27th sept,
saturday

PILE FOUNDATIONS

- Deep Foundation.
- Punching shear failure occurs

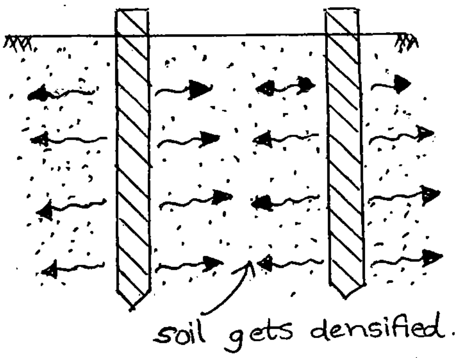
→ Necessity of Pile foundation :

- if loads are heavy and soil is poor.
- in expansive soils (like black cotton soil)
- to transfer loads onto a hard stratum.
- to resist uplift loads, horizontal loads etc.
- to reduce settlements.

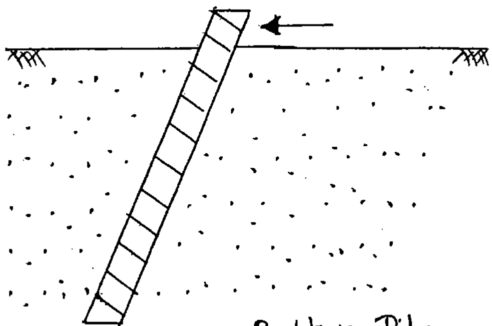
→ Classification of Piles :

* Based on Function (or purpose)

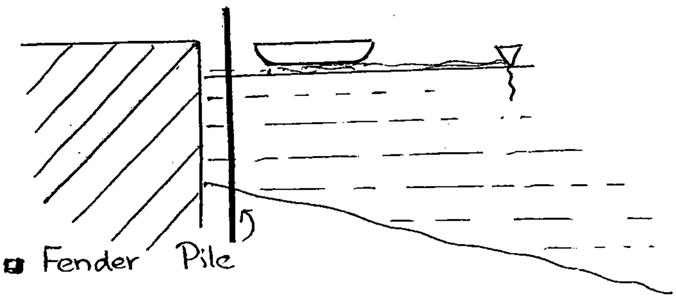
- compaction pile : to compact the soil (loose & medium sand,
- tension pile : to resist uplift loads.
- batter pile : inclined pile to resist lateral load.
- anchor pile : to anchor the structure
- Fender or dolphin pile : for protection of water front structures



Compaction pile.



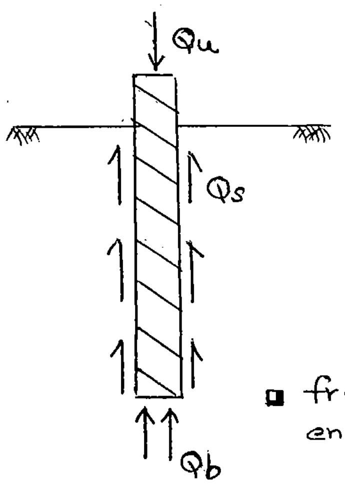
Batter Pile.



Fender Pile

* Based on Load Transfer.

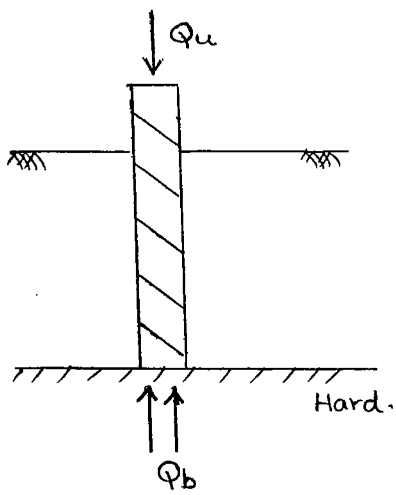
- Friction Pile : generally in clays.
- End bearing Pile : pile resting on hard stratum
- Friction cum end bearing pile : generally in sands



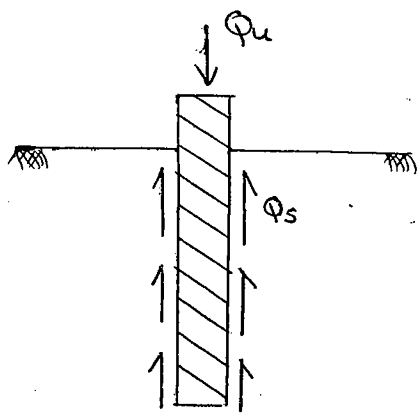
$Q_b \rightarrow$ end bearing resistance.

$Q_s \rightarrow$ skin frictional resistance.

