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Strength and Stability analyses of Straight Shafted Pile foundation in cohesion less soil conditions using Finite Element Method.

Yogesh K S, Channabasava

Abstract: ***Foundation is an arbitrator structure to transfer the load from superstructure to the soil effectively, without any failure for both the structure and the soil. Pile foundations are meant to transfer the enormous load to the deeper depth. Straight shafted file are widely used in cohesion less soil conditions than in expensive soils. Now days these piles are designed not only to transfer the load, as a group they act as settlement reducers. These piles may be cast in situ or precast, and are required as the primary foundation support for a wide range of buildings, towers, dams and other massive structures. Analysis of pile-soil interaction is more complicated, practical testing to analyse the strength and settlement of each pile is cumbersome. The pile capacity is often difficult to assess even by means of a static loading test. The oldest approach is simply to state that the ultimate load in a test is equal to the applied load when the movement of the pile head is 10 percent of the pile toe diameter, so a proper and reliable analytical method was in urgent need to be developed. In this study analysis of straight shafted pile for has been carried out under cohesion less soil conditions (sand) by varying the length and diameter, to determine the ultimate strength and maximum displacement. For the suitability of natural condition non linear analysis need to performed implementing all the non linear characteristics of soil and linear characteristics of pile. So one of the Finite Element software's ANSYS have been used foe the analysis. Two dimensional axisymmetric model, with pile as linear and pile soil interaction as nonlinear behaviour was considered for the modelling. Nonlinear elastic- perfectly plasticity behaviour of pile-soil interaction was assigned using Drucker-Prager constitutive model, where in interaction was modelled using Targe 169 and Conta 172 elements to produce best interaction and accurate results. Here nonlinear analysis with Incremental – iterative mixed method was carried out to obtain accurate results for axial compression loads, applied on each node. It has been identified that the pile capacity and settlement increases with increase in length and diameter of pile. But the diameter of the pile has more significance in load carrying capacity, pile capacity increases more with the increases in diameter than increases in length of the pile. The work has been concluded admitting 4m length and 0.4m diameter pile combination showed a most optimum result as compared to other combinations in case of cohesion less soil conditions.***

Index Terms: Stright Shafted Pile, Cohesion less soil, Finite Element Method, Drucker-Prager Constitutive Model, Incremental – iterative mixed method.

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I. INTRODUCTION

A foundation is an integral part of a structure and transmits its weight to the underlying soil or rock. It supports superstructure weight, resists horizontal forces from the adjacent ground. The stability of a structure depends upon the stability of the supporting soil. A building foundation must be stable against shear failure of the supporting soil and it must not settle beyond a tolerable limit to avoid damage to the structure. Foundations are mainly divided into two categories namely, shallow foundations and deep foundations. Shallow foundations are meant to transfer the load to the soil at shallow depths. These are economical foundations when soils of good bearing capacity are available at shallow depth. Deep foundations are meant to transfer the load to the deeper depth. The structural loads may be transferred to deeper firm strata by means of piles. Piles are relatively long, slender members that transmit foundation loads through soil strata of low bearing capacity to deeper soil or rock strata having a high bearing capacity. They are used when it is desirable to transmit loads to strata beyond the practical reach of shallow foundations.[01]

II. LOAD TRANSFER MECHANISM

The most predominant component on which load carrying capacity depend is the method of installation and the type of soil encountered. The bearing capacity of a pile is the combination of shaft and toe capacity. When the load is applied on the pile, the shaft capacity is generated when soil particles moves away from the pile in cohesion less soil condition and when soil particles moves towards the pile in case of cohesive soil conditions. The above phenomenon is due to the mobilization of shear. When the shaft is pushed inside the ground, positive shaft resistance is mobilized for compression loading. Similarly negative shaft resistance is mobilized for tension loading. The pile capacity (the ultimate load) is more difficult to identify by means of a static loading test. The oldest approach is simply stated that the ultimate load is equal to the applied load when the movement of the pile head is 10 percent of the pile toe diameter.[02]

III. LOAD CARRYING CAPACITY OF PILE FOUNDATIONS

When a single pile of uniform diameter D and length L driven into a homogeneous mass of soil of known physical properties and subjected to a static vertical load on the top.

