

UNIT II

SHALLOW FOUNDATIONS

1. What is ultimate bearing capacity? (April/May 2004), (May/June 2013)
The ultimate bearing capacity is defined as the minimum gross pressure intensity at the base of the foundation at which the soil fails in shear.
2. What is consolidation settlement? (April/May 2004)
The consolidation settlement is the long term settlement taking place over a long period of time due to the gradual expulsion of water without replacing it by air from the soil pores.
3. List the various components of settlement. (Nov/Dec 2005), (April/May 2010)

The settlement of foundation base is due to (a) Elastic / Immediate settlement (b) Consolidation Settlement (c) Secondary Consolidation Settlement

4. Give the Terzaghi's bearing capacity equation of strip footing for local shear failure. (Nov/Dec 2005)

$$Q_f = \frac{2}{3} CN'_c + \gamma D_f N'_q + 0.5 \gamma B N'_\gamma$$

5. Compare general and local shear failure. (May/June 2009)

S.NO	General Shear Failure	Local Shear Failure
1	Well defined failure pattern	Well defined wedge and slip surfaces only beneath the foundation
2	A sudden – catastrophic failure accompanies by tilting of foundation.	There is no tilting of foundation. Slip surface not visible beyond the edges of the foundation.
3	Bulging of ground surface adjacent to the foundation.	Slight bulging of ground surface adjacent to the foundation.
4	The load – Settlement curve indicates the ultimate load clearly.	The load – Settlement curve does not indicate the ultimate load clearly.

6. What is meant by allowable settlement? (May/June 2009)

Allowable Settlement:

- It is the maximum settlement beyond which the foundation fails due to excessive settlement
- Permits a maximum allowable settlement of 40 mm for isolated foundation on sand and 65 mm for those on clay.
- For raft foundations on sand 40 mm to 65 mm and that on clay 65 mm to 100 mm.

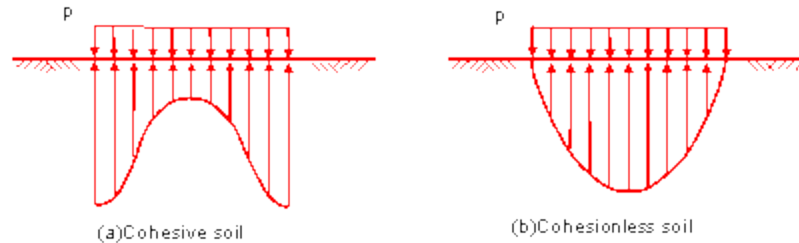
7. List the factors affecting bearing capacity of soil. (April/May 2010)

- Nature of the soil and its Physical and engineering properties.
- Nature of the foundation.
- Total and differential settlements that the structure can withstand without functional failure.
- Location of ground water table.
- Initial Stresses, if any.

8. What is spread footing? (Nov/Dec 2009)

Spread footing is a foundation which transmits the load to the ground through one or more stepped footings. One spread foot is PAD. Two or more spread step is stepped footing.

9. Sketch the pressure distribution beneath a rigid footing on cohesive and cohesionless soil. (Nov/Dec 2009), (May/June 2012)



10. Define safe bearing capacity. (Nov/Dec 2010)

Safe bearing capacity is the maximum intensity of loading that the soil will safely carry with a factor of safety without risk of shear failure of soil irrespective of any settlement that may occur.

11. What is the equation used to determine the immediate settlement? (Nov/Dec 2010)

$$S_i = \frac{I q B (1 - \mu^2)}{E}$$

Where, I = influence factor which depends on the shape of footing and rigidity

q = intensity of contact pressure

B = least lateral dimension of footing

E and μ = Young's modulus and Poisson's ratio of the soil

12. What are the criteria used for the determination of bearing capacity? (Nov/Dec 2010)

The following criteria must always be used in evaluating the bearing capacity.

1. Adequate factor of safety against failure (collapse)
2. Adequate margin against excessive settlement. Although failure or collapses of foundation have been reported from time to time, by far the most common difficulty of foundations arises from excessive settlement. Therefore, this criterion warrants skillful and careful attention of the practicing engineers.

(Or)

Determination of bearing capacity:

1. Skin friction
2. Bearing load

3. Base area etc.

13. A footing was designed based on ultimate bearing capacity arrived for the condition of water table at the ground surface. If there is a chance for raise in water level much above the ground level do you expect any change in the bearing capacity, why? (Nov/Dec 2010)

The raise in water level above the ground level would not change the bearing capacity of the soil. Because the soil under submerged condition when the water reaches the ground surface. Therefore the water above the ground level does not affect the unit weight of soil.

14. Discuss the methods for determining immediate settlement of foundation on clay. (April/May 2011)

The immediate settlement is mainly due to the expulsion of air and to the elastic deformation and reorientation of the soil particle on loading. Based on the theory of elasticity principles, immediate settlement is computed from the following equations.

$$S_i = \frac{I q B (1 - \mu^2)}{E}$$

Where, I = influence factor which depends on the shape of footing and rigidity

q = intensity of contact pressure

B = least lateral dimension of footing

E and μ = Young's modulus and Poisson's ratio of the soil

15. A footing 2m square is laid at a depth of 1.3 m below the ground surface. Determine the net ultimate bearing capacity using BIS formula. Take $\gamma = 20 \text{ kN/m}^3$, $\phi = 30^\circ$ and $c = 0$. For $\phi = 30^\circ$, take $N_c = 30.1$, $N_q = 18.4$ and $N_\gamma = 22.4$. (April/May 2011)

$$q_{nu} = q (N_q - 1) S_q d_q + 0.5 \gamma B N_\gamma S_\gamma d_\gamma$$

$$q = 1.3 \times 20 = 26 \text{ kN/m}^2$$

$$S_q = 1.2 \text{ for square footing}$$

$$S_\gamma = 0.8 \text{ for square footing}$$

$$d_q = d_\gamma = 1 + 0.1 \frac{D_f}{B} \tan (45^\circ + \frac{\phi}{2})$$

$$= 1 + 0.1 \times 1.3/2 \times \tan (45^\circ + 30^\circ/2)$$

$$= 0.112 + 1$$

$$= 1.112$$

$$q_{nu} = 26 (18.4 - 1) 1.2 \times 1.112 + 0.5 \times 20 \times 2 \times 0.8 \times 1.112$$

$$= 603.68 + 17.792$$

$$= 621.472 \text{ kN/m}^2$$

16. Define punching shear failure. (Nov/Dec 2012)

Punching Shear failure occurs when there is relatively high compression of soil under the footing, accompanied by shearing in the vertical direction around the edges of the footing. Punching shear may occur in relatively loose sand with relative density.

