GATE – CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

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Pile Foundation

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PILE FOUNDATIONS

A Pile is a relatively long, smaller diameter, which is driven or installed into the ground by suitable means.

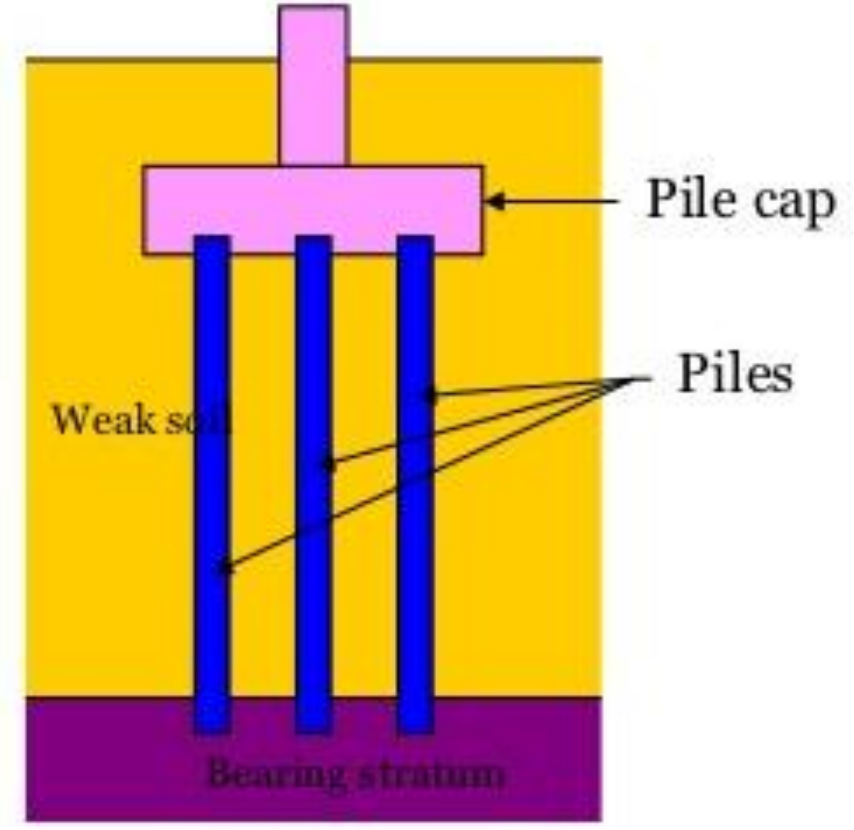
The piles are usually driven in groups to provide foundations for structures.

The pile groups may be used to resist

a. vertical compressive loads

b. uplift or tensile forces, and

c. horizontal or inclined loads.



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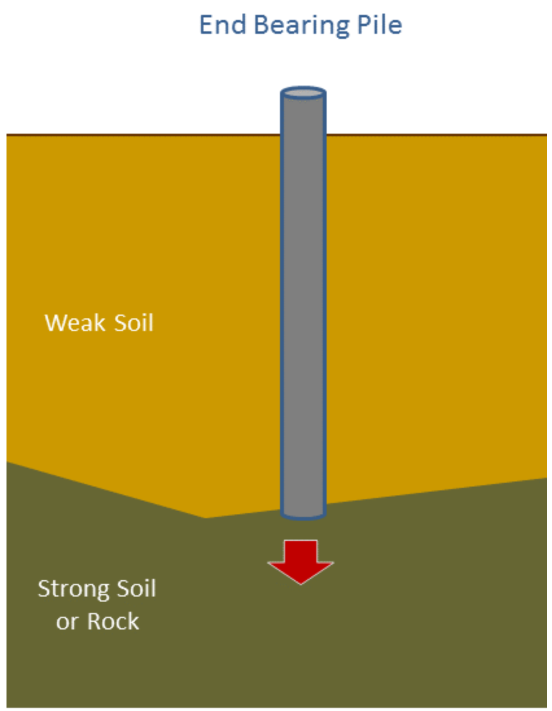
Classification of piles

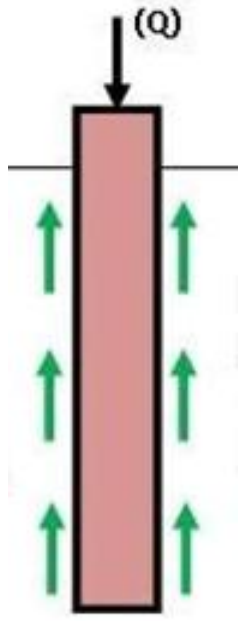
Based on function or action

a. **End (or point) bearing piles:** are used to transfer the load through soft soil or water to a suitable bearing stratum.

b. **Friction piles:** are used to transfer the load through friction along the length of piles.



End bearing piles



Friction piles

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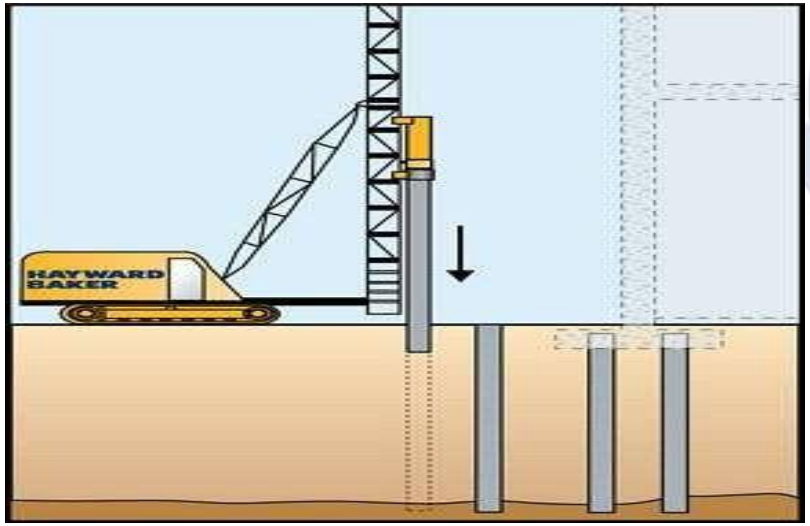
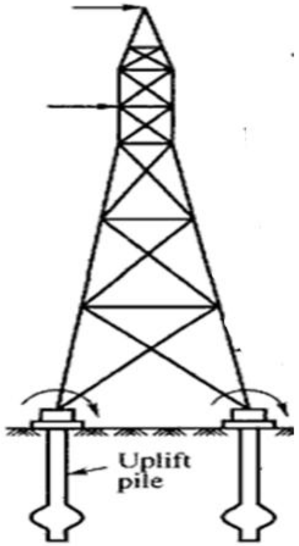
c. **Compaction piles:** are used to compact loose granular soil which gets densified by the vibrations set up on driving.

- Compaction piles themselves do not carry any load.
- Compaction piles are made of weaker material - sometimes sand only
- To compact the soil, pile tube driven is taken out and sand is filled in its place, thus forming a sand pile.

d. **Tension or uplift piles:** are used to resist uplift loads due to hydrostatic pressure or due to over turning moment.



Compaction piles



Tension piles

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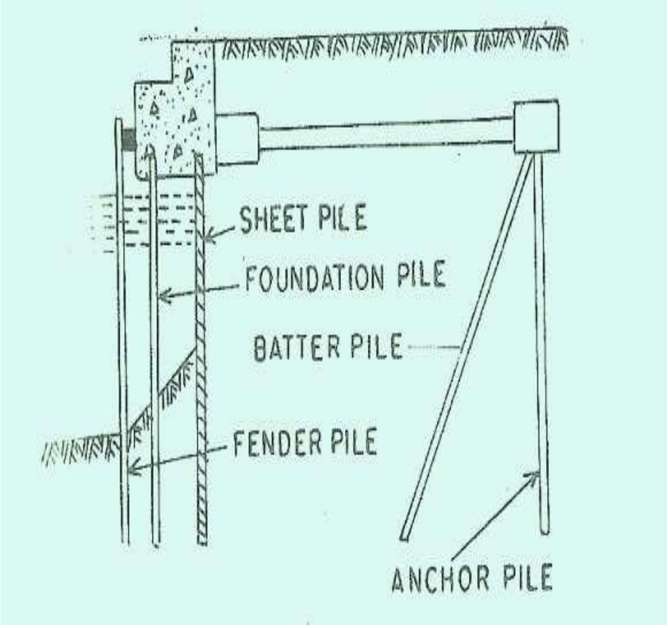
e. **Anchor piles:** are used to provide anchorage against horizontal pull from sheet piling or other pulling forces.

f. **Fender Piles :** are used to protect water front structures against impact from ships or other floating objects.

g. **Sheet piles:** are used as bulkheads, or cut-offs to reduce seepage and uplift in hydraulic structures.



Anchor piles

Fender Piles

Sheet piles

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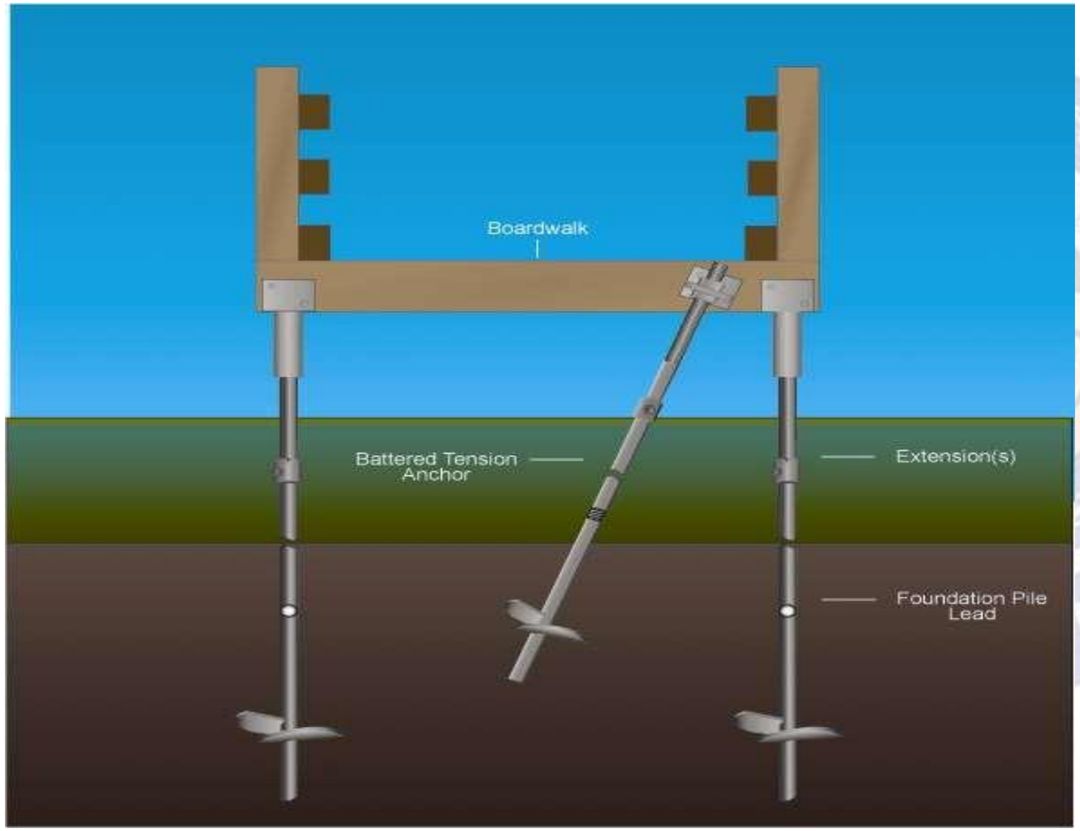
h. **Batter piles:** Piles are driven at an angle used to resist large horizontal and inclined forces, particularly in water front structures.

i. **Laterally loaded piles:** are used to resist horizontal forces.



