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Analysis of Pile Group under Vertical Loading in Clay and Sand using FEM

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Abstract: Pile foundations are the preferred choice for supporting heavy structures when hard bedrock is situated at considerable depths beneath weak soil conditions. The ultimate load-carrying capacity of these piles hinges on several factors, including material composition, soil properties, geometric attributes, and the mechanism of load transfer (end bearing or friction). This research focuses on investigating the load-bearing capacity and settlement characteristics of end-bearing piles in both soft clay and medium sand. The study explores these parameters by varying pile diameter, length, and spacing within a pile group. Utilizing ANSYS for analysis, the study draws comparisons between clay and sand. The study's findings reveal that clay exhibits a higher load-carrying capacity compared to sand. Additionally, it highlights that sand experiences significantly greater settlement compared to clay when an optimal pile diameter of 0.4 meters and a length of 4 meters are employed.
Keywords: Pile foundation, End bearing, Friction piles, Pile group, ANSYS.

I. INTRODUCTION

Structurally designed structures, for example, high rise structures, spans, flyovers, dams, holding dividers get extreme backing from soil. Soils must have safe bearing capacity to withstand the superstructural load coming over it. Foundation acts as the interface between the superstructure and the soil and it effectively transfers the structural load to soil.

Foundation is the substructure which transfers the load from superstructure to soil in such a way that the soil supporting the structure is not heavily stressed and finds no excessive settlement of structure. Foundation not only carries the structural load but also resists wind and seismic forces coming over it. Selection of type of foundation depends on types and magnitude of loads acting on the structures, nature and strength parameters of the soil bearing the loads and the type of superstructure. They are broadly classified into Shallow and Deep foundation. Shallow foundation is one where the structural load is transferred to earth very near the surface. The depth of shallow foundation is either less than or equal to its width. This kind of foundation can be used where the bearing capacity of soil is good enough to carry the superstructural load and allowable settlement is considerable. Deep foundation is generally used where bearing capacity of soil is low and it has weak compressible layers, the depth of foundation is greater than the width of foundation. The important types of deep foundations are pile foundation, pier foundation and well foundation. Whenever it becomes difficult to provide suitable shallow foundation to carry the load from superstructure in that situation deep foundations are provided.

Pile foundation is usually a long cylindrical member inserted into earth to act as a firm support for structures. This type of foundation is used to transfer the loads to deeper earth where soil has good bearing capacity or pile reaches the hard strata. In some situations, single pile alone cannot take the load of entire structure where piles are provided in a group. Pile group is a combination of number of piles having a pile cap so that whole pile system acts as a single component. The load acting on pile cap distributes among all the individual piles. Piles in group are driven in defined pattern to carry structural loads effectively. The ultimate load carrying capacity of pile group depends on length, diameter and spacing of piles. For friction piles used in clay, friction between piles and surrounding soil plays an important role in determining ultimate load capacity and settlement.

A. Efficiency of Pile Group

The load-carrying capacity of a pile group may be equal to or less than the sum of carrying capacities of individual piles. The former holds true in case of friction piles, driven into progressively stiffer materials. To estimate bearing capacity of friction piles, a reduction factor is multiplied to efficiency of pile group.

$$Q_{ug} = nQ_{up}\eta_g$$

Where Q_{ug} = load carried by group of pile.
Q_{up} = load carried by each pile.
n = number of piles.
η_g = efficiency of pile.

The important factors that affect efficiency of pile group are the characteristic features of pile like length, spacing between piles, diameter, material of pile, number of piles.

B. Settlement in Pile Group

Settlement of pile group in clay is calculated by assuming clay present between top of piles and their lower third point is incompressible and that is applied to soil at this lower third point of pile. The load acting is assumed to be distributed uniformly and spreads at an angle of 30° with vertical settlement is given by

$$s \quad \frac{HC_c}{1+e_0}\log_{10}\left(\frac{\sigma^0+\Delta\sigma}{\sigma^0}\right)$$

Where, s = primary settlement
H = height of the layer
C_c = pressure index
e_0 = void ratio
σ^0 = overburden pressure
$\Delta\sigma$ = increase in effective stress

C. Methods of Analysis

Functional approximation method requires the selection of function among well defined classes which suits the target problem in the specific way. Approximation method is not applied for practical problem cases as there are no ideal guidelines for the selection of constraints.