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The Ultimate load applied on the top of the pile is Q_u, out of which a part of the load is transmitted to the soil along the length of the pile and the remaining part of load is transmitted to the pile base. The load transmitted to the soil along the length of the pile is called the ultimate friction load or skin friction load Q_f and that transmitted to the base is called the base or point load Q_b. The total ultimate load Q_u is expressed as the sum of these two i.e, [02]

$$Q_u = Q_b + Q_f$$

The ultimate bearing capacity (Q_U) of piles in cohesionless soil is given by the equation, [03]

$$Qu = A_p\left(0.5D\gamma N_\gamma + P_D N_q\right) + KP_D \tan\delta\, A_s$$

Where

- A_P = cross-sectional area of pile toe in m^2.
- D = pile diameter in m.
- γ = effective unit weight of soil at pile toe in kN/m^3.
- P_D = effective overburden pressure at pile toe in kN/m^2.
- N_γ and N_q = bearing capacity factors depending upon the angle of internal friction Ø.
- K = coefficient of earth pressure.
- δ= angle of wall friction between pile and soil, in degrees (Taken equal to 2Ø /3)
- A_s = surface area of pile m^2

IV. LITERATURE REVIEW

In the literature study, analyses of straight shafted pile had been carried out. Abdul muqtadir [04] carried out a load deformation test on straight shafted pile in sand (cohesionless soil). He developed a non linear incremental finite element procedure to analyze the axially loaded piles in sand. The pile shaft was idealized using beam or column elements and the soil is modeled as a series of independent springs. As per the analysis of M. S. Ranadive it has been proven that, the behavior of the pile soil system subjected to the axial load in elastic range behavior is important for finalizing the conventional design system [05]. Shaymaa Tareq Kadhim showed a proper procedure for the analyses of a straight shaft pile under clay soil condition [06], Three dimensional SOLID45 and SOLID65 elements were used to model the soil and the reinforced concrete pile respectively. Drucker- Prager model is chosen to simulate the non-linear elastic-plastic clayey soil. As per the experimental results of pullout test conducted by Srirama Rao it can be concluded that, pullout load tests that granular pile anchors of larger surface area resulted in higher pullout capacity and increase in diameter and length of granular pile anchor also increases the uplift capacity[07].

V.METHODOLOGY

Understanding thorough litrature's, it can concluded that there is a need for proper and reliable analytical methodology for the analysis and design of straight shafted pile. Analytical method should provide accurate solution including all the natural parameters of soil and pile. Experimental methods are used to test the prototypes or full scale models. However experimental methods are not economical and are not feasible in certain cases. Numerical methods are the most preferable techniques for engineering analysis which can treat complex geometries also. Finite element method is one of the effective and economic numerical methods for analyzing foundations. In this work, analyses of pile foundation were done using one of the powerful Finite Element Software's ANSYS. Methodology involved providing appropriate Plane element to pile and soil. Pile-Soil interaction should be interfaced with target and contact element. Further the linear material property for the pile like Young's modulus, Poisson's ratio, density of concrete and non linear properties of soil like Young's modulus, Poisson's ratio, density of soil, Cohesion, friction and flow angle were assigned through Druker-Prager constitutive model for the cohesion less soil conditions. Solid model is prepared according to required size of pile and soil. Free mesh was done for entire model after dividing into required number of elements. Contact elements have been modeled at the interface of pile and soil, to induce the surface friction at the interface. Boundary conditions on nodes were applied to incorporate field. Further, load on each nodes were applied. A non linear analysis of soil and pile is carried out using incremental iterative mixed method for accurate result. Finally the ultimate load carrying capacity of file and its corresponding settlement for different cases were observed from the analysis

A. Elements used for Soil and Pile.

In this analysis the pile was modeled as a linear isotropic and the soil was modeled as an elasto-plastic. For both pile and soil, PLANE82 was used as the element type. The contact elements CONTA172 (for the soil) and TARGET169 (for pile) at soil-pile interface were considered for the analysis. PLANE82 is suitable for modeling pile foundation. It is a higher order version of the 2-D, four-noded element (PLANE42). The 8-noded element is defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The 8-noded elements have compatible displacement shapes and well suited to curved boundaries as shown in figure.1. [08]

