PILE FOUNDATION (DEEP FOUNDATION)

($D_f >> B$)

1) Pile foundation is a deep foundation which is mainly used for bridge construction.

2) There are three types of deep foundation
   a) pile foundation
   b) Pier foundation
   c) Cassion foundation

3) Pier foundation is mainly used for small culverts where the excavation is carried out upto till hard stratum is found and then concrete or masonary is used as foundation material.

The main diff. between pile & pier is the mode of construction, incase of pile excavation is not required i.e., only driving is used but incase of pier foundation excavation is compulsory till hard stratum is reached.

4) There are three type of cassion
   a) Box cassion
   b) Open cassion (well foundation)
   c) Pneumatic cassion

5) Box cassion is a readymade box type structure having hexagonal (or) circular c/s made up of Rcc which is drop in the excavated region below the bed of River. On the top of box cassion pier is erected to support the bridge.

It is used for small bridge construction where depth of foundation is 5-7m

6) The Box caission cannot develope very good anchorage with surrounding soil due to excavation of the soil and hence it is not suitable for large bridges with high flood level, where there is more change of scouring

7) Open caission is known as well foundation which is most poputarly used in india for foundation of bridges. It is cast in situ structure below the bed of river and hence their is sufficient grip with surrounding soil & hence their is less change of scouring. It consist of cutting edge at the bottom, curb just above the cutting edge, steining supported by curb, sand filling or concrete filling in the central zone & cap at the top most to support the pier.

It is adopted for a depth of 7-12 m

8) If the depth of foundation is more than 12 m It become very uneconomical to pump out water for well foundation. In such case only pneumatic caission shall be used. where compressed air is supplied in working chamber of excavation so that seepage water cannot rise up. It is similar to well foundation The maxm depth of pneumatic caission below HFL is 35 m. The maxm tolerrance pressure on human chest is 3.5 kg/cm^2

$P = \gamma h$

$3.5 \times 10^4 \text{ kg/m}^2 = 1000 \text{ kg/m}^3 \times h$

$h = 35 \text{ m}$

9) Pile foundation is adopted in following circumstances:-

① If the top soil is very loose or very soft for greater depth where excavation is uneconomical

② If timbering of side of cuft is uneconomical

③ If their is heavy seepage where pumping out of water is very difficult

4) If the building is near river bank where chance of scouring

5) If the building is near sea shore

10) Types of Pile :-

The pile is classified based on following category

(a) Based on function

b) Based on material

c) Based on (driving operation) installation

d) Based on method of construction

11) Based on funch their are following types :-

1) Bearing pile (pt bearing pile)
2) Friction pile
3) Compaction pile
4) Tens^n pile
5) Uplift pile
6) Sheet pile
7) Anchor pile
8) Fender pile
9) Batter pile
10) Dolphin pile

12) The ultimate load carrying capacity of a pile is the external load on the pile on which the pile sinks downward without further increment of load.

The safe load is the ultimate load divided by FOS.

where, FOS is dependent on the method used

13) There are following methods to det^n load carrying capacity of the pile.

1. Static formula method
2. Dynamic formula method
3. Pile load test
4. Cone penetration test

14) In static formula method the capacity of soil supporting the pile is taken into account where skin friction & PE bearing are considered

⇒ Skin friction is based on adhesion & the actual friction developed by the soil. If the soil is of c-ϕ characteristic the both adhesion & friction are considered.

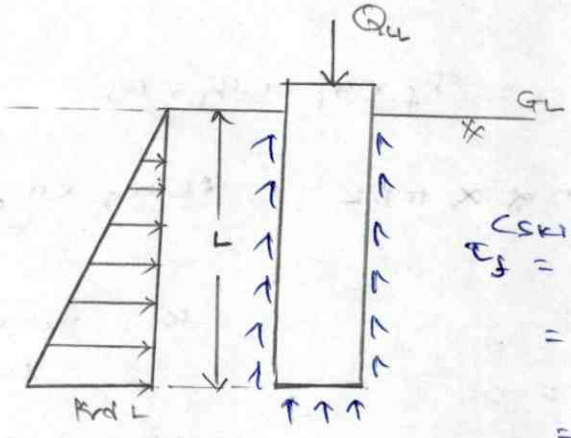
If the soil is of pure cohesion ($\phi = 0$) then friction is neglected ($\delta = 0$) & only adhesion is considered (αc)

where,

α = adhesion factor

c = cohesion.

If the soil is cohesionless ($c=0$) only friction is considered ($\sigma \tan\delta$)



(Skin friction)

$\tau_f = \alpha c + \sigma \tan\delta$

$= \alpha c + K\left(\frac{0+\gamma L}{2}\right)\tan\delta$

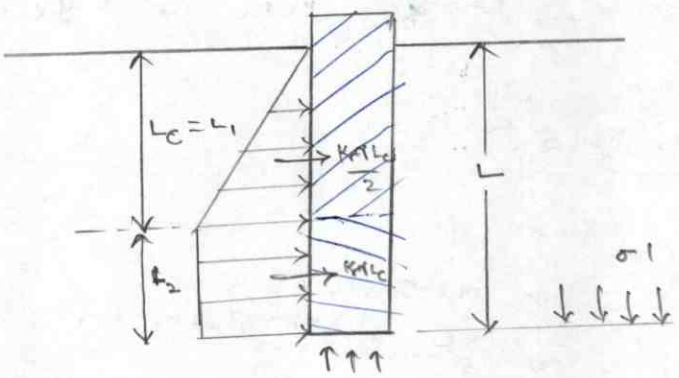
$= \alpha c + K\frac{\gamma L}{2}\tan\delta$

$q_b = cN_c + 0.5\gamma B N_\gamma + \gamma L N_q$ (KN/m^2)

(IS bearing)

$q_b = 1.3cN_c + 0.3\gamma B N_\gamma + \gamma L N_q$

(Dr. Terzaghi)



$cN_c + 0.5\gamma B N_\gamma + \sigma' N_q$

$Q_u = Q_f + Q_b$

$Q_u = \tau_f \times A_f + q_b A_b$

$\tau_f = \alpha c + K\bar{\sigma}\tan\delta$

$A_f = \pi D L$

$q_b = cN_c + \sigma' N_q + 0.2\gamma B N_\gamma$ (Neglected)

$A_b = \pi/4 D^2$

$\sigma' = \gamma_1 h_1 + \gamma_2 h_2 + \dots + \gamma_{eff} h_n$

For pure cohesive soil :-

($\Phi = 0$)

$q_u = Q_f + Q_b$

$= (cN_c \times \frac{\pi}{4}D^2) + (\alpha c \times \pi D L)$

$N_c = 9$, Q_b, Q_f

$\Rightarrow Q_s = \frac{Q_u}{FOS}$, $FOS = 2.5$ to 3

α = adhesion factor

For cohesionless soil:-

($C = 0$)

$$Q_u = Q_f + Q_b = q_f \times A_f + q_b \times A_b$$

$$Q_u = \frac{K \gamma L}{2} \tan\delta \times \pi D L + \gamma L N_q \times \frac{\pi}{4} D^2$$

$$\Rightarrow Q_s = \frac{Q_u}{FOS \rightarrow (2.5 \text{ to } 3)}$$

K = co-efficient of Earth pressure

δ = wall friction angle

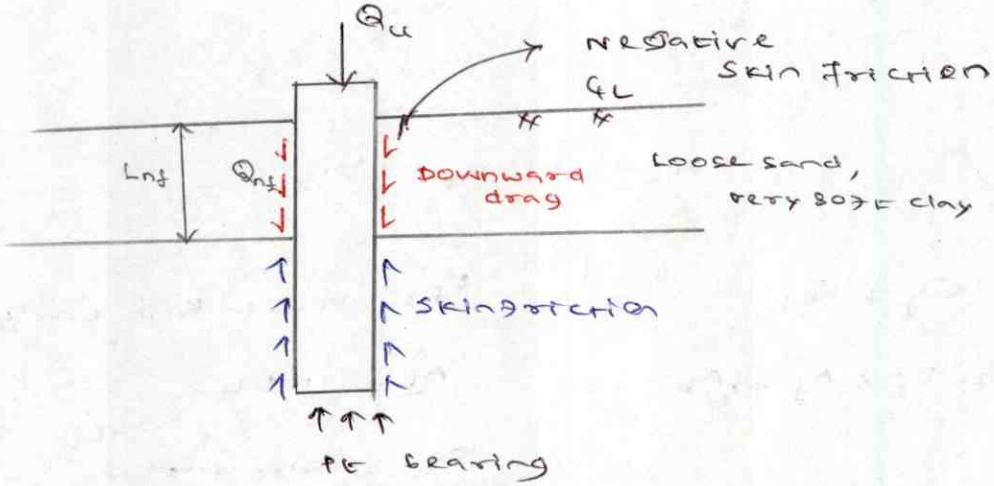
$\delta = \frac{1}{2}\phi$ to $\frac{3}{4}\phi$

For c-ϕ soil:-

$$Q_u = Q_f + Q_b$$

$$Q_u = \left(\alpha C + \frac{K \gamma L}{2} \tan\delta\right) \pi D L + (\beta C + \gamma L N_q) \times \frac{\pi}{4} D^2$$

