Foundation Engineering

1. DEFINE END BEARING PILE

End bearing piles are used to transfer load through water or soft soil to a suitable bearing stratum. The end bearing pile is driven through poor soil strata and rests on a firm incompressible stratum such as rock, developing the bearing pressure of its base and passing it to that firm stratum.

2. Define group efficiency of pile.

The ratio of resting capacity of a pile group to the sum of individual capacities of piles in the group is termed as group efficiency.

$$\text{Group efficiency , n} = \frac{Q_g}{N_p \times Q_p}$$

Where, Q_g - Group capacity

Q_p – Pile load on single pile

N_p – Number of piles

3. List out the type of pile based on material used?
   - Timber pile,
   - Concrete pile,
   - Steel pile,
   - Composite pile
4. . How is the selection of pile carried out?

The selection of the type, length and capacity is usually made from estimation based on the soil condition and magnitude of the load.

5. What is mean by group settlement ratio?

The settlement of pile group is found to be many times that of a single pile. The ratio of the settlement of the pile group to that of a single pile is known as the group settlement ratio.

6. What are the factors consider while selecting the type of pile?

- The loads
- Time available for completion of the job
- Availability of equipment
- The ground water conditions
- The characteristics of the soil strata involved

7. What are the types of hammer used for pile driving?

- Drop hammer,
- Diesel hammer,
- Double acting hammer,
- Single acting hammer,
- Vibratory hammer

8. What is pile driver?

Piles are commonly driven by means of a hammer supported by a crane or by a special device known as a pile driver.

9. What are methods to determine the load carrying capacity of a pile?

- Dynamic formulae
- static formula
- pile load test
- penetration test

10. What are the two types of dynamic formulae?

- Engineering News Formula
- Hiley‟s Formula

11. What is meant by single-under reamed pile?

The pile has only one bulb is known as single under reamed pile

12. Write down the static formulae?

The static formulae are based on assumption that the ultimate bearing capacity Qup of a pile is the sum of the ultimate skin friction Rf and total ultimate point or and bearing resistance Rp.

Qup=Rf+Rp

Qup=Asrf+Ap.rp

13. Define modulus of subgrade reaction?

The ratio of soil reaction (p) to the deflection (y) at any point is defined as the modulus of sub grade reaction Es or soil modulus.

14. What are the limitations of dynamic pile load test?

- It is largely depend on the nature of the ground through which the pile was driven to get down to finished level.
- It takes very little account of the effect of friction on sides of pile, and this friction tends only to develop later.

15. List the piles based on materials of installation.

- End bearing pile
- Friction pile
- Compaction pile
- Tension pile
- Anchor pile
- Fender pile and dolphins
- Batter pile
- Sheet pile

16. What are anchor piles?

Anchor piles are the type of the piles which provide anchorage edge against horizontal pull from the sheet piling or other pulling forces.

17. What are fender piles?

Fender piles are the type of the piles which are used to protect water front structures against impact from ships or other floating objects.

18. What are the factors governing selection of pile?

- Soil condition
- Type of structure or building
- Adjacent site condition
- Construction techniques availability
- Location of ground water table
- Durability etc.

19. Define negative skin pressure

Negative skin friction force for a single pile is equal to the sharing resistance times the surface area of the pile. Therefore the negative skin friction on a pile group is

$Fn = \tau Lp + \gamma LA$ for group

$Fn = n\ \tau\ L$ ȷ d for individual

20. What are the conditions where a pile foundation is more suitable than a shallow foundation?

- Huge vertical load with respect to capacity
- Very weak soil
- Huge lateral loads
- For fills having very large depth
- Uplift situation
- Urban areas for future and huge construction near the existing building.\

21. What is meant by friction pile?

Friction piles are used to transfer loads to a depth of a friction load carrying material by means of skin friction along the length of the pile.

22. What is floating raft foundation?

If the weight of the soil removed is equal to the total load of the building imposed on the raft foundation, then the raft is a floating raft. Since it is not transferring any, pressure on the bearing soil below the raft, the result is zero settlement of the building.

23. For identical soil conditions, the load permitted on bored pile is lesser than driven pile of identical shape and dimensions, why?

The load carrying capacity of bored cast in situ pile will be much smaller than that of a driven pile in sand. The angle of shearing resistance of the soil is reduced by 30, to account for the loosening of the sand due to the drilling of the hole.

24. Define negative skin friction.

When the soil layer surrounding a portion of the pile shaft settles more than a pile, a downward drag occurs on the pile. The downward drag is known as negative skin friction.