Batter piles

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Based on material and composition:

a. **Timber Piles:**

- Perform well in fully dry condition or submerged condition.
- Alternate wet and dry condition reduce life and maximum design load about 250 kN.

b. **Steel Piles:** i. H Piles ii. Pipe pile iii. Sheet pile.

c. **Concrete Piles:**

i. Precast piles

ii. Cast-in-situ piles

a. Driven piles : cased or uncased

b. Bored piles: pressure piles or under-reamed piles.

- Under-reamed pile is a bored pile having bulb or increased diameter at some point in its length to anchor the foundation in expansive soil subjected to alternate expansion and contraction.

d. **Composite piles:**

i. Concrete and timber ii. Concrete and steel.

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Based on cross section:

a. Circular b. Square c. Hexagonal

d. I section e. H Section e. Pipe etc.

Based on shape:

a. Cylindrical b. Tapered c. Under-reamed

Based on forming:

a. Precast b. Pre-stressed c. Cast-in-situ

Based on Installation:

a. Driven piles b. Bored piles c. Vibrated piles d. Jetted piles.

Pile load capacity in compression:

The ultimate load capacity (Q_u) of the pile is given by $Q_u = Q_{pu} + Q_f$

For point bearing pile, $Q_{pu} >> Q_f$

For friction pile, $Q_f >> Q_{pu}$

Q_{pu} : Ultimate point load $= q_{pu}.A_b$

Q_f : Ultimate skin friction resistance $= f_s.A_s$

$$Q_u = q_{pu}.A_b + f_s.A_s$$

q_{pu} : Unit point bearing resistance $= c.N_c + \bar{\sigma}.N_q + 0.5\gamma.B.N_\gamma$

For deep foundations, $0.5\gamma.B.N_\gamma$ is quite small and hence neglected.

$$q_{pu} = c.N_c + \bar{\sigma}.N_q$$

For granular soil, $c = 0$; $q_{pu} = \bar{\sigma}.N_q$

B : Width or diameter of pile

$\bar{\sigma}$: Overburden pressure at the tip of the pile $= \gamma.L$

N_c , N_q and N_γ : Bearing capacity factors

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c : Unit cohesion

L : Length of embedment of the pile

γ : Effective unit weight of the soil

C_{ub} : Undrained shear strength of clay at the base of the pile.

A_b : Sectional area of the pile at its base

Q_f : Ultimate skin friction resistance = $f_s.A_s$

f_s : Unit skin friction resistance

A_s : Surface area of the pile in contact with the soil.

$$Q_u = q_{pu}.A_b + f_s.A_s \qquad f_s = \sigma_h \tan\delta = k\bar{\sigma}\tan\delta \qquad q_u = \bar{\sigma}.N_q A_b + k\bar{\sigma}\tan\delta.A_s$$

For clays, $q_{pu} = c_{ub}.N_c \quad ; \quad f_s = \alpha \, . \, c_u$

$$Q_u = c_{ub}.N_c.A_b + \alpha.c_u.A_s$$

α = Adhesive factor

c_u = Undrained cohesion in the embedded length of the pipe

Allowable load on piles

Allowable load, $Q_a = \dfrac{Q_u}{F}$

Q_u : Ultimate load

F : Factor of safety

Dynamic pile formulae:

- used to estimate pile capacity
- based on the laws governing the impact of elastic bodies.
- The input energy of the hammer blow is equated to the workdone in overcoming the resistance of the ground to the penetration of the pile.

Engineering News Formula:

The ultimate pile load capacity (Q_u) is given by $Q_u = \dfrac{W.H}{F(S+C)}$

W : Weight of hammer, kg

H : Height of fall of hammer, cm

F : Factor of safety = 6

S : Real set (or penetration) per blow, cm/ blow

Average of 5 blows for drop hammer, average of 20 blows for steam hammer is considered for final set.

C : Empirical constant, allowing reduction in the theoretical set, due to energy losses.

= 2.5 cm for drop hammer

= 0.25 cm for single or double acting steam hammers.

Modified Hiley formula $Q_u = \dfrac{W.H.\eta.\eta_b}{(S+0.5C)}$

W : Weight of hammer

H : Height of drop hammer

S : Penetration or set per blow

C : Total elastic compression

η : Efficiency of hammer

η_b : Efficiency of hammer blow

Group action of piles

- Single driven pile often moves laterally during driving and eccentricity of load may result in the development of bending stresses.
- A minimum number of three piles are used under a column in a triangular pattern, even the design does not gives the use of three piles.
- The piles are to be arranged symmetrically with respect to load when the number of piles required is more than three.
- Pile cap is a reinforced slab or beam provided at the top of group of piles to transfer the load.
- Pile cap may be above ground, partially or fully buried below ground level.

Ultimate load capacity of pile groups

- The ultimate load capacity of a pile group may or may not be equal to the sum of the individual load capacities of the piles in the group.
- Efficiency of pile group (η) is the ratio of the ultimate load capacity of the pile group (Q_{ug}) to the sum of the individual load capacities of the pile in the group.

$$\eta = \frac{Q_{ug}}{n.Q_u}$$

n : Number of piles in the group

Q_u : Ultimate load capacity of one pile

- During installation of piles, disturbance of soil and overlap of stresses between adjacent piles may cause group efficiency less than 1.
- For smaller spacing between piles, $\eta < 1$ and for larger spacing between piles, $\eta \approx 1.0$

Pile groups in clay

- A group of piles may fail either by block failure or by individual pile failure.
- A block failure occurs when piles are spaced less than 2 to 3 D
- Individual pile failure occurs for wider spacings. η approaches unity when pile spacing is about .
- In block failure, the soil bound by the perimeter of the pile group and the embedded length of the pile acts as one unit or a block.

The ultimate load capacity of the pile group by block failure (Q_{ug}) is given by

$$Q_{ug} = c_{ub}.N_c.A_b + p_b.L.c'_u$$

c_{ub}: Undrained strength of clay at the base of the pile group.

c'_u : Average undrained strength of clay along the length of block

N_c: Bearing capacity factor = 9

A_b : Cross sectional area of the block

p_b: Perimeter of the block

L : Embedded length of the pile.

For individual pile failure, $Q_{ug} = n.Q_u$

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Pile groups in sands:

In sand, when the piles are driven with closer spacing, is greater than 1 and tends to approach unity when pile spacing is increased to 5 to .

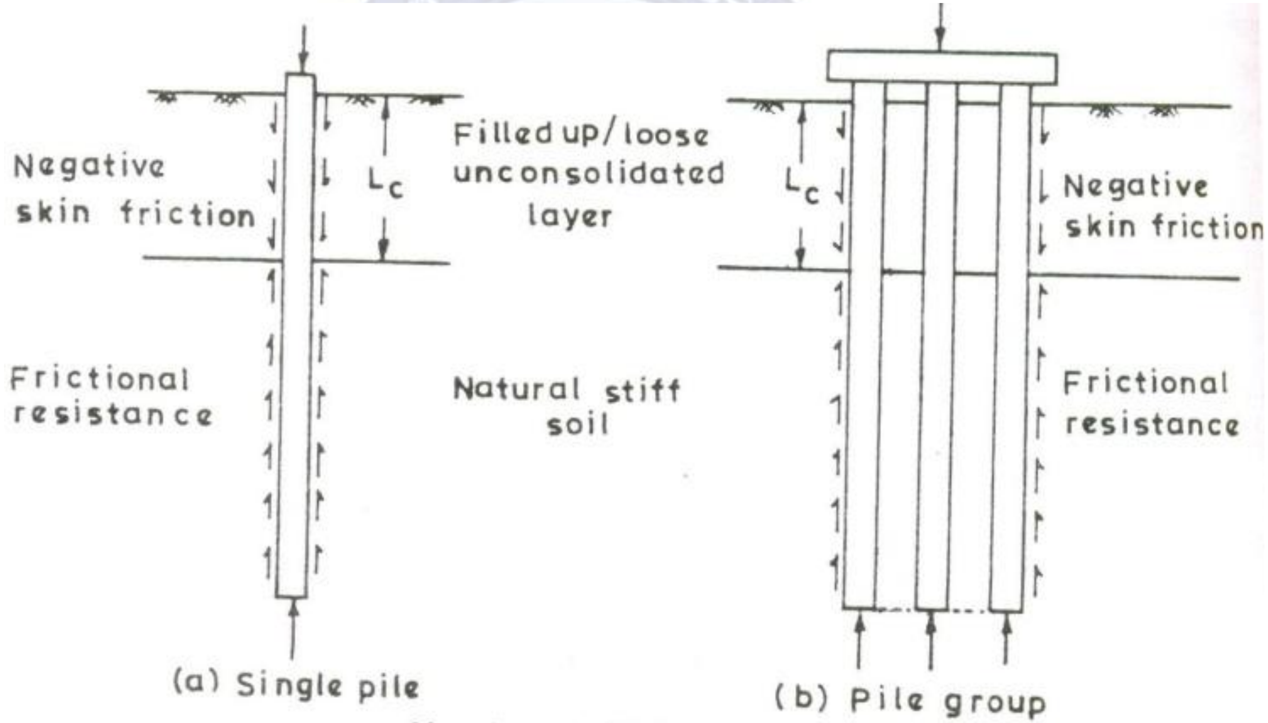
In dense sand, η is always less than 1.

Negative skin friction :

Negative skin friction is a downward drag on the pile surface, when the soil moves down relative to the pile.

- Negative skin friction has an effect of reducing the allowable load on the pile.
- Negative skin friction occurs due to
    - a. the fill material is a loose sand deposit ie., soft, unconsolidated stratum.
    - b. lowering of the ground water table which increases the effective stress.
    - c. Reconsolidation occurring due to disturbance caused by pile driving in sensitive clay stratum etc,.

- Negative skin friction increases gradually as the consolidation of the clay layer proceeds since the effective overburden pressure gradually increases due to dissipation of excess pore pressure.
- In field, negative skin friction can be reduced in pre-cast piles by painting the pile surface with bitumen.



Negative skin friction

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For individual piles, the negative skin friction (F_n) may be taken as follows.

a. For cohesive soils $F_n = p.L_c.c_a$

p : Perimeter of pile

L_c : Length of the pile in compression stratum

c_a : Unit adhesion $= \alpha.c_u$

c_u : Undrained cohesion of the compressible layer

b. for cohesionless soils, $F_n = \frac{1}{2} p.L_c^2.\gamma.k.\tan\delta$

k : Lateral earth pressure coefficient

δ : Angle of friction between pile and soil. $\left(\frac{\phi}{2} \text{ to } \frac{2}{3}\phi\right)$

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For a group of piles, the negative skin friction (F_{ng}) may be taken as higher of the following.

$$F_{ng} = n.F_n$$

$$F_{ng} = c_u.L_c.p_g + \gamma.L_c.A_g$$

n : Number of piles in the group

p_g : Perimeter of the group

γ : Unit weight of the soil within the pile group up to a depth

A_g : Area of pile group within the perimeter

$$\text{Factor of safety} = \frac{\text{ultimate load capacity of single or a group of piles}}{\text{working load + negative skin friction load}}$$

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Piles subjected to uplift loads:

- Tension piles or uplift piles are subjected to uplift forces and overturning moments.
- Uplift piles are provided with an enlarged area at the base in the form of a bulb or bell.
- Piles develop resistance to pull out only from the skin friction developed along the embedded length.
- Weight of pile is included in the uplift resistance
- Point bearing resistance is not considered.

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Piles in clay:

The ultimate pull out resistance of piles (Q_{ut}) is given by

a. When the diameter of pile is uniform

$$Q_{ut} = f_{st}.A_s + W_p$$

f_{st} : Unit skin friction in tension

A_s : Embedded area of the pile shaft

W_p : Weight of the pile.

b. When the base of the pile is enlarged in the form of a bulb or bell, the smaller of the following is used to arrive at the pull out capacity under undrained conditions.

1. Based on the failure assumed through full mobilization of frictional resistance

$$Q_{ut} = \alpha c_u \overline{A_s} + W_s + W_p$$

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2. Based on the bearing capacity failure of the base

$$Q_{ut} = 2.25\pi\left(D_b^2 - D^2\right)c_u + W_p$$

$\overline{A}_s$: Surface area of the vertical cylinder above the base

D_b : Diameter of the base

D : Pile shaft diameter

k : a coefficient

W_s : Weight of the soil included in the annulus between the pile shaft and the vertical cylinder above the base.