Finite difference method solves the differential equations only at nodes by ensuring continuity but at grid lines as there are no nodes, no equations are solved and present outside the boundaries are also not analysed. It is not possible to analyse the engineering problems with irregular shapes, anisotropic materials and complex boundary conditions.

Finite Element method (FEM) is a procedure for finding inexact answers for limit esteem issues for halfway differential conditions. This technique utilizes subdivision of an entire issue area into less complex parts called limited components. From this meshing methodology of FEM precise representation of complex geometry, consideration of different material properties, and easy representation of total solution and capture of total load are effective. Some assumed simple functions are chosen to approximate the variation of each nodal displacement called displacement models. Finite element analysis needs the use of computer, software like ANSYS, PLAXIS, ABAQUS, NISA, STAAD.Pro and others are developed based on finite element method with required needs and useful facilities.

ANSYS was developed using finite element analysis tool for structural analysis including linear, non-linear, static and dynamic studies founded in 1970. It is sophisticated Finite element software ANSYS WORKBENCH 14.5 is used to analyse grouped pile foundation. It is used to analyse complex engineering problems with advanced facilities in computer. Material properties and field conditions can be incorporated easily. Modelling, meshing, modification of geometry and analysis of complicated structure is also easy.

II. LITERATURE REVIEW

Anusha George and Lovely [1] conducted work on “Analysis of pile subjected to lateral loading in clay” to understand its behaviour when subjected to lateral loading in clay and sand to evaluate the deflection using ANSYS 14.5. In their study, soil was modelled as linear springs using COMBIN14 element Winkler method was adopted for analysis of lateral loaded piles. They concluded that deflection is more in clayey soil than in sand.

Chaudhari and Kadam [2] studied effect of piled raft foundation using ANSYS considering soil structure interaction to check the influence of pile length on behaviour of high-rise buildings under vertical loading. They concluded that settlement and load carrying capacity depends on type of soils and usage of different shapes of pile models like U shape, V shape that is by varying length of pile reduces settlement and also the quantity of concrete.

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Kanimozhi [3] directed study keeping in mind the load sharing and settlement reduction behaviour of circular piled raft resting on sand, 1 g model tests on Pile group in sand of various thickness the impact of heap parameters, for example, length, measurement and number of heaps on burden sharing and settlement lessening are brought out. Heap lengths of 0.6 times the measurement of pontoon gives off an impression of being compelling in lessening the settlement of heaped flatboat in homogenous sand. Finite element analysis using MISO idealization for soil compared well with the experimental findings. At lower settlements piles shared more load whereas raft shared higher load with increase in settlement.

Naveen Kumar [4] conducted numerical analysis of piled raft foundation using FEM with interaction effects and concluded that pile spacing affects maximum settlement and load carrying capacity greatly, increasing pile number decreases total and ultimate settlement and increase in load carrying capacity. Soil type is a major factor affecting load settlement behaviour and concluded that dense sand produces better results than loose sand.

Reza Ziaie Moayed and Meysamsafavian [5] studied behaviour of piled raft with varying pile diameter and evaluated settlement under unequal point loads in gravelly soils by using ANSYS 14.5. Gravelly soil was idealized by Drucker-Prager elastoplastic continuum and they concluded that increase in pile diameter decrease the amount of settlement in foundation.

Srilakshmi and Chethan Gowda [6] conducted behavioural studies on two-dimensional plain strain finite element model of piled raft foundation using ANSYS software by varying number, length, diameter of pile and size, thickness of raft to measure ultimate load carrying capacity and settlement of foundation in sand.

They concluded that increase in raft size and pile length increase ultimate bearing capacity of foundation They found that there was a reduction in settlement linearly with increase in the diameter of the pile.

SriLakshmi and Darshan Moudgalya [7] conducted parametric study on two-dimensional finite element modelling of pile raft foundation in sand under plain strain using ANSYS. They have varied pile diameter and found that ultimate load and settlement increased with increase in pile diameter. They also concluded that variation in pile length had no much significant influence on load carrying capacity and combination of piles of different diameter with pile of greater diameter at the centre increased ultimate load carrying capacity.

