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Effect of Relative Density, Arrangement of Helical Plates and Load Inclination on Carrying Capacity of Helical Pile

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ABSTRACT

This research mainly aimed to study the response of two model helical piles of 60cm length and 3.0 cm outer diameter embedded in poorly graded (SP Type) sand at 20% and 40% of relative density under vertical as well as inclined loading. Laboratory tests on helical piles with different helices diameters and different arrangement of helices under various loading condition at different relative density were carried out. The effects of the different arrangement of helices, different soil density was monitored and comparative study between helical piles were accomplished. It was concluded that bearing capacity of helical pile decrease with increase in load inclination with vertical axis. Also load carrying capacity of pile tested at 20% relative density is less than the pile tested at 40% relative density.

Keywords: Helical Pile; Helical Plate; Inclined Loading; Pile head Deflection; Relative density

INTRODUCTION

The solid/hollow central shaft with one or more helical flights welded near the pointed toe (for easy installation) or along the shaft at particular interval is defined as helical pile. They are innovative and versatile solutions for stabilizing structures and transferring loads to the soil.The helical piles are installed into the ground by applying rotating moment (torque) to their shafts. The helical shaped, self-propelled anchor element generates drag forces, which help the pile penetrate into the soil. Helical pile foundation became very popular, where is need of counteract uplift pressure or required anchors to support foundation.Due to ample of its benefits like easy installation, environmentally sound, minimal noise & vibration, etc. there is an exponential surge in the field of helical pile.

Elements of helical pile are shown in fig. 1.1.

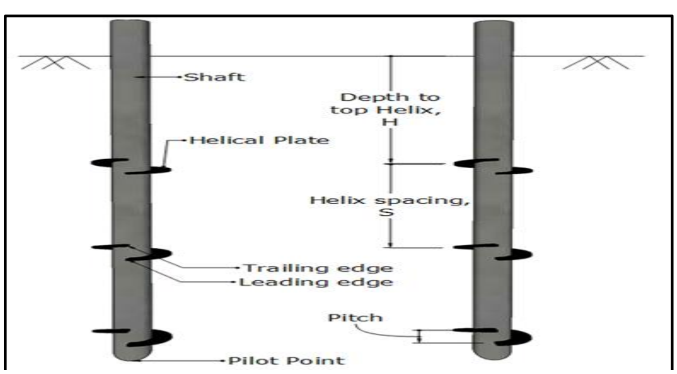


Fig. 1.1: Elements of Helical pile

MATERIAL OF INVESTIGATION

Soil

The soil for this experiment work was brought from orsang river, bhadarpur, vadodara, gujarat, which was naturally dried. The various index and engineering properties were determined by laboratory tests based on IS 2720-4(1985), IS 2720-13(1986), IS 2720-14(1983), IS2911-3(1980), IS 2911-4(2013), IS 2386-2(1980), properties are described in below table:

Table 1: Soil Properties

Soil Type	Poorly Graded Sand (SP)
D_{10}	0.442
D_{30}	0.702
D_{60}	1.161
Coefficient of Uniformity (Cu)	2.627
Coefficient of Curvature (Cc)	0.961
Specific Gravity(G)	2.68
Silt Content, %	2.423
Minimum Dry Density, (γ_{dmin})	14.91 kN/m^3
Maximum Dry Density, ($\gamma_{dmax\backslash}$)	18.11 kN/m^3
Sand Density, γ_d	15.48kN/m^3@20% I_D 16.03kN/m^3@ 40% I_D
InternalFrictional Angle, ϕ	29°@15.48kN/m^3 31°@16.03kN/m^3

EXPERIMENTAL STUDY

Model Tank Specification

To perform pile load test on model helical pile, square model tank was used having dimension of 1.5m×1.5m ×1.5 m. Semi-circular loading frame was attached to model tank which has hydraulic assembly for movement of frame and hydraulic jack was also attached to loading frame to apply load at desire inclination. Proving ring having capacity of 25kN (PRC= 27.0592 N/div.) was used to take measurements of applied load. LVDT having sensitivity of 0.01 mm and Capacity of 100 mm was used to measure displacement.

Fig 3.1: Model Foundation Tank

Helical Pile and Helical Plate Specification

- Length of pile = 60 cm
- Diameter of pile
  Outer dia. = 3.0 cm
  Inner dia. = 1.5 cm
- Helix diameter =1.5d(4.5 cm)
  =2.0d(6.0 cm)
  =3.0d(9.0 cm)
- Spacing
  of helices = 15 cm

Fig3.2: Model Helical Piles

Each pile has 3 number of helical plates with diameter of 1.5d, 2d, 3d which is 45mm, 60mm and 90mm. One of these piles (P1) has bigger helical plate (90 mm) at top and at the spacing of 150 mm other two helical plates are attached in decreasing size. Whereas other pile (P2) has smaller helical plate (45mm) at top and at the spacing of 150 mm other two helical plates are attached in increasing order.

