Chapter 11

Bearing Capacity

CHAPTER HIGHLIGHTS

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Introduction

The loads from superstructure are transferred to the ground through foundation. Therefore, the foundation is to be designed in such a way that the soil below does not fail in shear and, also should not undergo excessive settlements. The pressure which the soil can safely withstand without shear failure and excessive settlement is known as allowable bearing pressure or bearing capacity. Hence, the present chapter outlines the various methods for determination of allowable bearing pressure for different soil types, shapes of footing and water table effects.

Types of Foundation

1. **Shallow foundation:** A foundation is considered shallow if it's depth is less than or equal to the width of footing.

   That is, if $\frac{D}{B} \leq 1 \Rightarrow$ Shallow foundation

   $\frac{D}{B} > 1 \Rightarrow$ Deep foundation

   The above values are based on Terzaghi's criteria.

   Example: Stripfooting, isolated footing or spread footing, combined footing, strap footing, raft or mat foundation.

2. **Deep foundation:** A foundation is considered deep if depth is greater than width.

   Example: Pile foundation, pier foundation, well or caisson foundation.

Definitions

1. **Ultimate bearing capacity (q_u):** Minimum gross pressure at the base of footing at which soils fails in shear.

2. **Net ultimate bearing capacity:** The net increase in pressure at the base of footing at which soil fails in shear. It is equal to gross pressure minus overburden pressure.

$$q_{nu} = q_u - \gamma D_f$$

Where

q_u = Ultimate bearing capacity (gross)

γ = Unit weight of foundation soil

D_f = Depth of foundation

3. **Net safe bearing capacity (q_{ns}):** It is the net soil pressure which can be safely applied without any shear failure.

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

Where, F = Factor of safety, usually taken as 3.0.

4. **Gross safe bearing capacity (q_s):** Maximum gross pressure which can be applied safely without shear failure.

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

$$q_s = \frac{q_{nu}}{F} + \gamma D_f$$

5. **Net safe settlement pressure ($q_{n\rho}$):** It is the net pressure which the soil can carry without exceeding the allowable settlement. The maximum allowable settlement, generally, varies between 25–40 mm.

6. **Net allowable bearing pressure (q_{na}):** The maximum allowable bearing pressure at which the soil neither fails in shear nor undergoes excessive settlement.
   - It is smaller of safe bearing capacity (q_{ns}) and net safe settlement pressure ($q_{n\rho}$).

$$q_{na} = q_{ns} \text{ if } q_{n\rho} > q_{ns}$$
$$q_{na} = q_{n\rho} \text{ if } q_{ns} > q_{n\rho}$$

   - It is also known as allowable soil pressure or allowable bearing pressure or allowable bearing capacity.

Criteria for Determination of Bearing Capacity

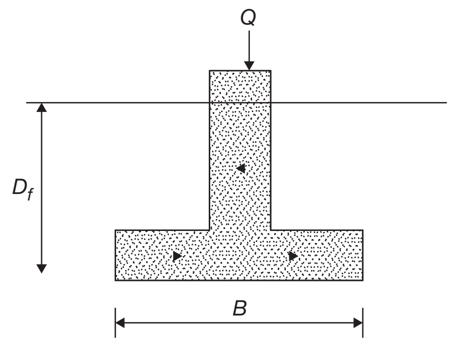
1. Shear failure of the foundation or bearing capacity failure shall not occur.
2. The probable settlements, differential as well as total, of the foundation must be limited to allowable magnitudes.

Factors Affecting Bearing Capacity

1. The nature of soil and its physical and engineering properties.
2. The nature of foundation and other factors, such as shapes, size, depth below the ground surface and rigidity of the structure.
3. Location of ground water table.
4. Initial stresses, if any.

Compensated Raft or Floating Raft

For footing not backfilled:



$$q_n = \frac{Q}{A} - \gamma D_f$$

$$q_n \approx q_{na}$$

$$q_{na} = \frac{Q}{A} - \gamma D_f$$

$$\frac{Q}{A} = q_{na} + \gamma D_f$$

In case of footing not backfilled, the load carrying of a foundation is increased and

$$\frac{Q}{A} = \gamma D_f$$

If the net footing pressure reduces to zero i.e., pressure applied is just balanced by pressure released. This is known as the principle of compensated raft foundation.

Methods of Determination of Bearing Capacity

Rankine's Analysis

- An approximate and conservative method for practical use, based on Rankine's earth pressure theory.
- Generally used to determine the minimum depth of foundation.

