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PERFORMANCE OF HELICAL PILES UNDER DIFFERENT INSTALLATION AND LOADING CONDITIONS: AN EXPERIMENTAL AND ANALYTICAL REVIEW

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ABSTRACT
The performance of helical piles under varying installation and loading conditions has been widely investigated through experimental studies and numerical modeling. Installation time has proven to be a determining factor in axial resistance due to the "setup" phenomenon, which is especially relevant in cohesive soils. The recovery of soil strength after disturbance can increase load-bearing capacity over time, whereas rapid installations tend to induce greater disturbance and lower initial strength. Research such as that by Wang et al. (2025) proposes innovative over-flighted installation techniques to reduce insertion effort and improve in-service resistance. The helix geometry and spacing, as shown by Lanyi-Bennett and Deng (2019), directly affect the resistance mechanisms mobilized, with adequate spacing favoring individual bearing behavior. Schiavon et al. (2024) showed that reused piles, when reinstalled deeper, can partially or fully recover their capacity under cyclic loading. The influence of helix deformation, studied by Malik et al. (2019), reveals that the performance of piles with bent helices can be significantly reduced, emphasizing the need for optimized design. Furthermore, Malik and Kuwano (2020) highlight performance loss under one-way cyclic loading, stressing the importance of accounting for these effects in structures subjected to repetitive loads. The study by Masatoshi et al. (2017) confirms the reduction in capacity under cyclic reversal loading but also shows that continuous helix piles maintain their tip resistance, making them effective in environments with cyclic demands. Collectively, the studies reinforce the superiority of helical piles over traditional alternatives, emphasizing the importance of design tailored to real soil and loading conditions.

Keywords: Helical piles. Cyclic loading. Installation time. Inter-helix spacing. Load-bearing capacity.

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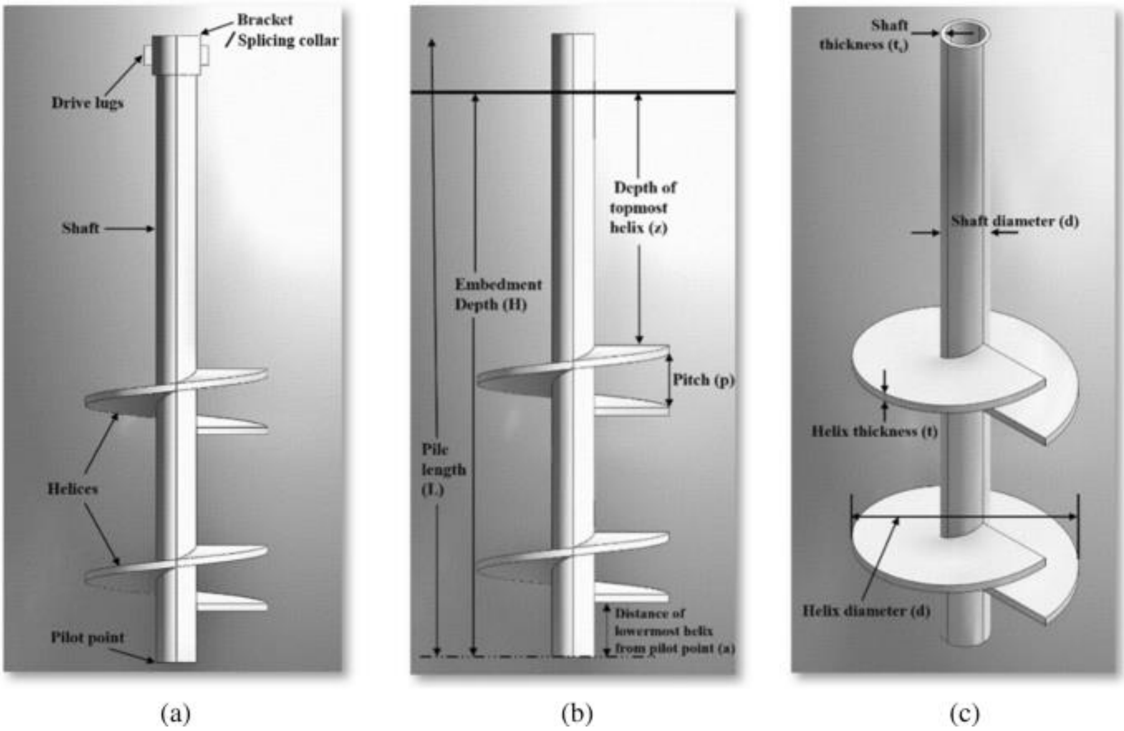
INTRODUCTION

The relationship between installation time and the load-bearing capacity of continuous flight auger (CFA) piles is a key consideration in geotechnical engineering, as it directly impacts their performance after placement. These piles are installed by drilling into the ground and inserting a continuous helix, forming the pile in situ. The duration of this process can affect the interaction between the pile and surrounding soil, thereby altering axial load resistance. Over time, the disturbed soil tends to regain strength through a phenomenon known as "setup," which is especially significant in cohesive soils. As the soil consolidates, the pile’s capacity may improve, although immediately after installation, the resistance might be lower due to incomplete soil recovery. Additionally, longer installation times may enhance pile-soil contact and reduce the volume of disturbed material, improving performance and stability.