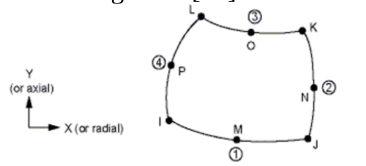

Figure.1. Plane 82 element [20]

B. Drucker-Prager model

Drucker Prager is an elasto-plastic constitutive model which is relatively well suited for granular soil. In addition to linear material properties such as Young's modulus (E) and Poisson's ratio (μ), we can also input material cohesion strength (c), Friction angle (Ø), flow angle (ψ) parameters are Drucker-Prager model. [08]

C. Elements used for Interface between Soil and Pile

TARGE 169 is used to represent 2-D "target" surfaces for the associated contact elements. The target surface is modeled through a set of target segments. Several such segments comprise one target surface. The target surface may be rigid or deformable based on situation. For modeling rigid-flexible contact, the rigid surface must be represented by a target surface.

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CONTA172 is used to represent contact and sliding between 2-D "target" surfaces and a deformable surface. This element is located on the surfaces of 2-D elements with midsize nodes. Contact occurs when the element surface penetrates one of the target segment elements on a specified target surface. [08]

D.Boundary conditions and Axisymmetric modeling.

Without the imposition of boundary conditions the element and assemblage stiffness matrices will become singular. Nodes constituting bottom of the soil zone fixed against movement at both vertical and horizontal directions by assuming that the displacement is insignificant. The zone away from pile, i.e., the vertical surface of soil at the boundary is restricted against horizontal movements.

In this work, the analysis was performed on a circular pile with varying lengths and diameters. The soil is taken 15 times the pile diameter along the horizontal plane and 20 times the diameter below the pile-end. Once the load is applied in the vertical direction, the symmetry shall be observed due to symmetry of loading and geometry. [09] Hence the analysis is carried out considering the pile soil system as 2-D axi-symmetric as shown in the Fig 2a using darkened lines. The complete axi symmetric model with meshing and boundary conditions was simulated using ANSYS is as shown in Fig 2b.

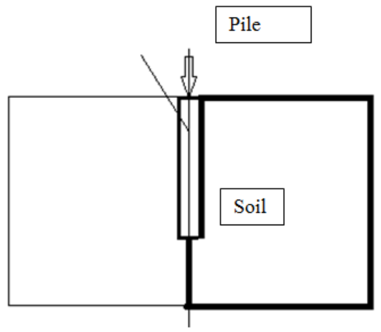

Figure.2a. Soil - Pile system in the Field

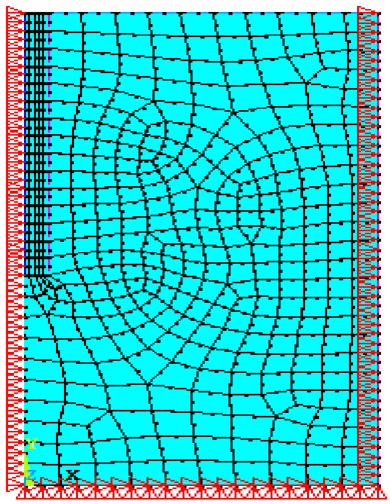

Figure.2b. Axi symmetric model with Meshing and Boundary Conditions

VI. VALIDATION BY ANSYS SOFTWARE

Validation of software was done for the experimental results carried out by Fan zhenhui et.al.[09] which signifies the factors affecting the settlement of pile foundation of bridge structures. Comparison of experiment results with software results was done to perform the validation of software. The soil constitutive model was assumed to be Drucker-Prager elastic-plastic model, the concreted pile shaft was considered as the linear elastic model and the soil-pile interface was simulated by contact elements. The bridge site consist layered soil condition with following details as tabulated in Table I.

Table I: Material properties after soil investigation. [09]

Characteristics	Miscella-neous Fill	Clay	Sandy clay	Pile
Layer Depth(m)	0-2.8	2.8-21	21-70	
Layer Height(m)	2.8	18.2	49	
***E*(Mpa)**	3	28	50	31500
μ	0.4	0.3	0.3	0.2
ρ (kg·m^{-3})	1900	1920	1950	3600
***C*(kPa)**	15	25	18	
Φ(deg)	8	20	35	

The load settlement curve for the study is as shown in figure.3. It showed that the load-settlement curve belonged to a slowly changing style and the ultimate bearing capacity is controlled by the pile-top settlement.

