Chapter 12

Pile Foundation

CHAPTER HIGHLIGHTS

- *Introduction*
- *Necessity of pile foundations*
- *Classification of piles*
- *Pile driving*
- *Load carrying capacity of piles*
- *Negative skin friction*
- *Dynamic formulae*
- *Pile load test*
- *Group action of piles*
- *Efficiency of pile group (η_g)*
- *Group capacity of piles (Q_g)*
- *Under reamed piles in clay*

Introduction

When the soil at or near the ground surface is not capable of supporting a structure, deep foundations (in the form of pile, pier and caisson) are required to transfer the loads to deeper strata. Deep foundations are, therefore, used when surface soil is unsuitable for shallow foundation, and a firm stratum is so deep. Hence, the present chapter outlines the concept of pile foundations. The load carrying capacities of pile foundation by various methods are also discussed and the concept of negative skin friction is also discussed.

Necessity of Pile Foundations

1. When the strata at or just below the ground surface is highly compressible and very weak to support the load transmitted by structure.
2. A pile foundation is required to reduce differential settlement.
3. To transfer the loads through deep water to a firm stratum, pile foundation are required.
4. To resist horizontal forces due to wind and earthquake in earth retaining structures and tall structures, pile foundations are used.
5. Piles are used for foundations of structures subjected to uplift.
6. Piles are used to transfer the load below the active zone is case of expansive soils.

Classification of Piles

Piles can be classified according to:

1. The material used
2. The mode of transfer of load
3. The method of construction
4. The use
5. The displacement of soil.

Classification According to Material Used

1. **Steel piles:** Steel piles are, generally, either in the form of thick pipes or rolled steel.
   H-sections. Epoxy coating or concrete encasement at site is done as a protection against corrosion.
2. **Concrete piles:** Concrete piles are either precast or cast in-situ and cement concrete is used in the construction of concrete piles.
3. **Timber piles:** The timber used should be straight, sound and free from defects. The life of the timber piles can be increased by preservatives, such as creosote oils, and timber piles should not be used in marine environments where these are attacked by various organisms.
4. **Composite piles:** A composite pile is made of two materials. The combinations are steel and concrete or timber and concrete.

Classification Based on Mode of Transfer of Loads

1. **End-bearing piles:** These piles transfer the loads through their bottom tips if a firm stratum is available at a reasonable depth. Also, known as point bearing piles. The ultimate load carried by the pile (Q_u) is equal to the load carried by the point or bottom end (Q_p).

$$\boxed{Q_u = Q_P}$$

2. **Friction piles:** These piles transfer the load though skin friction between the embedded surface of the pile and the surrounding soil. Used when hard stratum is not available at a reasonable depth. These are also known as floating piles. The ultimate load carried by the piles (Q_u) is equal to the load transferred by skin friction (Q_s).

$$\boxed{Q_u = Q_s}$$

3. **Combined end-bearing and friction piles:** These piles transfer the load by the combination of end bearing at the bottom of pile and friction along the surface of pile. The ultimate load carried by a pile is equal to the sum of the load carried by the pile point (Q_p) and the load carried by skin friction (Q_s).

$$\boxed{Q_u = Q_p + Q_s}$$

Classification Based on Method of Installation

1. **Driven piles:** By applying blows on their tops, piles are driven in to the soil.
2. **Driven and cast in situ piles:** Formed by driving a casing with a closed-bottom end in to the soil. The casing is later filled with concrete. The casing may or may not be withdrawn.
3. **Bored and cast in situ piles:** These piles are formed by excavating a hole into the ground and, then filling it with concrete.

Classification Based on Use

1. **Load bearing piles:** Used to transfer the load of the structure to a suitable stratum by end bearing, by friction or by both.
2. **Compaction piles:** Used to increase the bearing capacity of loose granular soils.
3. **Tension piles:** Piles are used to anchor down the structure subjected to hydrostatic uplift forces or overturning forces.
4. **Sheet piles:** These are used for retaining earth or water.
5. **Fender piles:** These are used to protect water front structures from impacts of ships and vessels.
6. **Anchor piles:** Used to provide anchorage for anchored sheet piles. These piles provide resistance against horizontal pull for a sheet pile wall.

Classification Based on Displacement of Soil

1. **Displacement piles:** If the soil surrounding the pile is displaced during installation of pile, then it is called 'displacement pile'. All driven piles are displacement piles as the soil is displaced laterally when the pile is installed.
2. **Non-displacement piles:** Bored piles are non-displacement piles.

Pile Driving

- Piles are driven into the ground by means of hammer or by using a vibratory driver.
- Hammers used for driving are of the following types:

(a) **Drop hammer:** It is an oldest method. Because of very slow rate of hammer blows, these days, it is rarely used.

