after the application of the load.
- The settlement are generally determined indirectly by using static cone penetration test or by using the chart developed by SPT test as indicated below.

1. **<u>Static cone penetration test:</u>**

- In this method soil layer is divided into small layers such that each small layer has approximate constant value of cone resistance. The average value of cone resistance of each small layer is obtained.

$$\mathbf{S_i = H/C \log_e (\sigma_0 + \delta \sigma / \sigma_{0'})}$$

H= thickness of layer

$\sigma_{0'}$ = effective overburden pressure

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

C = Compressibility constant

2. **SPT chart**

- SPT can be used for the determination of the settlement of foundation on cohesionless soil.
- The settlement under any other pressure is computed assuming that settlement is proportional to the intensity of pressure.
- If the W.T. is at a shallow depth, the settlement are divided by correlation factor Rw2.

Rw2= 0.5* [1+ Zw2/B]

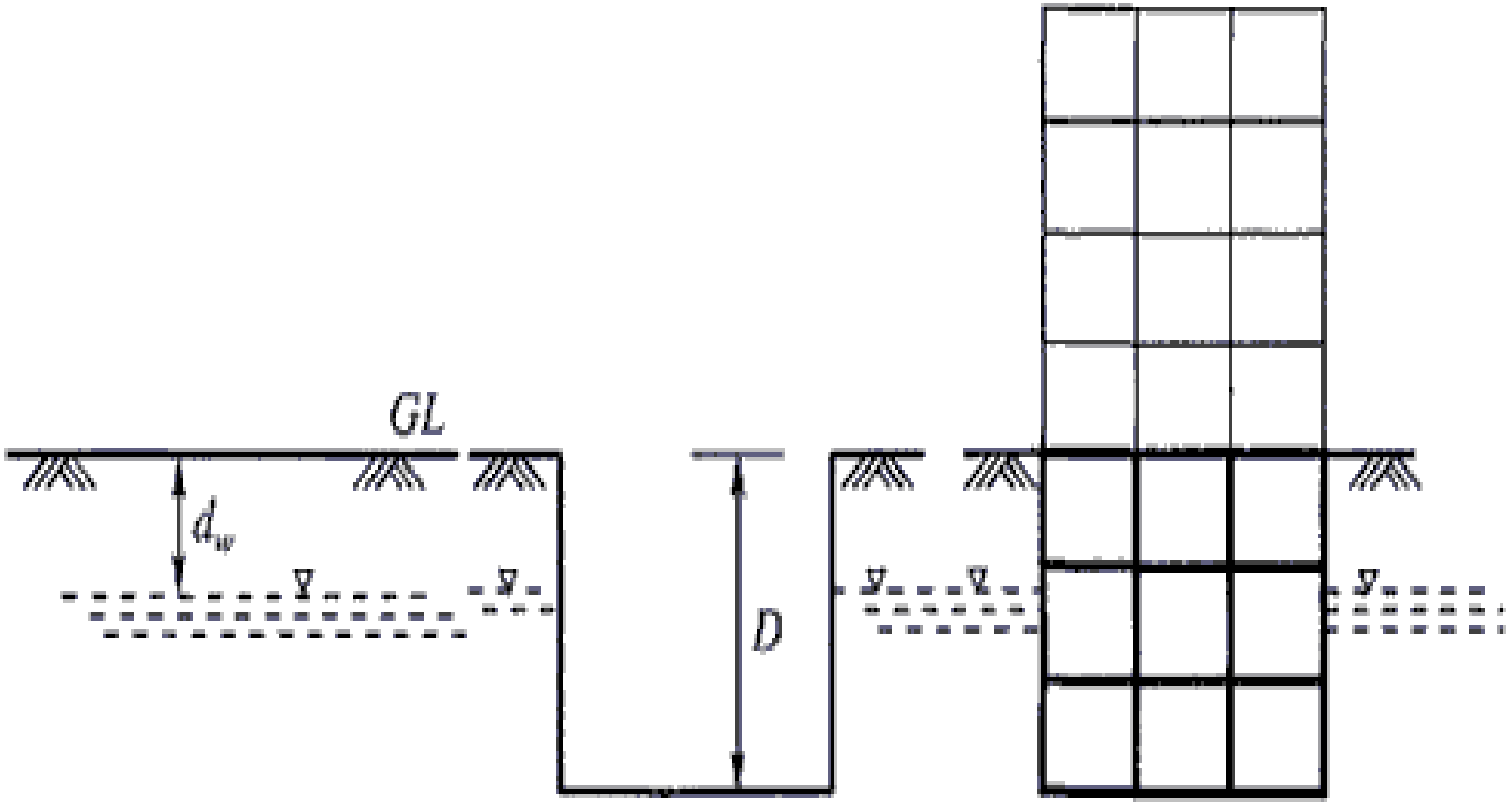
Factor affecting bearing capacity

The various factors affecting bearing capacity are:

- Position of ground water table
- Relative density
- Width of footing
- Depth of footing
- Unit weight of soil

Floating foundation

- A floating foundation of a building id defined as a foundation in which the weight of the building is approximately equal to the weight of soil and water removed from the site of the building.


GL
d_w
D

Contact pressure

- Contact pressure is defined as vertical pressure acting at the surface of contact between the base of a footing and under lying soil mass.
- In order to simplify the design footing, it is usually assumed that under a uniformly loaded the distribution of contact pressure is uniform.
- If the footing is flexible the distribution of contact pressure is uniform irrespective of the type of underlying soil.
- If the footing is rigid the distribution of contact pressure depends on the type of soil mass.

Contact Pressure On Saturated Clay

Flexible Footing

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

Rigid Footing

When a footing is rigid, the settlement is uniform. The contact pressure distribution is minimum at the center and the maximum at the edges. The stresses at the edges in real soils can not be infinite as theoretically determined for an elastic mass. In real soils, beyond a certain limiting value of stress, the plastic flow occurs and the pressure becomes finite.

- Contact pressure on saturated clay

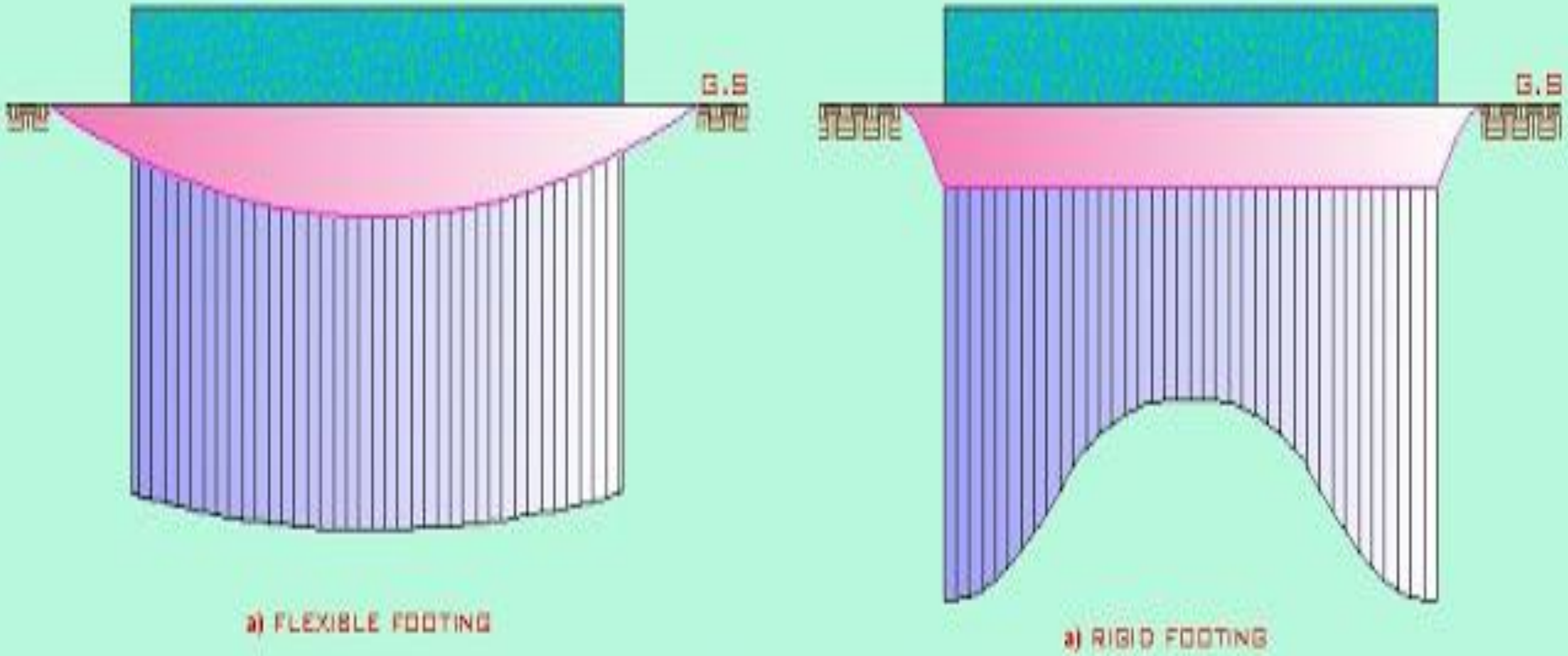


FIG. 1 CONTACT PRESSURE ON SATURATED CLAY

Contact pressure on sand

- **Flexible footing**
- In this case, the edges of flexible footing undergo a large settlement than at the centre. The soil at the centre is confined and, therefore, has a high modulus of elasticity and deflects less for the same contact pressure. The contact pressure is uniform.
- **Rigid footing**
- If the footing is rigid, the settlement is uniform. The contact pressure increases from zero at the edges to a maximum at the centre. The soil, being unconfined at edges, has low modulus of elasticity. However, if the footing is embedded, there would be finite contact pressure at edges.