25. What is the use of batter pile?

The batter piles are used to resist large horizontal forces or inclined forces.

<u>16 MARKS</u>

1. Briefly explain static and dynamic formulae of load carrying capacity of piles.

Static analysis:

$Q_{up} = Q_p + Q_s$ where, Q_{up} = ultimate load on pile.

Q_p = tip resistance

$= q_n \times A$

Q_s =skin resistance = $\pi\, D\, l \times l_s$

Where, f_s = unit skin friction between pie and soil. (4)

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Dynamic analysis:

(i) ENS formula: $Q_a = \frac{WH}{F\,S+C}$

Where, Q_a= allowable load on pile

H = height of fall,

W =weight of hammer

F =factor of safety =6

S = final set per blow.

C =empirical constant = 2.5 cm for drop hammer and

η_h η_b = 0.25 cm for single and double acting steam hammer.

For double acting hammer

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

Where, a = effective area of piston.

P= mean effective steam pressure.

(ii) Hailey's formula:

$Q_{up} =\frac{\eta h\ WH\ \eta b}{S+C/2}$

Where, Q_{up}= ultimate load on pile.

W = weight of hammer

S= set of penetration per blow

C= total elastic compression = $C_1+C_2+C_3$

$C_1+C_2+C_3$ =temporary elastic compression of dolly and packing, pile and soil respectively.

η_h =efficiency of hammer

η_b=efficiency of hammer blow

2. **A group of 9 piles with 3 piles in a row was driven into soft clay extending from ground level to a great depth. The diameter and length of piles were 30 cm and 10 cm respectively. The unconfined compression strength of clay is 70 kN/m^2. If the piles were spaced at 90cm centre to centre, compute the allowable load on the pile group on the basis of shear failure criteria for a factor of safety of 2.5, neglect bearing at the tip of piles, take m = 0.6 for shear mobilization around each pile.**

n = 9 piles with 3 piles in a row.

S= 90cm = 0.9 m c/c

D=30cm = 0.3m

L=10m

q_u =70kN/m^2

$\therefore$ C= $\frac{70}{2}$= 35 kN/m^2

F.S. =2.5m =0.6

(i) Ultimate load on pile based on group action:

Size of pile group = (2S + d) x (2S + d)

=2.1m x 2.1m

Q_f= Q_s

=f_s x A_s

= C x P x L

= 35 x (d x 2.1) x 10 = 2940 kN

(ii) Ultimate load on pile based on individual action:

$Q_f = (\pi\, I \times L) \times m \times n$

Ultimate load on pile = least = 1781.3 kN

When the pile acting individually,

$\therefore$ Safe load on pile = $\frac{1781.3}{2.5}$= 712.5 kN.

3. **In a load test conducted at a depth of 1 meter below ground with a square plate of 30cm side on a granular soil, load required to cause 25mm settlement was 72 kN.**

Find out the size of a square column footing which will be having its base at a depth of 2.5 m below ground level and is required to take a load of 1750kN. The settlement of the footing is restricted to be 10mm only and factor is to be 3 only. Unit weight of soil 19kN/m^2. N_c =12 and N_r = 6.

For 25mm of settlement, allowable load was 72kN for square plate of 30cm side.

∴ Allowable pressure = $\frac{7.2}{0.3}$ x 0.3 = 800kN/m^2.

∴ Allowable pressure for settlement S_q q_u = $\frac{10}{25}$ x 800 = 320 kN/m^2

For square footing, q_u =1.3 C N_c + $\gamma D N_q$ +0.4 $\gamma B N_v$

∴ 320 = (1.3 C x 25) + (19 x 1 x 12) + (0.4 x 19 x B x 6)

Solving, B =2.6 m

∴ Size of footing = 2.6m x 2.6m.

4. Describe precast concrete piles with their merits and de merits?

Precast concrete piles

Merits

1. Material of pile can be inspected before it goes into ground

2. Stable in squeezing ground

3. Not damaged by ground leave when driving adjacent piles

4. Can be readily carried above g.l. especially in marine structures.

Demerits

1. May break during hard driving causing delays and replacement charges

2. Noise and vibration during driving may cause delays and replacement charges

3. Cannot be driven in very large diameters.

5. What do you understand by under-reamed piles and what situations dictate their use?

Under-reamed piles:

-are bored cast-in-situ concrete piles having one (or) more bulbs formed by enlarging the bore hold for the pile stem by an under reaming tool

These piles find applications in widely varying situations in different types of soils where foundations are required to be taken down to a certain depth to avoid the undesirable effect of seasonal moisture changes as in expansive soils or to reach strata or to obtain adequate capacity for download, upward and lateral loads or to take the foundations below scour level and for moments

When the piles has only one bulb ,it is known as single under –reamed pile, while the pile with more than one bulb is known as multi-under –reamed bulbs is kept equal to2.5 times the diameter of pile stem.

