DESIGN OF A PILE GROUP BY USING SOIL PROPERTIES

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Abstract
The silty clay soil is a type of soil which is not capable of supporting a structure, deep foundations are required to transfer the loads. The most common types of deep foundations are Piles, Piers and Caissons.

By using the soil properties such as Liquid limit, Saturated density, Optimum moisture content etc,. The pile foundation can be designed.

A pile is a slender structural member made of steel, concrete or wood, which is either driven into the soil or formed in-situ by excavating a hole and filling it with concrete.

Application of pile foundation:
➢ If the plan of the structure is irregular relative to its outline and load distribution, it can be used to reduce differential settlement.
➢ It can resist horizontal forces in addition to support vertical loads for earthquake prone areas & tall buildings.
➢ Piles are used for foundations of some structures such as, transmission towers, off-shore platforms which are subjected to uplift.

➢ Piles are used to transfer the load beyond the zone of possible moisture changes in collapsible soils.

INTRODUCTION
A pile foundation is a slender structural member made of steel, concrete or wood, which is either driven into the soil or formed in-situ by excavating a hole and filling it with concrete.

CLASSIFICATION OF PILE FOUNDATION:

Based on the function:
➢ End bearing pile
➢ Tension or uplift pile
➢ Compaction pile
➢ Fender pile and dolphins
➢ Anchor pile
➢ Friction pile
➢ Batter pile

Based on materials and composition:
➢ Concrete pile
➢ Timber pile
➢ Steel pile
➢ Composite pile

REVIEW OF LITERATURE
Pile Foundation: Pile is one of the types of deep foundations, which are used when surface soil is unsuitable for shallow foundation. A pile is a slender member made of steel, concrete or wood. It is either driven into soil or formed in-situ by excavating a hole and filling it with
concrete. These are mostly used for the foundations in case of expansive soils such as black cotton soil and collapsible soils such as loess.

**Design of pile group**
Most of the pile foundations consist not of a single pile, but of a group of piles, which act in the double role of reinforcing the soil, and also of carrying the applied load down to deeper, stronger soil strata. Failure of the group may occur either by the failure of individual piles or as failure of the overall block of soil. The supporting capacity of a group of vertically loaded piles can, in many cases, be considerably less than the sum of the capacities the individual piles comprise the group. Group action in piled foundation could result in failure or excessive settlement even though loading tests made on a single pile have indicated satisfactory capacity in all cases. The elastic and consolidation settlements of the group are greater than those of single piles carrying the same working load as that on each pile within the group. This is because the zone of soil or rock which is stressed by the entire group extended to a much greater width and depth than the zone beneath the single pile.

**Necessity of pile groups:**
Pile groups are used when
1) Column load is heavy
2) Method of installation of piles is by driving.

**Classification of pile groups:**
Pile groups are classified as:
1) Free standing pile group
2) Piled foundation

**Free standing pile group:**
These are used where the foundation soil is expansive in nature. Pile cap does not transfer any of the column loads directly to foundation soil.

**Piled foundation:**
As pile cap is made to rest on the ground surface, it helps in transfer of part of column load directly to foundation soil. These are used in expansive soils.
**Pile spacing and pile arrangement:**

In certain types of soil, especially in sensitive clays, the capacity of individual Piles within the closely spaced group may be lower than for equivalent isolated pile. However, because of its insignificant effect, this may be ignored in design. Instead the main worry has been that the block capacity of the group may be less than the sum of the individual piles capacities. As a thumb rule, if spacing is more than 2 - 3 pile diameters, then block failure is most unlikely it is vital importance that pile group in friction and cohesive soil arranged that even distribution of load in greater area is achieved. Large concentration of piles under the center of the pile cap should be avoided. This could lead to load concentration resulting in local settlement and failure in the pile cap. Varying length of piles in the same pile group may have similar effect for pile load up to 300kn; the minimum distance to the pile cap should be 100mm. For higher than 300kn, this distance should be more than 150 mm.

In general, the following formula may be used in pile spacing:

As per IS CODE
- End-bearing: \( S = 2.5 \, d \)
- Friction piles: \( S = 3.0 \, d \)
- Piles in loose sand: \( S = 2.0 \, d \)

Where:
- \( d \) = assumed pile diameter
- \( s \) = pile centre to centre distance (spacing)

**Pile groups in cohesion less soils:**

For driven piles embedded in cohesion less soils, the capacity of the large Equivalent pile (block) will be almost always greater than the sum of the capacities of individual piles, in view of the densification that occurs during driving. Consequently, for design, the group capacity is taken as the sum of the individual pile capacities or the product of the number of piles in the group and the capacity of the individual pile. This procedure is not applicable, if the pile tips rest on Compressible soils such as clays; in such cases, the pile group capacity is governed by the shear strength and compressibility of clay soil, rather than on the Characteristics of the cohesion less soil. Bored piles or cast-in-situ concrete piles are constructed by boring a hole of required diameter and depth and pouring in of concrete. Boring is accompanied invariably by some degree of loosening of the soil. In view of this, the group Capacity of such piles will be somewhat less than the sum of individual pile Capacities typically-about two-thirds of it. It may also be taken as the sum of Individual pile capacities approximately.

