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Performance of the Helical Pile Foundation in Cohesionless Soil

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Abstract. Helical piles have been used in construction applications for more than 150 years. Helical piles have gained in popularity that they are more frequently used for deep foundation types in geotechnical areas. In this paper the results of numerical analysis of the helical pile are presented. For analytical study a three-dimensional full scaled finite element model was created by using finite element software MIDAS GTS NX. Results obtained were compared with the conventional hollow pile. The various parameters considered for the study were: type of loading, number of Helix, Helix spacing and Helix diameter. The provision of such helices provides an ideal anchorage system due to the significant locking-up effect of the soil within the helices, resulting in increased pile capacity.

Keywords: Helical Pile, Ultimate Bearing Capacity, Finite Element Analysis, MIDAS GTS NX

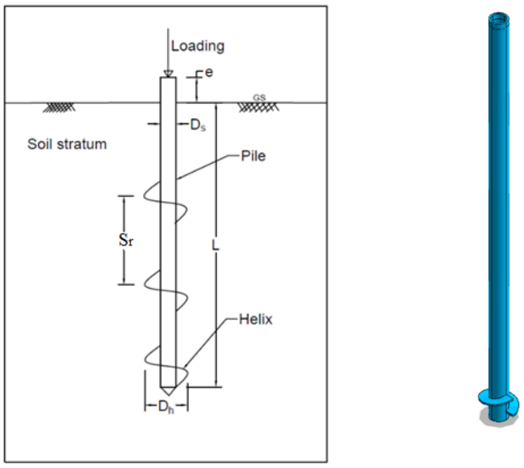
1 Introduction

A typical helical pile consists of a one or more pitched helix plates attached to either square or circular pile. Helical piles have been used in construction applications for more than 150 years. The first recorded use of helical piles was in 1836 by Alexander Mitchell when he used helical piles to underpin the Maplin Sands Lighthouse in England. The helical piles are installed into the ground by applying torque to its driving head. Helical piles have been used in various sites to provide high compressive, uplift, and lateral capacities for static and dynamic loads. Their current application includes commercial building, solar farms, wind turbines, machine foundation, offshore structures and bridges. The various advantages of helical piles are: ease in installation, can be driven in case of high ground water table, it provides high compression and uplift capacity and immediate loading can be applied after driving of the helical pile.

The compression capacity of helical piles in sand and clay was investigated by Zeyad *et. al*. (2015) by means of field testing and numerical analysis [1]. A full scaled study was carried out on helical pile to determine the ultimate bearing capacity and interaction between soil and pile. Bearing reduction factor was proposed for the vertical capacity of the helical pile. M. Sark *et. al* (2011) conducted the full-scale axial compression and tension (uplift) testing on large capacity helical piles installed in cohesionless soils [2]. B. George *et. al.* (2019) conducted a detailed investigation on a helical pile installed in cohesionless soil by displacement method [3]. Laboratory experiments and numerical analysis were conducted on models to study the various factors influencing the axial bearing capacities of helical piles. The piles installed by the displacement method exhibited a higher ultimate capacity and distinct failure pattern compared to piles installed by the non-displacement method.

2 Methodology

The behavior of the helical pile was analyzed using finite element software MIDAS GTS NX. The geometry of 3-D model of the helical pile and section of the helical pile considered for analysis is shown in Fig 1. The steel material is used for the hollow circular pile and loose sand for soil stratum. The properties assigned to pile and soil are shown in Table 1 and 2 respectively.



(a) (b)

Fig. 1. Typical helical pile model (a) used for analysis, (b) pile model developed in FEM software

Table 1. Properties assigned to helical pile for analysis

Sr. No.	Properties	Symbol	Values	Units
1	Young's modulus	E	2.1×10^8	kN/m^2
2	Density	ρ	75.5	kN/m^3
3	Poisson's ratio	υ	0.15	

Table 2. Properties assigned to soil layer

Properties	Unit weight	Young's modulus	Poisson's ratio	Angle of internal friction	cohesion
Symbols	γ	E	υ	Ø	c
Unit	kN/m^3	kPa	-	degree	kPa
Loose Sand	16.12	20133	0.3	28°	0

3 Numerical Analysis

The plan size of the model was more than 15 times the size of the maximum helix blade used in the analysis. The soil below the tip of the pile is sufficiently deep such that its effect was minimum. The sides of soil model were restrained in the x-direction and y-directions and the bottom boundary was restrained in all directions.