Table 3.1: Nomenclature and specifications of Helical pile

Pile Type	Length (mm)	Diameter of pile (mm)	Number of helices	Arrangement of helical plates (From top to Bottom)	Diameter of helices (mm)	Spacing Between helices (mm)
P1	600	30	3	Bigger to Smaller	Top=90 Middle= 60 Bottom=45	150
P2	600	30	3	Smaller to Bigger	Top=45 Middle= 60 Bottom=90	150

Experimental Procedure

The tests were performed on P1 & P2 piles two helical piles with different relative density of sand (20% & 40%). Load was applied at various degree of inclination viz:0°,30°,45°,60°,80° with respect to vertical axis.

The sand was filled in a tank in 10 cm layers and each layer was filled by means of free fall from hopper to achieve 20% of relative density and free fall with small amount of vibration with surface vibrator for 40% relative density. Sand was filled till level of pile head in model tank.

Sand layers were placed untill pile can be embedded up to 150 mm then after pile is pre-installed applying rotating motion in sand bed. Pile was kept vertical with help of levelling tube and centring is done using plumb bob.

Pile top was attached to the proving ring with help of ball socket joint mechanism (ball socket joint can be seen in figure 3.4,3.5&3.6), for the application of vertical as well as inclined loading.

Flat square plate was placed between proving ring and ball socket joint for measurement of displacement and for inclined loading condition 3 mm thick mild steel strip was used for measuring the displacement of pile head in the direction ofinclined load

For loading, hydraulic jack and pile top were aligned with plumb bob in vertical line. For the inclined loading the hydraulic jack adjusted on semi-circular loading frame as desired inclination of loading. The care was taken while applying load such that line of action of applied load should pass through the centre of pile head.

Two LVDTs of capacity 100 mm with sensitivity of 0.01 mm were used to measure displacement of pile head in the direction of load.

As per IS-2911 (4), Maintained Load Test (MLT) method was used for all test performed in laboratory. In following procedure, load was applied for approximately 1 mm displacement and that load was maintained till rate of displacement of the pile top is either 0.02 mm in first 30 minutes or 0.04 mm in first one hour whichever occurs first.

After displacement get stable reading were taken for load from proving ring and displacement of pile head in the direction of load was recorded from LVDT.

Test was continued in this way with successive load increments till the load becomes constant or with progressive higher displacement.

