Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Visakhapatnam Chapter

Experimental Investigation on Performance of Helical Pile in Cohesionless Soil

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Abstract. Structures such as transmission towers, high-rise buildings, offshore structures and suspension bridges are subjected to uplift, compressive forces and overturning moment due to wind or waves. Helical pile is a popular foundation choice in many countries and used to resist uplift, compressive forces and overturning moment. Helical piles are easy to install without generating the spoils and can take load immediately after the installation that offer the cost-reducing alternative methods to reinforced concrete grouted anchors and driven piles. In this paper, to study the behavior of helical pile in sand, laboratory tests are conducted on small scale model piles of mild steel by varying the loading conditions and helical blade diameter. Results obtained from the tests are compared with conventional hollow pile. The length of pile, relative density, type of soil and pitch distance are kept constant during investigation. The provision of such helices may provide an ideal anchorage system because of the significant locking up effect of the soils within the helices, resulting in increased pile capacity.

Keywords: Model Test, Helix, Helical Pile, Sand, Deep Foundation.

1 Introduction

Helical piles were invented by Alexander Mitchell in 19th century. This pile type was first used as the foundation for Maplin Sands Lighthouse in England. Helical pile is made up of steel shaft either a solid square shaft or a circular pipe with one or more helices welded to it with required pitch distance. They are installed into the soil by applying a torque to the upper end of the shaft. Helical piles are used to resist uplift, compressive forces and overturning moment. They are used in the construction of structures such as telecommunication and power transmission towers, machine foundations, residential and commercial buildings, buried pipelines and bridges. The advantages of helical pile over conventional concrete and steel piles are that it is light weight, it has high vertical and uplift capacity, quick installation and it can be installed in limited access condition. Helical piles do not produce loud noise during installation process. In case of high ground water level, helical piles save dewatering or pumping of construction site.

2 Literature Review

B. E. George *et al.* (2019)[1] conducted a detailed investigation on a helical pile installed in cohesionless soil by displacement method. Laboratory experiments were conducted on models to study the various factors influencing the axial bearing capacities of helical piles. To augment the investigation, finite-element analyses were carried out using PLAXIS 3D AE software and compared with experimental results. The piles installed by the displacement method exhibited a higher ultimate capacity and distinct failure pattern. F. M. Abdrabbo *et al.* (2016)[2] conducted experimental investigation on helical piles with different helices diameters, numbers and spacing subjected to the horizontal loadings. The effect of these parameters was monitored and comparative study between helical piles and piles without helices was accomplished. They found that the most beneficial helical depth ratio was between 1/3 and 1/2. Farhad Nabizadeh *et al*. (2016)[3] conducted field test on the piles with various numbers of helices to investigate the behaviour of helical piles in sand and silty clay soils. Furthermore, the effect of post grouting on the strength of these piles was assessed. In sandy soil, pile resistance increased due to the penetration of grouting, but in clayey soil because of the compaction grouting, there was less increase. M. Sakr (2011)[5] conducted the full-scale axial compression and tension testing on large capacity helical piles installed in cohesionless soils. He concluded that helical piles with relatively large diameter up to 508 mm were successfully installed into dense to very dense soils.

3 Experimental Investigations

To study the performance of helical pile under vertical loads, uplift loads and lateral loads, laboratory model tests were conducted on helical piles with different helix diameter.

3.1 Test Setup

The test setup for vertical load tests on helical pile consisted of test tank, hydraulic jack, loading frame, dial gauges and proving ring. The M.S. tank with an inside dimension of 0.65 m (length), 0.65 m (width), and 0.65 m (depth) was used for the experimental investigation. The hydraulic jack was used for loading. The settlements were measured with the help of two dial gauges with 25mm travel and least count of 0.01mm. The dial gauges with magnetic base were fixed to the sides of the tank. A proving ring (5 kN capacity) was used to precisely record load applied on the pile. The model pile load test on conventional pile was conducted according to IS:2911-(part 4) 1985 and the vertical load capacity was evaluated. Ultimate vertical capacity of helical pile was considered as the load at which the displacement equal to 5% of helix diameter (D_h). The test setup is shown in fig 1.

Fig.1. Test setup used for vertical loading on Helical piles

The lateral load test was conducted according to IS:2911- (part 4) 1985 and lateral load on the piles was applied with the help of pulley and non-extensible wire system as shown in Fig. 2. A dial guage of 0.01 mm sensitivity, horizontally fixed on side edge of tank was used to measure the lateral displacement of pile at the top. Standard weights were used for loading.

