4.5 Pile Driving Methods

- Displacement Piles
- Non Displacement Piles

1.Displacement Piles

Methods of pile driving can be categorized as follows:

- Dropping weight
- Vibration
- Jacking (restricted to micro-piling)
- Jetting

2. Non Displacement Piles

- Under reamed Pile

Drop Hammer Method of Pile Driving:

A hammer with approximately the weight of the pile is raised a suitable height in a guide and released to strike the pile head. This is a simple form of hammer used in conjunction with light frames and test piling, where it may be uneconomical to bring a steam boiler or compressor on to a site to drive very limited number of piles.

There are four types of drop hammers:

1. Single-acting steam or compressed-air hammers
2. Double-acting pile hammers
3. Diesel hammer
4. Steam hammer

1.Single-acting steam or compressed-air:

Single-acting steam or compressed-air comprise a massive weight in the form of a cylinder. Steam or compressed air admitted to the cylinder raises it up the fixed piston rod. At the top of the stroke, or at a lesser height which can be controlled by the operator, the steam is cut off and the cylinder falls freely on the pile helmet.

2.Double-acting pile hammers

Double-acting pile hammers can be driven by steam or compressed air. A piling frame is not required with this type of hammer which can be attached to the top of the pile by leg-guides, the pile being guided by a timber framework. When used with a pile frame, back guides are bolted to the hammer to engage with leaders, and only short leg-guides are used to prevent the hammer from moving relatively to the top of the pile. Double-acting hammers are used mainly for sheet pile driving.

Figure-1: Pile driving using hammer

[Fig1 https://www.dreamstime.com/photos-images/drop-hammer.html]

3. Diesel pile hammer

A modern diesel pile hammer is a large two-stroke diesel engine. The weight is the piston, and the apparatus which connects to the top of the pile is the cylinder. Pile driving is started by raising the weight; usually a cable from the crane holding the pile driver This draws air into the cylinder. Diesel fuel is injected into the cylinder. The weight is dropped, using a quick-release. The weight of the piston compresses the air/fuel mixture, heating it to the ignition point of diesel fuel.

4.Steam Hammer

Air/Steam Hammer can be classified as either single-acting or double-acting. These external combustion hammers use an external power source such as air compressors or steam boilers to power the ram upward or downward.

Single –acting /Steam hammers allow air or steam to raise the movable portion of the hammer and allows it to free-fall. This type of impact hammer can be readily used in all soil conditions, with an average of 50-60 blows per minute.

Double–acting /steam hammers allow air or steam to raise the ram of the hammer, and adds additional energy during down stroke for a higher frequency of blows (90-150 per minute). The hammer applies additional air or steam pressure to the top of the piston to enable shorter strokes.

Pile Driving by Vibrating:

Vibratory hammers are usually electrically powered or hydraulically powered and consists of contra-rotating eccentric masses within a housing attaching to the pile head. The amplitude of the vibration is sufficient to break down the skin friction on the sides of the pile. Vibratory methods are best suited to sandy or gravelly soil. **Jetting**: to aid the penetration of piles in to sand or sandy gravel, water jetting may be employed. However, the method has very limited effect in firm to stiff clays or any soil containing much coarse gravel, cobbles, or boulders.

Jetting

Water jetting can be used to assist the infiltration of piles into sediment or gravel-filled soil. The method has, however, very limited success against stiff clays or any land that contains a lot of coarse gravel, cobbles, or pebbles.

Non Displacement Pile:

1.Under reamed Pile:

- 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 loadsor to take the foundations below scour level and for moments.

Types of Under reamed pile:

1. Single-bulb cast-in-situ pile,
2. Multiple-bulb pile.

- A single bulb attached at the bottom end of a pile is called a single bulb under reamed pile. The pile with two bulbs is called a double bulb under reamed pile. And the pile with more than two bulbs is called a multiple bulb 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 up to 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 bulb is 1.5m or 2 D_u whichever is greater.

- Under reamed piles can be made at a better also, for sustaining large lateralloads, 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.