▪ friction cum end bearing piles



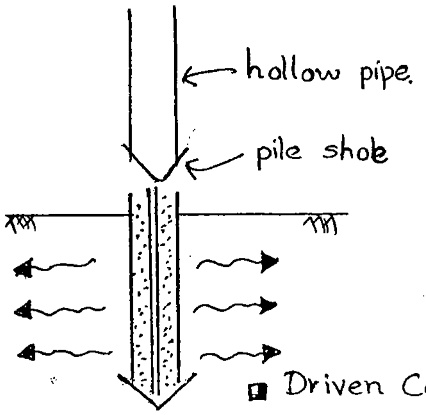
▪ End bearing piles



▪ friction piles

* Based on Construction

- Precast driven pile : in loose sand & medium dense sand
- Driven cast-in-situ pile.: in loose sand & "
- Bored cast-in-situ pile.: in clays.



- Hollow pipe is driven into soil
- Pile is casted in site using steel rft. & concrete in the hollow pipe.
- Hollow pipe is removed using cranes immediately after casting the piles.

▪ Driven Cast in-situ pile.

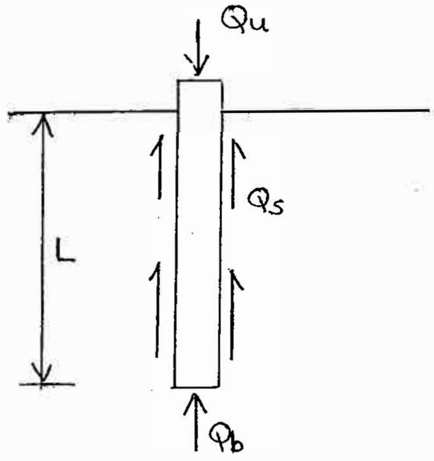
→ Pile driving Equipment :

- Simple drop hammer
- Single acting steam hammer.
- Double acting steam hammer
- Diesel hammer
- vibratory driving system.: least noise. (no hammers used in loose soils).

→ Load Carrying Capacity of Pile :

1. Static Formulae
2. Dynamic Formulae.
3. Pile load tests.
4. N- Value method (N-SPT value)

* Static Formulae :



$$Q_u = Q_b + Q_s$$

$$= A_b f_b + A_s f_s$$

A_b → area of pile at pile base ($= \pi/4 \, d^2$).

f_b → bearing capacity of soil at pile base level.

A_s → skin. surface area of pile. ($= \pi d l$).

f_s → shear resistance of soil, surrounding the pile shaft

a) For clays : ($\phi = 0$)

$$f_b = C_1 N_c$$

C_1 : cohesion at pile base level.

$N_c = 9$ (for $\phi = 0$)

$S = c + \sigma \tan\phi$

$S = c + 0.$

$$f_s = \alpha C_2$$

C_2 : cohesion of soil along the pile shaft.

α : shear mobilisation factor (or) adhesion factor

$\alpha = 1$; for soft clay

$\alpha < 1$; for stiff clay.

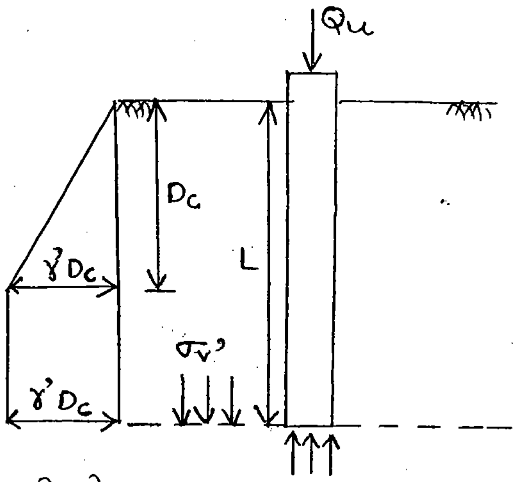
$$\therefore \boxed{Q_u = A_b C_1 N_c + A_s \alpha C_2}$$

$$Q_{safe} = \frac{Q_u}{F}$$

29th Sept,
MONDAY

b) Single Pile in Sand ($c=0$)

$$Q_u = A_b f_b + A_s f_s$$



To find f_b:

$$f_b = \sigma_v' N_q$$

σ_v' = effective vertical stress at pile base level.

D_c → critical depth : depth upto which σ_v' increases and then remains a constant.

D_c = 10 d to 20 d ; depending on soil type

$$\therefore f_b = \sigma_v' N_q$$

$$\Rightarrow \boxed{\begin{aligned} \sigma_v' &= \gamma' D_c \quad ; \text{ if } L \geq D_c \\ &= \gamma' L \quad ; \text{ if } L < D_c \end{aligned}}$$

To find f_s:

$$f_s = k \cdot \sigma_a' \cdot \tan\delta$$

σ_a' → average effective vertical stress along the pile shaft.

K → coeffecient of lateral earth pressure.

'K' is found out from field in-situ test for pile.

$\boxed{K = 1 \text{ to } 3}$; depending on soil type.