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Piles in $c-\phi$ soil:

For shallow depths $(L \le H)$

$$Q_{ut} = \pi c.D_b.L + \frac{\pi}{2}.s.\gamma'.D_b L^2.k_u.\tan\phi + W_p$$

$$= K_u.\bar{\sigma}_{av}.A_s.\tan\phi$$

For larger depths $(L > H)$

$$Q_{ut} = \pi c.D_b.H + s.\gamma'.D_b(2L-H)H.k_u.\tan\phi + W_p$$

L :Embedded length of the pile

H : Limiting height of failure surface above the base

s : Shape factor $= 1 + \frac{mL}{D_b}$ with a minimum value of $1 + \frac{mH}{D_b}$

m : Coefficient depending on ϕ

γ': Effective unit weight of soil

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k_u: Earth pressure coefficient

$\bar{\sigma}_{av}$: Average effective pressure

Based on the bearing capacity failure of the base of the pile,

$$Q_{ut} = \frac{\pi}{4}(D_b^2 - D^2)(c.N_c + \bar{\sigma}_b.N_q) + A_s.f_s + W_p$$

The value of is Q_{ut} taken as smaller of the values obtained through above equations.

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Numerical Questions

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1. A pile of length 6 m is driven by 1200 kg hammer, falling through 1.2 m, to a final set of 10 mm per blow. Using Engineering News formula, the ultimate load on the pile is ……..

Ans: 6857.1 kg

Engineering News formula, $$Q_u = \frac{WH}{6(S+0.25)} = \frac{1200 \times 120}{6(1+2.5)} = 6857.14kg$$

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2. A Pile is driven with a single acting hammer of weight 18 kN with a fall of 1200 mm. The average penetration of the last few blows is 15 mm. Using Engineering News formulae, the ultimate load on the pile is ………..

Ans: 205.7 kN.

Engineering news formula for single acting hammer

$$Q_u = \frac{WH}{6(S+0.25)} = \frac{18\times120}{6(1.5+0.25)} = 205.7\text{kN}$$

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3. A pile is to be driven for carrying a safe load of 220 kN with a steam hammer of weight 15 kN falling through a height of 1 m.

i. The penetration per blow of the pile is ………

$$Q_u = \frac{WH}{6(S+0.25)} \Rightarrow 220 = \frac{15\times 100}{6(1+2.5)} \Rightarrow 1320S + 330 = 1500$$

$$S = 0.886 \text{ cm/blow}$$

ii. The depression for last 20 blows is ………..

$$\text{For 20 blows} = 0.886\times 20 = 17.72 \text{ cm}$$

4. A pile is driven with a single acting hammer of weight 80 kN with a free fall of 1200 mm. The total penetration for the last 20 blows is 240 mm. The efficiency of hammer is 80% and the efficiency of the hammer blow is 75%. Using Modified Hiley formula,

i. The ultimate load carrying capacity of soil is ………..

$$W = 18\text{kN} \qquad H = 1200\,\text{min} \qquad n = 20 \qquad \eta_h = 0.8 \qquad \eta_b = 0.75$$

$$\text{Total S} = 240 \qquad S = \frac{240}{20} = 12mm/blow$$

$$Q_u = \frac{WH.\eta_h.\eta_b}{(S+0.5C)} = \frac{18\times120\times0.8\times0.75}{(1.2+0.5\times0.25)} = 978.11\text{kN}$$

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ii. If the factor of safety is 3, the ultimate safe load on pile is ……….

$$Q_{us} = \frac{978.11}{3} = 326.03\text{kN}$$

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5. A 30 cm diameter pile penetrates a deposit of soft clay of length 12 m and rests on sand, the clay has unconfined compressive strength of 100 kN/m^2. Adhesion factor of clay is 0.6. If the factor of safety is 3, then the safe frictional resistance of the pile is ………..

Ans: 113.1 kN

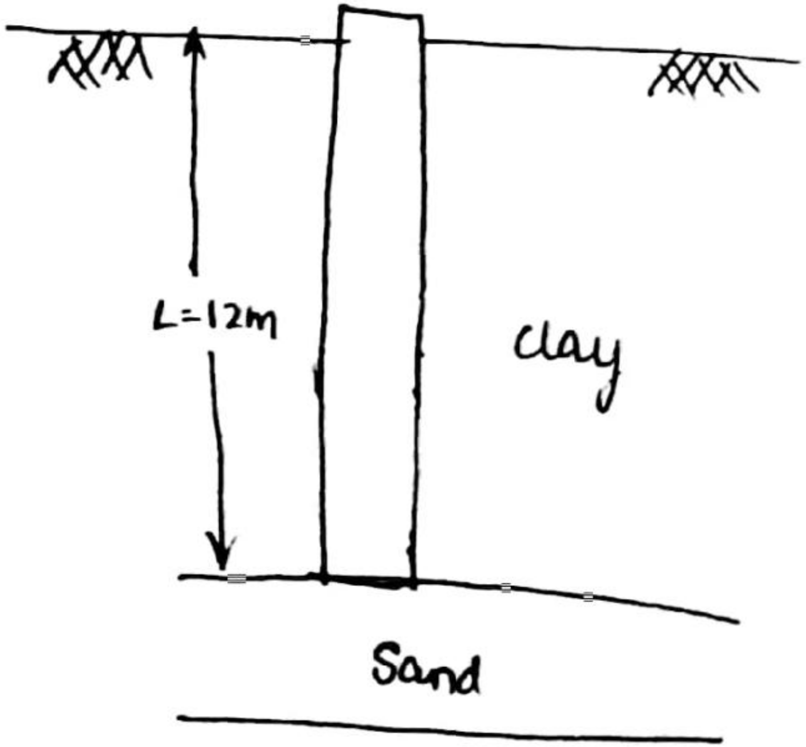
Q_u : Ultimate load carrying capacity if pile

$$Q_u = Q_{pu} + Q_f$$

$$= cN_c A_f + \alpha c_u A_f$$

$$Q_u = 0.6 \times 50 \times \pi \times 0.3 \times 12 = 339.3\text{kN}$$

$$\text{Safe load} = \frac{Q_u}{F_s} = 113.1\text{kN}$$



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6. A Square pile 300 mm size penetrates into soft clay with unit cohesion of 60 kN/m^2 for a depth of 10 m and rests on stiff soil. The adhesion factor for clay is 0.75. If the factor of safety is 2.5, the frictional resistance of the pile is ……….

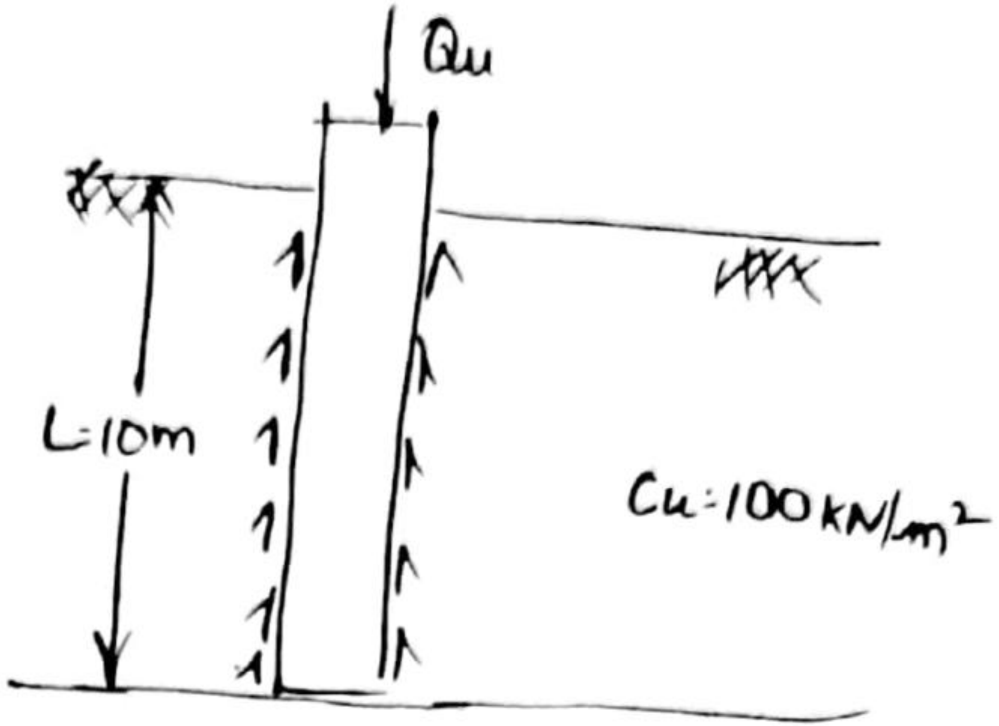
Ans: 540 kN/m^2

$$c_u = 60\text{kN/m}^2 \quad L = 10m \quad \alpha = 0.75$$

$$Q_u = cN_cA_c + \alpha c_u A_f$$

$$Q_u = 0.75 \times 60 \times 4 \times 0.3 \times 10 = 540\text{kN}$$

$$\text{Safe load} = \frac{Q_u}{F_s} = \frac{540}{2.5} = 216\text{kN}$$



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7. A group of 9 piles each of 300 mm diameter is arranged with a pile spacing of 1 m centre to centre. Piles are10 m long and embedded in soft clay with cohesion of 40kN/m^2. Adhesion factor for clay is 0.7. Neglecting end bearing at the tip of the piles, the ultimate load carrying capacity of the pile group is …………

Ans: 2375 kN

For Individual failure of piles

$$Q_{ug} = n.Q_u$$

$$Q_u = cN_cA_b + \alpha c_u A_s$$

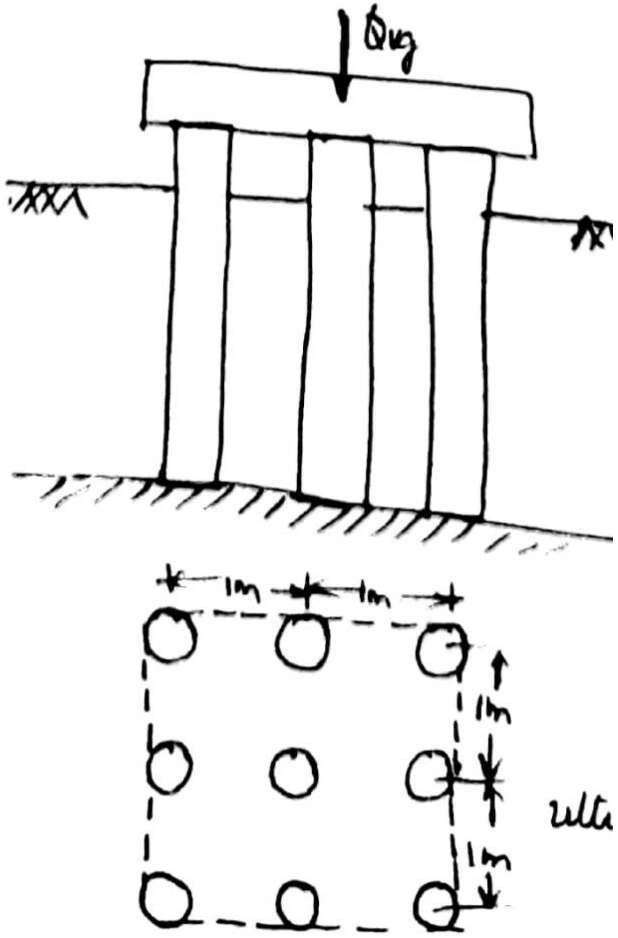
$$Q_u = 0.9 \times 40 \times \pi \times 0.3 \times 10 = 2639\text{kN}$$

$$Q_{ug} = 9 \times 263.9 = 2375\text{kN}$$

For block failure

$$Q_{ug} = c_{ub}N_cA_b + \alpha c_u A_s$$

$$Q_{ug} = 0.7 \times 40 \times 4 \times 2.3 \times 10 = 2576\text{kN}$$



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Previous GATE Questions

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01.A timber pile of length 8 m and diameter 0.2 m is driven with a 20 kN drop hammer, falling freely from a height of 1.5 m. The total penetration of the pile in the last 5 blows is 40 mm. Use the Engineering News Record expression. Assume a factor of safety of 6 and empirical factor (allowing reduction in the theoretical set, due to energy losses) of 2.5 cm. The safe load carrying capacity of the pile (in kN, round off to 2 decimal places) is ……… CE2 2019