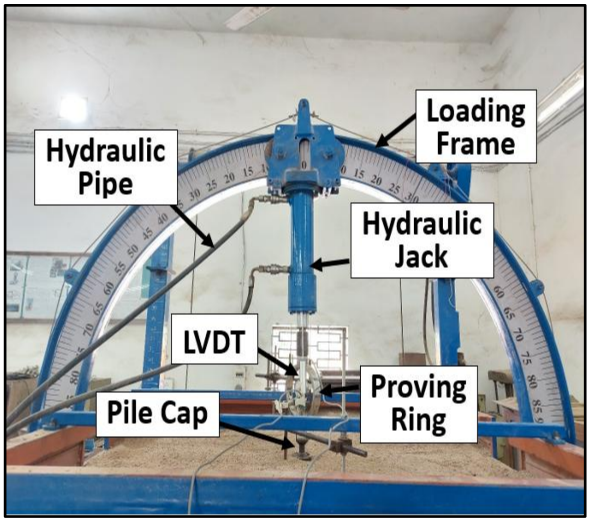


Fig. 3.3: Test set up during vertical loading condition

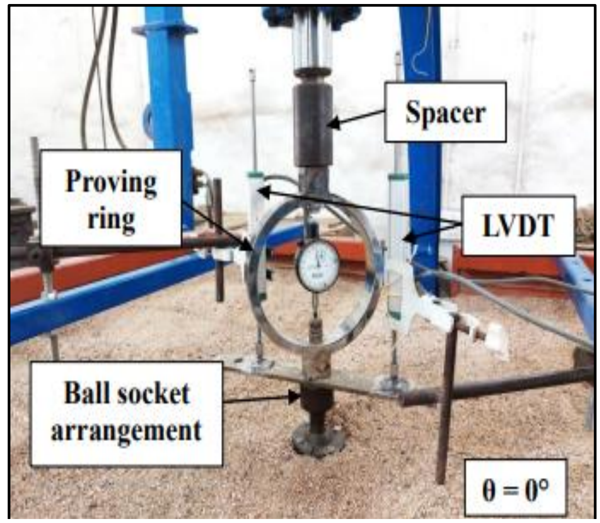


Fig. 3.4: Proving ring & LVDT arrangement for vertical loading condition

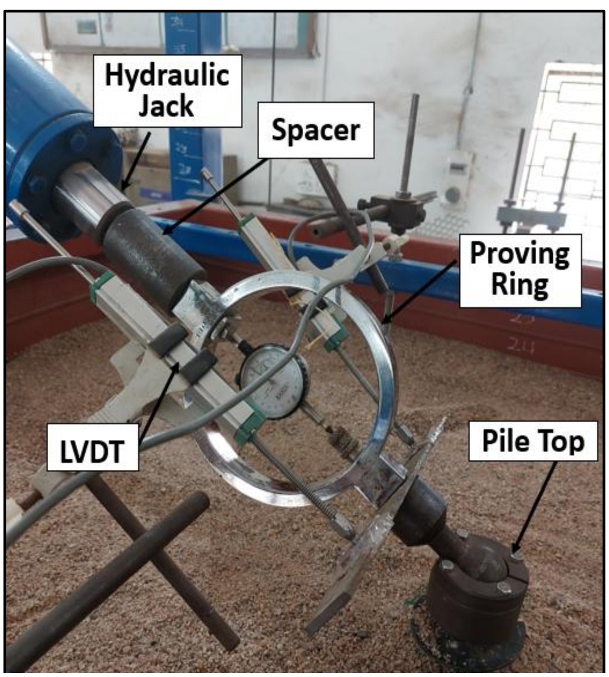


Fig. 3.5: Proving ring & LVDT arrangement for load inclination 45° to vertical axis

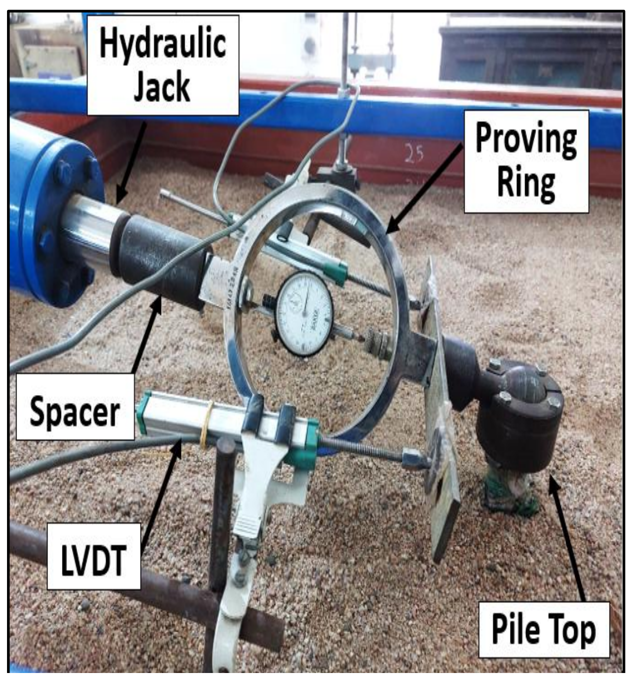


Fig.3.6: Proving ring & LVDT arrangement for load inclination 80° to vertical axis