$$D_f = \frac{q}{\gamma}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

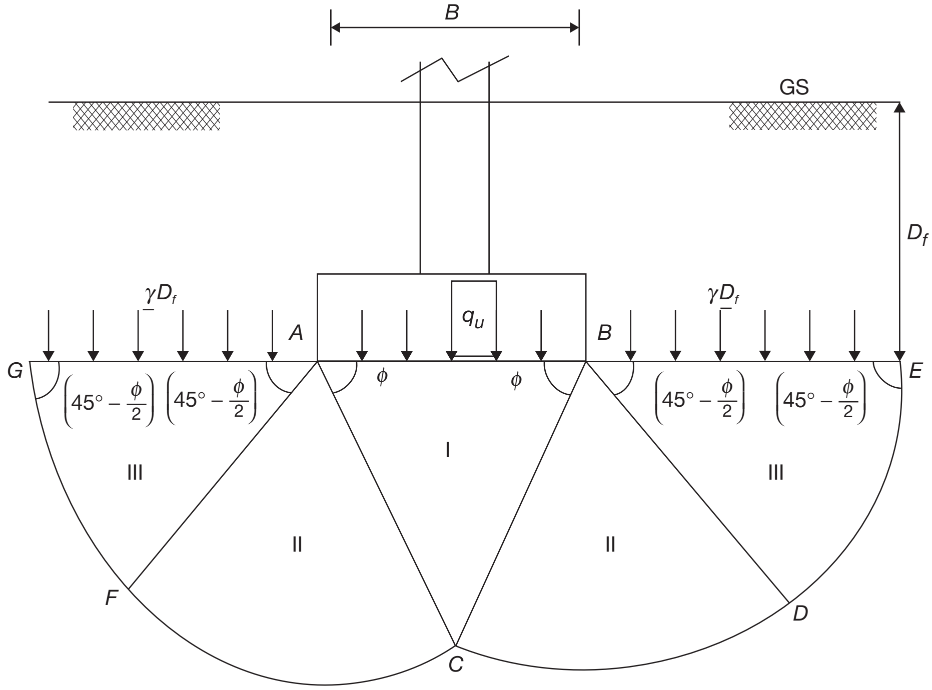
Where, q = Load intensity at base

Terzaghi's Bearing Capacity Theory

Assumptions:

1. Footing base is rough and is laid at a shallow depth (i.e., $D_f < B$).

2. The shear strength of soil above the base of footing is neglected. The soil above the base is replaced by a uniform surface, γD_f.
3. The load on the footing is vertical and uniformly distributed.
4. Footing is long, i.e., L/B ratio is infinite, where B is width and L is the length of the footing.
5. Shear strength of soil is governed by Mohr–Coulomb equation.



Terzaghi analysis zones

Zones: Zone I is elastic zone, zone II is radial shear zone and zone III is passive zone.

Terzaghis Bearing Capacity Equation

$$q_u = CN_c + \gamma D_f N_q + 0.5\,\gamma B N_\gamma$$
$$q_u = CN_c + q_0 N_q + 0.5\gamma B N_\gamma$$

Where, N_c, N_q, N_γ are bearing capacity factors which depends on the angle of shearing resistance (ϕ) and are the dimensionless numbers.

q_u = Ultimate bearing capacity of a strip footing
net ultimate bearing capacity, $q_{nu} = q_u - \gamma D_f$.

$$q_{nu} = CN_c + \gamma D_f (N_q - 1) + 0.5\gamma B N_\gamma$$

Safe bearing capacity

$$q_s = \frac{1}{F}(CN_c + \gamma D_f (N_q - 1) + 0.5\gamma B N_\gamma) + \gamma D_f$$

For pure cohesive soils ($\phi = 0°$)

$$N_c = 5.7,\ N_q = 1.0,\ N_\gamma = 0.0$$

For clays

$$q_u = 5.7c + \gamma D_f$$

$$q_{nu} = 5.7c$$

$$q_s = \frac{1}{F}[5.7c] + \gamma D_f$$

Bearing capacity of square and circular footing

1. **Square footing:**

$$q_u = 1.2CN_c + \gamma D_f N_q + 0.4\gamma B N_\gamma$$

Where, B is the dimension of each side of footing.

2. **Circular footing:**

$$q_u = 1.2\,CN_c + \gamma D_f N_q + 0.3\,\gamma B N_\gamma$$

Where, B is the diameter of footing.

3. **Rectangular footing:**

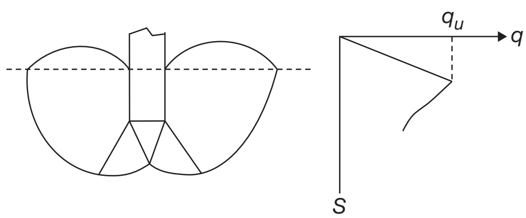
$$q_u = CN_c\,(1 + 0.2B/L) + \gamma D_f N_q + 0.5\,\gamma B N_\gamma (1 - 0.2\,B/L)$$

Where, L = Length of footing

TYPES OF SHEAR FAILURE

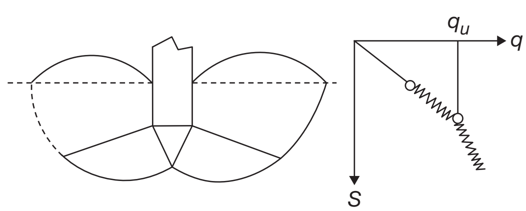
Vesic classified the bearing capacity failures into three categories. These are:

1. **General shear failure:**
   - It occurs in dense sand or stiff clay.
   - A heave on the sides is always observed in general shear failure.
   - The failure surfaces extend up to the ground leve.



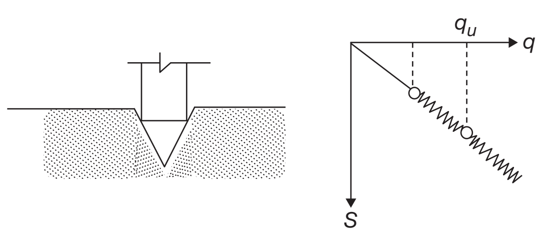
General shear failure

2. **Local shear failure:**
   - It occurs in medium-dense sand or on in clay of medium consistency.
   - Failure surface extend to the ground surface after considerable vertical movement.
   - A heave is observed only when there is a substantial vertical settlement.



Local shear failure

3. **Punching shear failure:**
   - It occurs in loose sand or soft clay.
   - No heave is observed and failure surface does not extend upto the ground level.
   - Only vertical movement of footing.



