

UNIT-IV SHALLOW FOUNDATIONS

Types of Foundation

Foundations may be broadly classified into two categories

1) Shallow Foundation

2) Deep Foundation

1. Shallow Foundation :- According to Terzaghi

a foundation is shallow if its depth is equal to or less than width.

$$\text{i.e., } D_f \leq B$$

Shallow Foundations are provided where structural load is less and soil is medium to dense at shallow depth.

Shallow foundations are divided into

following categories

i) spread footing

ii) Strap footing

iii) Combined footing

2) Deep Foundation : Deep foundation are

used in situations when,

*. The strata of good bearing capacity

is not available near the ground

and.

* Structure load is too heavy and top soil is loose followed by dense soil.

Deep foundations are of following types

- 1) Pile Foundations
- 2) Pier Foundations
- 3) Well Foundations
- 4) Caisson Foundations

Factors affecting the selection of type of foundation.

The choice of type of foundation to be used in given situation depends mainly on following factors.

- a) Soil profile
- b) Bearing capacity of soil
- c) Type of structure
- d) Type of load
- e) Permissible differential settlement
- f) Environmental and construction considerations
- g) Economy

Choice of Foundation

* The choice of foundation to be used in given situation depends mainly on following factors.

1) Soil profile

2) Bearing capacity

3) Type of Structure

4) Type of load

5) Permissible differential settlement

6) Environmental condition

7) Economy

Deciding depth of footing

*. Footing should be taken below the top

soil, miscellaneous debris or muck

*. Depth of foundation should always be

greater than depth of first action i.e.

negative of bearing capacity of soil

*. Footing should be taken below the

possible depth of corrosion due to

natural causes like surface water

run off

*. The minimum depth of footing on this

count is usually taken as 30 cm for

single and two storey constructions.

While it is taken as 60 cm for

heavier construction.

*. Footing on sloping ground be constru

-cted with a sufficient edge distance

For protection against erosion.

* **Gross bearing Capacity** :- Gross safe bearing capacity is the maximum gross pressure which the soil can carry safely without shear failure. It is equal to the net safe bearing capacity plus the original overburden pressure.

* **Net safe bearing capacity**

* It is the Net soil pressure which can be safely applied to the soil

considering only shear failure -

* It is obtained by dividing the net ultimate bearing capacity by a suitable factor of safety.

Gross safe bearing capacity

= Net safe bearing capacity + Original

overburden

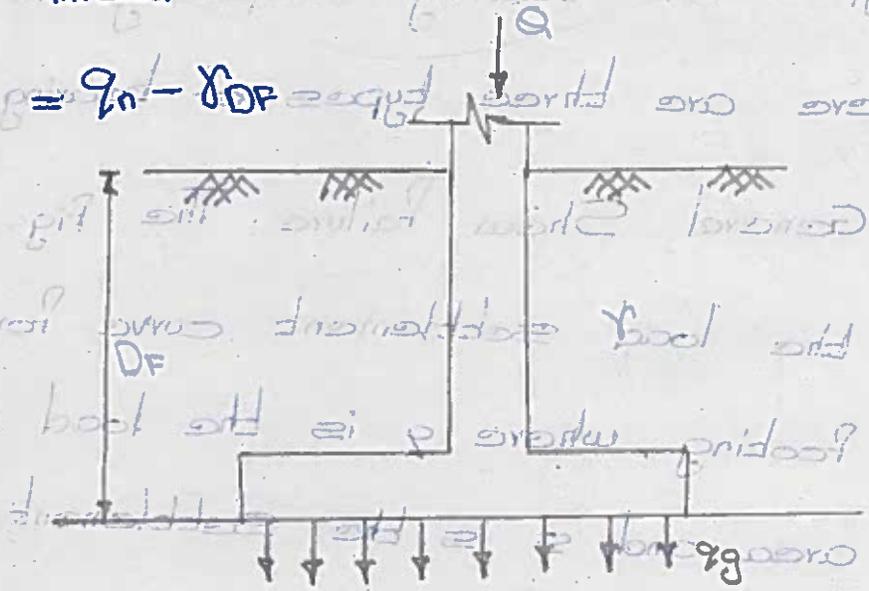
Net safe bearing capacity :-

$$= \frac{\text{Net ultimate bearing capacity}}{\text{Factor of safety}}$$

Net Pressure Intensity (q_n)