Fig. 2. Test setup for lateral loading on Helical pile

The uplift load tests were conducted on piles in accordance of IS: 2911-(part 4) 1985. The uplift load was applied in number of increments by adding standard weights through a loading arrangement as shown in Fig. 3. Pile head movement was measured for each load increment. When the pile head movement was stopped, the next load increment was applied. The procedure was repeated till the failure displacement of pile was recorded for the sudden pull out of pile occurred.

Fig. 3. Test setup for uplift loading on Helical pile

3.2 Materials

The model helical piles used for experimental investigation were made from Mild Steel. Piles were 300 mm in length and 12 mm in diameter. Helical piles with different helical blade diameter are as shown in Fig. 4. For the model tests, uniformly graded dry cohesionless sand was used. Properties of sand are as shown in Table 1.

Fig. 4. Model helical pile used in experimental investigation

Table 1. Properties of sand.

Sr. No.	Properties of sand	Values
1	Specific Gravity	2.65
2	γ_{max} (kN/m^3)	17.94
3	γ_{min} (kN/m^3)	15.45
4	Angle of internal friction (ϕ)	36°
5	Cohesion (kN/m^2)	0
6	IS classification	SP (Medium Sand)

3.3 Sand Bed Preparation and Installation of Model Pile

The relative density of sand bed was maintained by using sand raining technique. The height of fall to achieve the desired relative density was determined prior by performing a series of trials with different height of fall. In this study the height of fall was selected as 24 cm and the corresponding relative density was maintained at 55%. Initially tank was filled up to the pile tip and the pile was placed vertically at the center of tank by using special guide. The non-displacement method of pile installation was used. Remaining tank was filled by using same technique. Pile was kept vertical during this process. The top surface of the sand bed was leveled and checked by spirit level.

3.4 Test Program

Experimental tests were carried out on model helical pile and conventional circular pile embedded in cohesionless soil. Parameters selected for study are presented in Table 2.

Table 2. Parameters selected for the study

Sr. No	Details of Parameters	Constant Parameters	Varying Parameters
1	Length of Pile	300 mm	-
2	Diameter of pile (Ds)	12 mm	-
3	Slenderness ratio (L/D)	25	-
4	Type of soil	Sand	-
5	Density of sand	55%	-
6	Type of loading		Vertical, Lateral, Uplift loading
7	Helix diameter ratio (D_h/ Ds)		2, 2.5 and 3

4 Test results and discussions

The pile load tests were carried out on conventional circular pile and helical piles with different helix diameter ratio (D_h/ Ds) and load settlement curves was plotted to study the performance of helical pile. Fig. 5 and Fig. 6 show the performance of circular and helical pile subjected to vertical loads in medium dense sand.

