

Bearing Capacity:

Foundation:

→ A foundation is the part of structure which is in direct contact with & transmits loads to the ground.

Footing:

→ Footing is the part of the foundation of a structure which transmits loads directly to the soil.

Bearing capacity:

→ The supporting power of soil 'or' rock is called a bearing capacity.

Gross pressure intensity (GPI): — (q).

→ The G.P.I (q) is the total pressure at the base of the footing due to the weight of the super-structure, self weight of the footing & the weight of the earth fill.

Net pressure Intensity (NPI): — (q_n)

→ The difference in intensities of the gross pressure after the construction of the structure & original overburden pressure.

$$q_n = q - \bar{q}$$

$$\Rightarrow q_n = q - rD$$

Ultimate bearing capacity (UBC): — (q_f)

→ 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.

$$q_f = q_{nf} + \bar{q}$$

$$\Rightarrow q_f = q_{nf} + rD$$

Net ultimate bearing capacity: — (q_{nf})

→ It is the minimum net pressure intensity causing shear failure of soil.

$$q_{nf} = q_f - \bar{q}$$

\bar{q} = Effective surcharge at the base of the foundation.

Net safe bearing capacity (q_{ns}) :-

→ The net safe bearing capacity is the net ultimate bearing capacity divided by a factor of safety.

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

Safe bearing capacity :-

→ The minimum pressure which the soil can carry safely without risk of shear failure.
→ It is equal to the net safe bearing capacity plus original overburden pressure.

$$q_s = q_{ns} + \bar{\sigma}$$

$$= q_{ns} + \gamma D$$

Theories of failure 'or' types of bearing capacity failure :-

(1) General shear failure (G.S.F)

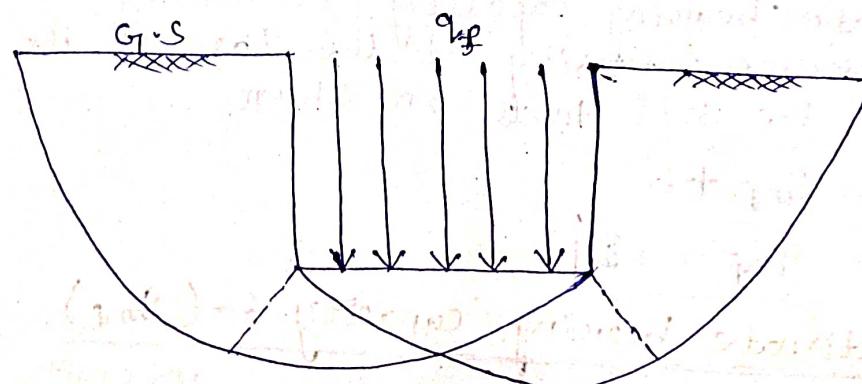
(2) Local shear failure (L.S.F)

(3) Parching shear failure (P.S.F)

(1) General shear failure :-

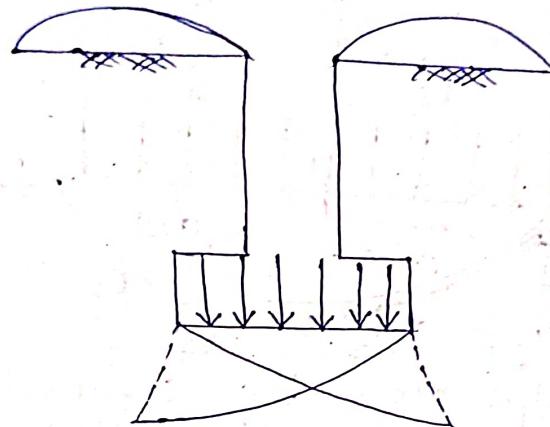
→ In this case of general shear failure, continuous failure surface develop between the edges of the footing & the ground surface.

→ When the pressure approaches the value of q_f , the state of plastic equilibrium is reached initially in the soil around the edges of the footing & it then gradually spread downward & outward.



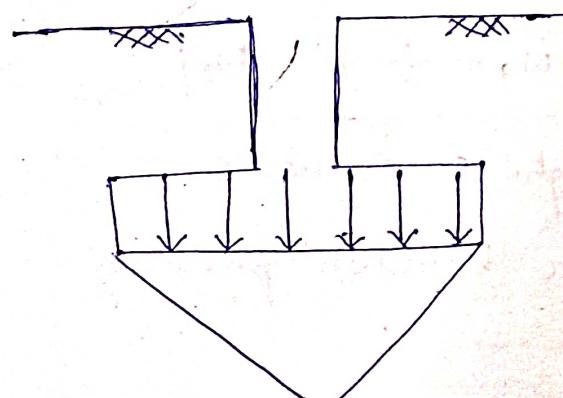
2) Local shear failure :-

- In local shear failure the compression of the soil under the footing & partial development of state of plastic-equilibrium. Due to this reason the failure surface don't reach the ground surface & only side having occurred.
- The characteristics of local shear failure are :-
 - (i) Failure pattern is clearly define only indirectly below the footing.
 - (ii) The failure surface is don't reach the ground surface.
 - (iii) There is only side bulging of soil around the footing.
 - (iv) Failure is defined by large settlement.
 - (v) Ultimate bearing capacity is not well define.



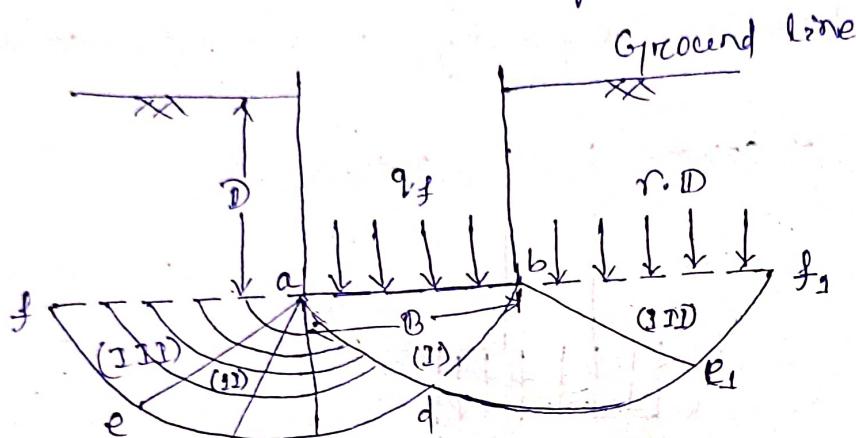
3) Punching shear failure :-

- Punching shear failure occurs where there is relatively high compression of soil under the footing. The following characteristics of punching shear failure are :-
 - (i) No failure pattern is observe.
 - (ii) The failure surface which is vertical or widely inclined.
 - (iii) There is no bulging of soil around the footing.
 - (iv) The ultimate bearing capacity is not define.
 - (v) Failure is characteristics in terms of very large settlement.



Terzaghi's Analysis:

- In Terzaghi's analysis the condition of complete bearing capacity failure usually termed as generally shear failure can be made by assuming that the soil behaves like an ideally plastic material.
- Terzaghi's derive a general bearing capacity equation from a modification of eqⁿ proposed by Picardot.
- A footing of width 'B', loading intensity ' q_f ' & the depth 'D' of the footing is equal to 'or' less than the width 'B' of the footing.



- The loaded soil fails along the composite surface $f_1 - f_2$, this region can be divided into 3 zone i.e. Zone-I, two pairs of Zone-II & two pairs of Zone-III.
- Zone-I remains in a state of elastic equilibrium.
- Zone-II is called as the zone of the radial shear.
- Zone-III is called as the zone of the linear shear.
- The boundary of zone -III rise at $(45 - \frac{\phi}{2})$ with the horizontal.

→ The upward forces are:-

- The resultant passive pressure P_p one each of the surface
- The vertical component of cohesion acting along the length.

$$q_{eff} = C N_c + \bar{\sigma} N_q + \frac{1}{2} D r N_r$$

This is the Terzaghi's equation..

Where,

$\bar{\sigma}$ = Effective over burden pressure

$$\bar{\sigma} = r \cdot D$$

For purely cohesive soil,

The bearing capacity is given by

$$q_f = C N_c + \bar{\sigma} N_q \\ = 5 \cdot 7 C + \bar{\sigma}$$

N_c , N_q , N_r are the bearing capacity factors.
In general & local shear failure,

$$q_f = \frac{2}{3} C N_c + \bar{\sigma} N_q + 0.5 B r N_r$$

Angle of shearing resistance:

For $\phi > 36^\circ \rightarrow$ General shear failure

$\phi < 28^\circ \rightarrow$ Local shear failure

Terzaghi Analysis Assumption:

- The soil is homogeneous & isotropic & its shear strength is represented by Coulomb's equation.
- The strip footing has a rock base.
- The elastic zone has straight boundaries inclined at $\psi = \phi$ to the horizontal & plastic zone fully developed.
- Failure zone don't extend above the horizontal plane through the base of the footing.