17. What is mean by swelling potential? (Nov/Dec 2012)

The swelling potential of expansive soils is defined as the percentage swell of a laterally confined soil sample, when tested in a consolidometer test, when soaked under a surcharge load of 7 kN/m^2 after being compacted to maximum dry density at O.M.C (Optimum moisture content) according to AASHO compaction test.

18. What is net pressure intensity? (May/June 2013)

The difference in intensity of gross pressure after the construction of a structure and the original overburden pressure is called Net pressure

$$\text{Net pressure intensity} = \frac{\text{Net load on the base of the foundation}}{\text{Area of footing}}$$

19. What is safe bearing pressure? (May/June 2013)

In conventional design, the allowable bearing capacity should be taken as the smaller of the following two values.

- The safe bearing capacity based on ultimate capacity
- The allowable bearing pressure on tolerable settlement.

20. What is the total settlement of a footing? (May/June 2013)

Total settlement is defined as the settlement due to elastic settlement, consolidation settlement and secondary settlement.

$$S = S_i + S_c + S_s$$

21. What are the major criteria to be satisfied in the design of a foundation? (Nov/Dec 2013)

Foundation design is based on providing a means of transmitting the loads from a structure to the underlying soil without

- A soil shear failure, shear failure means that, it is a plastic flow and/ or a lateral expulsion of soil from beneath the foundation.
- Causing excessive settlements of the soil under the imposed loads.

22. What is the effect of rise of water table on the bearing capacity and the settlement of a footing on sand? (Nov/Dec 2013)

The pressure of water affects the unit weight of soil. Hence bearing capacity is affected due to the effect of water table. For practical purpose it is more sensitive when the water table rises above depth 13 m from footing.

23. Define allowable bearing pressure.

The maximum allowable net loading intensity on the soil at which the soil neither fails in shear nor undergoes excessive or intolerable settlement, detrimental to the structure.

24. Define settlement and its types.

The term settlement indicates the sinking of the structure due to compression and deformation of the underlying soil.

Types:

1. Uniform settlement
2. Non uniform or differential settlement

SIXTEEN MARKS

UNIT I

SITE INVESTIGATION AND SELECTION OF FOUNDATION

1. What are the objectives of soil exploration? (April/May 2004)
(6)

Objectives of soil exploration:

1. Determination of the nature of the deposits of soil.
2. Determination of the depth and thickness of various soil strata and their extent in horizontal direction.
3. Location of ground water and fluctuations in ground water level.
4. Obtaining soil and rock samples from the various strata.

column loads and their approximate locations should be obtained. In the case of bridges span length and the load carried by the piers and abutments should be ascertained.

In the case of a dam, the geotechnical engineer should get information about the type of dam, its height, base width and other salient features or characteristics.

Study of maps:

- Topographical maps called toposheets – survey of India and geological survey of India
- Soil conservation maps may also be available.
- Faults, folds, cracks, fissures, dikes, skills and caves and such other defects in rock and soil strata may be indicated.
- Maps showing the earthquake zones of different zones of different degree of vulnerability are available.
- Seismic potential is a major factor in structural design especially in the construction of major structures such as dams and nuclear power plants.

UNIT II

SHALLOW FOUNDATIONS

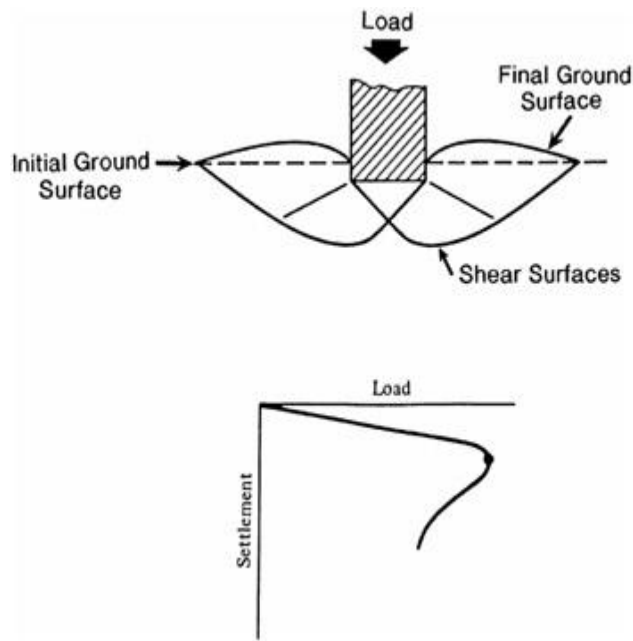
1. Explain in detail the various types of shear failure. (10 or 8)

Types of shear failure:

- General shear failure
- Local shear failure
- Punching shear failure

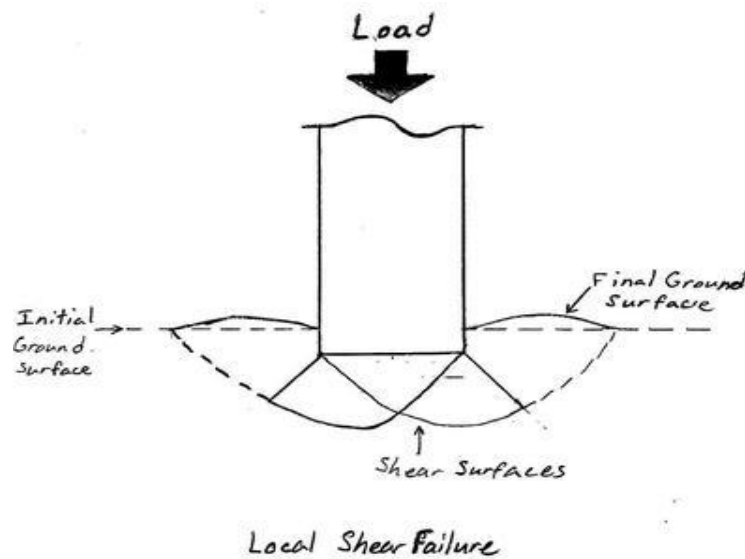
Characteristics of General Shear Failure:

- It has well defined failure surface reaching up to ground surface.
- There is considerable bulging of sheared mass or soil adjacent to the footing.
- Failure is accompanied by tilting of foundation.
- Failure is sudden with pronounced peak resistance.
- The ultimate bearing capacity is well defined.