(b) **Single-acting hammer:** Air or steam pressure is used to raise the hammer and, it is then allowed to fall under gravity on pile cap.

(c) **Double-acting hammer:** Air or steam pressure is used to raise the hammer and, also used to fall on pile cap.

(d) **Diesel hammer:** Diesel hammers are not suitable for driving piles in soft soils. Diesel hammer are self-contained and self-activated.

(e) **Vibratory pile driver:** A vibratory pile driver is useful only for sandy and gravelly soils. The method is used where vibrations and noise of conventional driving methods cannot be permitted.

Load Carrying Capacity of Piles

1. **Static methods:**

For driven piles in sand:

The ultimate capacity of a single-pile driven into the sand is given by,

$$\boxed{Q_u = Q_p + Q_s}$$

Where

$$\boxed{\begin{array}{l} Q_p = q_p A_p \\ Q_s = f_s A_s \end{array}}$$

Q_p = Ultimate bearing capacity of the soil at pile tip

A_p = Area of the pile tip

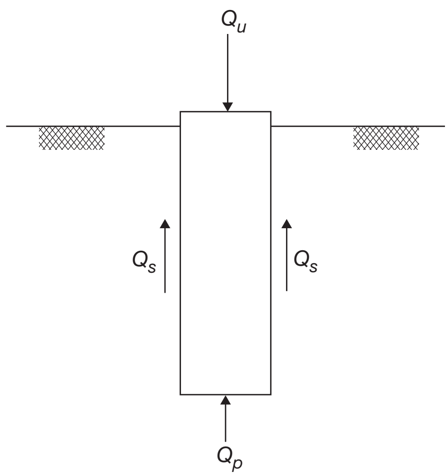
f_s = Average unit skin friction between the sand and the pile surface

A_s = Effective surface area of the pile in contact with the soil

Q_u = Ultimate failure load

q_p = Point (or based on tip) resistance of the pile

Q_s = Shaft resistance developed by friction (or adhesion) between the soil and the pile shaft



Determination of Q_p: The ultimate bearing capacity (q_p) of the soil at the pile tip is similar to that of bearing capacity equation for a shallow foundation.

For sandy soils,

$$\boxed{q_p = \sigma_v' \ N_q + 0.4_{\gamma} BN_{\gamma}}$$

Where

σ_v' = Effective vertical pressure at pile tip

B = Pile tip width (or diameter)

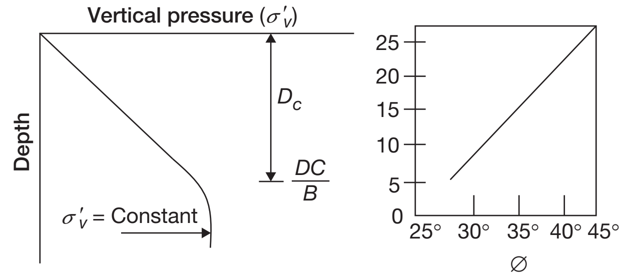
γ = Unit weight of soil in the zone of pile tip

N_q and N_γ = Bearing capacity factor for deep foundation

- In driven piles, $0.4_{\gamma} BN_{\gamma}$ is very small and neglected.

Therefore, $\boxed{q_p = \sigma_v' N_q}$

- In case of driven piles, the effective vertical pressure (σ_v') increases with depth only up to a certain depth known as critical depth and it remains constant.



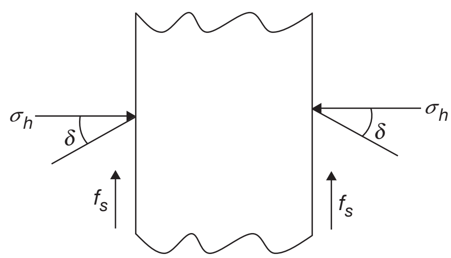
- The critical depth depends on ϕ and B (or diameter of pile).
  - For loose sands
  - For dense sands

$$\boxed{\begin{aligned} D_c &= 10 \times B \\ &= 20 \times B \end{aligned}}$$

B: width (or diameter) of pile

Therefore, $$\boxed{\begin{aligned} \sigma_v' &= \gamma' L, \text{ if } L < D_c \\ &= \gamma' D_c, \text{ if } L \geq D_c \end{aligned}}$$

Determination of Q_s: The frictional resistance (Q_s) is obtained after estimating the unit skin friction (f_s).