Sri Lakshmi and Yashwanth [8] conducted parametric studies on pile group under vertical loading using finite element software ANSYS.

They have done the analysis by varying pile length, diameter and spacing of pile and pile cap thickness and it was concluded that increase in the diameter, spacing and pile cap thickness found to have good ultimate load bearing capacity whereas change in the length had no much significant effect on either settlement or ultimate load carrying capacity. They have also concluded that increase in spacing reduces the pile-to-pile interaction and thus increase load carrying capacity, but larger spacing between piles is not recommended as it increases pile thickness and is uneconomical.

Huchegowda et al. [9] employed the finite element method (FEM) to assess the lateral load capacity of piles within a range of diameters spanning from 0.15 to 2.0 meters, all embedded in layered soil. The performance of the pile-soil system is contingent upon the specific properties of both the soil and the pile itself.

They demonstrate that the lateral capacity of a pile foundation is intricately tied to several factors, including the pile's cross-sectional area and material composition, the boundary conditions applied at the pile's top and bottom, as well as the horizontal subgrade modulus of the topsoil, which is 6 times the pile's diameter (6D, where D represents the pile's diameter).

Notably, as the diameter of the pile increases, ranging from D to 2D, the lateral capacity of the pile experiences a remarkable 2.5-fold increase.

Al-Qaissy et al. [10] employs a three-dimensional analysis using the finite element method to predict how pile foundations respond to dynamic loads. A specific case study is conducted to explore the impact of soil particle size, pile length, spacing between piles, and pile cap size on the dynamic behavior of pile foundations. The findings reveal that the highest amplitude of displacement in pile foundations subjected to dynamic loads is observed in loose sand, when compared to other types of sand. Furthermore, it is observed that an increase in pile length results in a reduction in displacement amplitude due to the increased mass of the foundation.

III.EXPERIMENTAL METHODOLOGY

In this work FEM software ANSYS is used to analyse the pile group for different parameters. The behaviour of pile group under vertical loading in clay and sandy soil and influence of pile behaviour by changing the pile diameter, pile length and spacing between piles are studied. The schematic sketch and geometrical model of Pile cap modelled using ANSYS is shown in Figure 1.

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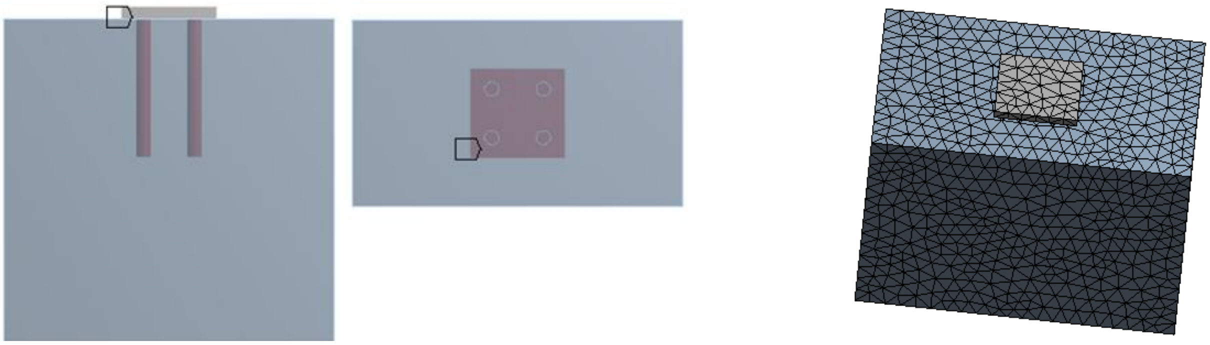

(1a) (1b)

Fig. 1 Schematic sketch of pile group (1a); Discretised geometrical model (1b)

IV. PARAMETRIC STUDIES IN STIFF CLAY

A. Effect of Pile Diameter

The influence of pile diameter has been studied keeping all other parameters like length, spacing and thickness of pile cap constant. The load carrying capacity and equivalent settlement are observed for varying pile diameters in this study. Properties of pile and clay are given in Table I.

TABLE I
PROPERTIES OF PILE AND CLAY

Properties	Pile	Clay
E (MPa)	30000	150
μ	0.15	0.3
P (kg/m^3)	2500	1190
C (kPa)	-	45

The influence of pile diameter on the load carrying capacity and settlement of pile group by keeping the other parameters constant (3m length, 2.5d spacing) is studies and the results obtained after the analysis is shown in Table II.

