Deep Foundation

A deep foundation is designed to transfer a superstructure load to the below layer of soil. It is required when the top layer of the soil stratum does not have the sufficient bearing capacity to transfer the loads. The bearing capacity of soil is the strength of the soil element that it can take before the failure occurs.

The criteria for the foundations to be deep foundation depends on the various parameters. According to **Dr Karl Terzaghi,** a foundation is called a deep foundation if its depth is longer than its width (ie. $D_f/B > 1$). Where D_f is the depth of the foundation and B is the width of the foundation.

Types of Deep Foundation

Deep foundations can be classified based on different parameters. It can be classified based on the type of soil present below the foundations. Based on the capacity of the soil, it can be classified into different types as below.

- Basement foundations
- Raft foundations
- Caissons
- Shaft foundations
- Cylinders
- Pile foundations

Bearing Capacity of Piles

The ultimate bearing capacity of a pile is the maximum load it can carry without failure or excessive settlement of the ground. The bearing capacity of piles also depends on the methods of installation. Let us check out various methods used in deep foundation:

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 the base of the 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) $Q_{safe} = Q_{up}/F_s$ where F_s = Factor of safety.

(vi) $Q_{safe} = (Q_{eb}/F_1) + (Q_{sf}/F_2)$

(vii) For Pure Clays $Q_{up} = 9CA_b + \alpha \bar{C} A_s$

B. Dynamic Approach

Dynamic methods are suitable for dense cohesionless soil only.

(i) Engineering News Records Formula

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

(b) $Q_{ap} = Q_{up}/FOS$

where,

- Q_{up} = Ultimate load on pile
- Q_{ap} = Allowable load on pile
- W = Weight of hammer in kg.
- H = Height of fall of the 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

$Q_{ap} = WH/\{6(S+2.5)\}$

(d) For single Acting Stream Hammer

Q_{ap} = WH/{6(S+0.25)}

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

$Q_{up} = \eta_h.\eta_b.WH/(S+0.5C)$

$Q_{ap} = Q_{up}/F_s$

- where, F_s = Factor of safety = 3
- η_h = Efficiency of hammer
- η_b = Efficiency of the blow
- η_h = 0.75 to 0.85 for single-acting steam hammer
- η_h = 0.75 to 0.80 for double-acting steam hammer
- η_h = 1 for drop hammer.

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

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

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

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 the pile, pile cap and soil
- H = Height of fall of the hammer.

C. Field Method

(i) Use of Standard Penetrations Data

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

where,

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

$Q_{ap} = Q_{up}/F_s$

F_s = Factor of safety = 4 → For driven pile

= 2.5 → for the bored pile.

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

(ii) Cone penetration test

$Q_{up} = q_c A_b + 0.5\ \bar{q_c}\ A_s$

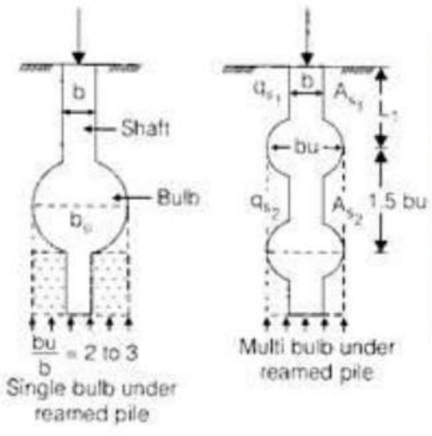
where

- q_c = static cone resistance of the base of the pile in kg/cm^2
- q_c = average cone resistance over depth of pile in kg/cm^2

A_b = ¼ $(b_u)^2$ =Area of the bulb $(m)^2$

What is an 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 in sandy and in clayey soils. In this type of deep foundation, ratio of bulb size to the pile shaft size may be 2 to 3; usually, a value of 2.5 is used.



$A_{s1} = \pi b L_1$ and $q_{s1} = \alpha C$; $\alpha<1$

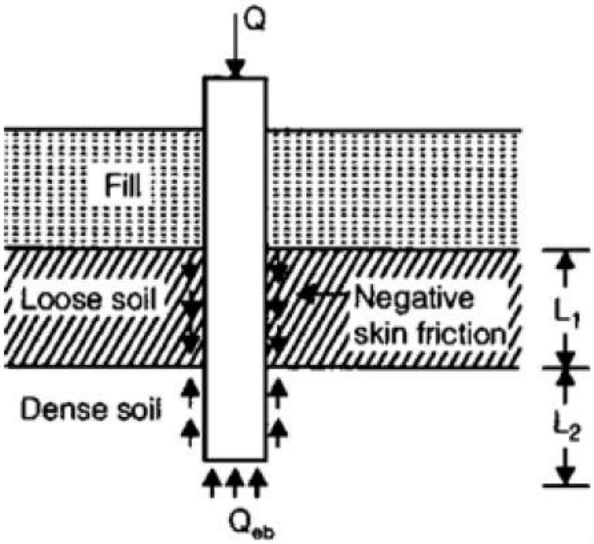
$A_{s2} = \pi b_u L_2$ and $q_{s2} = \alpha C$; $\alpha=1$

where, b_u = dia of bulb, Spacing = 1.5 b_u.