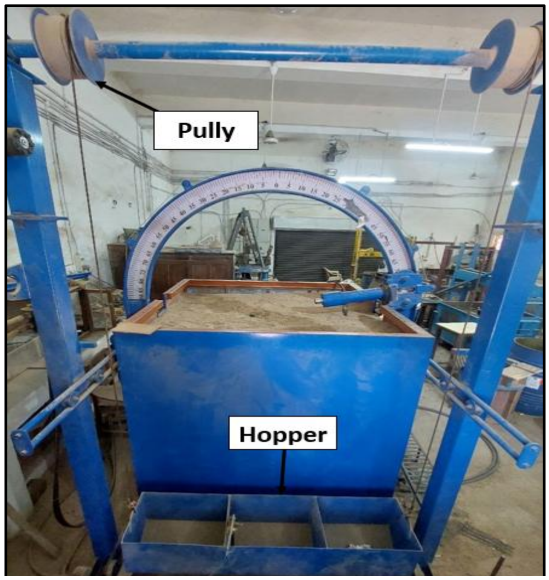


Fig. 3.7: Hopper & Pully arrangement for sandraining

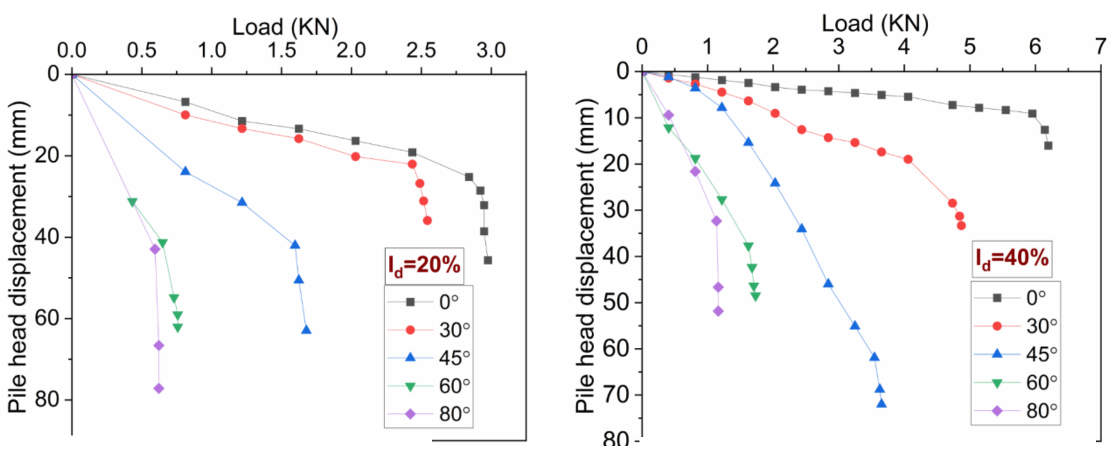
RESULTS AND ANALYSIS

In all, total 20 experiments were conducted and for each load vs pile head displacement in the direction of load curve was plotted to determined ultimate load carrying capacity of soil, then comparison has been done with different relative density and different helical piles.

LOAD VS PILE HEAD DISPLACEMENTIN THE DIRECTION OF LOAD CHARACTERISTICS

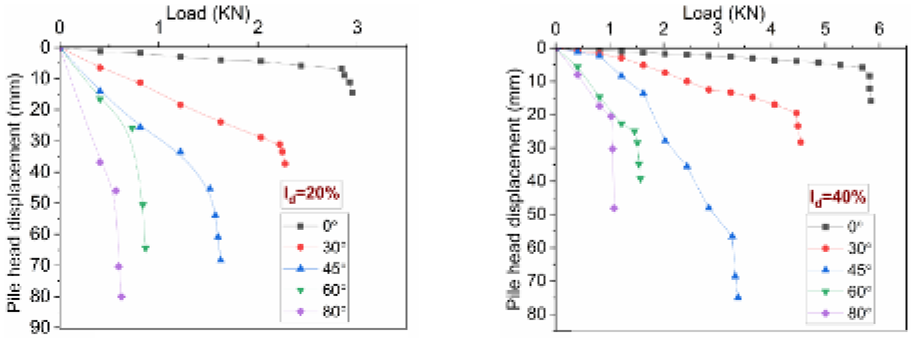
Effect of Load Inclination

For analysing the effect of load inclination, experiments wereperformed in laboratory on pile P1 and P2 at 20% and 40% relative density at load inclination at 0°, 30°, 45°, 60°,80° with vertical axis.The curves are presented for P1 pile in figure 4.1 and those for P2 pile are presented in figure 4.2. 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 was at very slow rate. 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.