(5) Negative skin friction



a) A downward drag

b) Reduce load carrying capacity of pile

c) Develops due to loose sand or very soft clay

d) " " comp^n of surrounding soil

e) " " lowering of WT

f) " " increase in effective stress

g) " " consolidation of soil due to increase in ext. pressure (oil)

(h) $Q_u + Q_{nf} - Q_f - Q_b = 0$

$$\Rightarrow \boxed{Q_u = Q_f + Q_b - Q_{nf}}$$

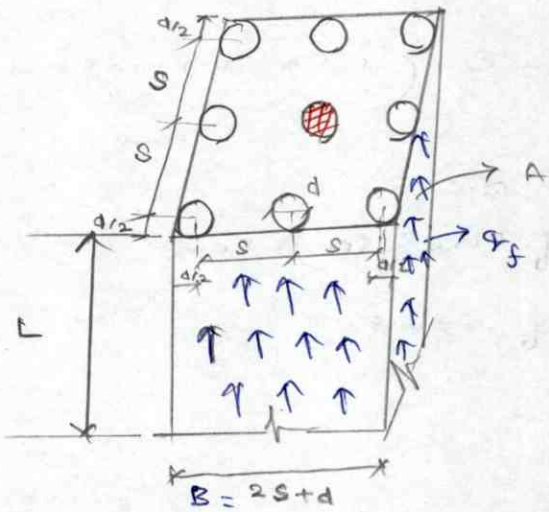
$\Rightarrow (\downarrow) Q_{nf} = \tau_f \times A_f$

$= (\alpha C + K_f \bar{\sigma}' \tan\delta) A_f$

$= \alpha C \times \pi d L$ for pure clay ($\Phi = 0$)

$(\downarrow) Q_{nf} = \frac{K_f d L_{nf}}{2} \times \tan\delta \times \pi d L$ for sandy soil ($C = 0$)

(16) Pile group



$Q_{ug} = 9C \times B^2 + C(4B \times L)$ for pure cohesive soil

$= \gamma L N_q \times B^2 + \frac{K_f \gamma L}{2} \tan\Phi \times 4B \times L$ for cohesionless soil

IS : 2911

$S = 2.5d$ (PE bearing pile)

$= 3d$ (Friction pile)

$= 2d$ Compaction pile)

b) Efficiency in pile group

$$\eta_g = \frac{Q_{ug}}{n \times Q_{u1}}$$

where, n = number of pile

Q_{u1} = capacity of one pile

Q_{ug} = capacity of pile group

c) $\eta_g < 100\%$.

$= 100\%$.

$> 100\%$.

d) $\eta_g = 100\%$.

$\Rightarrow Q_{ug} = n \times Q_{u1}$

$S = ?$

e) By converse Labbarre formula! -

$$\eta_{group} = 1 - \frac{\theta}{90^\circ}\left(\frac{n(m-1)+m(n-1)}{mn}\right)$$

$\tan\theta = d/s$

$\theta = \tan^{-1}(d/s)$

↑ degree

n = number of piles in a row

m = number of rows

f) Mr. Feld rule

$$\eta = 1 - \frac{\text{number of contact}}{16}$$

① $\eta = 1 - 1/16$

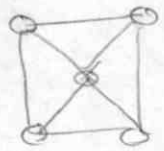
$= 15/16$

② $\eta = 1 - 3(1/16)$

$= 13/16$

② $\eta = 1 - 2(1/16)$

$= 14/16$



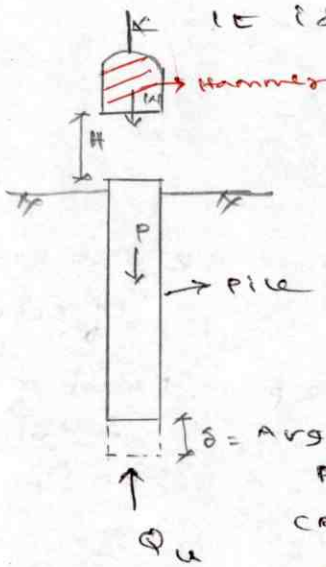
$$\eta_g = \frac{4 \times \left(1 - \frac{3}{16}\right) + 1 \times \left(1 - \frac{4}{16}\right)}{5}$$

$$\eta = 0.8 \approx 80\%$$

(17) Dynamic Formulae :-

a) Mr. Wellington's dynamic formulae is called Engineering News Formula

It is used to detn load carrying capacity of pile



$$Q_s = \frac{WH}{F(S + C_{avg})}$$

$\Rightarrow$ External WD = Internal energy

$$WH = Q_u \times S$$

$$\Rightarrow \boxed{Q_u = \frac{WH}{S}}$$

According to mr. Wellington,

$$Q_s = \frac{WH \rightarrow cm}{F(S + C)}$$

(cm) (cm)

F = 6 (FOS)

C = 2.5 (Drop Hammer) (constant) (cm)

= 0.25 (For steam Hammer) (cm)

$$\Rightarrow Q_s = \frac{WH}{6(S + C)}$$

W = wt of Hammer (Rammer / monkey) (1-3 tonnes)

H = Ht of fall in cm

b) Hiley formula (ISI formula)

(IS : 2911 - 1979)

$$Q_u = \frac{W H \eta_h \times \eta_b}{(S + C/2)}$$

η_h = hammer efficiency
η_b = eff. of blow
S = Avg. settlement per blow
C = elastic compn in cm

$$Q_s = \frac{Q_u}{F} \qquad F = 2 \text{ or } 2.5$$

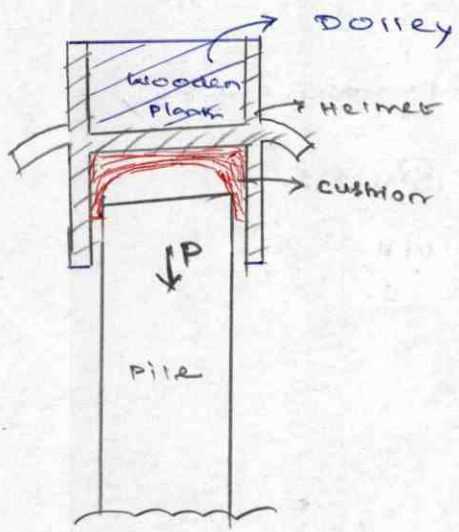
η_h = 100 % (drop hammer)
= 60 % (for other hammer)

$(H \times \eta_h)$ = Effective ht of drop hammer

$$\eta_b = \frac{W + e^2 P}{W + P} \quad \text{If } W > eP$$

$$= \frac{W + e^2 P}{W + P} - \left[\frac{W - eP}{W + P}\right]^2, \text{ If } W \le eP$$

e = co-efficient of restitution (e<1) (energy absorption)
P = wt of hammer + dolley



c) There are following drawbacks on dynamic formulae :-

* In case of loose sand under WT their is chance of liquifaction*
* Dynamic formulae are valueless in saturated clay. where friction / cadhesion, is affected.
* There is no correlation between soil property & pile.
* There are number of co-efficients which are complecated to find.
* Dynamic formulae may be applied for coarse grained soil where their is high dissipation of pore water pressure.

18) According to IS-2911, The safe load carrying capacity of pile can be determined by pile load test & the separation of skin friction & bearing from total capacity is determined by cyclic pile load test

a) 50% of load applied on the pile causing settlement = $\frac{1}{10}$ th of pile dia

b) $\frac{2}{3}$ of load applied on the pile causing settlement = 12 mm

settlement criteria

c) $\frac{2}{3}$ of load applied causing net settlement = 6 mm (net) (After removal of load)

d) $\frac{Q_u \text{ (ultimate load)}}{F}$ obtained by intersection of two tangents (plastic settlement) (shear criteria)

Whichever is least one

① A pile of 50cm dia & 10m long is embedded in clay deposite the undrained shear parameters are 60kPa, 0° $\alpha = 0.6$

Soln:-

$$Q_f = q_f \times A_f$$

$$= \alpha c \times \pi D L$$

$$= 0.6 \times 60 \times \pi \times 0.5 \times 10$$

$$\boxed{Q_f = 565.5 \text{ kN}}$$

② A group of 16 pile of 10m length & 50cm dia is installed in 10m thick clay. take $\alpha = 0.4$ & shear strength = 100kPa

Determ base resistance of bearing pile also determ group side resistance assuming 100% efficiency.

Soln:-

i) $Q_b = q_c \times \frac{\pi}{4} d^2$

$$\boxed{Q_b = 176.7 \text{ kN}}$$

$Q_f = \alpha c \times \pi d L$

$Q_f = 628.318 \text{ kN}$

ii) $Q_{ug} = n \times Q_{n_1}$

$q_c \times B^2 + C(4BXL) = 16 \times (q_c \times \pi/4 d^2 + \alpha c \times \pi d L)$

$$Q_{ug} = n \times Q_{g_1}$$

$$= 16 \times 628.3$$

$$\boxed{Q_{ug} = 10052.8 \text{ kN}}$$

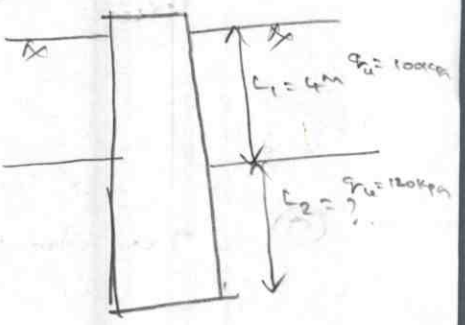
③ Dren the length of the pile, if the safe load is 200kN & FOS = 2.5

Take, unconfined compressive strength of clay = 100kPa

for 4m & 120kPa for remaining.