Specialization of Terzaghi's equation:

- Terzaghi's original equation is expressed as,

$$q_f = C N_c + \bar{\sigma} N_q + \frac{1}{2} B r N_r$$

(i) frictional cohesive soil ($C-\phi$ soil):

- For circular footing,

$$q_f = 1.3 C N_c + \bar{\sigma} N_q + 0.3 B r N_r$$

Where, B = Diameter of the footing

- For square footing,

$$q_f = 1.3 C N_c + \bar{\sigma} N_q + 0.4 B r N_r$$

B = width or length of the footing

- For rectangular footing,

$$q_f = C N_c \left(1 + 0.3 \frac{B}{L}\right) + \bar{\sigma} N_q + 0.4 B r N_r$$

(Or)

$$q_f = C N_c \left(1 + 0.3 \frac{B}{L}\right) + \bar{\sigma} N_q + 0.5 B \gamma N_r \left(1 - 0.2 \frac{B}{L}\right)$$

(2) Cohesive Soil ($\phi=0$ & $C>0$) :-

→ For circular footing,

$$q_f = 1.3 C N_c + \bar{\sigma} N_q$$

→ For rectangular & square footing,

$$q_f = C N_c \left(1 + 0.3 \frac{B}{L}\right) + \bar{\sigma} N_q$$

(3) Non-Cohesive Soil ($\phi>0, C=0$) :-

→ For strip footing,

$$q_f = \bar{\sigma} N_q + 0.5 B \gamma N_r$$

→ For rectangular & square footing;

$$q_f = \bar{\sigma} N_q + 0.4 B \gamma N_r$$

→ For circular footing,

$$q_f = 0.3 B \gamma N_r$$

E A square footing 2.5m by 2.5m is built in a homogeneous bed of sand of unit weight 20 KN/m³ & having an angle of shearing resistance of 36°. The depth of the base of footing 1.5 m below the ground surface. Calculate the safe load that can be carried by a footing with factor of safety of 3 against concrete shear failure. Use Terzaghi's analysis. Use $N_c = 65.4$, $N_q = 49.4$, $N_r = 54.0$.

Sol) Given data:-

Depth of footing = 1.5m

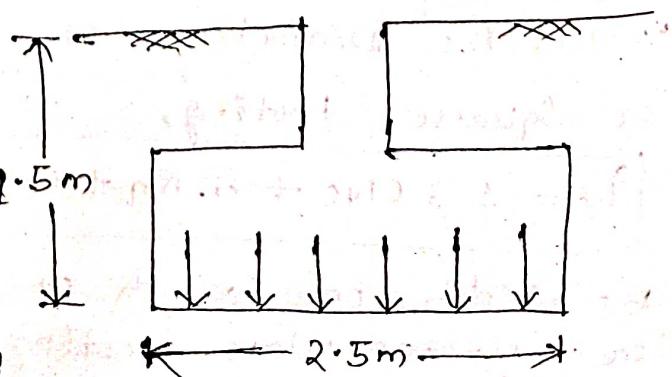
$$\gamma = 20 \text{ KN/m}^3$$

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

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

Angle of shearing resistance
(ϕ) = 36° → General shear
failure occurs

$$F.O.S = 3$$



$$N_c = 65.4$$

$$N_q = 49.4$$

$$N_r = 54.0$$

$$\text{Safe load} = ?$$

By using general shear failure,

$$q_{nf} = r \cdot D (N_q - 1) + 0.4 B r N_r$$

$$q_{nf} = 20 \times 2.5 (49.4 - 1) + 0.4 \times 2.5 \times 20 \times 54.0$$
$$= 2532 \text{ KN/m}^2$$

$$(i) \text{ Safe load, } q_s = \frac{q_{nf}}{F}$$
$$= \frac{2532}{3} + 20 \times 1.5 = 874 \text{ KN/m}^2$$

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

$$= (2.5)^2 \times 874 = 5462.5 \text{ KN}$$

(ii) what will be the max^m safe load if the soil is loose sand of unit weight 16 KN/m³ & the angle of shearing resistance = 25°.

$\phi = 25^\circ \rightarrow$ Local shear failure occurs

$$r = 16 \text{ KN/m}^3$$

Loose sand i.e., $c = 0$, $N_q = 5.6$, $N_r = 3.2$

$$q_{nf} = r \cdot D (N_q - 1) + 0.4 B r N_r$$
$$= 16 \times 1.5 (5.6 - 1) + 0.4 \times 2.5 \times 16 \times 3.2$$
$$= 161.6 \text{ KN/m}^2$$

$$\text{Safe load, } q_s = \frac{q_{nf}}{F}$$
$$= \frac{161.6}{3} + 16 \times 1.5$$
$$= 77.87 \text{ KN/m}^2$$

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

$$= (2.5)^2 \times 77.87$$

$$= 486.68 \text{ KN}$$

Ans

Q A strip footing 1m wide at its base is located at depth of footing 0.8 m below the ground surface. The properties of the foundation soil are $f = 30 \text{ KN/m}^2$, $C = 30 \text{ KN/m}^2$, $\phi = 30^\circ$. Determine the safe bearing capacity of the soil using a factor of safety of 3. Use Terzaghi's analysis. Assume that the soil fails by local shear. $N_c = 33.8$, $N_q = 3.9$, $N_r = 1.7$.

Given data:

$D_f = 0.8 \text{ m}$ below the ground surface

$D = 3 \text{ m}$

$C = 30 \text{ KN/m}^2$

$f = 30 \text{ KN/m}^2$

$\phi = 30^\circ$

$F.O.S = 3$

$N_c = 33.8$

$N_q = 3.9$

$N_r = 1.7$

Dry using Terzaghi's Analysis

Ultimate bearing capacity,

$$q_u = \frac{2}{3} C N_c + \frac{1}{6} N_q + \frac{1}{2} B R N_r \\ = \frac{2}{3} \times 30 \times 33.8 + (18 \times 0.8) \times 3.9 + \frac{1}{2} \times 1 \times 18 \times 1.7 \\ = 307.46 \text{ KN/m}^2$$

Net ultimate bearing capacity,

$$q_{nf} = q_u - r \cdot D \\ = 307.46 - 18 \times 0.8 = 293.06 \text{ KN/m}^2$$

Safe bearing capacity,

$$q_s = \frac{q_{nf}}{F} + r \cdot D \\ = \frac{293.06}{3} + (18 \times 0.8) = 112.1 \text{ KN/m}^2 \quad \underline{\text{Ans}}$$

Birinch Hansen's Analysis:

According to Hansen the ultimate bearing capacity is,

$$q_u = C N_c S_c d_c i_c g_c \cdot b_c + \frac{1}{6} N_q \cdot S_q \cdot i_q \cdot g_q \cdot b_q + \frac{1}{2} B R \cdot N_r \cdot S_r \cdot d_r \cdot i_r \cdot g_r \cdot b_r$$

Where,

$\bar{\sigma}$ = Effective overburden pressure

$$\boxed{\bar{\sigma} = r \times D}$$

s = Shape factor

d = Depth factor

i = Inclination factor

q = Ground factor

b = Base factor

c = Cohesion

D = Depth of the foundation

r = Unit weight of soil

B = Width of foundation

$N_c, N_q, N_r \rightarrow$ Bearing capacity factor

Skempton's Equation for N_c :

Based on this theory Skempton observed that the factor N_c increases with the ratio $\frac{D}{B}$.

For purely cohesive soil $i=0, \phi=0$, then $N_c=q$ for square & circular footing.

$N_c = 7.5$ for strip footing.

When $D=0$, $N_c = 5.14$ for strip footing.

$N_c = 6.20$, square or circular footing.

Vesic bearing capacity equation:

Vesic bearing capacity equation is similar as Hansen's equation.

- The essential difference in Vesic & Hansen's are,
- (1) Use of slightly different value of N_r .
 - (2) A variation of some of Hansen inclination factor, base factor & ground factor.

