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Effect of Load Inclination and Arrangement of Helical Plate on Load Carrying Capacity of Helical Pile

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Abstract

Helical pile foundation is most suited for foundation expansion for vertical additions, strengthening of existing structures, communication tower support, solar and wind farms, bridge replacement, etc. In spite of large-scale applications; there are no standardized guidelines to create piles which are helical in shape. The objective of the study is to get comparative analysis of the helical pile's capacity under compressive load applied at various inclinations (0°, 30°, 45°, 60° and 90° with vertical) and with two different arrangements of helical plates. Also, the experimental results were validated in PLAXIS 3D. The laboratory study was performed on model helical piles embedded in sand filled in model foundation test set-up of size 1.5 m square steel tank at 60% of relative density. The top portion of the load frame is of semi-circular shape to apply load at required inclinations. From the results it was worth mentioning that as the inclination increases from 0° to 90° with vertical axis; the capacity of helical pile to carry load decreases. Moreover, the pile with the lower bottom helix plate diameter has a higher capacity than the pile with the larger top helix plate diameter.

Keywords

Helical plates, Helical piles, Load Carrying Capacity of Pile, Structural Engineering

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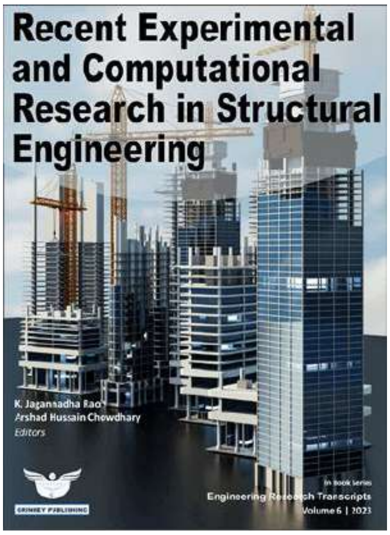


1. Introduction

One or more circular plates are welded to a central steel shaft at a specific depth and spacing to make up helical piles [1]. Its basic components are bearing plates with helices, shaft, pitch, spacing between two helical plate and pile cap. They can be adapted from an engineering/architecture point of view to support a wide range of structures with various problematic subsurface conditions. Their quick installation can frequently save the owner/developer money overall. Many of these benefits include:

- installation in a site with varying weather and other variables
- affordability and speedy installation
- simple removal, reuse, and transportation
- simple across a range of soil conditions
- instant use
- advantages over the traditional pile method, such as ease of installation using standard tools.

Furthermore, they can provide structural stability for loads in the areas of uplift tension, axial compression, lateral force, and overturning moment under static and dynamic conditions. Contractors can easily install them, and it is highly certain to determine their capability. These may rank among the most exciting, cutting-edge, and environmentally responsible solutions now available from the standpoint of the general population. Although the usage of helical piles is expanding, there is still no guideline for optimal design or how helices affect ultimate loads. There is no pulp material used during the installation of helical pile foundations, and the procedure is vibration-free, making it suitable for foundation reinforcing applications of sensitive structures. These characteristics make helical piles environmentally friendly [2-4]. Large capacity single and double helix piles were subjected to numerous tension and compression tests by Sakr [5] in soils of varying densities. He came to the conclusion that pile geometry, groundwater properties, soil profile, and installation techniques had an impact on general behavior. After conducting laboratory testing on helical piles with 2 and 4 helices grounded in saturated clay, Prasad and Narasimha [6] came to the conclusion that the helical pile's lateral capacity was 1.2–1.4 times more than that of a conventional shaft pile.

2. Methodology

2.1 Model Helical Piles

Two helical piles of length 600 mm were used in this study (Fig. 1). Both piles had 3 number of helices at 1.5d, 2d and 3d distance; taking d as the diameter of the shaft. The pile shaft's diameter was 30 mm and size of helices was kept as 45 mm, 60mm, and 90 mm. The spacing between helices was kept 150 mm in both piles. The pile P1 had 90 mm helical plate at the top followed by 60 mm and 45 mm. The pile P2 had 45 mm helical plate at the top followed by 60 mm and 90 mm. Bottom helical plate is placed at 30 mm up from pile tip.

2.2 Model ground

Sand from Badarpur, Sankheda, Gujarat was used for the study. It has the following characteristics:

- Condition = clean, dried and fine grain
- Specific gravity = 2.55
- Sand density ρd= 1.68 g/cc @ 60% relative density

From the sieve analysis test on the sand (Fig. 2); the Coefficient of Uniformity, C_u=2.627 and Coefficient of Curvature, C_c= 0.961, hence it was classified as Poorly Graded Sand according to Indian Standard.

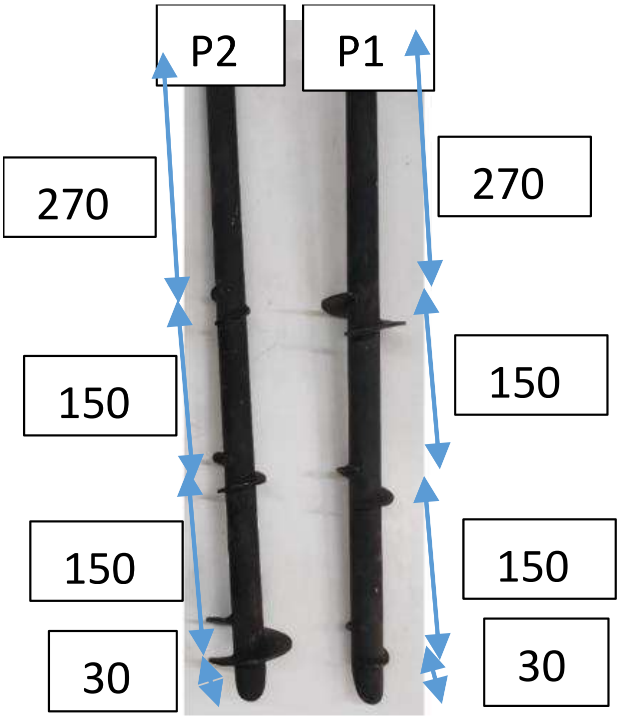


Fig. 1. Model Helical Pile (All dimensions in mm)

