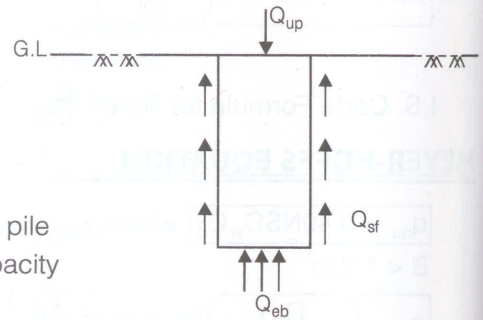
14. DEEP FOUNDATION

BEARING CAPACITY OF PILES

The ultimate bearing capacity of a pile is the maximum load which it can carry without failure or excessive settlement of the ground. The bearing capacity also depends on the methods of installation

A. Analytical Method



(i) $Q_{up} = Q_{eb} + Q_{sf}$

(ii) $Q_{up} = q_b A_b + q_s A_s$

where,

Q_{up} = Ultimate load on pile
Q_{eb} = End bearing capacity
Q_{sf} = Skin friction
q_b = End bearing resistance of unit area.
q_s = Skin friction resistance of unit area
A_b = Bearing area
A_s = Surface area

(iii) $q_b \sim 9C$ where, C = Unit Cohesion at base of pile for clays

(iv) $q_s = \alpha \bar{C}$ where, α = Adhesion factor
$\alpha \bar{c} = C_a$ = Unit adhesion between pile and soil.
$\bar{c}$ = Average Cohesion over depth of pile.

(v) $Q_{safe} = \dfrac{Q_{up}}{F_s}$ where, F_s = Factor of safety.

(vi) $Q_{safe} = \dfrac{Q_{eb}}{F_1} + \dfrac{Q_{sf}}{F_2}$ $F_1 = 3$ and $F_2 = 2$
$\simeq F_1 = F_2 = 2.5$

(vii) **For Pure Clays** $Q_{up} = 9C.A_b + \alpha \bar{c} A_s$

B. Dynamic Approach

Dynamic methods are suitable for dense cohesionless soil only.

(i) Engineering News Record Formula

(a) $Q_{up} = \dfrac{WH}{S+C}$

(b) $Q_{ap} = \dfrac{Q_{up}}{6} = \dfrac{WH}{6(S+C)}$

where,

Q_{up} = Ultimate load on pile
Q_{ap} = Allowable load on pile
W = Weight of hammer in kg.
H = Height of fall of hammer in cm.
S = Final set (Average penetration of pile per blow of hammer for last five blows in cm)
C = Constant
= 2.5 cm → for drop hammer
= 0.25 cm → for steam hammer (single acting or double acting)

(c) For drop hammer $Q_{ap} = \dfrac{WH}{6(S+2.5)}$

(d) For Single Acting Steam Hammer $Q_{ap} = \dfrac{WH}{6(S+0.25)}$

(e) For Double Acting Steam Hammer $Q_{ap} = \dfrac{(W+ap)H}{6(S+0.25)}$

where P = Steam pressure
and a = Area of hammer on which pressure acts.

(ii) **Hiley Formula (I.S. Formula)**

$Q_{up} = \dfrac{\eta_h . \eta_b . WH}{S + \dfrac{C}{2}}$ $Q_{ap} = \dfrac{Q_{up}}{F_s}$

where, F_s = Factor of safety = 3
η_h = Efficiency of hammer
η_b = Efficiency of blow.

$\eta_h = 0.75$ to 0.85 for single acting steam hammer

$\eta_h = 0.75$ to 0.80 for double acting steam hammer

$\eta_h = 1$ for drop hammer.

$$\eta_b = \frac{\text{Energy of hammer after impact}}{\text{Energy of hammer just before Impact}}$$

$$\eta_b = \frac{W + e^2P}{W + P}$$ when **w > e·p**

$$\eta_b = \left(\frac{W + e^2P}{W + P}\right) - \left(\frac{w - ep}{w + p}\right)^2$$ ... when **w < e·p**

where, w = Weight of hammer in kg.

p = Weight of pile + pile cap

e = Coefficient of restitutions

= 0.25 for wooden pile and cast Iron hammer

= 0.4 for concrete pile and cast Iron hammer

= 0.55 for steel piles and cast Iron hammer

S = Final set or penetrations per blow

C = Total elastic compression of pile, pile cap and soil

H = Height of fall of hammer.