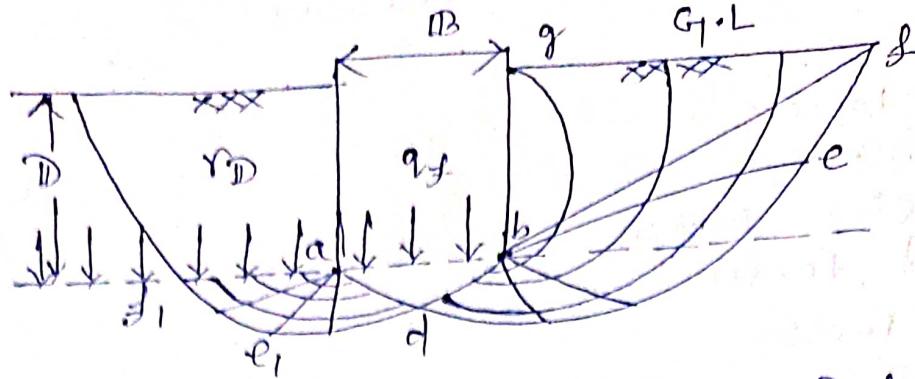
Vesic bearing capacity equation:

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

$$N_q = \tan^2(45^\circ + \phi/2) e^{\pi \tan \phi}$$

$$N_r = 2(N_q + 1) \cot \phi$$

Meyorchof's Analysis:



- Meyorchof extended the analysis of plastic equilibrium of a surface footing to shallow & deep foundation.
- In the Meyorchof analysis abd is the elastic zone, bde is the radial shear zone, bfg is the zone of mixed shear in which shear varies bet'n radial & mixed shear. Depending upon the depth & roughness of the foundation.
- The plastic equilibrium in this zone can be established from the boundary condition starting from the foundation shaft.
- Meyorchof gave the following equations for ultimate bearing capacity taking into shape factor, depth factor & inclination factor.

Q Design a strip footing to carry a load of 750 kN/m at a depth of 1.6 m in a $C-\phi$ soil having a unit weight of 18 KN/m^3 & shear strength parameter unit of cohesion $C = 20 \text{ KN/m}^2$ & $\phi = 25^\circ$. Determine the width of the footing & $FOS = 3$ against shear failure. Use Terzaghi's Analysis.
where, $N_C = 25.1$ & $N_q = 12.7$ & $N_r = 9.7$

Sol: Given data:-

Strip footing

$$\text{Load} = 750 \text{ KN/m}$$

$$\text{Depth} = 1.6 \text{ m}$$

$C-\phi$ soil

$$\text{Unit weight } (\gamma) = 18 \text{ KN/m}^3$$

$$C = 20 \text{ KN/m}^2$$

$$\phi = 25^\circ$$

$$\text{Width} = ?$$

$$F.O.S = 3$$

$$N_c = 25.1$$

$$N_q = 12.7$$

$$N_r = 9.7$$

Here general shear failure occurs.

Using Terzaghi's eqn

Ultimate bearing capacity

$$q_f = C N_c + Q N_q + \frac{1}{2} B \cdot r N_r$$

$$\Rightarrow q_f = (20 \times 25.1) + (18 \times 1.6 \times 12.7) + \frac{1}{2} \times B \times 18 \times 9.7$$

$$\Rightarrow q_f = 867.8 + 87.3B \quad \text{(2)}$$

Net intensity of pressure, at F.O.S = 3 at the base of footing

$$\frac{q_f}{F.O.S} = \frac{867.8 + 87.3B}{3} \quad \text{(22)}$$

$$\text{Applied load intensity} = \frac{\text{Load}}{A} = \frac{750}{A} = \frac{750}{B \times D}$$

According $D = 1$ unit

$$= \frac{750}{B} \quad \text{(22)}$$

Equating eqn (22) & (22)

$$\frac{867.8 + 87.3B}{3} = \frac{750}{B}$$

$$\Rightarrow 867.8 - 87.3B + 87.3B^2 = 2250$$

$$\Rightarrow 867.8B + 87.3B^2 - 2250 = 0$$

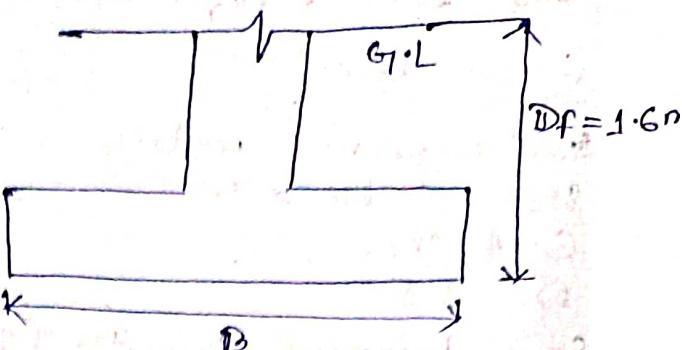
$$\Rightarrow B = 2.134$$

Ans

Q A rectangular footing $2m \times 3m$ rest on a C-φ soil with it's base at $1.5m$ below the ground surface. Calculate the safe bearing capacity using F.O.S of 3.

(i) Net ultimate bearing capacity

(ii) Ultimate bearing capacity



The soil is parameeter (C, ϕ, r)

$C = 10 \text{ KN/m}^2, \phi = 20^\circ, r = 18 \text{ KN/m}^3, N_c = 37.2, N_q = 22.5, N_r = 19.7$

Given data:

Rectangular footing

Size : $2 \text{ m} \times 3 \text{ m}$

$C-\phi$ soil

$D = 1.5 \text{ m}$

Safe bearing capacity (q_s)=?

F.O.S = 3

$C = 10 \text{ KN/m}^2$

$\phi = 20^\circ$

$r = 18 \text{ KN/m}^3$

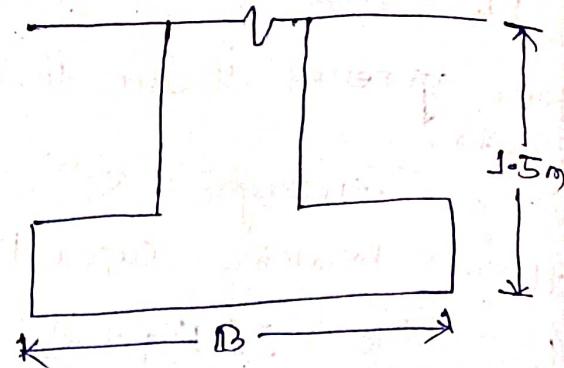
$N_c = 37.2$

$N_q = 22.5$

$N_r = 19.7$

$B = 2 \text{ m}$

$L = 3 \text{ m}$



Using Terzaghi's eqn

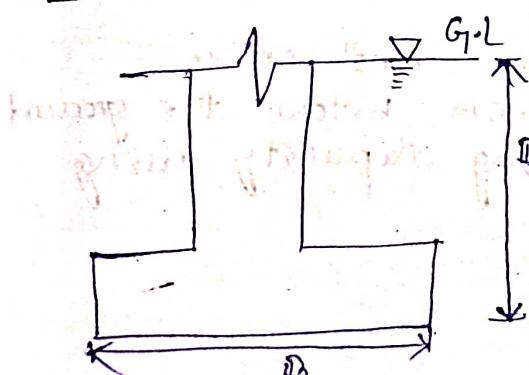
Ultimate bearing capacity,

$$q_f = C N_c \left(1 + 0.3 \frac{B}{L} \right) + N_q + 0.4 B \cdot r \cdot N_r$$
$$= 10 \times 37.2 \left(1 + 0.3 \times \frac{2}{3} \right) + (18 \times 1.5 \times 22.5) + 0.4 \times 2 \times 18 \times 19.7$$
$$= 1337.58 \text{ KN/m}^2$$

$$q_{nf} = q_f - rD = 1337.58 \times 18 \times 1.5$$
$$= 1310.58 \text{ KN/m}^2$$

$$q_s = \frac{q_{nf}}{F} + rD$$
$$= \frac{1310.58}{3} + 18 \times 1.5 = 463.86 \text{ KN/m}^2$$

Effect of Water table on bearing Capacity Ans



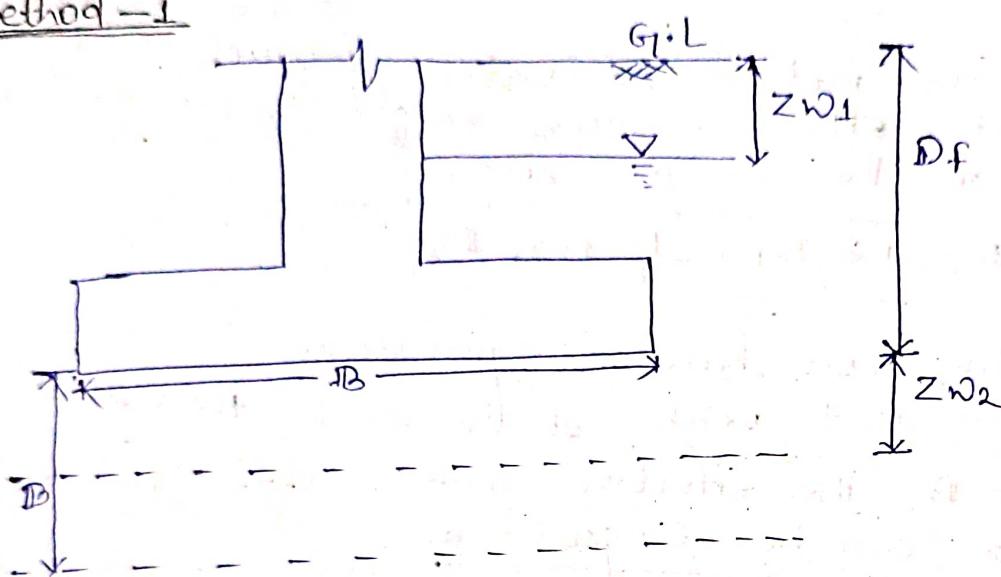
where,

B = Width of footing

Df = Depth of footing

- When the water table is above the base of the footing, the submerged weight γ' should be used for the soil below the water table for computing the effective pressure or the surcharge.
- When the water table is located some part below the base of the footing. The elastic wedge is partly of moist soil & partly of submerged soil & suitable reduction factor should be used with the wedge term, i.e. $\frac{1}{2} Br Nr$.