$Q_{up} = q_b A_b + q_{s1} A_{s1} + q_{s2} A_{s2}$

Negative Skin Friction in Piles

Negative skin friction in a pile is the frictional resistance offered by the surface of the pile. And it reduces the ultimate load capacity of the piles. Negative skin friction occurs in a pile due to a sandy layer surrounding the soil. It acts in the downward direction hence, reduces the overall bearing capacity.



(i) For Cohesive soil

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

where Q_{nf} = Total negative skin friction.

$F_s = (Q_{up} - Q_{nf})$ / Applied load
where F_s = Factor of safety.

(ii) For cohesionless Soils

Q_{nf} = P x force per unit surface length of the pile

$= \frac{1}{2} \times P \times K\gamma D^2{}_n. \tan\delta$

$Q_{nf} = \frac{1}{2} \times P \times K\gamma D^2{}_n. \tan\delta$

(friction force = μH)

Where γ = unit weight of soil.

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

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

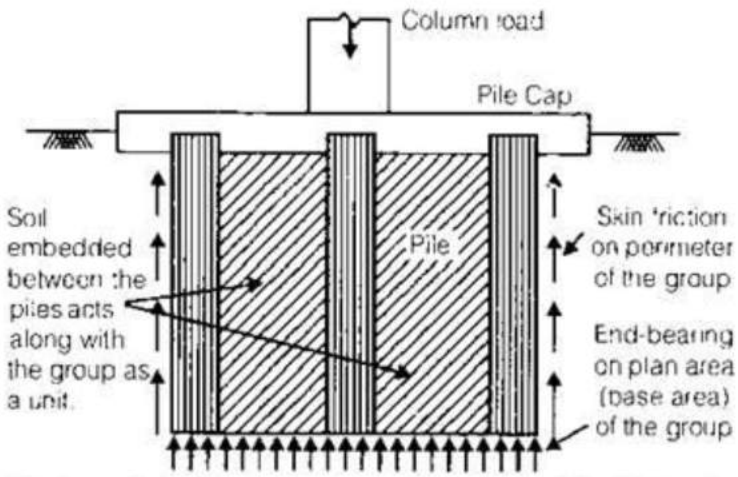
Group Action of Pile

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) the Ultimate load-carrying capacity of the single large equivalent (block) pile (Q_{ug}).

To determine the design or allowable load, apply a suitable safety factor.



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

(i) Group Efficiency (η_g)

$\eta_g = Q_{ug}/n.Q_{up}$

Q_{ug} = Ultimate load capacity of pile group

Q_{up} = Ultimate load on the single pile

For sandy soil → $\eta_g > 1$

For clay soil → $\eta_g < 1$ and $\eta_g > 1$

The minimum number of piles for the group = 3.

$Q_{ug} = q_bA_b + q_sA_s$

where q_b = 9C for clays

$A_b = B^2$

$q_s = C^{-}$

$A_s = 4BL$

- **For Square Group**

Size of group, B = (n – 1) S + D

where η = Total number of piles if the size of a group is x.x

They $\eta = x^2$

- $Q_{ug} = \eta . Q_{up}$
- $Q_{ag} = Q_{ug}/FOS$; where Q_{ag} = Allowable load on pile group.
- $S_r = S_g/S_i$

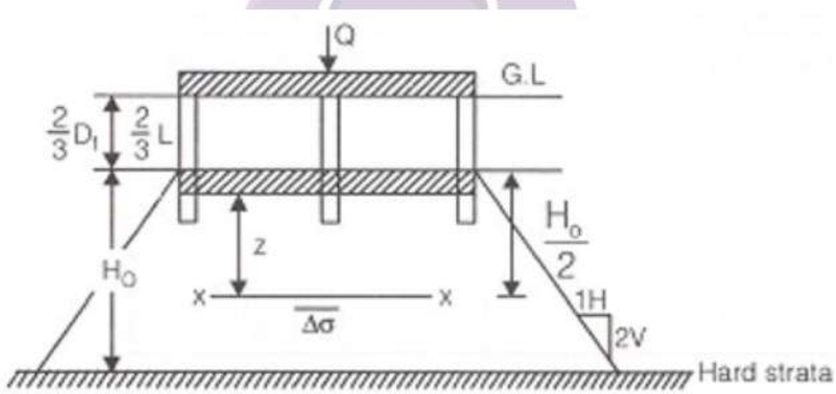
where, S_r = Group settlement ratio

S_g = Settlement of pile group

S_i = Settlement of individual pile.

(ii) When Piles are Embedded on a Uniform Clay

$$S_g = \Delta H = \frac{C_c H_0}{1+e_0}\log_{10}\frac{\overline{\sigma_0}+\overline{\Delta\sigma}}{\overline{\sigma_0}} \; and \; \overline{\sigma_0} = \frac{Q}{(B+z)^2}$$



(iii) In the case of Sand

$S_r = S_q/S_i = [(4B + 2.7)/(B + 3.6)]^2$

where B = Size of the pile group in meters.