



Evaluation of Key Parameters Affecting the Bearing Capacity of Helical Piles

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ABSTRACT

This experimental study examined the axial performance of helical piles subjected to compressive and tensile loads, with a particular focus on the effects of helix spacing, number of helices, soil compaction, and loading type. Employing a large-scale frustum-confining vessel (AUT-FCV) to accurately simulate in-situ stress conditions, the behavior of single- and double-helix piles was analyzed in medium- and low-density sandy soils. The findings revealed that soil compaction significantly enhanced pile performance, with medium-dense soils markedly increasing both the compressive and tensile capacities. Optimal performance was observed in double-helix piles with a helix spacing of 1.5 times the diameter, which demonstrated an improved load-bearing capacity and reduced displacement. Notably, in well-compacted soils, the tensile bearing capacity approached or equaled the compressive capacity, underscoring the suitability of helical piles for uplift-resisting applications in such conditions. These results contribute to the advancement of more effective design methodologies for helical pile foundations in sandy soils, particularly in coastal and urban geotechnical contexts.

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1. Introduction

In recent years, helical piles have gained significant attention as an innovative solution for improving foundation systems, particularly in loose soils. Their unique characteristics, such as rapid installation and adaptability in areas with limited access, offer distinct advantages over traditional deep foundation methods. Furthermore, helical piles provide an optimal solution in conditions where extensive excavation or the construction of concrete piles is impractical, making them an efficient choice for ground improvement. This research aims to investigate the influence of various parameters on the bearing capacity of helical piles, identifying optimal conditions and geometric configurations that enhance their performance across diverse soil environments. Micropiles, known for their ability to withstand substantial soil displacements—particularly in fill materials, soft clays, and loose sands—are considered a viable alternative. Their primary advantages include increased soil resistance and reduced displacement, both of which are essential for improving structural stability.

Numerous studies in recent years have investigated the bearing capacity of helical piles. Researchers have analyzed the behavior of these piles under various soil conditions and loading scenarios. Several studies have specifically explored the effects of loading type, pile embedment depth, and helix geometry on the performance of helical piles. The findings indicate that helical piles provide superior bearing capacity in loose soils compared to conventional piles.

Research indicates that the performance of helical piles is influenced by several factors, including installation torque, helix dimensions and spacing, soil type and density, installation method, loading conditions, and geometric design. Studies by Sakr (2013) and Spagnoli & Gavin (2015) have shown that helical piles outperform friction piles, with bearing capacity increases of up to 290% [1,2]. Furthermore, research by Chen et al. (2018, 2020) and Alnmr et al. (2023) has identified optimal ratios for pile length, embedment depth, and helix spacing, which can significantly enhance performance [3–5].

The effect of installation torque on the tensile and compressive capacity of helical piles has been extensively studied. Research by Ghaly and Hanna (1991), Perko (2000), and Tsuha and Aoki (2010) underscores its critical role, demonstrating its strong correlation with soil properties and the friction between the helix and the surrounding soil [6–8]. Additionally, studies by Sakr and Bartlett (2010) and Tsuha et al. (2012) confirm that increasing the helix diameter and number of helices enhances bearing capacity. However, the degree of this enhancement depends on soil properties and loading conditions, with specific optimal ratios for helix spacing and dimensions [9,10]. The research conducted by Abd el-Rahim et al. (2013) on the compressive and uplift bearing capacities of helical piles in sandy (cohesionless) soils demonstrates that these capacities are significantly enhanced with an increase in helix diameters and higher embedment ratios (D/d) [11].

Further investigations by Abdrabbo & El-Wakil (2016) and Al-Baghdadi et al. (2017) identified optimal depth-to-helix (H/L) and helix spacing-to-diameter (S/D) ratios, concluding that a two-helix configuration provides an optimal balance between performance and cost-efficiency [12,13]. Numerous studies, including those by Rao et al. (1991) and Mohajerani et al. (2016), have investigated the spacing ratio (S/D) and demonstrated that a ratio of approximately 1.5 typically results in cylindrical failure patterns [14,15]. Further research by El Sharnouby and El Naggar (2012), Lutenegeger (2011), and Tsuha et al. (2013) showed that ratios of approximately 3D are associated with individual plate behavior and independent load transfer [16–18]. Additionally, Lutenegeger (2009) and Nasr (2009) indicated that intermediate spacing values, such as 2D to 2.25D, represent a transitional zone between these two failure modes [19,20].

Research conducted by Di Bernardo (2012), Khazaei et al. (2014), and Ullah et al. (2023) indicates that helical piles perform more effectively in dense soils, and the stabilization period after installation can enhance their tensile capacity by up to twofold [21–23]. Garakani and Serjoie (2022) evaluated the

compressive and tensile bearing capacity of helical piles for 63 kV transmission tower foundations using analytical, numerical, and experimental approaches. Results showed that maximum bearing capacity occurs in unsaturated soils at optimal matric suction [24].