Method - I



For any position of water table the ultimate bearing capacity,

$$q_u = C N_c + \gamma D N_q R_{w1} + \frac{1}{2} Br Nr R_{w2}$$

where,

R_{w1} & R_{w2} are the reduction factors.

$$R_{w1} = 0.5 \left(1 + \frac{Zw_1}{D} \right)$$

At $Zw_1 = 0$, $R_{w1} = \frac{1}{2}$

$Zw_1 = D$, $R_{w1} = 1$

$$R_{w2} = 0.5 \left(1 + \frac{Zw_2}{B} \right)$$

At $Zw_2 = 0$, $R_{w2} = \frac{1}{2}$

$Zw_2 = B$, $R_{w2} = 1$

γ_1 = Average unit weight of the surcharge soil above the water table.

γ_2 = Average unit weight of the soil in the wedge zone situated within a depth B below the base of the footing.

Method - 2

It is called 2nd method.

The ultimate bearing capacity can be find out by using one reduction factor.

$$q_f = C N_c + \bar{\sigma} N_q + \frac{1}{2} B r N_r R_w$$

$$R_w = -R_w 2 = 0.5 \left(1 + \frac{z_w 2}{B} \right)$$

Method - 3

In the third method no water reduction factor is used, but effective unit weight (γ_e) is used for the soil in the wedge zone.

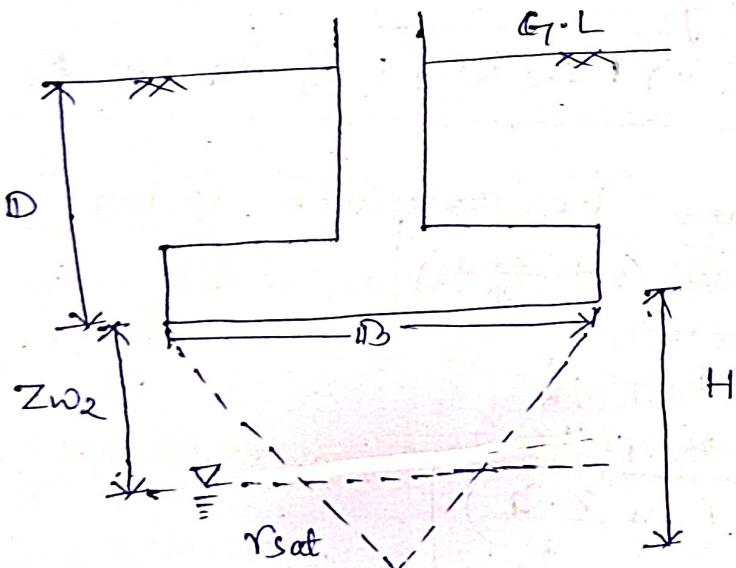
$$q_f = C N_c + \bar{\sigma} N_q + \frac{1}{2} B \gamma_e N_r$$

$\bar{\sigma}$ = Effective over burden pressure

γ_e = Effective unit weight of the soil in the wedge zone.

Taking $H = B$, the effective unit weight ' γ_e ' in the wedge term can be computed as

$$\gamma_e = \frac{\gamma z_w 2 + \gamma' (B - z_w 2)}{B}$$



Method - 3

- A strip footing 2m wide carries a load intensity of 400 KN/m² at a depth of 1.2 m in sand the saturated unit weight of sand is 19.5 KN/m³ & unit weight above water table is 16.8 KN/m³ the shear strength parameters are $C = 0$, $\phi = 35^\circ$, $N_q = 41.4$, $N_r = 42.4$

Determine the factor of safety with respect to shear failure for the following cases of location of water table.

- Water table is 4m below the ground level.
- Water table is 1.2m below the ground level.
- Water table is 1.3m below the ground level.
- Water table is 0.5m below the ground level.
- Water table is at ground level & self use Terzaghi's Analysis.

Given data :-

$$B = 2\text{ m}$$

$$D = 1.2\text{ m}$$

$$\gamma_{\text{sat}} = 19.5 \text{ KN/m}^3$$

$$\gamma = 16.8 \text{ KN/m}^3$$

$$\phi = 35^\circ$$

$$c = 0$$

$$\text{Load} = 400 \text{ KN/m}^2$$

$$N_q = 45.4$$

$$N_r = 42.4$$

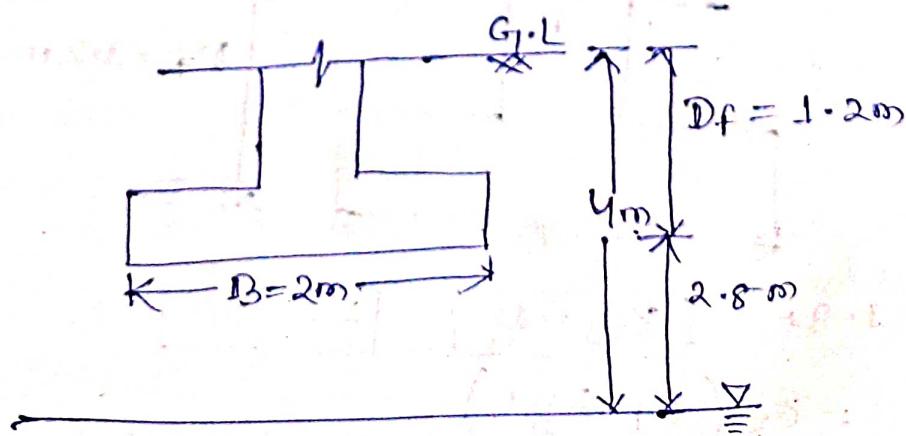
For steep footing the bearing capacity is,

$$q_f = C N_c + \sigma r N_r + \frac{1}{2} B r N_s$$

Using this water table position the water reduction factor taking into account the ultimate bearing capacity

$$q_f = \bar{\sigma} N_q R_w_1 + \frac{1}{2} \times B r N_r R_w_2$$

(e) Water table is 4m below the ground table :-



$$z_{w2} = 2.8 \text{ m}$$

$$4-1.2 = 2.8 \text{ m}$$

Use reduction factor below base of footing

$$D > B \text{ (i.e. } z_{w2} > B)$$

$$R_{w2} = 1$$

Another reduction factor

$$R_{w3} = 0.5 \left(1 + \frac{z_{w1}}{D} \right)$$

$$\begin{array}{|c|} \hline z_{w1} = D \\ \hline \end{array}$$

$$\begin{array}{|c|} \hline R_{w3} = 1 \\ \hline \end{array}$$

Hence there will be no effect of water table

$$\text{i.e. } r = 16.8 \text{ KN/m}^2$$

Ultimate bearing capacity.

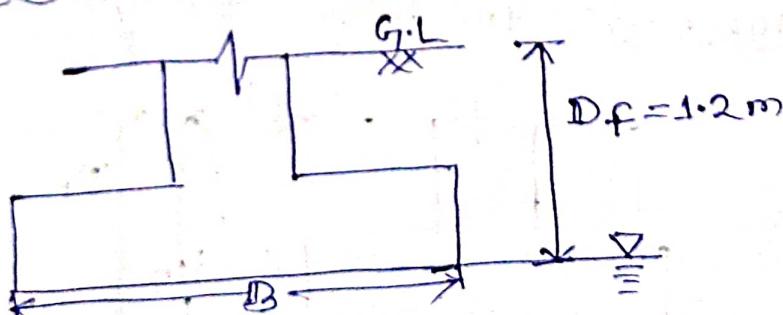
$$\begin{aligned} q_u &= \bar{r} N_q R_{w1} + \frac{1}{2} B r N_r R_{w2} \\ &= r D \cdot N_q \cdot R_{w1} + \frac{1}{2} B r N_r \cdot R_{w2} \\ &= 16.8 \times 1.2 \times 41.4 \times 1 + \frac{1}{2} \times 2 \times 16.8 \times 42.4 \times 1 \end{aligned}$$