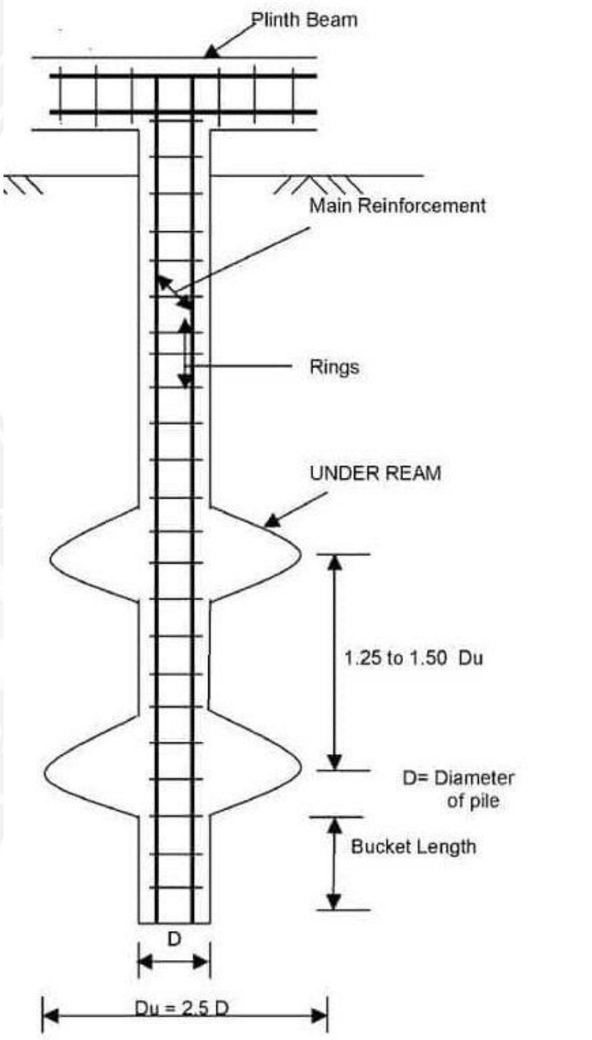


Fig 1 Under reamed pile with two under reamer

[Fig 1 https://expertcivil.com/under-reamed-pile/]

Under Reamed Piles Bulb Calculation

The width of the under-reamed bulbs might be 2 to 3 times the width of the stem. The distance between bulbs is 1.25 to 1.5 times the stem breadth. The topmost bulb's distance from the surface should not be less than 2 to 3 times the bulb's diameter.

Procedure:

Under-reamed piles are mostly artificially constructed. Tool for Such piles of construction are given below.

1. Spiral Auger
2. Under – reamer
3. Boring guide

- A spiral auger is used to drill a hole in the ground for an Under reamed piles. Cutter is attached at the end of Auger to easily dig ground. Below the spiral auger, the filling bucket is hung to remove soil. Auger handles are also used to increase depth.
- A special type of cutter is used to make the bulb; the diameter of the bulb can be increased by applying pressure on the handle of the auger.
- Excavation is carried out from the auger only after passing the handle of the auger through a special design made on the head of a tricycle placed on the ground so that the digging of the pile hole is done in the vertical direction only.
- After digging the pile hole and the bulb to the required depth, the auger is taken out and the Case of reinforcement is inserted in the hole. Then Concreting is done.
- All the piles are connected to each other by forming a beam at the head of the pile. The wall is constructed over the beams.

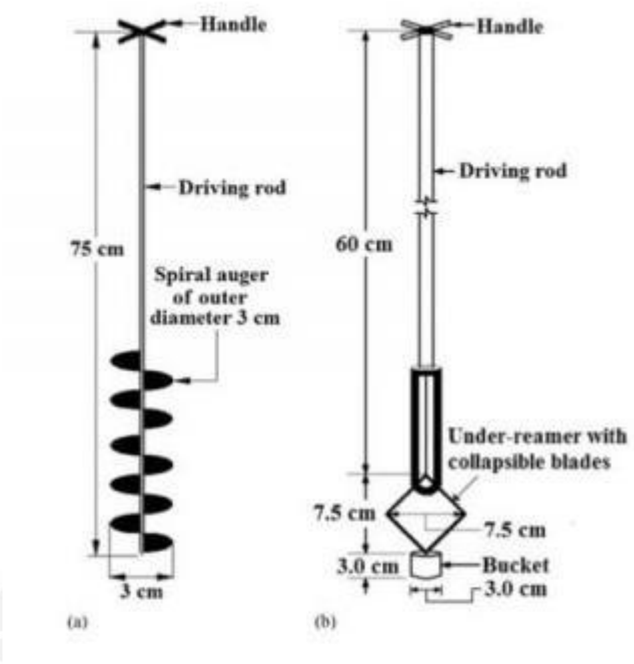


Fig1 Under reamed pile

[Fig1 https://www.civilengineeringweb.com/2020/07/under-reamed-piles.html]

Advantages of Under Reamed Piles:

- Such piles are 15 to 20% cheaper than strip footing.
- Less material is required for such a pile.
- No heavy digging is required, so operations can be carried out even in the rainy season.
- There is no need for back filling in such piles.
- Shoring is not required.
- Dewatering is not required.