$\delta \rightarrow$ angle of friction b/w pile and soil

$\boxed{\delta = \phi}$; as per BIS

For Clay:

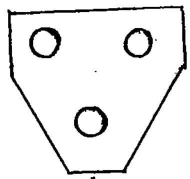
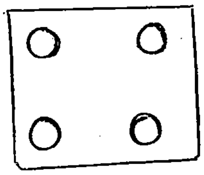
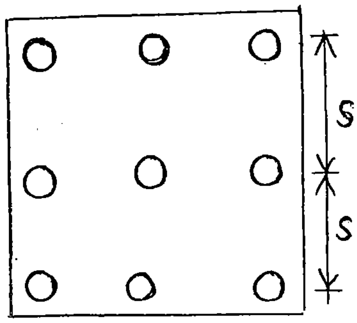
$$Q_u = A_b C_1 N_c + A_s \cdot \alpha C_2$$

For Sand:

$$Q_u = A_b \sigma_v' N_q + A_s K \cdot \sigma_a' \tan\delta$$

→ Group Piles

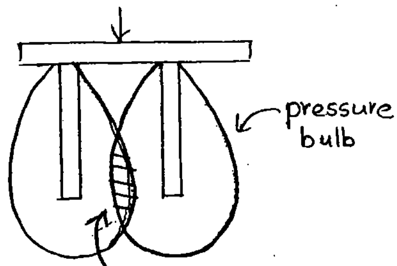
- under a column, a min. of 3 piles shall be used.

$S \rightarrow$ min spacing b/w c/c of piles.

$S = 3d$; for friction piles.

$\;\; = 2.5d$; for end bearing piles.



- Benefits of group piling are:
  a) Increases reliability.
  b) eccentricity is avoided.
- Min spacing is recommended to avoid "stress overlap"

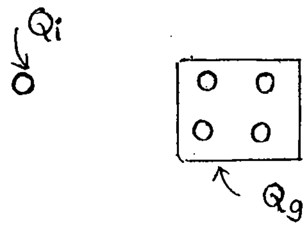
(Due to stress overlap, settlement increases)

* Pile Group Efficiency, $\eta_g = \dfrac{Q_g}{n \cdot Q_i} \times 100$

$Q_g \rightarrow$ total group capacity.

$n \rightarrow$ no. of piles in the group.

$Q_i \rightarrow$ capacity of single, in isolation.



η_g is the ratio of average capacity of a single pile in a group action to the single capacity of a pile in isolation. (OR) is the ratio of total capacity of a group pile to the sum of capacities of individual piles in isolation.

$\eta_g > 100\%$; for loose & medium dense sands

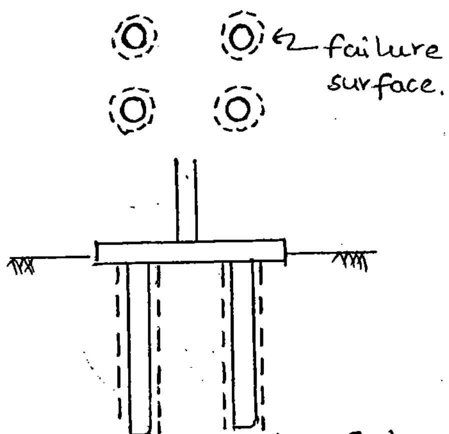
$\eta_g < 100\%$; for dense sand & clays

Loose and medium dense sands gets compacted upon group piling and $\therefore \eta_g > 100\%$.

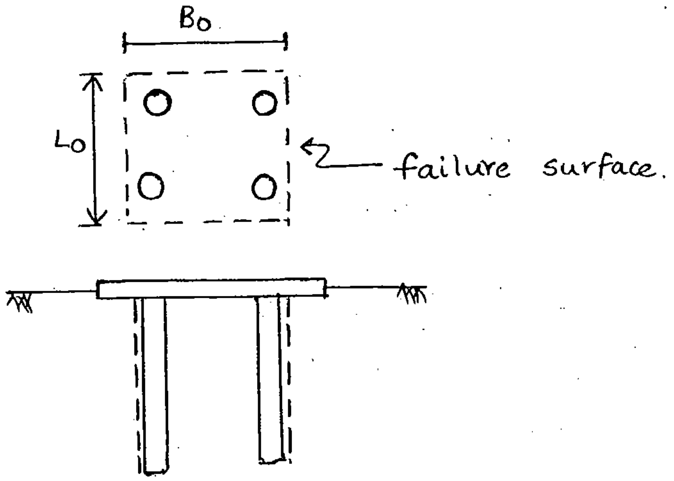
* Modes of failure of Pile Group:

(i) Individual Pile Failure.

(ii) Block Failure.



▫ individual pile failure



▫ Block Failure

* Pile Group Capacity based on Individual Failure mode

$$Q_{gi} = n Q_i$$

$$= n \left(A_b . C_1 N_c + A_s \alpha C_2 \right) \rightarrow \text{for clay}$$

$$= n \left(A_b \sigma_v' N_q + A_s K . \sigma_a' \tan \delta \right) \rightarrow \text{for sand}$$

* Pile Group Capacity based on Block Failure mode:

$$Q_{gb} = A_B \cdot C_1 N_c + A_s C_2 \quad \rightarrow \text{for clay}$$

$$= A_B \cdot \sigma_v' N_q + A_s \, K \cdot \sigma_a' \tan\delta \quad \rightarrow \text{for sand}$$

$A_B \rightarrow$ area of block $= B_o \cdot L_o$

$A_s \rightarrow$ perimeter of block $\times L = 2(B_o + L_o) \cdot L$

α is adhesion factor.