$$= 1546.9 \text{ KN/m}^2$$

Factor of safety = Ultimate bearing capacity
Load intensity

$$= \frac{1546.9}{400} = 3.86$$

(b) Water table is 1.2 m below ground level



$$z_{w1} = 1.2 \text{ m}$$

$$z_{w1} = D$$

$$z_{w2} = 0$$

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

$$= 0.5 \left(1 + \frac{1.2}{D} \right)$$

$$= 0.5 \times \left(1 + \frac{1.2}{1.2}\right) = 1$$

$$R_{w2} = 0.5 \left(1 + \frac{zw_2}{B}\right)$$

$$= 0.5$$

For the surcharged term used

$$r = 16.8 \text{ KN/m}^3$$

wedge term

$$r = r_{sat} = 19.5 \text{ KN/m}^3$$

Ultimate bearing capacity

$$q_f = r D \times N_q R_{w1} + \frac{1}{2} \times B r \cdot N_r \cdot R_{w2}$$

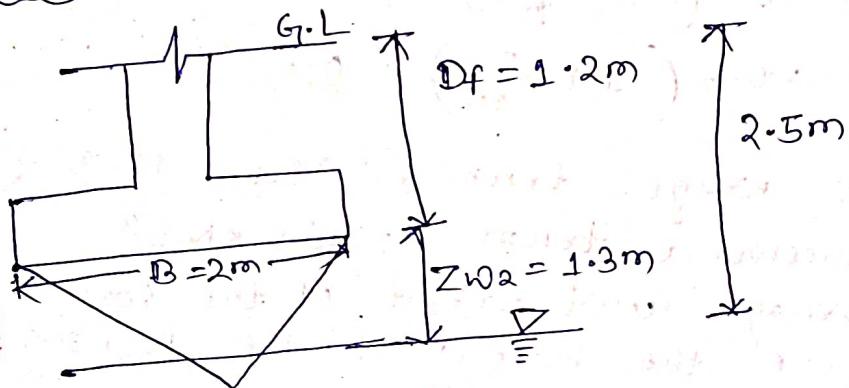
$$= 16.8 \times 1.2 \times 41.4 \times 1 + \frac{1}{2} \times 2 \times 19.5 \times 42.4 \times 0.5$$

$$= 1248.02 \text{ KN/m}^2$$

Factor of safety = $\frac{\text{Ultimate bearing capacity}}{\text{Load intensity}}$

$$= \frac{1248.02}{400} = 3.12$$

(C) Water table is 2.5m below the ground level



$$zw_2 < B$$

$$zw_2 = 2.5 - 1.2 = 1.3 \text{ m}$$

$$zw_1 = D$$

$$R_{w1} = 0.5 \left(1 + \frac{zw_1}{D}\right) = 1$$

$$R_{w2} = 0.5 \left(1 + \frac{zw_2}{B}\right)$$

$$= 0.5 \left(1 + \frac{1.3}{2}\right) = 0.825$$

$$q_f = r D N_q R_{w1} + \frac{1}{2} B r N_r R_{w2}$$

for the surcharged term

$r = 16.8 \text{ KN/m}^3$ for the wedge term r will be taken as average unit weight of soil situated below the base of the footing.

$$q_{avg} = \frac{(1.3 \times 16.8) + (0.7 \times 19.5)}{1.3 + 0.7}$$

$$= 17.745$$

Ultimate bearing capacity

$$q_f = \gamma D \cdot N_q \cdot R_{W_1} + \frac{1}{2} \times B \cdot r \cdot N_r \cdot R_{W_2}$$

$$= 16.8 \times 1.2 \times 41.4 \times 1 + \frac{1}{2} \times 2 \times 17.745 \times 42.4 \times 0.825$$

$$= 3455.5 \text{ KN/m}^2$$

$$\text{Factor of safety} = \frac{1455.5}{400} = 3.63$$

(d) Water table is 0.5 m below the ground level :-

$$Z_{W_1} = 0.5 \text{ m}$$

$$Z_{W_1} = D$$

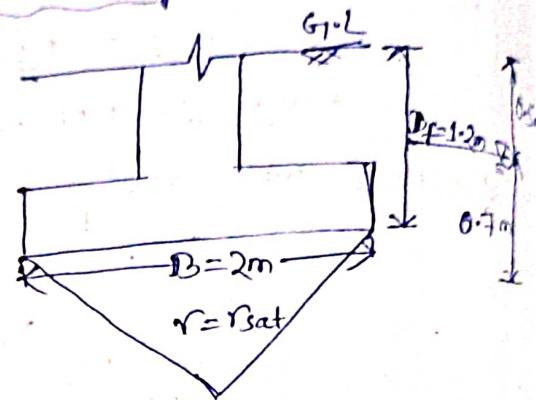
$$R_{W_1} = 0.5 \left(1 + \frac{Z_{W_1}}{D} \right)$$

$$= 0.5 \left(1 + \frac{0.5}{1.2} \right) = 0.703$$

$$Z_{W_2} = 0$$

$$R_{W_2} = 0.5 \left(1 + \frac{Z_{W_2}}{D} \right)$$

$$= 0.5 \left(1 + \frac{0}{1.2} \right) = 0.5$$



For the wedge term $r = r_{sat} = 19.5 \text{ KN/m}^3$

For surcharge term $r = 16.8 \text{ KN/m}^3$

r = Average unit weight of the soil situated above the base of the footing.

$$q_{avg} = \frac{(0.5 \times 16.8) + (0.7 \times 19.5)}{0.5 + 0.7}$$

$$= 18.37 \text{ KN/m}^2$$

Ultimate bearing capacity

$$q_f = \gamma D \cdot N_q \cdot R_{W_1} + \frac{1}{2} B \cdot r \cdot N_r \cdot R_{W_2}$$

$$= 18.37 \times 1.2 \times 41.4 \times 0.70 + \frac{1}{2} \times 2 \times 19.5 \times 42.5 \times 0.5$$

$$= 1059.53 \text{ KN/m}^2$$

$$\text{Factor of safety} = \frac{1059.53}{400} = 2.64$$

(e) Water table is at ground level :—

$$z_{w_1} = 0$$

$$z_{w_1} = D$$

$$R_{w_1} = 0.5 \left(1 + \frac{z_{w_1}}{D} \right) = 0.5 \cdot \left(1 + \frac{0}{1.2} \right) = 0.5$$

$$z_{w_2} = 0$$

$$R_{w_2} = 0.5$$

Ultimate bearing capacity

$$\begin{aligned} q_f &= r D N_q R_{w_1} + \frac{1}{2} \times B r N_r R_{w_2} \\ &= 19.5 \times 1.2 \times 41.4 \times 0.5 + \frac{1}{2} \times 2 \times 19.5 \times 42.4 \times 0.5 \\ &= 897.78 \text{ KN/m}^2 \end{aligned}$$

$$FOS = \frac{897.78}{400} = 2.24$$

IS code method for computing bearing capacity:

- IS code recommends a bearing capacity equation which is similar in nature to those given by Meyerhof & Brinch Hansen.
- The code depending upon the deformation associated with the load & the development of failure surface.
- (i) General shear failure
- (ii) Local shear failure
- (iii) Punching shear failure
- The bearing capacity equation for strip footing for C-φ soil.

(i) General shear failure :—

$$q_{nf} = C N_c + \bar{\sigma} (N_q - 1) + \frac{1}{2} B r N_r$$

(ii) Local shear failure :—

$$q_{nf} = \frac{2}{3} C N_c + \bar{\sigma} (N_q - 1) + \frac{1}{2} B r N_r$$

- Shape factor, depth factor & inclination factor, then general shear failure (G_{sf}).

→ For G_{sf} :—

$$q_{nf} = C N_c \cdot S_c \cdot D_c \cdot I_c + \bar{\sigma} (N_q - 1) S_q \cdot d_q \cdot i_q + \frac{1}{2} B r N_r S_r d_r i_r$$

For local shear failure:

$$q_{nf} = \frac{2}{3} C N_c \cdot S_c d_c \cdot c + \frac{1}{2} (N_q - 1) S_q d_q \cdot \epsilon_q + \frac{1}{2} B r N_r S_r d_r \cdot \epsilon_r$$

Effect of Water Table:

→ The effect of water table taken into account in the form of correction factor & reduction factor i.e. R_{W1} & R_{W2} .

Where,
 R_{W1} is used at the surcharge term for cohesion less soil.

R_{W2} is applied into wedge term.

→ If the water table is level to permanently remain at or depth i.e., $D + B$, beneath the ground level surrounding the footing.

→ Then the reduction factor $R_{W1} = 1$.

→ If the water table is located at depth D or level to rise to the base of footing or above then, the value of reduction factor shall be taken as 0.5.

→ If the water table is located at depth

$D < D_f < D + B$ the reduction factor is obtained

by linear equation.
i.e., $R_W = 0.5 \left(1 + \frac{D_f}{B} \right)$

Cohesion less soil ($c=0$):

For cohesion less soil having $c=0$. Is code recommended that the bearing capacity being calculated.

- (1) Based on relative density
- (2) Based on standard penetration resistance value
- (3) Based on static on penetration test.

