

Numerical Analysis of Lateral Load Capacity of Helical Piles

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ABSTRACT: Structures like lighthouses, solar panels, and other light structures employing helical piles are often subjected to significant lateral loads apart from axial loads. Under lateral loads, the response of helical piles can be different from that of a conventional pile due to the presence of the bearing provided by the helical blade. The paper presents a detailed numerical investigation carried out on the behavior of helical pile installed in loose cohesionless soil under lateral load. The analyses are carried out using three-dimensional finite-element software, Plaxis 3D AE assuming Mohr-Coulomb failure for soil. The soil was modeled using 10-node tetrahedral elements with a standard Mohr-Coulomb elastoplastic material. Pile is modeled as plate elements with a single helical blade attached to a hollow shaft. The load-deformation behavior under lateral load is compared with the results from a case study of field investigation reported. The model thus calibrated shall be used for a parametric study. A series of numerical analyses were carried out using Plaxis 3D on piles of different geometries, with and without a helical blade to investigate the response towards the lateral load. The lateral capacity of helical piles increases with an increase in installation depth and density of soil. The presence of a helical blade adds to the lateral load capacity significantly. The diameter of the helical blade is significant in reducing the lateral deformation and influencing the bending moment if the blade is within the embedment ratio of 15. The density of sand increases the maximum bending moment.

KEYWORDS: Lateral Load, Embedment ratio, Cohesionless soil, Helical pile.

I. INTRODUCTION

Helical piles are steel circular piles with helical blades, installed by applying a torque in the presence of vertical pressure. The use of helical piles for foundations offers many advantages, including their high compressive and uplift capacity (3 -5 times that of traditional steel piles with same shaft diameter and length), rapid speed of installation, suitability for construction in very limited access conditions, ease of installation in frozen or swampy soil conditions and cost-effectiveness. Under lateral loads, the response of helical piles can be different from that of a conventional pile due to the presence of the bearing provided by the helical blade. However, the proper design remains a concern due to the lack of work carried out on the lateral capacity of helical piles. The lateral performance of helical piles is significant because they can act as efficient alternatives to conventional piling systems in many applications.

This paper presents the results of the investigation of helical piles installed in cohesionless soil, subjected to lateral load. Plaxis 3D AE version was used. The dimension of the piles chosen and the properties of the pile material and sand is based on a laboratory model and Field model tests reported in the literature. The objective of this research study is to develop a numerical model for lateral load analysis of helical piles, to analyze the effect of parametric variations on the validated model on the ultimate lateral load and maximum deformation, to investigate the effect of pile dimension on bending moment and deformation pattern of helical piles.

II. RELATED WORK

The lateral load capacity of screw anchor piles with different number of helices were examined by Mittal et al. (2010) by experiments in sand. They found that the lateral load capacity of piles increases with addition of helical blades. Prasad and Rao (1996) examined the lateral capacity of helical piles in clay by experiments on model piles and found that the lateral capacity of helical piles was more than that of the straight shaft piles. Sakr (2009) studied lateral performance of two section helical piles in soft soil. The investigation by Prasad and Chari (1999) reported that the pressure distribution across the diameter is not uniform for circular piles, but it is maximum at the centre and almost



zero at the two edges. Puri et al. (1984) after conducting model tests on single-helix, two-helix, and three-helix anchors installed in sand, proposed a mathematical model that was fashioned after Matlock and Reese’s elastic theory model. Elkasabgy and Nagggar (2015) investigated the lateral performance of full-scale large capacity helical piles in structured cohesive soils and reported the modulus of sub-grade reaction to be non-linear. Puri et al. (1984) after conducting model tests on single and multi-helix anchors in the sand, proposed a theoretical model based on Matlock and Reese’s elastic theory model. El-Kasabgy and El-Nagggar (2015) investigated the lateral performance of full-scale large-capacity helical piles in structured cohesive soils. It was reported the modulus of sub-grade reaction to being non-linear and commented that it is important to incorporate the effect of soil disturbance in design.