- Contact pressure on sand

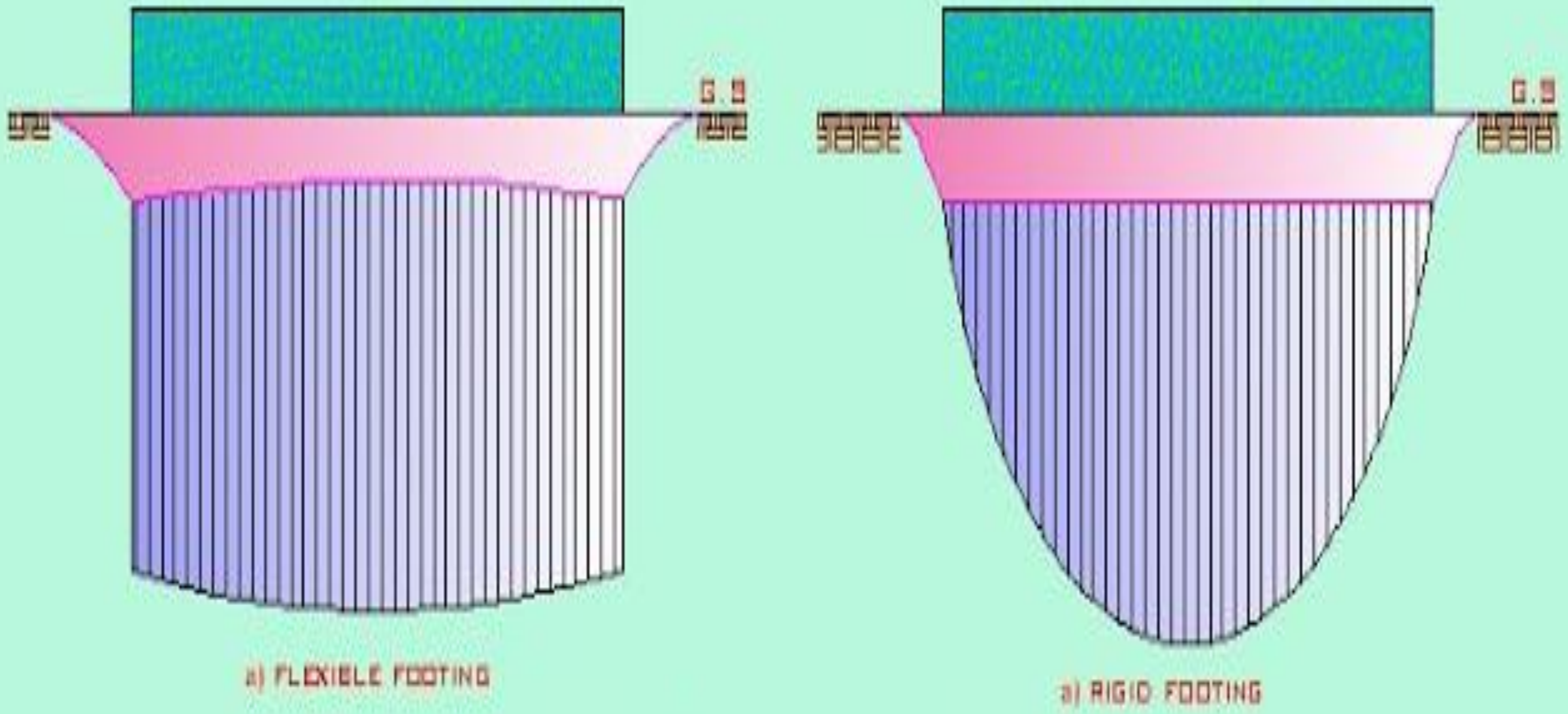


FIG. 2 CONTACT PRESSURE ON SAND.

PILE FOUNDATION

What is pile foundation. . . .?

- The pile foundation is used to describe a construction for the foundation of a wall or a pier, which is supported on the pile.
- Where it is placed ...?

  The piles may be **placed separately** or they may be **placed in the form of cluster throughout the length of the wall**.
- Where it is adopted ...?

  Piles are adopted **when the loose soil extended to a great depth**.

  The load of the structure is transmitted by the piles to hard stratum below or it is resisted by the friction developed on the sided of the piles.

Classification of Piles:

- **Based on the function;**
  1. End bearing Pile
  2. Friction Pile
  3. Compaction Pile
  4. Tension Pile or Uplift Pile
  5. Anchor Pile
  6. Fender Pile and Dolphins
  7. Batter Pile
  8. Sheet Pile

- **Based on the material & composition;**
  1. Concrete Pile
  2. Timber Pile
  3. Steel Pile
  4. Composite Pile: Concrete & Timber, Concrete & Steel

- **Based on the method of installation;**
  1. Driven Pile
  2. Cast-in-situ Pile
  3. Driven and cast- in- situ Pile

Types of pile

I. **Load bearing piles**
II. **Non-load bearing piles**

I. **Load bearing piles** :-

- It bear the load coming from the structure.
- The Piles are generally **driven vertically** or in near vertical position.
- When a **horizontal forces to be resisted**, the inclined piles may **be driven in an inclined position** and such inclined piles are termed the **batter piles**
- Load bearing piles are divided into,

i. **Bearing piles**
ii. **Friction Piles**

Bearing piles

- This **piles penetrate to through the soft soil and their bottoms rest on a hard bed**. Thus, they are end bearing piles and **act as columns** or piers.

- The soft ground through which the piles pass **also gives some lateral support** and **this increases the load carrying capacity** of the bearing piles.

Friction piles

- When loose soil extends to a great depth, the piles are driven up to such a depth that **the frictional resistance developed at the sides of the piles equals the load coming on the piles.**

- **Great care should be taken** to determine the frictional resistance offered by the soil and **suitable factor of safety should be provided in the design.**

Pile Driving

- The **process of forcing the piles into the ground without excavation** is termed as the pile driving.
- The piles should be **driven vertically**.
- However, a tolerance of eccentricity of 2 % of the pile length is permissible.
- The **eccentricity is measured by means of plumb bob**.
- The equipments required for pile driving are as follows,