Punching shear failure

Criteria for General Shear Failure and Local Shear Failure

1. For a cohesionless soil, if ϕ is >36°, a general shear failure is likely to occur and, if ϕ < 29°, local shear failure occurs.
2. If failure strain is less than 5%, general shear failure will occur and local shear failure occurs at a failure strain of 10–20%.
3. It relative density is greater than 70%, general shear failure would occur and if it is less than 35% local shear occurs.
4. If $N > 30$, GSF occurs and if $N < 5$, LSF occurs.
5. If $e < 0.55$, GSF occurs. If $e > 0.75$, LSF occurs.

Ultimate Bearing Capacity in Case of Local Shear Failure

- Terzaghi has given the ultimate bearing capacity for strip footing considering general shear failure.
- In case of local shear failure, corrections are to be applied.

  ⇒ For local shear failure,

$$q_u = c_m N_c' + \gamma D_f N_q' + 0.5\gamma B N_y'$$

Where

c_m = Mobilized cohesion $= \frac{2}{3}c$

N_c', N_q', N_γ' are based on mobilized angle of shearing resistance (ϕ_m).

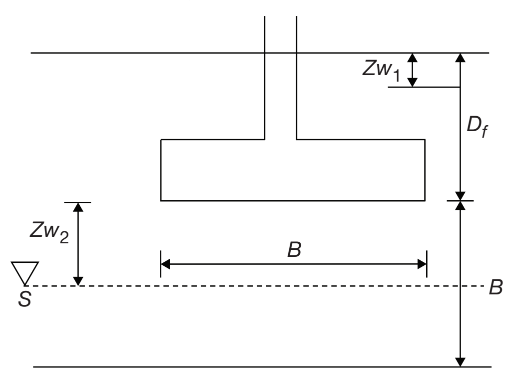
ϕ_m = Mobilized angle of internal friction

$\phi_m = \tan^{-1}(2/3 \tan\phi)$

C_m and ϕ_m are empirical reduction to the actual cohesion and angle of shearing resistance given by Terzaghi.

EFFECT OF WATER TABLE ON BEARING CAPACITY

- The bearing capacity equation is developed based on the assumption that water table is at a greater depth.
- The correction factors need to be applied if WT lies above and below the footing.



- Bearing capacity equation after the application of water table correction factor is:

$$q_u = CN_c + \gamma D_f N_q Rw_1 + 0.5\,\gamma B N_\gamma Rw_2$$

Where, R_{w_1} and R_{w_2} are correction factors for WT.

$$\boxed{R_{w_1} = 0.50\left[1+\frac{Z_{w_1}}{D_f}\right]}$$

$$\boxed{R_{w_2} = 0.50\left[1+\frac{Z_{w_2}}{B}\right]}$$

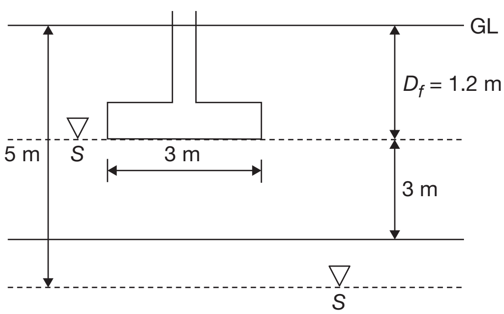
Range of R_{w_1} and R_{w_2} is from 0.50 to 1.0.

SOLVED EXAMPLES

Example 1

A footing of 3 m square carries a gross pressure of 350 kN/m^2 at a depth of 1.2 m in sand. The saturated unit weight of sand is 20 kN/m^3 and the unit weight above the water table is 17 kN/m^3. The shear strength parameters are $c = 0$ and $\phi = 30°$ [for $\phi = 30°$, $N_q = 22$ and $N_\gamma = 20$]. Determine the factor of safety with respect to shear failure for the following cases. **[GATE, 2000]**

(a) Water table is 5 m below the ground level.
(b) Water table is at 1.2 m below the ground level.



Solution

(a) WT is 5 m below ground level

Since WT is 5 m below the ground level, there is no effect of water table.

$\therefore q_u = 1.2CN_c + \gamma D_f N_q + 0.4\gamma B N_\gamma$, for square footing.

For sand, $C = 0$

$\therefore q_u = \gamma D_f N_q + 0.4\,\gamma B N_\gamma$

$= [17 \times 1.2 \times 22] + (0.4 \times 17 \times 3 \times 20)$

$q_u = 856.8$ kN/m^2

$q_{nu} = q_u - \gamma D_f$

$= 856.8 - (17 \times 1.2)$

$q_{nu} = 836.4$ kN/m^2

External net pressure

q_n = Gross pressure – Overburden pressure

$= 350 - \gamma D_f = 350—17(1.2)$

$q_n = 329.6$ kN/m^2

Factor of safety $= \dfrac{q_{nu}}{q_n} = \dfrac{836.4}{329.6}$

$= 2.54.$

(b) Water table is at 1.2 m below the ground level

In this case, water table is below the footing use γ' for 3rd term ($0.4\,\gamma B N_\gamma$) and γ for 2nd term ($\gamma D N_q$).