* It is that part of gross pressure at the base of footing which is in excess to initial effective overburden pressure

$$q_n = q_g - \gamma D_f$$



Ultimate Bearing Capacity (q_u)

* It is defined as the minimum gross pressure at the base of the foundation at which the soil just fails in shear

Net Ultimate bearing capacity (q_{nu})

* It is that maximum net pressure which can be applied safely without risk of shear failure at the base of foundation.

Safe bearing capacity (q_s)

$$q_s = \frac{q_u - \bar{\sigma}}{F} + \bar{\sigma}$$

*. It is that gross pressure at the base of footing which can be applied safely without risk of shear failure

Types of bearing Capacity Failure

There are three types of bearing failure

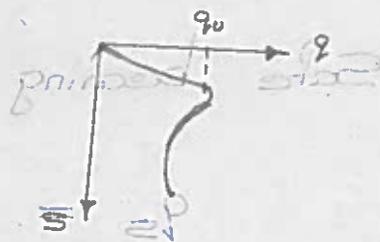
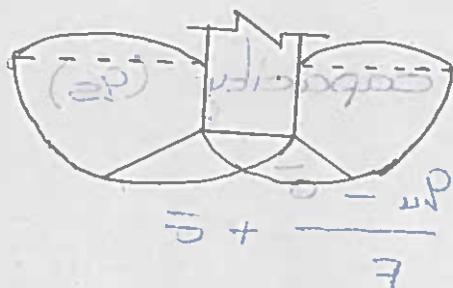
1) General Shear Failure: The Fig. Shows the load settlement curve for the footing, where q is the load per unit area and s is the settlement.

*. At a certain load intensity equal to q_u , the settlement increase suddenly

*. A shear failure occurs in the soil at that load and the failure surfaces extends to the ground surface

*. This type of failure is known as general shear failure.

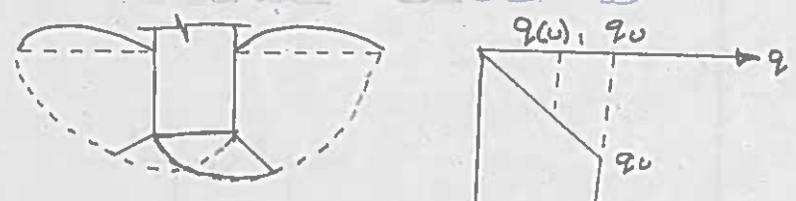
*. A heave on the sides is always observed in general shear failure.



2) Local Shear Failure

* Fig. Shows a Strip Footing resting on medium dense sand or on clay of medium consistency.

* Fig. also shows the load - settlement Curve.



* When the load is equal to a certain value $q_u(1)$. The foundation movement is accompanied by sudden jerks

* The failure surfaces gradually extend outwards from the foundation.

* However, a considerable movement of the foundation is required for the failure surface to extend to the ground surface

* The load at which this happens is equal to q_u

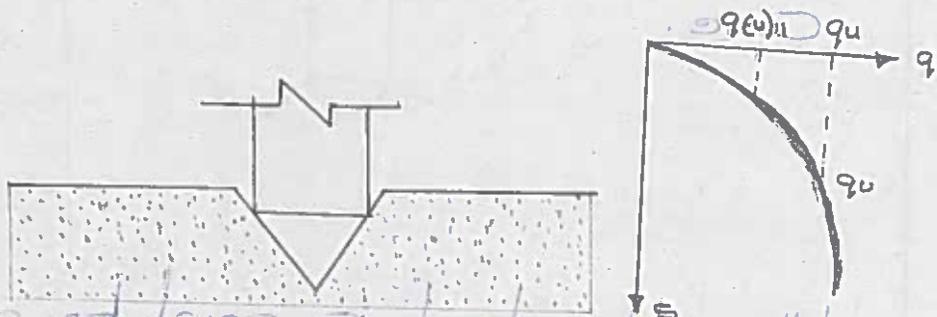
* Beyond this point, an increase of load is accompanied by a large increase in settlement

* This type of failure is known as local shear failure.