Disadvantages of Under Reamed Piles:

- Required great workmanship.
- Skills required for placing of such type of piles.
- Maintaining verticality in ground is difficult. Because some time such pile are driven by hand-operated machine and it is very difficult.
- Required strict and regular supervision with great quality control.

Clayey soils:

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

Q_u =Ultimate bearing capacity

A_p=C/s area of pile

N_c=Bearing capacity factor

C_p=Cohesion of the soil

$$A_a = \frac{\pi}{4}(D_u^2 - D^2)$$

C_a'=Average cohesion of soil around the bulb

A_s'=Surface area of the cylinder

A= reduction coefficient (usually 0.5 for clays)

Sandy soils:

$$Q_u = \frac{\pi}{4}(D_u^2 - D^2)\left[\frac{1}{2} D_u n.\gamma N_\gamma + \gamma N_q \sum_{r=1}^{r=n} dr\right] + \frac{\pi}{4}(D^2)\left[\frac{1}{2} D_u \gamma N_\gamma + \gamma D_f N_q\right] + \frac{1}{2}\pi D\gamma K \tan\delta (d_1^2 + d_f^2 + d_n^2)$$

D_u= Diameter of under reamed bulb

D= diameter of stem

D_f=Depth of pile

Pile settlements

Pile settlement can be estimated as follows.

Compute the average pile axial force in each segment of length L, average cross-section & A_{av} and shaft modulus of elasticity E_p from the pile butt to point. That is.

$$\Delta Hs,s = \frac{P_{av} \times \Delta L}{A_{av} \times E_p}$$

and sum the several values to obtain the axial total compression

$$\Delta H_a = \sum \Delta Hs,s$$

Compute the point settlement using the equation below

$$\Delta H_{pt} = \Delta q D\left(\frac{1-\mu^2}{Es}\right) m I_S I_F F_1$$

Where,

$mI_s = 1$

I_f= Fox embedment factor, with values as follows:

I_f=0.55 if L/D≤5

I_f =0.5 L/D>5

D = diameter of the pileμ =Poisson's ratio

q= bearing pressure at point = input load/ A_pE_s = Young's modulus

SPT: Es= 500 (N+15)

CPT: 3-6 q_c

F1 is the reduction factor as follows

0.25 if the axial skin resistance reduces the point load Pp ≤0

0.5 if the point load Pp >0

0.75 if the point bearing

Problems:

1.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 ofthe 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.

$$\therefore \text{Allowable pressure } = \frac{7.2}{0.3} x0.3 = 800KN/m^2$$

∴ Allowable pressure for settlement S_q

$$q_u = \frac{10}{25} x800 = 320KN/m^2$$

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.

2.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

Load = 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

Load on the plate = 320 kN/m^2

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

$$= 0.8 \left[\frac{2.6(0.3 + 0.3)}{0.3(2.6 + 0.3)}\right]^2$$

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

∴ Settlement of footing for 266.27 kN/m^2

$$= \frac{266.27}{320} x25.72$$

= 21.4 mm

Group capacity by different methods:

1.Converse – Labarra formula:

$$\eta_g = 1 - \frac{\theta}{90^0}\left[\frac{(n-1)m + (m-1)n}{mn}\right]$$

m= number of rows

n=number of pile in a row

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

d = Diameter of pile

S= spacing of pile

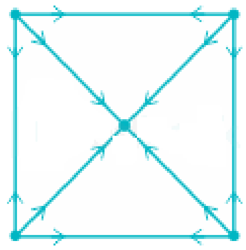
2.Seiler -Keeny formula:

$$\eta_g = [1 - 0.479\,(\frac{s}{s^2 - 0.093})\,(\frac{m+n-2}{m+n-2})] + \frac{0.3}{m+n}$$

S=Average spacing from center to center

3. Feld's rule:

It is reduced by 1/16 on account of the nearest pile in each diagonal or straight row. The spacing of the pile is not considered.