$\therefore q_{nu} = 1.2CN_c + \gamma D_f(N_q) + 0.4\,\gamma' B N_\gamma - \gamma D_f$

Where, $c = 0$ for sand and $\gamma = 17$ kN/m^3

$\gamma' = \gamma_{sat} - \gamma_w$

$= 20 - 10$

$\gamma' = 10$ kN/m^3

$\therefore q_{nu} = (17 \times 1.2 \times 22) + (0.4 \times 10 \times 3 \times 20) - 17 \times 1.2$

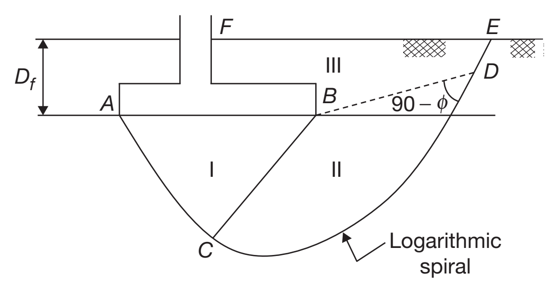
$q_{nu} = 668.4$ kN/m^2

Factor of safety $= \dfrac{q_{nu}}{q_n}$

$= \dfrac{668.4}{329.6} = 2.03.$

Meyerhaf's Bearing Capacity Theory

The important difference between Meyerhof's and Terzaghi's theory is that the Meyerhof's theory considers the shearing resistance of the soil above the base of the foundation, while the Terzaghi's theory neglects it and failure surface extends up to the ground level in case of Meyerhof's theory and up to foundation level in case of Terzaghi's theory.



Zones

Zone I: Elastic zone (ABC) – AC and BC make an angle varied between ϕ and $\left(45° + \dfrac{\phi}{2}\right)$.

Zone II: Radial shear zone (BCD) The curved rupture surfaces were assumed to be logarithmic spiral.

Zone III: Mixed shear zone ($BDEF$). In this zone, shear varies between plane shear and radial shear.

- Meyerhof's equation for the ultimate Bearing capacity of strip footing is given by:

$$q_u = CN_c + \gamma DN_q + 0.5\gamma BN_\gamma$$

Where, N_c, N_q, N_γ are Meyerhof's bearing capacity factors.

- N_c, N_q, N_r depends on roughness of base, depth of footing and the shape of footing in addition to the angle of shearing resistance (ϕ).

NOTE

The main advantage of the Meyerhof's theory is that it can also be used for deep foundations and for footings on slopes.

Skempton's Analysis for Cohesive Soils

- Skempton proposed the bearing capacity equation only for purely cohesive soils.
- Skempton's observations based on investigations founded that the factor N_c depends on the depth of foundation and also its shape.
- The net ultimate bearing capacity is given by

$$q_{nu} = CN_c$$

Wherein, N_c is given as follows:
For strip footing

$$N_c = 5\left(1 + 0.2\frac{D_f}{B}\right)$$

With a limiting value of N_c of 7.5 for $D_f/B > 2.5$

For square or circular footings

$$N_c = 6\left(1 + 0.2\frac{D_f}{B}\right)$$

(B is side of square or diameter of circular footing)
With a limiting value of N_c of 9.0 for $D_f/B > 2.5$.
For Rectangular footing,

$$N_c = 5\left[1 + 0.2\frac{B}{L}\right]\left[1 + 0.2\frac{D_f}{B}\right]$$

$$\text{for } \frac{D_f}{B} \le 2.5 \text{ and}$$

$$N_c = 7.5\left[1 + 0.2\frac{B}{L}\right] \text{ for } \frac{D_f}{B} > 2.5$$

Where
B = Width of rectangular footing
L = Length of rectangular footing

Settlement Analysis

1. **Loads for settlement analysis:**
   - Dead load and live load are considered only in the design if wind load is <25% of the combined dead and live load.
   - When wind (or seismic) load is >25% of the combined dead and live load, the foundation is designed such that the pressure due to combination of dead, live and wind (seismic) loads do not exceed the allowable bearing capacity by more than 25%.
   - In case of coarse-grained soils, the settlements should be estimated corresponding to dead load, live load and wind (seismic) load.
   - In case of fine-grained soils, settlements are estimated corresponding to permanent loads. Generally, dead load and one-half of live load is taken as permanent load.
2. **Immediate settlement in cohesive soils (Elastic settlement):** The linear theory of elasticity is used to determine the vertical elastic settlement of the footing on saturated clay.
   Immediate settlement

$$s_i = q \cdot B\left[\frac{1-\mu^2}{E_s}\right]$$

Where
q = Net intensity of contact pressure (kN/m^2)
B = Least lateral dimension of loaded area (m)
E_s = Undrained modulus of elasticity (kN/m^2)
I = Influence factor, depends on rigidity and shape of loaded area
$\mu = p$ Pison's ratio of the soil

The values of the influence factor 'I' for saturated clay is given in the following table.

Values of Influence Factor I

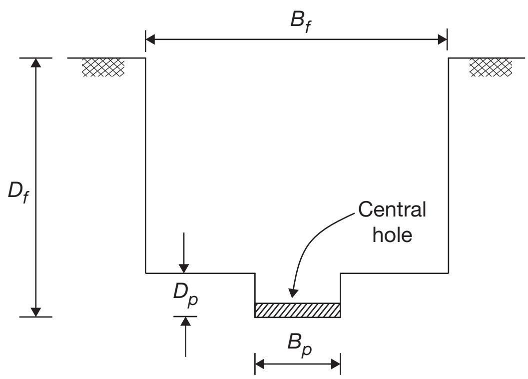
Shape	Flexible Footing			Rigid Footing
	Centre	Corner	Average	
Circle	1.0	0.64 (edge)	0.85	0.79
Rectangle L/B = 1.0	1.12	0.56	0.95	0.90
L/B = 1.5	1.36	0.68	1.20	1.09
L/B = 2.0	1.53	0.77	1.31	1.22
L/B = 5.0	2.10	1.05	1.83	1.70

NOTES

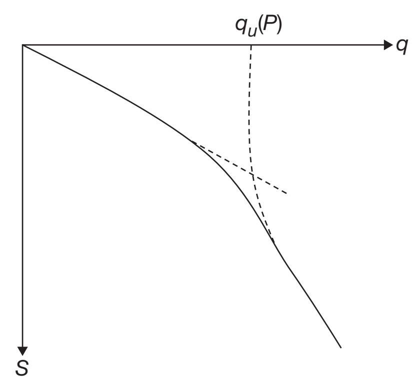
1. The aforementioned theory is valid for foundations located at ground surface.
2. Depth factor correction is to be applied for footings located at certain depth.