Ans: 151.52

Length of the pile, L = 8 m

Diameter of the pile, D = 0.2 m

Weight of drop hammer, W = 20 kN

Height of falling of drop hammer, h = 1.5 m= 150 cm

Total penetration of the pile in last 5 blows = 40 mm

Set value, S = 8 mm = 0.8 cm

Factor of safety, F = 6

Empirical factor, c =2.5cm

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Safe load carrying capacity of pile, $Q_s = ?$

According to Engineering News Record expression,

$$Q_s = \frac{W.h.\eta_h}{F(S+c)} = \frac{20\times150\times1}{6(0.8+2.5)} = 151.52\ kN$$

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02. A reinforced concrete circular pile of 12 m length and 0.6 m diameter is embedded in stiff clay which has an undrained unit cohesion of 110 kN/m^2. The adhesion factor is 0.5. The Net Ultimate Pullout (uplift) Load for the pile (in kN, round off to 1 decimal place) is…… CE1 2019

02. 1244

Length of pile, L=12m

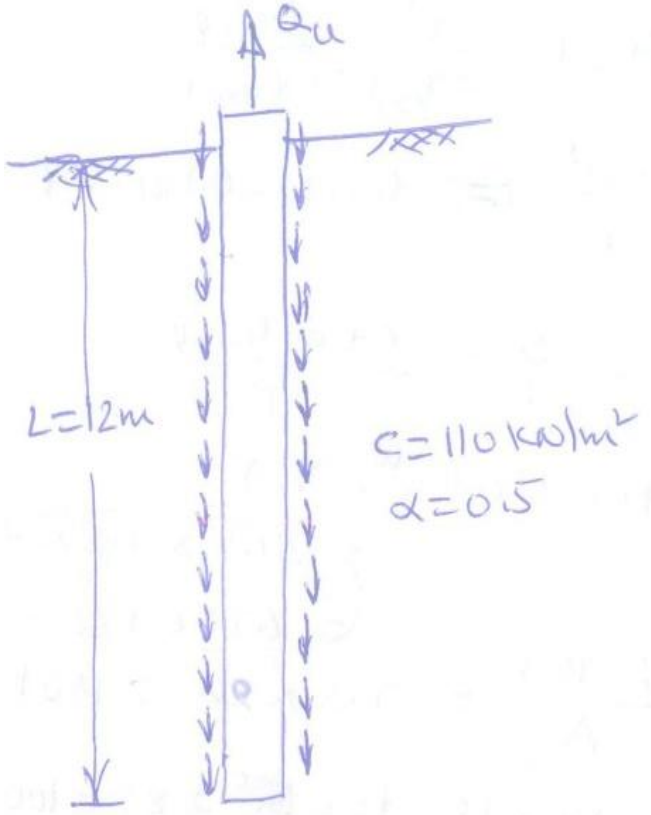
Diameter of pile, D=0.6m

Undrained unit cohesion, C_u =110KN/m^2

Adhesion factor, α = 0.5

Net upward pullout (uplift) load for the pile, $Q_u = ?$

$$Q_u = f_s.A_s = \alpha c.\pi DL = 0.5\times110\times\pi\times0.6\times12 = 1244\,kN$$



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03. A group of nine piles in a square pattern is embedded in a soil strata comprising dense sand underlying recently filled clay layer, as shown in the figure. The perimeter of an individual pile is 126 cm. The size of pile group is 240 cm 240 cm. The recently filled clay has undrained shear strength of 15 kPa and unit weight of 16 kN/m^3. The negative frictional load (in kN, up to two decimal places) acting on the pile group is CE2 2018

Ans. 472.32

The perimeter of individual pile, P = 126 cm = 1.26 m

Size of pile group = 2.40 m × 2.40 m

Undrained shear strength of recently filled clay, C = 15 kPa

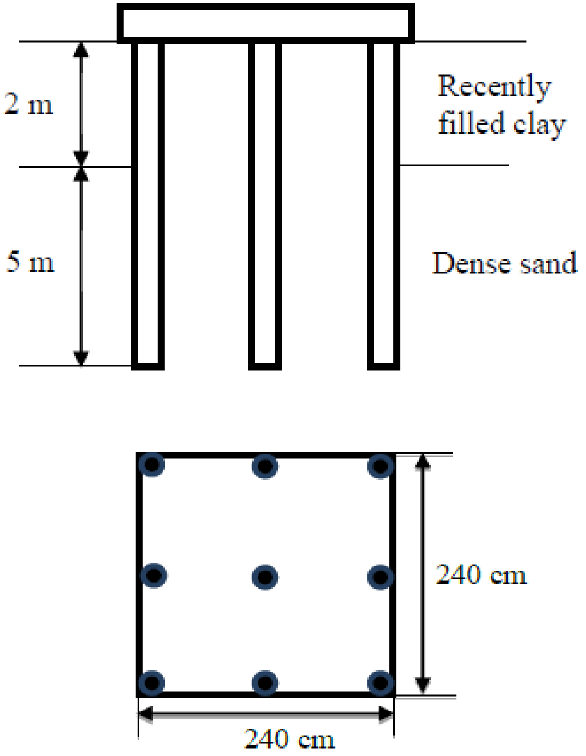
Unit weight of recently filled clay, γ = 16 kN/m^3

Negative friction load acting on the pile group = ?

For individual action of pile, negative skin friction,

$$F_{ng} = n.F_n = n.\alpha.c.p.L$$

$$= 9 \times 1 \times 15 \times 1.26 \times 2 = 340.2\ kN$$



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For group action of piles, negative skin friction,

$$F_{ng} = \alpha.c.p.L + \text{weight of soil in negative zone}$$

$$= (1\times 15\times 4\times 2.4\times 2) + (2.4\times 2.4\times 2\times 16) = 288 + 184.32 = 472.32\, kN$$

Negative skin friction is the maximum value of above cases = 472.32 kN

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04. A square concrete pile is to be driven in a homogeneous clayey soil having undrained shear strength, C_u =50 kPa and unit weight, γ =18.0 kN/m^3. The design capacity of the pile is 500 kN. The adhesion factor α is given as 0.75. The length of the pile required for the above design load with a factor of safety of 2.0 is CE1 2018

a. 5.2 m b. 5.8 m **c.** 11.8 m d. 12.5 m

04. c

Size of concrete pile = 0.5 m×0.5 m

Undrained shear strength of soil, C_u = 50 Kpa

Unit weight of soil, γ = 18 KN/m^3.

Design capacity of pile, Q_u = 500 KN

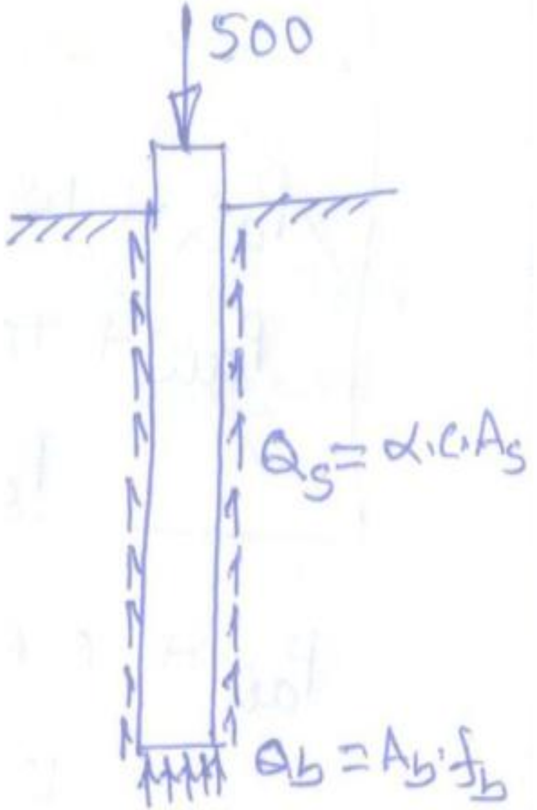
Adhesion factor, α = 0.75

Factor of safety, F = 2.0

Length of the pile, L = ?

For clayey soil, $\phi = 0$

$$N_c = 9, \Rightarrow f_b = c.N_c = 9c$$



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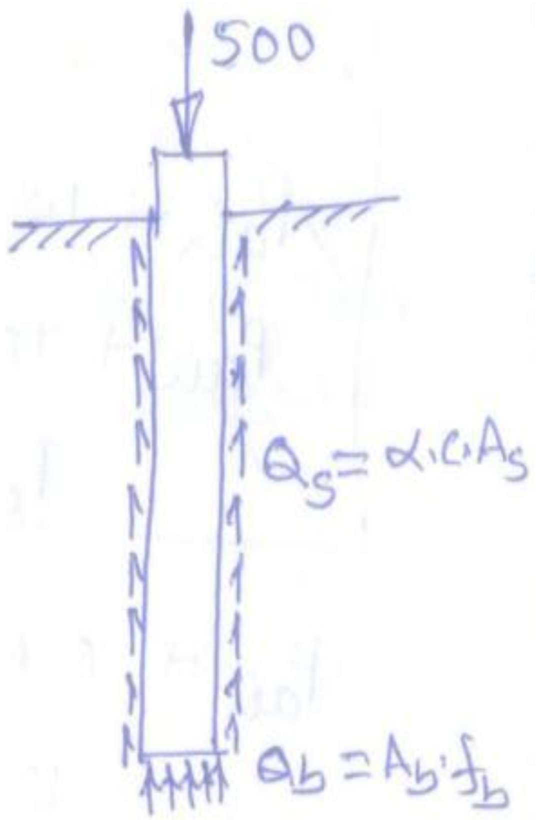
$$Q_u = Q_b + Q_s$$

$$F.Q_u = A_b.f_b + \propto .C.A_s = A_b.9C_u + \propto C\,A_s$$

$$2 \times 500 = 0.5 \times 0.5 \times 9 \times 50 + 0.75 \times 50 \times 4 \times 0.5 \times L$$

$$1000 = 112.5 + 75L$$

$$L = 11.83\ \text{m}$$



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05. It is proposed to drive H-piles up to a depth of 7 m at a construction site. The average surface area of the H-pile is 3 m^2 per meter length. The soil at the site is homogenous sand, having an effective friction angle of 32°. The ground water table (GWT) is at a depth of 2 m below the ground surface. The unit weights of the soil above and below the GWT are 16 kN/m^3 and 19 kN/m^3, respectively. Assume the earth pressure coefficient, K = 1.0, and the angle of wall friction, δ =23°. The total axial frictional resistance (in kN, up to one decimal place) mobilized on the pile against the driving is CE1 2017

05. 390.7

Surface area of H pipe = $3m^2/m$

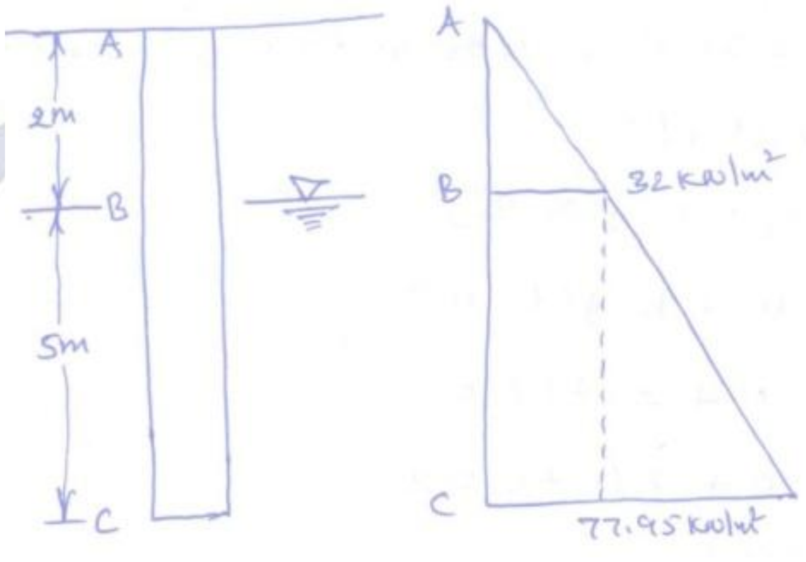
Effective angle of friction, $\phi = 32^0$

