13. SHALLOW FOUNDATION & BEARING CAPACITY

BEARING CAPACITY

The load carrying capacity of foundation soil or rock which enables it to bear and transmit loads from a structure.

GROSS PRESSURE INTENSITY

It is the total pressure at the base of the footing due to the weight of the super structure, self weight of the footing and weight of the earth fill.

NET PRESSURE INTENSITY

It is defined as excess of gross pressure to over burden pressure.

$\boxed{q_{net} = q_g - \bar{\sigma}}$ where, q_{net} = Net Pressure Intensity

q_g = Gross Pressure

$\bar{\sigma}$ = Effective Stress = $\gamma' D_f$.

NET ULTIMATE BEARING CAPACITY

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

$\boxed{q_{nu} = q_u - \bar{\sigma}}$ where, q_{nu} = Net ultimate bearing capacity

q_u = Ultimate bearing capacity

NET SAFE BEARING CAPACITY

$\boxed{q_{ns} = \dfrac{q_{nu}}{F_s}}$ where, q_{ns} = Net safe bearing capacity

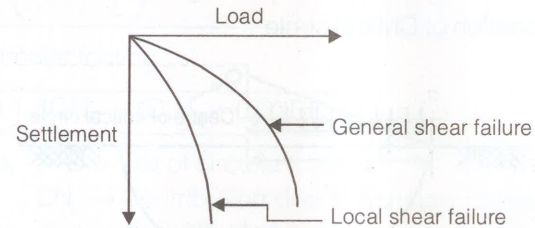
F_s = Factor of safety

SAFE BEARING CAPACITY

$\boxed{q_s = q_{ns} + \bar{\sigma}}$ where, q_s = Safe bearing capacity.

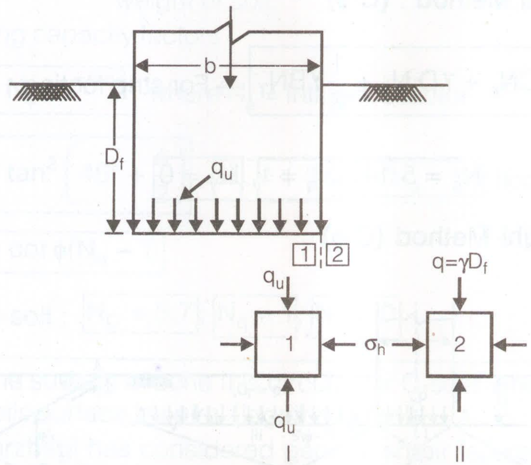
Remember

Parameter	General shear failure	Local shear failure
1. Friction angle (ϕ)	> 36°	< 28°
2. Strain of failure	≤ 5%	≥ 15%
3. S.P.T number	> 30	< 5
4. Relative density	> ~~17%~~ 70%	< 20%
5. Void ratio	< 0.55	> 0.75
6. Unconfined compressive strength	> 100 kN/m²	< 80 kN/m²



METHOD TO DETERMINE BEARING CAPACITY

(i) **Rankines Method (ϕ – soil)**



Rankine's method for bearing capacity of a footing

$$\boxed{q_u = \gamma D_f \tan^4\left(45^\circ + \frac{\phi}{2}\right)} \text{ or } \boxed{q_u = \gamma D_f \left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2}$$

(ii) **Bells Theory (C – ϕ)**

$\boxed{q_u = CN_c + \gamma D_f N_q}$ where, N_c and N_q are bearing capacity factors.