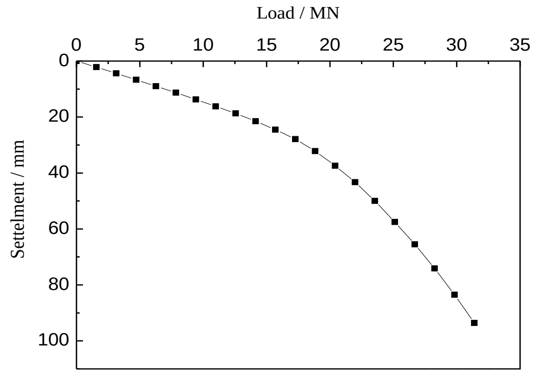

Figure.3. Load settlement curve [09]

In this case study, pile diameter of 2m and the length of 25m were analyzed for axial loading conditions. To satisfy boundary condition in FEM simulation, the influence zone extends to 30 m in the horizontal direction and 40 m below the pile-end. Under the design load of 10.2 MN, the pile-top settlement was 14.94 mm ensures enough safety for the bridge. The same problem was analyzed using ANSYS software for the above mentioned data as shown on figure - 4. Load v/s settlement results ware compared. Figure-5 shows settlement comparison graph between experimental and analytical results.

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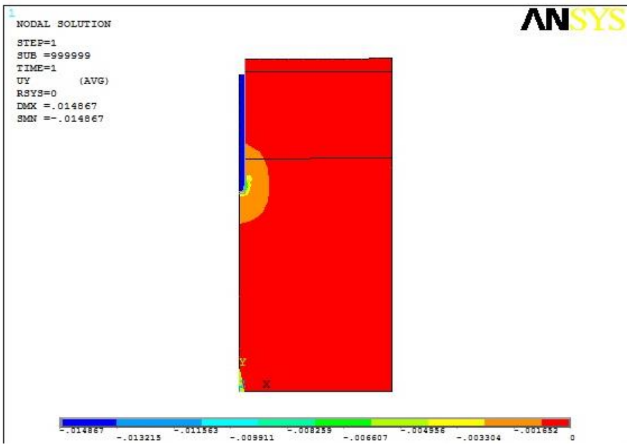

Figure.4. Displacement contours straight shafted pile in vertical direction

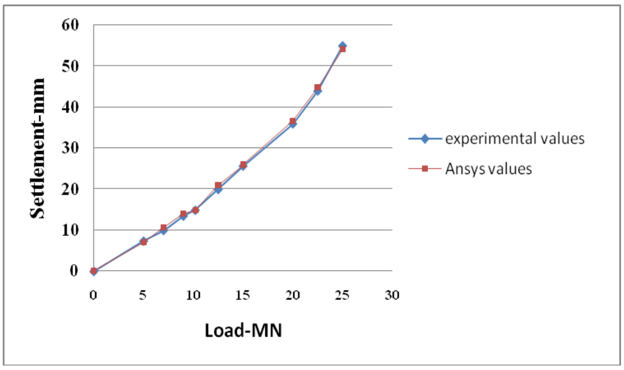

Figure. 5. Comparative Load v/s settlement curve.

From the above graph we can understand that the load settlement values obtained from the experimental results and analytical results are almost same. Therefore it can be concluded that methodology and parameters included for the analyses in most validated and can proceed with the parametric studies.

VII. ANALYSES OF STRAIGHT SHAFTED PILE IN COHESION LESS SOIL CONDITION

In these analyses, the length and diameter of pile foundation was varied to find out the ultimate load bearing capacity and settlement in sand. The length was varied from 3.0m to 5.0m each at 0.5m interval. Similarly diameter of pile for the above combination of length was varied from 0.3m to 0.5m each at 0.05m interval. The soil and pile properties taken for these parametric studies are given in Table II.