Take $\alpha = 0.6$; $\Phi = 50cm$

Soln:-



$$Q_u = Q_s \times F$$

$$qc \times \frac{\pi}{4} d^2 + \alpha c \times \pi d L = 200 \times 2.5$$

$$194.38 + 103.67(L_1 + L_2) = 500$$

$$\Rightarrow L_2 = 3.63^m$$

$$L = 7.63^m$$

18-01-10

Imp. formulae:

① $Q_u = q_b A_b + q_f A_f$

$= (cN_c + 0.3\gamma B N_\gamma + \gamma D N_q) \frac{\pi}{4} d^2 + (\alpha c + K \gamma \frac{L}{2} \tan\alpha) \pi d L$

② $Q_{ug} = (cN_c + 0.3\gamma B N_\gamma + \gamma L N_q) B^2 + (c + K\gamma \frac{L}{2} \tan\Phi)(4BxL)$

③ $\eta = \frac{Q_{ug}}{n \cdot Q_u}$ $< 100\%$.

$= 100\%$.

$> 100\%$.

④ $Q_{ug} = qc \times B^2 + c \times 4BL$ ($\Phi = 0$)

⑤ $Q_u = qc \times \frac{\pi}{4} d^2 + \alpha c (\pi d L)$ ($\Phi = 0$)

(6) $\eta_g = 1 - \frac{\theta}{90^\circ}\left(\frac{n(m-1)+m(n-1)}{mn}\right)$ (converse Labbane)

$\tan\theta = d/s$

(7) $\eta_g = 1 - \frac{\text{number of contact}}{16}$ (Mr. Feld)

(8) Q_u = Lesser of individual effect & Block failure

= Lesser of $(n \cdot Q_{u_1})$ & (Q_{ug})

(9) To find spacing for 100% efficiency

$Q_{ug} = n Q_{u_1} \Rightarrow$ B = ?

s = ?

(10) Engineering News Formula (Wellington's formula)

$$Q_s = \frac{W \cdot H}{F(S + C)}$$

(11) Hilry formula,

$$Q_s = \frac{W H \eta_h \eta_b}{F(S + C/2)}$$

$\eta_h \times H$ = eff. fall

$\eta_b = \frac{W + e^2 p}{W + p}$; $W > e$

$= \frac{W + e^2 p}{W + p} - \left[\frac{W - ep}{W + p}\right]$

$W \leq ep$

(12) Q_s = 50% Q_u causing 10% pile dia settlement

$= 2/3\, Q_u$ causing settlement of 12mm

$= 2/3\, Q_u$ causing net settlement of 6mm

$= \frac{1}{FOS}$ [$Q_{\text{tangent rule}}$] → shear criteria

(13) Settlement of Pile Group

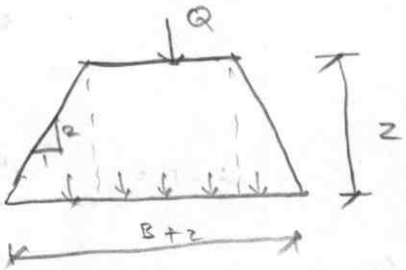
$$S = \frac{C_c \cdot H}{1+e_0} \log_{10}\left(\frac{\sigma_0' + \Delta\sigma'}{\sigma_0'}\right)$$

Considering an imaginary shallow footing at '$\frac{2}{3}$ L' from the top

$S_r e_0 = w \cdot G_s$

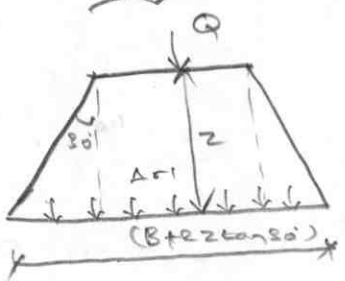
$C_c = 0.009(LL - 10\%)$

$\Delta\sigma'$ → Based on 2:1 Rule



$$\Delta\sigma' = \frac{Q_{safe}}{(B+Z)^2}$$

$\Delta\sigma'$ → Based on 30° Rule



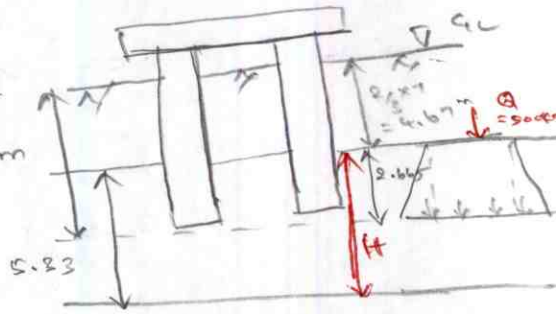
$$\Delta\sigma' = \frac{Q}{(B+2Z\tan 30°)^2}$$

4) A pile group consisting of 4 piles is driven in fully saturated clay having thickness 10m. The length of each pile is 7m. The WT at GL. The saturated unit wt is 20 KN/m³, γ_w = 10 KN

LL = 60% ; w_n = 30% ; G_s = 2.7 ; S = 1m c/c

ϕ_{pile} = 30 cm . Determine consolidation settlement

Take Safe Load = 500 KN



Solvn:-

$\sigma_0 = \gamma_{sub} \cdot h$

$= (20-10)(4.67 + 2.665)$

$\sigma_0 = 73.35$ KN/m²

B = 1 + 0.15 × 2

= 1.3 m

$\therefore \Delta\sigma' = \frac{Q_u}{(B+2)^2}$

$= \frac{500}{(1.3 + 2.665)^2}$

$\Delta\sigma' = 31.804$ KN/m²

$S_r \cdot e = w \cdot G_s$; $C_c = 0.009(LL - 10\%)$

$e = \frac{30}{100} \times 2.7$

$C_c = 0.45$

$e = 0.81$

By 2:1 method

$S = \frac{C_c H}{1+e_0} \cdot \log_{10}\frac{\sigma_0' + \Delta\sigma'}{\sigma_0'}$

0.1564 ; 0.207

$= 0.3284$ m

$= 32.84$ cm

⇒ 30° Rule

$\Delta\sigma' = \frac{Q}{(B + 2z\tan 30°)^2}$

$= \frac{500}{(1.3 + 2 \times 2.665 \times \tan 30°)^2}$

$\Delta\sigma' = 26.095$ KN/m²

By 30° Rule

$S = \frac{0.45 \times 5.33}{1+0.81} \log\left(\frac{73.35 + 26.095}{73.35}\right)$

$S = 0.175$ m

(5) A pile group consist of 16 piles arrange in square pattern having spacing 1.5m c/c & dia 50cm for each pile. The length of each pile is 12m The unconfined compressive strength of clay (q_u) = 100 kPa for a depth of 5m & it is 120 kPa below 5m ; Take $\alpha = 0.6$ & FOS = 2.5

Determine Safe Load carrying capacity of pile group. Also determine efficiency of pile group.

Solvⁿ:-

$$Q_{u_1} = 9C \times \pi/4 d^2 + \alpha C \times \pi d L$$

$$= 9 \times 60 \times \frac{\pi}{4} \times 0.5^2 + 0.6 \times 50 \times \pi \times 0.5 \times 5$$

$$+ 0.6 \times 60 \times \pi \times 0.5 \times 7$$

$$Q_{u_1} = 737.48 \text{ kN}$$

$$\Rightarrow Q_u = 16 \times Q_{u_1} = 11800 \text{ kN} \quad \text{---} (1)$$

$$Q_{ug} = 9C \times B^2 + C(4B \times L)$$

$$= 9 \times 60 \times 5^2 + 50 \times (4 \times 5 \times 5)$$

$$+ 60 \times (4 \times 5 \times 7)$$

$$Q_{ug} = 26900 \text{ kN} \quad \text{---} (2)$$

$B = 3S + d/2 + d/2$

$= 3 \times 1.5 + 0.5$

$B = 5m$

Q_u = lesser of individual effect & block effect

$Q_u = 11800$ kN

$Q_s = \frac{Q_u}{F} = 4720$ kN

$\eta = \frac{Q_{ug}}{n Q_{u_1}} \times 100$

$= \frac{26900}{1800}$

$\eta = 227.9\%$

⑤ Detn capacity of pile group consisting of 12 piles arranged in three rows. The load carrying capacity of 1 pile is 300 kN. Dia of RCC pile is 50 cm & spacing of piles 1.5 m.