*. A heave is observed only when there is substantial vertical settlement

3) Punching Shear Failure

*. Fig. Shows a strip footing resting on a loose sand or soft clay.



*. In this case, the failure surface do not extend upto the ground surface.

*. There are jerks in foundation at a load of q_u .

*. The footing fails at a load of q_u at which stage the load settlement curve become steep and practically linear. It is called punching shear failure.

*. No heave is observed. There is only vertical movement of footing.

Terzaghi's Method

*. The bearing capacity of a soil can be determine by analytical method using a bearing capacity equation or by the field test data.

A. Terzaghi's method

* This method is an expansion over Prandtl's method. Terzaghi considered the base of the footing to be rough whereas Prandtl considered it smooth.

Assumptions

1. Footing is located at a depth D_f below the ground surface such that $D_f \leq B$, where B is the width of the footing.
2. Base of foundation is rough.
3. Footing is continuous, this makes the analysis two-dimensional.
4. Failure is general shear failure and at the time of failure soil reaches into plastic state.
5. The stress zone of the soil extends upto foundation level and not upto ground level.

* Terzaghi divided the stressed soil in the three zones as shown in

- Fig.
- zone - I (Central zone)
 - zone - II (Radial Shear zone)
 - zone - III (Linear Shear zone)

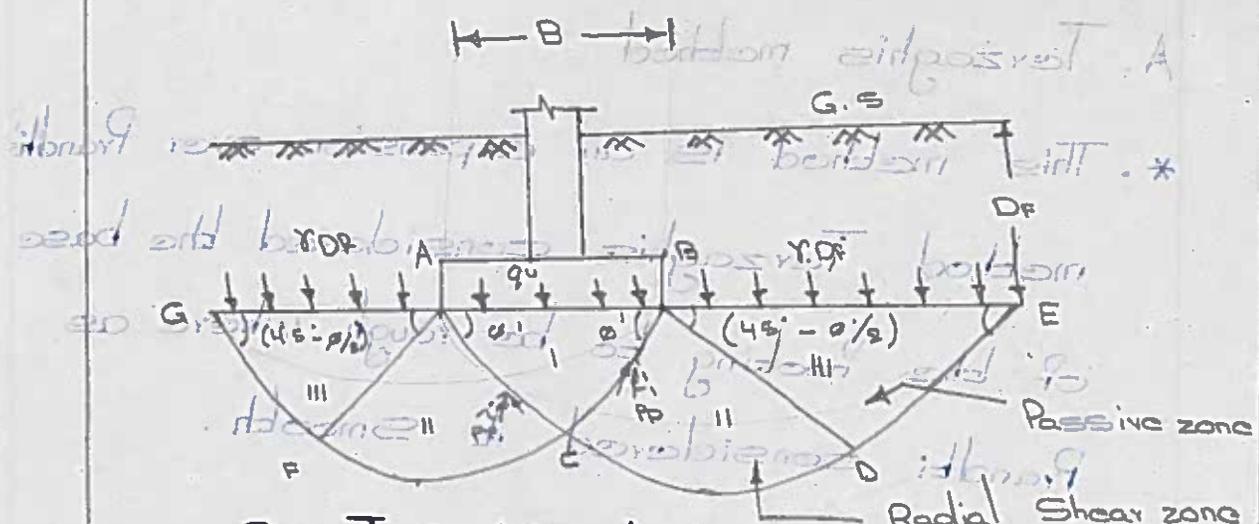


Fig. Terzaghi's Analysis

Zone - I (Central Zone):