Kurian and Shah (2009) carried out studies on screw piles by finite element method using marc version 2003 software. Drucker-Prager constitutive model was used to model the behavior of soil. The axial and lateral response of screw piles were investigated and reported that they exhibit a higher ultimate load than their plane counterparts, 139% in the typical dimension considered. The ultimate capacity was observed to be more for helical blades of lower pitch. *Papadopoulou et al. (2014)* carried out the experimental and finite element analysis of helical micro-piles. Helical piles used in field study were of 220mm blade diameter and 76mm shaft diameter. The length of the piles was 1.6m to 4.2m. The piles were tested for tension, compression, and lateral load capacity. However, the helical blades were modeled as a conical surface in the axisymmetric model. Linear elastoplastic behavior was assumed for soil. It was observed from FEM that the maximum contribution in tensile strength arose from the bearing of the upper blade while for compression, from the bearing of the lower blade, corresponding to the assumptions of *Rao et al. (1993)*. The comparison between numerical and field results agreed better in case of cohesive soils.

III. METHODOLOGY

3.1 Modelling in AutoCAD

Helical pile models are prepared in AutoCAD software by variation in parameters from referred journals. The pile parameters used for modelling are given in the table below:

D _s (mm)	D _h (mm)	P (mm)	H (mm)	Remarks
177.8	355	150	5200	Values referred from <i>Sakr,(2009))</i> and <i>Mohammed Sakr (2009))</i>
177.8	406	150	5200	
177.8	533	150	5200	
177.8	266	150	5200	
324	486	152	5600	Referred from <i>Mohammed Sakr (2010)</i>
324	972	152	5600	
324	762	152	5600	
324	648	152	5600	
324	810	152	5600	
324	0	0	5600	
324	648	152	3600	
324	648	152	4600	
324	648	152	5600	
324	648	152	6600	
324	648	152	7600	
102	0	0	1200	

Table 3.1 : Numerical Data Collected from Journals

Parametric Variations in different journals are as follows:

Journal 1 - Lateral Capacity of Model Rigid Piles in Cohesionless Soils by - *Yenumula V.S.N Prasad and T.R.Chari (1999)*:

From this journal, piles without helix are considered for analysis. The dimension of the pile is referred from the journal, and an AutoCAD model of the same is created. While analysing the depth is kept constant and density is varied.

Journal 2 and 3:

Journal 2- Lateral Resistance of Helical Piles in Oil Sands by *Mohammed Sakr, P.Eng., Ph.D. (2009)*

Journal 3 - Performance of helical piles in oil sand by *Mohammed Sakr (2009)*

From these journals, the Pile Depth (H), Pitch of Helical Blade (P), Shaft Diameter (D_s) and Helical Blade Diameter (D_h) are referred and AutoCAD models are created. H, P and D_s are kept constant and D_h is varied.

Journal 4: Lateral resistance of high capacity helical piles by *Mohammed Sakr (2010)*, Almita Manufacturing Ltd., Ponoka, Alberta, Canada

From the above journal, the Pile Depth (H), Pitch of Helical Blade (P), Shaft Diameter (D_s) and Helical Blade Diameter (D_h) are referred and AutoCAD models are created. H, P and D_s are kept constant and D_h is varied. Parametric studies are carried out from the same journal keeping D_s , P and D_h constant and varying H.

3.2 Numerical modelling

The soil properties are based on a laboratory test carried out by the authors. The geometries of piles used for the present analysis are given in Table 3.1, with notations in the format $D_s/D_h/P$, where D_s is the diameter of shaft in mm, D_h is the diameter of helical blade in mm and P is the helical blade pitch in mm.

Soil was modelled using the well-known Mohr-Coulomb constitutive model available in Plaxis 3D. It is a perfectly elasto-plastic model with fixed yield surface and gives reasonable results with relatively fast computation. Two relative densities of sand, properties of which are based on the laboratory tests are used here. Direct shear interface tests were conducted on the steel section used for the laboratory studies to arrive on the interface coefficient.