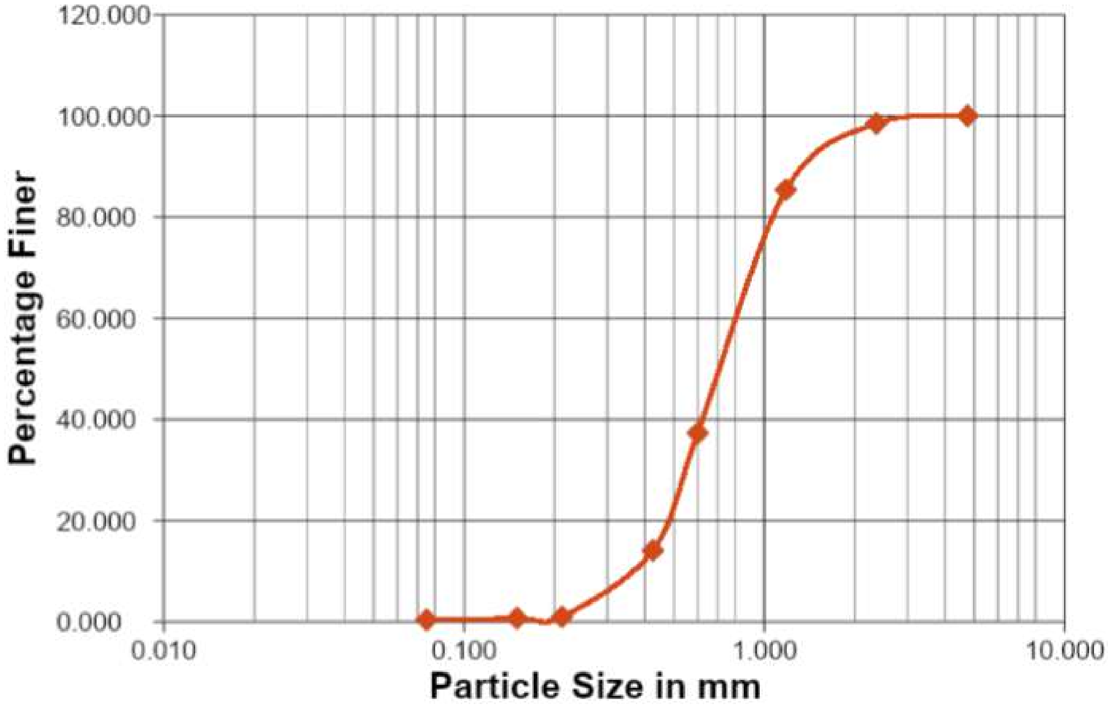


Fig. 2. Particle Size Distribution curve for sand

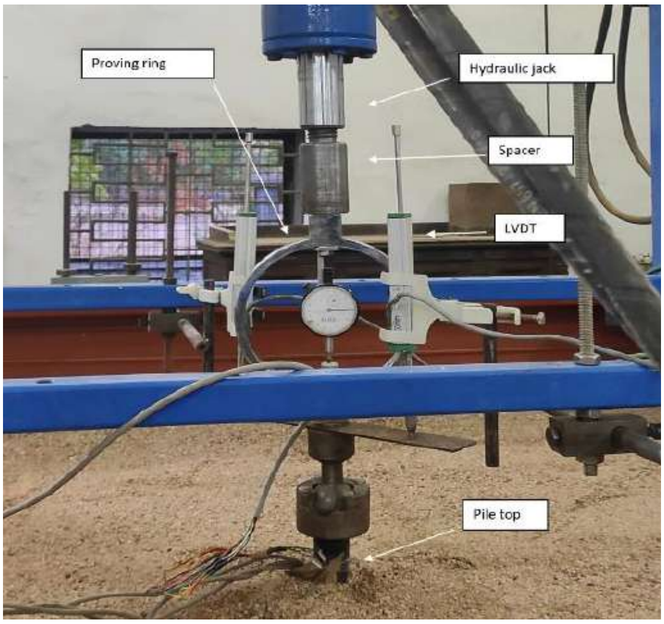
2.3 Model Tank

The model ground was prepared in a model square tank of 1.5 m of size (Fig. 3). The loading frame comprises of mild steel sections capable of applying 10-ton load. The top portion of the load frame is of semi-circular shape. The motorized hydraulic jack was fitted on semi-circular frame and it will move electronically from one end to other end of semi-circular arch such that load will be applied at various inclination from 0° to 90° with vertical axis on either side. The frequency of the motorized hydraulic jack with three phase 440 volt is 50 Hz. LVDT were used to find the pile head displacement.

Fig. 3. Model Foundation test Set-up

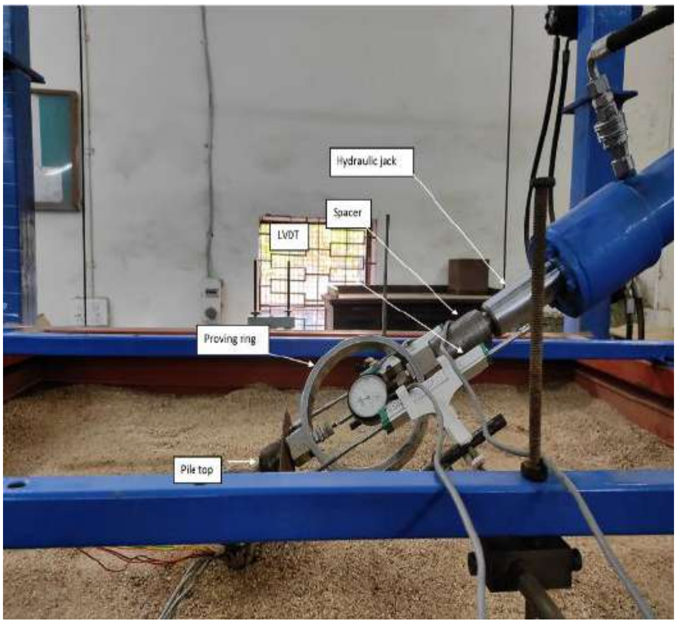
3. Experimental Work

The model ground was prepared in the model foundation test set-up by vibrating the sand in 10 cm thick layer to achieve 60% relative density. The pile was installed by pre-installation process. The load was applied by hydraulic jack at various load inclinations (0°, 30°, 45°, 60° and 90° with vertical). Pile top is attached with proving ring for the application of inclined load. LVDT is used for measurement of pile head displacement in the direction of load applied. Maintained load test (MLT) method is used for all test. The arrangement of proving ring and LVDT for various loading condition is shown in Fig. 4.

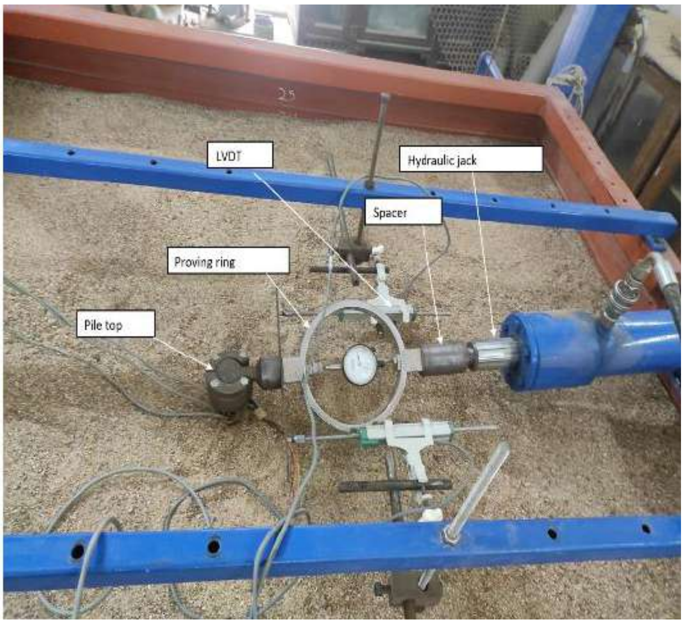


Load applied at 0° with vertical

Load applied at 45° with vertical



Load applied at 60° with vertical



Load applied at 90° with vertical

Fig. 4. Proving ring and LVDT arrangement for various loading condition

4. Numerical Modeling using Plaxis 3D

Numerical model of current model helical piles was modelled in PLAXIS 3D. Sand and pile properties used in analysis part is listed in (Table 1). Soil is modelled using Mohr-Coulomb Model and helical pile was made using plate element to create hollow shaft. Modulus of Elasticity is derived from stress strain curve.