Factors affecting bearing capacity eqn of foundation

Soil:

- (1) C, ϕ & r
- (2) Water table location
- (3) $B, D_f, q_f = f(q, C, \phi, B, D_f, r, w, T)$ location

Field methods plate load test & it's limitation:-

1) Plate load test

2) Standard penetration test (SPT)

3) Plate load test:-

The object of test is to determine:

1) To find q_f of foundation soil.

2) To find foundation settlement under design load.

Principle of test:-

A square or circular steel plate i.e. $(30-75) \times (30-75) \times 2.5\text{cm}$ is placed at the foundation level & loaded. Then the settlement of plate is then recorded.

Procedure of test:-

→ A rigid plate of size $(30\text{ cm} - 75\text{ cm}) \times (30-75) \times 2.5\text{ cm}$ is used may be circular or square. Usually smaller size plate is used for dense or stiff soil.

→ A pit is excavated at site to the depth of foundation level. A pit size is not less than 5 times that of plate size.

→ The plate is kept in the middle of the pit & loaded by the gravity loading method or reaction loading method using Jack, Anchors, diagonal & proving ring.

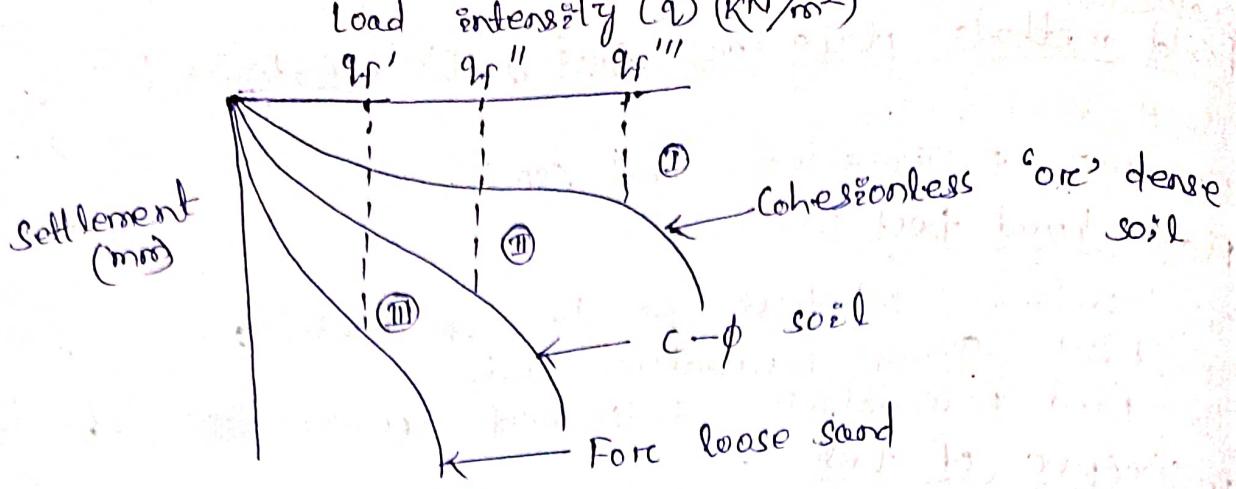
→ A sitting pressure is 7 KN/m^2 is first applied & then released before starting the load test.

→ The loading is applied in increments of $\frac{1}{10}$ th of design load each load increment is maintained for 24 hours.

→ Settlements are recorded by dial gauges & loading by proving ring for each load increases. Loading is continued either to failure 'or' still settlement is reached to 25 mm.

→ When 25 mm settlement is not reached 'or' failure does not occur then test is continued up to 2 times of design load.

→ A plot or graph is prepared settlement versus ' q_f ' (load) is prepared from where q_f is found.



Objective :-

Estimation of q_f :-

(i) q_f of foundation resting on clay :-

$$q_{ff} = q_{fp}$$

Where,

q_{ff} = Ultimate bearing capacity for foundation.

q_{fp} = Ultimate bearing capacity of plate.

(ii) q_f of foundation resting on sand :-

$$\frac{q_{ff}}{q_{fp}} = \frac{B_f}{B_p}$$

Where,

B_f = Base width of foundation

B_p = Base width of plate.

Estimation of settlement :-

(i) For foundation resting on clay :-

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

Where,

S_f = Settlement of foundation

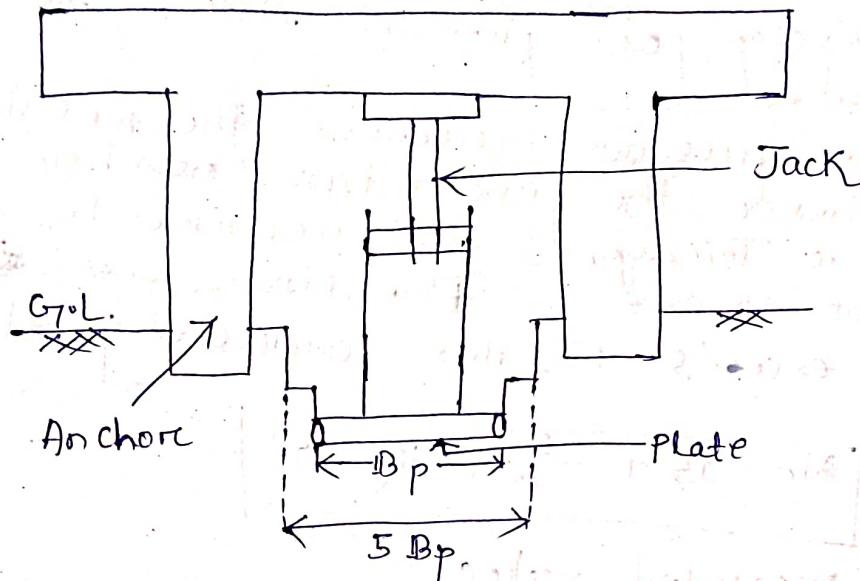
S_p = Settlement of plate

for foundation resting on sand :-

$$\frac{S_f}{S_p} = \left\{ \frac{B_f (B_p + 3D)}{B_p (B_f + 3D)} \right\}^2$$

Limitation of plate load test :-

- The zone of stress due to loading causing settlement on sand extend up to depth 1.5B to 2.0B below the base of the footing.
- In case of sandy soil bearing capacity increases with increase of foundation size.
- Result of plate load test are not applicable for strip footing.
- The test on smaller size plate give less q_f.



(2) Standard Penetration test :-

- The standard penetration test is the most commonly used in-situ test especially for cohesionless soil.
- The test is used for determining the relative density, angle of shearing resistance of cohesionless soil & the unconfined compressive strength of cohesion soil.
- The test is conducted in a bore hole 55-150mm diameter using a standard split spoon sampler.
- When the bore hole has been drilled to the desired depth the drilling tools are removed & sampler is lowered to the bottom of the hole.
- The sampler is driving into the soil by a drop hammer of 63.5 Kg mass falling through a height of 750 mm at the rate of 30 blows per minute.
- The number of hammer blows required to drive 150mm sample is counted. The sample is further driven by 150 mm & the number of blows are recorded.

- If $n > 50$ the sampler penetrates $< 2.5 \text{ cm}$ refused is said to having reached & boring is advanced to next location of test.
- The average 'N' value betw base of footing & depth to be from base is calculated.
- The average 'N' value is calculated for overburden pressure & submerged dilatancy.

Dilatancy Correction:

- In very fine, silty & saturated sands below the water table develop pore pressure which is not easily decipated.
- The pore pressure increased the resistance of soil & hence the penetration number 'N'.
- According to Terzaghi & peak recommended the following correction in case of fine sand. When observe value N exceeds 15, then corrected penetration number

$$N_c = 15 + \frac{1}{2} (N_r - 15)$$

N_r = Recorded value

If $N_r \leq 15$, $N_c = N_r$

Overburden pressure Correction:

In granular soils the overburden pressure affect the penetration resistance.

According to Gibbs & Holtz's recommended the use of the following eq for dry 'or' moist clean sand.

$$N_c = N_r \times \frac{350}{\bar{s} + 70}$$

N_r = Observed 'N' value

N_c = Corrected 'N' value

\bar{s} = Effective overburden pressure.

- If the two soil having same relative density but different confining pressure are tested. One with a higher confining pressure gives a higher penetration number.

Q) An N value of 35 was obtained for a fine sand below water table. What is the corrected value of N.

$$N_R = 35$$

$$\begin{aligned} N_C &= 15 + \frac{1}{2}(N_R - 15) \\ &= 15 + \frac{1}{2}(35 - 15) \\ &= 25 \end{aligned}$$

Q) A square footing located at a depth of 1.3 m below the ground has to carry a safe load of 800 kN. Find the size of footing. If the desired F.O.S is 3 the soil has the following properties void ratio = 0.55, degree of saturation = 50%, specific gravity = 2.67, $\phi = 30^\circ$, $C = 8 \text{ kN/m}^2$, use Terzaghi's analysis.