The unit skin friction acting at any depth is given by:

$$\boxed{f_s = \sigma_h \tan\delta \text{ or } K\sigma_a' \tan\delta}$$

Where

K = Earth pressure coefficient

σ_a' = Effective vertical pressure at that depth

δ = Angle of friction between pile and the soil

- The value of δ may be taken equal to ϕ according to the Indian standards.

$$\boxed{Q_u = A_q \sigma_v' N_q + A_s K \sigma_v' \tan\delta \Rightarrow \text{For sands}}$$

Static methods for Driven piles in saturated clay:

$$\boxed{Q_u = q_p A_p + f_s A_s}$$

q_p is the unit point resistance, equal to the ultimate bearing capacity of soil.

$$\boxed{q_p = CN_c}$$

C = Cohesion of the soil at the pile tip
N_c = Bearing capacity factor for deep foundation = 9.0 is, generally, used
f_s = Unit adhesion (or skin friction) developed between clay and pile shaft

$$\boxed{f_s = \alpha c}$$

- Where α the adhesion factor and C is the average cohesion along the shaft.
- The value of α depends on the consistency of clay.
- As per the Indian standards, α is taken as unity for soils having soft to very soft consistency.

$$\boxed{Q_u = A_p C N_c + A_s\, \alpha\, c \rightarrow \text{For clays}}$$

Allowable load or safe load (Q_s):

$$\boxed{Q_s = \frac{Q_u}{F_s}}$$

- Minimum factor of safety on static formula shall be 2.5.

SOLVED EXAMPLES

Example 1

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 of internal friction = 0. The skin friction capacity (kN) of the pile for an adhesion factor of 0.6, is

(A) 671 (B) 565
(C) 283 (D) 106

Solution

Given

Cohesion, $c = 60$ kN/m^2

Adhesion factor, $\alpha = 0.6$

Length of pile, $L = 10$ m

Diameter of pile, $d = 0.50$ m

Skin friction of pile = $Q_s = f_s A_s$

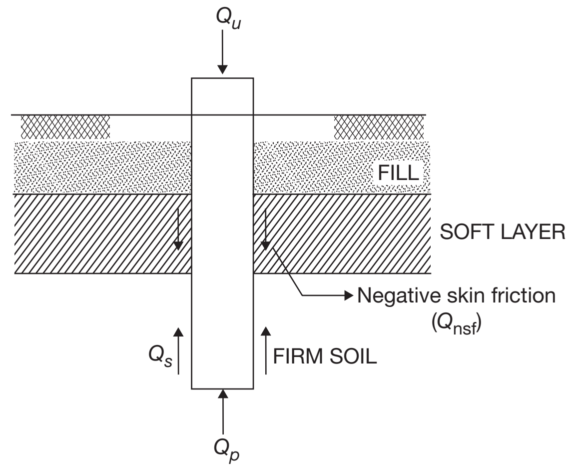
$= (\alpha c)(\pi d \cdot L)$

$= (0.6 \times 60)(\pi \times 0.50 \times 10)$

$Q_s = 565$ kN.

Negative Skin Friction

- When the soil layer surrounding a portion of the pile shaft settles more than the pile, a downward drag occurs on pile known as negative skin friction.
- Negative skin friction develops when a soft or loose soil surrounds the pile.



- The net ultimate load carrying capacity of the pile is given by:

$$\boxed{Q'_u = Q_u - Q_{\text{nsf}}}$$

Where
Q_{nsf} = Negative skin friction
Q'_u = Net ultimate load

- Negative skin friction $\boxed{Q_{\text{nsf}} = \pi d\, L_c c} \Rightarrow$ for clays
- Due to Q_{nsf}, the ultimate load carrying capacity of pile is decreased.
- It can be eliminated by providing a protective sleeve or a coating for the section which is surrounded by settling soil.

Dynamic Formulae

- The dynamic formula are based on the assumption that the kinetic energy delivered by hammer during driving operation is equal to work done on the pile.
- The method gives good results in case of free draining sands and hard clays in which high pore water pressure does not develop during the driving of piles.
- In saturated fine-grained soils, the method does not give reliable results.
- Not applicable for submerged, uniform fine sands.

1. **Engineering news record formula:**

Ultimate load $\boxed{Q_u = \dfrac{Wh\eta_h}{S + C}}$

Where
S = Penetration of pile per hammer blow (cm)
C = Constant
= 2.54 cm for drop hammer
= 0.254 cm for steam hammer
W = Weight of hammer
h = Free height of drop
η_h = Efficiency of pile hammer

- Safe load $\boxed{Q_s = \dfrac{Q_u}{FS}}$
- A factor of safety of '6' is recommended.
  The product ($w \times h$) can be replaced by rated energy of hammer (E_n) in kN/cm.