Unit weight of soil above GWT, $\gamma = 16$ kN/m^3

Unit weight of soil below GWT, $\gamma = 19$ kN/m^3

Earth pressure coefficient, k = 1.0

Angle of wall friction, $\delta = 23^0$



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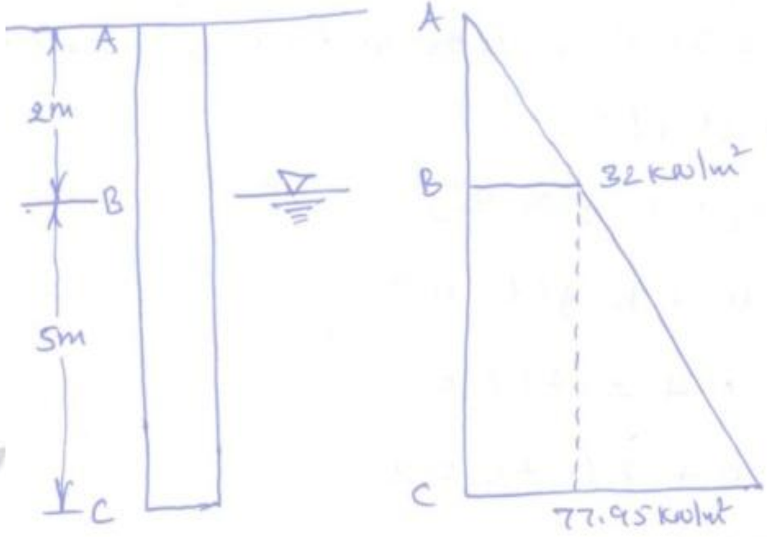
Total axial frictional resistance on the pile against driving, $Q_f = K.\sigma_{av}.\tan\delta.A_s$

Intensity of stress at B $= 16 \times 2$ = 32 kN/m^2

Intensity of stress at C $= 16 \times 2 + (19 - 9.81)5$ = 77.95 kN/m^2

For AB portion, $\sigma_{avg} = \dfrac{0+32}{2}$ = 16 kN/m^2



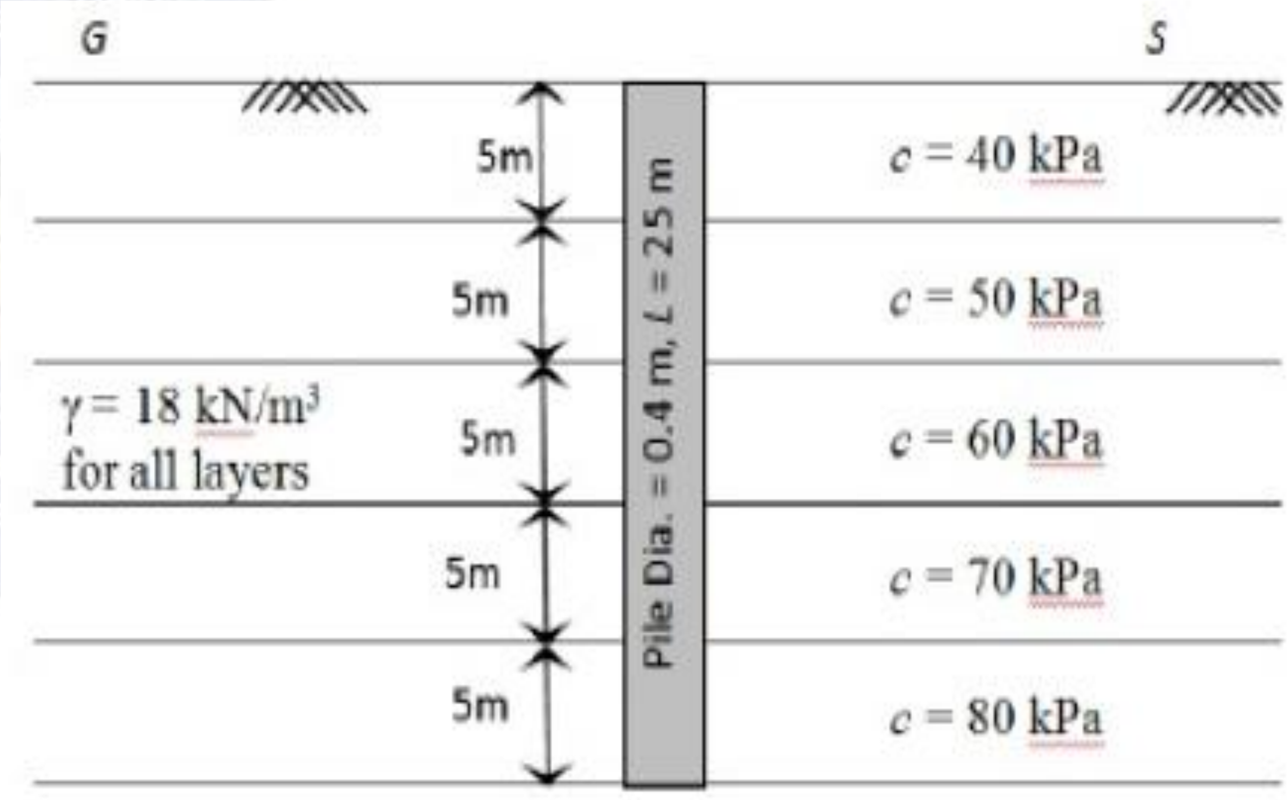
For BC portion, $\sigma_{avg} = \dfrac{32+77.95}{2}$ = 54.97 kN/m^2

$$Q_f = 1.0 \times 16 \times \tan 23^0 \times 3 \times 2 + 1.0 \times 54.97 \times \tan 23^0 \times 3 \times 5$$

$$Q_f = 390.75\,\text{kN}$$

06. A pile of diameter 0.4 m is fully embedded in a clay stratum having 5 layers, each 5 m thick as shown in the figure below. Assume a constant unit weight of soil as 18 kN/m^3 for all the layers. Using $\lambda = 0.15$ for 25 m embedment length) and neglecting the end bearing component, the ultimate pile capacity (in kN) is… CE2 2015

Ans.



Diameter of pile, d = 0.4 m

Unit weight of soil, γ =18 kN/m^3

Length of the pile, L = 25 m

Average cohesion, c = 60 kPa

Parameter, $\lambda = 0.15$

Ultimate pile capacity,

$$Q_u = \lambda\left(\sigma_{v,avg} + 2C_u\right)A_s$$

$$Q_u = 0.15\left[18\times12.5 + 2\times60\right]\pi\times0.4\times25$$

$$Q_u = 1625.8\ kN$$

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07.A single vertical friction pile of diameter 500 mm and length 20 m is subjected to a vertical compressive load. The pile is embedded in a homogeneous sandy stratum where: angle of internal friction $(\phi)= 30^0$, dry unit weight (γ_d) = 20 kN/m^3 and angle of wall friction ($\delta = 2\phi/3$) . Considering the coefficient of lateral earth pressure (K) = 2.7 and the bearing capacity factor (N_q) = 25, the ultimate bearing capacity of the pile (in kN) is __ CE2 2014

Ans. 5105

Diameter of the pile, d = 500mm

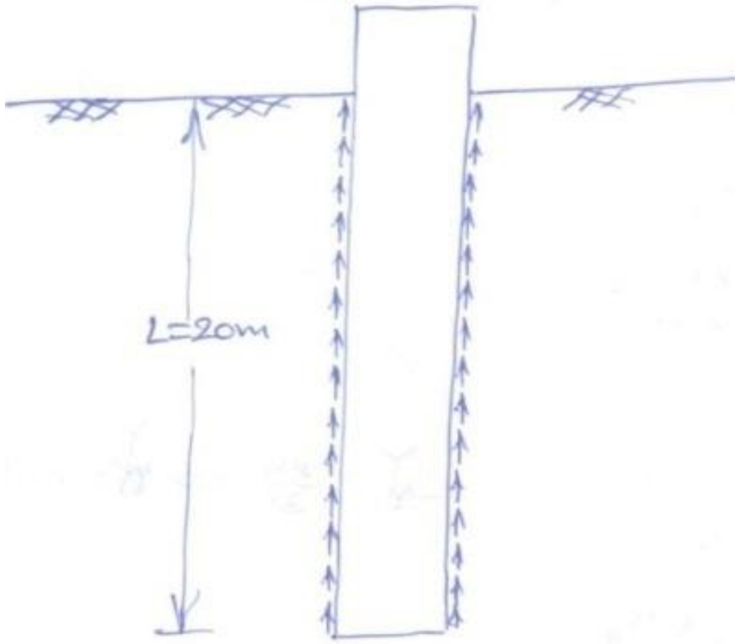
Length of the pile, L = 20 m

Angle of internal friction of soil, $\phi = 30^0$

Dry unit weight of soil, $\gamma_d = 20\,\text{kN/m}^3$

Angle of wall friction, $\delta = \frac{2}{3}\phi = \frac{2}{3}\times 30 = 20^0$

Coefficient of lateral earth pressure, $k = 2.7$



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Ultimate bearing capacity of the pile, $Q_u = ?$

$$Q_u = q_{pu}.A_b + f_s.A_s$$

For granular soil, q_{pu} : Unit point bearing resistance

$$q_{pu} = \bar{\sigma}.N_q = \gamma.L.N_q$$

Unit skin friction resistance, $f_s = \sigma_h.\tan\delta \;\; = K.\bar{\sigma}_{av}.\tan\delta \leq 100\,\text{kN/m}^2$

$\bar{\sigma}_{av}$: Average effective overburden pressure over the embedded length of the pile

$$Q_u = \gamma.L.N_q.A_b + K.\bar{\sigma}_{av}.\tan\delta.A_s$$

$$= 20\times 20\times 25\times\frac{\pi}{4}(0.5)^2 + 2.7\times 20\times\frac{0+20}{2}\times\tan 20^0\times\pi\times 0.5\times 20$$

$$\boxed{Q_u = 8138.1\text{kN}}$$

or

$$Q_u = 20\times 20\times 25\times\frac{\pi}{4}(0.5)^2 + 100\times\pi\times 0.5\times 20 = 5105.1\text{kN}$$

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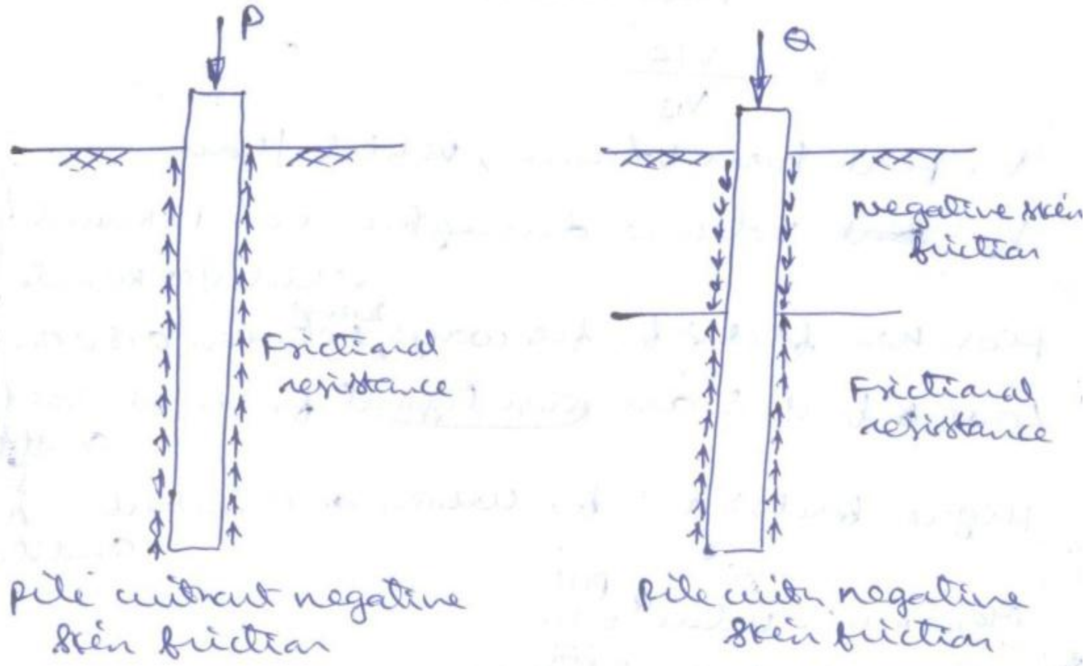
08. The action of negative skin friction on the pile is to CE1 2014

a. increase the ultimate load on the pile **b.** reduce the allowable load on the pile

c. maintain the working load on the pile d. reduce the settlement of the pile

08. b

Negative skin friction is a downward drag on the pile surface, when the soil moves down relative to the pile. The negative skin friction adds to the structural loads. Therefore, negative skin friction has an effect of reducing the allowable load on the pile.



