Example 25.10: A building has to be supported on R.C raft foundation of dimensions 14m x 21m. The soil is clay, which has an average u.c.s of 15 kN/m^2. The pressure on the soil due to weight of the building and the loads that it will carry will be 140 kN/m^2 at the base of the raft. The building has provision for basement floors. At what depth should the bottom of the raft be placed to provide a F.O.S of 3 against shear failure? $\gamma_{clay} = 19$ kN/m^3, use Skempton's approach for b.c calculations.

Soln:- Skempton's equation

$$q_{nf} = 5\left[1+0.2\,D/B\right]\left[1+0.2\frac{B}{L}\right]c$$

$q_u = 15$ kN/m^2, $c = q_u/2 = 7.5$ kN/m^2, $B = 14$m, $L = 21$m.

$$q_{nf} = 5\left[1+0.2\times\frac{14}{21}\right]\left[1+0.2\frac{D}{14}\right]\times 7.5$$

$$q_{nf} = 42.5\left(1+0.01429D\right]$$

$$q_s = \frac{q_{nf}}{F} + \gamma D = \frac{42.5}{3}\left(1+0.01429D\right)+19\cdot D$$

actual load intensity = 140 kN/m^2

Equating the two, $\frac{42.5}{3}\left(1+0.01429\right]+19D = 140$

$$19.2024D = 125.83$$

so, $D = 6.55$m.

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I.S CODE OF PRACTICE FOR DESIGN OF RAFT FOU

IS : 2950-1965 gives the code of practice for design and construction of raft foundations.

the maximum differential settlement should not exceed 40mm in the foundation on clayey soils and 25mm in foundations on sandy soils.

the maximum settlement should generally be limited to the following values:

Raft foundation on clay : 65 to 100 mm ✓

Raft foundation on Sand : 40 to 65mm ✓

There are two approaches for design : →

i. conventional method

ii. elastic method or the soil line method.

1. Conventional method : the conventional method is based on the following two basic assumptions:

(i) the foundation is infinitely rigid and therefore, the actual deflection of the raft does not influence the pressure distribution below the raft.

(ii) The soil pressure is assumed to be planer linearly such that the centroid of the soil pressure coincides with the line of action of the resultant force of all the loads acting on the foundations.

TION

In the conventional method, the allowable bearing pressure is found using the following formulae

$$q_1 = 21.4 N^2 B R_{W1} + 64(100+N^2) D R_{W2}$$

$$q_2 = 1950 (N-3) R_{W2}$$

where q_1 and q_2 = allowable soil pressure under raft foundation in kg/m² (using f.o.s of 3)

R_{W1} and R_{W2} = reduction factors on account of subsoil water

The smaller of the two values of q_1 and q_2 should be used for design.

- In case of saturated silts, the equivalent penetration resistance Ne, for the values of N greater than 15 should be taken for design as explained

The pressure distribution (q) under raft should be determined by the following formula:

$$q = \frac{Q}{A} \pm Q\frac{e_y'}{I_x'}y \pm Q\frac{e_x'}{I_y'}x$$

where
Q = total vertical load on the raft.
x, y = co-ordinates of any given point on the raft with respect of the x and y axes passing through the centroid of the area of the raft.

I_x', I_y', e_x', e_y' = moment of inertia and eccentricities about the principal axes through the centroid of the section.

A = total area of the raft.

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I_x', I_y', e_x' and e_y' can be calculated from the following equations

$$I_x' = I_x - \frac{I_{xy}^2}{I_y} \; ; \; I_y' = I_y - \frac{I_{xy}^2}{I_x}$$

$$e_x' = e_x - \frac{I_{xy}}{I_x} e_y \; ; \; e_y' = e_y - \frac{I_{xy}}{I_y} e_x.$$

where I_x, I_y = M.O.I of the area of the raft respectively about x and y axes through the centroid

$I_{xy} = \int xy \, dA$ for the whole area about x and y axes through the centroid.

2. Elastic method

A number of methods have been proposed based on two approaches
1. Simplified elastic foundation
2. Truly elastic foundation.

Simplified elastic foundation.

the soil in this method is replaced by an infinite number of isolated springs.

Truly elastic foundation

the soil is assumed to be continuous elastic medium obeying Hooke's law

These methods are to be used in case the foundation is comparatively flexible and the load tends to concentrate over small areas.

The ~~this~~ method assumes in addition to other factors that the modulus of subgrade reaction, determined from test, is known.

the modulus of subgrade reaction (ks) is applicable to the case of load through a plate of size 30cm x 30cm or beam 30 cm wide on soil area.

given in Table 25.2 for cohesionless soil & Table 25.3 for cohesive soils.

the value of ks are corresponding to a square plate of size 30cm x 30cm.