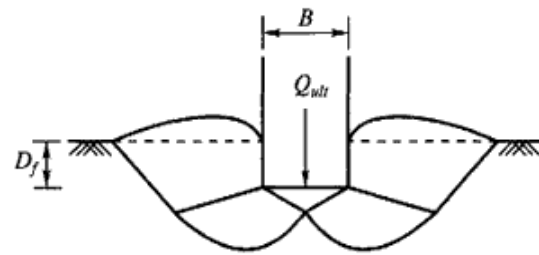
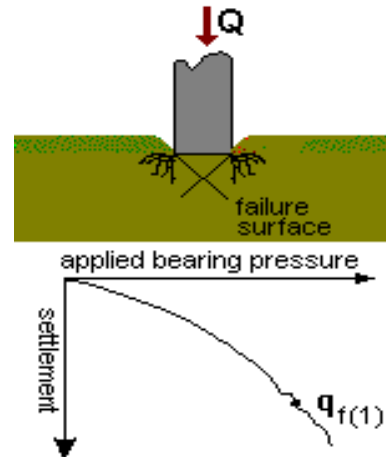
Characteristics of Local Shear Failure:

- Failure pattern is clearly defined.
- Failure surface do not reach ground surface.
- There is only slight building of soil around the footing.
- Failure is not sudden and there is no tilting of footing.
- Failure is defined by large settlement.
- Ultimate bearing capacity is not well defined.

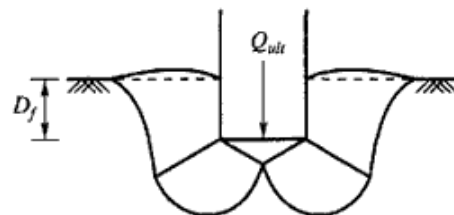
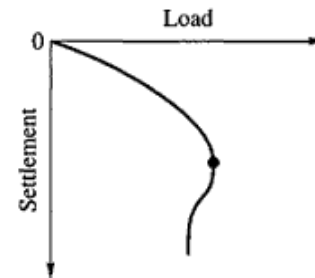


Characteristics of Punching Shear Failure:

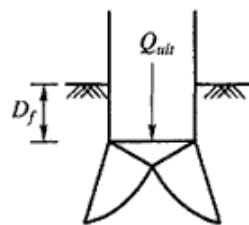
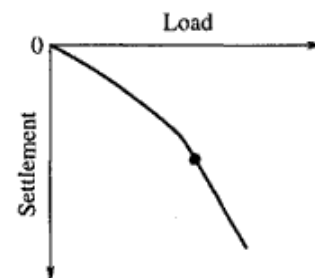
- No failure pattern is observed.
- The failure surface which is vertical or slightly inclined follows the perimeter of base.
- There is not building of soil amount the footing.
- There is no tilting of foundation.
- Failure is characteristics in terms of very large settlement.



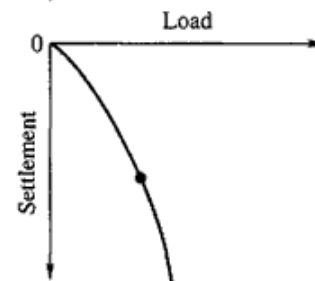
(a) General shear failure



(b) Local shear failure



(c) Punching shear failure



2. List the various factors that affect the depth of foundation.

(10 or 12)

Depth of Footing

To perform its function properly a footing must be laid at a suitable bellow the ground surface. The vertical distance between ground surface and the base of the footing is known as the depth of the footing(D_f).The depth of the footing contains the ultimate bearing capacity and the settlement. While fixing the depth of footing, the following points should be considered.

1. Depth of top soil:

The footing should be located bellow the top soil consisting the organic materials which eventually decompose. The top soil should be removed over an area slightly larger than the footing.

2. Frost depth:

The footing should be carried bellow the depth of frost penetration. If the footing is located at insufficient depth, it would be subjected to the frost damage due to formation of ice lenses and consequent frost heave. During summer, thawing occurs from the top downwards and the melted water is entrapped

3. Zone of soil volume change:

Some clay, especially clays having high plasticity, such as black cotton soil, undergoes excessive volume changes. Such soil shrinks upon drying and swells upon wetting. The volume changes are generally greater near the ground surface and decreases with increase in depth. Large volume change beneath a footing may cause lifting and dropping. The footing should be placed bellow as strata that are subjected to large volume change.

4. Adjacent footing and property lines:

- The footing should be so located that no damage is done to the existing structure. The adjacent structure may be damaged by construction of a new footing due to vibrations, undermining or lowering of the water table. The new footing may also impose additional load on the existing footing which may cause settlement.
- In general deeper the new footing and closer to the existing structure the greater is the potential damage to the existing structure. This is this is particularly more severe if the new footing is lower than the existing footing.
- As far as possible, the new footing should be placed at a small depth as the old ones and the sites of excavation adjacent to the existing structure should be suitably supported. If the footings are placed at the different levels, the slope of the line joining the two footings should not be steeper than two horizontal to one vertical as per IS: 1904-1978.

5. Sloping ground:

If a footing is located adjacent to a sloping ground, the sloping ground surface should not encroach upon a frustum of bearing material under the footing having sides making an angle of 30° with the horizontal. Moreover, the minimum distance from lower edge of the footing to the sloping ground surface should be 90cm.

6. Water table :

The footing should be placed above ground water table as far as possible. The presence of ground water within the soil immediately around a footing is undesirable as it reduces the bearing capacity of the soil and there are difficulties during construction. The water proofing problem also arises due to dampness.

7. Scour depth:

The footings located in streams, on water fronts or other locations where there is a possibility of scouring should be placed below the potential scour depth.

8. Underground defects:

The depth of footing is also affected by the presence of underground defects such as faults, causes and mines. If there are manmade discontinuities, such as sewer lines, water mains, underground cables, these should be shifted or footing should be relocated.

9. Root holes:

If there are root holes or cavities caused by burrowing animals or worms, the footing should be placed below such a zone of weakened soil.

10. Minimum depth:

IS 1904 – 1978 specifies that all foundations should extend to a depth of at least 50cm below the natural ground surface. However in case of rocks, only its top soil should be removed and the surface should be cleaned and if necessary stepped.