i. Pile fames

ii. Pile hammers

iii. Leads

iv. Winches

v. Miscellaneous

Pile Driving

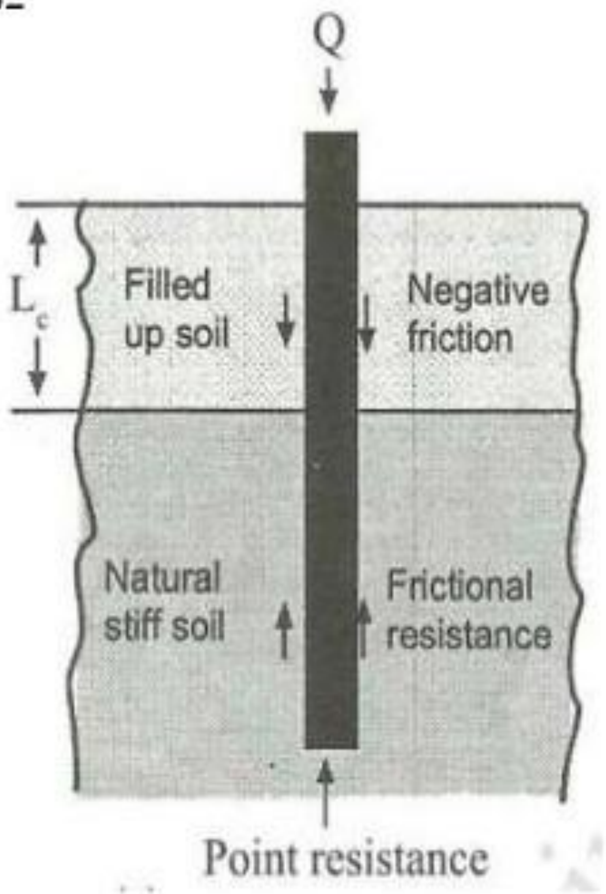
- Piles are commonly driven by means of a hammer supported by a crane or a special device known as a Pile Driver.
- Hammers adopted for driving the pile are of the following types:
  1. Drop hammer
  2. Single acting hammer
  3. Double acting hammer
  4. Diesel hammer
  5. Vibratory hammer.

Factors affecting pile capacity

- Surrounding soil
- Installation technique (like driven or bored).
- Method of construction (like pre cast or cast in situ).
- Location of pile in a group.
- Spacing of piles in a group.
- Symmetry of the group.
- Shape of pile cap
- Location of pile cap (like above soil or below soil).
- Drainage condition in soil.

Negative Skin Friction

- *Negative friction is a down-ward drag acting on a pil due to the downward mo vement of the surroundir compressible soil relative to the pile.*
- *It is shown in figure asid*
- ***Figure shows the pile passing through a recently constructed cohesive soil fill. The soil below the fill is completely consolidated under its overburden pressure.***



Cont…

- **Negative Skin Friction will occur due to the following reasons:**
- ✓ When the surrounding compressible soil has been recently filled.
- ✓ If the fill material is loose cohesion less soil.
- ✓ By lowering the ground water which increases the effective stress causing consolidation of the soil with resultant settlement and friction force being developed on the pile.
- ✓ It also occurs when the fill is over the peat or a soft clay stratum.

Pile load test

OBJECTIVE

- This test is used to determine the "LOAD CARRYING CAPACITY" of a pile.
- This test gives us the value of