For finding the values of K corresponding to different sizes and shapes. the following relation should be used

(i) Effect of size : $K = K_s\left(\frac{B+30}{2B}\right)$ for cohesionless soil

$K = x\frac{K'}{B'}$, for cohesive soil

where K = modulus of subgrade reaction for footing width B cm

Ks = " " " " square plate 30cm x 30cm

K' = " " " for footing width x cm

(ii) Effect of shape: for cohesive soils $K_1 = K_2\frac{2}{3}\left(1+\frac{B}{2L}\right)$

K1 = modulus of subgrade reaction for rectangular footing having a length L and width B.

K2 = " " " for square footing of side B.

Example 25.13. A building is to be supported on a reinforced concrete raft covering an area of 14x21m. The subsoil is clay with a UCS of 84 kN/m^2. The pressure on the soil due to weight of the building and loads it will carry, will be 120 kN/m^2, at the base of the raft. If the unit weight of the building and loads it will carry, will be 120 kN/m^2, at the base of raft. If the unit weight of excavated soil is 15 kN/m^3. at what depth should the bottom of the raft be placed to provide a f.o.s of 3?

Solution:-

$$q_u = 84 \text{ kN/m}^2, \quad c_u = q_u/2 = 42 \text{ kN/m}^2$$

using Skempton equation for B.C of raft

$$q_{nf} = 5c_u\left(1+0.2\times\frac{B}{L}\right)\left(1+0.2\frac{D}{B}\right)$$

or $\cdot$ $$q_{nf} = 5\times 42\left(1+0.2\times\frac{14}{21}\right)\left(1+0.2\frac{D}{14}\right)$$

$$= 238\,(1+0.01429D)$$

$$q_s = \frac{q_{nf}}{F} + \gamma D = \frac{238}{3}(1+0.01429\,D) + 15\,D$$

$$= 79.33 + 16.134D$$

Actual load in density $q_a = 120 \text{ kN/m}^2$

$$79.33 + 16.134D = 120$$

$$so, D = 2.52$$

Check factor $5\left(1+0.2\frac{D}{B}\right) = 5.18 < 7.5$ Hence OK.

Deep foundation

Definition

A deep foundation is a type of foundation which transfers the building load of the structure to the ~~earth~~ subsurface whose depth is more than shallow foundation.

Depth > width . D > B

when use

when the soil at or near the ground surface is not capable ~~of~~ of supporting a structure, deep foundations 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 that it cannot be reached economically by shallow foundations.

Type of deep foundation

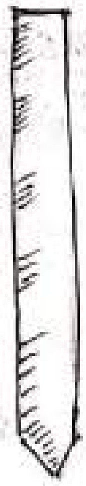
The most common type of deep foundations are (i) piles
(ii) piers
& (iii) caissons

The mechanism of transfer the load to the soil is essentially same in all types of deep foundations.

A deep foundation is generally much more expensive than a shallow foundation. It should be adopted only when the shallow foundation is not feasible.

In some cases the soil is improved by various method to make it suitable for a shallow foundation.

Pile foundation | pier foundation | caisson



Steel or reinforced concrete

bricks

height 30 m = 3000 cm
dia 700 mm (upto) 70 cm

20x20 or 30 x 30 cm
180 cm

an underground structure of steel and concrete used by building builders to support bridge abutment and piers.

Necessity of pile foundations or use

Pile foundations are used 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 out line 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 load through deep water to a firm stratum.

(4) Pile foundations are used to resist horizontal forces in addition to support the vertical loads in earth-retaining structures and tall structure 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) In case of expansive soils, such as black cotton soil, which swell or shrink as the water content changes, piles are used to transfer the load below the active zone.

Classification of Piles

Piles classified according to (I) material used

(II) mode of transfer of load

(III) method of construction/method of installation

(IV) the use

(V) displacement of soil.

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Classification according to material used

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

1. Steel piles:

→ Steel piles are generally either in the form of thick pipes (cylindrical) or rolled steel H-section.

→ pipes steel piles are driven into the ground with their ends open or closed.

→ piles are provided with a driving point or shoe at the lower end.

Epoxy coating are applied in the factory during manufacture pipes to reduce corrosion of steel pipe.

To take into the account of corrosion concrete encasement at site or extra additional thickness of steel section usually recommended.

2. Concrete piles.

→ Cement concrete is used in the construction of concrete piles.

→ Concrete piles are either precast or cast-in-situ.

