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Strength & Stability Analysis of Straight Shafted Pile Foundation in Cohesive Soil Condition using Finite Element Analysis

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Abstract: Pile foundation is one of the effective forms of deep foundation. This is to be used where the load has to be transferred to deeper layers of soil and it can with stand uplift forces in foundations in expansive soil and also in case of floating foundations. The finite element method is one of the most versatile and comprehensive numerical technique which can be used for analysis of structures or solids of complex shapes and complicated boundary conditions. There are different variables which influence the load carrying capacity of pile foundation. But only some of those have significant influence on load carrying capacity. Here those variables are considered and the variation of load carrying capacity with the change in value of those variables is observed. Those variables are pile length and pile diameter, analysis of pile foundation was carried out to determine the ultimate load carrying capacity of pile for different lengths and diameters in cohesive soil, the corresponding settlement was also determined.
Keywords: Straight Shafted Pile, Cohesive soil, Finite Element Method, Drucker-Prager Constitutive Model, Incremental – iterative mixed method.

I. INTRODUCTION

Pile is an element of construction made of concrete, timber or steel. It is used in the ground either vertically or slightly inclined to increase the load carrying capacity of soils. 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. In addition to supporting structures, piles are also used to anchor structures against uplift forces and to assist structures in resisting lateral and overturning forces. Piles are commonly required in the following conditions. When one or more upper soil layers are highly compressible and too weak to support the load transmitted by the superstructure, piles are used to transmit the loads to underlying bedrock or a stronger soil layer. In the regions where a high wind or earthquake force normally occurs, pile foundations are used for tall structures and also in the construction of earth-retaining structures to resist bending. In case where expansive and collapsible soils are present, if shallow foundations are used the structure may suffer considerable damage. So, pile foundations may be considered as an alternative. The foundations of some structures, such as transmission towers, offshore platforms and basement mats below water table are subjected to uplifting forces. Piles are sometimes used for these foundations to resist the uplifting force. [01]

A. *Load Carrying Capacity of Straight Shafted Pile*

The load carrying capacity of a single pile depends upon 1) Type, size and length of pile, 2) Type of soil, 3) The method of installation. The load carrying capacity depends primarily on the method of installation and the type of soil encountered. The capacity of a single pile increases with an increase in the size and length. The position of the water table also affects the load carrying capacity.In order to be able to design a safe and economical pile foundation, the interaction between the pile and the soil has to be analysed for establishing the modes of failure and for estimating the settlement from soil deformation under dead load, service load etc. The design should comply with the following requirements. It should ensure adequate safety against compression and buckling failure; the factor of safety used depends on the importance of the structure and on the reliability of the soil parameters and the loading systems used in the design. The settlements should be compatible with adequate behaviour of the superstructure to avoid impairing its efficiency. [02]

B. *Load Transfer Mechanism*

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. The ultimate load carrying capacity Q_u of the pile can be calculated as follows. When the ultimate load applied on the top of the pile is Q_u, 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 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, that is, [04]

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$$Qu = Qb + Qf$$

The ultimate bearing capacity (Q_U) of piles in cohesionless soil is given by the following formula (3):

$$Qu = AP\,(0.5\,D\,\gamma\,N\gamma + PDNq) + K\,PD\,\tan\delta\,As$$

Where:

AP = 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.
PD = effective overburden pressure at pile toe in kN/m^2.
Nγ and Nq = bearing capacity factors depending upon the angle of internal friction Φ
K = coefficient of earth pressure.
δ= angle of wall friction between pile and soil, in degrees (taken equal to 2 Φ /3)
As = surface area of pile m^2.

II. METHODOLOGY

Finite element method is one of the effective and economic numerical methods for analysing foundations. This is usually implemented into a computer program and provides a complete structural analysis of pile foundations. It is capable of analysing unusual and complex pile shapes, pile with different diameters, piles transferring large moments and axial forces from laterally loaded shear walls or frames and piles in which structure rigidity affects its behaviour and stress distribution.

