The effect of water injection pressure on the performance of conical helical piles

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ABSTRACT

Loess deposits exist in some areas of Golestan Province, and the type of sedimentation of these deposits has caused a loose honeycomb structure with low density, which is the cause of geotechnical and structural challenges. There are several solutions for improving such problematic soils, one of which is the use of conical helical piles. In this study, eight three-blade conical helical piles with a length of 6.2 m and a blade-to-diameter ratio of 3, under installation stresses of 200-400-450 kPa in two dry and wet conditions, were used to improve the performance of loess soil located at the Dashli Borun site in Golestan Province. In the dry method, the piles were installed and loaded under three stresses, and in the wet method, the optimal water injection pressure was first determined, and then the performance of the piles was examined. The results show that with increasing installation stress, the capacity of conical piles in both dry and wet states increases, and the injection pressure is an effective parameter on the behavior of these types of piles, and non-use of optimal water injection pressure causes a 45% reduction in the pile's bearing capacity.

KEYWORDS

Loess soil, conical helical pile, Installation stress, Injection pressure, Wet implementation

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1. Introduction

Loess is a type of soil that has undergone prolonged sedimentation processes and remains relatively stable under natural conditions. Its characteristic honeycomb and porous structure leads to significant variations in compressibility and high sensitivity upon contact with water [1, 2]. Vast areas in northeastern Iran contain collapsible loess deposits, which have caused extensive damage to infrastructure and technical structures, particularly following wetting and loading events [3]. In recent years, the use of a novel pile type called helical piles has been increasingly adopted due to their unique characteristics. Helical piles consist of a central shaft with one or more helical plates that are installed through rotation and pressure, and they have seen widespread application[4]. Various factors influence the tensile and compressive performance characteristics of helical piles, including soil type, helix geometry, number of helices, helix diameter and spacing, pitch length, shaft diameter and type, and installation angle [5, 6]. Arabameri and Eslami (2021) investigated two different geometries of uniform helical piles (single-helix and double-helix piles with spacing-to-diameter ratios of 1.5 and 3) using both dry and wet installation methods. Their results demonstrated that double-helix piles with a spacing-to-diameter ratio of 3 exhibited superior performance in terms of bearing capacity and improvement of soil geotechnical properties. Furthermore, the wet installation method, involving compressive loading combined with water injection, resulted in improved compaction and enhanced strength parameters of loess soil compared to dry installation [7].

Limited research has been conducted on full-scale helical piles to quantitatively examine the effects of helix rotation and movement during installation on soil geotechnical properties [8]. Due to the significant limitations of individual improvement methods, this study employs a combined approach integrating hydraulic, compaction, and reinforcement techniques simultaneously. Accordingly, drilling operations incorporating static pressure through both dry and wet installation methods were conducted, using multi-helix piles as reinforcing elements to improve the loess soils in Golestan Province. The behavior of three-helix conical piles with 6.2 m length and spacing-to-diameter ratio of 3 was investigated under both dry and wet installation conditions. In this research, piles were first installed using three different installation stresses under dry conditions to determine their bearing capacity. Additional piles were installed using the wet method with injection pressures of 2, 4, and 6 bar to identify the optimal injection pressure. Ultimately, piles were installed under optimal wet conditions (4 bar injection pressure) and their performance was evaluated.

2. Methodology

The study area for this research was selected in the Dashli Borun village region, located 150 km from the center of Golestan Province in Iran near the Turkmenistan border. To accurately characterize the site soil conditions, two machine borings to depths of 15 m and one boring to 30 m were drilled using continuous core sampling methods near structures and village access roads. Figure 1 shows images of the study site in Dashli Borun and the damage to technical structures in northeastern Iran.

Figure 1: Image of the research site in the Dashli-Brun area (adjacent damage)

According to the Unified Soil Classification System (USCS), the studied soil is classified as low plasticity silt (ML) with a minimum dry density of 1.29 g/cm³. Based on collapse potential tests (I_e) conducted in accordance with ASTM D5333-03 standard, the degree of collapsibility falls within the severe range according to the standard's classification table. To evaluate helical pile performance at full scale, eight large-scale helical piles were installed and tested on-site in loess soils. The geometry and dimensions of the helical piles are presented in Table 1.