P: Allowable load on pile when it not subjected to negative skin friction

Q: Allowable load on pile when it is subjected to negative skin friction

$$P > Q$$

09. Four columns of a building are to be located within a plot size of 10 m×10 m. The expected load on each column is 4000 kN. Allowable bearing capacity of the soil deposit is 100 kN/m^2. The type of foundation best suited is 2013

a. isolated footing
b. raft foundation
c. pile foundation
d. combined footing.

09. c

$$\text{Load on each column} = 4000\,\text{kN}$$

$$\text{Allowable bearing capacity of soil} = 100\ \text{kN/m}^2$$

$$\text{Plan area of footing required} = \frac{4 \times 4000}{100} = 160\ \text{m}^2 > \text{Area of plot} = 100\,\text{m}^2$$

Therefore, Pile foundation is suitable for the building.

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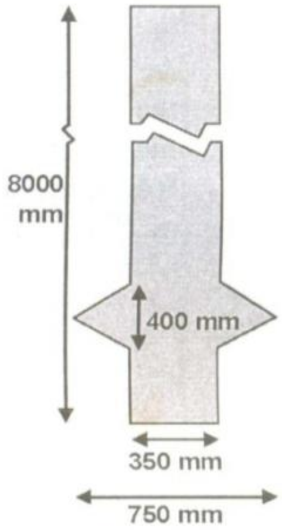
Foundation type	use
Isolated footings	Most economical and widely used when the column loads are small and / or SBC of soil is high
Combined footing	When two columns are closely spaced such that their isolated footings overlap. when the column is located near the boundary of property line, combined footing is used such that it will not project beyond the property line.
Raft foundation	when the soil is weak and / or column loads are large such that the area of footing required is more than 50% of plan area.
Pile foundation	When the soil is very poor, soft, underwater and their use prevents excessive settlement.

10. A singly under-reamed 8 m long, RCC pile (shown in the adjoining figure) weighting 20 KN with 350 mm shaft diameter and 750 mm under-ream diameter is installed with stiff, saturated silty clay (undrained shear strength is 50 kPa, adhesion factor is 0.3, and the applicable bearing capacity factor is 9) to counteract the impact of soil swelling on a structure constructed above. Neglecting suction and the contribution of the under-ream to the adhesive shaft capacity, what would be the estimated ultimate tensile capacity (rounded off to the nearest integer value of KN) of the pile? 2011



a. 132 kN b. 156 kN c. 287 kN **d.** 301 kN

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10. d

The ultimate tensile capacity of the pile is smaller of the following.

i. $Q_{ut} = c_u.\bar{A}_s.k + W_s + W_p$

$\bar{A}_s$: Surface area of the vertical cylinder above the base =

c_u : Undrained cohesion in the embedded length of the pile = 50 kpa

k : Constant = 0.5 for stiff clay

W_s : Weight of the soil included in the annulus between the pile shaft and the vertical cylinder above the base = $\frac{\pi}{4}\left(D_b^2 - D^2\right)\gamma L$

W_p : Weight of the pile = 20 kN

$$Q_{ut} = 50\times\pi\times0.75\times8\times0.5 + (19\ -\ 9.8)\frac{\pi}{4}\left(0.75^2 - 0.35^2\right)\times8+20$$

= 471.2 + 25.43 +20 = 516.63 kN

ii. $Q_{ut} = 2.25\pi\left(D_b^2 - D^2\right)c_u + W_p$

= 2.25 $(0.75^2 – 0.35^2)$ × 50 +20 = 155.5 + 20 = 175.5 kN

Q_{ut} =175.5 + $\alpha.c_u.\pi DL$ $=175.5+0.3\times50\times\pi\times0.35\times7.6$ = 175.5 + 125.3

= 300.8 kN

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11. The ultimate load capacity of a 10m long concrete pile of square cross section 500mm × 500mm driven into a homogenous clay layer having undrained cohesion value of 40 kPa is 700 KN. If the cross section of the pile is reduced to 250mm × 250mm and the length of the pile is increased to 20 m, the ultimate load capacity will be 2010

a. 350 kN **b.** 632.5 kN c. 722.5 kN d. 1400 kN

11. b

For Pile 1:

Ultimate load carrying capacity is given by $Q_u = c_u.N_c.A_b + m.c_u.p_b.L$

Ultimate load carrying capacity, Q_u = 700 kN

Cohesion, c_u = 40 kPa

Bearing capacity factor, N_c = 9

Bearing area, A_b = 0.5×0.5

Adhesion factor, $m = ?$

Perimeter of the pile, P_b = 4×0.5

Length of the pile, L = 10 m

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$700 = 40×9×0.5×0.5 + ×40×4×0.5×10$

$m = 0.7625$

For Pile 2:

$c_u = 40$ kPa, $N_c = 9$, $A_b = 0.25×0.25$

$m = 0.7625$, $P_b = 4×0.25$, $L = 20$ m

Ultimate load carrying capacity is given by $Q_u = c_u.N_c.A_b + m.c_u.p_b.L$

$Q_u = 40×9×0.25×0.25+0.7625×40×4×0.25×20 = 632.5$ kN

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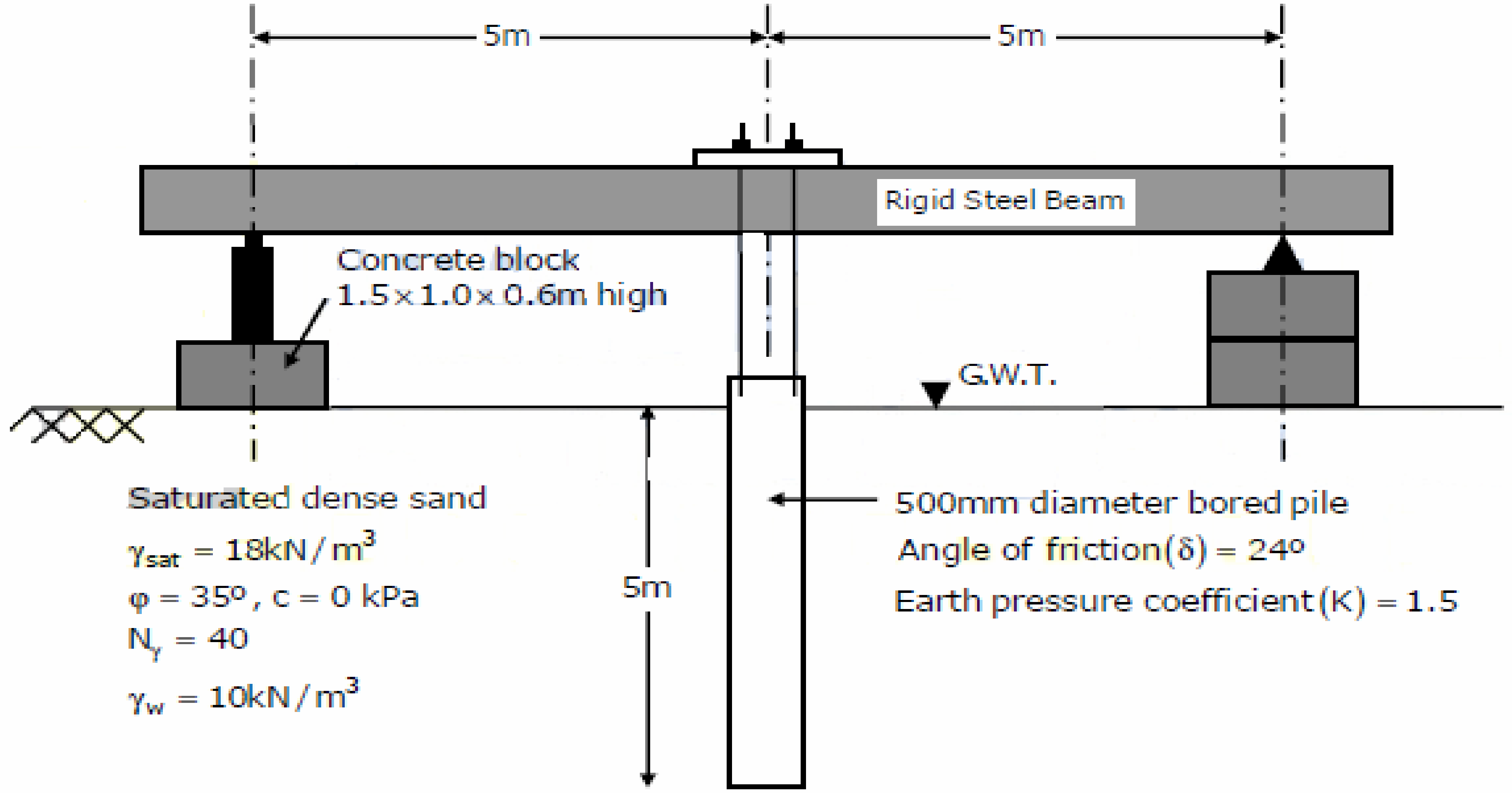
Common Data Questions: 12 & 13

Examine the test arrangement and the soil properties given below. 2009



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12. The maximum pressure that can be applied with a factor of safety of 3 through the concrete block, ensuring no bearing capacity failure in soil using Terzaghi's bearing capacity equation without considering the shape factor, depth factor and inclination factor is

a. 26.67 kPa b. 60 kPa c. 90 kPa d. 120 kPa

12. a

Terzhaghi's bearing capacity equation for rectangular footing is given by

$$q_u = c.N_c + \gamma D.N_q + 0.5\gamma.B.N_\gamma$$

$$C = 0, \quad B = 1.0\text{m}, \; D = 0, \; N_\gamma = 40$$

$$\gamma_{sat} = 18 \text{ kN/m}^3, \quad \gamma_w = 10 \text{ kN/m}^3$$

Since soil is submerged, $\gamma' = \gamma_{sat} - \gamma_w$

$$= 0 + 0 + 0.5\,(18 - 10)1.0\;40 = 160 \text{ kN/m}^2$$

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$$\text{Factor of safety, } F.S = \frac{\text{Ultimate pressure}\,(q_u)}{\text{Actual pressure}\,(q_a)}$$

$$q_a = \frac{q_u}{F.S} = \frac{160}{3} \times \frac{1}{2} = 26.67 \text{ kN/m}^2 = 26.67\text{kPa}$$