Efficiency of corner pile(3adjacent pile), $\eta = \frac{16-3}{16} = 81.25\%$

Efficiency of central pile(3adjacent pile), $\eta = \frac{16-4}{16} = 75\%$

$$Average = \frac{(81.25x4) + (75x1)}{5} = 80\%$$

Group Action

Piles are generally used in groups with a common pile cap. A group may consist of two or three, or as many as ten to twelve piles depending on the design requirement. The load carrying capacity of a group of piles is given by

$$(Q_u)_g = N q_u n$$

where,

$(Q_u)_g$= Load carrying capacity of pile group

N = number of piles

q_u= allowable load per pile

n = group efficiency

- Its value for bearing or friction piles at sites where the soil strength increases with depth is foundto be 1.
- For friction piles in soft clays the value on n is less than 1. The actual value of n depends onsoil type, method of pile installation, and pile spacing.

- When piles are driven in loose, sandy soils, the soil is densified during driving, and n >1 in suchcases.
- It has been observed that if the spacing between piles is more than 2.5 times the pile diameter,the group efficiency is not reduced.
- The large pile to pile spacing will increase the overall cost of construction. The reduction in loadcapacity due to the group effect can be estimated empirically.
- The use of Feld's rule is probably the simplest. It states that the load capacity of each pile in agroup is reduced by 1/16 on account of the nearest pile in each diagonal or straight row.

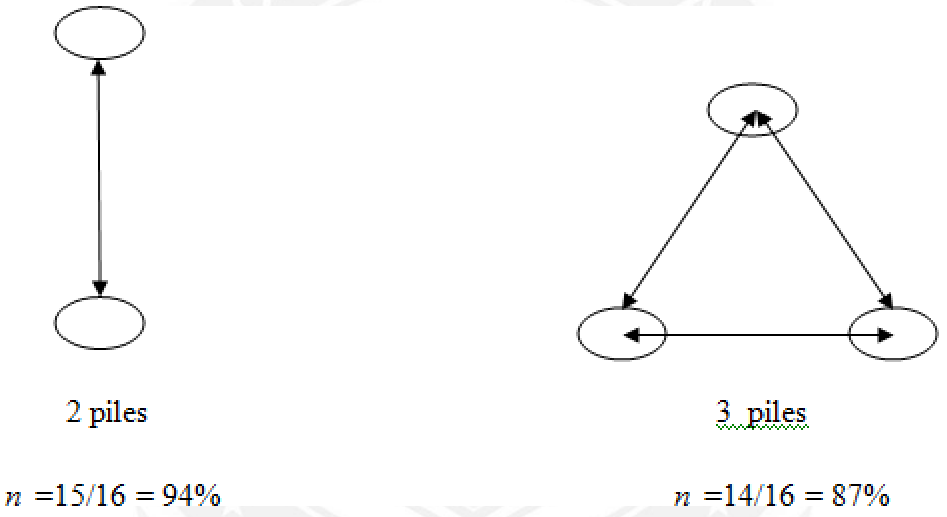


Fig. 6: Group action of piles- Feld's rule

[Fig6 https://aits-tpt.edu.in/wp-content/uploads/2018/08/pile-foundations-theory.pdf]

A group of piles may fail as a block, i.e., by sinking into the soil and rupturing it at the peripheryof the group Fig.7.

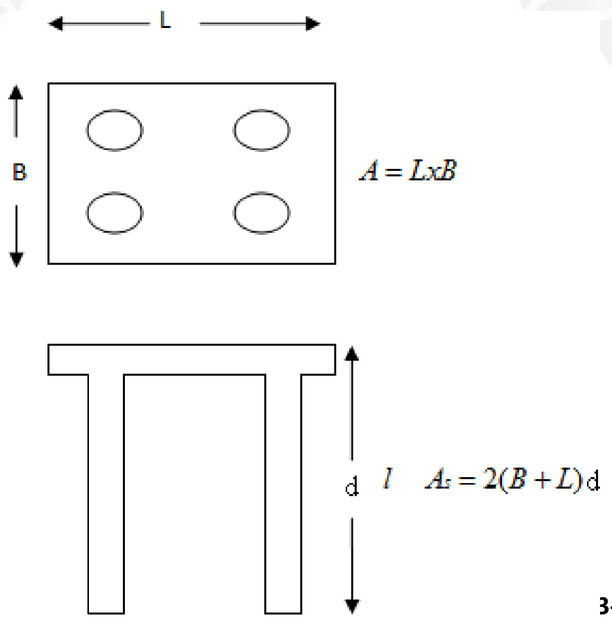


Fig7: Failure of a pile group as a block

[Fig 4 https://aits-tpt.edu.in/wp-content/uploads/2018/08/pile-foundations-theory.pdf]

Ultimate Load Carrying Capacity for the Pile Group

The ultimate load carrying capacity for the pile group taken as a block is given by

$$(Q_u)_g = C_u N_c A_b + C_u A_p$$

where Ap and Ab are the area of the base and the surface area of block. i.e. Ab = LB

where, L and B are the dimensions of the pile cap.