6. **Complete the settlement of a rigid footing 2.6m x2.6m carrying a load of 1800kN, supported on a sandy soil, if a plate load test gives a settlement of 8mm under a load of 320 kN/m^2. Size of plate 30cm x30cm.**

Given

Size of footing = 2.6 x 2.6m

Lead = 1800 kN

=1800/2.6 x 2.6

=266.27kN/m^2

Settlement of pate ρ_p = 8mm

Plate size B_p = 0.3 x 0.3

Lead on the plate = 320 kN/m^2

$$\frac{\rho_f}{\rho_p} = \left(\frac{B\,(B_p+0.3)}{B_p\,(B+0.3)}\right)^2$$

$$=8\left(\frac{2.6(0.3+0.3)}{0.3(2.6+0.3)}\right)^2$$

=25.72 mm(for 320kN/m^2 loading.)

∴ Settlement of footing for 266.27 kN/m^2

$= \frac{266.27}{320}$ x 25.72

= 21.4 mm

7. A group of 16 friction piles is to support a column load of 4000kN. The piles will be driven in four rows with four numbers in each column. The piles are 35 cm diameter. And the c/c spacing is 1m both ways. What set value must be attained by the piles when driven by a single acting 22.5kN steam hammer with 90cm stroke so that the pile group can carry the column load?

Load carried by group action

Q_u =c {4[3s +d] L} + $\alpha\ CPD$

Assuming L= 10m

4000=c {4[3 x 1 + 0.35] 10} +0.6c x 4 3.35 0.35

C=22kN/m^2

∴ load carried by individual pie for 10m length.

Q = n [(m c) (n‟d L) + 9 C A_p

=16[(0.7 x 22.98) ($\pi \times 0.35 \times 10$) + 9 x 22 x $\pi/4$ x 0.352]

Q_u =2628 kN

∴ Individual pile fails first.

Engineering news formula

Q_u =WH/6(S+C) for stream hammer

C=0.254

2628 = [22.5 x 0.9 x 100]/ [6(S + 0254)]

2628 = 20.25/ [6S+1.524]

2628(6S + 1.524) = 20.25 x 100 (neglect the sign)

6S + 1.524 = 0.77

6S = 0.752

$S = 0.125$ cm

$S_{el} = 1.25$ mm

8. A reinforced concrete pie weighing 30 kN is driven by a drop hammer weighing 40 kN and having an effective fall of 0.80m. The average set per bow is 1.40 cm. The total temporary elastic compression is 1.80 cm, assuming the coefficient of restitution as 0.25 and factor of safety of 2. Determine the ultimate bearing capacity and the allowable load for the pile.

Given

P = 30 k W

W = 40 K W

η_n H = 0.8 m = 80 cm

S = 1.4 cm

C = 1.8 cm

$\eta_n = 1$ for drop hammer.

P x e = 30 x 0.25

= 7.5 k w

$\therefore$ w> p e

Efficiency hammer blow

$\therefore \eta_b = w + e\,2\,p / (w + p)$

= 40 + 0.252 x 30 / (40 + 30)

$\eta_b = 0.598$

Ultimate load on pile

$Q_f = \eta_n\, w\, H\, \eta_b / (s + c/2)$

= 1 x 40 x 80 x0.598/ (1.4 + 1.8/2)

= 1914.286 / (1.4 + 0.9)

Q_f = 832.3 k W

Allowable load = Q_f/ FOS

= 832.3 /2.0

Q_f =416.2 k W

9. Design a friction pile group to carry a load of 3000 KN including the weight of the pile cap at a site where the soil is uniform clay to a depth of 20 m underlain by rock. Average unconfined compressive strength of the clay is 70kN/m^2. The clay may be assumed to be of normal sensitivity and normally loaded, with liquid limit of 60%. A factor safety of 3 is required against shear failure.