2-i, Pre cast

precast concrete piles are prepared in a factory or a casting yard. the reinforcement is provided to resist handling and driving stresses. precast piles are

2.ii Cast-in-situ

→ It is constructed by making a hole in the ground and then filling it with concrete.

→ A cast in situ piles is ~~constructed~~ may be cased or uncased

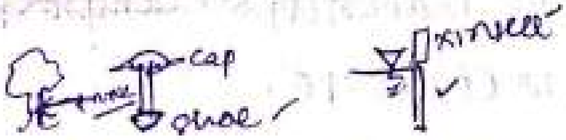
2.iii Cased

A cased pile is constructed by driving a steel into the ground and filling it with concrete.

2.iii Uncased

An uncased pile is constructed by driving the casing to the desired depth and gradually withdrawing casing when fresh concrete is filled.

3. Timber Piles.



timber piles are made from tree trunks after proper trimming.

the timber used should be straight, sound and free from defects.

Steel shoe are provided at bottom and metal band or cap at the top will be provided to prevent damage during driving.

Timber pile below the water table have generally long life. However, above the water table, these are attack by insects.

4. Composite piles

concrete (cast-in-situ) / steel   steel / wood

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

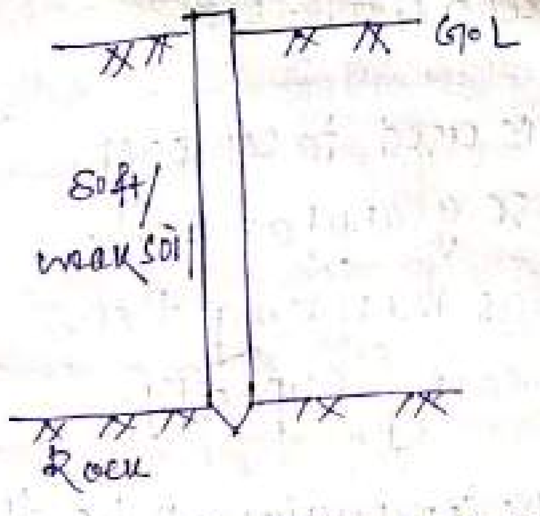
A composite pile may also have the lower portion of timber below the permanent water table and upper portion of concrete.

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

Classification based on mode of transfer of load

1. (i) End bearing piles
2. (ii) Friction pile
3. (iii) Compaction pile
4. (iv) Combined end-bearing and friction pile
5. (v) Sheet pile

End bearing pile



→ It is used to transfer the load of the structure through water or soft soil to a suitable stratum.

→ the E-B-P transmit the load through their bottom tips.

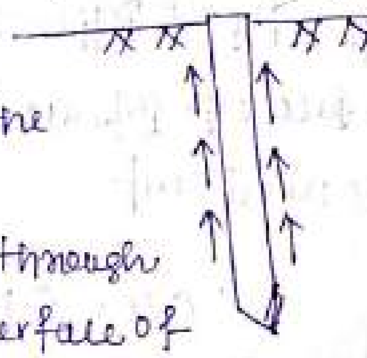
→ If hard rock is located within the reasonable depth, pile can be extended to the rock.

→ the ultimate capacity of the pile depend upon the capacity of rock.

→ It is also known as point bearing piles

$Qu = Qp$ [Qu = ultimate load carry by pile
Qp = " " the point or bottom end]

Friction pile



→ friction pile do not reach the hard stratum.

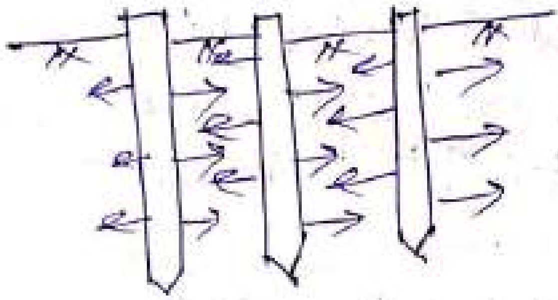
→ these piles transfer the load through skin friction between the surface of the pile and the surrounding soil.

→ the friction piles are used when a hard stratum does not ~~reach~~ exist at a reasonable depth.

$Qu = Qs$ Qs = ultimate load carry the skin friction.

→ friction piles are also known as floating piles.

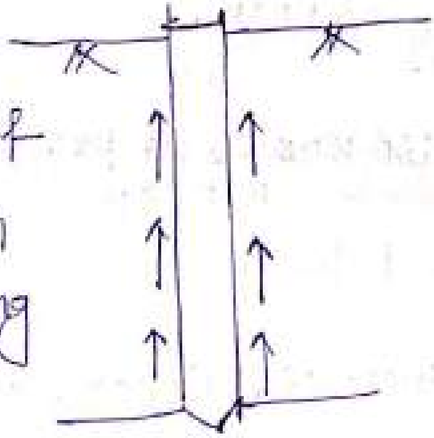
Compaction pile



It is used to compact loose granular soil. thus increasing their bearing capacity.

the compaction piles themselves donot carry any load.