$\alpha = 1$ for block failure because contact is b/w soil & soil.

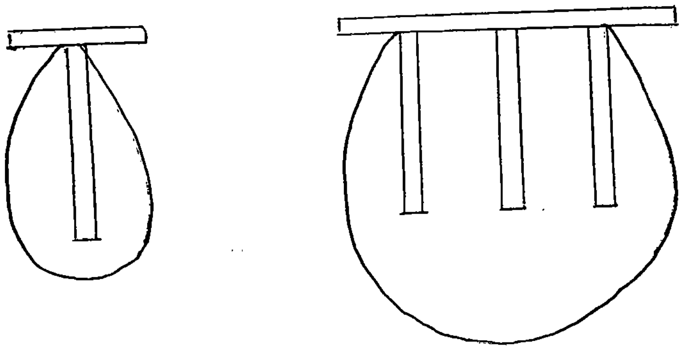
$\alpha < 1$ for individual pile as contact is b/w soil & pile.

$\therefore$ Pile group capacity, Q_g = Smaller of Q_{gi} & Q_{gb}

Safe capacity, $= \dfrac{Q_g}{F}$

NOTE:

Settlement of a group pile is always more than that of a single pile. (due to larger size of pressure bulb)

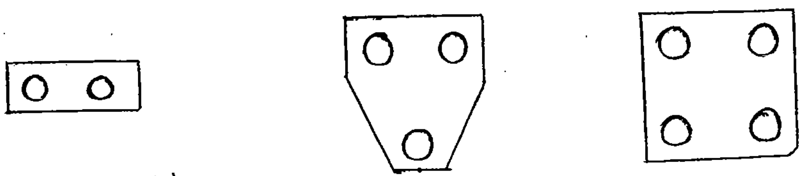


larger pressure bulb
$\Rightarrow$ more soil gets compressed, and
$\therefore$ more settlement.

→ Empirikal Formulae to find η_g:

1. Feld's Rule.

In this rule, for every nearby pile, $\frac{1}{16}$th capacity is reduced. (for all types of soil)

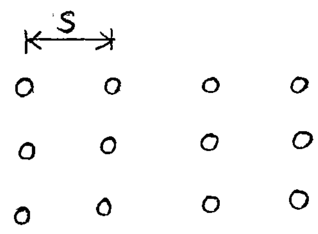


$\eta_g = 1 - \frac{1}{16} = \frac{15}{16}$ //

$\eta_g = 1 - 2 \times \frac{1}{16} = \frac{14}{16}$ //

$\eta_g = 1 - 3 \times \frac{1}{16} = \frac{13}{16}$ //

2. Converse - Lebarre Formula.



$$\eta_g = 1 - \frac{\theta^{\circ}}{90}\left[\frac{m(n-1)+n(m-1)}{m.n}\right]$$

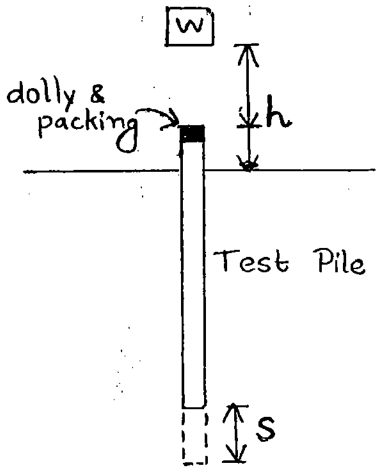
$$\theta^{\circ} = \tan^{-1}\left(\frac{d}{s}\right)$$

m = no: of rows of piles.

n = no: of piles in each row.

$d \rightarrow$ diameter of pile ; $s \rightarrow$ spacing b/w piles

→ Dynamic Formulae:



1. Engineering News Formula

$S \rightarrow$ set value or settlement per blow.

$$Q_{safe} = \frac{W h \eta_h}{F(s+c)}$$

$c \rightarrow$ a constant

$C = 2.54$ cm for drop hammer

$= 0.254$ cm for steam hammer

$F \rightarrow$ factor of safety (min. of 6)