3.2 Analysis in Plaxis 3D

A soil model of sufficient depth is created in the software. The point load is applied and the mesh is created on the soil body and the pile. The depth of water table is also provided. The phases are created and the analysis is run. After the successful completion and calculation of all the phases, the output can be obtained.

3.3 Parametric study

Pile was defined as Linear-Elastic material which is the simplest stress strain relationship available. The geometry of the numerical model was constructed to match that of the model pile tested in all aspects including the helical blade. The finite frictional interaction between the pile and adjacent soil was simulated using interface elements created along the circumference of the pile and also the helical blade so that relative displacement and separation is allowed between the pile wall and soil mass. The roughness of the interaction is determined by the value for the strength reduction factor (R_{inter}) in the interface, the value of which defined based on the frictional coefficient between soil and pile wall.

IV. EXPERIMENTAL RESULTS

4.1 Journal Validation

4.1.1 Journal 2 & 3 : Lateral Resistance of Helical Piles in Oil Sands by *Mohammed Sakr, P.Eng., Ph.D. (2009)* and Performance of helical piles in oil sand by *Mohammed Sakr (2009)*

The models used for the journal validation is given in Table 3.1. During the validation it was found that, as the helix diameter increases, there is a slight decrease in the deformation of the pile. The effect of helix diameter on the deformation depends on the region of influence of the helix. In Journal 2 (Lateral Resistance of Helical Piles in Oil

Sands by *Mohammed Sakr, P.Eng., Ph.D. (2009)* and in Journal 3 (Performance of helical piles in oil sand by *Mohammed Sakr (2009)*), the same sets of piles were analyzed. The deformation patterns obtained were similar to that of the available literatures, and hence the model was validated.

Fig (4.1) was obtained by inputting the soil parameters from the journal Lateral Resistance of Helical Piles in Oil Sands by *Mohammed Sakr, P.Eng., Ph.D. (2009)*. It shows the variation of deflection with respect to depth of pile having depth of pile (D_s) 177.8mm, diameter of helix (D_h) 266mm, 355mm, 406mm and 533mm, pitch (P) 150mm and depth of 5200mm. The deflection is shown in (mm) and the depth in (m).