The minimum depth of foundation (D_f) according to Rankine's formula

$$(D_f)_{\min} = \frac{q (1 - \sin \phi')^2}{\gamma (1 + \sin \phi')}$$

3. Explain Terzaghi's bearing capacity theory. (16)

Terzaghi's bearing Capacity Theory

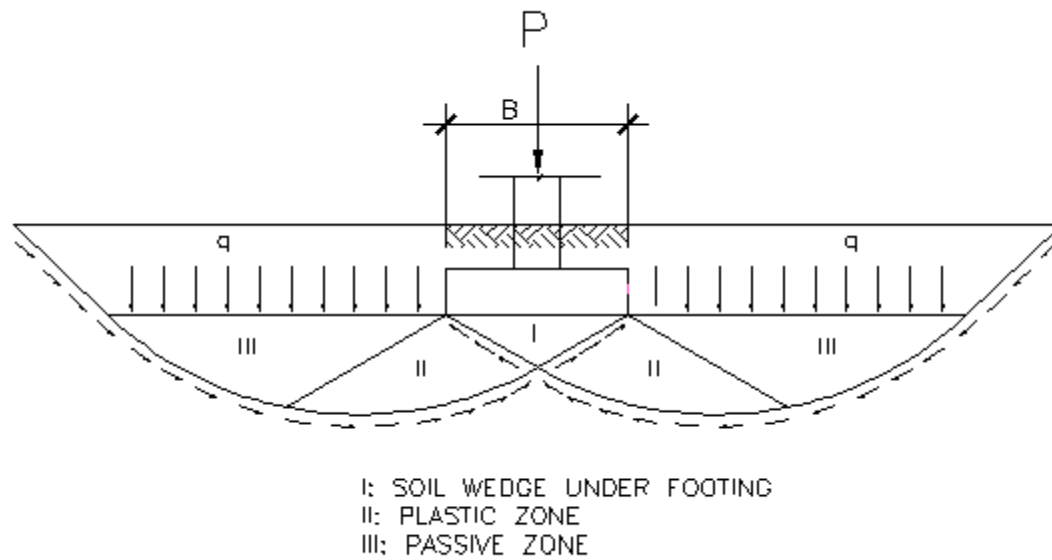
Terzaghi (1943) was the first to propose a comprehensive theory for evaluating the safe bearing capacity of shallow foundation with rough base.

Assumptions

1. Soil is homogeneous and Isotropic.
2. The shear strength of soil is represented by Mohr Coulombs Criteria.
3. The footing is of strip footing type with rough base. It is essentially a two dimensional plane strain problem.
4. Elastic zone has straight boundaries inclined at an angle equal to ϕ to the horizontal.
5. Failure zone is not extended above, beyond the base of the footing. Shear resistance of soil above the base of footing is neglected.
6. Method of superposition is valid.
7. Passive pressure force has three components (PP_C produced by cohesion, PP_q produced by surcharge and PP_γ produced by weight of shear zone).
8. Effect of water table is neglected.
9. Footing carries concentric and vertical loads.
10. Footing and ground are horizontal.
11. Limit equilibrium is reached simultaneously at all points. Complete shear failure is mobilized at all points at the same time.
12. The properties of foundation soil do not change during the shear failure

Limitations

1. The theory is applicable to shallow foundations
2. As the soil compresses, ϕ increases which is not considered. Hence fully plastic zone may not develop at the assumed.
3. All points need not experience limit equilibrium condition at different loads.
4. Method of superposition is not acceptable in plastic conditions as the ground is near failure zone.



Terzaghi's concept of Footing with five distinct failure zones in foundation soil

Concept

A strip footing of width B gradually compresses the foundation soil underneath due to the vertical load from superstructure. Let q_f be the final load at which the foundation soil experiences failure due to the mobilization of plastic equilibrium. The foundation soil fails along the composite failure surface and the region is divided into five zones, Zone I which is elastic, two numbers of Zone II which are the zones of radial shear and two zones of Zone III which are the zones of linear shear. Considering horizontal force equilibrium and incorporating empirical relation, the equation for ultimate bearing capacity is obtained as follows.

$$q_{ult} = (P_p)_\gamma + (P_p)_c + (P_p)_q$$

$(P_p)_\gamma$ = Component produced by cohesive stress.

$(P_p)_c$ = Component produced by surcharge $q = \gamma D_F$

$(P_p)_q$ = Component produced by the weight of soil in zone II, III.

$$q_{ult} = C N_c + q N_q + 0.50 \gamma B N_\gamma$$

N_c, N_q, N_γ = Bearing Capacity factor which are dimensionless depend on angle of shear resistance ϕ .

$$N_q = \left[\frac{a^2}{2 \cos^2 \left(45 + \frac{\varphi}{2} \right)} \right]$$

$$a = e^{\left(\frac{3\pi}{4} - \frac{\varphi}{2} \right) \tan \varphi}$$

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

$$N_\gamma = \frac{1}{2} \left[\frac{K_p}{\cos^2 \varphi} - 1 \right] \tan \varphi$$

Ultimate bearing capacity,

$$\gamma q f = cN_c + \gamma D N_q + 0.5 \gamma B N_\gamma$$

If the ground is subjected to additional surcharge load q , then

$$\gamma q f = cN_c + (\gamma D + q)N_q + 0.5 \gamma B N_\gamma$$

Net ultimate bearing capacity, $q_n = cN_c + \gamma D(N_q - 1) + 0.5 \gamma B N_\gamma - \gamma D$

$$\gamma q_n = cN_c + \gamma D(N_q - 1) + 0.5 \gamma B N_\gamma$$

Safe bearing capacity, $q_s = cN_c + \gamma D(N_q - 1) + 0.5 \gamma B N_\gamma / F + \gamma D$

Here, F = Factor of safety (usually 3)

c = cohesion

γ = unit weight of soil

D = Depth of foundation

q = Surcharge at the ground level

B = Width of foundation

N_c, N_q, N_γ = Bearing Capacity factors

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

$$N_q = e^{2(3\pi/4 - \phi/2)} \tan \phi / [2 \cos^2(45 + \phi/2)]$$

$$N_\gamma = (1/2) \tan \phi (K_{pr} / \cos^2 \phi - 1)$$

K_p = passive pressure coefficient.

$$K_p = \frac{1 + \sin \phi}{1 - \sin \phi} = \text{coefficient of passive earth pressure.}$$