Table II: Material properties after soil investigation (07)

Properties	Pile	Soil
Modulus of elasticity ,Es	$2.1*10^7$kPa	$4*10^4$kPa
Poisson's ratio, μ	0.15	0.30
Density ,ρ	2500 Kg/m³	1900Kg/m³
Cohesion ,c	-	10 kPa
Friction angle ,Φ	-	35°
Flow angle ,ψ	-	11°

A. Influence of pile length and diameter on load carrying capacity of straight shafted pile.

After the complete analyses, ultimate load for the various combinations on straight shafted pile in cohesion less soil condition had been determined. Table III shows the value of ultimate loads for different length and diameter of piles. With these results a designer can avail the pile capacity of an individual pile for the known length and diameter.

Table III: Variation of load carrying capacity with pile length and diameter.

Length (m) /diameter (m)	3.0	3.5	4.0	4.5	5.0
	Ultimate load carrying capacity (kN)				
0.30	70.00	78.10	92.40	103.18	112.2
0.35	73.04	94.82	109.20	119.90	127.6
0.40	96.36	115.00	123.64	135.00	141.9
0.45	118.36	132.00	139.50	146.30	156.2
0.50	137.50	149.20	169.40	176.00	200.2

It has been observed that the load carrying capacity of pile increases with increase in its length. As the pile length increases the ultimate bearing capacity also increases because as the contact area of pile and soil is increasing with the length, so the soil can afford more reaction forces on pile. Pile transfers most of their load to the adjacent soil through side resistance, often referred to as skin friction. It is observed that for 0.3m diameter pile and increase in pile length from 3m to 5m, load carrying capacity of pile increases by 60.3% and for 0.5m diameter pile the load carrying capacity increases by 45.6%. Influence of pile length on the load carrying capacity of the pile is shown on figure 6 below.

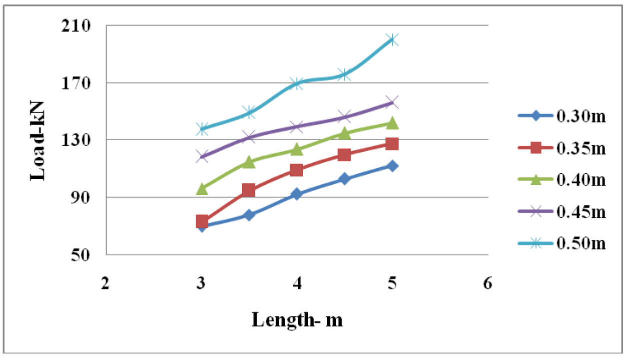

Figure.6. Influence of pile length on load carrying capacity.

The ultimate load carrying capacity of pile is also increases with increase in its diameter. But it is clear from the above discussion that the rate of increase in ultimate load carrying capacity is more compared to increase its length as seen above. For the pile length 3m, when pile diameter increases from 0.3m to 0.5m, the load carrying capacity increases by 96.4%, whereas for 5m pile, it increases by 78.4%. Influence of pile diameter on the load carrying capacity of the pile is shown on figure 7 below.

The ultimate load capacity of pile increased more with the increase in diameter rather with the increase with the pile length. For a pile of 4m the increase in pile capacity is 18% when the diameter of pile is increase from 0.3 to 0.35m. But the increase in capacity is 11% when the length of pile increased from 4 to 4.5m for the same diameter.

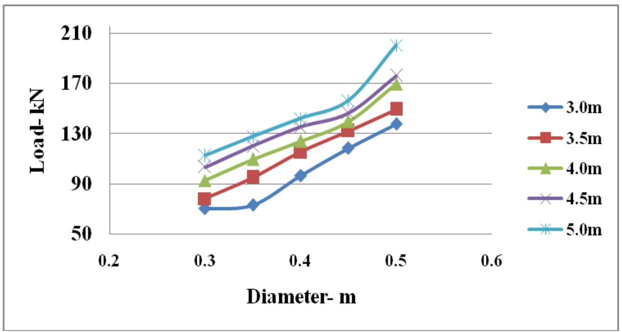

Figure.7. Influence of pile diameter on load carrying capacity.

B. Influence of pile length and diameter on the settlement of straight shafted pile.

The settlement values were also noted during the determination of ultimate load. Maximum settlement for the various combinations of pile length and diameter is tabulated in table IV.