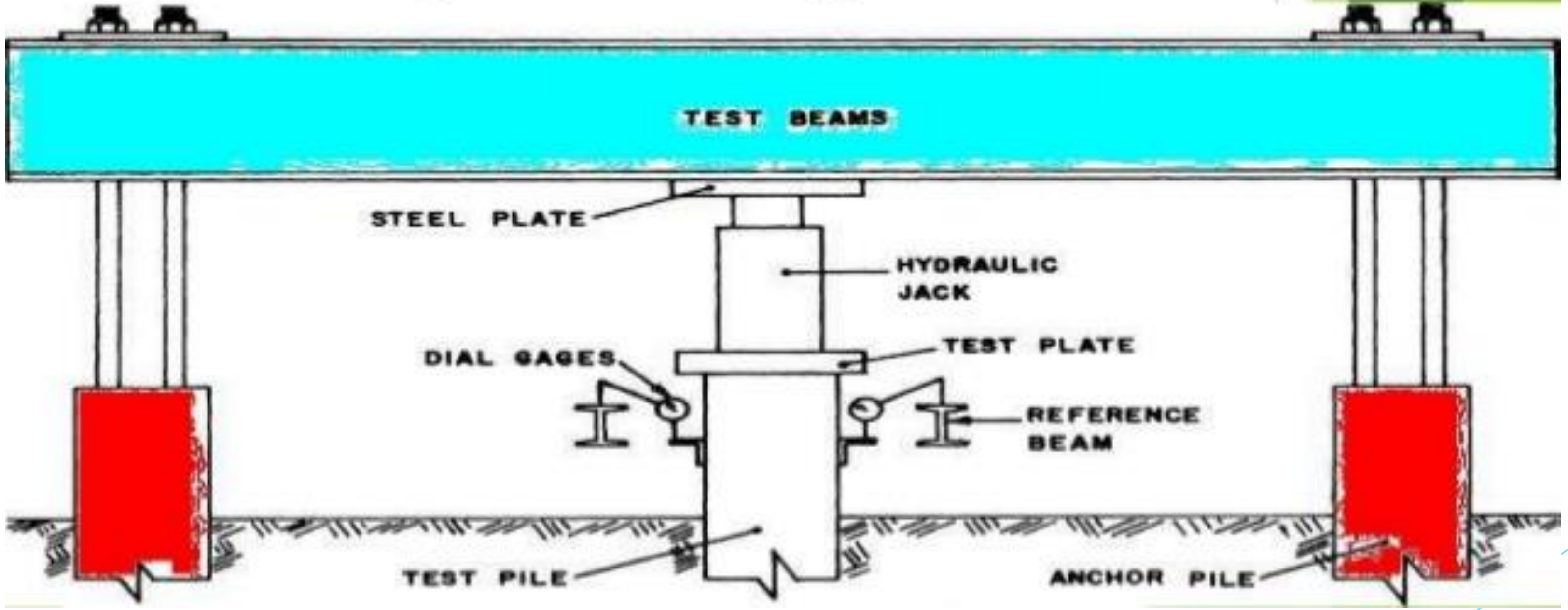
  -ULTIMATE LOAD VALUE

  -SAFE LOAD VALUE

  -SETTLEMENT UNDER DIFFERENT VALUES OF LOADS

EQUIPMENTS

- Anchor Girder or Reaction Girders
- Hydraulic Jack