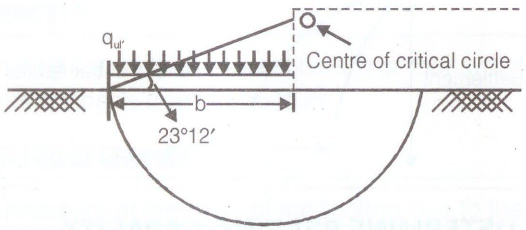
For pure clays → C = 4, q = 1

(iii) **Fellinious Method : (C-soil)**

- The failure is assumed to take place by slip and the consequent heaving of a mass of soil is on one side.

$$\boxed{q_{ult} = \frac{W \cdot l_r + CR}{b \cdot l_o}} \quad \boxed{q_{ult} = 5.5C}$$

- Location of Critical circle



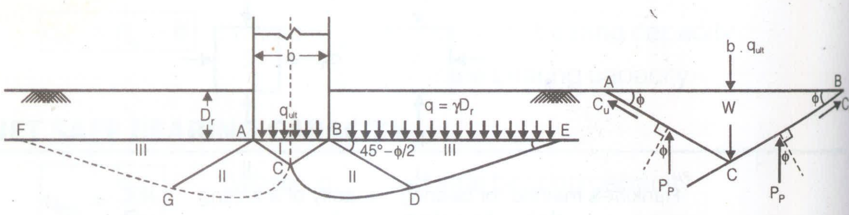
Location of critical circle for surface footing in Fellenius' method

(iv) Prandtl Method : (C-ϕ)

$$\boxed{q_u = CN_c + \gamma D_f N_q + \frac{1}{2}\gamma BN_\gamma} \rightarrow \text{For strip footing}$$

For C-soil $\boxed{N_c = 5.14}$, $\boxed{N_q = 1}$, $\boxed{N_\gamma = 0}$

(v) Terzaghi Method (C-ϕ)



(a) Terzaghi system for ideal soil, rough base and surcharge

(b) Forces on the elastic wedge

Terzaghi's method for bearing capacity of strip footing

Total zones = 5

For strip footing

$$\boxed{q_u = CN_c + \gamma D_f N_q + \frac{1}{2}\gamma BN_\gamma}$$

For square footing

$$\boxed{q_u = 1.3CN_c + \gamma D_f N_q + 0.4\gamma BN_\gamma}$$

For rectangular footing

$$\boxed{q_u = \left(1 + 0.3\frac{B}{L}\right)CN_c + \gamma D_f N_q + \frac{1}{2}\left(1 - \frac{0.2B}{L}\right)\gamma BN_\gamma}$$

For circular footing

$$\boxed{q_u = 1.3CN_C + \gamma D_f N_q + 0.3\gamma DN_\gamma}$$

where, D = Dia of circular footing

$CN_C \rightarrow$ Contribution due to constant component of shear strength of soil.

$\gamma D_f N_q \rightarrow$ Contribution due to surcharge above the footing

$\frac{1}{2}\gamma BN_\gamma \rightarrow$ Contribution due to bearing capacity due to self weight of soil.

Bearing capacity factors

$\boxed{N_q = N_\phi \cdot e^{\pi \tan\phi}}$ where N_ϕ = Influence factor

$\boxed{N_\phi = \tan^2\left(45° + \frac{\phi}{2}\right)}$ $\boxed{N_\gamma = 1.8\tan\phi(N_q - 1)}$

$\boxed{N_C = \cot\phi(N_q - 1)}$

For C-soil : $\boxed{N_C = 5.7}$, $\boxed{N_q = 1}$, $\boxed{N_\gamma = 0}$

Remember

- The surface of zone II is circular for C-soils whereas for C-ϕ soils surface is spiral (logrithm spiral).
- Terzhagi has considered general shear failure but if soil is loose and failure is local shear failure then modified values of C and ϕ should be used.

$$C' = \frac{2}{3}C, \qquad \phi' = \tan^{-1}\left(\frac{2}{3}\tan\phi\right)$$

(vi) Skemptons Method (C-soil)

This method gives net ultimate value of bearing capacity. Applicable for purely cohesive soils only.

$$\boxed{q_{nu} = CN_c}$$

For strip footing. $\boxed{N_C = 5 \text{ to } 7.5}$

For circular and square footing. $\boxed{N_c = 6 \text{ to } 9.0}$

Values of N_C

- If $\frac{D_f}{B} = 0$ i.e. of the surface.

  Then $\boxed{N_C = 5}$ For strip footing

  $\boxed{N_C = 6.0}$ For square and circular footing.

  where D_f = Depth of foundation.