Table 1: specifications of large-scale conical helical piles

Pile Name	CH(D or W)
Number of Helices	3
Pile Length (cm)	620
Depth of Penetration (cm)	600
Helix Diameter (cm)	35,25,20
Helix Pitch (cm)	7.62
Helix Thickness (cm)	0.8
Shaft Diameter (cm)	8.89
Thickness of Shaft (cm)	0.5
Helix Spacing Ratio	3
Distance Tip to Helix End (cm)	15

The pile naming convention follows this pattern: the first two letters represent "Conical Helix" (CH), the subsequent letter indicates test conditions (D for dry, W for wet), and the following three numbers sequentially represent pile height, number of helices, and helix spacing-to-diameter ratio. The three-helix conical pile with a helix spacing-to-diameter ratio of 3 (S/D=3) was designed for 6 m depth. The constructed conical helical piles are shown in Figure 2.

Figure 2: View of the constructed conical helical pile

The helical piles were installed by applying torque and compressive force provided by a hydraulic drilling rig. The effects of compressive force applied at the pile tip (installation stress) and water pressure were investigated as two key factors modifying soil geotechnical properties and reducing collapse potential. The piles were installed at 6 m depth, with load testing conducted on each pile while measuring displacement at the pile head. Axial compressive load testing was performed according to ASTM D1143/D1143M-07(2013) standard [9]. The bearing capacity of each pile was evaluated at settlements equivalent to 5% and 10% of the average helix diameter. A loading plate, load cell, and hydraulic jack were installed at the center of each pile head, with sandbags and concrete blocks placed on the frame to provide the required reaction weight.

3. Discussion and Results

Researchers in various references [10-12] have defined the axial compressive capacity of piles at displacements equivalent to 10% of the pile diameter, ensuring sufficient displacement to mobilize the pile's ultimate capacity. Similarly, for conical helical piles, the axial compressive capacity can be defined at 10% displacement of the average helix diameter. In this study, load-displacement curves were analyzed at 5% and 10% of the average helix diameter under both dry and wet installation conditions. Figure 3 shows the load-displacement curves and capacity values at equivalent deformations for piles with S/D=3 ratio installed at 6m depth, comparing wet installation (4 bar water pressure) with dry installation under different installation stresses.

The maximum bearing capacity of helical piles was observed under dry installation at 450 kPa installation stress, reaching 98.8 kN at 10% average helix diameter displacement and 60.9 kN at 5% displacement. Corresponding values under wet conditions were 44 kN and 27 kN, respectively. The bearing capacity increased with higher installation stress, showing a 1.4-fold increase at 450 kPa compared to 200 kPa installation stress (10% displacement) in dry conditions, while wet conditions demonstrated a 1.62-fold increase. At 5% displacement, these increase factors were 1.5 (dry) and 1.9 (wet). The greater increase factors observed in wet installation at both 5% and 10% average helix diameter displacements clearly demonstrate the effectiveness of the wet installation method and water pressure in enhancing loess soil compaction and structural improvement.

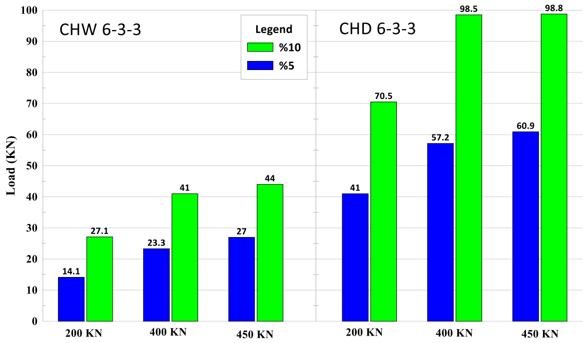

Figure 3: Comparison of Ultimate Load in Dry and Wet Conditions

4. Conclusions

This study employed eight piles underwent rapid static compressive load testing on loess soils in the Dashli Borun region, yielding the following key findings:

- The investigation revealed critical water pressure effects: insufficient pressure (below optimal) failed to adequately reduce interparticle friction, resulting in suboptimal compaction. Conversely, excessive pressure caused particle washout and excessive displacement, both contributing to reduced pile performance and bearing capacity. The identified optimal pressure balanced these factors, maximizing bearing capacity while maintaining soil integrity for conical multi-helix pile installation.

- A consistent positive correlation emerged between installation stresses and bearing capacity across both dry and wet conditions. Notably, the wet method demonstrated a steeper improvement gradient (higher rate of capacity increase per unit stress) compared to dry installation. This enhanced response underscores the combined effectiveness of water pressure and wet installation in densifying loess soils and improving their structural characteristics. The water-mediated particle rearrangement creates a more homogeneous, densely packed soil matrix that responds more efficiently to increasing loads than dry compaction alone.

5. References

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