2. Hiley's Formula.

$$Q_{safe} = \frac{W h \eta_h \cdot \eta_b}{F(s + c/2)}$$

$\eta_h \rightarrow$ efficiency of hammer

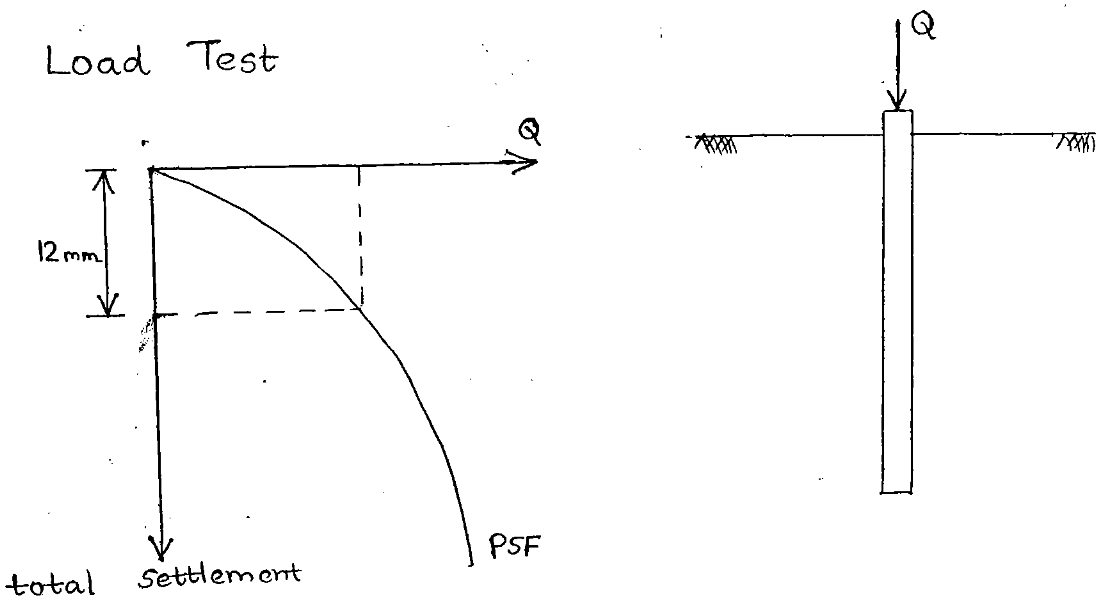
$\eta_b \rightarrow$ efficiency of blow.

$C \rightarrow$ total temporary elastic compression of soil, pile & packing.

$$C = C_1 + C_2 + C_3$$

As this test is based on 'short term loading', it is suitable only for sand and not for clays.

→ Pile Load Test



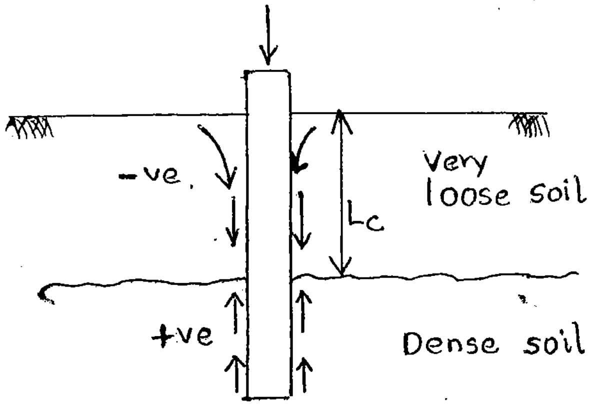
Safe load is taken as the smaller of the following:

(i) $\frac{2}{3}$ of load corresponding to a total settlement of 12 mm.

(ii) $\frac{2}{3}$ of load corresponding to a net settlement of 6 mm.

(iii) 1/2 of load corresponding to a total settlement of 10% d.

→ Negative Skin Friction:



When loose soil compacts, it drags the pile along with it. Negative skin friction occurs when settlement of loose soil due to compaction is more than the settlement of pile due to external loading.

* Negative Skin Friction occurs in the case of:

(i) Recently filled upsoil.

(ii) Very loose sand.

(iii) Soft clay.

(iv) Due to lowering of WT (σ' ↑ and settlement increases)

(v) Pile driving operations nearby.

* Negative Skin Friction can be reduced by:

(i) Keeping the surface of pile smooth in areas of loose sand.

(ii) Providing a sleeve to the pile and isolating it from surrounding loose sand.

* To calculate negative skin friction:

(i) In Clays:-

$$\boxed{Q_{nf} = \pi d L_c \alpha c.}$$ (usually $\alpha = 1$)

(ii) In Sands:-

$$\boxed{Q_{nf} = \pi d L_c \, k \cdot \sigma_a' \tan \delta}$$

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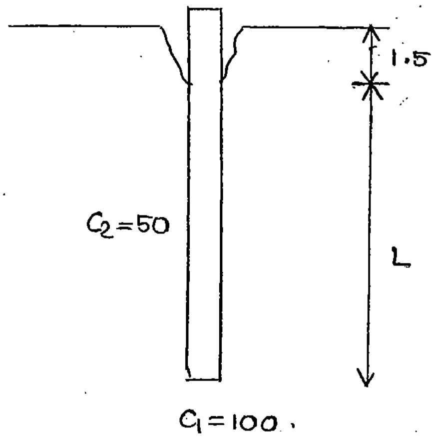


1. $Q_u = A_b C_1 N_c + A_s \alpha \cdot C_2$.