Strip footings: $Q_u = c N_c + \gamma D N_q + 0.5 \gamma B N_\gamma$

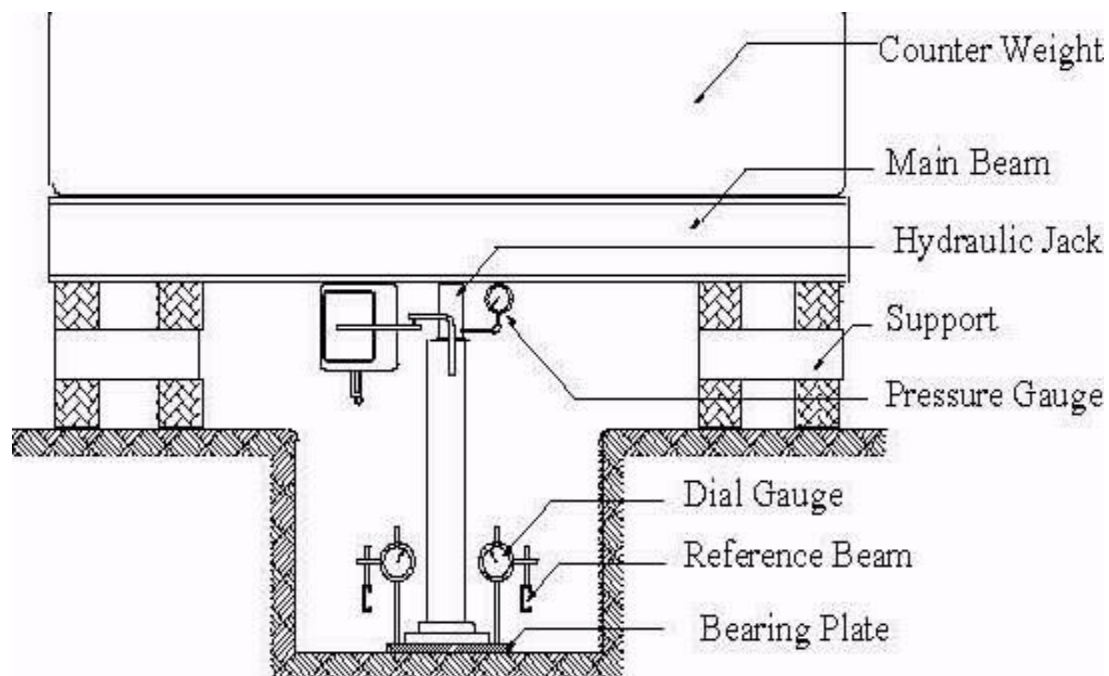
Square footings: $Q_u = 1.3 c N_c + \gamma D N_q + 0.4 \gamma B N_\gamma$

Circular footings: $Q_u = 1.3 c N_c + \gamma D N_q + 0.3 \gamma B N_\gamma$

4. Explain plate load test with sketch.

PLATE LOAD TEST

The allowable bearing pressure can be determined by conducting a plate load test at the site. To conduct a plate load test, a pit of the size $5B_p \times 5B_p$, where B_p is the size of the plate, is excavated to the depth equal to the depth of foundation (D_f). The size of the plate is usually 0.3m square. It is made of steel and is 25mm thick. Occasionally circular plates are also used. Sometimes large size plates of 0.6m square are used.



A central hole of size $B_p \times B_p$ is excavated in the pit the depth of the central hole (D_p) is obtained from the following relation

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

$$D_p = (D_f/B_f) B_p$$

$$= (B_p/B_f) D_f$$

Where,

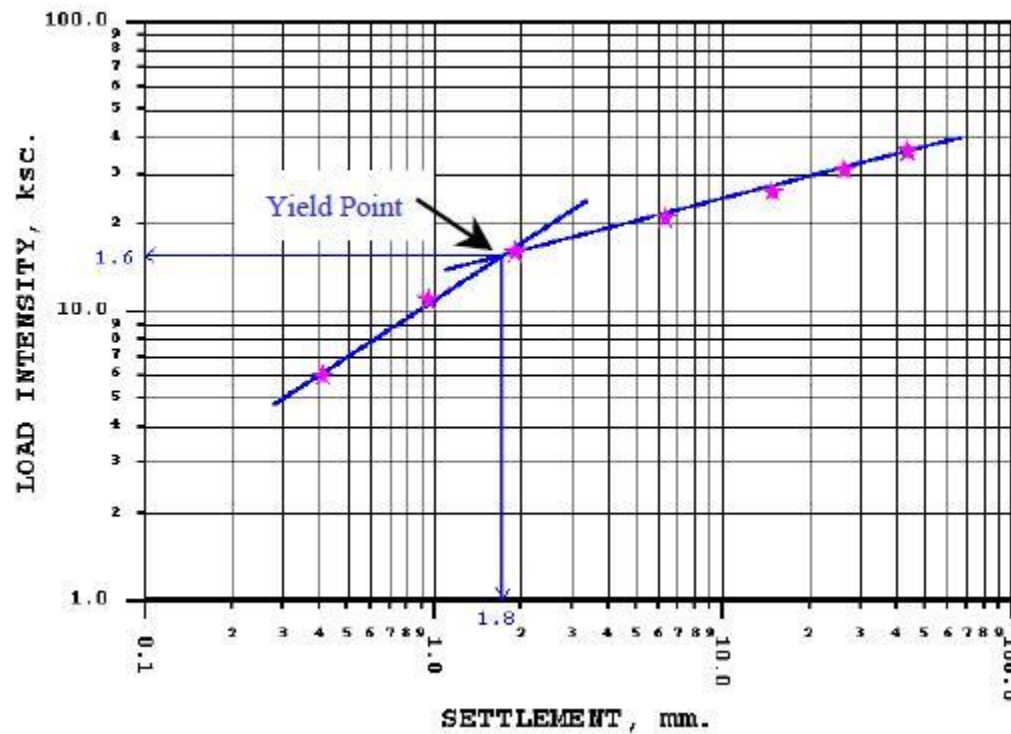
B_f - width of the pit

B_p - size of plate

The conducting the plate load test, the plate is placed in the central hole and the load is applied by means of a hydraulic jack. the reaction to the jack is provided by means of a reaction beam. Sometimes truss are used instead of a reaction beam to take up the reaction. Alternatively, a loaded platform can be used to provide reaction.

A seating load of KN/m^2 is first applied, which is released after the sometimes. The is then applied in increments of about 20% of the estimated safe load or $1/10^{\text{th}}$ of the ultimate load. The settlement is recorded after 1,5,10,20,40,60 minutes and further after an interval of one hour. These hourly observations are continued for clayey

soils, until the rate of settlement is less than 0.2mm per hour. The test is conducted until failure or at least until the settlement of 25mm has occurred



The ultimate load for the plate is indicated by a break on the log-log between the load intensity q and the settlements. If the break is not defined the ultimate load is taken as the corresponding to the settlement of $1/5^{\text{th}}$ of the plate width (B_p) on the natural plot. The ultimate load is obtained from the intersection of the tangents drawn.