Given

Q_{ug} = 3000k W

C = q_u/2 =70/2 =35 kN/m^2

Permission C = 35/3 kN/m^2

Let the length of pile =10 m

Diameter of the pile =0.3 m

Spacing of pile = 3 d =3 x 0.5 =1.5 m = 150 cm

Let the no. Of piles = n

Q_{ug} = n x 35/3 x π x 0.5 x 10

n = 16.37

For square arrangement keep n = 16

The modified length L will then have to increase by the ratio 16.37 /16

L= 10 x 16.37 /16

L =10.23

L = 11 m

Check for group action

B = 3 std = 3 x 150 + 50 = 500 cm = 50 m

Load taken by group action

$= 4\ BL \times C + A\ P.\ C\ N_c$

$= 4 \times 5 \times 11 \times (35/3) + [(5 \times 5) \times (39/3) \times 9]$

$=2566.7 + 2625$

Q_{ug} = 5191.7 kW > 3000 Kw

Hence safe,

10. Explain with neat sketch about pile load test method of determination of load carrying capacity of piles.

PILE LOAD TESTS:-

The pile load test can be performed either on a working pile which form the foundation of the structure or on a test pile. The test load is applied with the help of calibrated jack placed over a rigid circular or square plate which in turn is placed on the head of the pile projecting above ground level. The reaction of the borne by a truss or platform which have gravity loading or alternatively, the truss can be anchored to the ground with the help of anchor pile. In the later case, under-reamed piles or soil anchor may be used for anchoring the truss.

The load is applied in equal increments of about one-fifth of the estimated allowable load. The settlements are recorded with the help of three dial gauge of sensitivity 0.02mm, symmetrically arranged over the test plate, and fixed to an independent datum bar. A remote controlled pumping unit may be used to hydraulic jack. Each load increment is kept for sufficient time till the rate of settlement becomes less than 0.02mm per hour. The test pile areloaded until ultimate load is reached. Ordinarily, the test load is increased to a value 2.5times the estimated allowable load or to a load which causes a settlement equal to one-tenth of the pile diameter, whichever occur earlier. The results are plotted in the form of load settlement curve. The ultimate load is clearly indicated by load settlement curve approaching vertical. If ultimate load cannot be obtained from the load settlement curve, the allowable load taken as follows:

CYCLIC LOAD TEST:

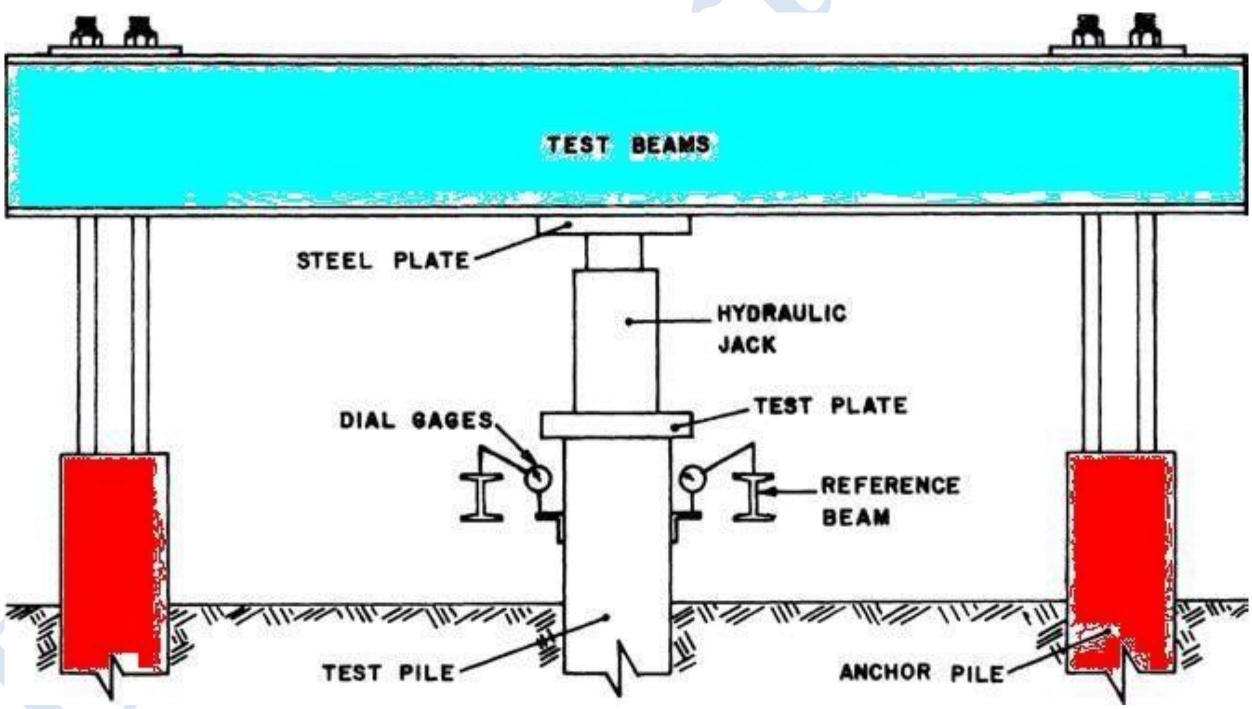
The cyclic load test is particularly useful in separating the load carried by the pile into the skin friction and point bearing resistance. Each load increment is kept on the pile for sufficient time till the settlement decreases the value less than 0.02mm per hour. The load is then completely removed and the elastic rebound of the pile top is measured by means of dial gauge. The next load is then applied and the process repeated. The cycle of loading and