$= \frac{\pi}{4} \times 0.3^2 \times 100 \times 9 + \pi \times 0.3 \times 5 \times 0.3 \times 50$.

$= \underline{\underline{134 \text{ kN}}}$

2. $Q_{safe} = \frac{1}{F}\left(A_b C_1 N_c + A_s \alpha C_2\right)$.

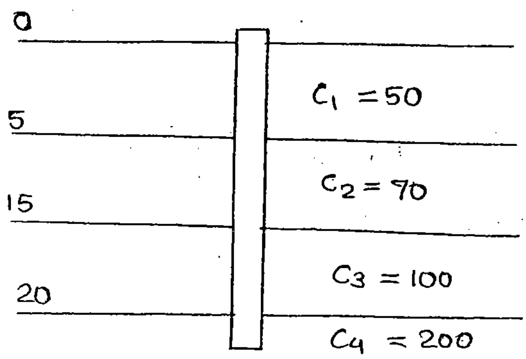
$400 = \frac{1}{2.5}\left(0.45^2 \times 100 \times 9 + 4 \times 0.45 \times L \times 0.75 \times 100\right)$.

$\Rightarrow L = \underline{\underline{6.05 \text{ m}}}$

3. $Q_{safe} = \frac{1}{F}\left(A_b C_1 N_c + A_s \alpha C_2\right)$

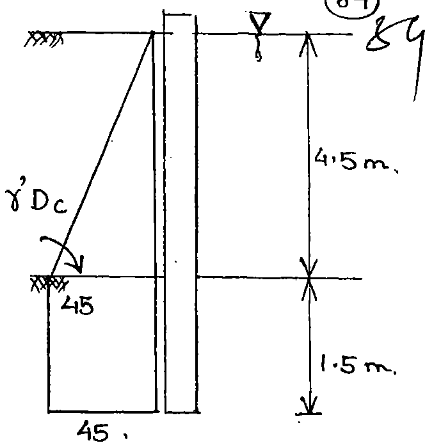
$= \frac{1}{2.5}\left(\frac{\pi}{4} \times 0.5^2 \times 200 \times 9 + \pi \times 0.5 \times 0.4 \left(50 \times 5 + 70 \times 5 + 100 \times 5 + 200 \times 5\right)\right)$

$= \underline{\underline{669.16 \text{ kN}}}$



04\. NOTE :

If critical depth is not mentioned in the case of cohesionless soils, then assume that D_c is more than length of piles and take linear vertical stress distribution to estimate capacity of pile.



$$\gamma_{sat} = 2 g/cc = 19.613 \ kN/m^3 \approx 20 \ kN/m^3$$

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

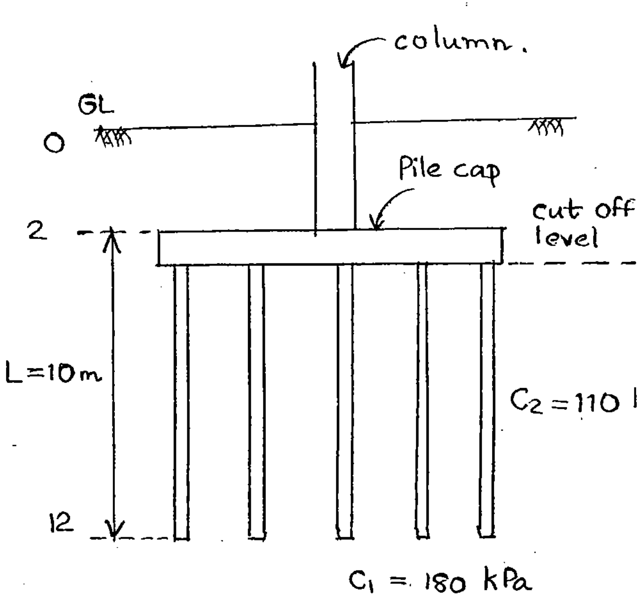
$$Q_u = A_b \sigma_v' N_q + A_s \, k . \sigma_a' \tan\delta$$

$$= \frac{\pi}{4} \times 0.45^2 \times 45 \times 18 + \pi \times 0.45 \times 4.5 \times 1.2 \left(\frac{0+4.5}{2}\right) \tan 20^\circ +$$

$$\pi \times 0.45 \times 1.5 \times 1.2 \left(\frac{45+45}{2}\right) \tan 20^\circ$$

$$= \underline{\underline{233 \ kN}}$$

05\. $B_o = L_o = 4s + d = 4.5 m$



$$Q_{gi} = n \ Q_i$$

$$= 25 \left(\frac{\pi}{4} d^2 . C_1 N_c + \pi d L \alpha C_2\right)$$

$$= 27390 \ kN.$$

$$Q_{gb} = A_B C_1 N_c + A_s C_2$$

$$= B_o L_o C_1 N_c + 2 (B_o + L_o) L \ C_2$$

$$= 52605 \ kN.$$

Q_g = Smaller of Q_{gi} & Q_{gb}.

$$= \underline{\underline{27390 \ kN.}}$$

06\. $B_o = L_o = (3s+d)$.