The analysis of pile foundation is carried out using ANSYS software. This is a leading finite element computer package, which uses the finite element method for solving problems in the static, dynamic and stability analyses of complex structures together with problems in fluid flow, thermodynamics, heat transfer, acoustics, magneto statics, electrostatics, seepage through porous media, medicine, electrical, mechanical and civil engineering, etc. ANSYS provides an integrated package consisting of whole module required for modelling, meshing, analysis and post processing of results. This software provides modelling flexibility and ease of input data modification at pre-processing stage. [05]

A. Elements Used for Soil & Pile

In this study, pile is considered as a rigid body and soil as a flexible body. The pile was modelled as a linear isotropic and the soil was modelled 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 modelling 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. TARGE 169 is used to represent 2-D “target” surfaces for the associated contact elements. The target surface is modelled 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 modelling rigid-flexible contact, the rigid surface must be represented by a target surface. 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. 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. Fig 1 & 2 shows the boundary conditions, meshing details and displacement contours in Y-direction at the ultimate load respectively. [04]

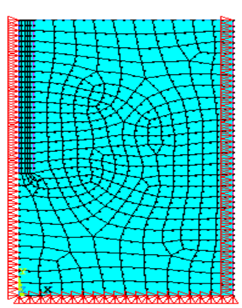

Fig 1. Fem model with Meshing and Boundary Conditions

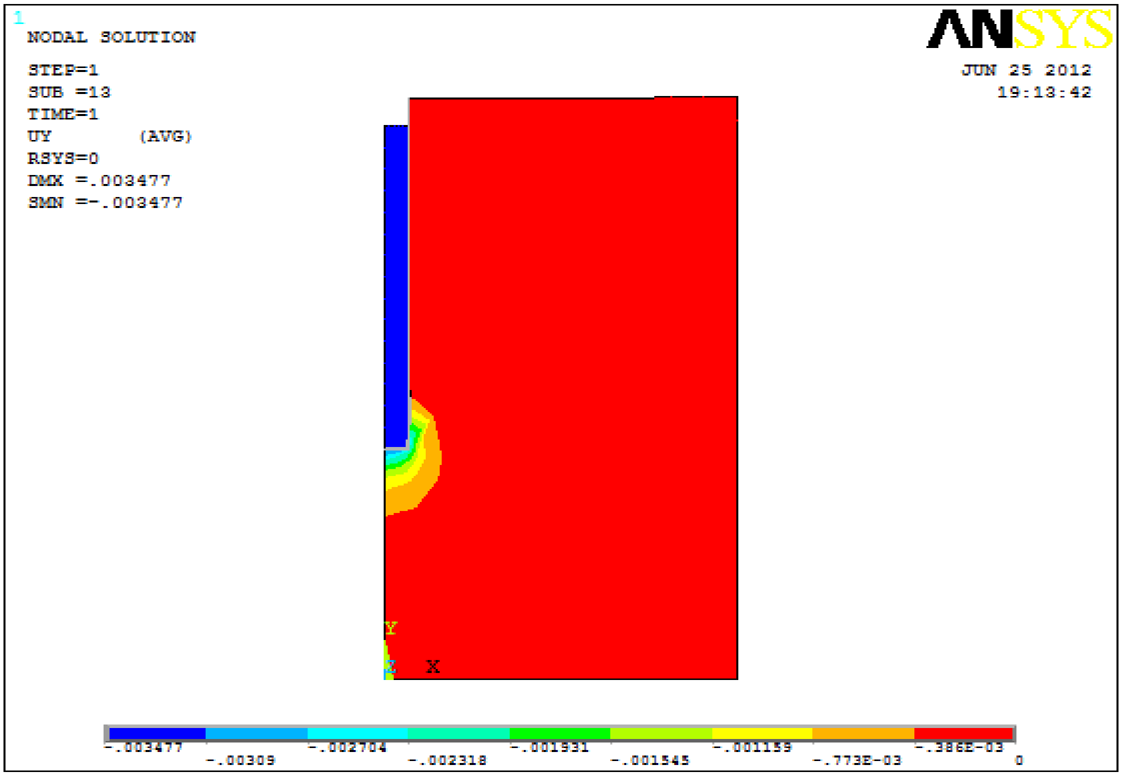

Fig 2. Displacement contours in Y-direction at the ultimate load

III. 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 clay. 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 I. [01]

Table I
Material properties after soil investigation

	Pile	**Soil**
Modulus of elasticity, Es	$2.1*10^7$kPa	$4*10^3$kPa
Poisson's ratio	0.15	0.30
Density, ρ	2500 Kg/m³	1700Kg/m³
Cohesion, c	-	25kPa
Friction angle, Φ	-	5°
Flow angle, ψ	-	1.5°

A. Influence Of Pile Length And Diameter On Load Carrying Capacity Of Pile

After the complete analyses, ultimate load for the various combinations on straight shafted pile in cohesion less soil condition had been determined. Table II 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.