a) Relative density=20% **b) Relative density=40%**

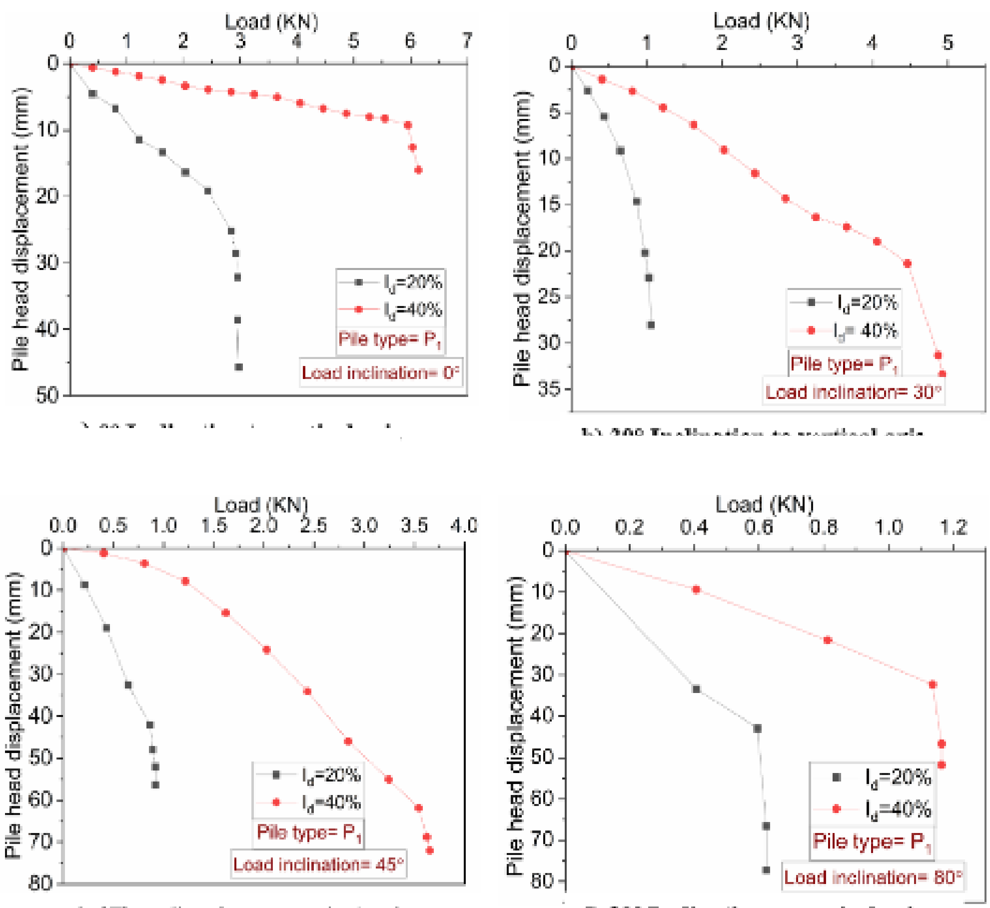
Fig.4.1: Load vs. displacement of pile head in direction of load curves for "P1 pile" having bigger to smaller arrangement with various load inclination as 0°,30°,45°,60° and 80° at 20% and 40% relative density



a) Relative density=20% b) Relative density=40%

Effect of Relative Density

To carryout effect of relative density, experiments were performed on two different helicalpile at 20% and 40% relative density. The curves are presented for P1 pile in figure 4.3 and those for P2 pile are presented in figure 4.4. From result it can be observed that the load carrying capacity of helical pile tested at 20% relative density is nearly half of the pile tested at 40% relative density and settlement in more than the helical pile tested at 40% relative density. In case of vertical loading condition curve initially displays stiffer behaviour in case of pile tested at 40% relative density than pile tested at 20% relative density, as the degree of inclination increases, curves falling down towards displacement axis.



c) 45° Inclination to vertical axis d) 80° Inclination to vertical axis

Fig.4.3: Load vs. displacement of pile head in direction of load curves for P1 pile having bigger to smaller arrangement at 20% and 40% relative density at inclination of 0°,30°,45°,80° to vertical axis

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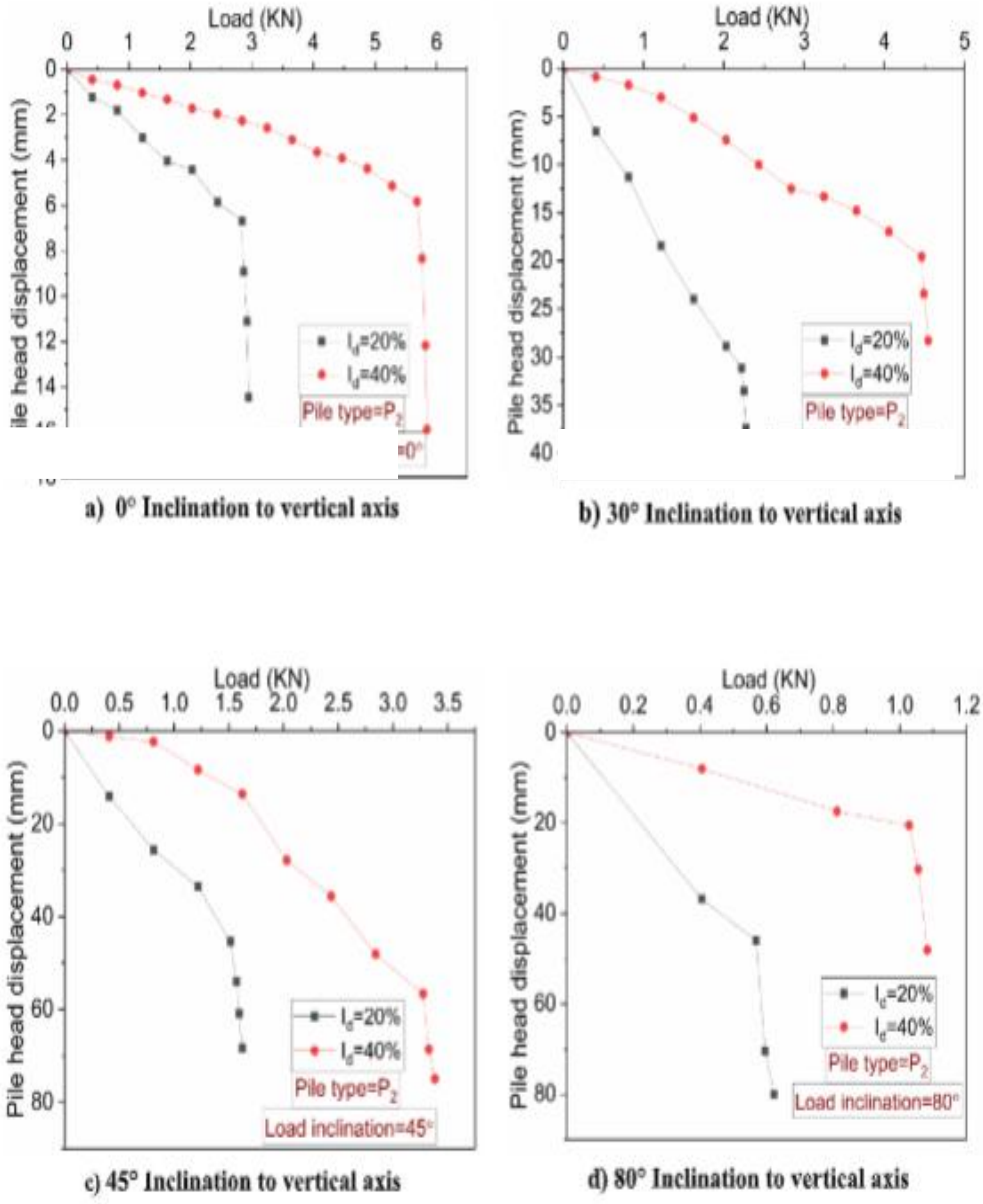