Soil was modeled using 10-node tetrahedral elements with a standard Mohr-Coulomb constitutive relationship. The pile shaft and the helix were modeled as linear isotropic elastic material. An interface element was created around the shaft and the helix plate to account the interaction between the soil and the helical pile. Mesh convergence criteria was used for selecting the mesh size for soil, pile shaft and helix blade. Fig. 2 shows the helical pile embedded in the soil layer after mesh generation. The non-linear analysis was carried out after mesh generation considering different pile geometry such as diameter of helix, inter helix spacing, number of helix plate and number of piles in group. The different constant and varying parameters used for the analysis are shown in the Table 3 and table 4 respectively.

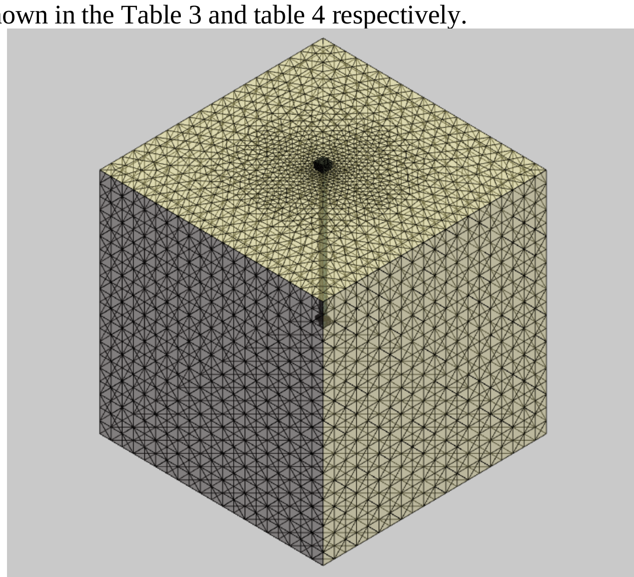


Fig. 2. Model of the helical pile after mesh generation

Table 3. Constant parameter used for numerical analysis

Sr. No.	Type	parameter	Values
1	Dimensions for Pile	Length	11.75 m
		Diameter of pile	0.5 m
2	Soil	Loose	

Table 4. Varying parameters used for numerical analysis

Sr. No.	Parameter	Details of parameters
1	Type of Loading	i. Axial Loading ii. Uplift Loading ii. Lateral Loading
2	Helix Diameter (D_h)	$1.5D_s$, $2D_s$, $2.5D_s$
3	Number of Helix	1, 2 and 3
4	Inter helix spacing (S_r)	$2D_h$, $2.5D_h$, $3D_h$ and $3.5D_h$
5	Inter helical pile spacing (S_p)	$1.5D_h$, $2D_h$, $2.5D_h$, $3D_h$ and $3.5D_h$
6	Number of piles	Single pile Pile group with 3, 4 and 6 piles

Where,

D_h = Diameter of helix
D_s = Diameter of shaft
Sr = Spacing between helix plate
S_p = Inter helical pile spacing

4 Results and Discussions

4.1 Effect of Helix Diameter Ratio

Initially the analysis was carried out for conventional pile and single helical pile subjected to vertical, uplift and lateral loading in loose cohesionless soil with different helix diameter. A failure settlement criterion of 5% of the helix diameter was considered for vertical and uplift loading; whereas 12 mm displacement at pile head was considered for lateral loading condition. For conventional pile, a settlement criterion of 10% of shaft diameter was considered. The ultimate capacities of conventional and single helical pile, considering different helix diameters as determined from the load settlement curves are presented in the Table 5.

Table 5. Ultimate Capacities of helical pile with different helix diameter

Loading condition	Ultimate capacities of pile (kN)			
	Conventional pile	Helix diameter Ratio D_h/D_s		
	$D_h/D_s = 1$	1.5	2	2.5
Vertical	963	1147	1703	2485
Uplift	307	915	1468	2150
Lateral	200	265	270	220

The variation in ultimate vertical, uplift and lateral capacity of the helical pile with different helix diameter ratio (D_h/D_s) are shown in the Fig. 3 (a), Fig. 3 (b) and Fig. 3 (c) respectively. Fig. 3 (a) and (b) show that the ultimate vertical and uplift capacities of the helical pile are much higher than that of conventional pile and increase with the increase in helix diameter. But in the case of lateral loading condition, the ultimate lateral capacity increases up to helix diameter ratio (D_h/D_s) = 2 and decreases with further increase in helix diameter ratio. Helix diameter greater than $2D_s$ induces instability and assist the lateral movement of the pile. So, helix diameter of $2D_s$ is adopted as optimum for further analysis.