Table 1. Sand and Pile Properties used in Plaxis 3D

Properties	**Values**
Drainage type	Drained
Unit weight of soil (γ)	16.5 kN/m^3
Modulus of elasticity of soil (E)	40,076 kN/m^2
Poisson's ratio (υ)	0.3
Internal frictional angle (ϕ)	36°
Pile Material model	Elastic
Pile Thickness	3 mm
Unit weight (γ) of Pile material	78.5 kN/m^3
Modulus of Elasticity (E) of Pile material	210,000 kN/m^2

In modelling of helical pile due to drawing limitation of PLAXIS 3D helical plates are considered as flat plates (Fig. 5).

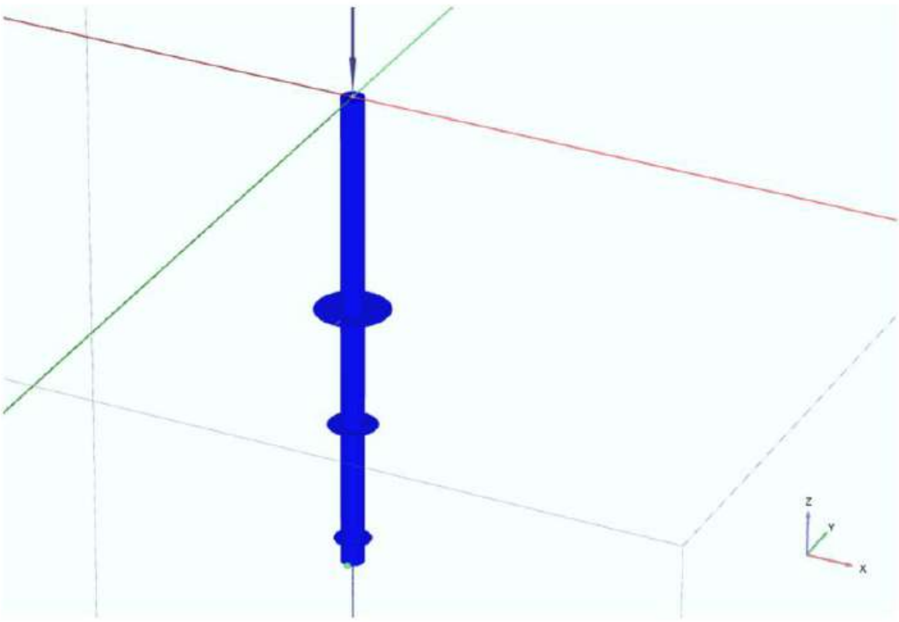


Fig. 5. Helical pile model as plate element in PLAXIS 3D

The below figures show the deflection pattern for the piles P1 and P2 when they are loaded at 0°, 45° and 90° degrees to the vertical (Fig. 6- Fig. 11). In case of pile P1 which has smaller diameter of helical plate at the bottom shows almost uniform deflection pattern at the end and periphery of the pile as compared to the pile P2 which shows maximum deflection at the ends as compared to its periphery when they are loaded at 0° to the vertical. For the loads applied at 45° and 90° to the vertical, the deflection is more in the pile P2.

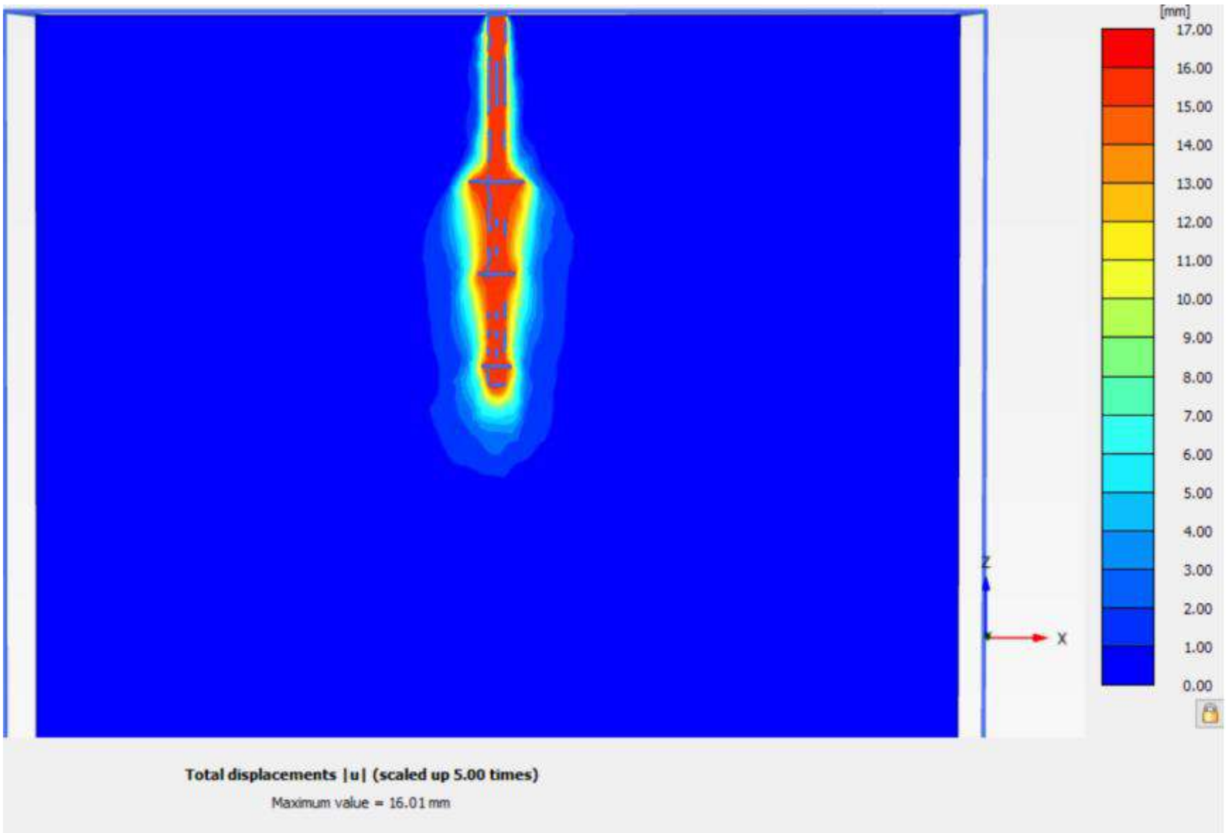


Fig. 6. Deformed soil strata due to vertical loading condition in PLAXIS 3D for P1