2. Hiley formula:

Ultimate load $\boxed{Q_u = \dfrac{W \cdot h \cdot \eta_b \eta_h}{\left(S + \dfrac{C}{2}\right)}}$

Where

η_b = Efficiency of hammer below

η_h = Efficiency of hammer

W = Weight of hammer

h = Height of free fall of ram or hammer (cm)

S = Final set or penetration per blows (cm)

C = Sum of temporary elastic compression of the pile, dolly, packings and ground = $C_1 + C_2 + C_3$

C_1 = Temporary compression of dolly and packing

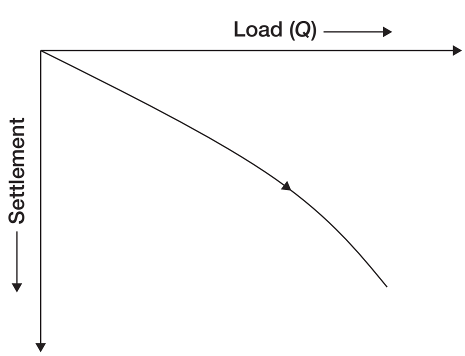
C_2 = Temporary compression of pile

C_3 = Temporary compression of ground

- Safe load $\boxed{Q_s = \dfrac{W_h \eta_b \eta_h}{FS\left(S + \dfrac{c}{2}\right)}}$

Pile Load Test

- It is the most reliable method for determining the load-carrying capacity of pile.
- The load is applied in equal increment of about 20% of the allowable load.
- Under each load increment, settlements are observed at 0.5, 1, 2, 4, 8, 12, 16, 20, 60 minutes.
- The loading should be continued up to twice the safe load or the load at which the total settlement reaches a specified value.
- The load settlement curve obtained from a pile load test is shown in the following figure.



According to the Indian standards, the safe load is taken as the least of the following

(a) One-half of the load at which the total settlement is equal to 10 percent of pile diameter.

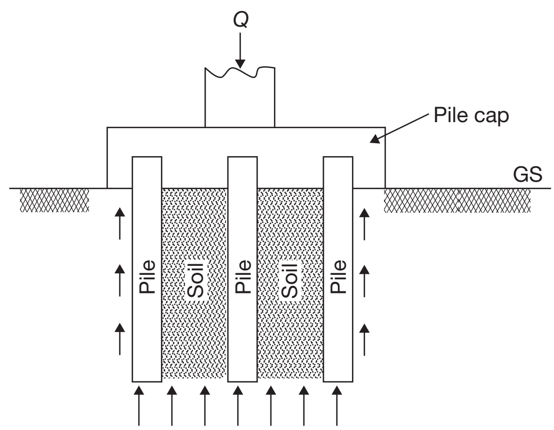
(b) Two-thirds of the final load at which the total settlement is 12 mm.

(c) Two-thirds of the load which causes a net settlement of 6 mm.

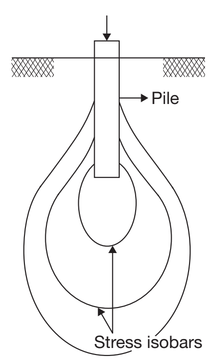
The test described above is known as initial test or slow-maintained test as the load is applied in steps.

Group Action of Piles

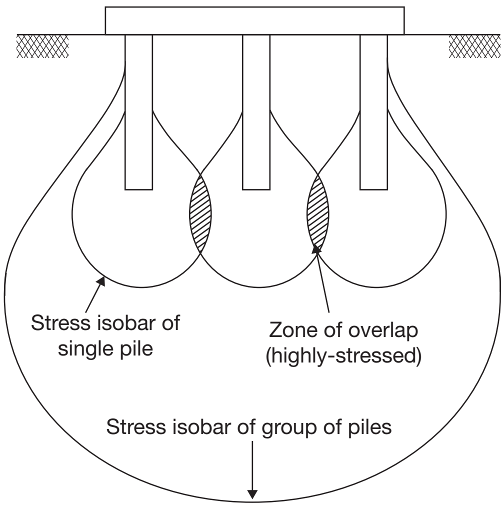
- In practice, structural loads are supported by several piles acting as a group.
- For columns a minimum of three piles in a triangular pattern are used.
- For walls, piles are installed in a staggered arrangement on both sides of its centre line.
- The loads are usually distributed to the piles though a reinforced concrete slab known as pile cap.



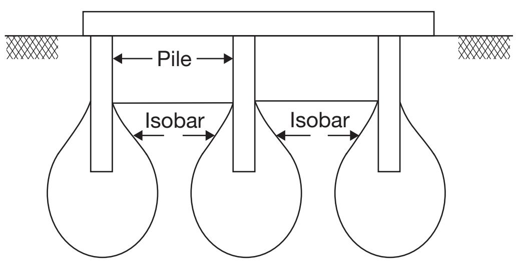
- The load carrying capacity of a pile group is not necessarily equal to the sum of the individual capacity of piles.
- If piles are sufficiently spaced, the (Q_u) is equal to the sum of individual capacity of piles.
- If the piles are closely-spaced, the stresses transmitted by the piles to the soil may overlap, and this may reduce the load carrying capacity of the piles.