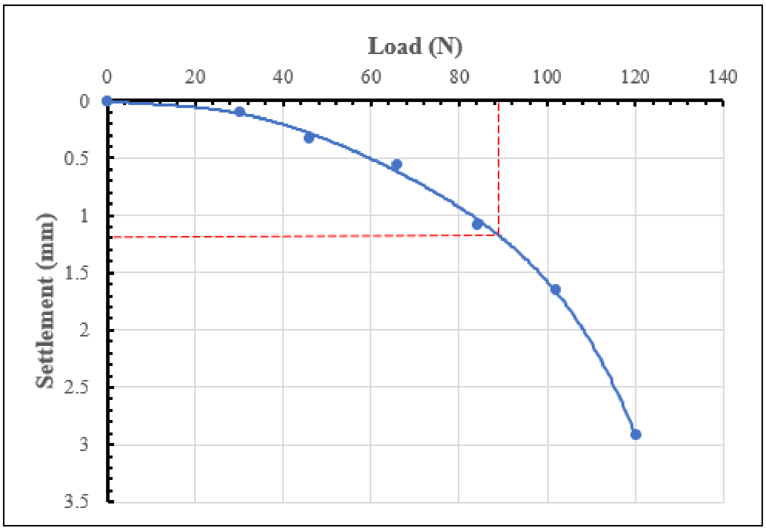

Fig. 5. Load-Settlement curve for circular pile

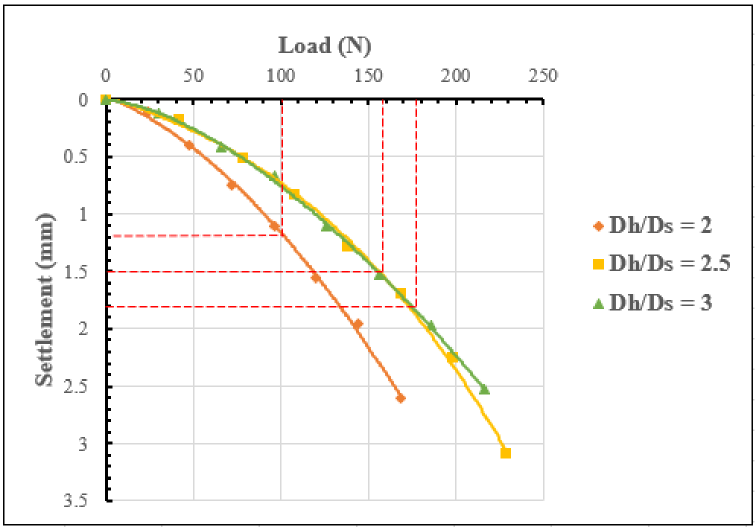

Fig. 6. Load-Settlement curve for helical piles with different helix diameter ratio

Fig. 7 and Fig. 8 show the performance of circular and helical pile subjected to lateral loads in medium dense sand. For ultimate lateral capacity, the failure criteria taken as the load at which displacement is equal to 5 mm.

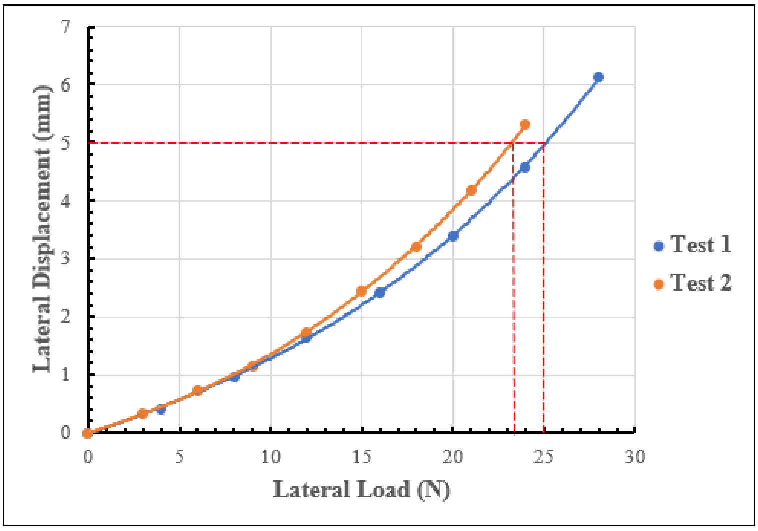

Fig. 7. Lateral Load vs displacement curve for circular pile

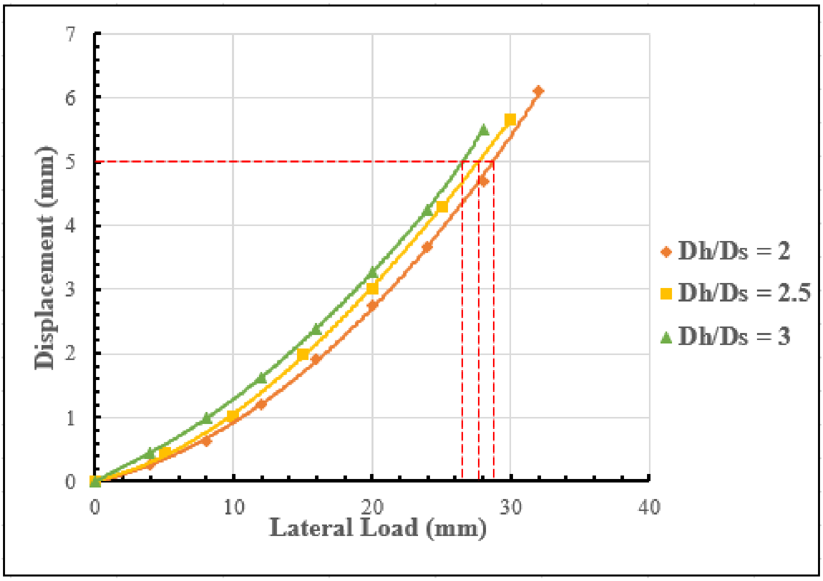

Fig. 8. Lateral Load vs displacement curve for helical piles with different helix diameter ratio (D_h/ Ds)

Fig. 9 and Fig. 10 show the performance of circular and helical pile subjected to uplift loads in medium dense sand.