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13. The maximum resistance offered by the soil through skin friction while pulling out the pile from the ground is

a. 104.9 kN b. 209.8 kN c. 236 kN d. 472 kN

13. a

Negative skin friction, $Q_f = P.L.K.\sigma'_a.\tan\ \delta$

Perimeter of pile, $P = \pi D$

Length of the pile, $L = 0.5$

Diameter of the pile, $D = 0.5$

Coefficient of lateral earth pressure, $K = 1.5$

Average effective vertical stress along the length of pile, $\bar{\sigma}_a = \frac{1}{2}[0+\gamma' L]$

$$= \frac{1}{2}[0+8\times 5] = 20\,\text{kN/m}^2$$

Angle of friction between the pile and soil, $\delta = 24^0$

$$Q_f = \pi \times 0.5 \times 5 \times 1.5 \times 20 \times \tan 24^0 = 104.9\,\text{kN}$$

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14. A precast concrete pile is driven with a 50 kN hammer falling through a height of 1.0 m with an efficiency of 0.6. The set value observed is 4 mm per blow and the combined temporary compression of the pile, cushion and the ground is 6 mm. As per modified Hiley formula, the ultimate resistance of the pile is 2009

a. 3000 kN **b.** 4285.7 kN c. 8.333 kN d. 11905 kN

14. b

Weight of hammer, W = 50 kN

Height of fall of hammer, h = 1.0 m

Efficiency, η = 0.6

The observed set value, S = 4 mm per blow

Compression of the pile, C = 6 mm

The ultimate resistance of the pile as per Modified Hiley formula is given by

$$R = \frac{W.h.\eta}{S + 0.5C} = \frac{50 \times 1 \times 0.6}{(4 + 0.5 \times 6)10^{-3}} = 4285.7 \text{ kN}$$

15. A pile of 0.50 m diameter and length 10 m is embedded in a deposit of clay. The undrained strength parameters of the clay are cohesion = 60 KN/m^2 and the angle in internal friction = 0. The skin friction capacity (kN) of the pile for an adhesion factor of 0.6, is 2008

a. 671 **b.** 565 c. 283 d. 106

15. b

Skin friction capacity of clay is given by, $Q_s = \alpha.c.A_s$

Adhesion factor, α = 0.6

Undrained cohesion, c = 60 kN/m^2

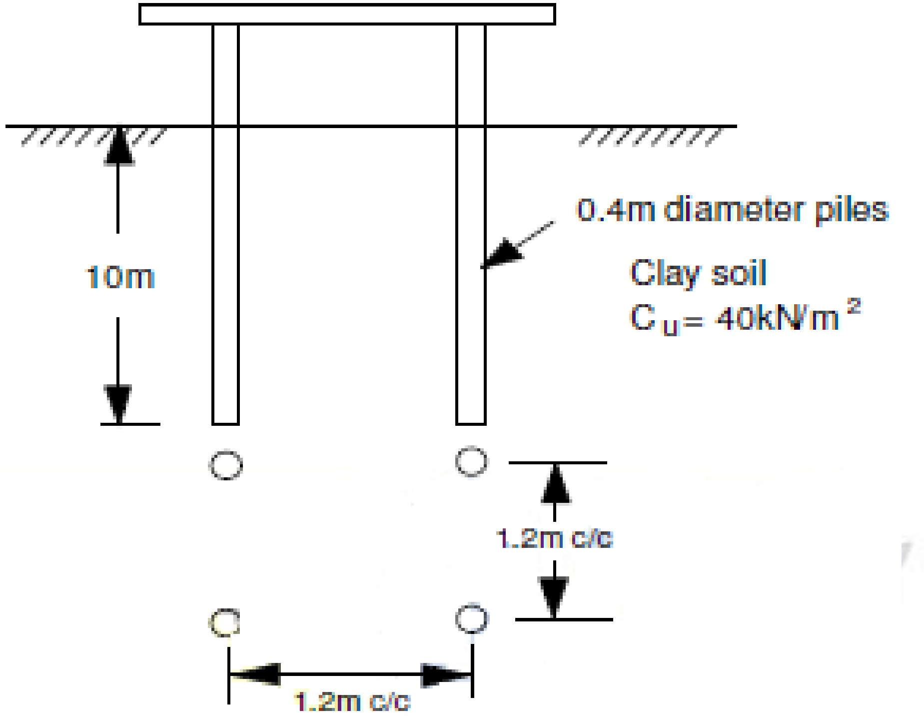
Effective area in developing friction, $A_s = \pi d.l$

Diameter of the pile, d = 0.5 m

Length of the pile, l = 10 m

$$Q_s = 0.6 \times 60 \times \pi \times 0.5 \times 10 = 565.48\,\text{kN} \approx 565\,\text{kN}$$

16. What is the ultimate capacity in kN of the pile group shown in the figure assuming the group to fail as a single block ? 2007



a. 921.6 b. 1177.6 c. 2438.6 **d.** 3481.6

16. d

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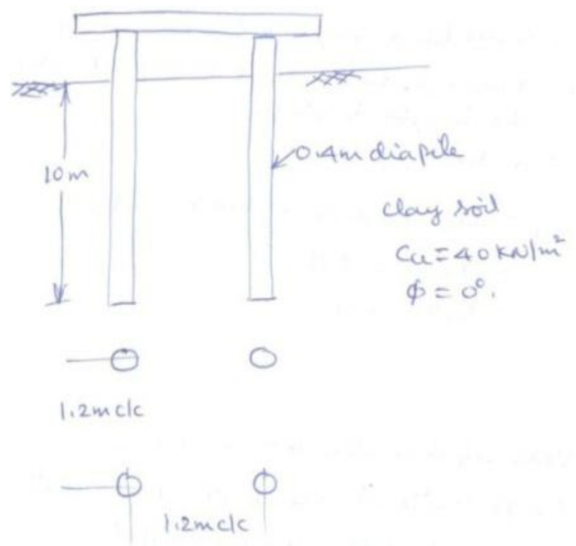


The ultimate load capacity of the pile group by block failure Q_{ug} is given by

$$Q_{ug} = c_{ub}.N_c.A_b + P_b.L.c'_u$$

Undrained strength of clay lat the base of the pile group, c_{ub} = 40 kN/m^2

Bearing capacity factor, N_c = 9

Cross sectional area of the block, A_b = (1.2 + 0.4)^2 = 2.56 m^2

Perimeter of the block, P_b = 4 (1.2 + 0.4) = 6.4 m

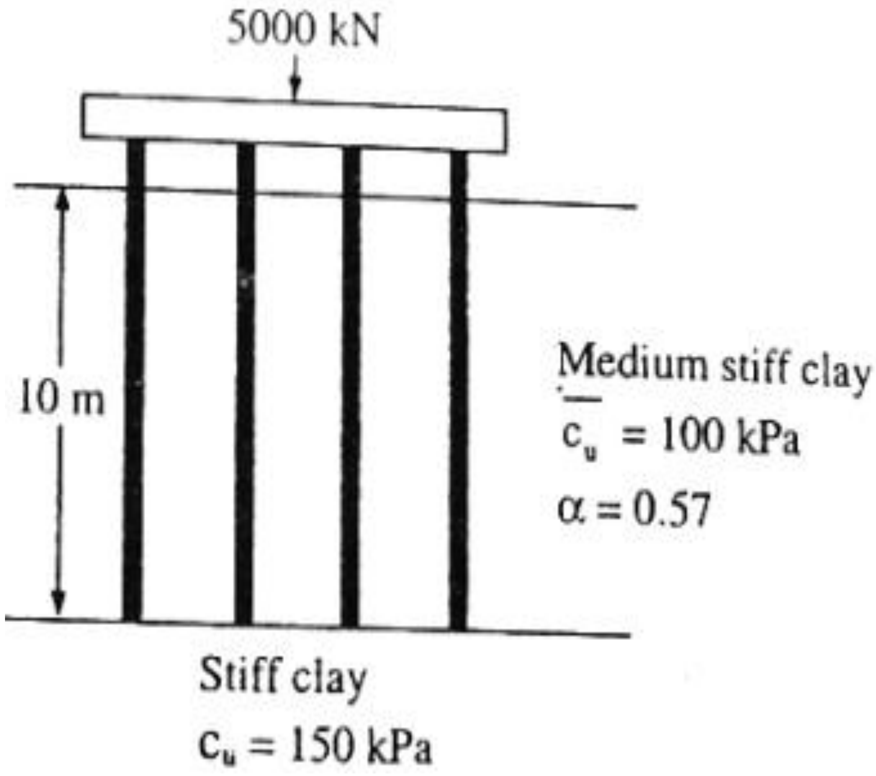
Embedded length of the pile, L = 10 m

Average undrained strength of clay along the length of block, c'_u = 40 kN/m^2

Q_{ug} = 40 9 2.56 + 6.4 10 40 = 921.6 + 2560 = 3481.6 kN

17. For the soil profile shown in figure below, the minimum number of precast concrete piles of 300 mm diameter required to safely carry the load for a given factor of safety of 2.5 (assuming 100% efficiency for the pile group) is equal to

2006



a. 10 b. 15 **c.** 20 d. 25

17. c

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The ultimate load capacity of piles = Load on piles × Factor of safety.

P_u = 5000 × 2.5 = 12,500 kN.

Load capacity of single pile, $P = c_{ub}.N_c.A_b + \alpha.c_u.A_s$

Undrained cohesion at the base of the pile, c_{ub} = 150 kPa = 150

Bearing capacity factor for a deep foundation, N_c = 9

Sectional area of the pile at the base, $A_b = \dfrac{\pi}{4}(0.3)^2 = 70.68 \times 10^{-3}\,\mathrm{m}^2$

Adhesion factor, α := 0.57

Undrained cohesion in the embedded length of the pile, c_u = 100 kPa.

Surface area of the pile in contact with the soil, $A_s = \pi(0.3)10 = 9.425\,\mathrm{m}^2$

P = 150×9×70.68×10^{-3} + 0.57×100×9.425 = 95.42 + 537.22 = 632.64 kN

Number of piles required $= \dfrac{P_u}{P} = \dfrac{12,500}{632.64}$ = 19.76 ≈ 20

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18. Negative skin friction in a soil is considered when the pile is constructed through

a. fill material b. dense coarse sand

c. over consolidated stiff clay d. dense fine sand 2005

Ans. a

Negative skin friction is experienced when the soil around the pile settles at a faster rate than pile. Thus piles installed in freshly placed fills of soft compressible deposits are subjected to a downward drag. The downward drag on the pile surface, when the soil moves down relative to the pile, adds to the structural loads and is called negative skin function.

Data for Q. 19-20 are given below. Solve the problems and choose the correct answers.