Given data:-

Square footing

$$\text{Depth (D)} = 1.3 \text{ m}$$

$$\text{Safe load} = 800 \text{ kN}$$

$$\text{F.O.S} = 3$$

$$S_r = 50\%$$

$$G_f = 2.67$$

$$\phi = 30^\circ$$

$$C = 8 \text{ kN/m}^2$$

$$N_C = 37.2$$

$$N_q = 22.5$$

$$N_R = 39.7$$

$$e = 0.55$$

Using Terzaghi's analysis,

$$q_u = C N_C + \sigma_v + \frac{1}{2} B f N_R$$

$$f = \frac{(G_f + e \cdot S_r) \cdot f_0}{1+e}$$

$$= \frac{(2.67 + 0.55 \times 0.5) \times 9.81}{1+0.55} = 18.639 \text{ kN/m}^2$$

Terzaghi bearing capacity eqn for square footing,

$$q_u = 3.3 C N_C + 5.0 N_q + 0.4 B f N_R$$

$$= (1.3 \times 8 \times 37.2) + (18.639 \times 1.3 \times 22.5) + (0.4 \times 8 \times 18.639 \times 39.7)$$

$$q_u = 932.1 + 146.88 B$$

Safe load bearing capacity,

$$q_s = \frac{q_u}{F} + \tau D$$

$$q_{nf} = q_f - r D$$

$$\Rightarrow q_{nf} = 932.1 + 146.88 B - 18.639 \times 1.3$$

$$\Rightarrow q_{nf} = 907.87 + 146.88 B$$

$$q_s = \frac{907.87 + 146.88 B}{3} + (18.639 \times 1.3)$$

$$\Rightarrow q_s = \frac{907.87}{3} + \frac{146.88 B}{3} + 24.23$$

$$\Rightarrow q_s = 302.62 + 48.96 B + 24.23 \quad \text{①}$$

$$\Rightarrow q_s = 326.86 + 48.96 B$$

Actual load intensity (q_A) $\leftarrow \frac{\text{Load}}{A} = \frac{800}{B^2}$ ②

Equating eqn (1) & eqn (2)

$$326.86 + 48.96 B = \frac{800}{B^2}$$

$$\Rightarrow 326.86 B^2 + 48.96 B^3 = 800$$

$$\Rightarrow 326.86 B^2 + 48.96 B^3 - 800 = 0$$

$$\Rightarrow B = 1.4 \text{ m}$$

Ans

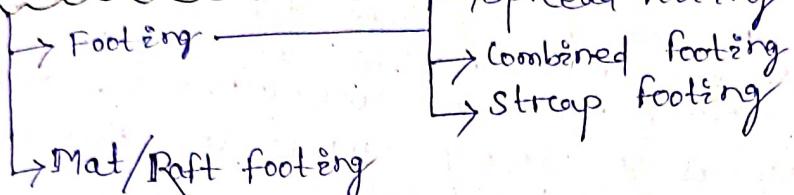
Shallow Foundations

According to Terzaghi's a foundation is shallow if its depth is equal to or less than breadth ($D_f \leq B$).

Types of foundations :-

- (1) Shallow Foundation
- (2) Deep Foundation

(1) Shallow Foundation :-



→ Strip footing

→ Isolated footing

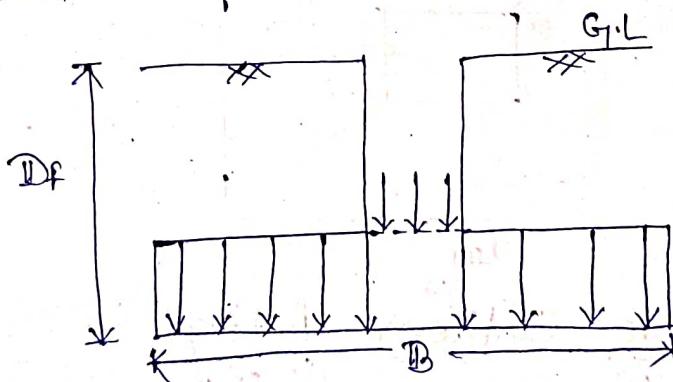
Isolated footing

Circular footing

Rectangular footing

(a) Spread footing :-

A spread footing is a type of shallow foundation used to transmit the load of an isolated column over a large area. The base of the column or wall is enlarged or spread to provide individual support for the load.



It is of two types

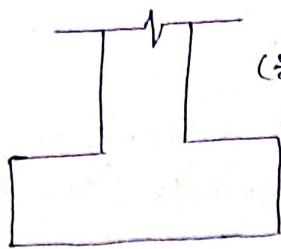
- (i) Strip footing
- (ii) Isolated footing

(i) Strip footing :-

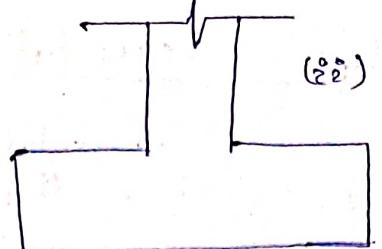
A strip footing is provided for a load bearing wall, a strip footing is also provided for a row of columns. Strip footing is also called as continuous footing.

(ii) Isolated footing :-

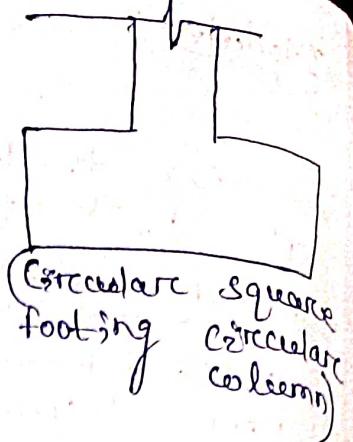
It is the spread footing that supports the columns. Isolated footing may be square or circular.



(square footing)



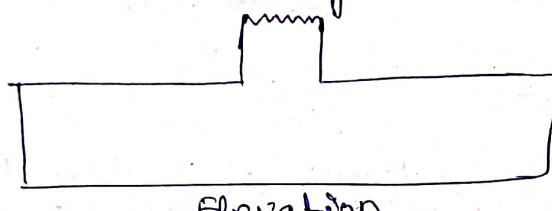
(Rectangular footing)



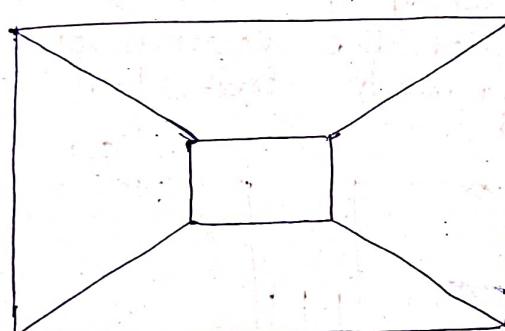
(Circular, square
footing Circular
column)

(b) Combined footing:

- A common footing is provided for two or more columns as known as combined footing. When the two columns are placed so closely that individual footing some close to end column. & hence construction is practicable.
- When the column is so closely impossible to constructed to footing.
- When the footing of individual columns close to each other.
- When the properties line are straight line.

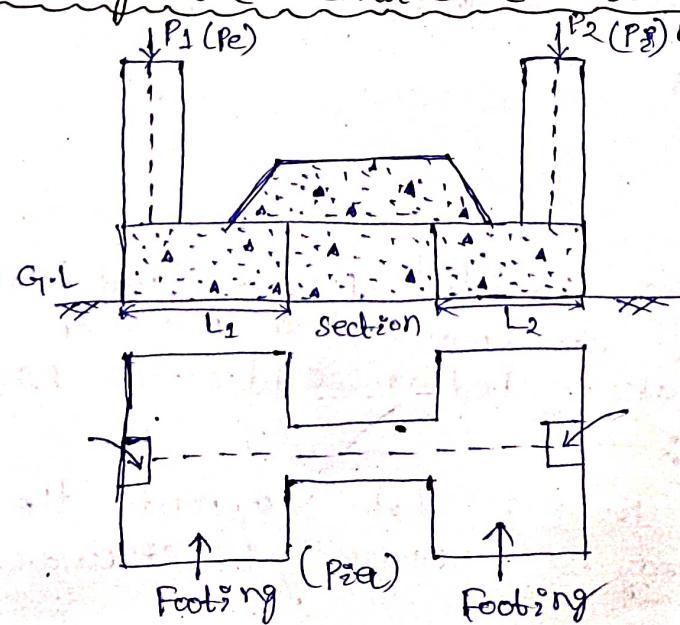


Elevation



Plan

(c) Strip footing or Cantilever footing:



It is use when:-

The footing of an external column consists allow to extend into the adjoining private properties.