TABLE III
VALUES OF ULTIMATE LOAD AND SETTLEMENT

Pile diameter (m)	Ultimate load (kN)	Settlement (mm)
0.30	300	55.142
0.35	315	44.601
0.40	397	39.234
0.45	429.42	49.901
0.50	461.22	53.645

1) It is observed that when pile diameter increases from 0.30m to 0.50m, the ultimate load increases by 35%, whereas the corresponding settlement decreases by 40.7% respectively.
2) It is very clear that when the diameter increases, the surface area and the surface friction resistance also increase and even the end bearing resistance also increases. So, the diameter will show significant influence on ultimate load carrying capacity.
3) The rate of increase in ultimate load carrying capacity has been observed as maximum when the diameter increased from 0.35m to 0.40m and it is measured 33%.
4) Even it is observed that settlement is less at the diameter of 0.4m relatively with other diameters and the ultimate load is approximately 400 kN and settlement is 39.23 mm. So we can select 0.4m as optimum pile diameter from economic point of view also.

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The displacement contours in clayey soil for pile diameters of 0.30m and 0.50m is as shown in Figure 2.

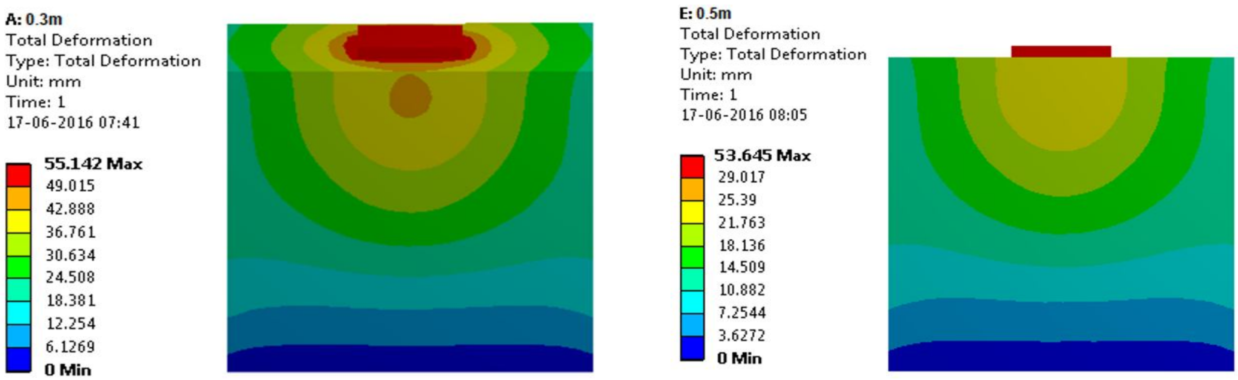

Fig. 2 Displacement contours in Clay for Pile diameter of 0.30m and 0.50m

B. *Influence of Pile Length*

The effect of the pile length has been analysed by keeping other parameters like spacing 2.5d and thickness of pile cap 250mm constant with optimum pile diameter 0.4m. The results obtained after the analysis is shown in Table III.

TABLE IIIII
VALUES OF ULTIMATE LOAD AND SETTLEMENT WITH VARYING PILE LENGTH

Pile length (m)	Ultimate load (kN)	Settlement (mm)
3	183.16	34.475
3.5	225.17	36.253
4	285.83	38.391
4.5	340	40.266
5	389	41.242

1) It is found that increase in pile length from 3m to 5m, the ultimate load carrying capacity was increased by 52.9% and the corresponding settlement was increased by 16%
2) It is very clear that when the length increases, the surface area and base area also increases thus the ultimate load carrying capacity also increases but is comparatively less than in case of pile diameter as the base friction and perimeter is less in case of varying length.
3) The rate of increase in ultimate load carrying capacity can be observed when the length increased from 3.5m to 4m and is measured as 22%, so 4m is taken as optimum pile length and can be used from economic point of view.

C. *Influence of spacing of piles in Pile group*

The influence of pile spacing is studied by keeping the length of pile 4m and pile diameter 0.40m as constant. The results after the analysis is shown in Table IV.