- Test Pile
- Anchor Pile
- Dial Gauges
- Reaction Truss (in case of truss loading)



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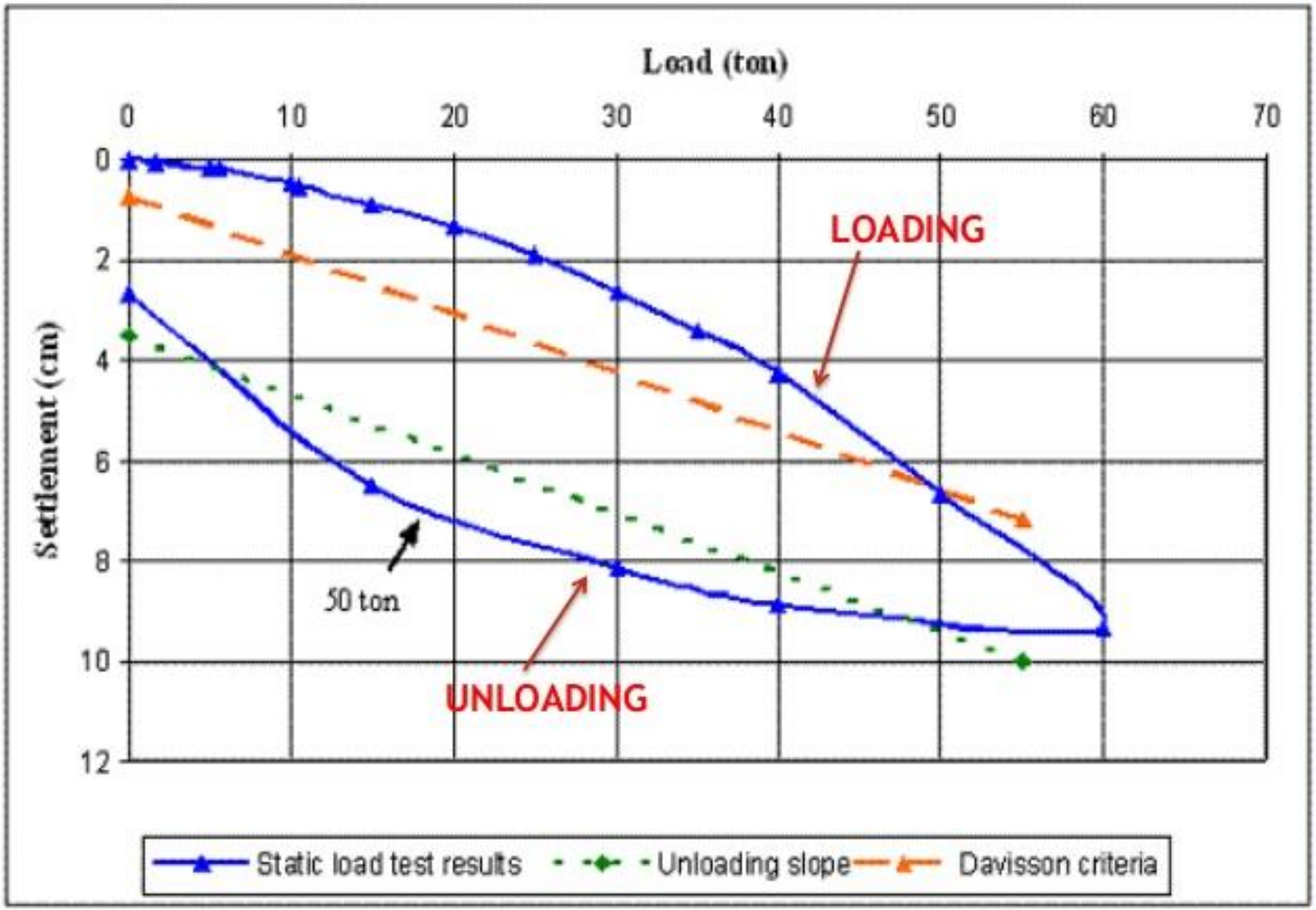
PROCEDURE:-