When the distance bet' the column is than the combined trapezoidal footing wide aware with high bending moment.

$$\text{where } \frac{l_1}{l_2} < 4S$$

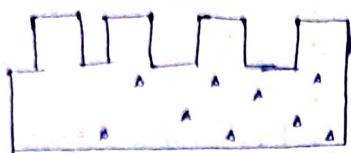
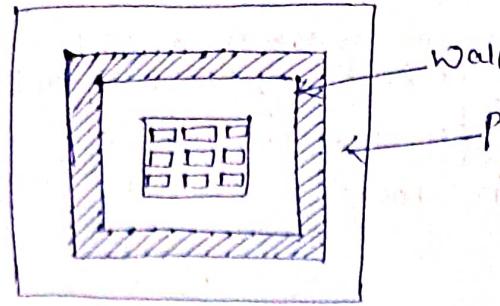
1) Solution of trapezoidal footing finding A & B it possible, Where $\frac{l_1}{l_2} < \frac{x}{l_2}$.

Strap footing consists of isolated footing of two columns connected by strap beam. The strap beam is rigid if it is not contact the soil so doesn't fixidity rigid. If it is not contact the soil so doesn't transfer any pressure in the soil. The footing are design at isolated footing considering land intensity q_a at the allowable bearing capacity of soil then the strap to transfer column load to the soil with equal & uniform soil factor that is q_a under both footing.

Mat & Raft Foundation :-

Uses:-

- If soil is poor & loads are very heavy.
- Raft is a combined footing which supports all the wall & column of a structure.
- It is use where allowable soil stress q_a at foundation level is low & structure load is high such as individual footing & combine footing are provided the total footing area of building plane area.
- Where the super structure need a specific different for its proper functioning.
- When the sub-soil condition is very e it is not possible to determine the difference settlement.
- Raft foundation is also use to reduce settlement above highly compressible soil by making the weight of structure & raft appropriately required to the width of soil excavated.



Proportioning of frictioning dimensions L & B of combined footing:

- Frictioning dimensions L & B of combined footing is done by making the centre of gravity of column loads to coincide with centroid of footing area. So that the consequently footing base pressure will be reasonably uniform.
- The base pressure should be less than q_s (Safe bearing capacity).

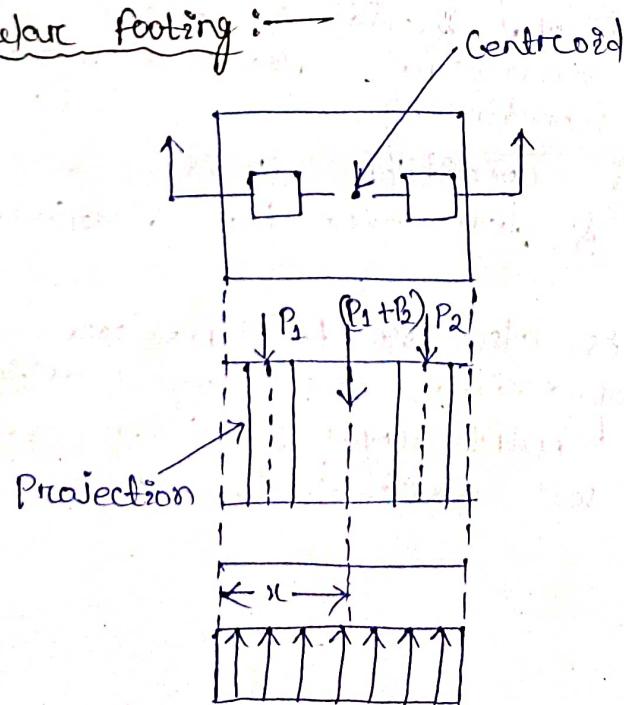
$$\text{Base Pressure} = \frac{P_1 + P_2}{B \times L} = q_s$$

Where, q = Per centimetre mean pressure.

Types of Combined footing:

- Rectangular
- Trapezoidal

(3) Rectangular footing:



It is used under 2 condition:

1) If rectangle can extend beyond each column in the necessary distance to make centroid of footing on C.G. line of two columns.

2) If the footing supports an exterior column at the property line when the projection has to be limited to the interior column carrying the greater load.

In this case the footing length is established by adding the projection of footing beyond exterior column to satisfy principle-1 & proportioning. The width B is obtained as per principle-2

$$B \times L \times q_a = P_1 + P_2$$

$$\Rightarrow B = \frac{P_1 + P_2}{(q_a \times L)}$$

Trapezoidal Footing:

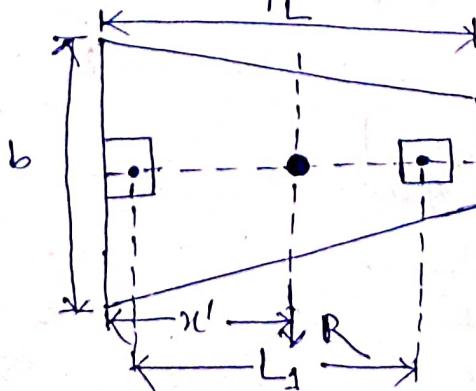
When the two column loads are unequal the exterior column carrying higher loads & lying close to the property line.

A trapezoidal combine footing is used:

- 1. It may be used even when the exterior column carrying heavier load but in this case the width of trapezoidal will be higher in the inner side.
- 2. The location of C.G. of resultant column loads established the location of the centroid of trapezoidal, the length is limited of the property line of one end.
- 3. The width of either end of trapezoidal can be determine from two simultaneous equation.

$$A \times q_a = P_1 + P_2$$

A = Area of trapezoidal footing



$$x' = \frac{P_2 \times L_1}{P_1 + P_2}$$

Q Determine the depth at which a circular footing of 2m diameter be founded to provide a factor of safety as 3. If it has to carry a safe load of 1600 kN the foundation soil has $C = 10 \text{ KN/m}^2$, $\phi = 30^\circ$, unit weight, $\gamma = 18 \text{ KN/m}^3$, Use Terzaghi's Analysis $N_C = 37.2$, $N_q = 22.5$, $N_r = 19.7$.

Soln: Given data:-

Circular footing

$$\text{F.O.S} = 3$$

$$\text{Diameter} = 2\text{m}$$

$$\text{Safe load} = 1600 \text{ KN}$$

$$C = 10 \text{ KN/m}^2$$

$$\phi = 30^\circ$$

$$\gamma = 18 \text{ KN/m}^3$$

$$N_C = 37.2$$

$$N_q = 22.5$$

$$N_r = 19.7$$

Terzaghi's bearing capacity Eqⁿ for circular footing

$$q_{nf} = 1.3 C N_C + \frac{1}{3} (N_q - 1) + 0.3 \gamma B N_r$$

$$= 1.3 \times 10 \times 37.2 + (18 \times 10) (22.5 - 1) + 0.3 \times 2 \times 18 \times 19.7$$

$$q_{nf} = 696.36 + 387 D$$

$$\begin{aligned} q_s &= \frac{q_{nf}}{F} + rD \\ &= \frac{696.36 + 387 D}{F} + 18 D \\ &= \frac{696.36}{3} + \frac{387 D}{3} + 18 D \\ &= 232.12 + 129 D + 18 D \\ &= 232.12 + 147 D \end{aligned} \quad (1)$$

Actual load intensity = $\frac{\text{Load}}{\text{Area}}$

$$\begin{aligned} \Rightarrow q_a &= \frac{1600}{\frac{\pi}{4} D^2} \\ &= \frac{1600}{\frac{\pi}{4} \times (2)^2} \\ &= 509.29 \text{ KN/m}^2 \end{aligned} \quad (2)$$

Equating eqⁿ (2) & (2)

$$232.12 + 147D = 509.29$$

$$\rightarrow 147D = 509.29 - 232.12$$

$$\rightarrow 147D = 277.17$$

$$\rightarrow D = 277.17 / 147$$

$$\rightarrow D = 1.89 \text{ m}$$

Ans

Deep foundation :-

If $D_F > B$, we call it is deep foundation.

Deep foundation based on the mechanism from which the foundation gets its bearing capacity.

Shape & material.

Types of deep foundation:-

There are 3 types:

- (i) Pile foundation
- (ii) Pier foundation
- (iii) Well foundation

(i) Pile foundation:-

- Piles are long & slender members that are driven into ground or cast in site in the above hole.
- They are used in storage buildings & bridges in a group.

Types of pile foundation:-

Based on different criteria piles are classified as follows:

(i) Based on function or load transfer piles:-

(i) Friction pile

(ii) End bearing pile

(iii) friction + end bearing pile

(ii) Based on construction or installation:-

(i) Pre-cast pile

(ii) Cast-in situ

(a) Bored pile

(b) Driven pile

Equating eqⁿ (1) & (2)

$$232 \cdot 12 + 147 D = 509 \cdot 29$$

$$\Rightarrow 147 D = 509 \cdot 29 - 232 \cdot 12$$

$$\Rightarrow 147 D = 277 \cdot 17$$

$$\Rightarrow D = 277 \cdot 17 / 147$$

$$\Rightarrow D = 1.89 \text{ m}$$

Ans