TABLE IVV
VALUES OF ULTIMATE LOAD AND SETTLEMENT

Pile spacing (m)	Ultimate load(kN)	Settlement (mm)
2d	429.41	44.17
3d	278.71	33.35
3.5d	230.59	31.78

With the increase in spacing, the interface of piles is getting reduced, so the load carrying capacity of pile group is also decreasing. So, it can be concluded that 2d is better spacing which gives more ultimate load carrying capacity for pile diameter 0.4m and length of 4m.

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V. PARAMETRIC STUDIES IN MEDIUM SAND

A. Effect of Pile Diameter

The ultimate load carrying capacity and corresponding settlement are observed for varying pile diameters in this study. Pile and sand properties are given in Table V.

TABLE V
PROPERTIES OF PILE AND SAND

Properties	Pile	Sand
E(MPa)	30000	40
μ	0.15	0.3
ρ(kg/m3)	2500	1900
c(kPa)	-	10
Φ	-	30
Ψ	-	9

The effect on ultimate load carrying capacity of pile group is analysed under the varying pile diameter by keeping pile length 3m, spacing 2.5d and pile cap thickness 250mm are constant. The analysis results are shown in Table VI.

TABLE VI
VALUES OF ULTIMATE LOAD AND SETTLEMENT WITH VARYING PILE DIAMETER

Pile spacing (m)	Ultimate load (kN)	Settlement (mm)
0.30	72.106	53.834
0.40	118.080	41.769
0.50	180.628	73.968

1) It is observed that when pile diameter increases from 0.30m to 0.50m, the ultimate load increased by 60%, whereas the corresponding settlement increases by 27% respectively.
2) The rate of increase in ultimate load carrying capacity can be observed when the diameter increased from 0.3m to 0.4m and is measured as 38%, so we can take 0.40m as optimum pile diameter from economic point of view.

The displacement contours in clayey soil for pile diameters of 0.30m and 0.50m is as shown in Figure 3.

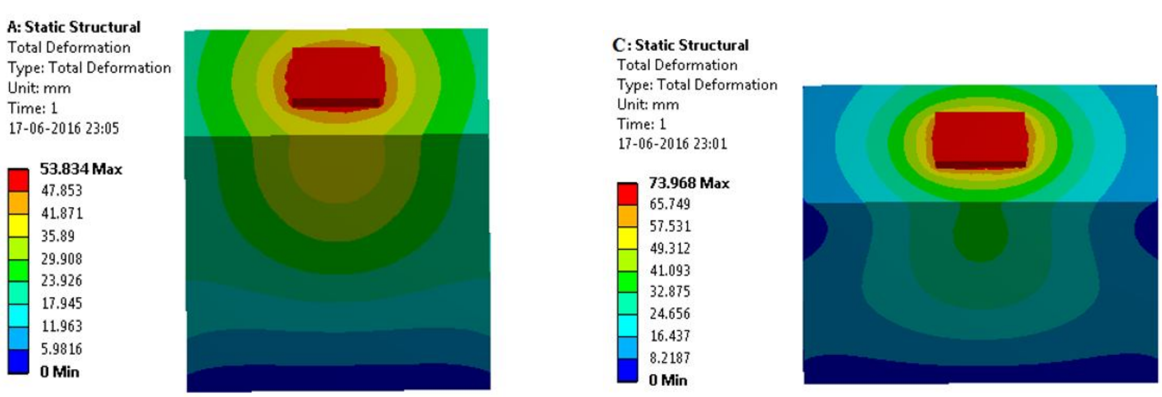


Fig. 3 Displacement contours in Sand for Pile diameter of 0.30m and 0.50m

B. Influence of Pile length

The influence of pile length on the load carrying capacity of pile group by keeping the other parameters optimum diameter 0.40m and spacing 2.5d as constant has been studied. The analysis results is as indicated in Table VII.

TABLE VII
VALUES OF ULTIMATE LOAD AND SETTLEMENT WITH VARYING PILE LENGTH

Pile spacing (m)	Ultimate load (kN)	Settlement (mm)
3	118.080	60.691
4	137.114	57.319
5	156.125	52.977

1) It is found that increase in pile length from 3m to 5m, the ultimate load bearing capacity increase by 24% and the equivalent settlement decrease by 12.7%
2) The rate of increase in ultimate load carrying capacity can be observed when the length increased from 3m to 4m and is measured as 14%, so 4m is taken as optimum pile length and can be used from economic point of view.