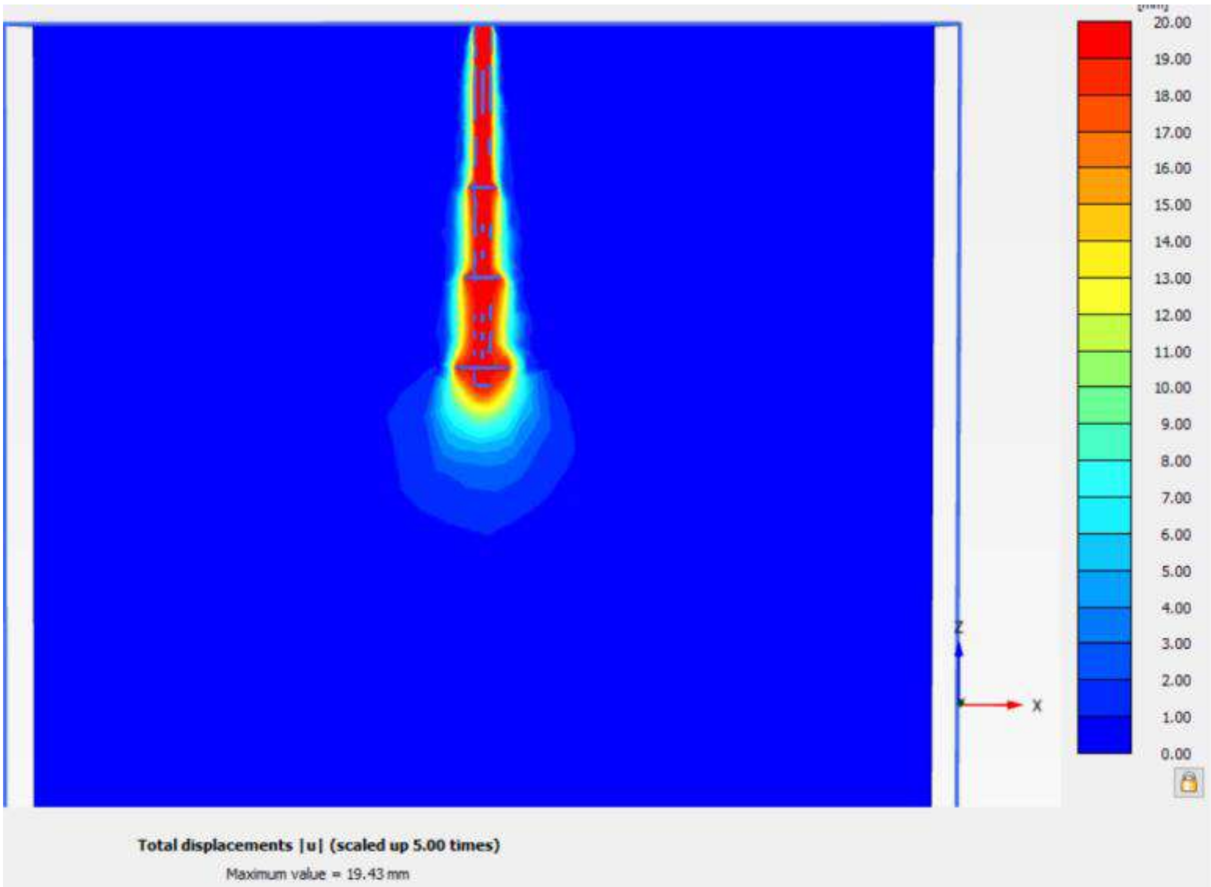


Fig. 7. Deformed soil strata due to vertical loading condition in PLAXIS 3D for P2

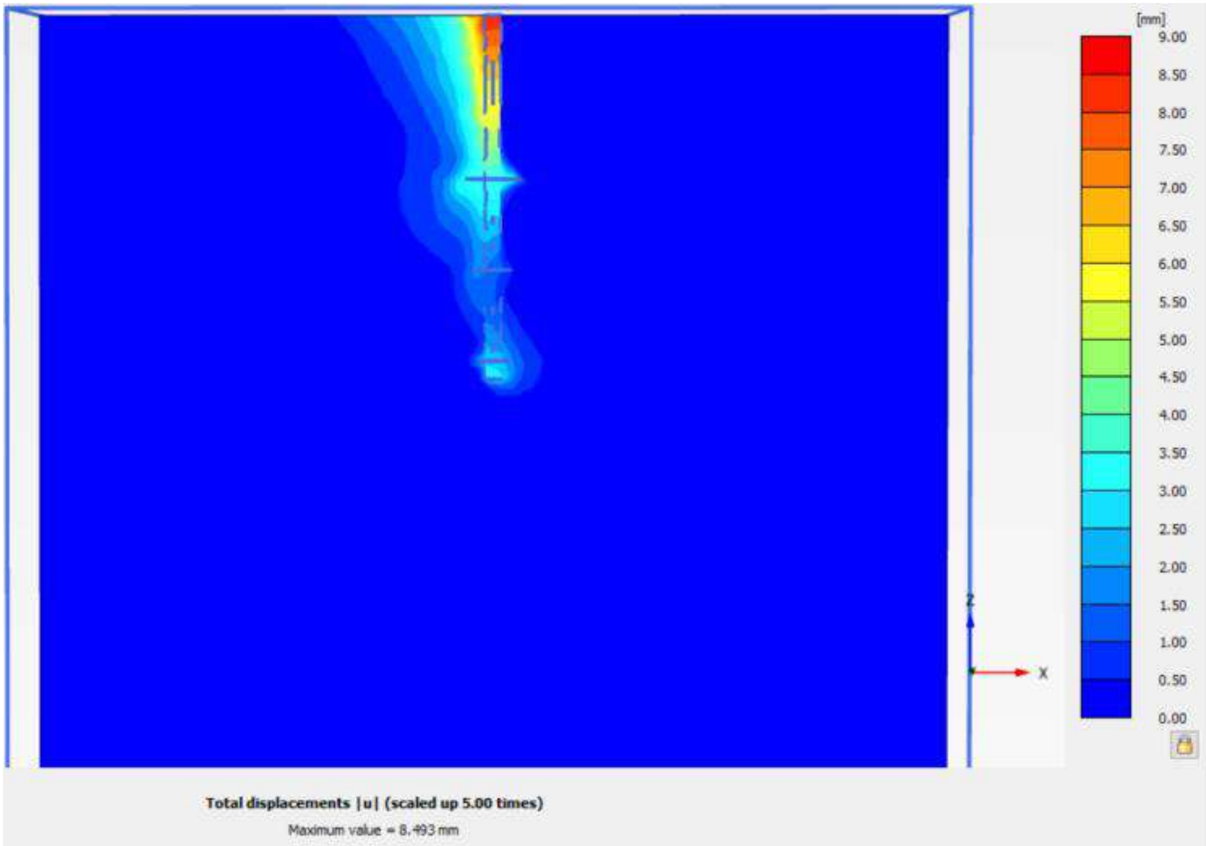


Fig. 8. Deformed soil strata due to 45º inclined loading condition in PLAXIS 3D for P1