Ap is the perimeter of the block times the embedded length of the pile.

Efficiency of a Pile Group:

The efficiency of a pile group is defined as

$$\eta_g = \frac{\text{Ultimate bearing capacity of the group}}{n \times \text{ultimate bearing capacity of single pile in the group}}$$

where n = number of piles in the group

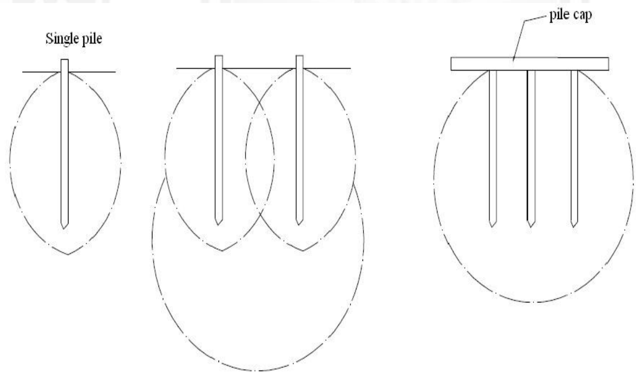


Fig. 8: Group action of Piles

[Fig8 https://aits-tpt.edu.in/wp-content/uploads/2018/08/pile-foundations-theory.pdf]

Settlement of Pile Groups

Due to group action, both immediate and consolidation settlement values of a pile group aregreater than those for a single pile.

For bearing piles the total foundation load is assumed to act at the base of the piles on an imaginary foundation of the same size as the plan of the pile group as show in Fig 9

For friction piles it is virtually impossible to determine the level at which the structural load is effectively transferred to the soil. The level used in design is at a depth of two-thirds the penetration depth.

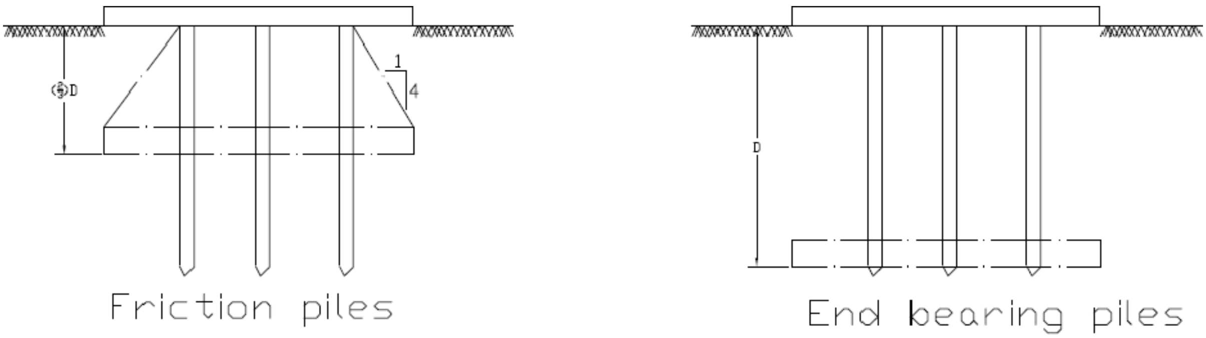


Fig.9: Equivalent foundations for pile

[Fig 9 https://aits-tpt.edu.in/wp-content/uploads/2018/08/pile-foundations-theory.pdf]

Uplift Resistance of Pile:

Clay:

$$Q_{uu} = W_p + \alpha C A_s$$

W_p=weight of pile

A=adhesion factor

C=average undrained shear strength of clay along the pile shaft.

Negative Skin Friction:

Negative skin friction is usually a downward shear drag acting on a pile or pile group because of downward movement of surrounding soil relative to the piles. This shear drag movement are anticipated to occur when a pile penetrates into compressible soil layer that can consolidate. It is reported that, a small relative movement between the soil and the pile of around 10 mm may be adequate for the full negative skin friction to materialize. Moreover, the time of ending the negative skin fiction of piles is estimated to be around 2 years and the degree of consolidation of the soft soils reaches 90%. Finally, this article presents different aspect of negative skin friction on piles and pile group.