Plate Load Test

- In plate load test, a test pit of width of size equal to five times the width of plate and depth equal to the depth of the foundation (D_f) is to be excavated.
- Test plates are usually square or circular in shape.
- Size of plate varying from 300–750 mm is used and minimum thickness recommended is 25 mm.



- The maximum load that is to be applied corresponds to 1.50 times the probable ultimate load or 3 times the allowed bearing pressure.
- The ultimate load for the plate $q_u(p)$ is indicated by a break on the log-log plot between the load intensity (q) and the settlement.
- On the natural plot, the ultimate load is obtained from the intersection of tangents as shown.



- If the break is not well-defined, the ultimate load is taken as that corresponding to a settlement of one-fifth of plate width (B_p).
- The ultimate bearing capacity of the proposed foundation $q_u(f)$ can be obtained from the following relations.

  (a) For clayey soils:

$$q_u(f) = q_u(p)$$

  (b) For sandy soils:

$$q_u(f) = q_u(p) \times \frac{B_f}{B_P}$$

  Where, B_f = Foundation width

- The relations between the settlements of the plate (S_p) and that of foundation (S_f) for the same load intensity are given below.

  (a) For clayey soils:

$$S_f = S_p \times \frac{B_f}{B_p}$$

  (b) For sandy soils:

$$S_f = S_p \left[\frac{B_f(B_p + 0.3)}{B_p(B_f + 0.3)} \right]^2$$

  In the above equations, B_f is the width of the foundation in meters and B_p is the width of the plate also in meters.

Limitations of the Plate Load Test

1. **Size effect:** The results of a plate load test do not directly reflect the bearing capacity of the foundation since the size of test plate and foundation are different. The ultimate bearing capacity of saturated clays is independent of the size of the plate. For cohesionless soils, it increases with the size of plate.
2. **Time effect:** Plate load test is a short duration test and, hence does not give the ultimate settlement for clayey soils.
3. **Water table:** The level of water table affects the bearing capacity of sandy soils. If the water table is above the level of the footing, it should be lowered just below the footing level. Even if water table is located within 1 m below the footing test should be conducted at the level of W.T itself.

Example 2

A plate load test was conducted in sand on a 300 mm diameter plate. If the plate settlement was 5 mm at a pressure of 100 kPa, the settlement (in mm) of a 5 m × 8 m rectangular footing at the same pressure will be **[GATE, 2001]**

(A) 9.4 (B) 18.6
(C) 12.7 (D) 17.8

Solution

For cohesionless soils, such as sand:

$$\frac{S_f}{S_p} = \left[\frac{B_f(B_p + 0.3)}{B_p(B_f + 0.3)} \right]^2$$

Where B_f and B_p to be used in m.

Given,

$$S_p = 5 \text{ mm}$$

$$B_f = 5 \text{ m}, B_p = 0.3 \text{ m}$$

$$\therefore \frac{S_f}{5} = \left[\frac{5(0.3+0.3)}{0.3(5+0.3)} \right]^2 \quad S_f = 17.80 \text{ mm.}$$

Exercises

1. The width and depth of a footing are 2 m and 1.5 m respectively. The water table at the site is at a depth of 3 m below the ground level. The water table correction factor for the calculation of the bearing capacity of soil is

(A) 0.875 (B) 1.000
(C) 0.925 (D) 0.500

2. The following two statements are made with reference to the calculation of net bearing capacity of a footing in pure clay soil ($\phi = 0$) using Terzaghi's bearing capacity theory. Identity if they are true of false.

I. Increase in footing width will result in increase in bearing capacity.
II. Increase in depth of foundation will result in higher bearing capacity.

(A) Both statements are true.
(B) Both statements are false.
(C) I is true but II is false.
(D) I is false but II is true.

3. In a plate load test conducted on cohesion less soil, a 600 mm square test plate settles by 15 mm under a load intensity of 0.2 N/mm^2. All conditions remaining the same, settlement of a 1 m square footing will be

(A) less than 15 mm (B) greater than 25 mm
(C) 15.60 mm (D) 20.50 mm

4. Two circular footings of diameters D_1 and D_2 are resting on the surface of the same purely cohesive soil. The ratio of their gross ultimate bearing capacities is

(A) $\frac{D_1}{D_2}$ (B) 1.0
(C) $D_1^2\, D_2^2\, D$ (D) $\frac{D_2}{D_1}$

5. The ultimate bearing capacity of a sol is 300 kN/m^2. The depth of foundation is 1 m and unit weight of soil is 20 kN/m^3. Choosing a factor of safety of 2.5, the net safe bearing capacity is