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TABLE II
Variation of load carrying capacity with pile length and diameter

Length (m) / Diameter (m)	3.0	4.0	5.0
	Ultimate load carrying capacity (kN)		
0.30	39.16	45.10	53.20
0.35	44.20	57.86	62.70
0.40	77.00	81.40	83.60
0.45	84.70	92.30	97.50
0.50	102.3	105.30	111.30

The load carrying capacity of pile increases for a given diameter with the increase in pile length. But the load carried by pile in cohesive soil (clay) is much lesser compared to load carried by cohesion less soil (sand). It is observed that for 0.3m diameter pile, increase in pile length from 3m to 5m, load carrying capacity of pile increases by 26% and for 0.5m diameter pile, load carrying capacity increases by 8%. as represented in fig 3.0

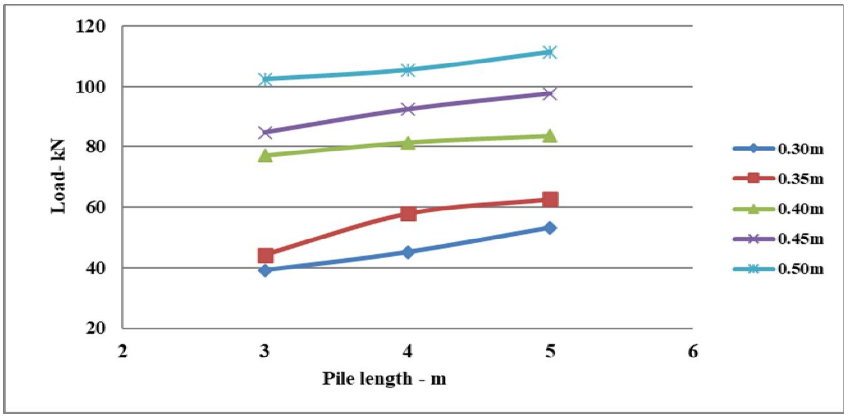

Fig 3. Influence of length on load carrying capacity

It has been observed that there is significant increase in load carrying capacity of pile with the increase in pile diameter for same length. For the pile length 3m and pile diameter from 0.3m to 0.5m, load carrying capacity increases by 62%, whereas for 5m pile it increases by 53% as represented in fig 4.0.

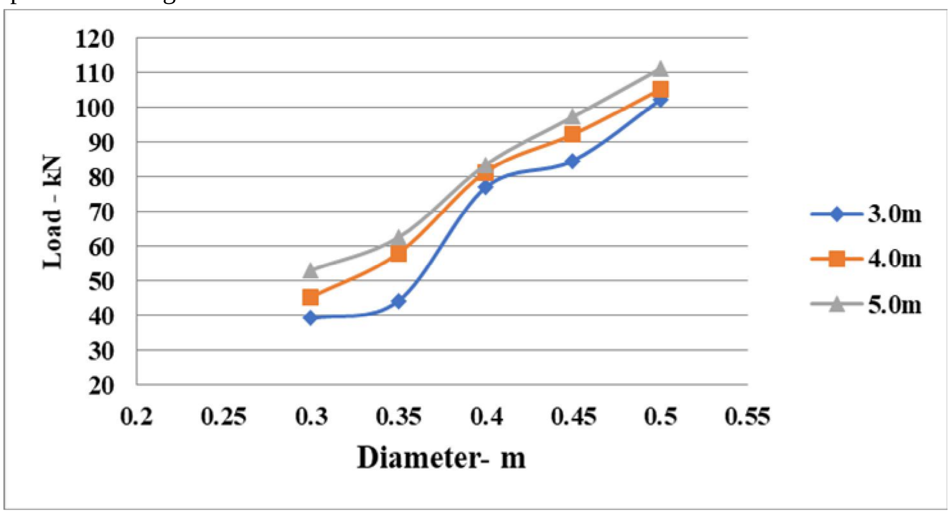

Fig 4. Influence of diameter on load carrying capacity

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B. Influence Of Pile Length And Diameter On Settlement Of Pile

After the complete analyses, settlement 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 settlement with pile length and diameter

Length(m) / Diameter(m)	3.0	4.0	5.0
	Settlement (mm)		
0.30	26.17	24.70	27.13
0.35	29.32	31.18	33.31
0.40	38.45	35.40	37.45
0.45	42.20	35.80	42.33
0.50	42.30	36.01	45.15

It is observed that the settlements for 4m piles are less compared to 3m and 5m pile at their ultimate loads. Only for 0.35m diameter pile-settlement increases slightly with length. Prediction of load-deformation response of piles in clay exactly is not possible. Fig.5 shows the settlement behaviour of pile in clay at its ultimate load for varying diameters of pile length.