Fig.4.4: Load vs. displacement of pile head in direction of load curves for P2 pile having bigger to smaller arrangement at 20% and 40% relative density at inclination of 0°,30°,45°,80° to vertical axis

Effect of Arrangements of Helical Plates

To carryout effect of helical plates arrangement, experiments were performed on two different helical plate arrangements at 20% and 40% relative density.Figure 4.5 shows results at 20% relative density and figure 4.6 shows results at 40% relative density.P1 has bigger helical plate of 3d (90mm) diameter at top ,2d (60 mm) diameter at middle and small plate of 1.5d (45 mm)diameter at bottom and P2 has smaller helical plate of 1.5d diameter at top, 2d dia. at middle and big plate of 3d diameter at bottom. Bothpiles show nearly same behaviour but Pile P1 shows slightly more load carrying capacity than the Pile P2 and less settlement compared to P2 in case of vertical loading.

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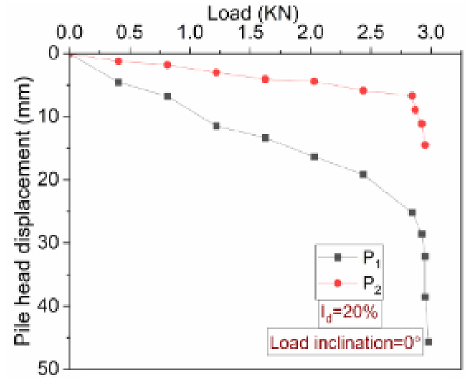
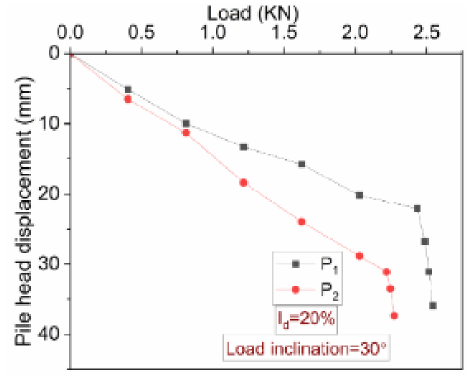
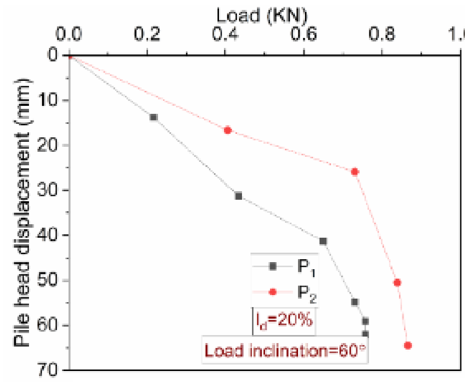


