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ANALYSIS OF THE BEHAVIOR AND CAPACITY OF HELICAL PILES IN DIFFERENT SOIL CONDITIONS

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ABSTRACT
Helical piles, also known as continuous helical piles or CFA piles, have gained attention in geotechnical engineering due to their efficiency and high load-bearing capacity. Studies on the axial behavior of these piles, such as those conducted by Elkasabgy and El Naggar (2015), Lanyi-Bennett and Deng (2019), and others, show that factors like helix diameter, spacing between helices, and soil conditions directly influence their performance. Analyzing the volume of soil displaced during installation is a critical component to ensure the integrity and performance of the piles, optimizing material use, and preventing structural issues such as voids and bulging. Additionally, the research revealed that helical piles offer significant advantages compared to other foundations, especially in cohesive and cohesionless soils. Numerical models and digital monitoring methods have helped improve the understanding of these piles' behavior, allowing for more accurate predictions of their load capacity. Estimates based on CPT tests have also shown great precision, with prediction methods developed to calculate the uplift capacity of piles according to their geometric parameters, such as the spacing between helices and helix diameter. These advancements are crucial for developing safer and more efficient foundation solutions. Helical piles, with their high load capacity and ease of installation, have proven to be a promising alternative, especially for applications in expansive soils and in industrial and infrastructure construction areas. The ongoing improvement of analysis and prediction techniques allows for more rigorous control of the quality and performance of these foundations, promoting their adoption in a variety of civil construction contexts.

Keywords: Helical piles. Load capacity. Soil analysis. Prediction method. Deep foundations.

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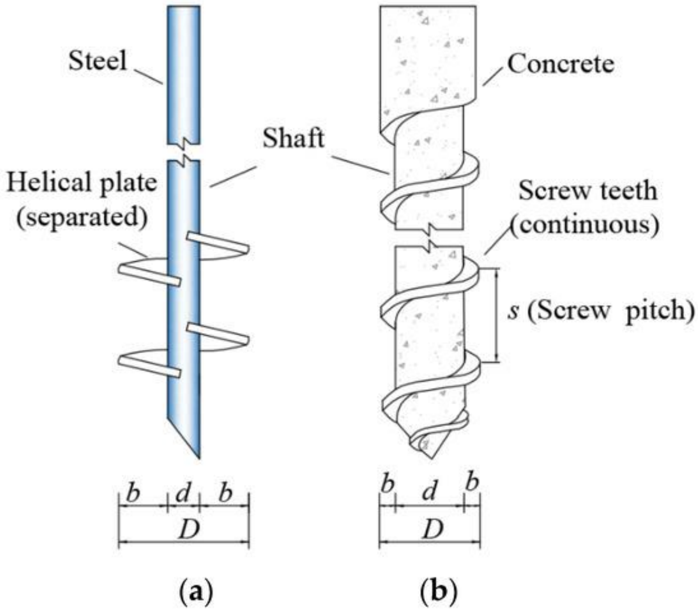
INTRODUCTION

Continuous helix piles, or continuous flight auger (CFA) piles, have become a widely used foundation solution in geotechnical engineering due to their ease of installation and strong load-bearing capacity. An essential aspect of designing and implementing these piles is understanding the volume of soil displaced during installation. This volume is critical, as it directly affects the pile's structural integrity and performance. The process involves assessing the soil removed by the auger and determining the amount of concrete or grout needed to fill the resulting void. Accurate calculations of the soil volume are crucial to ensure an adequate material supply, minimize waste, and avoid issues such as voids or bulging that can compromise the pile's effectiveness.

Figure 1: Schematic diagram. (a) Steel screw pile and (b) concrete screw pile.



Source: Ma et al. (2022).

The factors influencing the soil volume include pile diameter and depth, soil type, groundwater conditions, as well as the auger's penetration rate and rotational speed. In cohesive soils, the auger tends to retain more soil, whereas in granular soils, more material is lost during the extraction process. Monitoring the soil return and comparing it with theoretical values can help detect anomalies during construction. To enhance the precision of these estimates, modern construction practices now incorporate digital monitoring systems and modeling tools. These tools assist engineers in making realtime decisions that improve safety, reduce costs, and increase overall construction efficiency.