unloading with measurement of settlement and recovery is continued till the final load which causes a marked progressive settlement of the pile is reached. The result plotted between loads versus settlement.

The elastic compression of the pile corresponding to any load Q can be calculated from the following expression based on HOOK‟s law,

Elastic compression = $((Q-R_f/2)L)/AE$

The separation of Q at any stage of loading into R_p and R_f is based on the experimental finding of A.F. Van Weele (1957) that the load on the pile toe increases linearly with the elastic compression of soil, and that straight line showing the relationship between point resistance and elastic compression of soil is parallel to the straight line portion of the curve drawn between the load on the pile and elastic compression of soil. The elastic compression of the soil is equal to the total elastic recovery of the pile top minus the elastic compression of the pile. The procedure described in the following steps:



STEPS:

1. If R_f is not known to start with, it is assumed that the elastic compression of the pile is zero, and hence the elastic compression of the soil is equal to the total elastic recovery of the pile top. A curve OA_1 is then drawn between load Q on pile top as abscissa and the elastic compression of the soil as ordinate.

2. Through origin O, a line OA_1“ is drawn parallel to the straight portion of bearing R_p and skin friction R_f.
3. For various loads Q_1, Q_2, Q_3, etc., the skin friction R_{f1}, $R_{f2\ \Delta}$, R_{f3} etc., are determined.
4. Corresponding to each value of R_f, the elastic compression of pile is determined. The elastic compression of the soil is calculated from the relation.

$$\Delta_{soil} = \Delta - \Delta_{pile}$$

Where, Δ = total elastic recovery of the pile top.

5. Knowing Δ_{soil} for each load Q_1 ,Q_2,Q_3etc. A curve is drawn between Q and Δ_{soil}.
6. Through the origin O, line OA_2“ is drawn parallel to the straight line portion of curve OA_2“.
7. Step 3, 4, 5 and 6 are repeated to get the final curve and OA“ parallel to the straight line portion of curve OA. The third trial of curves gives sufficiently accurate results. From this two, any load Q can be divided to skin friction and point resistance. The value of skin friction and point resistance corresponding to a load causing a total settlement of one-tenth of the pile diameter are by factors of safety of 2 and 2.5 respectively and added together to give the allowable load for the pile.

11. Enumerate the various types of pile in detail.

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 and
5. Displacement of soil

1. Classification according to material used

There are four types of piles according to materials used

(i) Steel piles
(ii) Concrete piles
(iii) Timber piles
(iv) Composite piles

(i) Steel piles

Steel piles are generally either in the form of thick pipes or rolled steel H- section. Pipe steel piles are driven into ground with their ends open or closed. Piles are provided with a driving point or shoe at the lower end.

Epoxy coatings are applied in the factory during manufacture of pipes to reduce corrosion of the steel pipes. Sometimes concrete encasement at site is done as a protection against corrosion. To take into account the corrosion, an additional thickness of the steel section is usually recommended.

(ii) Concrete piles

Cement concrete is used in the construction of concrete piles. Concrete piles are either precast or cast in- situ. Precast concrete piles are prepared in a factory or a casting yard. The reinforcement is provided to resist handling and driving stresses. Precast piles can also be pre-stressed using high strength steel pre-tensioned cables.

A cast in-situ pile is constructed by making a hole in the ground and then filling it with concrete. A cast in situ pile may be cased or uncased. A cased pile is constructed by driving a steel casing into the ground and filling it with concrete. An uncased pile is constructed by driving to the desired depth and gradually withdrawing casing when fresh concrete is filled. An un-casted pile may have a pedestal.

(iii) Timber piles

Timber piles are made from tree trunks after proper trimming. The timber used should be straight, sound and free from defects.

Steel shoes are provided to prevent damage during driving. To avoid damage to the top of the pile, a metal bond or a cap is provided. Splicing of timber piles is done using pipe sleeve or metal straps and bolts. The length of the pipe sleeve should be atleast five times the diameter of the pile.