**Pile groups in cohesive soils:**

When piles are driven into clay soils, there will be considerable re-moulding especially when the soil is soft and sensitive. The soil between the piles may also have since compaction cannot be easily achieved in soils of such low permeability. Bored piles are generally preferred to driven piles in such soils.
However, if driven piles are to be used, spacing of piles must be relatively large and the driving so adjusted as to minimize the development of pore pressure. The mode of failure of pile groups in cohesive soils depends primarily upon the spacing of piles. For smaller spacing’s, 'block failure' may occur, in other words, the group capacity as a block will be less than the sum of individual pile capacities. For larger spacing’s, failure of individual piles may occur; or, it is to say that the group capacity is given by the sum of the individual pile capacities, which will be smaller than the strength of the group acting as a unit or a block. The limiting value of the spacing for which the group capacities obtained from the two criteria-block failure and individual pile failure- are equal is usually considered to be about 3 piles –diameters.

**Settlement of Groups of Piles:**

The computation of settlement of groups of piles is more complex than that for a Single pile.

**Settlement of pile groups in sands**

Settlements of pile groups are found to be many times that of a single pile. The ratio, $F_g$, of the settlement of a pile group to that of a single pile is known as the group settlement ratio.

$$F_g = \frac{S_g}{S}$$

Where $F_g$ = group settlement ratio, $S_g$ = settlement of pile group, and $S$ = total settlement of individual pile

Vesic has obtained the relation between $F_g$ and $B/d$, where $B$ is the width of the pile group (centre to centre of outer most piles), and $d$ is the diameter of the pile (Only pile groups ,square in plan, are considered).

These results have been obtained for medium dense sand. For sands with other Density indices the results could be different.
Settlement of pile groups in clay

The equation for consolidation settlement may be used treating the pile group as a block or unit. The increase in stress is to be evaluated appropriately under the influence of the load on the pile group. When the piles are embedded in a uniform soil (friction and end-bearing piles), the total load is assumed to act at a depth equal to two-thirds the pile length. Conventional settlement analysis procedures assuming the Boussinesq or Westergaard stress distribution are then applied to compute the consolidation settlement of the soil beneath the pile tip. When the piles are resting on a firmer stratum than the overlying soil (end-bearing piles), the total load is assumed to act at the pile tip itself. If the piles are embedded into the firmer layer in this case, the load is assumed to be transmitted to a depth equal to two-thirds of the embedment from the top of the firmer layer. The rest of the settlement analysis procedure is applicable.

The total pressure may be assumed to be distributed on a slope of 2 vertical to 1 Horizontal, for the purpose of computation of increment of stress, in an approximate manner.

LABORATORY TESTS AND RESULTS

Characteristics of soil considered in Pile foundation design:

For design the of pile foundation we considered some of the properties of soil such as

- Liquid limit
- Plastic limit
- Optimum moisture content
- Co-efficient of cohesion
- $E_o$ value

To find the characteristics of soil we have done some tests of the soil. They are

Liquid Limit:

We have conducted Casagrande’s liquid limit test for a sample of soil.
We have obtained a liquid limit of 25% from the test.

**Plastic Limit:**

Plastic limit is the water content below which the soil stops behaving as a plastic material.

The plastic limit of soil obtained is 20%.

**Compaction factor:**

From compaction factor test we can obtain the values of Optimum moisture content, Bulk density, $\gamma$ Dry density, $\gamma_d$ of the soil.

The values obtained from compaction factor test are:

- $\text{OMC} = 8\%$
- Bulk density, $\gamma = 26.22 KN/m^3$
- Dry density, $\gamma_d = 24.28 KN/m^3$

**Type of soil:**

According to the plasticity chart, corresponding to the values of liquid limit...
=25% and plastic limit = 20%, the soil is inorganic clay with medium plasticity.

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DESIGN

A pile group to be installed in a saturated silt clay deposit \([C_U = 40 KN / M^2, \ L.L = 2.5\%, \ G = 2.7, \ NMC = 8\%, \ \gamma_d = 24.28 Kg / M^3] \)
\[\gamma = 26.22 Kg / M^3\] is designed and estimated the settlement of pile groups assuming water table at 2m depth below ground level is performed.