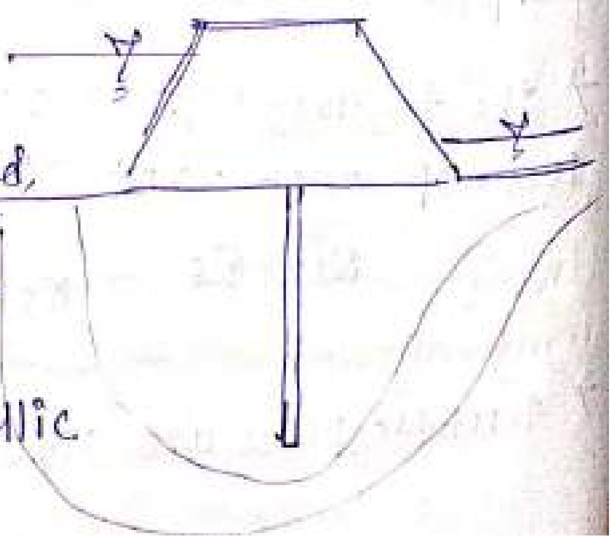
Combined end bearing and friction pile



these pile transfer the load by a combination of end bearing at the bottom of pile and friction along the surface of pile and surrounded soil.

$$Q_u = Q_p + Q_s$$

Sheet pile



It is used as bulk head, or as impervious cutoff to reduce seepage and uplift under hydraulic structure.

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Classification based on method of installation

Based on method of construction, the pile may be classified into the following catagories

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

(iv) Screw piles
These piles are screwed into the soil.

(v) Jacked piles
these piles are jacked into the soil by applying a downward force with the help of a hydraulic jack.

Classification based on use

(I) Load bearing piles. these piles are used to transfer load of the structure to a suitable stratum by end bearing, by friction or by both.

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

(iii) Tension piles. (anchor) these piles are in tension. these piles are used to anchor down structures subjected to ~~hydrostatic~~ hydro uplift forces or overturning forces →

(iv) Sheet piles

Sheet piles form a continuous wall or bulk head which is used for retaining earth or water.

(v) Fender piles

Fender piles are used to protect water-front structures from impact of ships and vessels. any structure which is inside or at side of water bodies

(vi) Anchor piles.

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

(2) Classification based on displacement of soil

Based on the volume of the soil displaced during installation

(i) Displacement piles. ⇐ precast or closed-end pipe, H

→ All driven piles are displacement piles as the soil is displaced 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 piles are high displacement piles. steel 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 cause very little change in the stresses in the surrounding soil.

Pile Driving :→

piles are driven in to the ground by means of hammers or by using a vibratory driver.

Such piles are called driven piles

The following methods are commonly used.

1. Hammer Driving.

It consists of a hoist mechanism, a guiding frame and a hammer device. The hammers used for pile driving are of the following types.

cushion cap

(a) Drop hammer: A drop hammer is raised by a winch and allowed to drop on the top of the pile under gravity from a certain height.

→ During the driving ~~mechanism~~ operation a cap is fixed to the top of the pile ~~under gravity~~ and a cushion is generally provided between the pile and the ~~cap~~ cap.

→ Another cushion, known as hammer cushion, is placed on the pile cap on which the hammer causes the impact.

→ The drop hammer is the oldest type of hammer used for pile driving. It is rarely used these days because of very slow rate of hammer blows.

(ii) Single acting hammer – In a single-acting hammer, the ram is raised by air (or steam) pressure to the required height. It is then allowed to drop under gravity on the pile cap provided with a hammer cushion.

(iii) Double-acting hammer.

→ In double-acting hammer, air (or steam) pressure is used to raise the hammer. When the hammer has been raised to the required height, air (or steam) pressure is applied to the other side of the piston and the hamm is pushed downward under pressure.

→ This increase the impact energy of the hammer.

(iv) Diesel hammer.

A diesel hammer consists of a ram and a fuel injection system. It's also provided with an anvil block at its lower end.

The ram is first raised manually and the fuel is injected near the anvil. As soon as the hammer is released, it drops on the anvil and compresses the air-fuel mixture and ignition takes place.

The pressure so develop pushes the pile downward and raises the ram. The fuel is injected and the process is repeated.

the ram lift automatically. It has to be manually raised only once at the beginning.