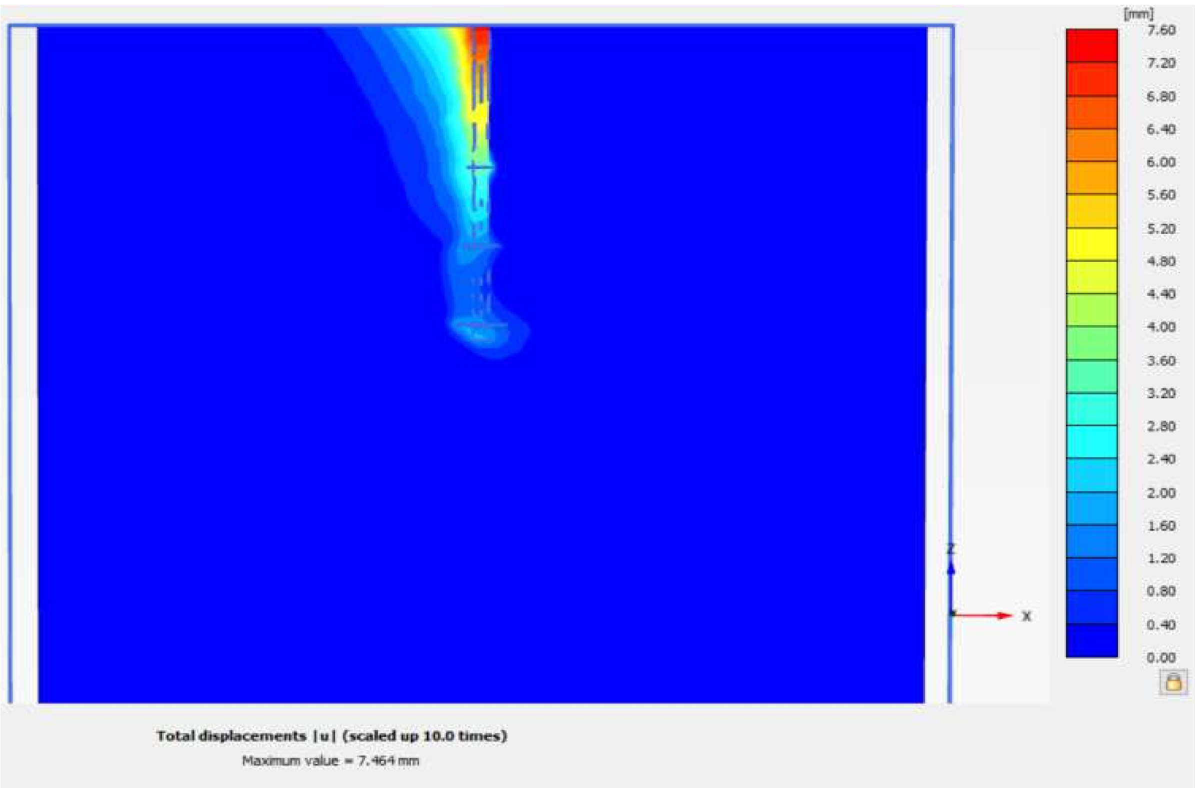


Fig. 9. Deformed soil strata due to 45º inclined loading condition in PLAXIS 3D for P2

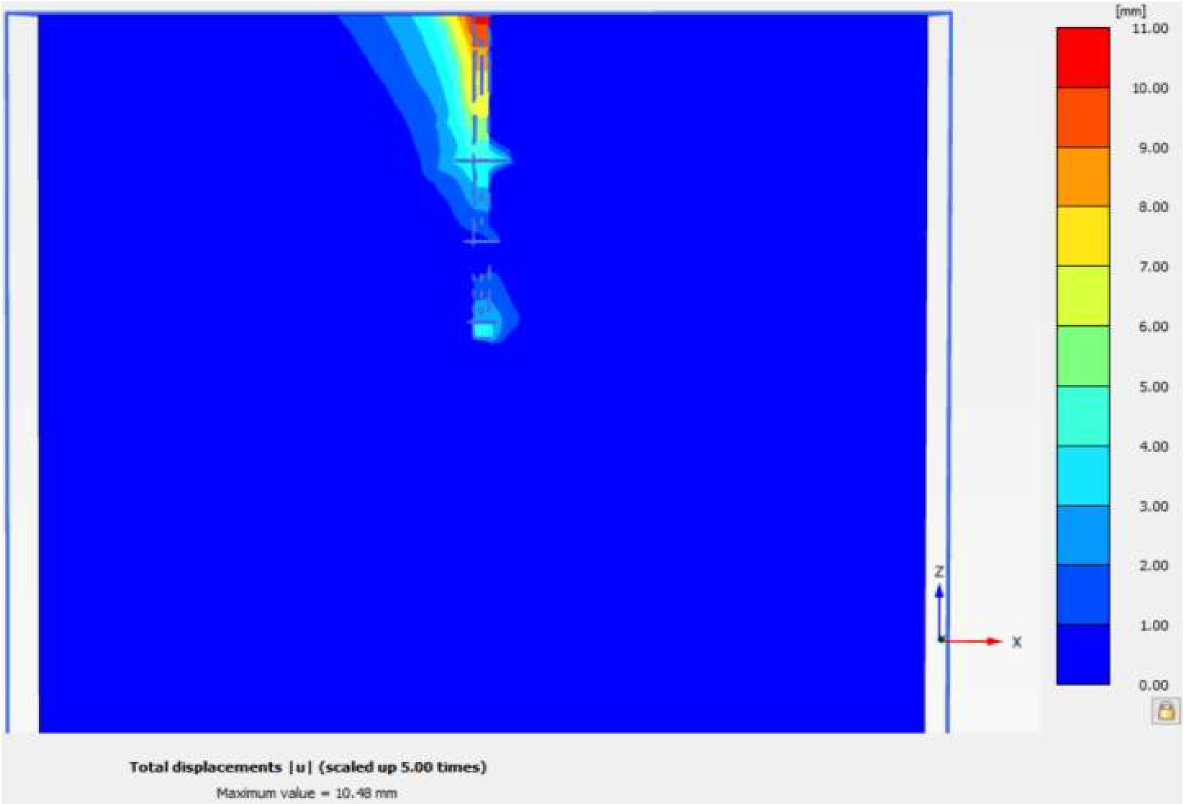


Fig. 10. Deformed soil strata due to 90º inclined loading condition in PLAXIS 3D for P1