Figure 1: Helical piles.



Source: Debnath & Singh (2022).

In line with this topic, Wang et al. (2025) explored the use of upscaled screw piles as an alternative, quieter foundation system for offshore jacket structures and renewable energy infrastructure. The study suggests replacing conventional pitch-matched installation techniques with over-flighted methods for single-helix screw piles, aiming to reduce vertical crowd force and torque during installation. By using discrete element method (DEM) modeling, the researchers extended their analysis to multi-helix piles, examining how helix spacing and advancement ratios influence performance. The findings highlight that, under the right conditions, multi-helix piles with reduced spacing may be easier to install and retain or enhance their tensile resistance if the first helix is properly embedded.

Lanyi-Bennett and Deng (2019) contributed to the understanding of inter-helix spacing by examining its effects on pile behavior under axial compression. Instrumented piles with two helices were tested in clay, and results indicated that a spacing-to-diameter ratio of 1.5 or greater favors individual bearing behavior, aligning more closely with theoretical models. However, the study also found that actual helix bearing and shaft adhesion factors were lower than conventional design assumptions. In evaluating short-term soil strength, they discovered that installation had minimal impact on pore pressure and did not significantly affect immediate pile capacity, though long-term behavior still benefits from soil setup.

Another significant contribution comes from Schiavon et al. (2024), who investigated the tensile cyclic response of single-helix piles in dry and saturated sands after experiencing failure due to monotonic uplift. Through centrifuge model testing, they examined both post-failure cyclic loading and the effects of re-installing piles at greater depths. The research showed that previous failure events substantially affect cyclic performance, where only a few cycles can result in critical displacements. However, re-installing the pile 2D deeper (where D is the helix diameter) can restore part or all of its performance, depending on the load amplitude, suggesting a viable approach for rehabilitating failed piles.

The effect of helix deformation on pile performance was explored in depth by Malik et al. (2019). Their work focused on how helix bending influences load-settlement behavior and ultimate capacity. Screw piles generally exhibit superior bearing performance due to their larger helix, but excessive helix sizes can cause bending, diminishing ground resistance. Model tests with varying helix geometries showed that once helix deflection exceeds a critical threshold, load-settlement behavior deteriorates. The study also verified that Roark’s formula for flat plates accurately predicts helix deformation, and the authors proposed a revised equation to help determine optimal helix thickness, enhancing pile design reliability.

In a subsequent study, Malik and Kuwano (2020) evaluated helical piles under cyclic one-way compressive loading in dense sand. Given that real-world structures often experience repeated load cycles, this aspect is crucial but underexamined. Tests revealed that while larger helix diameters increase load transfer along the central shaft, they also make piles more vulnerable to performance drops under cyclic loads. Specifically, the ultimate capacity decreased by 10.8% during repeated loading, and helix bending caused up to a 41.5% reduction compared to piles under monotonic loading. Their work further contrasted screw piles with straight-shaft piles, emphasizing the importance of considering cyclic behavior in design practices.

Finally, Masatoshi et al. (2017) addressed the performance of steel piles with continuous helices under various loading types through laboratory and field experiments. While both continuous-helix and straight-sided piles were tested under monotonic and cyclic reversal loading in the lab, only continuous-helix piles were examined in the field. Results showed a 20%–40% reduction in capacity under cyclic conditions, with shaft friction identified as the primary factor in resistance loss due to soil disturbance. Interestingly, while straight-shaft piles experienced a decrease in tip resistance, continuous-helix piles maintained theirs, thanks to the helix acting as a barrier to soil loosening near the tip. These results affirm the durability of helical piles in conditions involving frequent load reversals.

Collectively, these studies underline the complex interplay between installation techniques, pile geometry, soil conditions, and cyclic loading in determining the performance of helical piles. They provide valuable insights for designing more resilient foundation systems, particularly in environments subject to dynamic or repetitive loads.

The analysis of the reviewed studies highlights the critical importance of factors such as installation time, helix geometry, inter-helix spacing, and loading type (monotonic or cyclic) in the structural performance of helical piles. The results indicate that installation time directly affects the axial resistance of piles, mainly due to the soil “setup” process, which tends to increase load-bearing capacity over time. In cohesive soils, this effect is even more significant, showing that proper installation planning can greatly enhance foundation performance.

Research also demonstrates that the installation method and helix spacing influence both the efficiency of the process and the load-bearing capacity of the piles. Techniques such as over-flighted installation reduce the required driving forces and, when well implemented, preserve or even enhance tensile resistance. Appropriate helix spacing, as demonstrated in clayey soils, promotes individual bearing mechanisms, optimizing the pile-soil interaction. Additionally, studies on reusing failed piles reveal the potential of reinstallation at greater depths as a strategy to recover performance in foundation projects.

Finally, the behavior of helical piles under cyclic loading, especially after monotonic failure, points to the need for greater attention in the design phase, as helix bending and the loss of soil confinement negatively impact load capacity. The maintenance of tip resistance in continuous helix piles, even under reversed cyclic loading, reinforces their superiority in scenarios with repetitive demands. These findings emphasize the relevance of continued research for optimizing the design and application of helical piles in varying geotechnical conditions.

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