Advantages:

1. The ultimate bearing capacity of the proposed foundation $q_u(f)$ can be obtained from the following relations

a) For clayey soils $q_u(f) = (q_u)_p$ ————— 1

b) For sandy soils $q_u(f) = (q_u)_p \times B_f / B_p$ ————— 2

where,

B_f —foundation width

2. The plate load test can also be used to determine the settlement for a given intensity of loading (q_0). The relations between the settlement of the plate (s_p) and that of the foundation (s_f) for the same load intensity

a) For clayey soils, $s_f = s_p(B_f/B_p)$ ————— 3

where s_p is obtained from the load intensity settlement curve for q_0

b) For sandy soils

$$s_f = s_p \left[\frac{B_f(B_p + 0.3)^2}{B_p(B_f + 0.3)} \right] \quad 4$$

Where B_f – width of foundation in meters

B_p – width of the plate in meters

3. For designing a shallow foundation for an allowable settlement of s_f , a trial and error procedure is adopted. First of all a value of B_f is assumed and value of q_0 is obtained as

$$q_0 = Q/A_f \text{ ————— } 5$$

where A_f - area of footing

Q – Load

For the computed value of q_0 the plate settlement (s_p) is determined from the load – settlement curve obtained from the plate load test the values of s_f is computed equation 3 if the soil is clay and using 4 if sand. The computed with the allowable settlement. The procedure is repeated till the computed value is equal to the allowable settlement

4. The plate load test can also be used for the determination of the influence factor, I

$$S = \frac{1-u^2}{E_s} \times I \times qB$$

The below graph shows a plot between settlements and the load qB , The slope of the line is equal to $\frac{(1-u^2)I}{E_s}$

LIMITATIONS OF PLATE LOAD TEST:

1. SIZE EFFECT:

The results of the plate load test reflect the strength and the settlement characteristics of the soil within the pressure bulbs. As the pressure bulb depends upon the size of the loaded area it is much deeper for the actual foundation as compared to that of plate. The plate load test does not truly represent the actual conditions to a large depth.

2. SCALE EFFECT:

The ultimate bearing capacity of saturated clays is independent of the size of the plate but for cohesionless soils. It increases with the size of the plate to reduce scale effect, it is desirable to repeat the plate load test with plates of two or three different sizes and the average of the bearing capacity values obtained.

3. TIME EFFECT:

A plate load test is essentially a test of short duration for clayey soils it does not give the ultimate settlement. The load settlement curve is not truly representative.

4. INTERPRETATION OF FAILURE:

The failure load is not well defined except in the case of a general shear failure an error of personal interpretation may be involved in other type of failures

5. REACTION LOAD:

It is not practicable to provide a reaction of more than 250 kN. Hence the test on a plate of size larger than 0.6 m width is difficult.

6. WATER TABLE:

The level of water table affects the bearing capacity of the sandy soils. If the water table is above the level of the footing it has to be lowered by pumping before placing at the water table level if it is within about 1 m below the footing.

5. A footing 2 m square rests on a soft clay soil with its base at depth of 1.5 m from ground surface. The clay stratum is 3.5 m thick and is underlain by a firm sand stratum. The void ratio of clay is 1.08 and compression index is 0.18, cohesion is 50 kN/m^2 . Compute the settlement that would result if the load intensity equal to the safe bearing pressure of soil were allowed to act on the footing. Natural water table is quite close to the ground surface. For given conditions, bearing capacity factor (N_c) is obtained as 6.9. Take factor of safety as 3. Assume load spread of 2 (vertical) to (horizontal).

Solution :

$$c=0.5 \text{ kg/cm}^2 = 5 \text{ t/m}^2$$

(a) determination of submerged unit weight γ'

$$\gamma' = \frac{G-1}{1+e} \gamma_w$$

$$\text{Where } e = \omega_{\text{sat}} \quad G = 0.4 \times 2.7 = 1.08 \quad \text{and } \gamma_w = 1 \text{ t/m}^3$$

$$\gamma' = \frac{2.7-1}{1+1.08} \times 1 = 0.817 \text{ t/m}^3$$

(b) Determination of footing load

$$q_{\text{nf}} = c N_C = 5 \times 6.9 = 34.5 \text{ t/m}^2$$

$$q_s = \frac{q_{\text{nf}}}{F} + \gamma' D = \frac{34.5}{3} + 0.817 \times 1.5$$

$$= 12.726 \text{ KN/m}^2$$

$$Q_s = q_s \times \text{area} = 12.726 \times 2 \times 2 = 50.9 \text{ t}$$

(c) Determination of settlement: consider level A A at mid depth of clay.

$$\sigma_o' = \gamma'(2.5) = 0.817 \times 2.5 = 2.043 \text{ t/m}^2$$

$$\text{Area of spread at level AA} = 3 \times 3 = 9 \text{ m}^2$$

$$\therefore \Delta \sigma' = \frac{Q_s}{A} = \frac{50.9}{9} = 5.656 \text{ t/m}^2$$

$$C_c = 0.009(\omega_L - 10) = 0.009(30 - 10) = 0.18$$

$$e_o = e = 1.08$$

$$\begin{aligned} \Delta H &= \frac{C_c H}{1+e_o} \log_{10} \frac{\sigma_o' + \Delta \sigma'}{\sigma_o'} \\ &= \frac{0.18 \times 2}{1+1.08} \log_{10} \frac{2.043 + 5.656}{2.043} = 0.1 \text{ m} = 10 \text{ cm} \end{aligned}$$

- 6. A square foundation of size $1.8 \text{ m} \times 1.8 \text{ m}$ is to be built at a depth of 1.6 m on a uniform clay strata having the following properties : $\phi = 0^\circ$, $c = 30 \text{ KN/m}^2$ and $\gamma = 18.2 \text{ KN/m}^3$**

m^3 . Find the safe load that the foundation can carry with a factor of safety of 3. Use Terzaghi's bearing capacity theory. If the ground water table subsequently rises from depth of 6m to the ground surface, find the load carrying capacity of the foundation. The submerged density of the soil is 10.5 KN/m^3 .

Given data:

Square foundation size= $18\text{m} \times 18\text{m}$

Depth of foundation = 1.6m

$\phi = 0$

$C=30 \text{ KN/m}^3$

$\gamma = 18.2 \text{ KN/m}^3$

Fos = 3

$\gamma_{\text{sub}}=10.5 \text{ KN/m}^3$

To find:

- i) case – i : water table at 6 m from G.L. safe load
- ii) case –ii: water table at the ground surface safe load

Solution:

Case (1) : water table at 6m from ground surface.