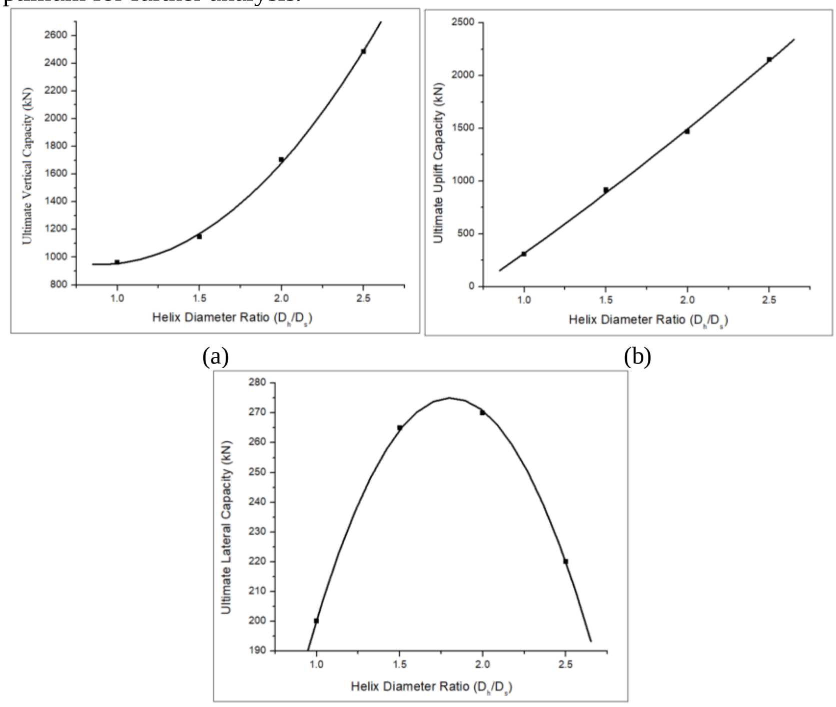


Fig. 3. Variation in ultimate capacity with respect to the helix diamater ratio (D_h/D_s) (a) Vertical, (b) Uplift and (c) Lateral Loading condition

The percentage increase in ultimate capacity of single helical pile as compared to that of conventional circular pile is in the range of 20 to 160% in case of vertical loading, 200 to 600% in case of uplift loading.

4.2 Effect of Inter-Helix spacing

Further analysis was carried out by varying the spacing between two helices for determining the effect of spacing between helix plate on ultimate vertical capacity. Variation in the ultimate vertical capacity of the helical pile with different inter-helix spacing ratio (S_r/D_h) is shown in Fig. 4. It is observed that the ultimate vertical capacity of the helical pile increases with the increasing inter-helix spacing upto (S_r/D_h) = 3 and further remains constant. So, inter-helix spacing ratio = 3 is adopted as optimum for further analysis.

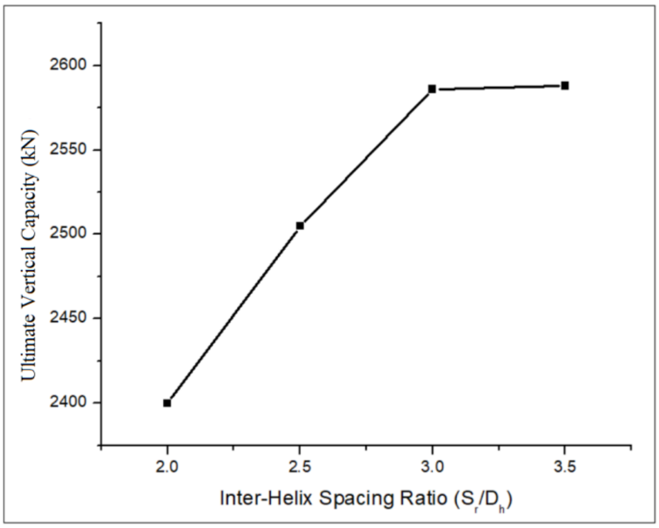


Fig. 4. Variation in the ultimate vertical capacity with different inter helix spacing

4.3 Effect of Number of helix

Further analysis was carried out with different number of helix plate in case of single helical pile with inter-helix spacing ratio = 3. Table 6 shows the Ultimate Vertical, uplift and lateral capacity of the single helical pile with different number of helix plates viz., 1, 2 and 3 helix. From the results, it is observed that the ultimate vertical and uplift capacity of the pile increases as the number of helix plate increases and the ultimate lateral capacity is much higher with 3 helix plates. The percentage increase in lateral capacity of single helical pile is significant only in case of pile with three helices.