* Zone - I is below the foundation and also called central zone

* Remain in state of elastic equilibrium

* On loading, it gets compacted and becomes part of footing

* It makes an angle of ϕ with horizontal

Zone - II (Radial Shear Zone)

* It is also called zone of Radial Shear

* The failure surface of zone - II may be circular or log spiral depending upon type of soil and their boundaries makes an angle of ϕ and $45^\circ - \phi/2$ with the horizontal.

* This is the zone of passive Rankine's State and soil in the zone reaches to plastic state.

Zone - III (Linear Shear Zone)

*. This is also the zone of passive Rankine's state and soil in this zone also reaches to plastic state

*. Their boundaries makes angle $45^\circ - \phi/2$ with horizontal.

Equation For Ultimate bearing Capacity:

*. Ultimate bearing capacity of strip footing is given by the equation.

$$q_u = CN_c + \gamma D_f N_q + \frac{1}{2} \gamma B N_\gamma$$

where, B = Width of footing
(least lateral dimension)

D_f = Depth of footing below G.L.

γD_f = Surcharge of foundation level (q).

*. N_c , N_q and N_γ are bearing capacity factors which depends upon frictional

angle of soil,

$$N_\phi = \tan^2 \left[45^\circ + \frac{\phi}{2} \right]$$

$$N_q = N_\phi e^{\pi \tan \phi}$$

$$N_\gamma = 1.8 \tan \phi (N_q - 1)$$

$$N_c = \cot \phi (N_q - 1)$$

For purely cohesive soils

$$\phi = 0^\circ$$

* This is also the case of passive

Rankine's state and soil in this zone

also applies to passive state

* Then boundaries $N_c = 5.7$

I.S. Code Method

* I.S. code has adopted mayerhoff's

equation with additional water table

Correction factor in third term

$$q_u = C N_c s_c d_c i_c + q' N_q s_q d_q i_q + \frac{1}{2} \gamma B N_r s_r d_r i_r$$

$$d_c = 1 + 0.2 \frac{D_f}{B} \sqrt{N_\phi}$$

$$d_q = d_r = 1 \text{ For } \phi \leq 10^\circ$$

$$d_q = d_r = 1 + 0.2 \frac{D_f}{B} \sqrt{N_\phi} \text{ For } \phi > 10^\circ$$

$$\text{where, } N_\phi = \tan^2 \left[45^\circ + \frac{\phi}{2} \right]$$

and i_c, i_q and i_r are load inclination factors

$$i_c = i_q = \left[1 - \frac{\alpha}{90^\circ} \right]^2$$

$$i_r = \left[1 - \frac{\alpha}{\phi} \right]^2$$

where, α = Inclination of the load to the

vertical, in degrees.

Shape of base of footing	Shape Factor Corrections		
	S_c	S_q	S_γ
Continuous Strip	1.00	1.00	1.00
Rectangle (B:L)	$1 + 0.2 \frac{B}{L}$	$1 + 0.2 \frac{B}{L}$	$1 - 0.3 \frac{B}{L}$
Square (B)	1.30	1.20	0.80
Circle (D)	1.30	1.20	0.60

* Bearing Capacity Factors can be computed from the following equation

$$N_c = (N_q - 1) \cot \phi$$

$$N_q = k \tan^2 \left[45^\circ + \frac{\phi}{2} \right] e^{\pi \tan \phi}$$

$$N_\gamma = 2 (N_q + 1) k \tan \phi$$

Effect of Water table

1) $R_w^* = 1$, if the water table remain permanently at or below a depth $(D_f + B)$ beneath the ground level.