Safe load $q_s = \frac{1}{F} [1.3CN_c + \gamma D(Nq - 1)RW_1 + 0.4\gamma BN_r RW_2] + \gamma D$

$ZW_2 = 6 - 1.6 = 4.4\text{m}$

$RW_1 = 1$

Since $ZW_2 > B$, $RW_2 = 1$

For $\phi = 0$ [Terzaghi's Bearing capacity factor]

$N_c = 5.7$, $N_q = 1.0$, $N_r = 0$

$q_s = \frac{1}{3} [1.3 \times 3.0 \times 5.7 + 18.2 \times 1.6(1 - 1) + 0] + 18.2 \times 1.6$

$= (0.33 \times 222.3) + 29.12$

$$=(74.1)+29.12$$

$$=103.22\text{KN/m}^2$$

Case (2) if water table at the ground surface

$$q_s = \frac{1}{F} [1.3 C N_c + \gamma_{\text{sub}} D (N_q - 1) R W_1 + 0.4 \gamma B N_r R W_2] + \gamma D$$

$$R W_1 = R W_2 = 0.5$$

$$q_s = \frac{1}{3} [1.3 \times 30 \times 5.7 + (10.5 \times 1.6(1 - 1) \times 0.5) + 0] + 10.5 \times 6$$

$$=(0.33 \times 222.3) + 16.96$$

$$q_s = 90.319 \text{ KN/m}^2$$

7. The result of two plate load tests for a settlement of 25.4 mm are given

Plate diameter	load
0.3m	31 KN
0.6m	65KN

A square column foundation is to be designed to carry a load of 800KN with an allowable settlement of 25.4mm. Determine the size of the foundation using Housel's method.

Given data:

$$Q_1 = 31\text{KN}, \quad d_1 = 0.3\text{m}$$

$$Q_2 = 65\text{KN}, \quad d_2 = 0.6\text{m}$$

$$Q = 800\text{KN}, 25.4\text{mm}$$

To find:

Size of the foundation using Housel's method.

Solution:

$$Q_1 = A_1 m + P_1 n$$

$$Q_2 = A_2 m + P_2 n$$

$$Q = A_m + P_n$$

$$A_1 = \frac{\pi}{4} d_1^2 = \frac{\pi}{4} \times 0.3^2 = 70.685 \times 10^{-3} \text{ m}^2$$

$$A_2 = \frac{\pi}{4} d_2^2 = \frac{\pi}{4} \times 0.6^2 = 282.74 \times 10^{-3} \text{ m}^2$$

$$P_1 = \pi \times d_1 = \pi \times 0.3 = 0.942 \text{ m}$$

$$P_2 = \pi \times d_2 = \pi \times 0.6 = 1.884 \text{ m}$$

$$31 = 70.685 \times 10^{-3} \text{ m} + 0.942 \text{ n} \text{ ----- A}$$

$$65 = 282.74 \times 10^{-3} \text{ m} + 1.884 \text{ m} \text{ ----- B}$$

Solving equation A and B

$$M = 21.22, n = 31.31$$

$$Q = A_m + P_n$$

$$800 = B^2 \times 21.22 + (31.31 \times 4B)$$

$$B = 3.86 \text{ m} \quad \text{say } 4 \text{ m} \times 4 \text{ m}$$

Result: Size of the foundation : $4 \text{ m} \times 4 \text{ m}$

8. A square footing for a column is $2.5 \text{ m} \times 2.5 \text{ m}$ and carries a load of 2000 kN . Find the factor of safety against bearing capacity failure, if the soil has the following properties.

Given:

$$C = 50 \text{ kN/m}^2$$

$$\phi = 15^\circ$$

$$\gamma = 17.6 \text{ kN/m}^3$$

$$N_c' = 12.5,$$

$$N_q' = 4.5 \text{ and}$$

$$N_y' = 2.5. \text{ the foundation is taken to a depth of } 1.5 \text{ m.}$$

$$N_c' = 12.5$$

$$N_q' = 4.5$$

$$N_y' = 2.5$$

$$D = 1.5 \text{ m}$$

$$B = 2.5 \text{ m}$$

$$\phi = 15^\circ$$

$$\gamma = 17.6 \text{ kN/m}^3$$

$$C=0$$

$$q_f = \gamma D N_q' + 0.4 \gamma B N_y'$$

$$q_{nf} = \gamma D (N_q' - 1) + 0.4 \gamma B N_y'$$

$$q_s = \frac{q_{nf}}{F} + \gamma D \text{ and } F=3$$

$$\text{Maximum safe load} = B^2 \times q_s$$

9. Compute the ultimate load that an eccentrically loaded square footing of width 2m width, an eccentricity of 0.315m can take at a depth of 0.45m in soil with $\gamma = 17.75 \text{ kN/m}^3$, $C=9 \text{ kN/m}^2$ and $\phi = 35^\circ$, $N_c=52$, $N_q=35$ and $N_y=42$.

$$q_f = \gamma D N_q' + 0.4 \gamma B N_y'$$

$$q_{nf} = \gamma D (N_q' - 1) + 0.4 \gamma B N_y'$$

$$q_s = \frac{q_{nf}}{F} + \gamma D \text{ and } F=3$$

$$\text{Maximum safe load} = B^2 \times q_s$$

10. The following data was obtained from a plate load test carried out on a 60cm square test plate at a depth of 2m below ground surface on a sandy soil which extends up to a large depth. Determine the settlement of a foundation 3.0m x 3.0m carrying a load of 1100KN and located at a depth of 3m below ground surface.

Load intensity, KN/m²: 50 100 150 200 250 300 350 400

Settlement, mm : 2.0 4.0 7.5 11.0 16.3 23.5 34.0 45.0

Solution :

The load- settlement curve is shown in fig

$$\text{Load intensity on the foundation} = \frac{1100}{3 \times 3} = 122 \text{ kN/m}^2$$

From fig. Settlement of the test pate, S_p corresponding to a load intensity of is 122 kN/m² from equation.

$$\begin{aligned} S_f &= S_p [B_f (B_p + 30) / B_p (B_f + 30)]^2 \\ &= 5 [300(60+30) / 60(300+30)]^2 \end{aligned}$$

$$=9.3\text{mm}$$

The effect of embedment must now be taken into account. Depth of embedment D is equal to or foundation measured from the level at which the test plate is placed.

$$\text{Thus } D=3.0-2.0 = 1\text{m.}$$

$$\text{Using fox's depth factor : for } D/\sqrt{LB} = 1/\sqrt{(3 \times 3)} = 0.33 \text{ and } L/B = 1$$

$$\text{Depth correction factor} = 0.91$$

$$\text{Actual settlement of foundation} = 0.91 \times 9.3 = 8.5 \text{ mm}$$

- 11. A foundation, 2.0m square is installed 1.2 Above the water table and a submerged density of 10kN/m^3 . The strength parameters with respect to effective stress $c'=0$ and $\phi=30^\circ$. Find the gross ultimate bearing capacity for the following conditions.**

1. Water table is well below the base of the foundation.
2. Water table raise to the level of the base of the foundation and
3. The water table rise to ground level. (For $\phi = 30^\circ$, Assume $N_q = 22$ and $N_r = 20$).