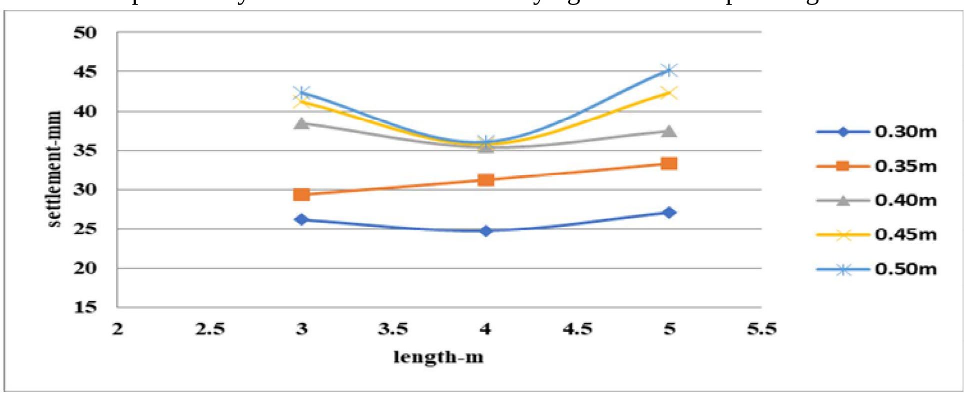

Fig 5. Influence of pile length on settlement

In the case of clay for 3m pile length and 0.3m pile diameter, load carrying capacity of pile decreases by 44% and for 0.5m it decreases by 22%when compared with that of sand. Similarly, for 5m pile length and 0.3m diameter decreases by 61% and for 0.5m diameter, load carrying capacity of pile decreases by 44%. Fig.6 shows the settlement behaviour of pile in clay at its ultimate loads for varying lengths of pile diameter. Here the settlement constantly increases with diameter.

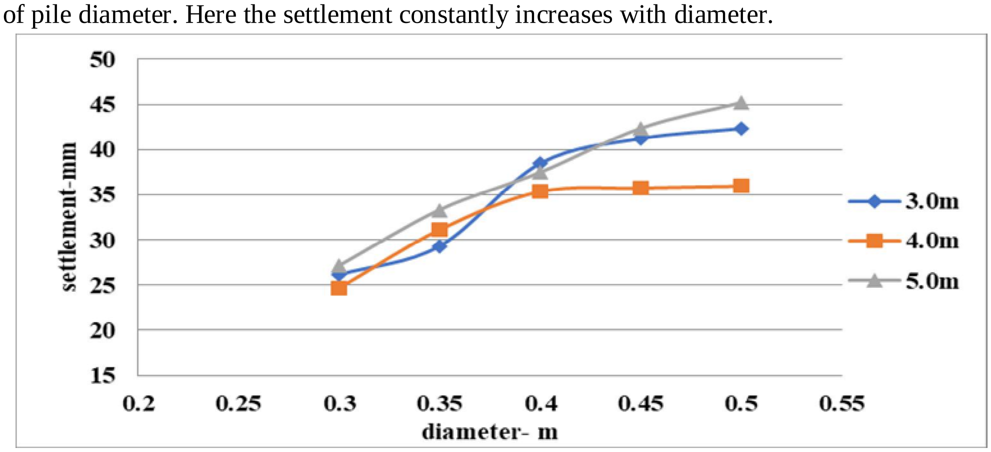

Fig 6. Influence of pile diameter on settlement

IV. CONCLUSIONS

In this article efforts have been made to analyse and compare the ultimate load and settlement of straight shafted pile's under cohesion less soil condition using a finite element software ANSYS, which is one of the most versatile and comprehensive numerical technique which can be used for analysis of structures or solids of complex shapes and complicated boundary conditions. This method can be applied even for non-homogeneous materials. The finite element analysis was started as an extension of matrix method of structural analysis.

Here 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 by assuming that the pile-soil system as a 2-D axisymmetric.

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