Soln:-

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

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

$$= \tan^{-1}\left(\frac{0.5}{1.5}\right)$$

$$= 18.43$$

$$= 1 - \frac{18.43}{90}\left[\frac{4\times2+3\times3}{4\times3}\right]$$

$$\eta_g = 70.98\ \%.$$

$$\Rightarrow \eta_g = \frac{Q_{ug}}{n \times Q_{u1}}$$

$$Q_{ug} = 0.7098 \times 12 \times 300$$

$$\boxed{Q_{ug} = 2555.63\ kN}$$

7) Detn the spacing of piles in a group consisting of 25 nos. Take adhesion factor 0.7. Neglect bearing

$$\eta = \frac{Q_{ug}}{n \cdot Q_{u1}}$$

$$100\% = \frac{\pi \times 4B \times L}{n \cdot \alpha \pi \times (\pi D L)}$$

$$n \cdot \alpha \pi \times d = 4 \times B$$

$$25 \times 0.7 \times \pi \times d = 4(4S+d)$$

$$B = 4S + d$$

$$B = 13.74\, d$$

$$\Rightarrow 4S + d = 13.74\, d$$

$$\Rightarrow \boxed{S = 3.185\, d}$$

(8) A concrete pile having dia 40 cm is driven in sandy soil having $\phi = 30°$; $\delta = 20°$

Co-eff. earth pressure = 1.5 ; $\gamma_{sat} = 20\ KN/m^3$; $N_q = 30$

$L_{Pile} = 10m$; WT is at GL

Determine 1) Safe load carrying capacity if FOS = 2.5

2) External pull required to pull out the pile

Soln:-

1)

$$Q_u = Q_b + Q_f$$

$$= \gamma' L N_q \times \frac{\pi d^2}{4} + \frac{K\gamma' L}{2} \tan\delta \times \pi d L$$

$$= (20 - 9.81) \times 10 \times 30 \times \frac{\pi}{4} \times 0.4^2 + \frac{1.5 \times (20 - 9.81) \times 10}{2} \tan 20° \times \pi \times 0.4 \times 10$$

$$\boxed{Q_u = 720\ KN}$$

$$\Rightarrow Q_s = \frac{Q_u}{F} = \frac{720}{2.5} = \boxed{288\ KN}$$

Note:- Safe pressure $= \frac{q_b}{F}$ or $\frac{q_f}{F}$

$= 1200\ kPa$ or $10.92\ kPa$

2)

External pull $= \frac{K\sigma'}{2} \tan\delta \times \pi d L$

$$\boxed{Q_f = 343\ KN}$$

(9) A concrete pile is driven by 30 kN wt of hammer. The eff. ht of drop is 80 cm. The Settlement per blow is 25 mm & Total elastic compn is 10 mm. The coefficient of restitution is 0.25; the FOS = 2.5; Detn safe Load carrying capacity Take wt of pile including dolly & Helmet = 40 kN

Solu^n:-

$$Q_u = \frac{W H \eta_h \eta_b}{(S + C_2)}$$

$$= \frac{30 \times 80 \times 0.464}{(2.5 + 1/2)}$$

$$Q_u = 371.2 \text{ kN}$$

$$\Rightarrow Q_s = \frac{Q_u}{F} = \boxed{148.48 \text{ kN}}$$ Ans

$$\eta_b = \frac{W + e^2 p}{W + p}$$

If $W > e_p$

$\Rightarrow 30 > 0.25 \times 40$

10

$$\therefore \eta_b = \frac{30 + 0.25^2 \times 40}{30 + 40}$$

$$\eta_b = 0.464$$

(10) During testing of a pile following data obtained. 1) Load at 30 mm penetration = 400 kN

2) " 12 mm " = 250 kN

3) " 6 mm plastic settlement = 200 kN

4) Load at shear failure = 300 kN

Detn the Load carrying capacity of pile. Take dia of pile = 30 cm & FOS = 3

Soln.--

1) $Q_s = \frac{50}{100}(400)$

$= 200$ kN

2) $Q_s = 2/3\,(250)$

$= 100$ kN

3) $Q_s = 2/3\,(400)$

$= 266.3$ kN

4) $Q_s = 1/3 \times 300$

$= 100$ kN

Adopt least one

$Q_s = 100$ kN

---

f-06 Kharagpur (11) Detn the minm number of concrete piles of 30cm dia to carry safe load 5000kN with FOS = 2.5 assume 100% efficiency. Take length = 10m ; $\alpha = 0.57$; shear strength = 100kPa above the base & 150 kPa below the base.

Soln.--

$\eta = \frac{Q_{ug}}{n\,Q_{u_1}}$

$n\,Q'_{u_1} = Q_{ug}$

$n\,[\alpha c \times \pi d L] = c \times 4B \times L$

$5000 \times 2.5 = n\,[\,9c \times \pi/4\, d^2 + \alpha c \times \pi d L\,)$

$\Rightarrow n = 19.75$

$n \simeq 20$

(12) Detn the ultimate capacity of pile group consisting 4 piles at spacing 1.2 m c/c. Dia of each pile is 40 cm. L = 10 m; Take C = 40 kPa consider single block failure.

B = S + d
= 1.2 + 0.4
= 1.6 m

$$Q_{ug} = 9cB^2 + C \times 4B \times L$$

$$= 9 \times 40 \times 1.6^2 + 40 \times 4 \times 1.6 \times 10$$

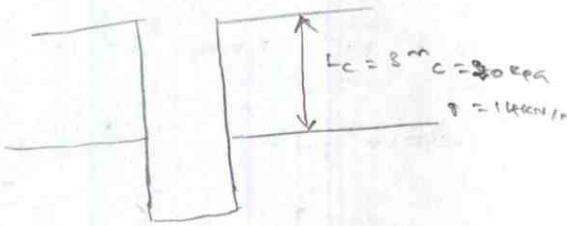
$$Q_{ug} = 3481.6 \text{ kN}$$

23-01-10

(13) A group of pile consist of 9 piles arranged in square pattern. The spacing of piles is 1.5 m c/c & dia of pile is 50 cm. The top most layer of soil having thickness 3 m is of recently filled soil having unconfined compressive strength 40 kPa. & unit wt 14 kN/m³. Detn -ve skin friction

Take $\alpha = 0.6$; $\phi = 0$

Soln:-

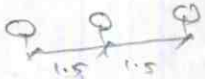


$$Q_{u_1} = \alpha c \times \pi d L_n$$

$$= 0.6 \times 20 \times \pi \times 0.5 \times 3$$

$$Q_{u_1} = 56.55 \text{ kN}$$

$$\Rightarrow Q_u = n \times Q_{u_1} = 9 \times 56.55 = 508.9 \text{ kN} \quad \text{---(1)}$$

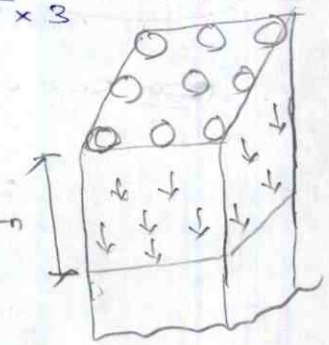


$$Q_{ug} = cx \, 4BL_n + \gamma B^2 L_n \quad \text{in soil}$$

S = 1.5 m
B = 1.5 + 1.5 + 0.5
= 3.5 m

$$= 20 \times 4 \times 3.5 \times 3 + 14 \times 3.5^2 \times 3$$

$$Q_{ug} = 1354.5 \text{ kN} \quad \text{---(2)}$$



∴ Adopt greater one for -ve skin friction

$Q_u = 1354.5$ kN ↓

(14) A group of pile consisting of 16 piles is bored pile. The dia of each pile is 40 cm & spacing is 1.2m c/c. The length of each pile is 10m. Detn safe load carrying capacity of pile group If shear strength of soil is 40kPa above the base & 50 kPa below the base.

Take $\alpha = 0.6$; $\gamma_{pile} = 24 kN/m^3$: $\gamma_{soil} = 18 kN/m^3$

FOS = 2.5

Soln:-

i) Individual action

$$Q_{u_1} + W_{pile} - W_{soil} = Q_{b_1} + Q_{f_1}$$

$$W_{pile} = 24 \times \pi/4 \times 0.4^2 \times 10 = 30.16 kN$$

$$W_{soil} = 18 \times \pi/4 \times 0.4^2 \times 10 = 22.62 kN$$

$$Q_{b_1} = 9c \times \pi/4 d^2 = 56.55 kN$$

$$Q_{f_1} = \alpha c \times \pi d \times L = 301.59 kN$$

$$\Rightarrow Q_{u_1} = (Q_{b_1} + Q_{f_1}) - (W_{pile} - W_{soil})$$

$$\boxed{Q_{u_1} = 350.6 kN}$$

ii) Group action

$$Q_u = n \times Q_{u_1}$$

$$\boxed{Q_u = 5609.6 kN}$$

$$B = 1.2 \times 3 + 0.4$$

$$= 4m$$

$$Q_{ug} = 9c_2 \times B^2 + \alpha c_1 \times 4B \times L)$$

$$\boxed{Q_{ug} = 13600 kN}$$

Adopt Lesser One

$\Rightarrow$ Q_u = Lesser of individual action & group action

$$Q_u = 5609.6 kN$$

$$Q_s = \frac{Q_u}{F} = \boxed{2243.84 kN}$$

$$\eta = \frac{Q_{ug}}{n \times Q_{u_1}} \times 100$$

$$\boxed{\eta = 242.4\%}$$

(15) Detn the safe load carrying capacity with the help of following data. Wt of hammer = 3 t

Wt of pile = 40 kN ; Ht of drop = 1 m ; Settlement per blow = 20mm

If it is steam acting hammer then what will be the load carrying capacity.