- The set-up consists of two anchor piles provided with an anchor girder or reaction girder at their top.
- The test pile is installed between the anchor piles as like foundation pile is installed. The test pile should be at lest **3B or 2.5m** clear from the anchor pile.
- The test is conducted after a rest period of 3 days after the installation in sandy soils and period of one month in silts and soft clays.
- The load is applied through a hydraulic jack resting on the reaction girder or Truss. The measurement of pile movement are taken with respect to a fixed reference mark.
- The load is applied in equal increment of about **20%** of the allowable load.

- Settlement should be recorded with **3 dial gauges**.
- Each stage of the loading is maintained till the rate of movement of the pile top is not more than **0.1mm per hour** in sandy soils and **0.02mm per hour** in case of clayey soils as maximum of two hours.
- Under each load increment, settlements are observed at **0.5, 1, 2, 4, 8, 12, 16, 20, 60 minutes**.
- The loading should be 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 & the final rebound recorded **24 hours** after the entire load has been removed.
- Plot a graph of **Load→Settlement** and make a curve for loading as well as unloading obtained from a pile load test.



1 cm = 0.39 in.
1 ton (metric) = 2.2 kips

Calculations

- Figure shows a typical Load-Settlement curve for loading as well as unloading from a pile load test.
- For any given load, the **net pile settlement (S_n)** is given by,