C. Field Method

(i) Use of Standard Penetrations Data

$$Q_{up} = 400N A_b + 2\bar{N} A_s$$

where, N = Corrected S.P.T. Number

$\bar{N}$ = Average corrected S.P.T. number for entire pile length

$$Q_{ap} = \frac{Q_{up}}{F_s}$$

F_s = Factor of safety

= 4 → For driven pile

= 2.5 → for bored pile.

$q_b = 400N$ and $q_s = 2\bar{N}$

- For non Displacement Pile (H-Piles)

$q_b = 200N$ $q_s = \bar{N}$

(ii) Cone penetration test $Q_{up} = q_c A_b + \frac{\bar{q}_c}{2} A_s$

Where, q_c = static cone resistance of the base of pile in kg/cm²

$\bar{q}_c$ = average cone resistance over depth of pile in kg/cm²

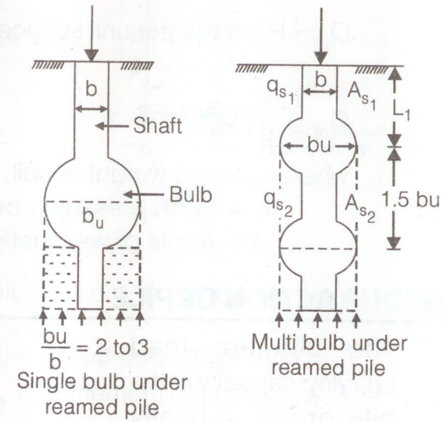
$$A_b = \frac{\pi}{4}(b_u)^2 = \text{Area of bulb } (m^2)$$

NOTE: q_c and $\bar{q}_c$ are in kg/cm², A_b and A_s are in m² and Q_{up} is in kN.

UNDER-REAMED PILE

An 'under-reamed' pile is one with an enlarged base or a bulb; the bulb is called 'under-ream'.

Under-reamed piles are cast-in-situ piles, which may be installed both in sandy and in clayey soils. The ratio of bulb size to the pile shaft size may be 2 to 3; usually a value of 2.5 is used.



Single bulb under reamed pile

Multi bulb under reamed pile

$A_{s_1} = \pi b L_1$

$q_{s_1} = \alpha C$ $\alpha < 1$.

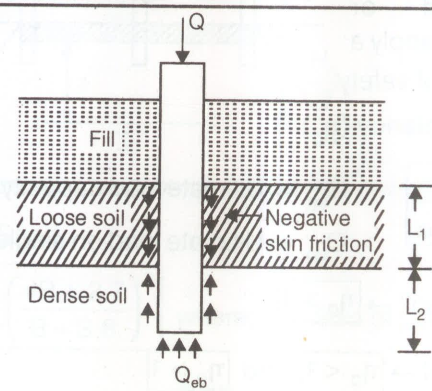
$A_{s_2} = \pi b_u L_2$

$q_{s_2} = \alpha C$ $\alpha = 1$ Where, b_u = dia of bulb, Spacing = 1.5 b_u.

$$Q_{up} = q_b A_b + q_{s_1} A_{s_1} + q_{s_2} A_{s_2}$$

Remember: The ratio of bearing resistance for double underreamed pile to that to single underreamed pile is 1.5 for sandy and clayey soils including black cotton soils.

NEGATIVE SKIN FRICTION



(i) **For Cohesive soil**

$\boxed{Q_{nf} = \text{Perimeter} \cdot L_1 \alpha C}$ for Cohesive soil.

where, Q_{nf} = Total negative skin frictions

$$\boxed{F_s = \frac{Q_{up} - Q_{nf}}{\text{Applied load}}}$$ where, F_s = Factor of safety.