For $\eta_g = 100\%$ (or for optimum condition)

$$Q_{gi} = Q_{gb}.$$

$$n(\pi d L \alpha c) = 4 \times B_o \times L\ C.$$

$$16(\pi \times d \times L \times 0.6\,c) = 4\,(3s + d)\,L\,c$$

$$\Rightarrow s = 2.18d$$

07. Safe capacity of single isolated pile,

$$Q_i = \frac{1}{F}\left(\frac{\pi}{4} d^2 \times C_1 N_c + \pi d L \alpha C_2\right).$$

$$= \frac{1}{2.5}\left(\frac{\pi}{4} \times 0.3^2 \times 150 \times 9 + \pi \times 0.3 \times 10 \times 0.57 \times 100\right).$$

For $\eta_g = 1$,

$$= 253.05 \text{ kN}$$

$$Q_g = n\,Q_i$$

$$\text{or} \quad n = \frac{Q_g}{Q_i} = \frac{5000}{253.05} = 19.75 \text{ no.s} \approx 20$$

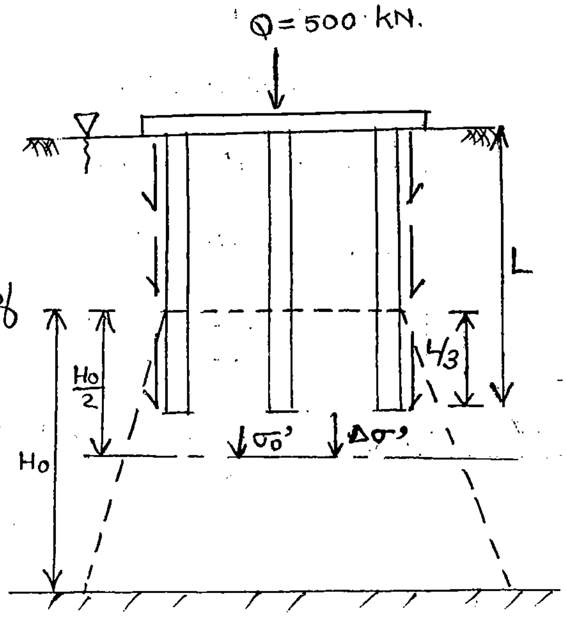
09. Rated energy, $Wh = 3500$ kN cm.

$$Q_{safe} = \frac{Wh\,\eta_h\,\eta_b}{F(s + C/2)}$$

$$S = \frac{25.4}{6} = 4.23 \text{ mm} = 0.423 \text{ cm}$$

$$\therefore Q_{safe} = \frac{3500 \times 0.8 \times 0.476}{4\,(0.423 + 1.8/2)} = 251 \text{ kN}$$

08. The given pile group is assumed to be friction pile group and the total load is assumed to be acting at lower $\frac{1}{3}$rd of length of pile for settlement calculations



$$S_f = H_o.\frac{C_c}{1+e_o}\log_{10}\left(\frac{\sigma_o' + \Delta\sigma'}{\sigma_o'}\right)$$

$H_o = 3.667$ m

$\sigma_o' = \left(3.33 + \frac{3.667}{2}\right)\gamma' = 51.63$

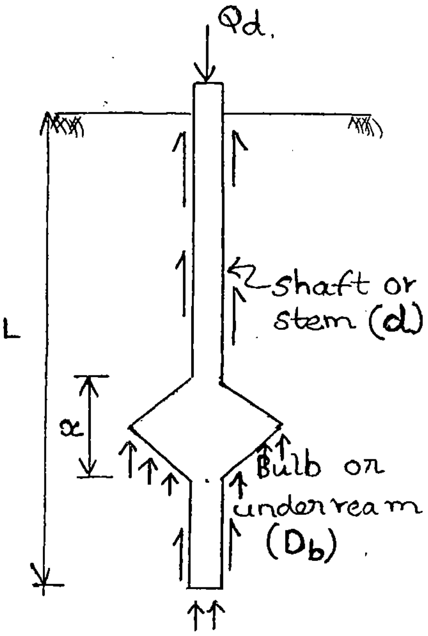
$\Delta\sigma' = \frac{Q}{(B_o+z)^2}$; $B_o = 2s+d$, $z = \frac{H_o}{2}$

$= \frac{500}{(1.2+1.8335)^2} = 54.335$ kN/m^2.

$S_f = 3.667 \times \frac{0.027}{(1+1.05)} \times \log_{10}\left(\frac{51.63+54.335}{51.63}\right) = \underline{15.08 \text{ mm}}$

→ Under-reamed Piles.

- The bulb provides anchorage against uplift caused by expansive soils.
- Generally used in B.C soil.
- Bulb diameter, $D_b \approx 2.5\,d$.
- Bored cast-in-situ piles.