Soln:—

Drop Hammer

$$Q_u = \frac{WH}{F(S+C)}$$

$$= \frac{30 \times 100}{6(2+0.25)} \quad 2.5$$

$$Q_u = 666.67 \text{ kN}$$

$$\Rightarrow Q_s = \frac{Q_u}{F} = \frac{}{6} = 111.11 \text{ kN}$$

;

Steam Hammer

$$Q_u = \frac{WH}{F(S+C)}$$

$$Q_u = 1333.33 \text{ kN}$$

$$\Rightarrow Q_s = \frac{Q_u}{F} = 222.22 \text{ kN}$$

Note:—

If Double acting steam hammer

$$Q_s = \frac{(W + ap)H}{F(S+C)}$$

; a = area of piston

p = steam pressure of piston

C = elastic compn

= 0.25

---

(16) Detn Ultimate load on a pile having length = 10m & dia = 40 cm ; the penetration value (N) is 8 for skin friction & 8 for bearing.

Note:— (Mayerhoff — based on cone penetration test)

$Q_u = 400 N \times A_p + 2\bar{N} \times A_f$ (Bored file)

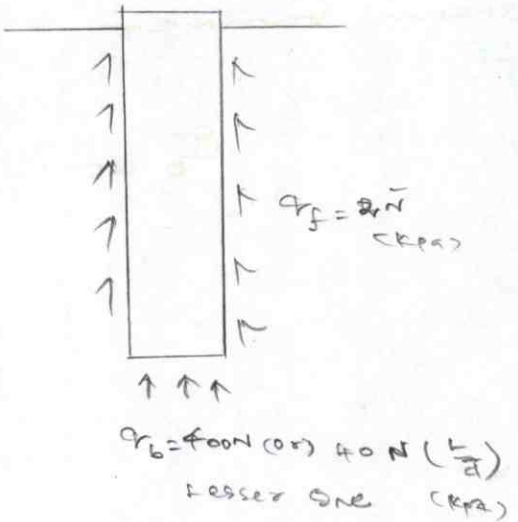
$= 400 \times 8 \times \pi/4 \times 0.4^2 + 2 \times 3 \times \pi \times 0.4 \times 10$

$Q_u = 477.5 \text{ kN}$

NOTE :-

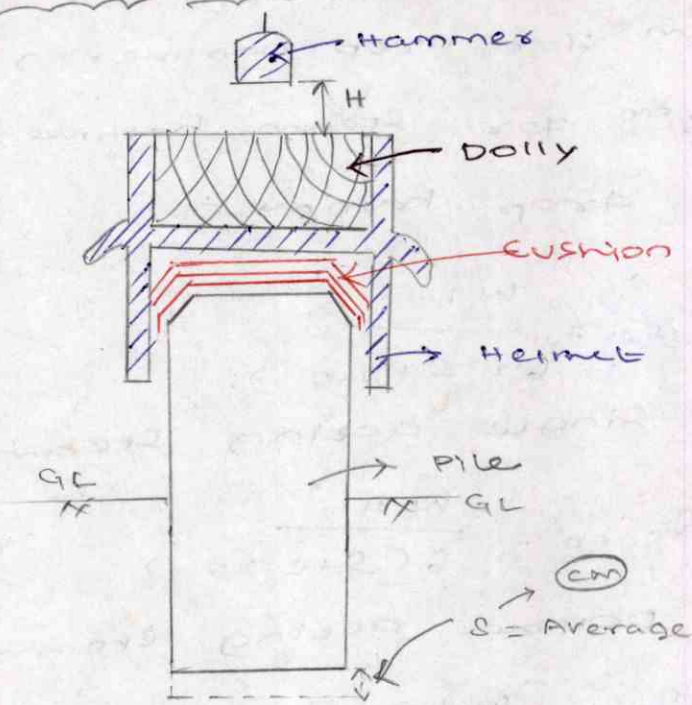
Mr. Mayor hoff developed an empirical relation to find bearing capacity of pile based on penetration number which is determined experimentally as given below.

$$Q_u = 400 \times N \, A_p + 2\bar{N} \times A_f \quad \text{(Bored pile)}$$



27-12-06
Wednesday

Dynamic Formulae:-



Dynamic formulae have been developed by

(i) Wellington
(ii) Hiley

(i) Wellington formulae:-

Wellington formula is also known as engineering news formula

According to mr. Wellington allowable load on a pile

$$Q_a = Q_{safe} = \frac{WH}{F(S+C)}$$

where,

W = Weight of Hammer
H = Height of fall in cm
F = FOS (6)
S = Final penetration per blow (usually taken as avg.. penetration in cm per blow for the last 5 blows of a drop hammer

External workdone = internal energy

$WH = Q_u \times S$

$Q_u = \frac{WH}{S}$ (S → correction)

$Q_u = \frac{WH}{S+C}$

$\Rightarrow Q_s = \frac{Q_u}{F} = \frac{WH}{F(S+C)}$

(or) 20 blows of a steam hammer.

C = empherical constant having value
(2.5 cm for drop hammer)
(0.25 cm for steam hammer)

in case of drop hammer

$$Q_a = Q_{safe} = \frac{W H}{6(S+2.5)}$$

in case of single acting steam hammer

$$Q_{safe} = \frac{W H}{6(S+0.25)}$$

in case of double acting steam hammer

$$Q_a = \frac{[W + ap] H}{6(S+0.25]}$$

where,
a = c/s area of piston
P = Mean eff. steam pressure

(2) Hiley formula :-

Indian std IS 2911 - 1964 gives the formula based on Hiley formula.

$$Q_u = \frac{W H \eta_h \eta_b}{(S + C/2)}$$

(Effective fall)

where,
W = wt of hammer
H = ht of drop of hammer in cm
S = penetration per blow in cm
C = Elastic compn constant.
η_h = Efficiency of hammer which is taken as 100% for drop hammer
65% - steam hammer
$H\eta_h$ = Effective fall

η_b = Efficiency of hammer blow which is given by formula.

$$\eta_b = \frac{W + e^2 P}{W + P} \quad ; \text{ when } W > eP$$

$$\eta_b = \frac{W + e^2 P}{W + P} - \left[\frac{W - eP}{W + P}\right]^2 \quad ; \text{ when } W < eP$$

where,

P = Wt of pile, helmet & Folley

e = co-efficient of restitution

The allowable load = $\frac{W_{ultimate}}{FOS}$

where,

FOS = 2 (or) 2.5

Comment on dynamic formulae:-

(i) The greatest objection is the uncertainity between dynamic & static resistance of soil

(ii) In case of submerged loose uniform fine sand impact may cause liquifaction of soil

(iii) For clay the dynamic formula are valueless because the skin friction developed in clay during driving is very much less than which occurs after a period of time.

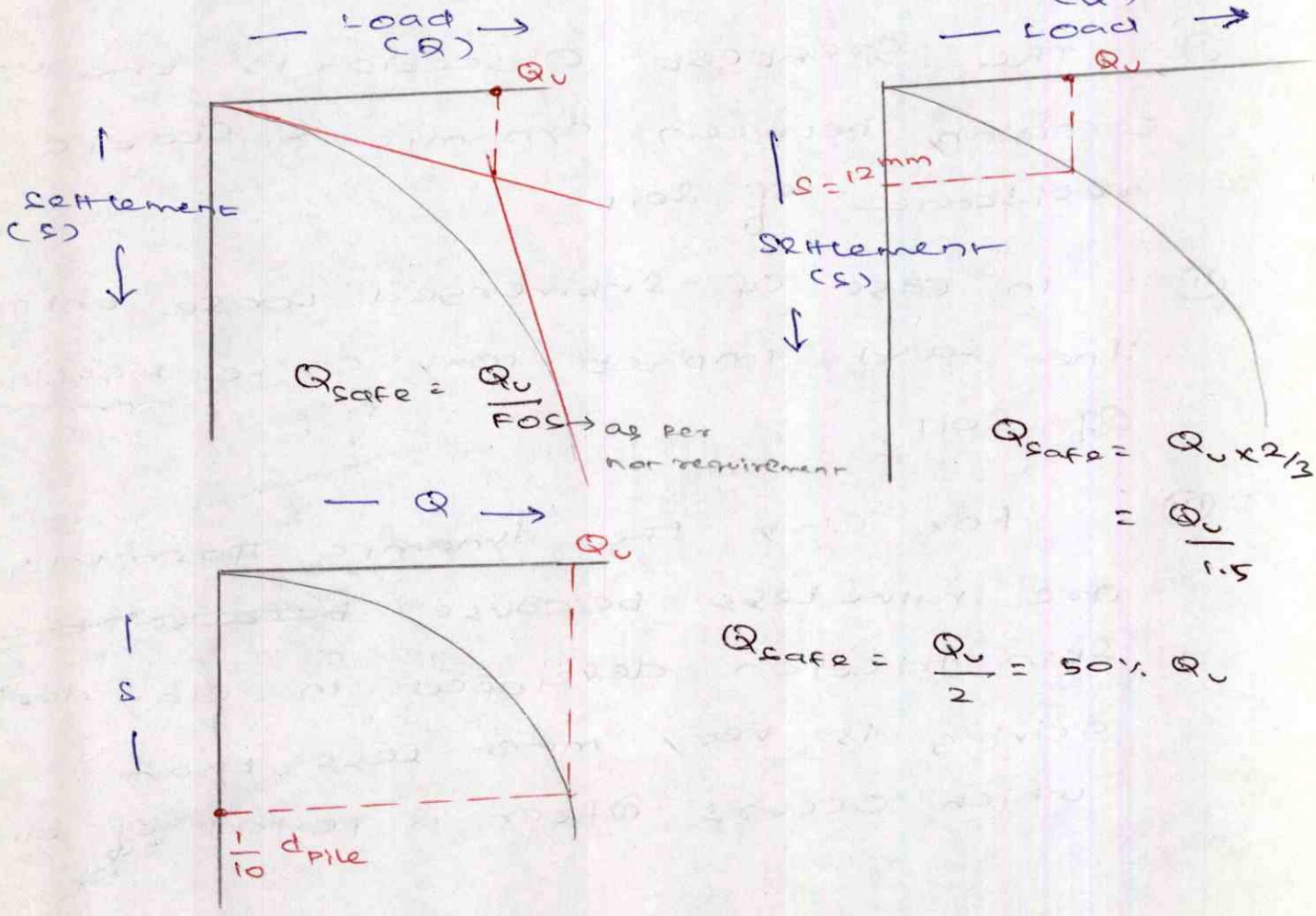
④ Dynamic formula are best suitated to coarse grained soil, for which the shear strength is independent of rate of loading.