Factors that cause negative skin friction on piles and pile group:

- Newly placed fill material on compressible soil before the completion of consolidation.
- If fill material is loose cohesion less soil
- When fill material is deposited over layer of soft soil or peat.

- Lowering groundwater which increases the effective stress causing consolidation of soil with resultant settlement and friction force being developed on the pile.
- Effect of negative skin friction on piles and pile groups
- Negative skin friction contributes to the uneven settlement of piles or pile group.
- For piles in compressible soils where pile capacity is contributed by both point resistance and shaft adhesion, the problem of negative skin friction should be considered a settlement problem.
- In bearing piles where the settlement of the pile is negligible, negative skin friction becomes a pile capacity problem.

1.Negative skin friction in single pile

The negative skin friction in single piles can be computed using the following expressions:

a. Negative skin friction of piles in cohesive soil

$$F_n = P L_c C_a - - - (1)$$

Where: F_n: negative skin friction

P: perimeter of the pile

L_c: pile length in compressible soil

C_a: unit adhesion and can be computed using equation 2

$$C_a = \alpha C_u - - - - (2)$$

Where: α: adhesion factor

C_u: Undrain Cohesion of the compressible layer

b. Negative skin friction of piles in cohesion less Soils:

$$F_n = 0.5 P L_c^2 \gamma K tan\delta - - - (3)$$

Where:

K: lateral earth pressure coefficient

γ: unit weight of soil

δ: angle of friction between pile and soil, which may vary from 1/2 to 2/3 .

2.Negative skin friction on pile groups

Negative skin friction in pile groups equal to the greater of equation 4 and equation 5:

$$F_{ng} = nF_n ----(4)$$

$$F_{ng} = C_u L_c P_g + \gamma L_c A_g ----(5)$$

Where:

n: number of piles in the group

Pg: perimeter of the group

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

Ag: area of pile group with in the perimeter Pg

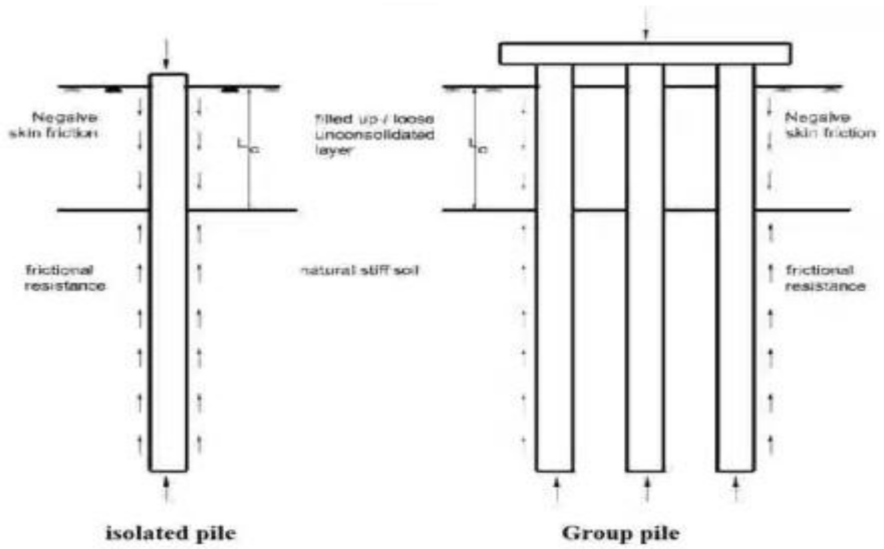


Fig.1: Negative skin friction on piles and group pile

[Fig1https://theconstructor.org/geotechnical/negative-skin-friction-piles/3376/]

The effect of negative skin friction on the factor of safety with respect to the ultimate load capacity of a pile or a pile group

The influence of negative skin friction on safety factor with respect to ultimate load carrying capacity of piles or pile group is considered by introducing the factor of safety, so: ultimate load capacity of a pile or a group of pile=(working load + negative skin friction load)(Factor of safety) Where it is anticipated that negative skin friction would impose undesirable, large downward drag on a pile, it can be eliminated by providing a protective sleeve or a coating for the section which is surrounded by the settling soil.

If a soil subsides or consolidates around a group of piles these piles will tend to support thesoil 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 remolding of clay during driving of the pile