(A) 100 kN/m^2 (B) 112 kN/m^2
(C) 80 kN/m^2 (D) 100.5 kN/m^2

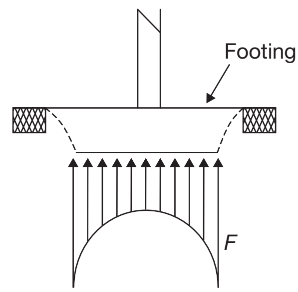
6. Two footings, one circular and the other square, are founded on the surface of a purely cohesionless soil. The diameter of the circular footing is same as that of the side of the square footing. The ratio of their ultimate bearing capacities is

(A) $\frac{3}{4}$ (B) $\frac{4}{3}$
(C) 1.0 (D) 1.3

7. A plate load test was conducted in sand on a diameter plate. If the plate settlement was 5 mm at a pressure of 100 kPa, the settlement (in mm) of a 5 m × 8 m rectangular footing at the same pressure will be

(A) 9.4 (B) 18.6
(C) 12.7 (D) 17.8

8. The figure given below represents the contact pressure distribution underneath a



(A) rigid footing on saturated clay.
(B) rigid footing on sand.
(C) flexible footing on saturated clay.
(D) flexible footing on sand.

9. Bearing capacity of a soil strata supporting a footing of size 3 m × 3 m will not be affected by the presence of ground water table located at a depth which is

(A) 1.0 m below the base of the footing.
(B) 1.5 m below the base of the footing.
(C) 2.5 m below the base of the footing.
(D) 3 m below the base of the footing.

10. Terzaghi's consolidation theory is applicable to

(A) for small load increment ratios.
(B) for large load increment ratios.
(C) for a load increment ratio of nearly one.
(D) in situations where there is no excess pore pressure.

11. As per Terzaghi's equation, the bearing capacity of strip footing resting on cohesive soil ($c = 10$ kN/m^2) for unit depth and unit width (assume N_c as 5.7) is

(A) 47 kN/m^2
(B) 57 kN/m^2
(C) 67 kN/m^2
(D) 77 kN/m^2

12. The minimum bearing capacity of a soil under a given footing occurs when the groundwater table at the location is at

(A) the bases of the footing.
(B) the ground level.
(C) a depth equal to one-half the width of footing.
(D) a depth equal to the width of footing.

13. A strip footing having 1.5 m width founded at a depth of 3 m below ground level in a clay soil having c = 20 kN/m^2. $\phi = 0°$ and unit weight $\gamma = 20$ kN/m^2. What is the net ultimate bearing capacity using Skempton's analysis?

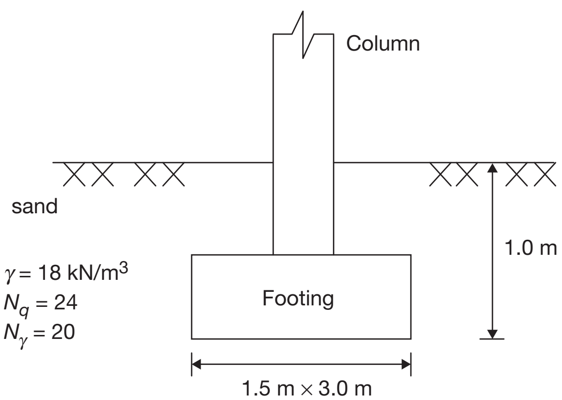
(A) 30 kN/m^2 (B) 60 kN/m^2
(C) 100 kN/m^2 (D) 140 kN/m^2

14. The bearing capacity factors N_c, N_q and N_γ are functions of
(A) width and depth of footing.
(B) density of soil.
(C) cohesion of soil.
(D) angle of internal friction of soil.

15. A strip footing (8 m wide) is designed for a total settlement of 40 mm. The safe bearing capacity (shear) was 150 kN/m^2 and safe allowable soil pressure was 100 kN/m^2. Due to importance of the structure, now the footing to be redesigned for total settlement of 25 mm. The new width of footing will be
(A) 5 m (B) 8 m
(C) 12 m (D) 12.8 m

Direction for question 16 and 17

A column is supported on a footing as shown in the given figure. The water table is at a depth of 10 m below the base of the footing

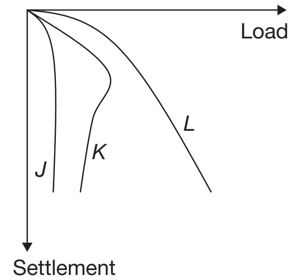


16. The net ultimate bearing capacity (kN/m^2) of the footing based on Terzahi's bearing capacity equations
(A) 216 (B) 432
(C) 630 (D) 846

17. The safe load (kN) that the footing can carry with a factor of safety 3 is
(A) 282 (B) 648
(C) 945 (D) 1269

18. An embankment is to be constructed with a granular soil (bulk unit weight = 20 kNm^3) on a saturated clayey slit deposit (underained 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
(A) 7.1 (B) 5.0
(C) 4.5 (D) 2.5

19. Group I contains representative load settlement curves for different modes of bearing capacity failures of sandy soil. Group II enlists the various failure characteristics. Match the load settlement curves with the corresponding failure characteristics.