C. Influence of spacing of Piles in Pile group

The influence of pile spacing is studied by keeping the length of pile 4m and pile diameter 0.40m as constant. The analysis results are shown in Table VIII.

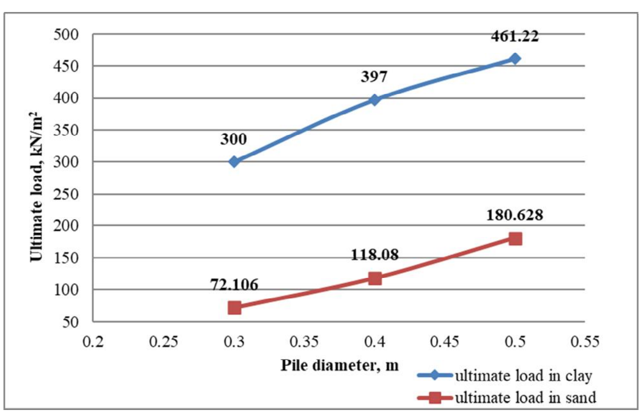
TABLE VIII
VALUES OF ULTIMATE LOAD AND SETTLEMENT WITH VARYING PILE LENGTH

Pile spacing (m)	Ultimate load (kN)	Settlement (mm)
2d	187.11	64.433
3d	135.62	52.804
3.5d	126.24	49.827

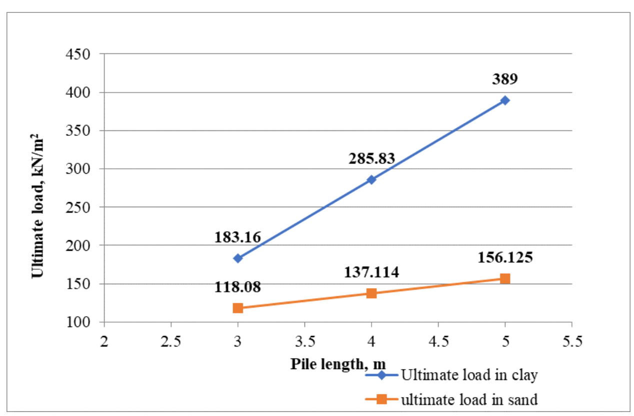
With the decrease in spacing, the interface of piles is getting reduced, so the load carrying capacity of pile group is also decreasing. So, it can be concluded that 2d is better spacing which gives more ultimate load carrying capacity for pile diameter 0.40m and length of 4m.

D. Evaluation of Values for Clay and Sand

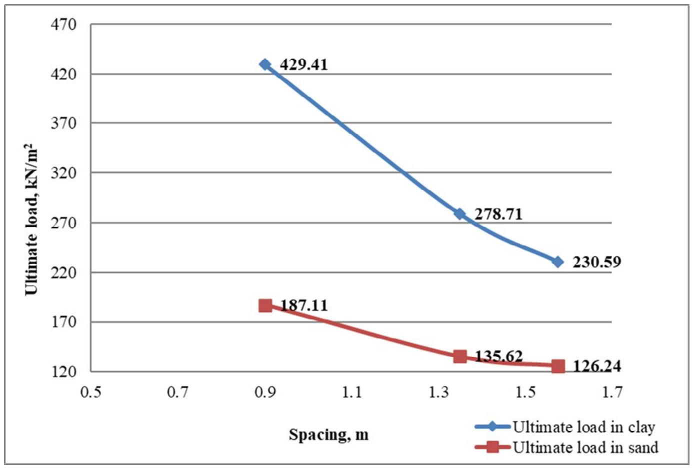
The behaviour of foundation system in clay and sand are compared in this section.