2) $R_w^* = 0.5$, if the water table is permanently located at a depth of D_f or likely to rise above the base of footing

3) $R_w^* = 0.5 \left[1 + \frac{d_w}{B} \right]$, When water table is permanently located within zone II i.e.,

$$D_f < d_w < (D_f + B)$$

Settlement Criteria

* In Shallow Foundation total settlement

can be divided into two parts

1) Immediate settlement

2) Consolidation settlement

1) Immediate Settlement (s_i)

* It occurs almost immediately after the load is imposed, as a result to distortion of the solid without any volume change.

* It is due to compression, expansion of pore air elastic deformation of solids and squeezing of water.

For cohesionless soils:

$$s_i = \frac{H_0}{C_s} \log_{10} \left[\frac{\bar{\sigma}_0 + \Delta \bar{\sigma}}{\bar{\sigma}_0} \right]$$

$$C_s = 1.5 \frac{C_r}{\bar{\sigma}_0}$$

where, C_r = Static cone resistance in KN/m^2

$\bar{\sigma}_0$ = Initial effective stress due to overburden pressure at the centre of layer

H_0 = Total thickness of soil layer initially

$\Delta \bar{\sigma}$ = Increase in effective stress at the center of layer due to application of load.

For Cohesive Soils

* The immediate deformation below the corner of a rectangular base foundation

is given by

$$S_i = \frac{q \cdot B(1-\mu^2)}{E_s} \cdot I_k$$

where; q = Pressure at the base of foundation

B = Width of foundation (dimension)

μ = Poisson's ratio of soil = 0.3-0.45

E_s = Young's Modulus of soil

I_k = Influence Factor

2) Consolidation Settlement (S_c): It consist

* Settlement due to primary consolidation

* Settlement due to Secondary consolidation

a) Settlement due to primary consolidation

* It occurs due to expulsion of pore water from a loaded saturated soil mass.

* In primary consolidation, the rate flow is controlled by pore pressure, the permeability and the compressibility of soil

* If Δe is change in void ratio due to increase in effective stress on soil

layer:

$$\frac{\Delta H}{H_0} = \frac{\Delta e}{1+e_0}$$

$$S_c = \Delta H_c = \frac{\Delta e}{1+e_0}$$

where,

e_0 = Initial void ratio at beginning of

consolidation

H_0 = Initial thickness of compression layer

b) Settlement due to Secondary Consolidation

* It is due to plastic readjustment of

solids

* It occurs at very slow rate and is

negligible in granular soils

$$S_c = \frac{C_s H_{100}}{1 + e_{100}} \log_{10} \left[\frac{t}{t_{100}} \right]$$

where,

C_s = Secondary compression Index

H_{100} = Thickness of compressible layer after primary consolidation

e_{100} = Void ratio at the centre

t_{100} = Time required to complete primary

consolidation

t = Time at which secondary settle-

ment is computed after completion of primary consolidation

The total settlement of soil is given by

$$S_t = S_i + S_c + S_{sc}$$

Allowable Bearing Pressure

* A Foundation is said to be safe, when

it is satisfy following conditions

- a) There should be adequate factor of safety against shear failure
- b) The settlement should be within permissible limit i.e., it should not be greater enough to damage the structure

* From above two conditions, whichever gives a lower value of load intensity is referred as the allowable bearing pressure.

1) For Granular soils:

* Governing criteria is safe settlement pressure except in narrow footing on loose sand

2) For cohesive soils

* Governed by shear criteria i.e. net safe bearing capacity.

Plate load Test

* Plate load test is used to determine.

*. Ultimate bearing capacity of soil based on shear criteria

*. Allowable bearing capacity of soil based on shear criteria.

*. Settlement of Foundation

The test is performed in following steps

1) Loading on the rigid plate which is placed at the level of foundation

2) Determining settlement corresponding to the load applied.

3) Plotting load settlement curve

4) Determining ultimate bearing capacity or allowable bearing pressure using load settlement curve.

Procedure :

*. The test is performed at the level of foundation

*. The plate load test is performed in a test pit dug upto the base level of the footing having general width equal to five times the width of test plate.