Timber piles below the water table have generally long life. However above the water table, these are attacked by insects. The life of the timber piles can be increased by preservatives such as creosote oil. Timber piles should be used in massive environment where these are attacked by various.

(iv) Composite piles

A composite pile is made of two materials. A composite pile may consist of the lower portion of steel and the upper portion of cast in-situ concrete.

A composite may also have the lower portion of timber below the permanent water table and the upper portion of the concrete.

As it is difficult to provide a proper joint between two dissimilar materials, composite piles are rarely used in practice.

2. Classification based on mode of transfer of load

Based on the mode of transfer of loads, the pile can be classified into three categories:

(i) End bearing piles

(ii) Friction piles

(iii) Combined end bearing and friction piles

(i) End bearing piles

End bearing piles transmit the loads through their bottom tips. Such piles act as columns and transmit the load through a weak material to a firm stratum below. If bed rock is located within a responsible depth, piles can be extended to the rock.

The ultimate capacity of the pile depends upon the bearing capacity of the rock. If instead of bed rock, a fairly compact and hard stratum of soil exists at a reasonable depth, piles can be extended a few minutes piles are 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)

(ii) Friction piles

Friction piles do not reach the hard stratum. These piles transfer the loads through skin friction between the embedded surface of the pile and the surrounding soil. Friction piles are used when a hard stratum does not exist at a reasonable depth.

The ultimate load (Q_u) carried by the pile is equal to the sum of the load carried by the pile is equal to the load transferred by skin friction (Q_s).

Friction piles are known as floating piles as these do not reach the hard stratum.

(iii) Combined end bearing and friction piles

The piles transfers loads by a combination of end bearing at the bottom of the pile and friction along the surface of the pile shaft, the ultimate load carried by the pile is equal to the sum of the load carried by the pile point (Q_p) and the load carried by the skin friction(Q_s).

3. Classification based on method of installation

Based on the method of construction, the piles may be classified into the following 5 categories

(i) Driven pile
(ii) Driven and cast in situ piles
(iii) Bored and cast in situ piles
(iv) Screw piles
(v) Jacked piles

(i) Driven piles

These piles are driven into the soil by applying blows of a heavy hammer on their tops.

(ii) Driven and cast in situ piles

These piles are formed by drawing a casing with a closed bottom end into the soil. The casing is later filled with concrete. The casing may or may not be withdrawn.

(iii) Bored and cast in situ pile

These piles are formed by a hole into the ground and then filling it with concrete.

(iv) Screw piles

These piles are screwed into soil.

(v) Jacked piles

These piles are jacked into the soil by applying a downward force with the help of a hydraulic jack.

4. Classification based on use

The piles can be classified into the following 6 categories depending upon their use.

(i) Load bearing piles
(ii) Compaction piles
(iii) Tension piles
(iv) Sheet piles
(v) Fender piles
(vi) Anchor piles

(i) Load bearing piles

These piles are used to transfer the load of the structure to a suitable stratum by end bearing by friction or by both.

(ii) Compaction piles

These piles are driven into the loose granular soil to increase the relative density. The bearing capacity of the soil is increased due to densification caused by vibrations.

(iii) Sheet piles

Sheet piles forms a continuous wall or bulk head which are used for retaining earth or water.

(iv) Fender piles

Fender piles are sheet piles which are used to protect water front structures from impact of ships and vessels.

(v) Anchor piles

These piles are used to protect anchorage for anchored sheet piles. These piles provide resistant against horizontal pull for a sheet pile wall.

5. Classification based on displacement of soil:

Based on the volume of the soil displacement during installation the piles can be classified into 2 categories

(i) Displacement piles
(ii) Non- displacement piles

(i) Displacement piles

All driven piles are displacement piles as the soil is displacement laterally when the pile is installed. The soil gets densified. The installation may cause heaving of the surrounding ground. Precast concrete pile and closed end pipe pile are high displacement piles. Sheet H-piles are low displacement piles.

(ii) Non- displacement piles

Bored piles are non- displacement piles. As the soil is removed when the hole is bored, there is no displacement of the soil during installation. The installation of these piles causes very little change in the stresses in the surrounding soil.