4a



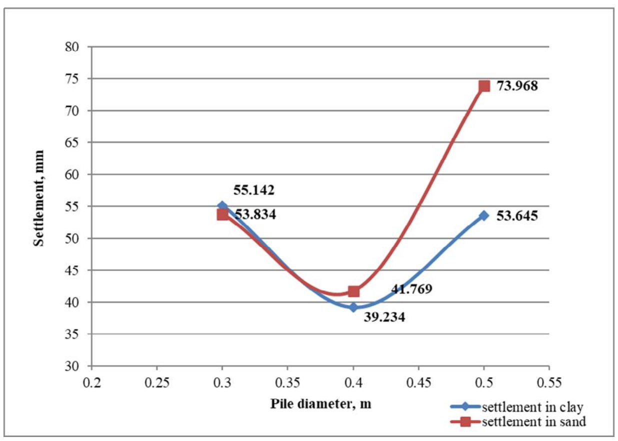
4b

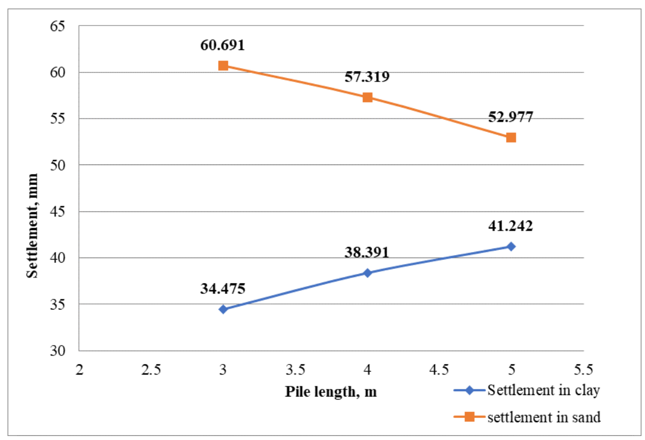


4c

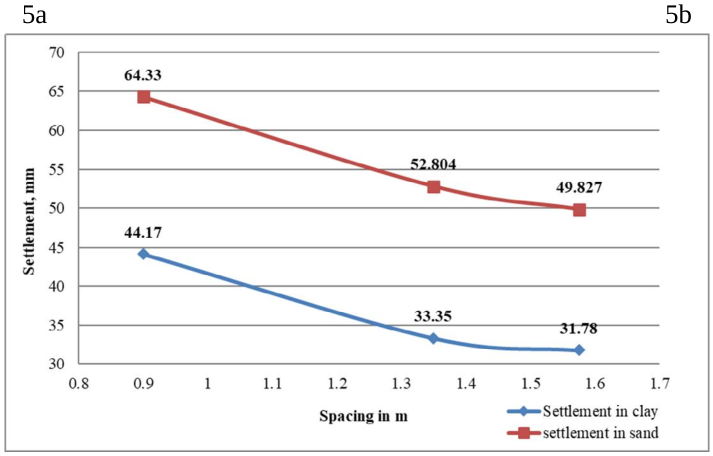
Fig. 4 Ultimate load on piles in Clay soil due to variations in Pile diameter (4a), Pile length (4b) and Spacing (4c).

From the present work, it is clearly observed that the load carrying capacity of pile group is more in the stiff clay than in the case of medium sand. So, it shows that cohesion plays predominant role on load carrying capacity of pile group.





5a 5b



5c

Fig. 5 Ultimate load on piles in Sandy soil due to variations in Pile diameter (5a), Pile length (5b) and Spacing (5c).

It is clearly observed that the settlement of foundation system is more in the medium sand than in the case of stiff clay. Presence of voids between sand particles bonding of loose particles may result in more settlement.

VI. CONCLUSIONS

In this work behavior of pile group was analyzed for different diameters, lengths and spacing using finite element software ANSYS workbench 14.5.

1) From the analysis it is found that increase in pile diameter from 0.30m to 0.50m in cohesive soil (clay), increases the ultimate load carrying capacity of pile group increases by 35%.
2) Settlement was found to reduce by 20% at 0.40m diameter of pile but was increased at 0.50m pile diameter by 16%.
3) As the pile length increase from 3m to 5m, ultimate load bearing capacity increase by 53% and the equivalent settlement was boosted by 17%.
4) Increase in pile spacing from 2d to 3.5 d, the ultimate load carrying capacity was decreased by 46% with reduction in amount of settlement by 28%.
5) In sand, increase in pile diameter increases the ultimate bearing capacity by 60%, with the increase in settlement by 27%.
6) When the pile length was increased from 3m to 4m, its ultimate bearing capacity was increased by 24% but it had no much significance on settlement.
7) Increase in pile spacing increase the decrease the ultimate load carrying capacity by reducing the settlement in the pile group foundation.
8) Ultimate load carrying capacity of clay was found more than that of sand at 0.40m pile diameter, 4m pile length and 3d pile spacing and corresponding settlement is comparatively less than that of sand.