For piles in saturated silt clay \([C_U = 40 KN / M^2]\)

For \(\phi_u = 0\)

\[N_c = 9\]
\[N_q = 1\]

The ultimate load capacity of the pile group according to static formula can be calculated as
\[Q_u = Q_p + Q_s\]

\(Q_u =\) Ultimate failure load

\(Q_p =\) Load carrying capacity of pile

\(Q_s =\) Shaft resistance developed by friction between the pile and shaft

\[Q_p = CN_c \times A_p\]

\(C =\) cohesion co-efficient of clay

\(N_c =\) Bearing capacity factor for deep foundation

[depends on \(\frac{D}{B}\) ratio, varies from 6 to 9 ]

\[Q_p = 40 \times 9 \times A_p\]

\[A_p =\] Area of the shaft that effective in developing in skin fricition

\[A_p = \frac{\pi d^2}{4}\]

\(d = 0.40\) m

Assume dia. Of pile = 40 mm

\[A_p = 0.125 M^2\]

\[Q_p = 40 \times 9 \times 0.125\]

\[Q_p = 45.239 KN\]

\[Q_s = C_a \times A_s\]

\(C_a =\) Skin friction developed between the pile surface and clay

\[C_a = \alpha \times c'\]

\(\alpha =\) Addition factor = 0.3 (at 6 meters depth)

\(c' =\) Average cohesion along the length of the shaft ( 50 KN/M² )

Consider \( c' = 40 KN/M^2\)

\(A_s =\) area of the shaft

\[A_s = 2 \times \pi \times r \times l\]

\[A_s = 2 \times \pi \times 0.200 \times 6\]
\( A_s = 7.539m^2 \)

\( Q_s = 0.3 \times 40 \times 7.539 \)

\( Q_s = 90.4778 \text{ KN} \)

\[ Q_u = \frac{Q_p}{F.S.O} + \frac{Q_s}{F.S} \]

\[ Q_u = \frac{45.239}{2.5} + \frac{90.4778}{1.5} \]

\( Q_u = 78.414 \text{ KN} \)

Assumed load = 1500KN

Number of piles required = \( \frac{\text{load}}{Q_u} \)

= \( \frac{1500}{78.414} \)

No. of piles required = 20

Ultimate carrying capacity of 20 piles acting individually = 20 \times 78.414

= 1568.28 \text{ KN}

Minimum spacing of piles = 3 \times d

= 3 \times 0.400

= 1.2 \text{ m}

Adopt 1.5 m as spacing between piles

For piles assuming as single block

\( Q_{fg} = q_f \times A \times b_g + C \times u_g \times A_{sg} \)

Where

\( q_f = q \times C_u \)

\( q_f = 9 \times 40 \)

\( q_f = 360 \text{ KN} / M^2 \)

\[ A \times b_g = 6.4 \times 4.9 \]

\( = 31.36 \text{ m}^2 \)

\[ A \times s_g = 4 \times 6.4 \times 6 \]

\( = 153.6 \text{ m}^2 \)

\[ Q \times f_g = (360 \times 31.36) + (40 \times 1536) \]

\( = 17433.6 \text{ KN} \)

Safe load = ultimate load / factor of safety

\( = 17433.6 / 2.5 \)

\( = 6973.4 \text{ KN} \)

Hence safe load from the above two criteria is 1568.28 KN which > 1500 KN

The allowable load carrying capacity of pile from block failure criteria is 6973.4 KN

Hence individual block failure governs the design
Design of pile cap:

Consider size of pile cap = 7.5 X 6.0 m

Bending movement at face of column = (5 x 1500)/20 + (0.4+1.5)/6
= 118.75 KN-M Factored bending movement
= 118.75 x 1.5 = 178.125 KN-M

Required depth,

Bending movement = 0.138 $f_{ck}$ bd^2

$142.5 \times 10 \times 6 = 0.138 \times 20 \times 7500 \times d^2$

$d^2 = (142.5 \times 10^6)/20700$

$d^2 = 6884.05$

But adopt, $d = 82.9$mm

Overall depth = 500mm

AREA OF TENSION STEEL:

Bending moment $BM, = 0.87fyAstd\left(1 - \frac{fyAst}{fckbd}\right)$

$178.1210^6 = 0.87 \times 415Ast \times 450 \left(1 - \frac{415Ast \times 1000 \times 450}{7.4916Ast^2 - 162.47 \times 10^3Ast + 178.125 \times 10^6} = 0\right)$

$\therefore Ast = 1158.21mm^2$

Assuming 20mm diameter bar,

Area of each bar $a_{st} = \frac{\pi}{4}d^2$

$= \frac{\pi}{4} \times 20^2 = 314.15mm^2$

No of bars $\frac{Ast}{ast} = \frac{1158.21}{314.15} = 3.6$

= say 4 nos.