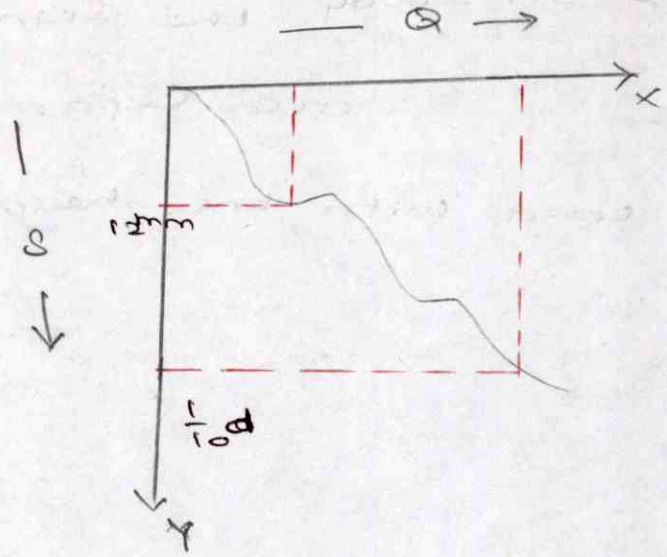
⑤ Dynamic formula give no indication about probable future settlement.

⑥ The formula donot take into account the reduced bearing capacity of pile when in a group.

⑦ In Engineering news formula the weight of the pile is neglected.

Pile load test





The test piles are mainly meant for testing, where the load applied is 2.5 times the estimated allowable load (or) to a load which causes a settlement = $\frac{1}{10}$ th of the pile dia whichever occurs earlier.

Working pile is a pile which is mainly meant for supporting the super structure. but it can be used for testing purpose where test load is 1.5 times the estimated allowable load.

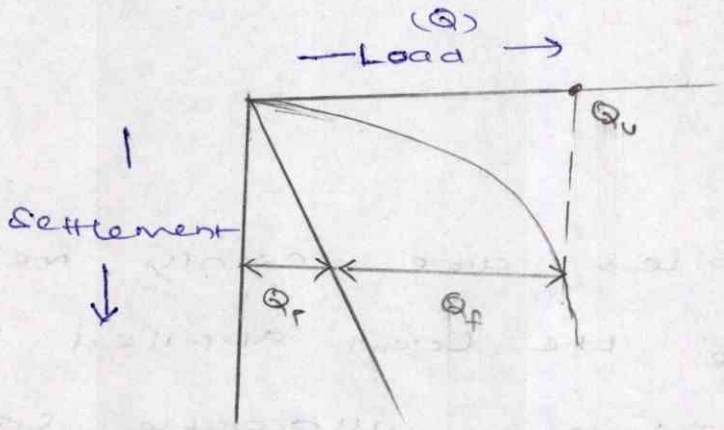
According to IS 2911 there are following methods to determine allowable load

(i) 50 % of the final load which causes settlement = 10% of pile dia

(ii) 2/3 of the final load which causes a total settlement of 12mm.

(iii) 2/3 of final load which causes a net settlement of 6mm (Residual after removal of load

According to IS 2911 - 1964 the skin friction & End bearing (Tip) (Point bearing) are separated from the total load with the help of cyclic load test.



NOTE :-

-ve skin friction is a downward drag acting on a pile due to settlement of surrounding compressible soil (loose) due to -ve skin friction the load carrying capacity of pile comes down.

-ve skin friction takes place due to following reasons.

① Settlement of recent fill soil

② Settlement of soft soil

*③ Lowering down of water table

- Due to lowering down of water table effective pressure increases.

$\sigma' = \sigma - u$

$= \sigma - 0$

$= \sigma$ Due to increase in eff. pressure consolidation settlement takes place & hence -ve friction developes.

NOTE:-

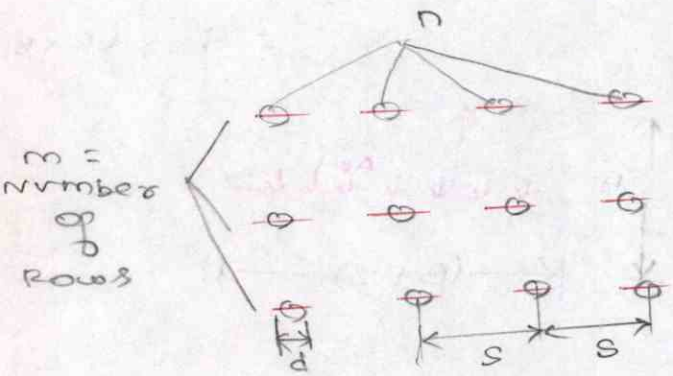
Efficiency of Pile Group

According to Mr. Converse Labbarre

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

where,

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



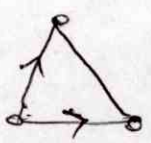
② Mr. Feld

$$\eta = \frac{16 - \text{No. of contacts}}{16}$$

① Two piles

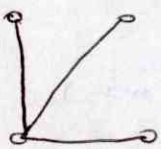
$$\eta = \frac{16-1}{16} = \frac{15}{16} = 93.75\%$$

②



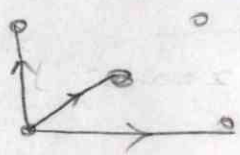
$$\eta = \frac{16-2}{16} = \frac{14}{16} = 87.5\%$$

③

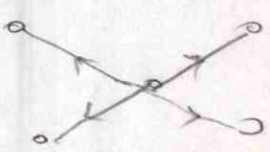


$$\eta = \frac{16-3}{16} = 81.25\%$$

④



$$\eta_1 = \frac{16-3}{16} = \frac{13}{16}$$



$$\eta_2 = \frac{16-4}{16} = \frac{12}{16}$$

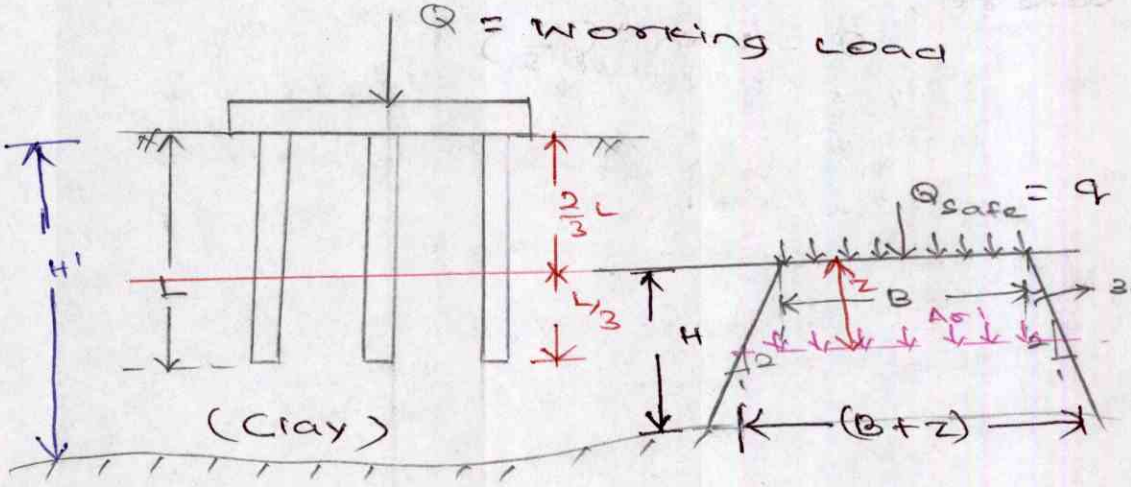
$$\eta_{avg} = \frac{\eta_1 \times 4 + \eta_2 \times 1}{4+1} = 80\%$$