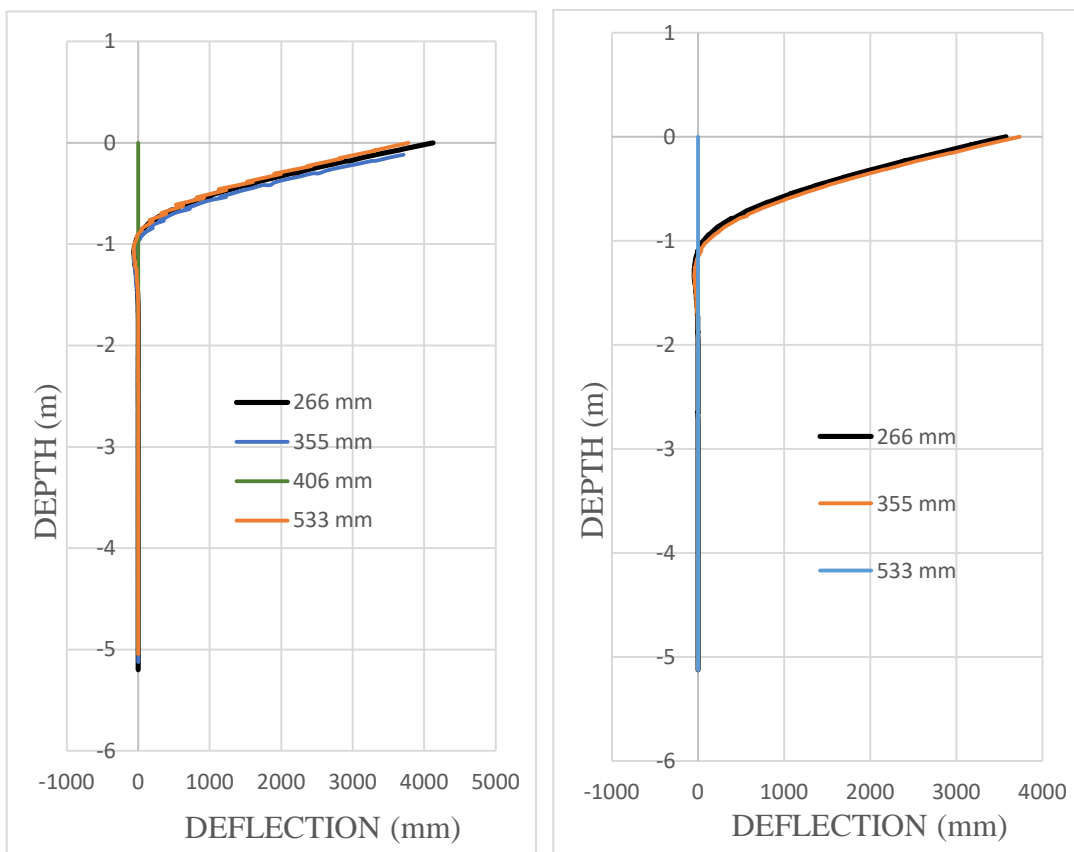


Fig 4.1(a) . Deformation Curve *Sakr (2009)*) and (b) *Mohammed Sakr (2009)*

Fig (4.2) was obtained by inputting the soil parameters from the journal Performance of helical piles in oil sand by *Mohammed Sakr (2009)*. It shows the variation of deflection with respect to depth of pile having depth of pile (D_s) 177.8mm, diameter of helix (D_h) 266mm, 355mm, 406mm and 533mm, pitch (P) 150mm and depth of 5200mm. The deflection is shown in (mm) and the depth in (m).

4.2 Parametric Variations

D _s (mm)	D _h (mm)	P (mm)	H (mm)	Remarks
324	486	152	5600	Referred from journal, Lateral resistance of high capacity helical piles by <i>Mohammed Sakr (2010)</i> , Almita Manufacturing Ltd., Ponoka, Alberta, Canada
324	972	152	5600	
324	648	152	5600	
324	762	152	5600	
324	810	152	5600	
324	0	0	5600	
324	648	152	3600	
324	648	152	4600	
324	648	152	5600	
324	648	152	6600	
324	648	152	7600	

Table 4.1 : Specifications of models used for parametric variation

4.2.1 Case 1

In the first case, the parametric variation is done by keeping the embedment depth as constant and varying its diameter, i.e. varying the embedment ratio in the format of 1.5, 2, 2.5. The models taken for this purpose are those with helical diameters 486mm, 810mm and 648mm (Table (4.1))

It was found that there was a noticeable reduction in lateral deformation due to the presence of helical blade. Moreover, the presence of larger diameter blade is evidently resulting in less lateral deformation as compared to the smaller diameter blade, every other parameter kept constant.

So in summary, presence of helical blade contributes to restraining the lateral deformation only if depth of blade is within a certain depths., after which it seizes.