- If $0 \le \frac{D_f}{B} \le 2.5$

  $$\boxed{N_C = 5\left[1 + 0.2\frac{D_f}{B}\right]}$$, for strip footing

  $$\boxed{N_C = 6\left[1 + 0.2\frac{D_f}{B}\right]}$$, for square and circular footing.

  $\boxed{B = D}$ in case of circular footing.

  $$\boxed{N_C = 5\left[1 + 0.2\frac{B}{L}\right]\left[1 + 0.2\frac{D_f}{B}\right]}$$ for rectangular footing.

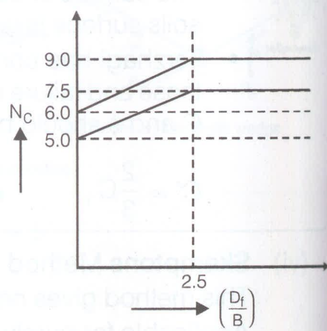
- If $\frac{D_f}{B} > 2.5$

  $\boxed{N_C = 7.5}$

  for strip footing

  $\boxed{N_c = 9.0}$

  for circular, square and rectangular footing.



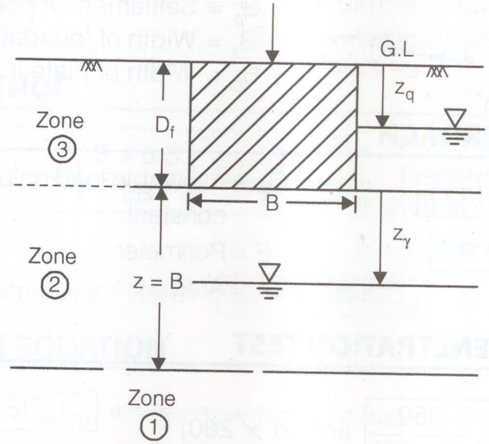
(vii) Meyorhoff's Method→(C – φ soil)

$$\boxed{q_u = CN_C \cdot s_C \cdot d_c \cdot i_c + \gamma D_f N_q \cdot s_q \cdot d_q \cdot i_q + \frac{1}{2}\gamma B N_\gamma s_\gamma \cdot d_\gamma \cdot i_\gamma}$$

where s, d and i are shape, depth and inclination correction factor.

EFFECT OF WATER TABLE

$$\boxed{q_u = CN_c + \gamma D_f N_q R_q^* + \frac{1}{2}\gamma B N_\gamma R_\gamma^*}$$



where R_q* and R_γ* are water table correction factor.

$$\boxed{R_q^* = \frac{1}{2}\left[1 + \frac{Z_q}{D_f}\right]}$$

when $0 \le Z_q \le D_f$

$$\boxed{R_\gamma^* = \frac{1}{2}\left[1 + \frac{Z_\gamma}{B}\right]}$$

when $0 \le Z_\gamma \le B$.

If $Z_\gamma > B$ they $R_\gamma^* = 1$

If $Z_\gamma \le 0$ they $R_\gamma^* = \frac{1}{2}$

If water table rise to G.L

$\boxed{R_q^* = \frac{1}{2}}$ and $\boxed{R_\gamma^* = \frac{1}{2}}$

PLATE LOAD TEST

(i) $\boxed{\frac{q_{uf}}{q_{up}} = \frac{B_f}{B_p}}$ ...for φ-soil

(ii) $\boxed{q_{uf} = q_{up}}$ ..for C-soil

(iii) $$\boxed{\frac{S_f}{S_p} = \left[\frac{B_f(B_p + 0.3)}{B_p(B_f + 0.3)}\right]^2}$$ ...for dense sand.