A group of 16 piles of 10 m length and 0.5 m diameter is installed in a 10 m thick stiff clay layer underlaine by rock. The pile-soil adhesion factor is 0.4; average shear strength of soil on the sides is 100 kPa; undrained shear strength of the soil at the base is also 100 kPa. CE 2004

19. The base resistance of single pile is

a. 40.00 kN b. 88.35 kN c. 100.00 kN **d.** 176.71 kN

Ans. d

No. of piles in a group, n= 16 Length of pile, L= 10 m

Diameter of pile, D= 0.5 m Pile-soil adhesion factor, α=0.4

Average shear strength of soil = 100 kPa = 100 kN/m^2

Undrained shear strength of soil at base, C_u= 100 kN/m^2

Base resistance of a single pile $= 9C_uA_b = 9 \text{x} 100 \text{x} \dfrac{\pi}{4} \text{x} (0.5)^2 = 176.71$ kN

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20. Assuming 100% efficiency, the group pile resistance is

a. 5026.5 kN b. 10000.0 kN **c.** 10053.1 kN d. 20106.0 kN

Ans. c

Efficiency of group piles $\eta = \frac{Q_{ug}}{n.Q_u}$

Q_{ug}= n.Q_u=$n.\alpha.C_u.P.L_c$=16x0.4x100x π x0.5x10=10053.1 kN

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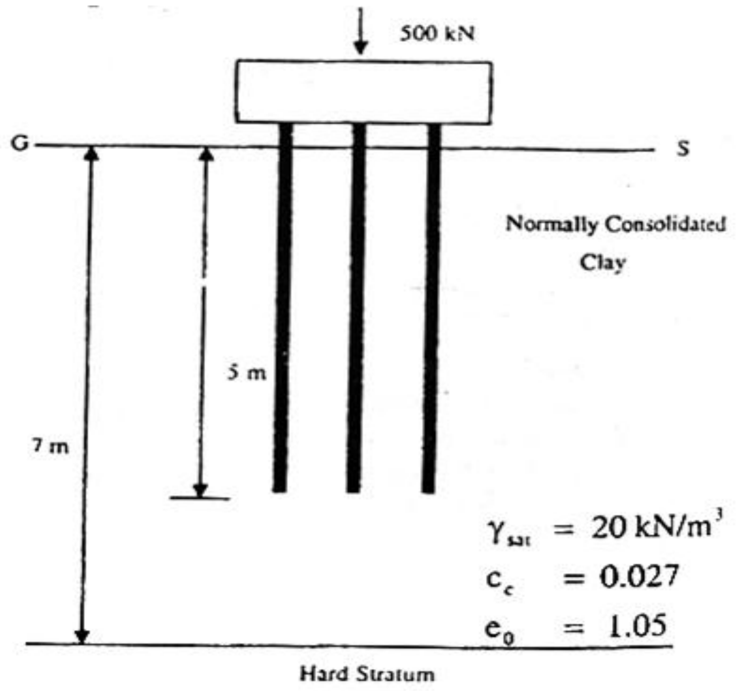
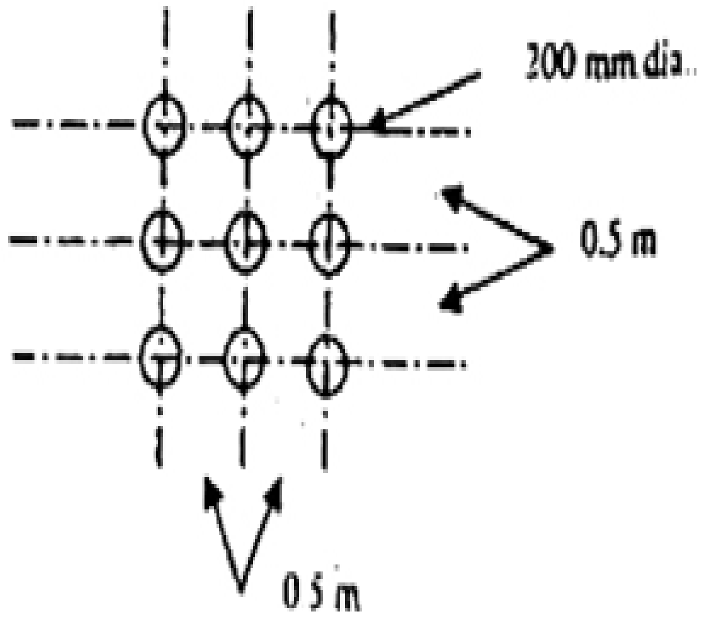
21. For the 3×3 pile group shown in the figure, the settlement of pile group, in a normally consolidated clay stratum having properties as shown in the figure, will be 2003

a. 13.2 mm b. 12.775 mm c. 7.345 mm d. none of these





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Ans. a

Thickness of the compressible structure $=\frac{2}{3}\times 5$ = 3.67 m

Consolidated settlement, $\Delta H = \frac{C_c.H}{1+e_0}\log\frac{\bar{\sigma}_0+\Delta\sigma}{\bar{\sigma}_0}$

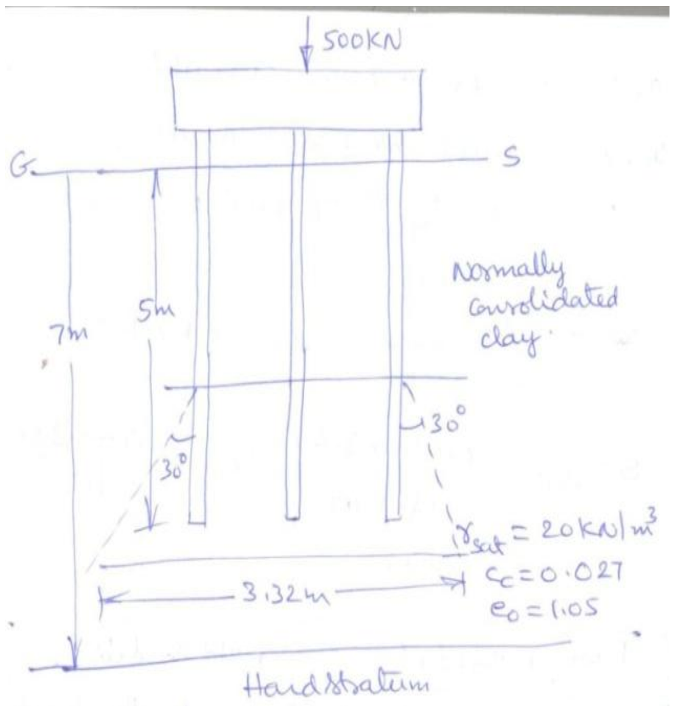
$\bar{\sigma}_0 = \gamma' D = (20-10)5.17 = 51.7\,\text{kN/m}^2$

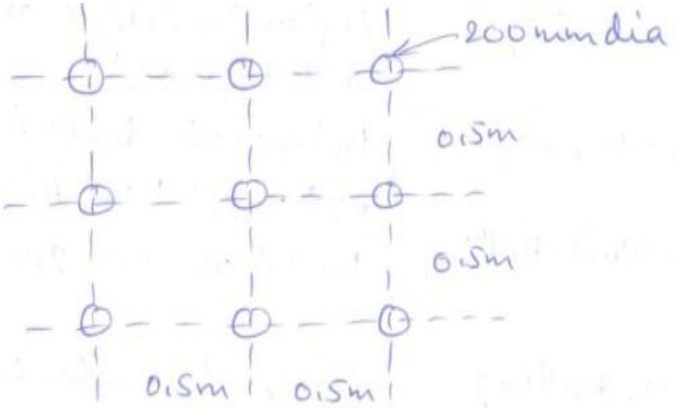
Increased width at a depth of 5.17 m =1.2+(7-5.17) tan $30^0\times2$

= 3.32m

$$\Delta\sigma = \frac{500}{3.32\times3.32} = 43.36\,\text{kN/m}^2$$

$$\Delta \text{H} = \frac{0.027\times3.67}{1+1.05}\log\left(\frac{51.7+43.36}{51.7}\right) = 13.2\,\text{mm}$$





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22. Identify the two TRUE statements from the following four statements. 2001

I. Negative skin friction is higher on floating piles than on end bearing piles.

II. All other things being the same in footings on sand, the footing with smaller width will have lower settlement at the same net pressure.

III. The void ratio of soils is always less than 1.0.

IV. For determining the depth of embedment of anchored sheet piles, net moment at the anchor elevation is set to zero.

a.1 & IV b. I & III **c.** II & IV d. II & III

Ans. c

I. When the settlements of the soil are larger than the pile settlements, negative skin friction develops along the shaft leading to an increase in the axial pile load. The boundary between positive and negative skin friction is defined by the neutral point. For end bearing piles the neutral point is located near the pile base, where the settlements of the surrounding soil cannot mobilize the full shaft resistance. For long friction piles the neutral point is located in the upper portion of the pile, where settlement of the soil and the pile are the same.

Therefore, negative skin friction is lower on floating piles than on end bearing piles. Statement I is false.

II. Immediate settlement, $S_i = q.B\left(\frac{1-\nu^2}{E_s}\right).I_f$

S_i: Immediate settlement at a corner of a rectangular flexible foundation of size LxB

B: width of the foundation

q: uniform pressure on the foundation

E_s: Modulus of elasticity of the soil beneath the foundation

ν : Poission's ratio of the soil

I_f : Influence value, depends on L/B

It depends on the elastic properties of foundation soil, rigidity, size and shape of foundation.

$$S_i \propto q.B$$

Therefore, the footing with smaller width will have lower settlement at the same net pressure. Statement II is true.

III. Void ratio of a soil is defined as the ratio of volume of voids to the volume of solids. Void ratio $e \geq 0$, since soil contain some voids but there cannot be an upper limit to the volume of voids. Therefore, void ratio can be more than 1.0. Statement III is false.

IV. The forces acting on the sheet pile are

a. Active pressure due to the soil behind the pile

b. Passive pressure due to the soil in front of the pile, and

c. Tension in the anchor rod

The forces acting on the pile wall are as shown in fig. The system is in equilibrium when sum of the moments of all the forces about any point is zero. For convenience, to find the depth of embedment of anchored sheet piles, the moments taken about the anchor rod is set to zero. Statement IV is true.

23. The group efficiency of pile group 2000

a. will be always less than 100%

b. will be always greater than 100%

c. may be less than 100% or more than 100%

d. will be more than 100% for pile groups in cohesionless soils and less than 100% for those in cohesive soils.

Ans. d

Efficiency of pile group, $\eta = \dfrac{Q_{ug}}{n.Q_u}$

Q_{ug}: Ultimate load capacity of the pile group

Q_u : Ultimate load capacity of one file

n : Number of piles in the group

For loose to medium sand, in driven piles the soil around the piles get densified.

The efficiency of pile group η may even be more than 1.

24. Well foundation are commonly used as foundation for the following structures:

a. Water tanks **b.** Bridges c. Buildings d. Reciprocating machines 1997

Ans. b

Well foundations are commonly used as foundation for bridges.

25. Negative skin friction occurs when 1996

a. an upward drag exists in the pile

b. the surrounding soil settles more than the pile

c. the pile passes continuously through a firm soil

d. the driving operation begins

Ans. b

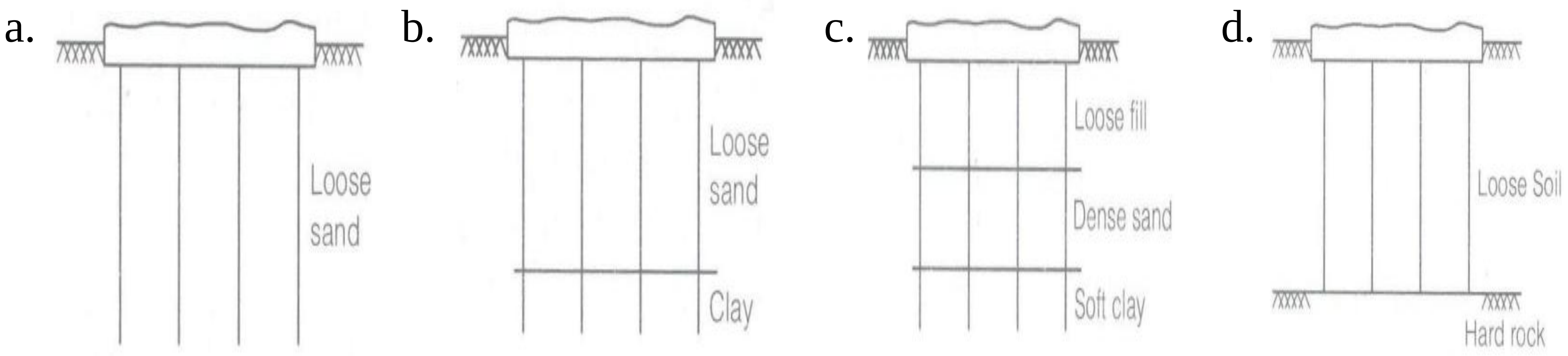
Negative skin friction occurs when the surrounding soil settles more than the pile.

26. Friction piles are also called ‘floating piles’. True / False 1995

Ans. True

A load-bearing pile is that which receives its principal vertical support from skin friction between the surface of the buried pile and the surrounding soil. Friction piles are also called floating piles.

27. In which one of the following conditions, is the pile system as shown in figure highly inappropriate? 1993



Ans. c

Pile foundations are used in situations where the soil at shallow depths is poor. In order to transmit the load safely, the depth of foundation has to be increased till a suitable soil stratum is met.

Option ‘c’ is inappropriate as the pile passes to soft clay through dense sand.

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