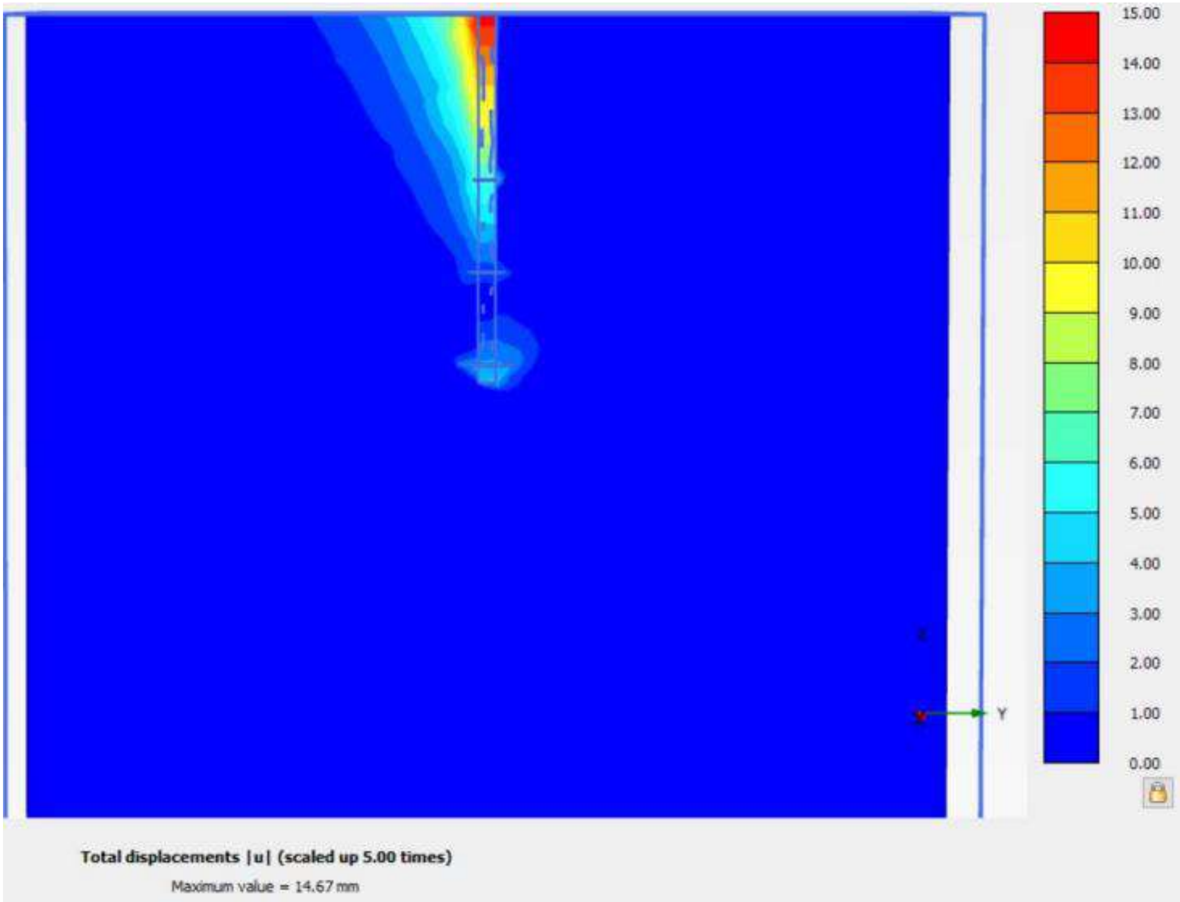


Fig. 11. Deformed soil strata due to 90º inclined loading condition in PLAXIS 3D for P2

5. Findings and Analysis

5.1 Experimental results of both the piles

We can see that as the load increases on the pile top, so does the displacement of the pile top. Initially this increase in the displacement is gradual; with further increase in loading, it turns curvilinear with convex upward. With addition in loading, it turns into straight line with high rate of progressive settlement. As the load inclination with vertical axis increases, the load carrying capacity decreases and the curves falls down towards the displacement axis (Fig.-12, Fig.-13).

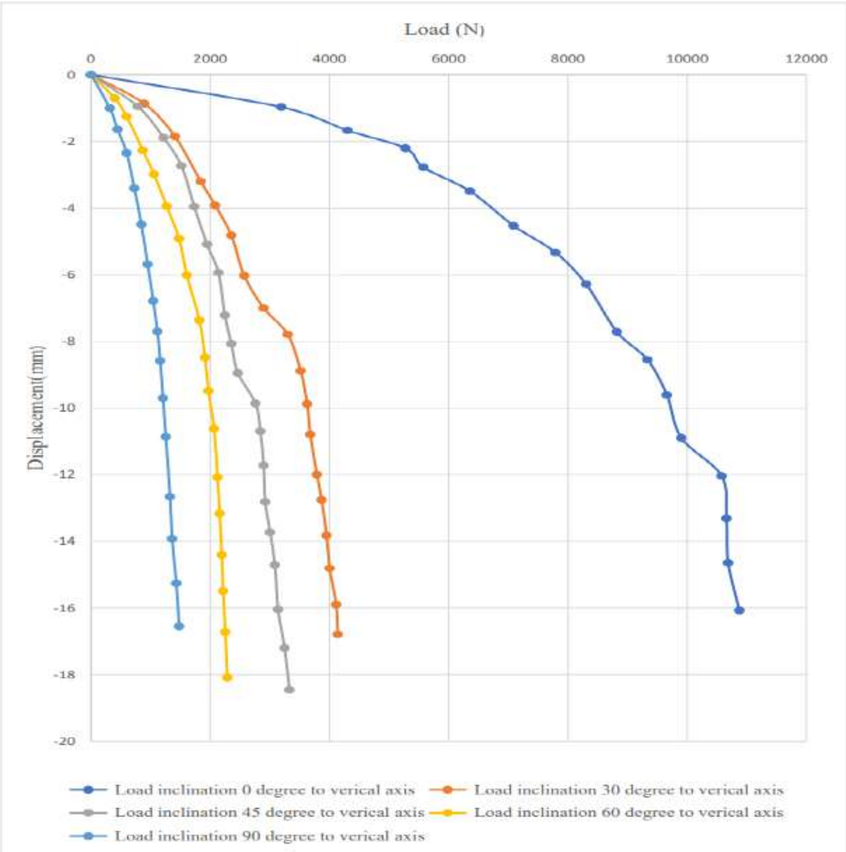


Fig. 12. Load(N) versus Displacement(mm) of the pile P1

5.2 Results of Numerical Analysis on both the piles

From numerical models in PLAXIS 3D for piles P1 and P2 (Fig.-14 & Fig.-15) shows load versus pile head displacement in the direction of load having diameter 30 mm and embedded length 60 cm at load inclinations 0º, 30º, 45º, 60º and 90º with vertical axis. It can be observed that as the load on pile top increases the displacement of pile top also increases. Initially this increase in the displacement is gradual with increase in loading which is curvilinear with convex upward. With further progress of loading, it turns into straight line with high rate of progressive displacement. As the load inclination with vertical axis increases, the load carrying capacity decreases and the curves falling down towards the displacement axis.