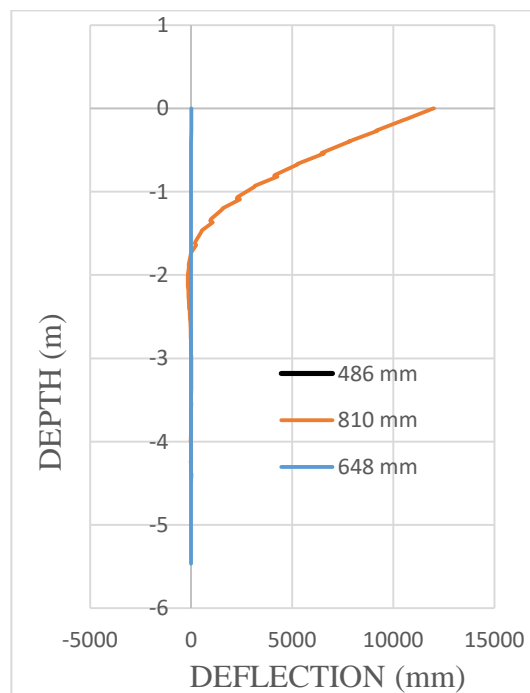


Fig 4.3: Comparison of Deformation Curve for Case 1

4.2.2 Case 2

In Case 2, the depth of installation was increased at a constant rate from 3600mm to 7600mm, while keeping all the other parameters constant. From Fig (4.4), it was found that deformation reduces with increase in depth up to a certain value.

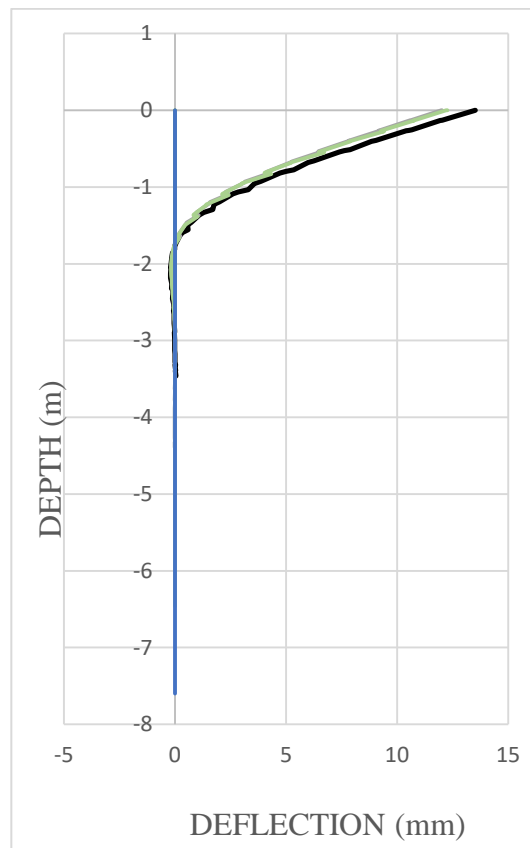


Fig 4.4 . Comparison of Deformation Curve for Case 2

It can be identified from above figure that the pile installed at a depth of 7600mm showed the least deformation.

4.2.2 Case 3

For Case 3, two models, one with a helical diameter of 810mm and the other with no helix, were installed at a same depth of 5600mm, and with the same shaft diameter of 324mm. On comparing the deformation curves in Fig (4.5), it was found that the pile with helix had a very little or no deformation on compared to its plane counterpart.

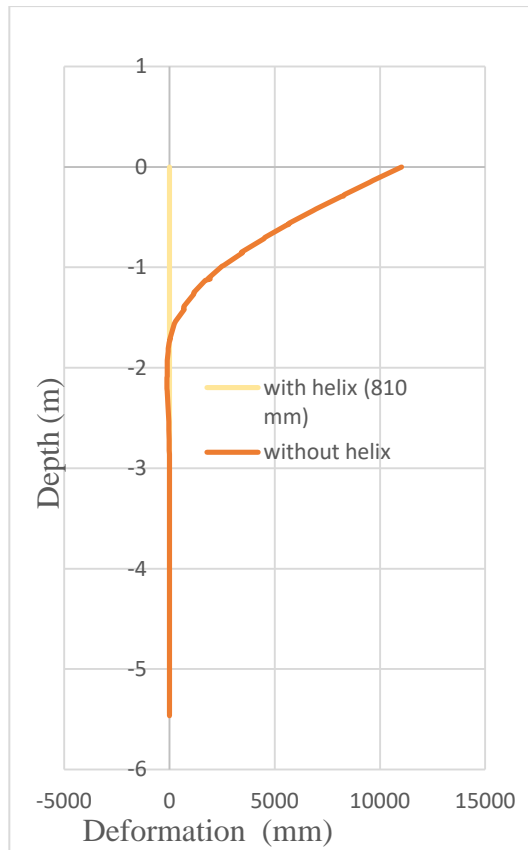


Fig 4.5 . Comparison of Deformation Curve for Case 3

4.3 Bending Moment Distribution

On considering the values from the journal Performance of helical piles in oil sands by, *Mohammed Sakr (2009)*, it was found that as the diameter of helix increases the bending moment also increases. It shows that the presence of helical blade contributes to lateral capacity of helical piles.