→ Diesel hammers are not suitable for driving piles in soft soils. In such soils, the downward movement of the pile is excessive and the upward movement of the ram after impact is small.
→ The height achieved after the upward movement of the hammer may not be sufficient to ignite the air-fuel mixture.

(2) Vibratory pile Driver.

A vibratory pile driver consists of two weights, called exciters, which rotate in opposite directions. 
The horizontal components of the centrifugal force generated by exciters cancel each other but the vertical components add.

Thus the sinusoidal dynamic vertical force is applied to the pile, which forces the pile downward.
The frequency of vibration is kept equal to the natural frequency of pile-soil system for better results.

A vibratory pile driver is useful only for sandy and gravelly soils. The speed of the penetration is good. The method is used where vibrations and noise of conventional driving methods cannot be permitted.

3. Jetting Techniques

when the pile is to penetrate a thin hard layer of sand or gravel overlying a softer soil layer, the pile can be driven through the hard layer by jetting techniques.

water under pressure discharged at the pile bottom point by means of a pipe to wash and loosen the hard layer.

4. partial Augering method

Batter pile (inclined piles) are usually advanced by partial augering. In this method, a power auger is used to drill the hole for a part of the depth. the pile is then ~~inserted~~ inserted in the hole and driven with hammers to the required depth.

Load Carrying Capacity Of Piles

the ultimate load carrying capacity or ultimate bearing capacity or the ultimate bearing resistance Q_{up} of a pile is defined as the maximum load which can be carried by a pile, and at which the pile continues to sink without further increase of load.

the allowable load Q_a is the safe load which the pile can carry safely and is determined on the basis of

(i) ultimate bearing capacity divided by suitable factor of safety. Q_{up}/F

(ii) the permissible settlement.

and (iii) overall stability of the pile foundation.

the load carrying capacity (Q_{up}) of a pile can be determined by the following methods

- (i) Dynamic formulae
- (ii) static formulae

} from empirical equations

- (iii) pile load test
- (iv) penetration tests.

} from field

Dynamic formulae

when a pile-hammer hits the pile, the total driving energy is equal to the weight of hammer ~~pile~~ times the height of drop or stroke. $W \times H$

In addition to this, in the case of double acting hammer some energy is also imparted by the stream pressure during the return ~~and~~ stroke the total downward energy is consumed by the work done in penetrating the pile and by certain losses

the various dynamic formulae are essentially based on this assumption.

It is also assumed that the soil resistance of dynamic penetration of pile is the same as to the penetration of pile under static or sustained loading.

following are some of the commonly used dynamic formule.

(1) Engineering News formule

It is proposed by A.M. Wellington (1818) in the following general formulae.

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

where, Q_a = allowable load W = weight of hammer

H = height of fall F = F.O.S = 6

S = penetration per blow

usually taken avg. penetration in cm per blow for the last 5 blows of a drop hammer, or 20 blows of a steam hammer.

C = empirical constant

= 2.5 cm for drop hammer.

= 0.25 cm for single and double acting hammers.

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(i) Drop hammers : $Q_a = \dfrac{WH}{6(S+2.5)}$

(ii) Single acting steam hammer : $Q_a = \dfrac{WH}{6(S+0.25)}$

(iii) Double " " " : $Q_a = \dfrac{(W+ap)H}{6(S+0.25)}$ $\dfrac{(W+\text{pistonforce})H}{6(S+0.25)}$

where, a = effecting area of piston (cm^2)
p = mean effective steam pressure (kg/cm^2)

(2) Hiley's formulas:

$$Q_f = \frac{\eta_h W H \eta_b}{S+\frac{C}{2}}$$

Q_f = ultimate load on pile
W = weight of hammer, in kg
H = Height of drop of hammer in cm.
S = penetration in cm per blow
C = total elastic compression = $C_1+C_2+C_3$
C_1 = temporary elastic compression of dolly and packing
C_2 = of pile
C_3 = of soil

η_h = efficiency of hammer (65–100%)
η_b = efficiency of hammer blow (ratio of the energy after impact to striking energy of ram)

$$\eta_b = \frac{W + e^2 P}{W + P} \quad \text{(for the case of } W > eP\text{)}$$

$$\eta_b = \frac{W + e^2 P}{W + P} - \left\{\frac{W - eP}{W + P}\right\}^2 \quad \text{(for the case when } W < eP\text{)}$$

P = weight of pile, helmet, follower.

e = coefficient of restitution (0 – 0.5)

Here number of constants are involved, which are difficult to determine.