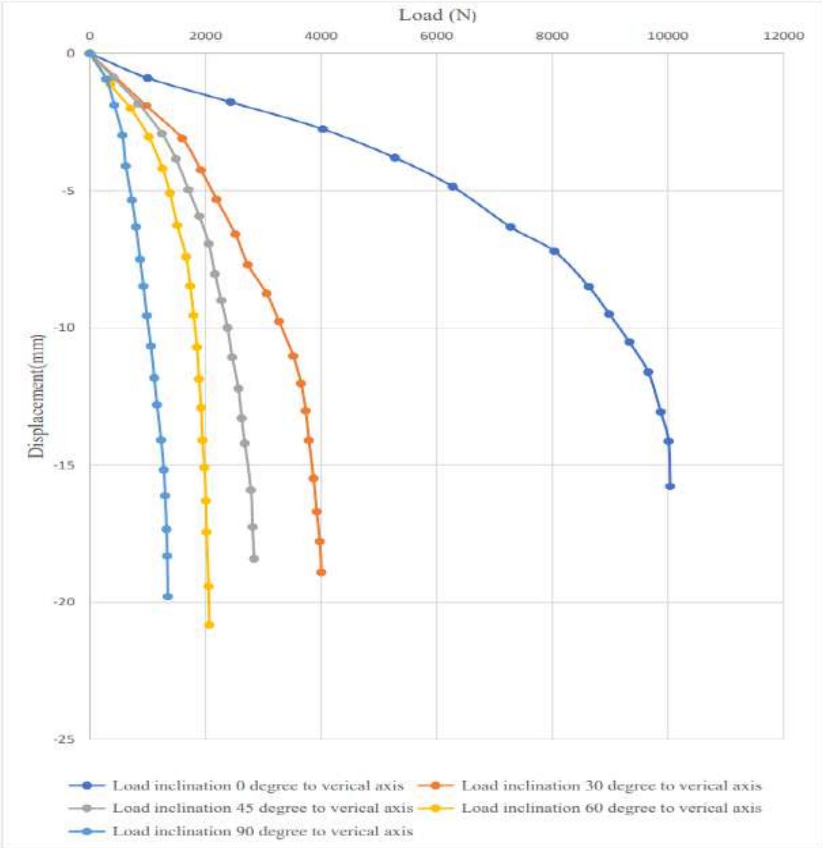


Fig. 13. Load(N) versus Displacement(mm) of the pile P2

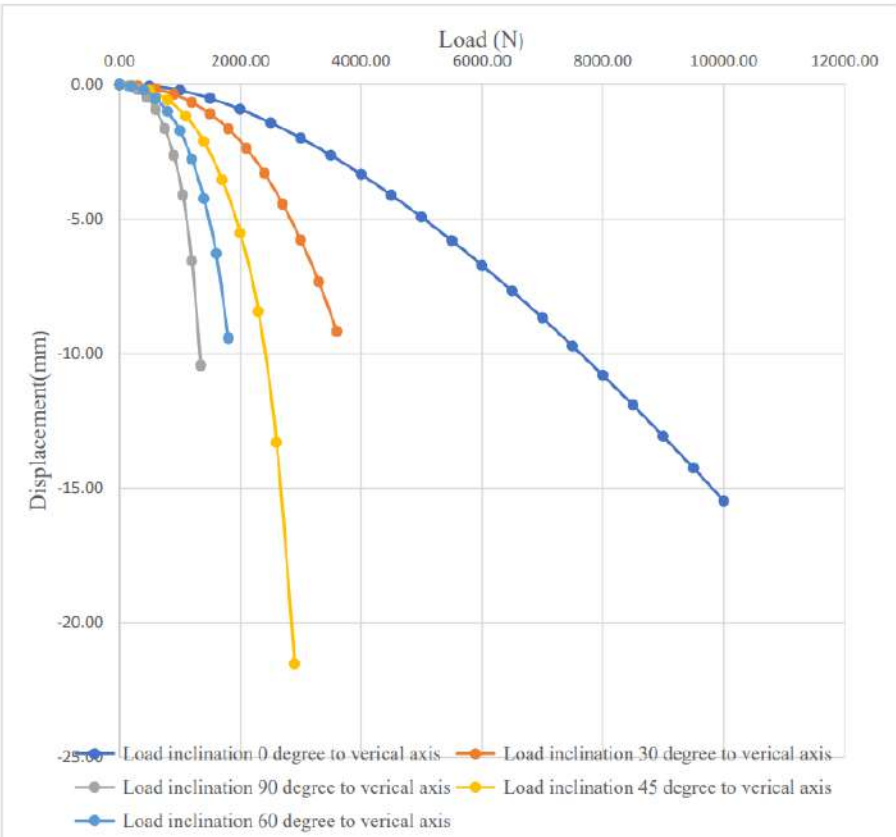


Fig. 14. Load(N) versus Displacement(mm) of the pile P1 from PLAXIS 3D

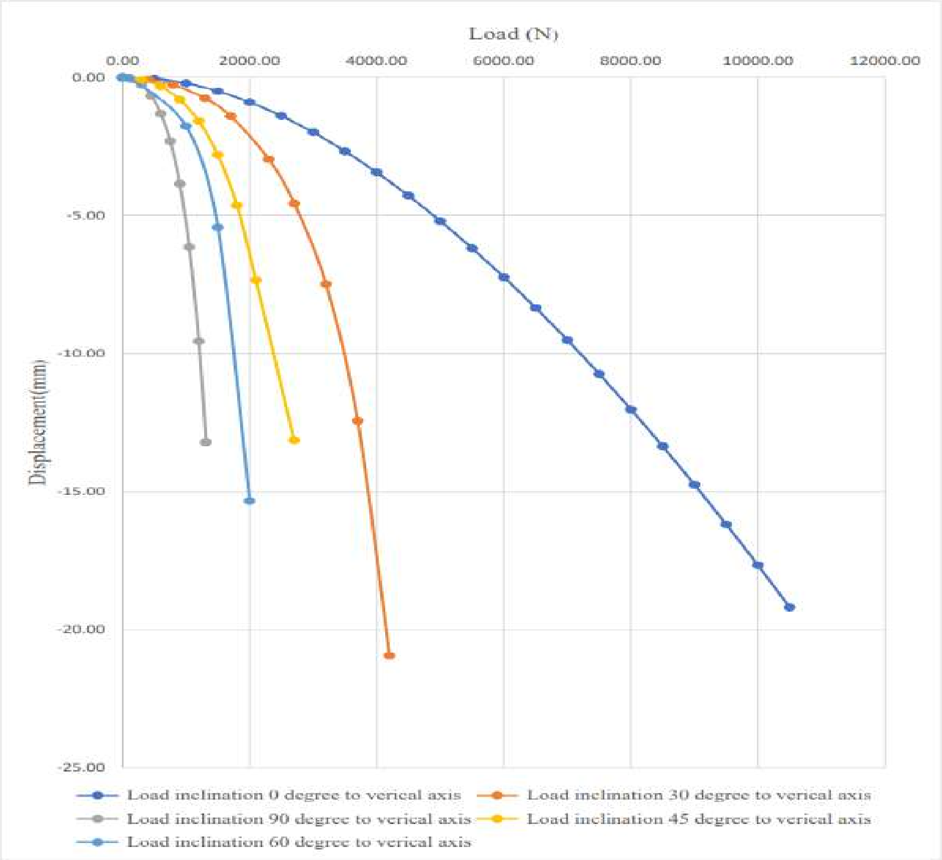


Fig. 15. Load(N) versus Displacement(mm) of the pile P2 from PLAXIS 3D

5.3 Comparison of Experimental and Numerical Approach of both the piles at various load inclinations

Results from experiments and PLAXIS 3D are compared in Fig.-16 and Fig.-17 at various load inclinations like 0º, 30º, 45º, 60º and 90º. The curves show approximate same behaviour of helical piles under various load inclination for both the piles.