Single pile



Closely spaced group of piles (with zones of stress over lap)



Widely spaced group of piles (without zones of stress overlap)

Efficiency of Pile Group (η_g)

- It is defined as the ratio of the ultimate load of the group to the sum of individual ultimate loads.
  Efficiency of pile group:

$$\boxed{\eta_g = \frac{Q_g}{(nQ_{ui})} \times 100} \quad \boxed{\eta_g = \frac{\left(\frac{Q_g}{N}\right)}{Q_{ui}} \times 100}$$

Where

Q_g = Ultimate load of the group

Q_{ui} = Ultimate load of the individual pile

N = Number of piles in the group

- Thus, the group efficiency is equal to the ratio of average load per pile in the group at which failure occurs to the ultimate load of a single pile.
- The group efficiency depends upon the spacing of the piles and type of soil.
- η_g may be >100% in loose and medium sands.
- η_g may be <100% in dense sands and clays.
- Spacing of piles is kept between 2.5B and 3.5B, where B is the diameter of the pile.

Group Capacity of Piles (Q_g)

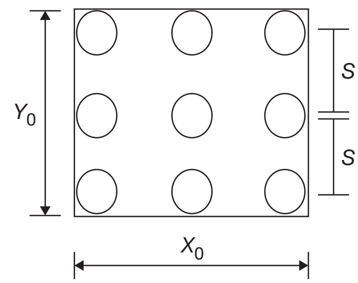
Failure in group of piles may be individual failure or group failure.

Individual failure criteria:

Group capacity $Q_{gi} = nQ_{ui}$

$$\boxed{Q_{gi} = n[A_p C N_c + A_s \, \alpha \, c]}$$

Block failure criteria



Group capacity $\boxed{Q_{gb} = A_B f_b + A_s f_s}$

Where

A_B = Area of block = $X_0 \times Y_0$

f_b = Bearing capacity at base

A_s = Surface area of block

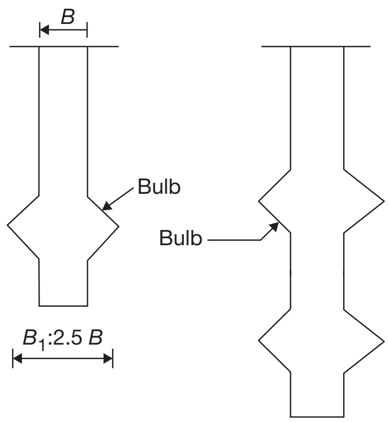
= $2(X_0 + Y_0)L$

- Group capacity of piles is taken as the smaller of Q_{gb} or Q_{gi}

Safe group capacity, $\boxed{Q_{g\text{safe}} = \frac{Q_g}{F}}$

Under Reamed Piles in Clay

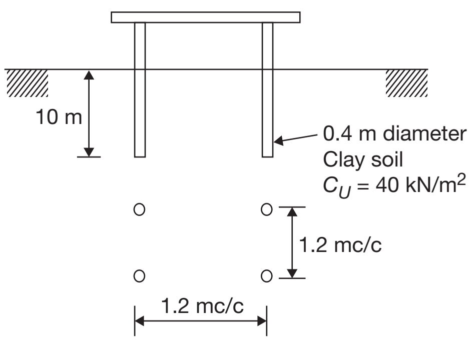
- It is suitable for expansive soils.
- Bored cast in situ concrete piles with a bulb or under ream at its bottom.
- In a double under reamed pile, there are two bulbs.
- As per the Indian standards, a maximum of two bulbs are recommended.
- The diameter of the bulb is taken as 2 to 3 times the shaft diameter (Generally, 2.5 times the shaft diameter).
- Spacing between two bulbs is usually kept 1.5–3 m.
- Minimum length of pile in deep expansive soils = 3.5 m.
- Minimum desirable depth of centre of upper bulb = 1.50 m or 2D_u whichever is greater.



Under reamed piles

Example 2

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



(A) 921.6 (B) 1177.6
(C) 2438.6 (D) 3481.6

Solution

Ultimate capacity of pile group as a single block.

$Q_{gb} = A_B C N_c + f_s A_S$

A_B = Area of block at base

$= (1.2 + 0.4) \times (1.2 + 0.4)$

$= (1.2 + 0.4)^2$

A_s = surface area of pile group

$= 4 \times (1.2 + 0.4) \times 10$

$f_s = \alpha c = 1 \times 40$

$N_c = 9$

$\therefore\ Q_{gb} = (1.2 + 0.4)^2 \times 40 \times 9 + 4 \times (1.2 + 0.4) \times 10 \times 40$

$Q_{gb} = 3481.6$ kN.