12. List the necessities of pile foundation.

Necessity of the pile foundation

Pile foundations are used for in the following conditions:

1. When the strata at or just below the ground surface is highly compressible and very weak to support the load transmitted by the structure.
2. When the plan of the structure is irregular relative to its outline and load distribution. It would cause non uniform settlement if a shallow foundation is constructed; a pile foundation is required to reduce differential settlement.
3. Pile foundations are required for the transmission of structural loads through deep water to a firm stratum.
4. Pile foundation are used to resist horizontal forces in addition to support the vertical load in earth retaining structures and tall structures that are subjected to horizontal forces due to wind and earthquake.
5. Piles are required when the soil condition are such that a wash out, erosion or scour of soil may occur from underneath a shallow foundation.
6. Piles are used for the foundation of some structures, such as transmission towers, off shore platforms, which are subjected to uplift.
7. In case of expansive soil, such as back cotton soil, which swell or shrink as the water content changes, piles are used to transfer the loads below the active zone.
8. Collapsible soils, such as losses, have a breakdown of structure accompanied by a sudden decrease in void when there is an increase in water content. Piles are used to transfer the load beyond the zone of possible moisture changes in such soil.

13. Explain the under reamed pile foundation with neat sketch.

Under – reamed pile foundation

- Under reamed piles are bored cast in-situ concrete piles having one or more bulbs formed by enlarging the bore hole for the pile stem by an under reaming tool.
- These piles find applications in widely varying situations in different types of soils where foundation are required to be taken down to a certain depth to avoid the undesirable effect of seasonal moisture changes as in expansive soils or to reach strata or to obtain adequate capacity for downward, upward and lateral loads or to take the foundations below scour level and for moments.
- When the pile has only one bulb, it is known as single under –reamed pile, while the pile with more than one bulb is known as multi –under –reamed pile. Generally, the diameter of under –reamed bulbs is kept equal to 2.5 times the diameter of pile stem.
- However, it may vary from 2 to 3 times the stem diameter, if required, depending upon the design requirements and feasibility of construction.

Details of pile and under reamed bulb:

- In deep layers of expansive soils, the minimum length of pile required is 3.5 m where the ground movements become negligible.
- In shallow depths of expansive soils and other poor soils depending upon the load poor soil requirements the length may be reduces and the piles may be taken upto at least 50 cm in stable zone pile length may be increased for higher loads.
- The diameter manually bored piles range from 20 cm to 37.5 cm.
- The spacing of the piles of the piles shall be considered in relation to the nature of the ground, the types of piles and the manner in which the piles transfer the loads to the ground.
- Generally, the center to center spacing for under-reamed piles should not be less than 3 D_u.
- It may be reduced to 1.5 D_u when a reduction in load carrying capacity of 10 % should be allowed.
- For the spacing of 2 D_u the bearing capacity of pile group may be taken equal to the number of piles multiplied by the bearing capacity of individual pile.
- If the adjacent piles are of different diameters, an average value for spacing should be taken.
- The maximum spacing of the under-reamed pile should not normally exceed 2 ½ meters so as to avoid heavy capping beams.
- In building, the piles should generally be provided under all wall junctions to avoid point loads on beams.
- Position of intermediate piles are then decided trying to keep the door opening fall in between two piles as far as possible.
- In double and multi-under-reamed piles of size less than 30 cm dia., the center-to-center vertical spacing between the two under reams may be kept equal to 1.5 D_u while for piles of 30 cm and more this distance may be reduced to 1.25 D_u. the upper bulb should not bu lb is 1.5m or 2 D_u whichever is greater.
- Under reamed piles can be made at a better also, for sustaining large lateral loads, thus making them suitable for tower footing, retaining walls and abutments. They have also been found useful for factory buildings, machine foundations and transmission line towers and poles.
- In black cotton soils and other expansive soils, the under reamed pile anchors the structures at a depth where the volumetric changes in soils due to seasonal and other variation is negligible.

- The under reamed pile is nominally reinforced with 10 to 12 mm dia. Longitudinal bars, and 6mm Ø rings. A clear cover of 4 cm is provided.