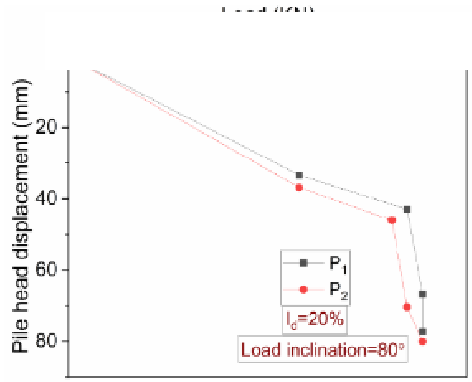
a) 0° Inclination to vertical axis



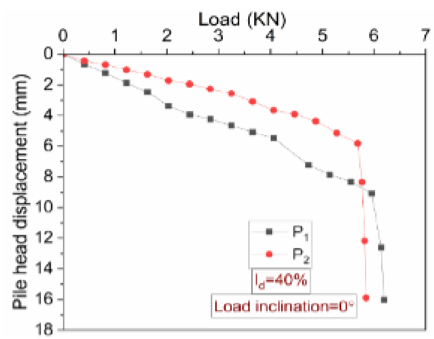
b) 30° Inclination to vertical axis



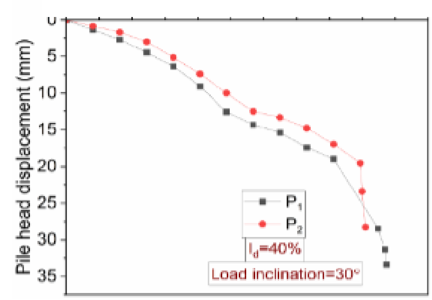
c) 60° Inclination to vertical axis



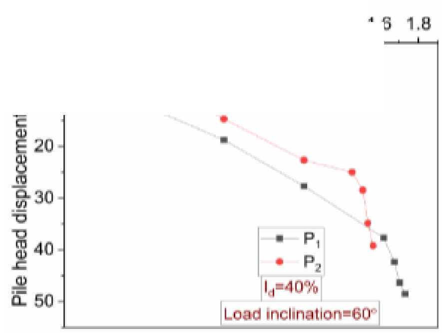
d) 80° Inclination to vertical axis



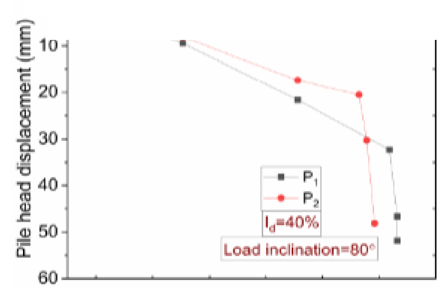
a) 0° Inclination to vertical axis



b) 30° Inclination to vertical axis



c) 60° Inclination to vertical axis



d) 80° Inclination to vertical axis

Ultimate Load Characteristics

Experiments were performed on two model helical piles of different helical arrangements under various load inclination. Sand density was kept 20% and 40% for finding effect of relative density. While performing all the experiments, pile was pre-installed. The values obtained from experiments done at 20% Relative density are listed in table 4.1 and value obtained from experiments done at 40% Relative density are listed in table 4.2. From Figure 4.7 and 4.8, it can be observed, that Pile P1 and P2 at 40% relative density have nearly 50% more load carrying capacity than pile tested at 20% relative density.

From Figure 4.8 and 4.9, it can be seen that both piles (P1 & P2) have nearly same ultimate load at 20% and 40% relative density with P1 has slightly more load carrying capacity than P2.