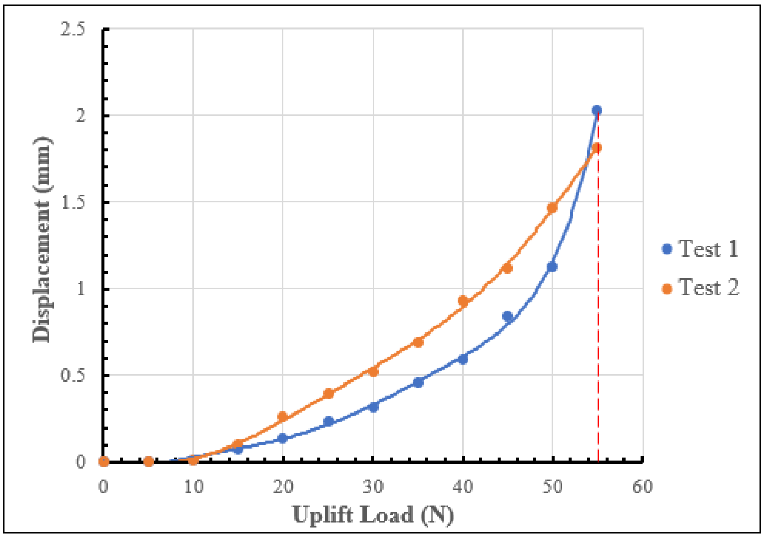

Fig. 9. Uplift Load vs displacement curve for circular pile

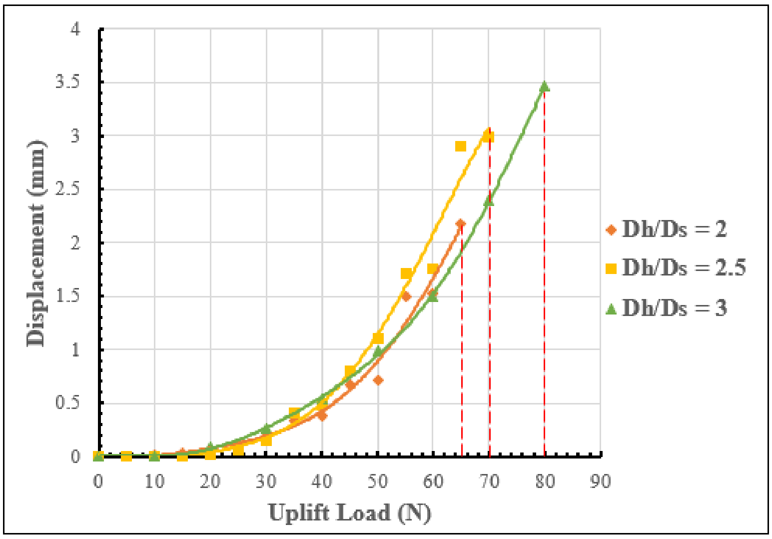

Fig. 10. Uplift Load vs displacement curve for helical pile with different helix diamater ratio

The ultimate vertical, lateral and uplift load capacities are determined from the load-settlement/displacement curves. The ultimate capacities of the piles are shown in Table 3 and Table 4.

The percentage increase in ultimate vertical capacity of helical pile with helix diameter ratio 2, 2.5 and 3 are 31%, 75% and 99% respectively as compared to conventional circular pile. The percentage increase in ultimate uplift capacity of helical pile with helix diameter ratio 2, 2.5 and 3 are 18%, 27% and 45% respectively as compared to conventional circular pile. The percentage increase in ultimate vertical capacity of helical pile with helix diameter ratio 2, 2.5 and 3 are 16%, 8% and 4% respectively as compared to conventional circular pile.

Table 3. Ultimate capacity of conventional circular piles.

Type of pile	Ultimate Vertical Capacity (N)	Ultimate Lateral Capacity (N)	Ultimate Uplift Capacity (N)
Circular	88	24	55

Table 4. Ultimate capacities of helical pile with different helix diameter ratio

Helix Diameter Ratio (D_h/ D_s)	Ultimate Vertical Capacity (N)	Ultimate Lateral Capacity (N)	Ultimate Uplift Capacity (N)
2	101	29	65
2.5	154	27	70
3	175	26	80

5 Conclusions

From the results of present study following conclusions are drawn:

1. The ultimate vertical capacity and uplift capacity of helical pile increases with increase in diameter of helical blade.
2. The ultimate lateral load capacity of helical pile decreases with increase in helix diameter ratio.
3. Upto 99% increment in vertical capacity is observed with varying helix diameter ratio as compared to the conventional circular pile.
4. Upto 45% increment in uplift capacity is observed with varying helix diameter ratio as compared to the conventional circular pile.
5. Maximum increment of 21% in lateral capacity is observed in helical pile with helix diameter ratio equals to 2.

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