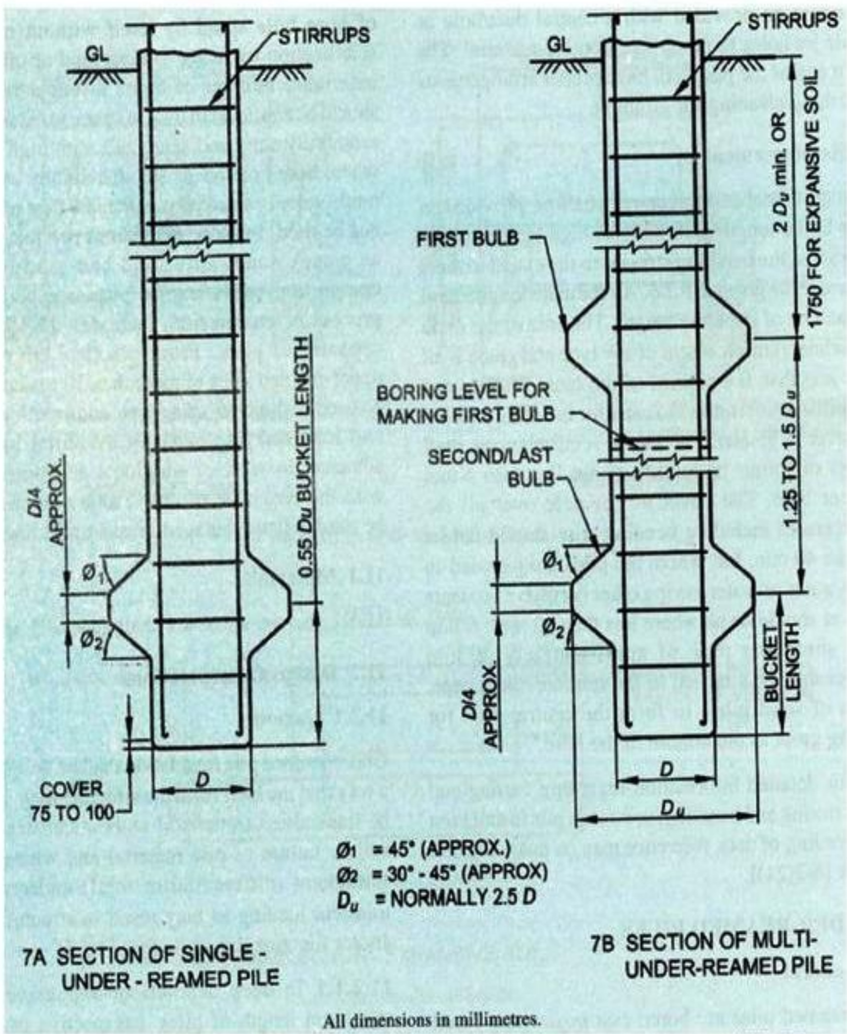
Clayey soils:

$$Q_u = A_p N_c C_p + A_a N_c C_a' + C_a' A_s' + \alpha C_a A_s$$

Sandy soils:

$$Q_u = \pi/2 (D_u^2 - D) [½ D_u . n . \gamma . N_\gamma + \gamma . N_q \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Typical Details of Piles



(NBC-2005)

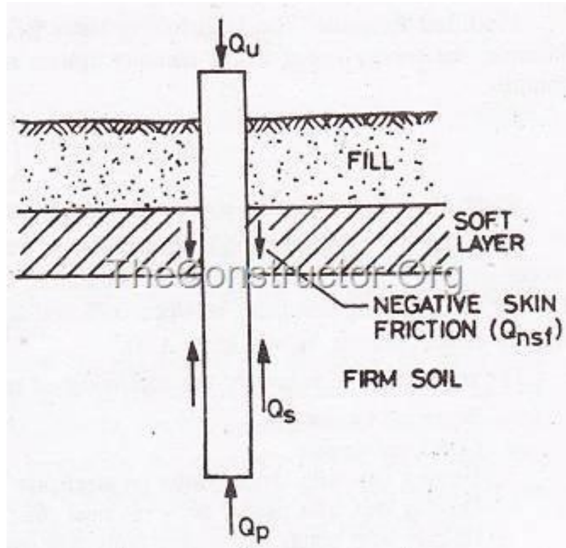
Typical Details of Bored Cast in-situ Under Reamed Pile Foundation

14. Explain negative skin friction.

If a soil subsides or consolidates around a group of piles these piles will tend to support the soil and there can be a considerable increase in the load on the piles.

The main causes for this state of affairs are

- Bearing piles have been driven into recently placed fill
- Fill has been placed around the piles after driving
- As a result of remoulding of clay during driving of the pile



If negative skin friction effects are likely to occur then the pile must be designed to carry the additional load. In extreme cases the value of negative skin friction can equal the positive skin friction. The value of negative skin friction is very least at the top of the pile and reaching some maximum values at its base.

The negative skin friction for a single pile is equal to the sharing resistance times the surface area of the pile. For a pile group negative skin friction acting on the entire pile group is equal to the weight of the block of soil held in between the piles plus the shear along the periphery of the pile group as a whole.

Therefore the negative skin friction on a pile group is

$F_n = \tau \, Lp + \gamma \, LA$ for group

$F_n = n \, \tau \, L \, \pi \, d$ for individual

Where, τ = UCC / 2