* $\eta_g = \frac{Q_{ug}}{\sum Q_{ui}}$ → Block action (As a whole) (Block failure)

→ Individual failure

(> 100%
< 100%)

Settlement of Pile Group



$$\Delta\sigma_1 = \frac{Q_{safe}}{(B+Z)(L+Z)}$$

where, $Z = H/2$

$H = H' - a_1 + \frac{a_2}{3}$

$$S = \frac{C_c \cdot H}{1+e_0} \log_{10} \frac{\sigma_0' + \Delta\sigma_1}{\sigma_0'}$$

where

C_c = comp index

$= 0.009(LL - 10\%)$

σ_0' = Effective over burden soil pressure at the $H/2$

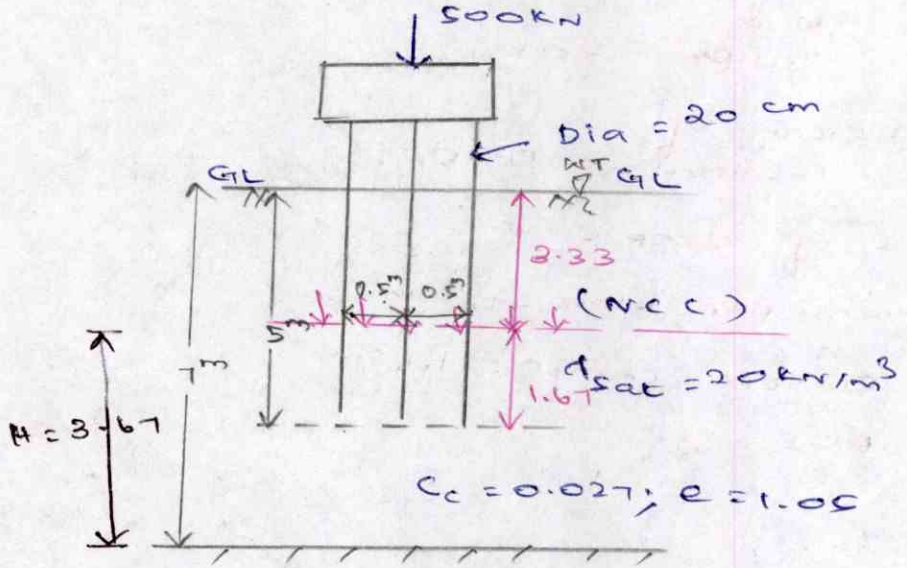
$= d_1h_1 + d_2h_2 - d_wh_w$

$$\Delta\sigma_1 = \frac{Q_{safe}}{(B+Z)^2} \quad (2:1 \text{ method})$$

$$= \frac{Q_{safe}}{[B + 2 \times Z \tan 30^\circ]^2} \quad (30^\circ \text{ Rule})$$

Numericals :-

① For the pile group shown in the fig. Determine the settlement of pile group



$$\Delta\sigma_1 = \frac{Q_{safe}}{(B+z)(L+z)} = \frac{500 \times 10^3}{\left(1.0 + \frac{3.67}{2}\right)^2} = 54.28 \text{ KN/m}^2$$

$$B = 0.5 + 0.5 + 0.2 \times 2 = 1.0 \text{ m}$$

$$\sigma' = 20 \times 5.165 - 9.81 \times 5.165 = 52.63 \text{ KN/m}^2$$

(with WT)

$$\sigma' = 20 \times 5.167 = 103.34 \text{ KN/m}^2$$

With WT

$$S = \frac{C_c H}{1+e_0} \log_{10} \frac{\sigma_0' + \Delta\sigma_0'}{\sigma_0}$$

$$= 14.87 \text{ mm}$$

With out WT

$$S = \frac{C_c H}{1+e_0} \log_{10} \frac{\sigma_0' + \Delta\sigma_1}{\sigma_{01}'}$$

$$= 8.8645 \text{ mm}$$

② Determine safe load carrying capacity of a pile with the help of following data

Wt of hammer = 20 KN

Wt of pile & Trolley = 40 KN

Co-efficient of restitution = 0.25

Height of drop = 1m

Settlement per blow = 12mm

Total elastic compn = 1.4cm

FOS = 2

Solvn :-

$$\eta_b = \frac{W + e^2 P}{W + P} = \frac{20 + 0.25^2 \times 40}{20 + 40} = 37.5\ \%$$

$$Q_{safe} = \frac{Q_u}{F} = \frac{W H \eta_b \eta_h}{F(S + C_1/2)}$$

$$= 20 \times 100 \times \frac{37.5}{100} \times \frac{}{2(1.2 + 1.4/2)}$$

$$Q_{safe} = 197.37\ KN$$

⑤ A cement concrete pile is driven below GL in sandy soil having $\phi = 30^\circ$ & $C = 0$. The length of pile is 12m. Determine safe load carrying capacity if FOS = 2.5. Take angle of wall friction $\delta = \frac{3}{4}\phi$ & co-efficient of Earth pressure = 1.5. Take, $N_q = 25$ & dia of pile 30 cm.

$\gamma = 17\ kN/m^3$

Soln:-

$$Q_u = Q_b + Q_f$$

$$= \left[1.3 \cancel{c} N_c^0 + \gamma L N_q + 0.3 \cancel{\gamma B} N_\gamma^0\right] \frac{\pi}{4} d^2 + \left(\cancel{\alpha c} + \bar{\sigma} \tan\delta\right) \pi d L$$

$\bar{\sigma} \rightarrow \frac{\gamma L}{2}$

$$= 17 \times 12 \times 25 \times \frac{\pi}{4} \times 0.3^2 + 1.5 \times \frac{17 \times 12}{2} \times \tan\left(\frac{3}{4} \times 30^\circ\right) \times \pi \times 0.3 \times 12$$

$$= 1077.24\ kN$$

$$Q_{safe} = \frac{Q_u}{F} = \frac{1077.24}{2.5} = 430.899\ kN$$

AM

⑥ A group of 16 piles of 10m length & 50 cm dia is installed in a 10m thick stiff clay underlained by rock. The adhesion factor is 0.4. Shear strength of soil on the sides 100kpa & at the base is also 100kpa determine the base resistance of a single pile & the group side resistance if Efficiency 100%.

(i) $Q_{b_1} = 9cx\frac{\pi}{4}d^2 \Rightarrow Q_{b_1} = 9\times100\times\frac{\pi}{4}\times0.5^2$

$Q_{b_1} = 176.71\ KN$ Ans

(ii)

$$\eta = \frac{Q_{ug}}{n\,Q_u}$$ → other data not given so take side resistance only ($n \times \alpha c \pi DL$))

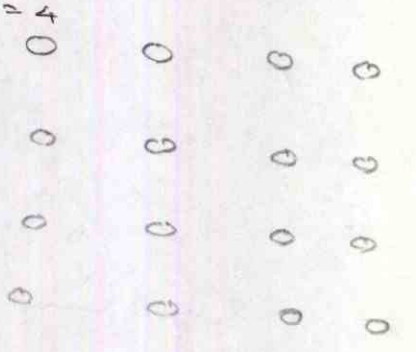
$$\frac{100}{100} = \frac{Q_{ug}}{16\times0.4\times100\times\pi\times0.5\times10}$$

$\Rightarrow Q_{ug} = 10053.096\ KN$ Ans

---

(7) Determine the efficiency of pile group consisting of 16 piles arrange in square pattern take dia of each pile 50 cm & spacing 1.5m also determine Load carrying capacity of Block action if length of Each pile is 15m ; $c = 50$ kpa ; $\alpha = 0.6$

Soln:- $n=4$; $m=4$



Ref. Converse Labbare

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

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

$= \tan^{-1}\left(\frac{0.5}{1.5}\right)$

$= 18.4^\circ$

$$\Rightarrow \eta_g = 1 - \frac{18.4^\circ}{90^\circ}\left[\frac{4\times3+4\times3}{4\times4}\right]$$

$\Rightarrow \boxed{\eta_g = 69.28\ \%}$

$\eta = \frac{Q_{ug}}{n\,Q_{u_1}} \Rightarrow Q_{ug} = \frac{69.28}{100}\times16\times\left[9\times50\times\frac{\pi}{4}\times0.5^2 + 0.6\times\frac{9}{2}\times\pi\times0.5\times1\right.$

$\boxed{Q_{ug} = 8814.81\ KN}$ Ans

NOTE :-

$B = 1.5 + 1.5 + 1.5 + \frac{0.5}{2} + \frac{0.5}{2}$

$= 5\,m$

$Q_{ug} = 9c \times B^2 + c \times 4BL$

$= 9 \times 50 \times 5^2 + 50 \times 4 \times 5 \times 15$

$Q_{ug} = 26250\ kN$

$\eta = \frac{Q_{ug}}{n \cdot Q_{u_1}} \Rightarrow \frac{26250}{16 \times Q_{u_1}} \Rightarrow 2.06$

$\eta = 206\%$

---

(8) Determine spacing of piles in a group neglecting tip resistance. Take $\alpha = 0.7$ (mobilization factor)

Dia. = 50 cm ; The soil is cohesive

Assume 16 piles.