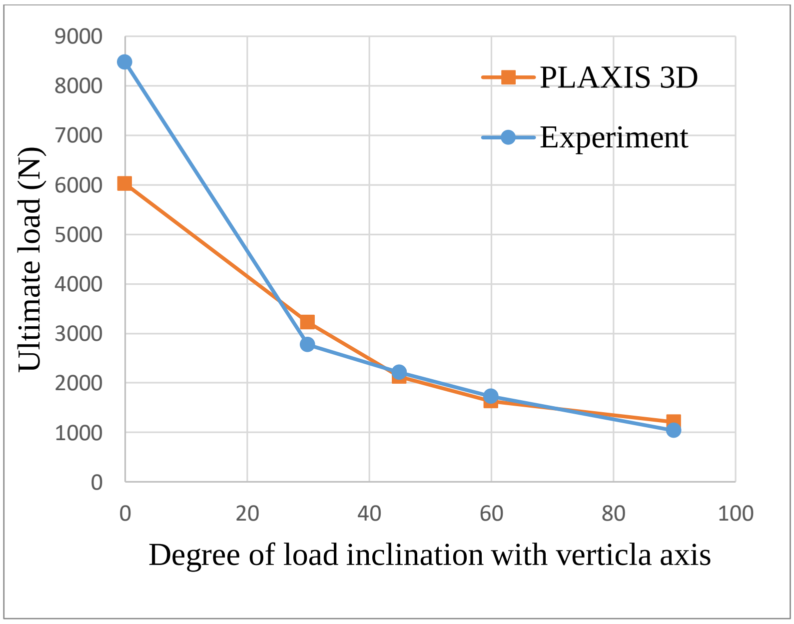


Fig. 16. Comparison of Ultimate Load v/s Degree of load inclination of Experimental results and PLAXIS 3D of Pile P1

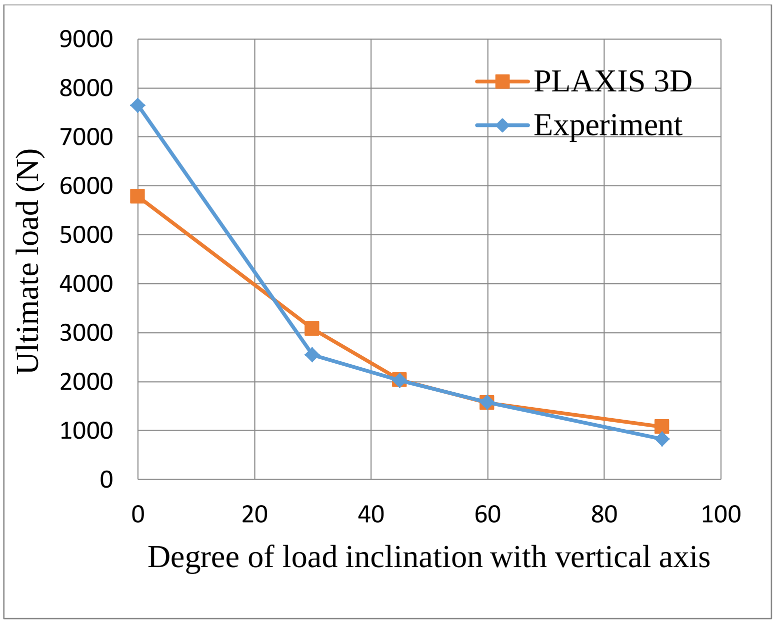


Fig. 17. Comparison of Ultimate Load v/s Degree of load inclination of Experimental results and PLAXIS 3D of Pile P2

5.4 Effect of arrangement of Helical Plates

To carryout effect of helical plates arrangement, experiments are performed on two different helical plate arrangements. The pile P1 has bigger helical plate of 3d (90mm) diameter at top and small plate of 1.5 d (45 mm) diameter at bottom. The pile P2 has smaller helical plate of 1.5d (45 mm) diameter at top and big plate of 3d (90mm) diameter at bottom. (Fig.18) shows comparison between the piles P1 and P2.

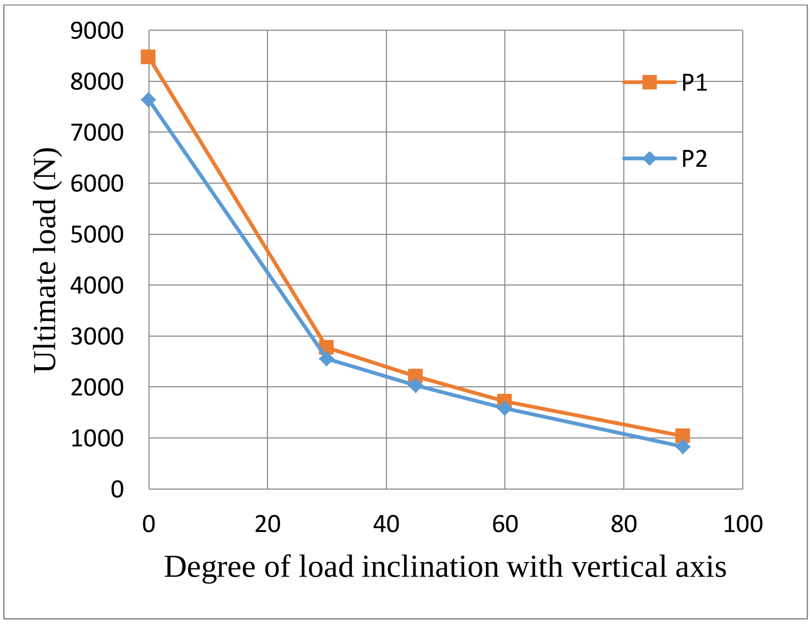


Fig. 18. Ultimate Load comparison between P1 and P2 from experiments

From comparison curves it can be observed that helical pile P1 shows slightly higher capacity as compare to pile P2 in experiments as well as in numerical modelling.

6. Conclusion

In this experimental study helical pile behaviour under different load inclination with vertical axis and different helical plate arrangement was analysed.

Important findings from the current study includes the following:

1. When inclination of load increases from 0º to 90º with vertical axis on pile head, Helical pile's carrying capacity declines and the load displacement curves display stiffer behaviour initially when load applied concentric along the pile axis. With increase in inclination of load with vertical axis, the curves show reduction in stiffness which are leaning towards displacement axis.
2. Ultimate loads decrease rapidly as inclination increases from vertical to 30º on pile head which decreases gently with further inclination of load from 30º to 90º with vertical on a pile head.
3. From experimental result we can say that pile P1 having smaller diameter helical plate at the bottom has slightly more capacity as compared to pile P2. The reason for the same may be the skin friction and end bearing in case of pile P1 is mobilised uniformly whereas in pile P2 the end bearing component is more utilised as seen from figures obtained from numerical analysis.
4. The results of ultimate load using numerical analysis by PLAXIS 3D of piles P1 and P2 agrees well with those obtained from experimental results for axial loading. As the load inclination increases with vertical axis both the results are matching well with each other.

Acknowledgement

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