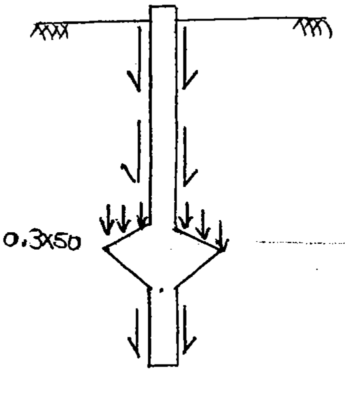


Ultimate downward load carrying capacity, $Q_d = \frac{\pi}{4}d^2 C_1 N_c + \frac{\pi}{4}\left(D_b^2 - d^2\right) C_2 N_c + \pi d\,(L-x)\,\alpha\, C_a$

C_a → avg. cohesion along pile length.

Ultimate uplift resisting capacity,

$Q_{up} = \frac{\pi}{4}\left(D_b^2 - d^2\right) C_2 N_c + \pi d\,(L-x)\,\alpha\, C_a + \text{self weight.}$

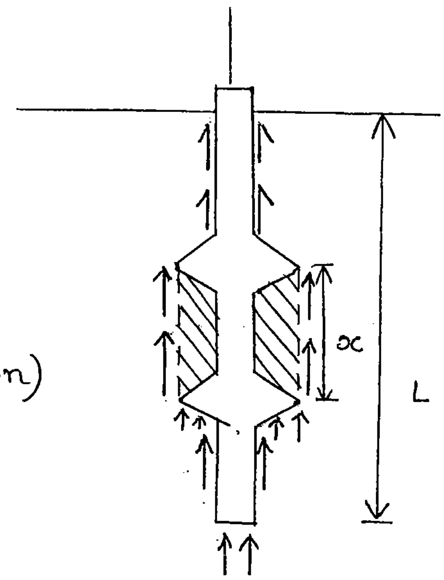


10. $Q = \frac{\pi}{4}\left(0.75^2 - 0.35^2\right) . 50 \times 9 + \pi \times 0.35\,(8-0.4) \times 0.3 \times 50$
$+ 20$

$= \underline{300.8}$ kN

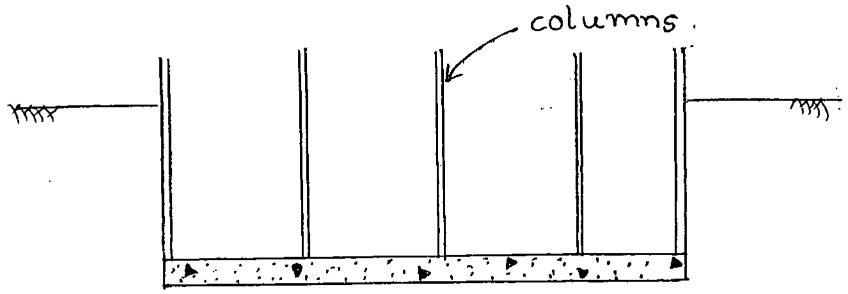
* Double Under-reamed Pile.

$$Q_d = \frac{\pi}{4} d^2 c_1 N_c + \frac{\pi}{4}(D_b^2 - d^2) c_2 N_c + \pi d (L - x)\, \alpha\, c_a + \pi D_b \cdot x \cdot c_a$$



→ Raft Foundations : (Mat Foundation)

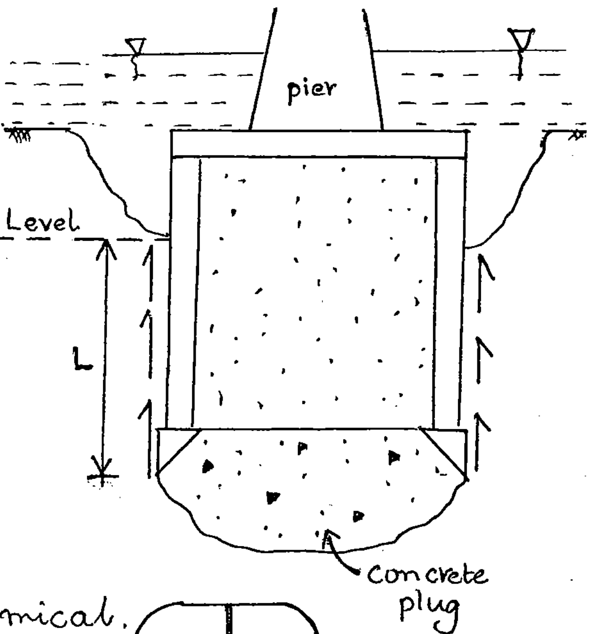
- common footing for all columns.



- shallow foundation
- to avoid differential settlement.
- also used in poor soils if loads are heavy.

→ Well Foundation :

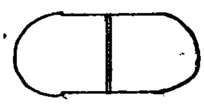
- used for bridges across rivers.



Max Scour level is depth at which max erosion occurs.

Depth of the well foundation below the max scour level is the 'Grip Length'

- double D shape is most economical.



- As per IS code of practise, the allowable tilt & shift are 1 in 60 & 1% of depth of sunk.