Direction for solved examples 3 and 4:

A group of 16 piles of 10 m length and 0.5 m diameter is installed in a 10 m thick stiff clay layer underlain 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 soil at the base is also 100 kPa.

Example 3

The base resistance of a single pile is
(A) 40.00 kN
(B) 88.35 kN
(C) 100.00 kN
(D) 176.71 kN

Solution

Given,

Length, $L = 10$ m

Diameter of pile, $d = 0.5$ m

Pile soil adhesion factor, $\alpha = 0.4$

Cohesion, $C_u = 100$ kPa

The base resistance of a single pile $= Q_p$

$Q_p = A_p C N_c$

$$= \frac{\pi \times 0.5^2}{4} \times 100 \times 9$$

$Q_p = 176.71$ kN.

Hence, the correct answer is option (D).

Example 4

Assuming 100% efficiency, the group side resistance is
(A) 5026.5 kN (B) 10000.0 kN
(C) 10053.1 kN (D) 20106.0 kN

Solution

Given $\eta_g = 100\%$

$$\eta_g = \frac{Q}{nQ_i} \times 100$$

Where

Q = Total ultimate group capacity

Q_i = Ultimate capacity of individual pile

$= A_s \cdot \alpha \cdot C$

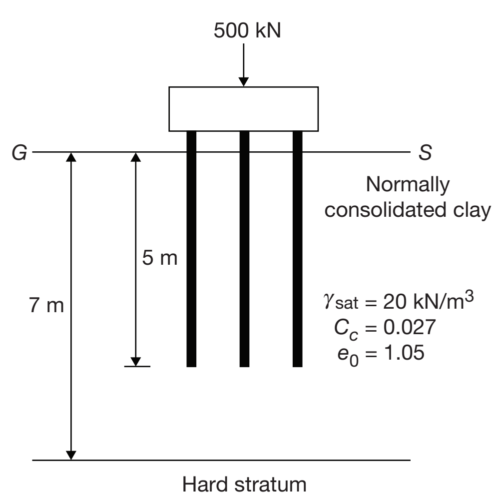
$$\therefore\ 100\% = \frac{Q}{16 \times A_s \alpha c} \times 100$$

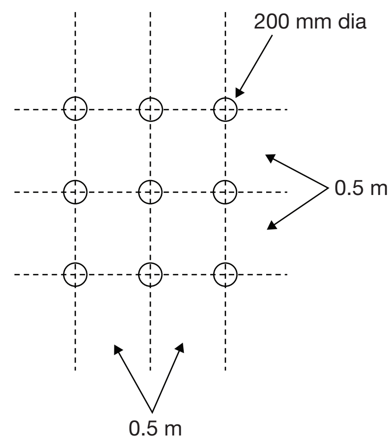
$$1 = \frac{Q}{16 \times \pi \times 0.5 \times 10 \times 0.4 \times 100}$$

$Q = 10053.1$ kN.

Exercises

1. Well foundation are commonly used as foundation for the following structures:
   (A) Water tanks
   (B) Bridges
   (C) Buildings
   (D) Reciprocating machines
2. The group efficiency of pile group
   (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 cohesion less soils and less than 100% for those in cohesive soils.
3. Negative skin friction in a soil is considered when the pile is constructed through a
   (A) fill material.
   (B) dense coarse sand.
   (C) over consolidated stiff clay.
   (D) dense fine sand.
4. Identify the two true statements from the following four statements.
   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 soil 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) I and IV (B) I and III
   (C) II and IV (D) II and III
5. 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





   (A) 13.2 mm (B) 12.775 mm
   (C) 7.345 mm (D) None of these

Direction for questions 6 and 7:

A group of 16 piles of 10 m length and 0.5 m diameter is installed in a 10 m thick stiff clay layer underlain 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.