(iv) $$\boxed{\frac{S_f}{S_p} = \frac{B_f}{B_p}}$$ ... for clays

(v) $$\boxed{\frac{S_f}{S_p} = \left(\frac{B_f}{B_p}\right)^{n+1}}$$

... for silts.

where, q_{uf} = Ultimate bearing capacity of foundation
q_{up} = Ultimate bearing capacity of plate
S_f = Settlement of foundations
S_p = Settlement of plate
B_f = Width of foundation in m
B_p = Width of plate in m

n → Index depends on c-φ soil
n ≃ 0.5

HOUSELS APPROACH

$$\boxed{Q_P = mA_p + nP_p}$$

$$\boxed{Q_f = mA_f + nP_f}$$

where, Q_p = Allowable load on plate m and n are constant
P = Perimeter
A = Area

STANDARD PENETRATION TEST

(i) $$\boxed{N_1 = N_0 \frac{350}{(\bar{\sigma}+70)}} \text{ and } \boxed{\bar{\sigma} \not> 280}$$

where, N_1 = Overburden pressure correction
N_0 = Observed value of S.P.T. number.
$\bar{\sigma}$ = Effective overburden pressure at the level of test in kN/m².

(ii) $$\boxed{N_2 = \frac{1}{2}(N_1 - 15) + 15}$$

where, N_2 = Dilatancy correction or water table correction.

PECKS EQUATION

$$\boxed{q_{a\,net} = 0.41NSC_w\,kN/m^2}$$

$$\boxed{C_w = 0.5\left(1 + \frac{D_w}{D_f + B}\right)}$$

where, D_w = depth of water table below G.L
D_f = Depth of foundation
B = Width of foundation
N = Avg. corrected S.P.T. no.
S = Permissible settlement of foundation
C_w = Water table correction factor
$q_{a\,net}$ = Net allowable bearing pressure.

TENG'S EQUATIONS

$$\boxed{q_{ns} = 1.4(N-3)\left(\frac{B+0.3}{2B}\right)^2 SC_wC_D\ kN/m^2}$$

$$\boxed{C_W = 0.5\left(1 + \frac{D_W}{B}\right)}$$

$$\boxed{C_D = \left(1 + \frac{D_f}{B}\right) \le 2}$$

where, C_w = Water table correction factor
D_w = Depth of water table below foundation level
B = Width of foundation
C_d = Depth correction factor
S = Permissible settlement in 'mm'.

I.S. CODE METHOD

$$\boxed{q_{ns} = 1.38(N-3)\left(\frac{B+0.3}{2B}\right)^2 SC_w}$$

q_{ns} = Net safe bearing pressure in kN/m²
B = Width in meter.
S = Settlement in 'mm'.

I.S. Code Formula for Raft: $\boxed{q_{ns} = 0.88NSC_w}$

MEYER-HOFFS EQUATION

$\boxed{q_{ns} = 0.49NSC_wC_d}$ where, q_{ns} = Net safe bearing capacity in kN/m².

B < 1.2 m

$$\boxed{C_d = \left(1 + \frac{D_f}{B}\right) \le 2} \qquad \boxed{C_w = \frac{1}{2}\left(1 + \frac{D_w}{B}\right)}$$

$$\boxed{q_{ns} = 0.32N\left(\frac{B+0.3}{B}\right)^2 .S.C_d.C_w}$$ B ≥ 1.2 m (where q_{ns} is in kN/m²)

CONE PENETRATIONS TEST

(i) $$\boxed{C = 1.5\left[\frac{q_c}{\bar{\sigma}_0}\right]}$$

where, q_c = Static cone resistance in kg/cm²
c = Compressibility coefficient
$\bar{\sigma}_0$ = Initial effective over burden pressure in kg/cm².

(ii) $$\boxed{S = 2.3\frac{H_0}{C}\log_{10}\left[\frac{\bar{\sigma}_0 + \Delta\sigma}{\bar{\sigma}_0}\right]}$$ where, 'S' = Settlement.

(iii) $\boxed{q_{ns} = 3.6q_sR_w}$ when B < 1.2 m.

where, q_{ns} = Net safe bearing pressure in kN/m².

(iv) $\boxed{q_{ns} = 2.7q_c.R_w}$ when B > 1.2 m

where, R_w = Water table correction factor.