Solution:

Square footing ($2\text{m} \times 2\text{m}$)

$$C = 0, \phi = 30^\circ$$

$$N_q = 22, N_r = 20$$

$$\gamma = 19\text{kN/m}^3$$

$$\gamma_{\text{sub}} = 10\text{kN/m}^3$$

i) Water table is well below the base of the foundation:

$$q_f = 1.3 c N_c + \gamma D N_q R_{w1} + 0.4 \gamma B N_r R_{w2}$$

$$R_{w1} = 1, Z_{w2} > B,$$

$$R_{w2} = 1$$

$$q_f = 0 + 19 \times 1.2 \times 22 \times 1 + 0.4 \times 19 \times 2 \times 20 \times 1$$

$$q_f = 805.6 \text{ kN/m}^2$$

Net ultimate bearing capacity (q_{nf})

$$Q_{nf} = q_f - \gamma D = 805.6 - 19 \times 1.2 = 782.8 \text{ kN/m}^2$$

ii) water table at base of the foundation:

$$R_{w1} = 0.5 \left(1 + \frac{2w_1}{D} \right)$$

$$0.5(1+1) = 1$$

$$R_{w2} = 0.5 \left(1 + \frac{2w_2}{D} \right)$$

$$0.5(1+0) = 0.5$$

$$q_f = 1.3 cN_c + \gamma D N_q R_{w1} + 0.4 \gamma B N_r R_{w2}$$

$$q_f = 0 + 19 \times 1.2 \times 22 \times 1 + 0.4 \times 10 \times 2 \times 20 \times 0.5$$

$$q_f = 501.6 + 80 = 581.6 \text{ kN/m}^2$$

$$q_{nf} = q_f - \gamma D = 581.6 - 19 \times 1.2 = 558.8 \text{ kN/m}^2$$

ii) water table rises the ground level

$$R_{w1} = 0.5$$

$$R_{w2} = 0.5$$

$$\gamma = \gamma_{\text{sub}}$$

$$q_f = 1.3 cN_c + \gamma_{\text{sub}} D N_q R_{w1} + 0.4 \gamma_{\text{sub}} B N_r R_{w2}$$

$$0 + 19 \times 1.2 \times 22 \times 0.5 + 0.4 \times 10 \times 2 \times 20 \times 0.5$$

$$q_f = 132 + 80 = 212 \text{ kN/m}^2$$

$$q_{nf} = q_f - \gamma_{\text{sub}} D = 212 - 10 \times 1.2 = 200 \text{ kN/m}^2$$

12. A footing 2.m square carries a gross pressure of 350 kN/m² at a depth of 1.2m in sand. A saturated unit weight of sand is 20 kN/m³ and the unit weight of sand above water table is 16 kN/m³. The shear strength parameters are C' = 0 , $\phi = 30^\circ$ (for $\phi = 30^\circ$, $N_q=22$, $N_r=20$). Determine the factor of safety with respect to shear failure for the following cases

i) W.T is 5m below the ground level

ii) W.T is 1.2m below the ground level

solution:

We will follow IS code method

For square footing in soil having $c=0$

$$q_f = \bar{\sigma} N_q + 0.4 \gamma_b N_r W'$$

case i): W.T at 5 m below G.L

$$\bar{\sigma} = 16 \times 1.2$$

$$= 19.2 \text{ kN/m}^2$$

$$D_w = 5 \text{ m}$$

$$D + B = 3 + 1.2 = 4.2 \text{ m}$$

Since $D_w > (D + B)$, $W' = 1$

$$\text{Also } \gamma = 16 \text{ kN/m}^2$$

$$q_f = \bar{\sigma} N_q + 0.4 \gamma_b N_r W'$$

$$= 19.2 \times 22 + 0.4 \times 16 \times 3 \times 20 \times 1$$

$$= 806.4 \text{ kN/m}^2$$

$$q_{nf} = q_f - \gamma D$$

$$= 806.4 - 16 \times 1.2$$

$$= 787.2 \text{ kN/m}^2$$

$$\text{Safe bearing capacity, } q_s = \frac{q_{nf}}{F} + \gamma D$$

$$= 787.2/F + 16 \times 1.2$$

$$350 = 787.2/F + 19.2$$

$$F = 2.38$$

Case ii): water table at 1.2m below the G.L

$$D_w = D \Rightarrow W' = 0.5$$

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

$$\sigma = 16 \times 1.2 = 19.2 \text{ kN/m}^2$$

$$q_f = \bar{\sigma} N_q + 0.4 \gamma_b N_r W'$$

$$= 19.2 \times 22 + 0.4 \times (20 - 9.81) \times 3 \times 20$$

$$q_f = 666.96 \text{ kN/m}^2$$

$$q_{nf} = q_f - \gamma D$$

$$= 666.96 - 16 \times 1.2$$

$$= 647.76 \text{ kN/m}^2$$

$$\text{Safe bearing capacity } q_s = \frac{q_{nf}}{F} + \gamma D$$

$$350 = 647.76/F + 19.2$$

$$F = 1.96$$

- 13. A circular footing is resting on a stiff saturated clay with unconfined compression strength of 250 kN/m². The depth of foundation is 2m. Determine the diameter of the footing if the column load is 700 KN.**

Assume a factor of safety as 2.5. the bulk unit weight of soil is 20KN /m³.

For stiff saturated clay, $\phi = 0$

$$N_c = 5.7, N_q = 1 \text{ and } N_r = 0$$

$$q_f = 250 \text{ kN/m}^2 \quad \because c = 250/2 = 125 \text{ kN/m}^2$$

$$q_f = 1.3 c N_r + \gamma D N_r + 0.4 \gamma B N_r$$

$$= 966 \text{ kN/m}^2$$

$$q_{nf} = q_f - \gamma D$$

$$= 966 - 20 \times 2 = 926 \text{ kN/m}^2$$

$$q_s = \frac{q_{nf}}{F} + \gamma D = 926/2.5 + 40$$

$$= 410.4 \text{ kN/m}^2$$

$$P = q_s \times A$$

$$= 700 - 410.4 \times \pi d^2/4$$

$$d = \sqrt{\frac{4 \times 700}{\pi \times 410.4}} = 1.47 \text{m}$$

what will be the change in ultimate , net ultimate and safe bearing capacity if the water table is at ground level ?

$$\begin{aligned} q_{nf} &= 1.3 c N_c + \gamma' D N_q \\ &= 1.3 \times 125 \times 5.7 + 10 \times 2 \times 1 \\ &= 946.25 \text{ KN/m}^2 \end{aligned}$$

$$\begin{aligned} q_n &= 946.25 - 20 \\ &= 926.25 \text{ KN/m}^2 \end{aligned}$$

$$q_s = 926.25 / 2.5 = 370.5 \text{ KN/m}^2$$