In relation to helical piles, the study conducted by Elkasabgy and El Naggar (2015) explored the axial compression performance of large-capacity helical piles, emphasizing their potential as an effective alternative to traditional foundation systems for structures like oil processing facilities, transmission towers, and industrial buildings. Through seven full-scale tests on 6.0 m and 9.0 m helical piles, as well as a 6.0 m driven steel pile, the research highlighted that helical piles developed ultimate resistances 1.2 to 1.8 times greater than those of the driven piles, demonstrating superior performance. The study also examined load-transfer mechanisms and the impact of soil disturbance during installation, which significantly affected the pile failure mode, regardless of the helix spacing-to-diameter ratio.

Another relevant study by Lanyi-Bennett and Deng (2019) focused on how inter-helix spacing influences the behavior of helical piles under axial compressive loads. The researchers conducted tests on piles equipped with strain gauges, each featuring two helices with varying spacings. These piles were installed in a homogeneous clay layer with an average undrained shear strength of 65 kPa. The results indicated that when the spacing-to-diameter ratio exceeded 1.5, the individual bearing model predominated. Additionally, the study examined the impact of soil setup on pile behavior by comparing the load-settlement responses of piles tested immediately after installation with those tested days later.

The work of Ali and Abbas (2019) analyzed the behavior of solid cylindrical screw piles in a soft clay and sandy soil bed. Tests were conducted on piles of different lengths (300 mm, 350 mm, and 400 mm) and helix configurations, with either one or two helices. The results showed that double-helix screw piles increased bearing capacity by 4% to 8% compared to single-helix piles, highlighting the significant influence of pile geometry on performance. This finding underlined the importance of considering factors like helix spacing and the number of helices when designing foundations for soft soils.

In a related study, Albusoda and Abbase (2017) investigated the behavior of square helical piles in expansive soil overlying a sandy base. Piles of varying lengths (150 mm, 200 mm, and 300 mm) and helix diameters (15 mm and 20 mm) were tested, including configurations with one and two helices. The study found that deeper piles with larger L/D ratios had better pullout capacity, and grouped helical piles demonstrated lower upward movement than single piles, reinforcing the advantage of using group configurations in expansive soils.

Li and Deng (2019) also conducted a study focusing on the axial behavior of small-diameter helical piles, which are increasingly used in Western Canada. Their research involved the installation and axial loading of 26 helical piles in both cohesive and cohesionless soils. The load-displacement curves were analyzed using Chin's hyperbolic assumption, which was found to accurately predict pile behavior. The study also developed a beam-on-nonlinear-Winkler-foundation model to better understand pile behavior, with the findings suggesting that an ineffective length of four helix diameters provided an accurate simulation of axial load-displacement behavior.

The work by Nait-Rabah et al. (2021) examined the performance of continuous helical piles in cohesionless soils, focusing on failure mechanisms and methods for predicting uplift capacity based on CPT tests. Their research found a cylindrical failure surface for all tested piles, with both the inter-helix spacing ratio (S/Dh) and the helix diameter (Dh) influencing uplift capacity. A new prediction method, based on CPT data, was proposed, which allows engineers to estimate the ultimate uplift capacity using geometrical parameters. The method was evaluated using statistical criteria such as best-fit lines, mean and standard deviation, cumulative probabilities, and distribution models, and showed a prediction accuracy of nearly 96% within a 20% margin of error.

Research on helical piles continues to evolve, demonstrating their great potential as an effective and efficient solution for foundation systems in geotechnical engineering. The reviewed studies highlight the importance of considering various parameters, such as the helix diameter, the spacing between helices, and soil conditions, which directly affect the performance of these piles. Analyzing the volume of soil displaced during installation is crucial to ensure the structural integrity of the piles and optimize material usage, as well as to prevent potential foundation failures. Moreover, the adoption of new prediction methodologies, such as CPT tests, has shown significant advancements in estimating the resistance and uplift capacity of helical piles.

The combination of experimental methods and digital monitoring tools has enabled a more accurate evaluation of the axial behavior of piles in different types of soil. Advanced numerical models, such as the beam-on-nonlinear-Winkler-foundation method, have also been useful in simulating and better understanding the piles' responses under load. These technological advances are essential to optimize the design of piles and ensure the safety and efficiency of deep foundations.

In terms of capacity and performance, helical piles have shown advantages over other foundation types, such as driven piles, especially in cohesive and cohesionless soils. Studies have demonstrated that factors such as helix configuration and pile length play a fundamental role in load resistance. The use of helical piles for foundations in areas with expansive soils, for example, has shown promising results, making them a viable and cost-effective solution in various civil construction contexts.

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