Static formulae

The static formulae are based on assumption that the ultimate bearing capacity Q_{up} of a pile is the sum of the total ultimate skin friction R_f and total ultimate point or end bearing resistance R_p.

$$Q_{up} = R_f + R_p$$

or

$$Q_{up} = A_s \cdot r_f + A_p \cdot r_p$$

where A_s = surface area of pile upon which the skin friction acts.

A_p = Area of cross section of pile on which bearing resistance acts.

r_f = avg. skin friction, r_p = toe resistance.

the allowable load.

(i) for cohesive soil.

for the pile in cohesive soil, point bearing is generally neglected for individual pile actions since it is negligible as compared to friction resistance.

the unit skin friction may be taken equal to the shear strength of the soil multiplied by a reduction factor 'α' (or m)

thus, r_f = Avg. skin friction along the length of the pile.

$= \alpha\bar{c}$ or $m\bar{c}$

and $r_p = C_p N_c = 9 C_p$

$Q_{up} = m\bar{c} A_s + 9 C_p A_p$

where m (or α) = 0.4 — 1 (Cintage for diff. consistency of clay) value α.
- soft to very soft
- medium
- stiff
- stiff to hard

$\bar{c}$ = Avg. undrained cohesion along the length of pile

C_p = Avg. undrained cohesion of soil at pile tip.

in the absence of $\bar{c}$ or C_p may be taken equal to $q_u/2$.

the allowable load for the pile is given by dividing Q_{up} by a suitable f.o.s F.

$$Q_a = Q_{up}/F$$

IS recommends F should taken as lesser value 2.5 and two f.o.s are adopted for shaft resistance (or skin friction) and base resistance we have $\boxed{Q_a = \frac{\eta \bar{c} A_s}{F_1} + \frac{q_c A_p}{F_2}}$

(ii) for non-cohesive soil

$Q_{up} = R_f + R_p$

$= A_s r_f + A_p r_p$

$r_f = K \tan\phi (\gamma z + q)$

$r_p = 0.3 \gamma B N_{\gamma q}$ (for circular pile)

$= 0.5 \gamma B N_{\gamma q}$ (for rectangular or square piles)

K = Coefficient of lateral earth pressure

γ = density of soil

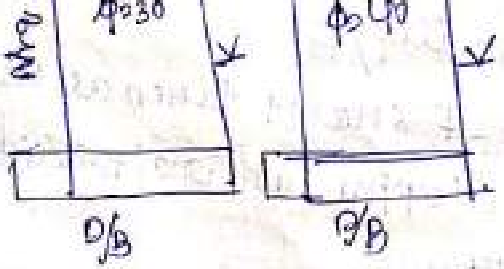
q = surcharge on the ground

z = depth of C.G of the pile below ground surface

B = least lateral dimension of rectangular or square pile (or dia. of circular pile)

ϕ = angle of internal friction.

$N_{\gamma q}$ = meyerhoff's non-dimensional factor



Pile Load Test

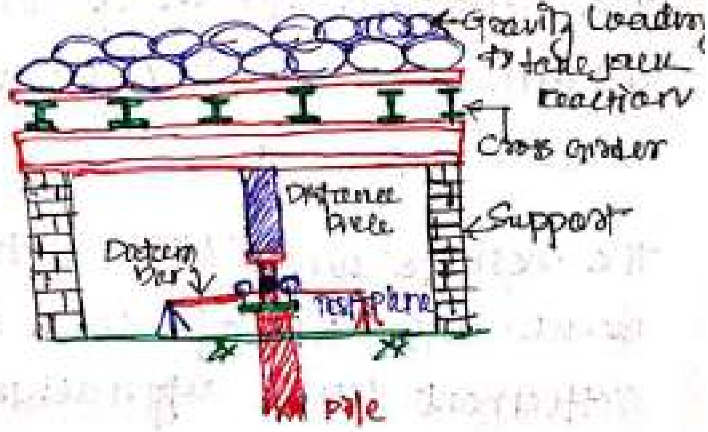
The most reliable method for determining the load carrying capacity of a pile is the pile load test.