Efficiency not given Assume 100%

Soln :-

$\eta = \frac{Q_{ug}}{n\,Q_{u_1}} \rightarrow \frac{Q_b}{\text{neglected}} + Q_f$

$\frac{100}{100} = \frac{\alpha \times 4B \times L}{16 \times \alpha \times \pi D \times L}$

$\Rightarrow \boxed{B = 4.398\,m}$

$3S + d/2 + d/2 = B$

$\Rightarrow \boxed{S = 1.3\,m}$ Ans

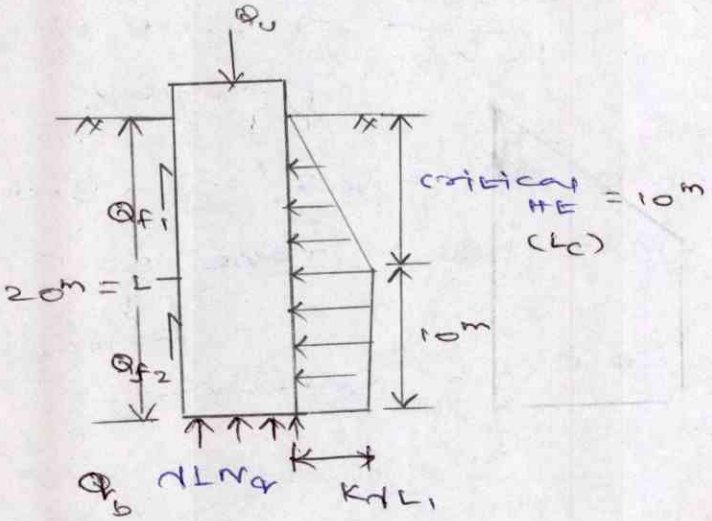
(a) Determine Load carrying capacity of a single pile driven in sand the length of pile is 20m & dia of pile is 50 cm use following data.

$\delta = 25°$; $N_q = 30$

$K = 1.2$; critical HT = 10m from top

$\gamma = 17.5\ KN/m^3$; FOS = 2.5

Solu^n :-



$$Q_u = Q_b + Q_{f_1} + Q_{f_2}$$

$$Q_b = \gamma L N_q \times \frac{\pi}{4} d^2 = 17.5 \times 20 \times 30 \times \frac{\pi}{4} \times 0.5^2$$

$$= 2061.6\ KN$$

$$Q_{f_1} = \left(0 + \frac{K\gamma L_1}{2}\right) \times \pi D L_1 = \frac{1.2 \times 17.5 \times 10}{2} \times \tan 25° \times \pi \times 0.5 \times 10$$

$$= 769.09\ KN$$

$$Q_{f_2} = K\gamma L_1 \times \tan\delta \times \pi D L_2 = 1.2 \times 17.5 \times 10 \times \tan 25° \times \pi \times 0.5 \times 10$$

$$= 3298.67\ KN \times \tan 25°$$

$$= 1538.195\ KN$$

$$\Rightarrow Q_u = Q_b + Q_{f_1} + Q_{f_2}$$

$$= \boxed{4368.88\ KN}$$

Ans

$$Q_{safe} = \frac{Q_u}{F} = 1747.55\ KN$$ Ans

⑥ Determine Load carrying capacity of Board pile with the help of following data

Dia = 20 cm

L = 10 m

properties of soil

$\Phi = 0^\circ$

unconfined compressive strength of clay = 120 kpa

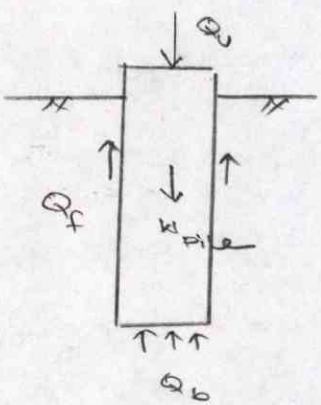
$\gamma_{pile} = 24\ KN/m^3$

$\gamma_{soil} = 18\ KN/m^3$

FOS = 3

$\alpha = 0.4$

Soln:-



$$Q_u + W_{pile} - W_{soil} = Q_b + Q_f$$

$W_{pile} = \gamma A L$

$= 24 \times 10 \times \frac{\pi}{4} \times 0.3^2 = 16.96 KN$

$Q_b = 9C \times \frac{\pi}{4} d^2 = 339.12\ KN$

$Q_f = \alpha C \times \pi d L = 226.19\ KN$

$W_{soil} = 18 \times \frac{\pi}{4} \times 0.3^2 \times 10 = 12.72 KN$

$Q_u = Q_b + Q_f - (W_{pile} - W_{soil})$

$Q_u = 260.12\ KN$

$Q_{safe} = \frac{Q_u}{F} = 86.7 KN$ Ans

Notes:-

(i) Co-efficient of Lateral Earth pressure
= 1.5 in case of Loose sand
= 4 ⇒ Dense sand

(ii) According to IS 2911 : 1979 the min^m spacing of piles shall be as below

(i) For tip resistance pile = 2.5 d (d = dia of pile)

(ii) In case of friction pile = 3 d

(iii) compaction pile = 2 d

(iv) In case of clay where block failure occurs spacing = (2 - 3) × dia of pile (d)

(v) If efficiency is 100% in case of clayey soil ; spacing = 8 d

(vi) In case of sandy soil spacing = 3d

(iii) The critical length of pile in case of sandy soil is dependent on angle of repose

i) If $\phi > 28°$ & $< 36.5°$ $\Rightarrow$ $L_c = d[5 + 0.24(\phi - 28°)]$

ii) $\phi > 36.5°$ (max^m 42°) $\Rightarrow$ $L_c = d[7 + 2.35(\phi - 36.5°)]$

(10) The Load carrying capacity of underreamed pile is

$$Q_v = 9c \times \frac{\pi}{4} d^2 + 9c \times \left[\frac{\pi}{4} D^2 - \frac{\pi}{4} d^2\right]$$

$$+ \alpha c \times \pi d L$$

(11) In case of compaction pile the angle of repose gets changed for a distance of (affected) 3.5 times dia of pile in each direction from the centre of the pile.

The angle of repose $= \left[\frac{\phi + 40^\circ}{2}\right]$ (ϕ → original ϕ)

(12) under reamed pile is a bored pile, case in situ, (uncased cement concrete pile)

which is mainly used for Black cotton soil (Expensive as well as shrinkable soil)

(13) According to Mr. meyerhoff ultimate Load carrying capacity of pile can be determined with the help of empirical formula.

$Q_v = 400 N A_b + \bar{N} \times A_f \times 2 \Rightarrow$ Driven pile

$= 400 N A_b + \bar{N} A_f \Rightarrow$ steel pile

$= 133 N A_b + 0.67 \bar{N} A_f \Rightarrow$ Bored pile

(2/3)

(iv) Settlement of pile group & settlement of individual pile is given by relation

$$\frac{S_g}{S_i} = \left[\frac{4B + 2.7}{B + 3.6}\right]^2$$

↓ width of group

(v) The Load carrying capacity of under-reamed pile based on pile Load test is given by —

Lesser one
- (i) 2/3 of Load causing 12 mm settlement
- (ii) 50% of Load causing 7.5% of Bulb dia settlement

(vi) The dia of Bulb is in a range of is in a range of (2-3) times dia of stem (or) shaft

General ($2.5 d$) ↑ stem dia

(vii) When the number of Bulb is increased from 1 to 2 then Load carrying capacity increases by 50%.

(viii) The spacing of under reamed pile is taken as 2 times dia of bulb
(min^m 1.5 times dia of bulb)

(ix) The spacing of Bulbs in vertical direction is 1.5 times dia of bulb
(minm 1.25 times dia of Bulb)

∴ Where,

N = penetration number

$\bar{N}$ = Avg. penetration Number (modified penetration Number)

A_b = Bearing Area in Sq.m

A_f = Frictional Area in Sq.m

Q_u in KN

(14) The Load carrying capacity of piles may be taken as below

Type of pile	Usual Length	max^m Length	Usual Design Load	max^m Design Load
i) Timber pile	10 - 18^m	30^m	150 - 200^{KN}	300^{KN}
ii) Precast concrete pile	10 - 15^m	30^m	300 - 600^{KN}	900 KN
iii) prestressed concrete pile	20 - 30^m	60^m	500 - 600^{KN}	900 KN
iv) Cast in situ concrete pile	15 - 25^m	40^m	300 - 700^{KN}	900^{KN}
v) Cast in situ bulb pile	15 - 25^m	45^m	600 - 2000^{KN}	9000^{KN}
vi) Steel pile	20 - 40^m	No Limit	300 - 1000^{KN}	2500^{KN} (max^m 1000^{KN})
vii) composite pile	20 - 40^m	60^m	300 - 900^{KN}	2000 KN