* The size of rigid plate varies from 300 mm to 750 mm and thickness not less than 25 mm which may be circular or square. Smaller size plates are used in dense or stiff soils where as larger are being used in loose or soft soils.

* The test plate is seated at the centre of pit over a thin layer of sand and load is applied with hydraulic jack or through cross loading.

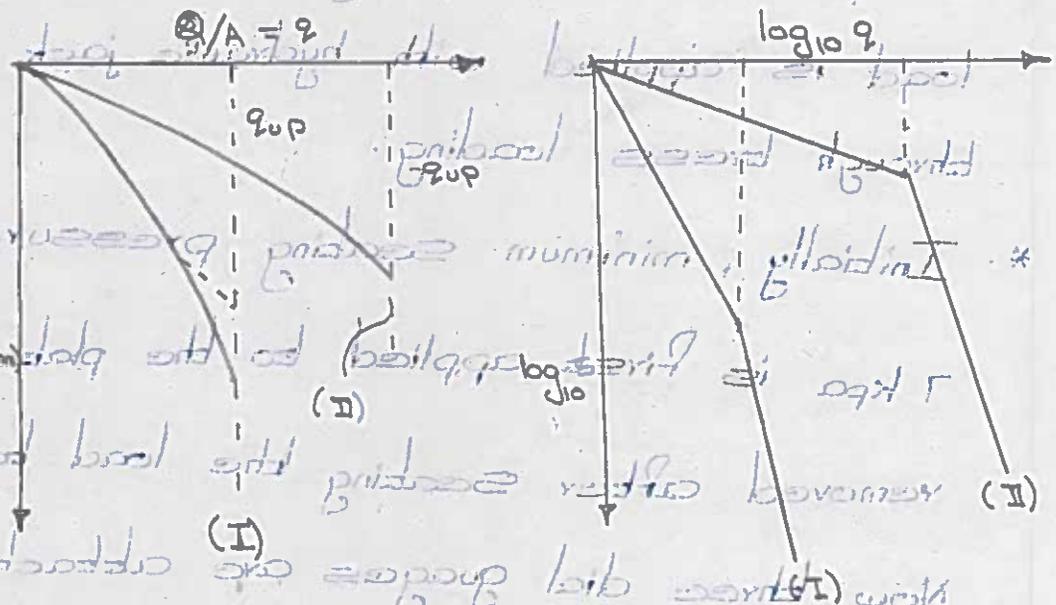
* Initially, minimum seating pressure of 7 kpa is first applied to the plate and removed after seating the load test. Now three dial gauges are attached at 120° to each other to record the settlement. The test load is applied in increments not more than 100 kpa or not more than 20% of expected ultimate bearing capacity.

* The settlement is recorded by taking average of the three dial gauges and load settlement curve is plotted

either on arithmetic scale or log scale

* The load is continued until, on the following stage is obtained

- 1) Settlement becomes progressive indicating Shear Failure
- 2) Loading pressure exceeds three times allowable pressure
- 3) Total settlements of plate becomes more than 10% of size of plate



Determination of ultimate Bearing Capacity

1) For clays :

* In clays, bearing capacity is independent of size of footing.

$$q_{uf} = q_{up}$$

q_{uf} = Ultimate bearing capacity of footing

q_{up} = Ultimate bearing capacity of Plate

2) For Sand :