Table 6. Ultimate Capacity with different number of helix plate

Loading condition	Ultimate Capacities of Pile (kN)			
	Number of Helix Plate			
	0	1	2	3
Vertical	963	1703	2580	3526
Uplift	307	1468	2364	3086
Lateral	200	270	212	273

As the number of helices increases, about 95% to 100% increment in ultimate vertical capacity, 300% to 350% increment in uplift capacity and about 35% increment in ultimate lateral capacity is observed.

4.4 Effect of Inter Helical Pile Spacing (S_p/D_h):

The analysis was carried out on a group of three helical piles. The variation in the ultimate vertical capacity of the helical pile with different inter helical pile spacing ratio is shown in Figure 5.

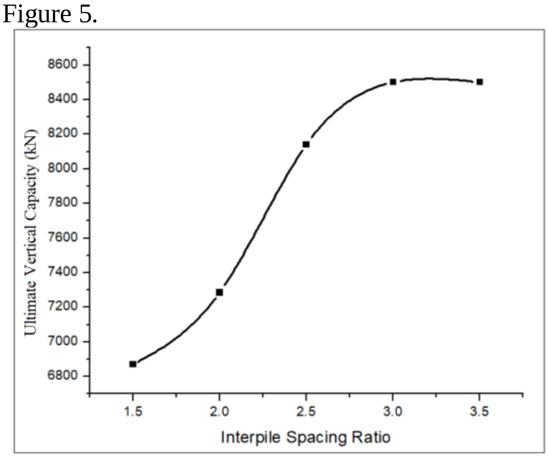


Fig. 5. Variation in ultimate vertical capacity with respect to the inter helical pile spacing ratio

From the above results, it is observed that the ultimate vertical capacity of the group of helical pile increases with the increasing inter helical pile spacing ratio upto $S_p/D_h = 3$ and remains constant with further increase in spacing ratio.

4.5 Performance of group of Helical pile

The analysis was carried on pile groups consisting of conventional as well as the helical piles subjected to different types of load. Number of piles in the group was varied as 3, 4 and 6. For the helical pile group analysis, three helix plate configurations was adopted. Table 7 presents the ultimate capacities obtained from the analysis of group of pile subjected to vertical, uplift and lateral loading condition.

Table 7. Ultimate capacity of piles in group

Loading condition	Ultimate Capacities of Pile (kN)					
	Number of Conventional Piles in group			Number of Helical Piles in group		
	3	4	6	3	4	6
Vertical	2630	3516	5304	8490	10383	13520
Uplift	904	1330	1806	7365	8980	12237
Lateral	459	1330	847	722	8980	1323

Percentage increase in ultimate vertical capacity of helical pile group as compared to that of conventional circular pile group is in the range of 150 to 200%, whereas 500% in case of ultimate uplift capacity, and about 50 % in case of ultimate lateral capacity.

5 Conclusions

Following broad conclusions are drawn from the analysis of helical piles

1. The ultimate vertical and uplift capacity of the helical pile increases with increase in number of the helices and diameter of the helix.
2. The optimum ultimate lateral capacity of the helical pile is achieved at the helix diameter ratio = 2.
3. The optimum Inter-helix spacing ratio of the helical pile is equal to 3.
4. Ultimate vertical capacity and uplift capacity of the single helical pile is higher up to 160% and 600% respectively, as compared to those of conventional circular pile in loose sand.
5. The percentage increase in ultimate lateral capacity is significant only in the case of pile with 3 helices.
6. With the increase in number of helix, about 100% increment in ultimate vertical capacity, 350% increment in uplift capacity and about 35% increment in lateral capacity is observed.
7. Ultimate vertical capacity, uplift capacity and lateral capacity of the group of helical pile is higher up to 200%, 500% and 50% respectively, as compared to group of conventional circular pile.

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