Table IV: Variation of settlement with pile length and diameter

Length(m) / diameter(m)	3.0	3.5	4.0	4.5	5.0
	Settlement (mm)				
0.30	3.58	4.11	5.12	5.85	6.30
0.35	3.06	4.22	5.30	5.80	6.23
0.40	3.48	4.37	4.74	5.32	5.74
0.45	3.83	4.44	4.65	4.90	5.33
0.50	3.96	4.60	5.02	5.17	6.20

By understanding the influence of pile length on the settlement we can say that, there is no significant change in the settlement with the increase in diameter for same length. If the load at the ground surface is gradually increased, maximum frictional resistance along the pile shaft will be fully mobilized when the relative displacement between the soil and pile is about 5 to 10 mm or 10 to 25% of the pile width or diameter as shown in figure 8. It can be observed that the settlements are within the expected outcome

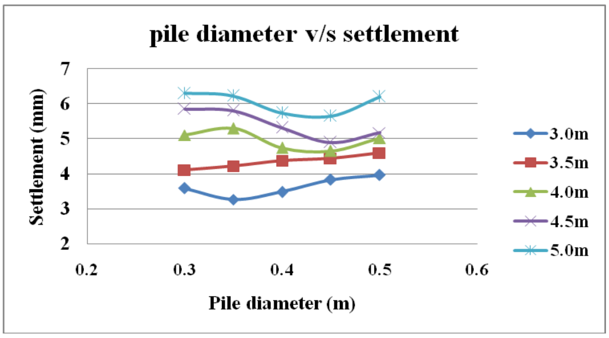

Figure.8. Influence of pile length on settlement.

It has been observed that the settlement is increasing with the increase in length for same diameter of pile. The figure 9 shows that the settlement is around 10 to 25% of pile diameter or around 5 to 10mm for all the cases.

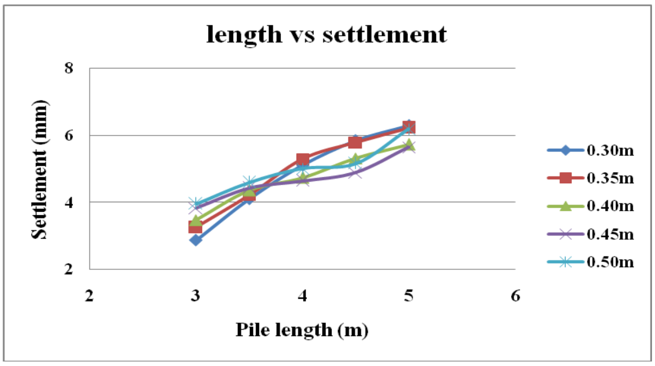

Figure.9. Influence of pile diameter on settlement.

VIII. CONCLUSION

In this work behavior of straight shafted pile foundation under cohesion less soil conditions were analyzed, efforts were also made to put in the results of ultimate load and settlement of various lengths and diameter of pile foundation. From the analyses we can conclude that, Finite Element Method is best suited to analyze the pile foundation inputting all the linear and non linear parameters of soil and pile. One of the powerful FEM tool ANSYS was used for the analyses and was validated with the data from literature and has been observed that it has given the reliable results up to 95% accuracy.

As per the parametric studies following conclusions can be drawn.

1. In case of cohesion less soil conditions, the load carrying capacity of straight shafted pile is governed both by skin friction as well as base strength (toe strength) of the pile.
2. The ultimate load carrying capacity increases with the increase in pile length and diameter. As the diameter increases surface area increases, providing more area for friction between soil and pile. So we can say that major load transfer from pile to the soil is by skin friction.
3. For 0.3m diameter pile, with the increase in pile length from 3m to 5m, load carrying capacity of pile increased by 60.3%. But for 0.5m diameter pile for the same varying length, load carrying was capacity increased by 45.6%.
4. For the pile length 3m and pile diameter from 0.3m to 0.5m, load carrying capacity increased by 96.42 %, where as for 5m pile it increases by 78.4%.
5. The load carrying capacity increases in both the cases of length and diameter but the diameter has more influence on the load carrying capacity than that of length in both cases.
6. Through the above graph, by understanding the influence of pile length and pile diameter both in consideration with settlement and load carrying capacity, as 4m and 0.4m pile combination shows an average value of load carrying capacity and settlement, in comparison with other combinations.

So we can conclude that 4m and 0.4m pile is the best combination for the design as its settlement is less at its corresponding ultimate load in cohesion less soil conditions.

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