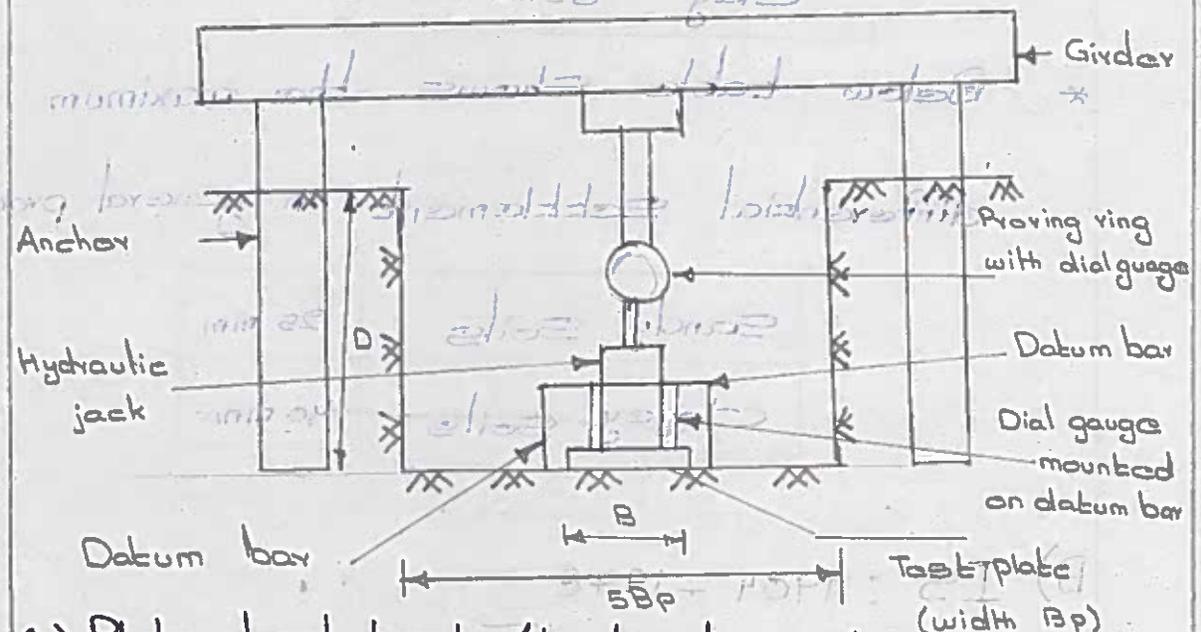
* In sandy soils bearing capacity is proportional to size of footing

$$q_{uF} = q_{uP} \times \frac{B_F}{B_p}$$

B_F = Width of footing

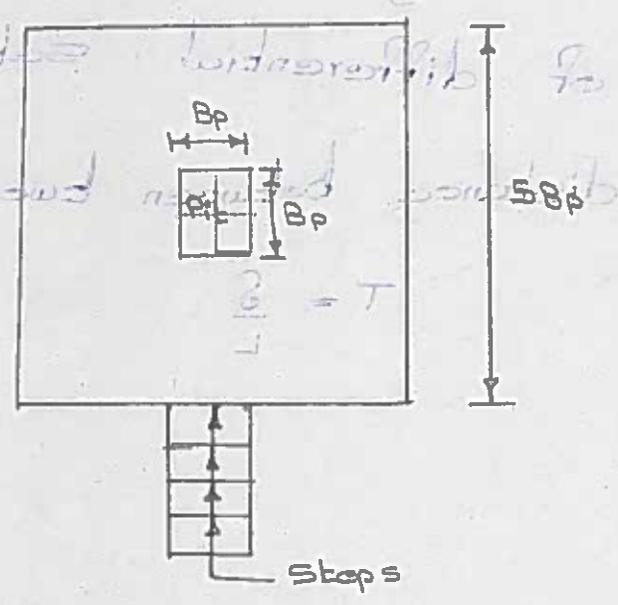
B_p = Width of plate

* Using FOS = 2.5 - 3.0. Safe bearing capacity can be determined.