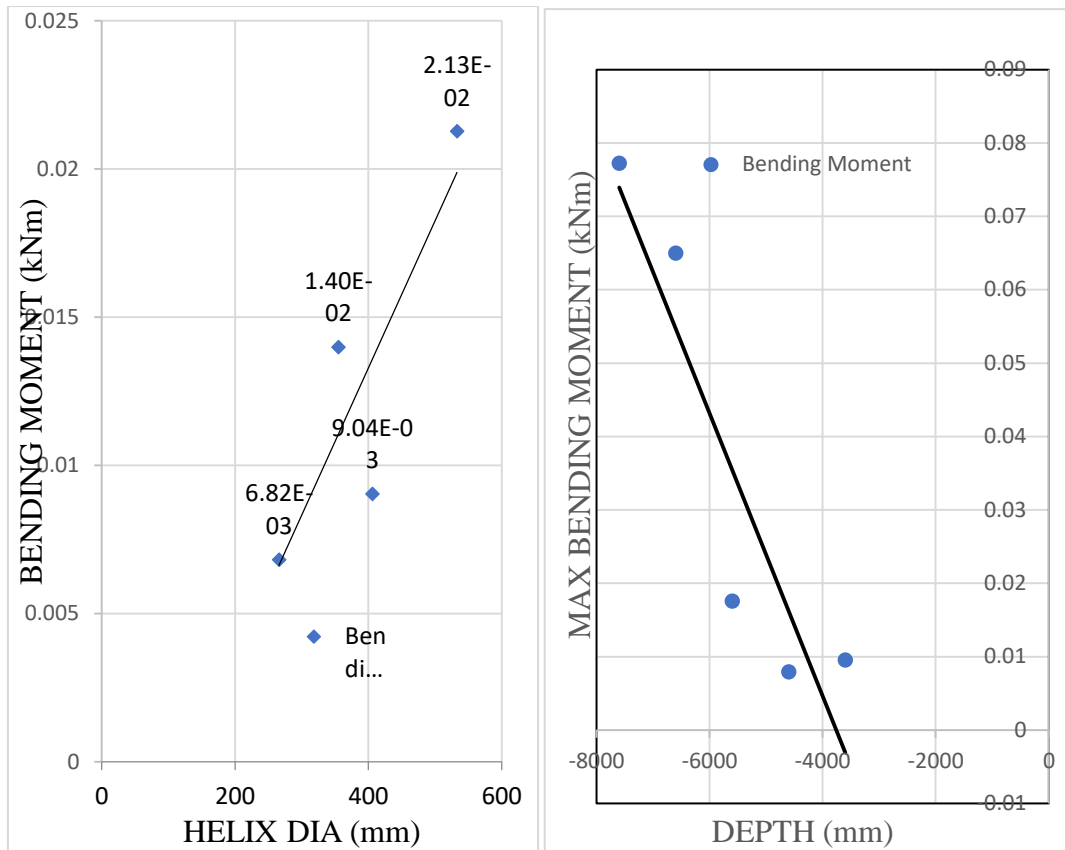


Fig 4.6. Bending Moment variation with (a) diameter of helix (b) depth

Keeping all the other parameters constant, the depth was varied. It was found that as the depth increases, the bending moment also increases.

4.4 Ultimate Lateral Load

Based on the values from the journal Lateral resistance of high capacity helical piles – Case Study by, *Mohammed Sakr, Almita Manufacturing Ltd, Ponoka, Alberta, Canada (2010)*, on increasing the depth of installation of the pile the ultimate lateral load was found to increase up to a certain value.