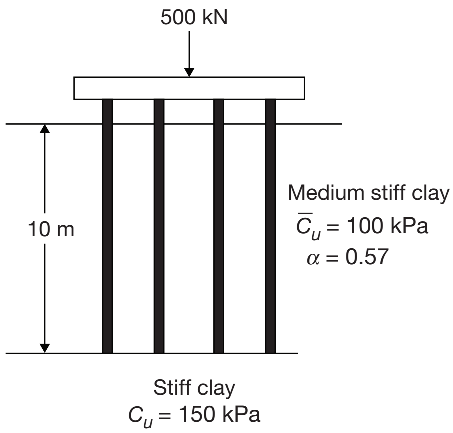
6. The base resistance of a single pile is
   (A) 40.00 kN (B) 88.35 kN
   (D) 100.00 kN (D) 176.71 kN
7. Assuming 100% efficiency, the group side resistance is
   (A) 5026.5 kN (B) 10000.0kN
   (C) 10053.1 kN (D) 20106.0 kN
8. Efficiency of a pile group is defined as
   (A) $\dfrac{\text{Load carried by the largest pile in the group}}{\text{Load carried by the smallest pile in the group}}$
   (B) $\dfrac{\text{Maximum load carried by a pile in the group}}{\text{Minimum load carried by a pile in the group}}$
   (C) $\dfrac{\text{Minimum load carried by a pile in the group}}{\text{Maximum load carried by a pile in the group}}$
   (D) $\dfrac{\text{Average load carried by a pile in the group}}{\text{Load carried by a single pile}}$
9. Consider the following statements regarding under reamed piles:
   I. They are used in expansive soils.
   II. They are of precast reinforced concrete.
   III. The ratio of bulb to shaft diameters is usually 2 to 3.
   IV. Minimum spacing between the piles should not be less than 1.5 times the bulb diameter.

   Which of these statements are correct?
   (A) I, II and III (B) I, III and IV
   (C) II, III and IV (D) I, II and IV

10. In the Engineering News Record formula for determining the safe load carrying capacity of a pile, the factor of safety used is
(A) 2.5 (B) 3
(C) 4 (D) 6

11. A drop hammer is used to drive a wooden pile. The hammer weight is 25 kN and its free falling height is 0.8 m. The penetration in the last blow is 12 mm. What is the nearest approximation to the load carrying capacity of the pile according to the Engineering News Formula?
(A) 125 kN (B) 110 kN
(C) 3000 kN (D) 90 kN

12. For the soil profile shown in the given figure, 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



(A) 10 (B) 15
(C) 20 (D) 25

13. The piles that are provided at an inclination, to resist lateral forces (or) inclined forces is known as
(A) Tension piles. (B) Anchor piles.
(C) Fender piles. (D) Batter piles.

14. Cantilever sheet pile is generally suitable for depths
(A) $d \le 5$
(B) $5 \le d \le 10$
(C) $d \ge 10$
(D) $d \ge 12$

15. Geotextiles are used for
(A) compacting loose soils
(B) reducing settlements
(C) separation and drainage
(D) Improve bearing capacity

Direction for questions 16 and 17:

A group of piles of 20 m length and 0.25 m diameter is installed in a 10 m thick stiff clay layer underlain by rock. The pile soil adhesion factor is 0.3, average shear strength of soil on the sides is 200 kPa, undrained shear strength of soil at base is 200 kPa.

16. The base resistance of a single pile is
(A) 88 kN
(B) 84.6 kN
(C) 86.2 kN
(D) 88.3 kN

17. The side friction resistance of single pile is
(A) 92.3 kN
(B) 94.2 kN
(C) 98 kN
(D) 96.5 kN

18. The efficiency of pile group for clays is
(A) >100%
(B) <100%
(C) = 100%
(D) None of these

19. Negative skin frictions developed from
(A) a cohesive fill placed over cohesion less soil deposit.
(B) lowering of ground water table with resulting ground subsidence.
(C) pile driving operations.
(D) All of these

20. A square group of 16 piles was driven into soft clay extending to a large depth. The diameter and length of the piles were 30 cm and 12 m respectively. If the cohesion of clay is given as $5t/m^2$, for the pile spacing 100 cm c/c what is the capacity of the pile group? (Take adhesion factor as 0.75 and FOS = 1.75)
(A) $733t$ (B) $417t$
(C) $550t$ (D) $623t$

21. A precast concrete pile is driven with a 50 kN diesel hammer ralling through a height of 1.0 m with an efficiency of 0.6. The average set value per blow is 25.0 mm. As per Engineering News formula, the ultimate resistance of pile is _______.
(A) 350 kN (B) 1050 kN
(C) 675 kN (D) 595 kN

22. A pile of 0.65 m diameter of length 12 m is embedded in a deposit of clay. The undrained shear strength parameters of clay are cohesion = 50 kN/m^2 and the angle of internal friction = 0. The skin friction capacity (kN) of the pile for an adhesion factor of 0.5, is
(A) 750 kN (B) 712 kN
(C) 612 kN (D) 512 kN

23. The ultimate load capacity of 10 m long concrete pile of 500 mm dia is driven into a homogeneous clay layer of 50 kPa is 800 kN. If the cross-section of pile is reduced to 300 mm dia and the length of pile is increased to 20 m, the ultimate load capacity will be _______.
(A) 800 kN
(B) 885 kN
(C) 925 kN
(D) 975 kN