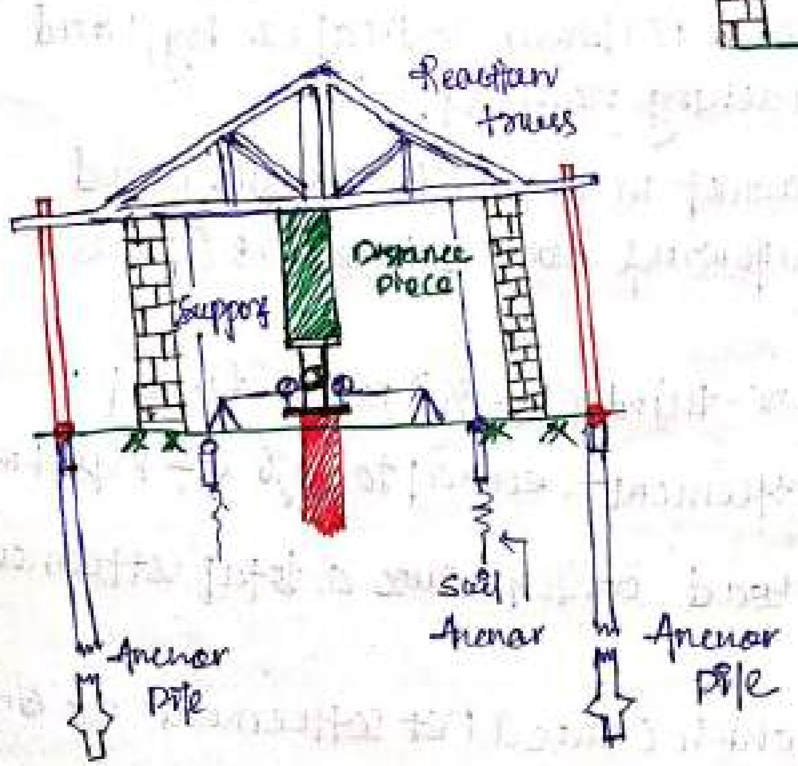
the setup generally consists of two/ arrays.

the pile load test can be performed either on a working pile which forms 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 jack is borne by a truss or platform which may have gravity loading (in the form of sand bags etc.) or alternatively, the truss can be anchored to the ground with the help of anchor piles.





$Q_a = R_f + R_p$

$= A_s r_f + A_p r_p$

$r_f = \alpha \bar{c}$ or $m\bar{c}$

$r_p = 9c_p$

α or m = 0.4–1 reduction factor

$\bar{c}$ or c_p is unit cohesi

The load is applied in equal increment of about one-fifth (1/5) of the estimated allowable load.

The settlement are recorded with the help of three dial gauges of sensitivity 0.02 mm. symmetrically arranged over the test plate and fixed to an independent datum bar.

A remote controlled pumping unit may be used for the hydraulic jack.

Each load increment is kept for sufficient time till the rate of settlement becomes less than 0.02 mm per hour.

The test pile are loaded until ultimate load is reached.

* Ordinarily, the test load is increased to a value of $2\frac{1}{2}$ times the estimated allowable load. or to a load which causes a settlement equal to one-tenth of the pile diameter, whichever occurs 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 the ultimate load cannot be obtained from the load settlement curve, the allowable load is taken as follows.

(i) {one-half} to one-third (1/2 - 1/3) to the final load which cause settlement equal to 10% of pile diameter

(ii) 2/3 of the final load which cause a total settlement of 12 mm, or

(iii) 2/3 of final load which cause a net settlement of 6 mm.

net settlement = residual settlement after the removal of load.

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 to a value less than 0.02 mm per hour.

The load is then completely removed and the elastic rebound of the pile top is measured by means of dial gauges.

The next load (increased load) is then applied and the process repeated.

The cyclic of loading and unloading with measurements of settlement and recovery is continued till the final load which causes a marked progressive settlement of the pile reached.

Group Action in Piles

1. Efficiency of pile group

→ conen general closely spaced piles are group together. It is reasonable to expect that the soil pressure developed in the soil as resistance will overlap.

→ the bearing capacity of a pile group may or may not be equal to the sum of bearing capacity of individual pile constituating a group.

theory and tests have shown that the total bearing value Q_{ug} of a group of friction piles, particulary in clay, may be less than the product of the friction bearing value Q_{up} of an individual pile multiplied by the number of piles n in a group.

However, there is no reduction due to grouping occurs in end bearing piles.

for combined end bearing and friction piles, only the load carrying capacity of the frictional portion is reduced.

A method of estimating the bearing capacity of a group of friction piles is to multiplying the quantity Q_{up} by reduction factor called the efficiency of pile group.

$$Q_{ug} = n\,Q_{up} \cdot \eta_g$$

where,

Q_{ug} = Load carried by group of friction piles.

Q_{up} = Load carried by each friction piles

n = number of piles ; η_g = efficiency of pile group

The efficiency of pile group depends upon the following factors.

1. characteristics of pile (length, diameter, material etc)
2. spacing of pile
3. total no. of pile in a row and no. of rows.

A no. of formulae are available for determining the efficiency of pile group.