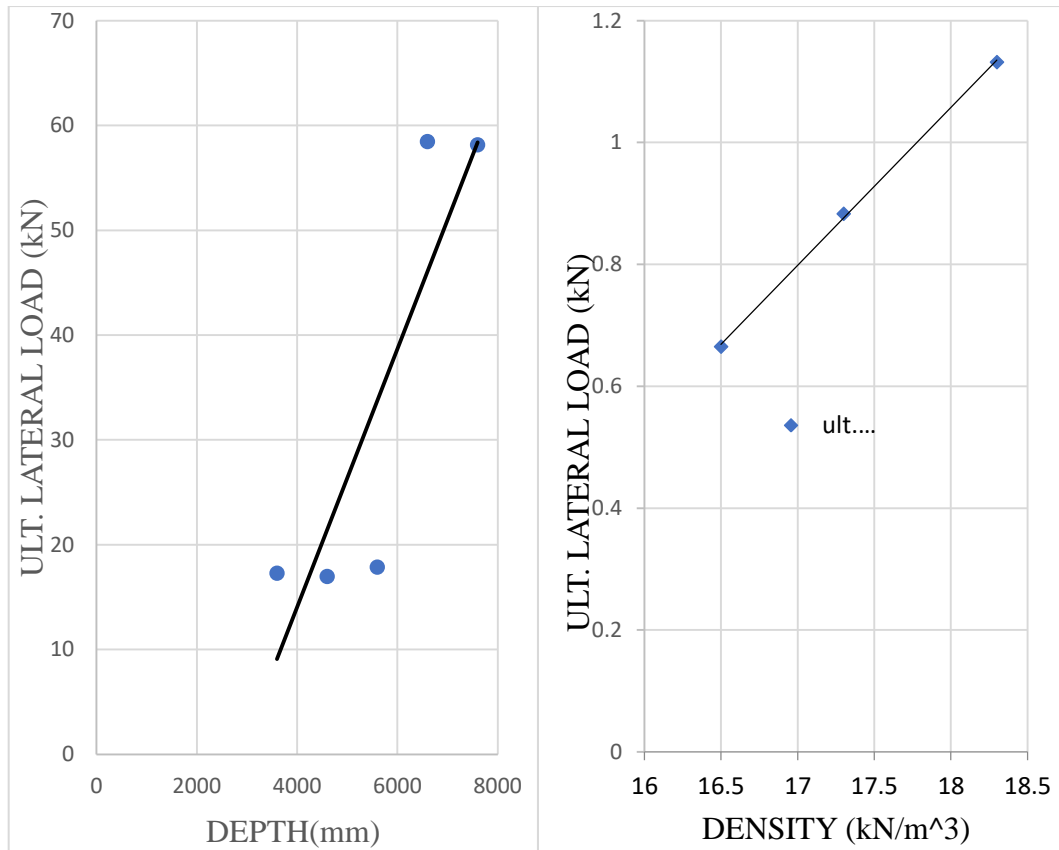


Fig 4.8. Variation of ultimate lateral load capacity with (a) depth of pile (b) density of soil

4.5 Relative Density

The relative density of the sand was varied in the range 30%, 40% and 50%. As the sand gets denser the lateral load capacity was found to increase.

V. CONCLUSION

A series of numerical analyses were carried out using Plaxis 3D on piles of different geometries, with and without a helical blade to investigate the response towards the lateral load. The influence of helical blade diameter, the relative density of soil and installation depth was also briefly studied and the following conclusions may be drawn based on the observations made:

- The lateral capacity of helical piles increases with an increase in installation depth and density of soil.
- Presence of a helical blade adds to the lateral load capacity significantly. However, its effect starts reducing after a certain embedment ratio.
- Diameter of the helical blade is significant in reducing the lateral deformation and influencing the bending moment if the blade is within the embedment ratio of 15.
- Pile shows good lateral load capacity in dense sand and the bending moment is found to increase with depth.



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