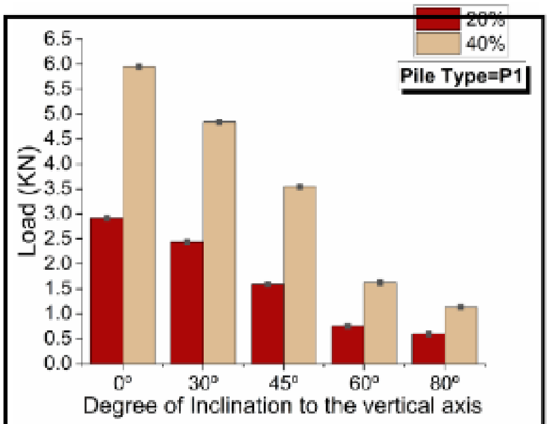


Fig.4.7: Ultimate Load comparison of P1 between 20% and 40% relative density

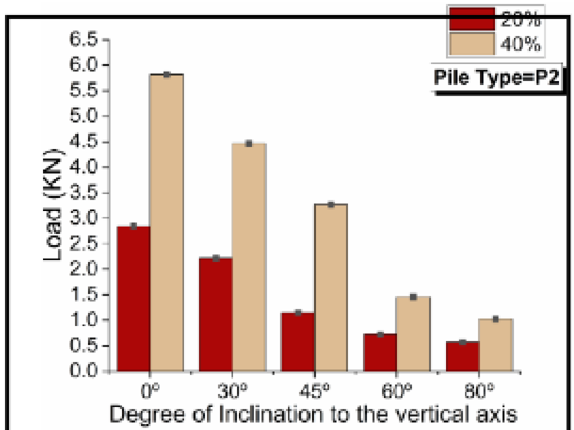


Fig.4.8: Ultimate Load comparison of P2 between 20% and 40% relative density

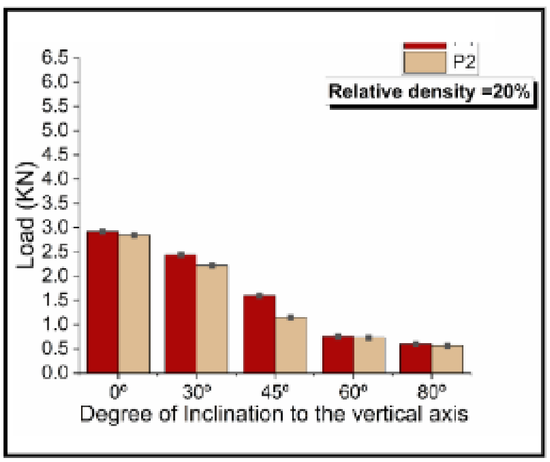


Fig.4.9: Ultimate Load comparison of P1& P2 between 20% relative density

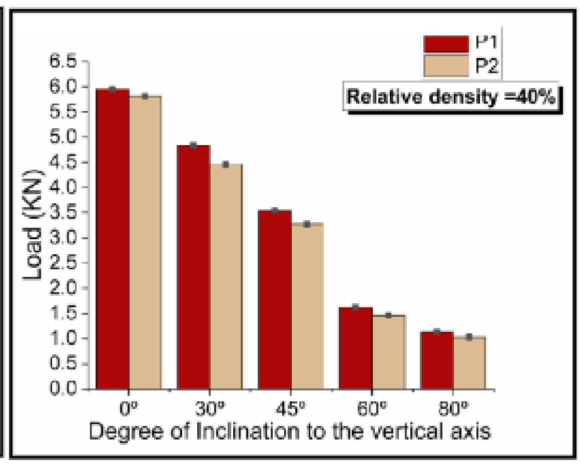


Fig. 4.10: Ultimate Load comparison of P1& P2 between 40% relative density

Table 4.1 Ultimate load of Helical Piles at 20% Relative Density

I_d=20%	Load Inclination to Vertical Axis				
Pile Type	0°	30°	45°	60°	80°
P1	2.920 KN	2.435 KN	1.596 KN	0.757 KN	0.595 KN
P2	2.847 KN	2.218 KN	1.151 KN	0.730 KN	0.568 KN

Table 4.2 Ultimate load of Helical Piles at 40% Relative Density

I_d=40%	Load Inclination to Vertical Axis				
Pile Type	0°	30°	45°	60°	80°
P1	5.952 KN	4.841 KN	3.544 KN	1.623 KN	1.136 KN
P2	5.817 KN	4.464 KN	3.274 KN	1.461 KN	1.028 KN

CONCLUSION

In this experimental study single helical pile behaviour under different load inclination with vertical axis was analysed. Helical pile used in this study was made of mild steel helical plates attached to it with various arrangement. Total 20 Number of experiments were performed for various combination of helical plate arrangement and load inclination.

The summary of findings and their salient conclusions are discussed below.

- When inclination of load increases to 0º to 80º with vertical axis, the carrying capacity of helical pile decreases and the load displacement curves display stiffer behaviour initially when load applied concentric along the pile axis at 40% relative sand density, and load displacement curves display less stiffer behaviour at initial stage in case of pile tested at 20% relative sand density. With increase in inclination of load with vertical axis, the curves show reduction in stiffness which are leaning towards displacement axis.
- Ultimate loads decrease rapidly as inclination increases from vertical to 30º with vertical on pile head which decreases gently with further inclination of load from 30º to 80º with vertical on a pile head. Also load carrying capacity of piles tested at 20% relative density is almost half of the piles tested at 40% relative density at various load inclination, same behaviour can be seen in each pile.
- From experimental result we can say that P1 having helical plate arrangement bigger to smaller from top to bottom of pile has more load carrying capacity as compared to P2 which was having smaller to bigger arrangement of helical plate from top to bottom of helical pile.

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STATEMENTS & DECLARATIONS

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Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Pooja J. Bhojani, Vedant H. Dave and Dr. Nitinkumar H. Joshi. The first draft of the manuscript was written by Vedant H. Dave and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability

The data and material generated during and/or analysed during the current study are available from the corresponding author on reasonable request.