Converse Labarre formulae:

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

where m = number of rows ; n = number of piles in a row

$\theta = \tan^{-1}\frac{d}{s}$ (degrees) ; d = diameter of piles

s = spacing of pile

Seiler-Kenney formulae:

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

where s = avg. spacing, centre to centre, in metres.

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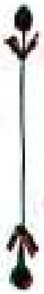
Feld's-Rule:

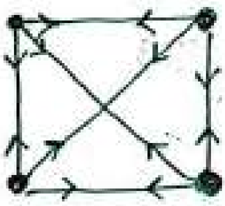
According to this rule, the value of each pile is reduced by one-sixteenth on account of the effect of the nearest pile in each diagonal or straight row of which the pile in question is a member.

Efficiency of pile groups By Feld's Rule

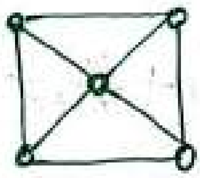


2 piles @ $\frac{15}{16}$ $\quad 1-\frac{1}{16}=\frac{15}{16}$ $\quad$ 93.5%

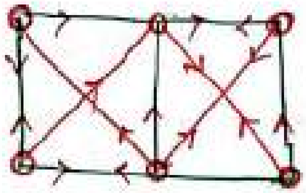
3 piles @ $\frac{14}{16}$ $\quad 1-\frac{2}{16}=\frac{14}{16}$ $\quad$ 87.5%



4 piles @ $\frac{13}{16}$ $\quad 1-\frac{3}{16}=\frac{13}{16}$ $\quad$ 87.3%



5 piles –
- 4 piles @ $\frac{13}{16}$ $\quad 1-\frac{3}{16}=\frac{13}{16}$ $\quad$ 80%
- 1 piles @ $\frac{12}{16}$ $\quad 1-\frac{4}{16}=\frac{12}{16}$



6 piles –
- 4 piles @ 13/16
- 2 piles @ 11/16

$1-\frac{5}{16}=\frac{11}{16}$

9 piles –
- 4 piles @ $\frac{13}{16}$
- 4 pile @ $11/16$
- 1 pile @ $8/16$

$1 - \frac{8}{16} = \frac{8}{16}$

Design of Pile Groups

The bearing capacity of single pile in clay is mainly due to friction, and the point bearing resistance may be negligible.

In a pile group, the piles are connected at its top by a pile cap which is rigid.

Hence the failure of a pile group is likely to occur at a load which may be smaller than the ultimate load carried by each pile multiplied by the number of piles in the group.

The area of the pile group, along failure surface is approximately equal to the perimeter P of the pile group multiplied by the length L of the pile.

The ultimate load will then be equal to

$$Q_{ug} = PL\tau_f + A \cdot q_p$$

where, A = cross-sectional area of pile group at base = $B \times B = B^2$

P = Perimeter of pile group = $4B$

τ_f = shear strength of soil = $\bar{c} = c = q_u/2$.

$$Q_{ug} = 4BL\tau_f + B^2 q_p = 4BL\bar{c} + B^2 (N_c c_p)$$

In absence of any other specific data, both $\bar{c}$ and c_p may be taken equal to $q_u/2$

If, however, piles of the group are so spaced that they act individually rather than acting in the group, the total load capacity of ~~piles~~ n piles is given by

$Q_{un} = n Q_{up}$, where Q_{up} = Load of individual pile.

The ultimate load (Q_u) of the pile groups will be then equal to lesser of Q_{ug} and Q_{un} determined above, and the permissible load will be equal to Q_u/F.

Settlement of Pile Group in clay

As a rough approximation, the settlement of a group of friction piles can be computed on the assumption that:- the clay contained between the top of the piles and their lower third point is incompressible and the load is applied to the soil at this lower third point of the pile.

The presence of pile below this level is ignored.

The load is ~~applied~~ ~~assumed~~ assumed to be uniformly distributed at this level and is assumed to spread at an angle 30° with the vertical.

the soil below this level is divided into a number of layer; and the σ_0 and $\Delta\sigma$ are calculated at the middle of each layer.

the settlement of each layer is calculated from the expression

$$\rho = \frac{H \times C_c}{1+e_0} \log_{10} \frac{\sigma_0+\Delta\sigma}{\sigma_0}$$

where, H = thickness of the layer
e_0 = initial void ratio
σ_0 = initial stress at centre of the layer $= \gamma z$
z = depth of centre of the layer below ground
$\Delta\sigma$ = additional stress due to piles.
= total pile load Q divided by the area of spread at the centre of layer.

the total settlement $= \rho_1 + \rho_2 + \rho_3 + \dots \rho_n$.