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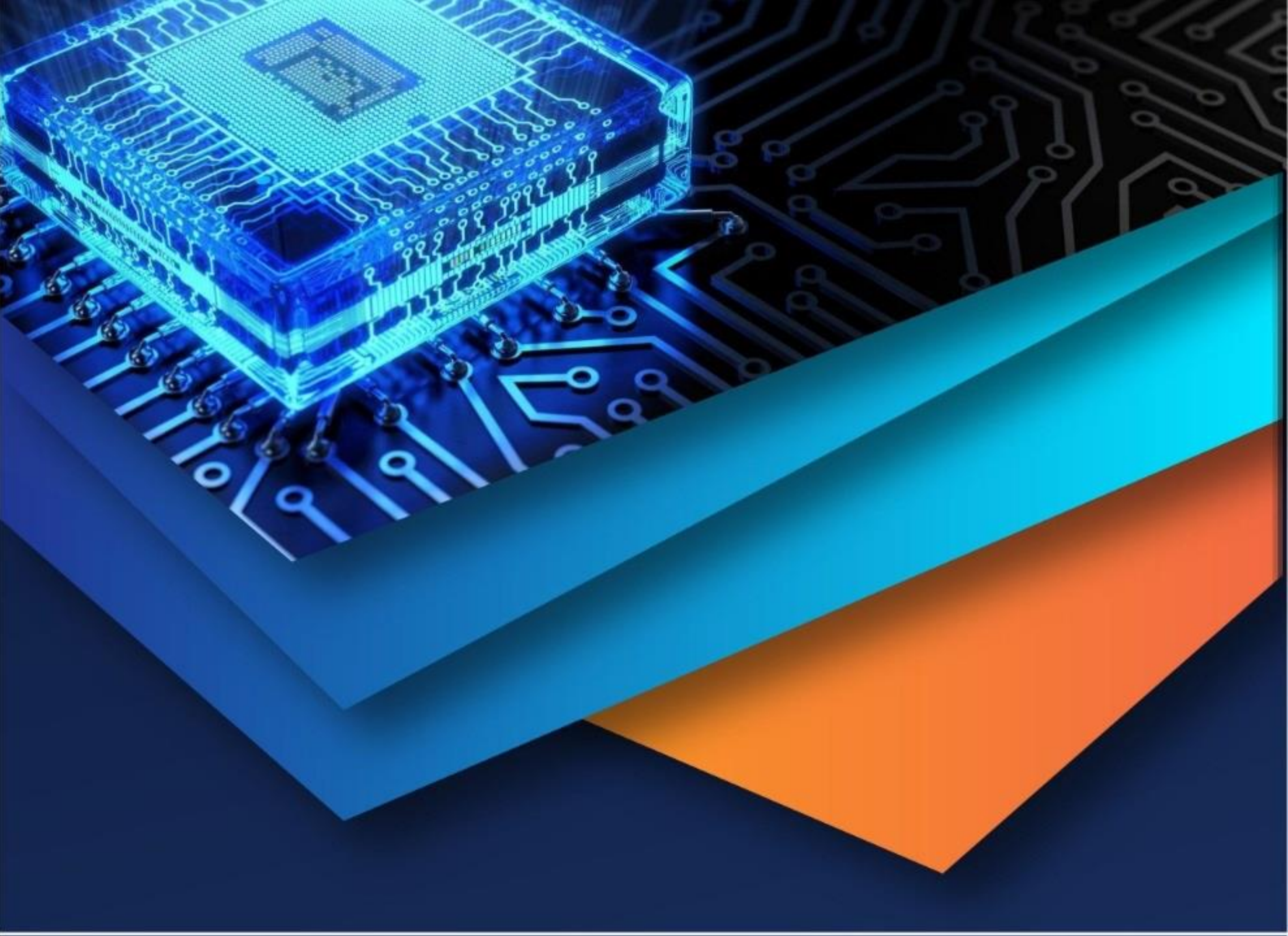

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