	Group I		Group II
P.	Curve J	**1.**	No apparent heaving of soil around the footing
Q.	Curve K	**2.**	Rankine's passive zone develops imperfectly
R.	Curve L	**3.**	Well defined slip surface extends to ground surface

(A) P – 1; Q – 3; R – 2
(B) P – 3; Q – 2; R – 1
(C) P – 3; Q – 1; R – 2
(D) P – 1; Q – 2; R – 3

20. A footing of 3 m × 2 m exerts uniform pressure of 150 kN/m^2 on soil.

Assuming a load dispersion of 2 vertical to 1 horizontal, the average vertical stress (kN/m^2) at 1 m below the footing is
(A) 50 (B) 80
(C) 45 (D) 100

21. Which of the following is true for general shear failure?
(A) $I_D < 20\%$ (B) $e > 0.75$
(C) $N > 30$ (D) $N < 5$

22. The ultimate bearing capacity (q_f) and net ultimate bearing capacity (q_{nf}) are connected by relation
(A) $q_{nf} = q_f + \gamma D$
(B) $q_f = q_{nf} + \gamma D$
(C) $q_f = q_{nf}/F + \gamma D$
(D) $q_f = (q_{nf} + \gamma D)/F$

23. The allowable settlement for isolated foundations as per in sand and hard clay is
(A) 75 mm (B) 50 mm
(C) 100 mm (D) 80 mm

24. A plate load test is conducted on sand on a 500 mm diameter plate. If the plate settlement is 10 mm at a pressure of 200 kPa, the settlement of 0.5 m × 8 m footing will be
(A) 17 mm (B) 20.3 mm
(C) 23.7 mm (D) 18.6 mm

25. When the water table rises to ground level in case of cohesion less soil, the bearing capacity is reduced by _______. If it is cohesive soil, the reduction will be _______.
(A) 20%, 50% (B) 40%, negligible
(C) 50%, negligible (D) negligible, 50%

26. Which of the following is false according to terzaghi's theory?
(A) Zone I is elastic zone
(B) Zone II is radial shear zone
(C) Zone III is Rankine's passive zone
(D) Zone IV is surcharge zone

27. The vertical stress at some depth below the centre of 3 m × 4 m rectangular footing due to certain load intensity is 100 kN/m^2. What will be the vertical stress in kN/m^2 below the corner of 1.5 m × 2 m rectangular footing at the same depth and same load intensity?

28. An unsupported excavation is made to the maximum depth in a clay soil having $\gamma = 21$ kN/m^3, $C = 80$ kN/m^2 and $\phi = 30°$. What will be the active earth at pressure the base level of excavation, according to Rankine's theory?
(A) 184.8 kN/m^2 (B) 92.4 kN/m^2
(C) 1462.4 kN/m^2 (D) 277.18 kN/m^2

29. A square footing of size 5 m × 5 m is resting on the surface of a deposit of saturated clay having an unconfined compressive strength of 54 kPa. What will be the net safe bearing capacity of the footing (in kPa) if factor of safety is given as 2.5?

30. In a plate load test with size of plate 30 × 30 cm; bearing capacity and settlement were noted as 15 kPa and 6 mm respectively in a sandy soil. Then find the bearing capacity and settlement under a footing of size 2.1 m × 2.1 m under the same pressure intensity.
(A) 15 kPa and 42 mm (B) 15 kPa and 18.4 mm
(C) 105 kPa and 18.4 mm (D) 105 kPa and 42 mm

31. A circular raft foundation of 10 m diameter and 0.8 m thick is provided for a tank that applies a bearing pressure of 55 kPa on sandy soil with youngs modulus, E_s' = 30 MPa and Poissons ratio, $\mu = 0.3$. The raft is made of concrete (E_C = 30 GPa and $\mu = 0.15$). Considering the raft as rigid, the elastic settlement (in mm) is (Take $I = 0.8$)
(A) 12.96 mm (B) 16.71 mm
(C) 13.34 mm (D) 17.72 mm

32. What is the safe bearing capacity of a rectangular footing 2 m × 4 m, placed at a depth of 3 m in a saturated clay having unit weight 19 kN/m^3 and unconfined compressive strength of 120 kN/m^2. Assume a factor of safety of 2.5. Use Skempton's theory.
(A) 180 kPa (B) 330 kPa
(C) 230 kPa (D) 460 kPa

33. A settlement of 5 mm was noted under a pressure intensity in a plate load test with size of plate was 30 × 30 cm in a sandy soil. Then the settlement under a footing of size 1.50 × 1.50 m under the same pressure intensity (in mm) is ______.
(A) 13.9 (B) 12.5
(C) 11.6 (D) 10.7

34. A circular raft foundation of 20 m diameter and 1.8 m thick is provided for a tank that applies a bearing pressure of 110 kPa on sandy soil with Young's modulus, E_s = 30 MPa and Poisson's ratio, $\mu_s = 0.3$. The raft is made of concrete (E_c = 30 GPa and $\mu_c = 0.15$) considering the raft as rigid, the elastic settlement in mm is ______.
(A) 50.3 mm (B) 53.3 mm
(C) 56.3 mm (D) 59.3 mm

35. A test plate 30 cm × 30 cm resting on a sand deposit settles by 10 mm under a certain loading intensity. A footing of 150 cm × 200 cm resting on the same sand deposit and loaded to same load intensity settles by ______.
(A) 2 mm (B) 27.8 mm
(C) 3.02 mm (D) 50 mm

Previous Years' Questions

1. The bearing capacity of a rectangular footing of plan dimension 1.5 m × 3 m resting on the surface of a sand deposit was estimated as 600 kN/m^2 when the water table is far below the base of the footing. The bearing capacities in kN/m^2 when the water level rises to depths of 3 m, 1.5 m and 0.5 m below the base of the footing are **[GATE, 2007]**
(A) 600, 600, 400
(B) 600, 450, 350
(C) 600, 500, 250
(D) 600, 400, 250

2. A test plate 30 cm × 30 cm resting on a sand deposit settles by 10 mm under a certain loading intensity. A footing 150 cm × 200 cm resisting on the same sand deposit and loaded to the same load intensity settles by **[GATE, 2008]**
(A) 2.0 mm (B) 27.8 mm
(C) 3.02 mm (D) 50.0 mm