Previous Years' Questions

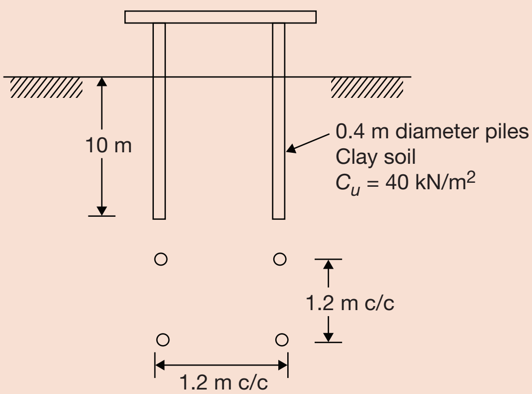
1. Match List I with List II and select the correct answer using the codes given below the lists: **[GATE, 2007]**

	List I		List II
a.	Constant head permeability test	**1.**	Pile foundation
b.	Consolidation test	**2.**	Specific gravity
c.	pycnometer test	**3.**	Clay soil
d.	Negative skin friction	**4.**	Sand

Codes:

	a	b	c	d		a	b	c	d
(A)	4	3	2	1	(B)	4	2	3	1
(C)	3	4	2	1	(D)	4	1	2	3

2. What is the ultimate capacity in kN of the pile group shown in the figure assuming the group to fail as a single block? **[GATE, 2007]**



(A) 921.6 (B) 1177.6
(C) 2438.6 (D) 3481.6

3. 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 **[GATE, 2008]**

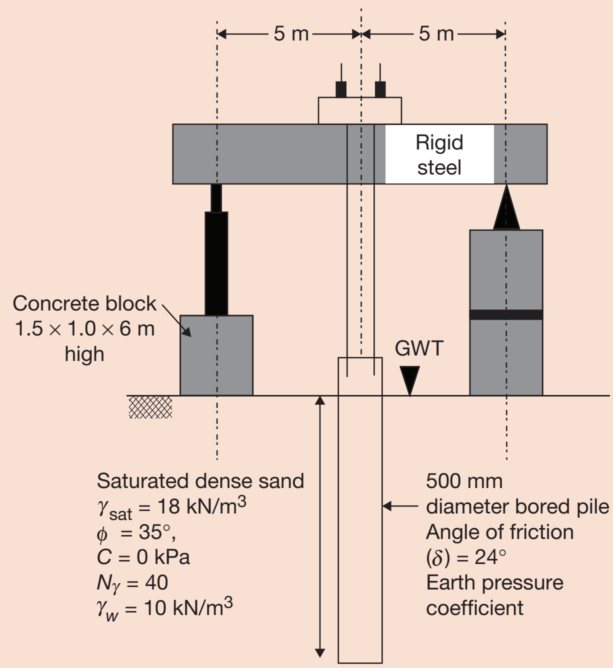
(A) 671 (B) 565
(C) 283 (D) 106

4. 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 below 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 **[GATE, 2009]**

(A) 3000 kN (B) 4285.7 kN
(C) 8333 kN (D) 11905 kN

Direction for questions 5 and 6:

Examine the test arrangement and the soil properties given in the following figure. **[GATE, 2009]**



5. 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

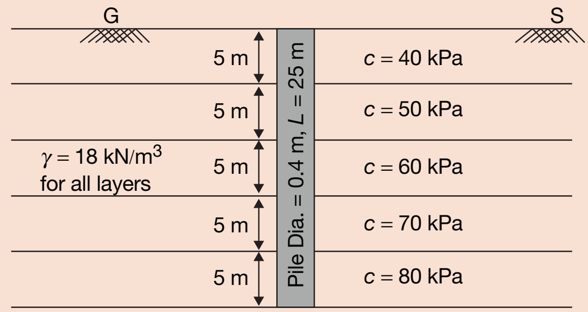
6. The maximum resistance offered by the soil through skin friction while pulling out the pile from the ground is

(A) 104.9 kN
(B) 209.8 kN
(C) 236 kN
(D) 472 kN

7. The action of negative skin friction on the pile is to **[GATE, 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.

8. 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 given figure. Assume a constant unit weight of soil as 18 kN/m^3 for all the layers. Using λ-method (λ = 0.15 for 25 m embedment length) and neglecting the end bearing component, the ultimate pile capacity (in kN) is ______________. **[GATE, 2015]**



Answer Keys

Exercises

1. B	**2.** C	**3.** A	**4.** C	**5.** D	**6.** D	**7.** C	**8.** D	**9.** B	**10.** D
11. D	**12.** C	**13.** D	**14.** A	**15.** C	**16.** D	**17.** B	**18.** B	**19.** D	**20.** B
21. D	**22.** C	**23.** B							

Previous Years' Questions

1. A	**2.** D	**3.** B	**4.** B	**5.** B	**6.** A	**7.** B	**8.** 1620 to 1630