(a) Plate load test (loading by reaction loading)

(vertical section)



(b) Plan

Allowable Settlement of Structure

Codal Provisions: *also please refer I - **

A) As per IS : 1904

* For isolated Foundation = $\frac{P}{B}$

Sand	40 mm
Clay	65 mm

* For raft Foundation = $\frac{P}{B}$

Sand	40 mm - 65 mm
Clay	65 mm - 100 mm

* Below table shows the maximum differential settlement in general practice

Sandy soils	25 mm
Clayey soils	40 mm

B) IS : 1904 - 1978

* The angular distortion is the ratio of differential settlement and the distance between two columns

$$T = \frac{S}{L}$$

Types of Foundation	Sand and Hard Clay		Plastic Clay	
	Maximum Settlement	Differential Settlement	Maximum Settlement	Differential Settlement
1) Isolated Foundation				
a. Steel Structure	50 mm	0.0033L	50 mm	0.0033L
b. RCC Structure	50 mm	0.0015L	75 mm	0.0015L
2) Raft Foundation				
a. Steel Structure	75 mm	0.0033L	100 mm	0.0033L
b. RCC Structure	75 mm	0.002L	100 mm	0.002L

For a Continuous Foundation of 0.9m depth and 1.2m width, using Terzaghi's bearing capacity factors determine the gross allowable load per unit area that the foundation can carry.

Given $\gamma = 18 \text{ kN/m}^3$, $c = 10 \text{ kN/m}^2$, $\phi = 20^\circ$, Factor of safety = 3. Assume general shear failure

A. Given.

Depth of Foundation, $D_f = 0.9 \text{ m}$
 Width $B = 1.2 \text{ m}$

Unit weight of Foundation soil, $\gamma = 18 \text{ kN/m}^3$
 $c' = 10 \text{ kN/m}^2$

Angle of Shear resistance, $\phi' = 20^\circ$

For

$$\phi' = 20^\circ$$

$$N_c = 14.7$$

$$N_q = 7.4$$

$$N_\gamma = 5$$

Under general shear failure condition the ultimate load carrying capacity given by

$$Q_u = 0.67 \cdot c \cdot N_c + \gamma D_f N_q + \frac{1}{2} \gamma B N_\gamma$$

$$= C' N_c + \gamma D_f N_q + \frac{1}{2} \gamma B N_q (\phi: c'=0, \phi_c)$$

$$= 10 \times 7.7 + 18 \times 0.9 \times 7.4 + \frac{1}{2} \times 18 \times 1.2 \times 5$$

$$Q_u = 350.88 \text{ kN/m}^2$$

$$Q_u \text{ Safe} = \frac{Q_u}{3} = \frac{350.88}{3}$$

$$= 116.96 \text{ kN/m}^2$$

Gross allowable load per unit area

$$= Q_u \text{ safe} \times \text{Area}$$

$$= 116.96 \times 0.9 \times 1.2$$

$$Q = 126.31 \text{ kN}$$

A Square Footing has dimensions of 2m x 2m and a depth of 3m. Determine its ultimate bearing capacity in pure clay with an unconfined strength of 45 kN/m².

$\phi = 0^\circ$ and $\gamma = 1.7 \text{ g/cm}^3$. Assume Terzaghi's

Factors For $\phi = 0^\circ$; $N_c = 5.7$; $N_q = 1$

and $N_\gamma = 0$.

Given data

Dimensions of footing = $2\text{m} \times 2\text{m}$

Depth = 3m

Unconfined Strength = 0.15 N/mm^2

Factor of safety = $\frac{0.15}{10^{-6}} \text{ N/m}^2$

= 150 kN/m^2

$C' = \frac{q}{2} = \frac{150}{2} = 75 \text{ kN/m}^2$

Unit weight of soil $\gamma = 1.7 \text{ g/cm}^3$

= $1.7 \times 10^3 \times 10 \times 10^6$

= 17 kN/m^3

For Square Footing

Ultimate bearing capacity,

$$q_u = 1.2 C' N_c + \gamma D_f N_q + 0.4 \gamma B N_{\gamma}$$

$$= 1.2 \times 75 \times 5.7 + 17 \times 3 \times 1 + 0.4 \times 17 \times 3 \times 1 +$$

$$0.4 \times 17 \times 2 \times 0$$

$$q_u = 564 \text{ kN/m}^2$$