3. A plate load test is carried out on a 300 mm × 300 mm plate placed at 2 m below the ground level to determine the bearing capacity of a 2 m × 2 m footing placed at same depth of 2 m on a homogeneous sand deposit extending 10 m below ground level. The ground water table is 3 m below the ground level. Which of the following factors does not require a correction to the bearing capacity determined based on the load test? **[GATE, 2009]**

(A) Absence of the overburden pressure during the test.
(B) Size of the plate is much smaller than the footing size.
(C) Influence of the ground water table.
(D) Settlement is recorded only over a limited period of one or two days

Direction for questions 4 and 5:
The unconfined compressive strength of a saturated clay sample is 54 kPa. **[GATE, 2010]**

4. The value of cohesion for the clay is
(A) Zero (B) 13.5 kPa
(C) 27 kPa (D) 54 kPa

5. If a square footing of size 4 m × 4 m is resting on the surface of a deposit of the above clay, the ultimate bearing capacity of the footing (as per Terzaghi's equation) is
(A) 1600 kPa (B) 316 kPa
(C) 200 kPa (D) 100 kPa

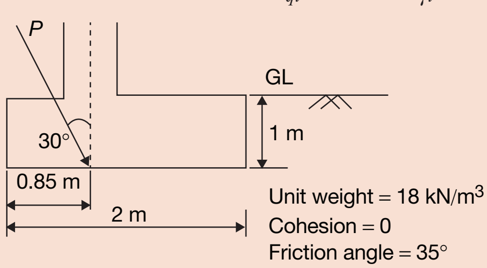
6. Likelihood of general shear failure for an isolated footing in sand decreases with **[GATE, 2011]**
(A) decreasing footing depth.
(B) decreasing inter granular packing of the sand.
(C) increasing footing width.
(D) decreasing soil grain compressibility.

7. Four columns of a building are to be located within a plot size of 10 m × 10 m. The expected load on each column is 4000 kN. Allowable bearing capacity of the soil deposit is 100 kN/m^2. The type of foundation best suited is **[GATE, 2013]**
(A) isolated footing.
(B) raft foundation.
(C) pile foundation.
(D) combined footing.

8. A square footing (2 m × 2 m) is subjected to an inclined point load, P as shown in the given figure. The water table is located well below the base of the footing. Consideration one-way eccentricity, the net safe load carrying capacity of the footing for a factor of safety of 3.0, is _______ kN. **[GATE, 2015]**

The following factors may be used:

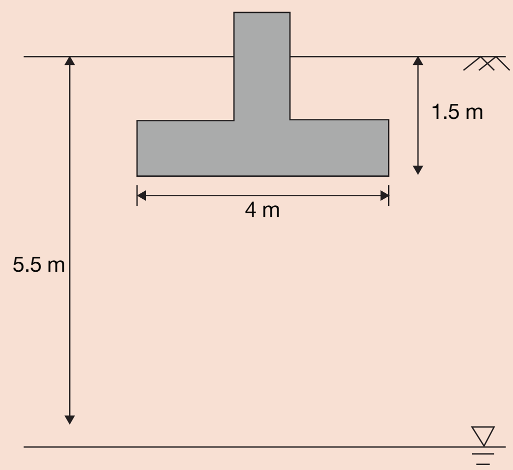
Bearing capacity factors, $N_q = 33.3$; $N_\gamma = 37.16$; Shape factors, $F_{qs} = F_{\gamma s} = 1.314$; Depth factors, $F_{qd} = F_{\gamma d} = 1.113$; Inclination factors, $F_{qi} = 0.444$, $F_{\gamma i} = 0.02$.



9. A strip footing is resting on the surface of a purely clayey soil deposit. If the width of the footing is doubled, the ultimate bearing capacity of the soil **[GATE, 2016]**
(A) becomes double. (B) become half.
(C) becomes four-times. (D) remains the same.

10. A 4 m wide strip footing is founded at a depth of 1.5 m below the ground surface in a c-ϕ soil as shown in the figure. The water table is at a depth of 5.5 m below ground surface. The soil properties are: $c' = 35$ kN/m^2, $\phi' = 28.63°$, $\gamma_{sat} = 19$ kN/m^3, $\gamma_{bulk} = 17$ kN/m^3 and $\gamma_w = 9.81$ kN/m^3. The values of bearing capacity factors for different ϕ' are given below. **[GATE, 2016]**

ϕ'	N_c	N_q	N_γ
15°	12.9	4.4	2.5
20°	17.7	7.4	5.0
25°	25.1	12.7	9.7
30°	37.2	22.5	19.7



Using Terzaghi's bearing capacity equation and a factor of safety $F_s = 2.5$, the net safe bearing capacity (expressed in kN/m^2) for local shear failure of the soil is ___________.

Answer Keys

Exercises

1. A	**2.** B	**3.** D	**4.** B	**5.** B	**6.** A	**7.** D	**8.** A	**9.** D	**10.** A
11. B	**12.** B	**13.** D	**14.** D	**15.** D	**16.** C	**17.** C	**18.** A	**19.** A	**20.** C
21. C	**22.** B	**23.** B	**24.** C	**25.** C	**26.** D	**27.** 25	**28.** B	**29.** 80	**30.** C
31. C	**32.** C	**33.** A	**34.** B	**35.** B					

Previous Years' Questions

1. A	**2.** B	**3.** C	**4.** C	**5.** C	**6.** B	**7.** C	**8.** 450	**9.** D
10. 298.50								