(ii) **For cohesion less soils**

$$Q_{nf} = P \times \text{force per unit surface length of pile} = P \times \frac{1}{2} K\gamma D_n^2 \cdot \tan\delta$$

$$Q_{nf} = \frac{1}{2} P D_n^2 K \tan\delta \cdot \gamma \qquad \text{(friction force} = \mu H)$$

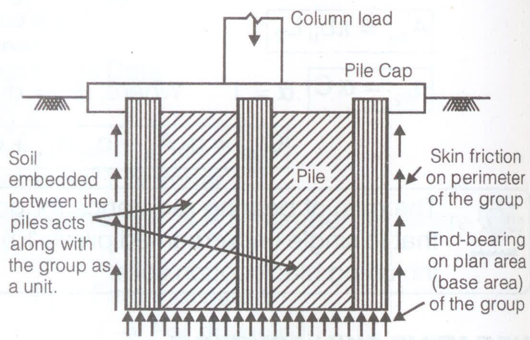
where γ = unit weight of soil.

K = Earth pressure coefficient ($K_a < K < K_p$)

δ = Angle of wall friction. ($\phi/2 < \delta < \phi$)

GROUP ACTION OF PILE

The ultimate load carrying capacity of the pile group is finally chosen as the smaller of the (i) Ultimate load carrying capacity of n pile ($n\,Q_{up}$) and (ii) Ultimate load carrying capacity of the single large equivalent (block) pile (Q_{ug}). To determine design load or allowable load, apply a suitable factor of safety.



Single equivalent large pile concept for a group (block failure)

(i) **Group Efficiency (η_g)**

$$\boxed{\eta_g = \frac{Q_{ug}}{n \cdot Q_{up}}}$$

Q_{ug} = Ultimate load capacity of pile group

Q_{up} = Ultimate load on single pile

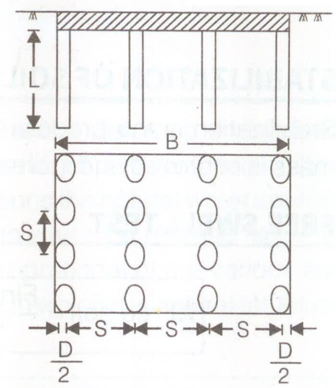
For sandy soil → $\boxed{\eta_g > 1}$

For clay soil → $\boxed{\eta_g < 1}$ and $\boxed{\eta_g > 1}$

Minimum number of pile for group action = 3.

$\boxed{Q_{ug} = q_b A_b + q_s A_s}$ where $\boxed{q_b = 9C}$ for clays

$\boxed{A_b = B^2}$ $\boxed{q_s = \bar{C}}$ $\boxed{A_s = 4B.L}$



- For Square Group

Size of group,

$\boxed{B = (n-1)S + D}$

where, η = Total number of pile

If size of group is x.x

They $\boxed{\eta = x^2}$

- $\boxed{Q_{ug} = \eta.Q_{up}}$

- $\boxed{Q_{ag} = \frac{Q_{ug}}{FOS}}$ where, Q_{ag} = Allowable load on pile group.

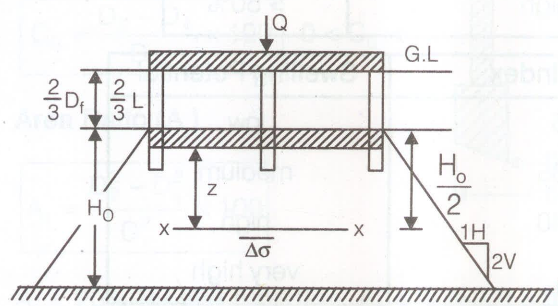
- $\boxed{S_r = \frac{S_g}{S_i}}$ where, S_r = Group settlement ratio

S_g = Settlement of pile group

S_i = Settlement of individual pile.

(ii) When Piles are Embended on a Uniform Clay

$$\boxed{S_g = \Delta H = \frac{C_c H_0}{1+e_0} \log_{10}\left(\frac{\bar{\sigma}_0 + \overline{\Delta\sigma}}{\bar{\sigma}_0}\right)} \quad \text{and} \quad \boxed{\bar{\sigma}_0 = \frac{Q}{(B+z)^2}}$$



(iii) In Case of Sand

$$\boxed{S_r = \frac{S_g}{S_i} = \left(\frac{4B + 2.7}{B + 3.6}\right)^2}$$ where, B = Size of pile group in meter.

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