Minimum area of steel = 0.12% bD

= $\frac{0.12}{100} \times 1000 \times 500$

= 600 mm^2

Hence provide 4 nos. of 20mmØ bars for 1m width of pile cap.

CHECK FOR SHEAR

Two-way shear:

Shear force $(V_u) = 1.5 \times 1500 \times 10^3$

= 2250 X $10^3$ N

Nominal shear stress $(\tau_v) = \frac{V_u}{bd}$

$= \frac{2250 \times 10^3}{6000 \times 450}$

$\tau_v = 0.833 n/mm^2$

Shear strength of $M_{20}$ concrete $= k_s \times \tau_c$

$k_s = 0.5 + \beta_c \quad (\beta_c = 1)$

$= 0.5 + 1 = 1.5$

$k_s > 1.0$

$\tau_c = 0.25\sqrt{f_{ck}}$

$= 0.25\sqrt{20} = 1.118 N/mm^2$

$\tau_c > \tau_v$

Hence safe in two – way shear.
One-way shear:

Shear force at column face = \( 5 \times \frac{1500}{20} \)  
\[ = 375 \text{ KN} \]

Factored shear load \( (V_f) = 1.5 \times 375 \)  
\[ = 562.5 \text{ KN} \]

Shear stress \( (\tau) = \frac{v_u}{bd} \)  
\[ = \frac{562.5 \times 10^3}{7500 \times 450} = 0.166 \text{ NJ/mm}^2 \]

Permissible shear according to \((100 \text{ Ast/}bd\))
\[ = \frac{100 \times 1158.21}{1000 \times 450} \]
\[ = 0.257 \text{ N/mm}^2 \]
\[ \tau < \tau_c \]

Hence depth is safe in one-way shear

Settlement of pile group in saturated clay:

Given that liquid limit = 25%
Natural moisture content \( (W) = 8\% \)
Specific gravity \( (G) = 2.5 \)

\( \gamma = 26.22 \text{ kn/m}^3 \)  \( \gamma_w = 9.81 \text{ kn/m}^3 \)

\[ \gamma_{sat} = \frac{(1+w)G\gamma_w}{(1+WG)} \]
\[ = \frac{(1+0.08) \times 2.7 \times 9.51}{(1+0.08) \times 2.7} \]
\[ = 23.52 \text{ kn/m}^3 \]

Water table is at 2m below ground level

Compression index \( Cc=0.009(\text{L.L}-10) \)
\[ = 0.009(25-10) = 0.135 \]

Change in void ratio, \( e_0 = wG \)
= 0.008×2.7 = 0.216

As pile group is friction pile group, the load is considered to be spread against 2V:1H

1st Layer

\[ \sigma_{o1} = 2 \times 24.28 + 1(23.52 - 9.81) + 3.5(23.52 - 9.81) \]

=110.255KN/m³

Cross sectional area at A= (B+Z₁)×(L+Z₂)

= (6.4+2.5)×(4.9+2.5)

=8.9×7.4

\[ \Delta_1 = \frac{1500}{8.9×7.4} = 22.77KN/m³ \]

2nd Layer

\[ \sigma_{o2} = 2 \times 24.28 + 1(23.52 - 9.81) + 6(23.52 - 9.81) + 2.5(23.52 - 9.81) \]

= 178.805KN/m³

Cross sectional area at B= (B+Z₁)×(L+Z₂)

= (6.4+2.5)×(4.9+2.5)

=8.9×7.4

\[ \Delta_2 = \frac{1500}{8.9×7.4} = 22.77KN/m³ \]

Settlement of soil, \( \Delta S_i = C_c \frac{H_i}{1+e_0} \log \left( \frac{\sigma_{o_i+\Delta_1}}{\sigma_{o_i}} \right) \)

\[ \Delta S_1 = 0.135 \times \frac{5}{1+0.216} \log \left( \frac{110.255+22.77}{110.255} \right) \]

=0.045m

\[ \Delta S_2 = 0.135 \times \frac{5}{1+0.216} \log \left( \frac{178.805+22.77}{178.805} \right) \]

=0.029m

Total settlement of pile group = \( \Delta S_1 + \Delta S_2 \)

= 0.045+0.029

= 0.074m

RESULTS AND FINDINGS

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CONCLUSIONS

As piles are the main load bearing members in the structures, hence they vital part in construction. The dead load of structures in considerably reduced by using pile foundation by the way of reducing the thickness of walls. Hence different modes of piles are adopted for different types of soil based on soil properties. Hence an attempt is made in this study to evaluate the parameters of design and also to focus the design criteria.

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