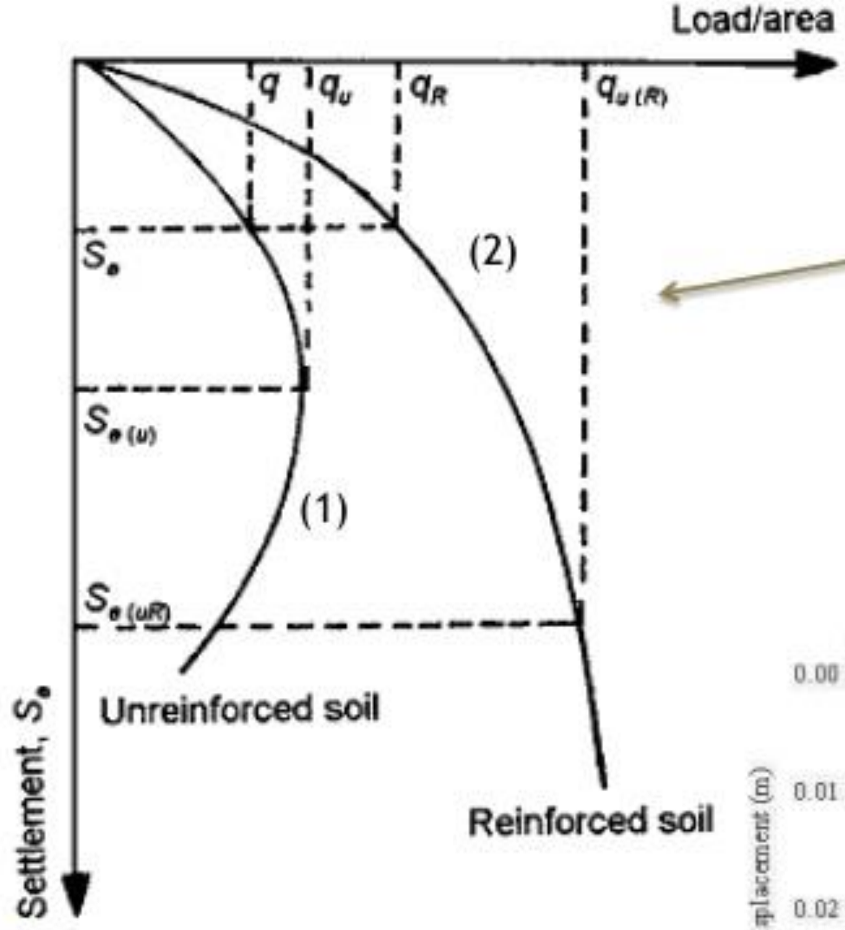
$$S_n = S_t - S_e$$

- Where ,

  S_t = Total settlement (gross settlement)

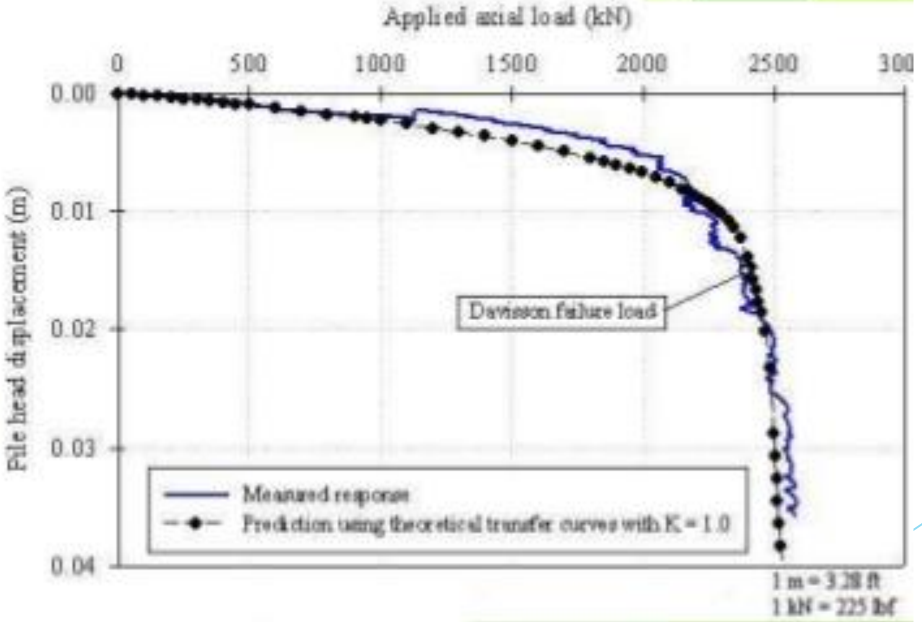
  S_e = Elastic settlement (rebound)

- Now, we will draw Net Load→Settlement curve.



Load/area
q
q_u
q_R
q_u (R)
S_e
S_e (u)
S_e (uR)
(1)
(2)
Unreinforced soil
Reinforced soil
Settlement, S_e

Fig. (A)



Applied axial load (kN)
0
500
1000
1500
2000
2500
300
0.00
0.01
0.02
0.03
0.04
Pile head displacement (m)
Davisson failure load
Measured response
Prediction using theoretical transfer curves with K = 1.0
1 m = 3.28 ft
1 kN = 225 lbf

Fig. (B)

RESULTS

- At the **ULTIMATE LOAD (Q_u)**, the load-settlement curve becomes either linear as curve (2)
- Or There is a sharp break as in the curve (1), as shown in Fig.(A).
- The safe load is usually taken as **one-half** of the **Ultimate load.**
- According to **IS:2911**,

1. the safe load is taken as **one-half** of the load at which the total settlement is equal to **10%** of the pile diameter or
2. two-third of the final load at which the total settlement is **12mm**, whichever is less.
3. Two-third of the final load which causes a net settlement(residual settlement after removal of load) of 6 mm.