Research by Sakr (2011) and Jamil & Abbas (2021) emphasizes the impact of installation method and pile group spacing on bearing capacity in various soil types [25,26].

In another study, Seifi et al. (2024) explored the simultaneous impact of geometric parameters of helical piles in two-layer soils (clay over sand) on the compressive and tensile capacity of helical piles using the finite element method [27]. Simonenko et al. (2024) undertook both experimental and numerical analyses to investigate the impact of the quantity and vertical spacing of helices in screw piles on their load-bearing capacity in sandy soils [28]. Asgari et al. (2025) investigated the bearing capacities of single-, double-, and triple-helix helical piles subjected to both compressive and tensile loads in dense sand. Their findings indicate that positioning the helices at shallower depths and employing smaller pitches enhances performance [29].

While previous studies have primarily focused on investigating the effects of individual parameters, such as helix spacing or installation method, this research provides a comprehensive and precise analysis using a large-scale and advanced laboratory device to simultaneously evaluate the influence of four key factors: helix spacing, number of helices, soil characteristics, and loading type on the bearing capacity of helical piles. Additionally, one of the novel aspects of this study is its focus on the behavior of helical piles under compressive and tensile loading in coastal soils, which has received limited attention in previous research. The findings of this study are expected to contribute to the optimization of helical pile design in coastal geotechnical settings and may offer practical insights for improving foundation performance in similar sandy environments.

2. Physical modeling

Full-scale field tests are of paramount importance for understanding the actual behavior of piles during installation and operation. These tests provide comprehensive data on bearing capacity and pile performance under actual site conditions, enabling the evaluation of the efficiency of installation methods.

However, the high costs and technical challenges associated with large-scale field tests often restrict their implementation, limiting the ability to extrapolate findings from a limited number of tests to a wide range of geological and construction conditions.

Laboratory-based physical modeling has become a viable alternative to field testing, especially for investigating pile behavior. This method provides precise control over key parameters such as grain size distribution, soil compaction, and pile geometry, allowing for the simulation of diverse conditions within a controlled environment.

Several physical modeling techniques have been developed to simulate real-world deep foundation conditions, including:

- 1 g modeling (simple chamber)
- Calibrated soil chambers
- Geotechnical centrifuges
- Layered soil boxes
- Frustum Confined Vessel (FCV)

These methods offer valuable insights into pile-soil interactions, thereby enhancing the reliability of experimental results for practical engineering applications.

Given the limitations of simple soil chambers, such as low-stress levels and uniform stress distribution in calibrated chambers, more advanced techniques—including layered soil boxes, geotechnical centrifuges, and the Fully Confined Conical Pressure Apparatus (FCV)—are preferred. These methods enable the application of variable stress levels at different depths, creating conditions that more accurately replicate real-world scenarios. Consequently, they yield more precise data for simulating pile behavior across diverse geotechnical environments.

2.1. Validation of the AUT-FCV model

To ensure that the results obtained from scaled laboratory tests using the AUT-FCV device are representative of full-scale pile behavior, comparative validation has been carried out. Esmailzade et al. (2025) performed a comprehensive study comprising 40 model-scale and 15 full-scale load tests on various pile configurations, including conventional, helical, and expanded piles installed in sandy soils. Their comparisons between model and field tests confirmed that the AUT-FCV can reliably simulate the geotechnical performance of piles under realistic stress conditions. These findings support the applicability of the present experimental results to practical field conditions [30].

The 1:4 scale ratio used in this study is based on previous research conducted with the AUT-FCV device, notably by Esmailzade et al. (2025). In their study, scaling theory and similitude laws were applied to correlate laboratory results with field tests. Careful attention was given to matching soil density and stress conditions between the model and the prototype to ensure a realistic simulation of soil behavior. The scaled load-displacement curves showed good agreement with field results, with less than 11% error margin based on the 10% helix diameter criterion.

The scale was selected to balance practical constraints such as apparatus size and soil volume while maintaining reliable soil–pile interaction. Although scale effects such as boundary influence and strain localization are inherent in physical modeling, the experimental setup minimized these by using appropriate embedment depths and chamber dimensions. This approach provides confidence in the reliability of the model results while acknowledging limitations inherent to scaled physical tests [30].

3. Research methodology

3.1. Soil and material properties

The soil used in this research was sourced from Babolsar City, and standard soil mechanic tests were conducted in the Soil Mechanics Laboratory at Amirkabir University. In Figure 1 soil particle distribution curve and SEM Image of the soil are presented. Based on grain size distribution analysis, the soil was classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS). The physical and mechanical properties of the soil are summarized in Table 1.

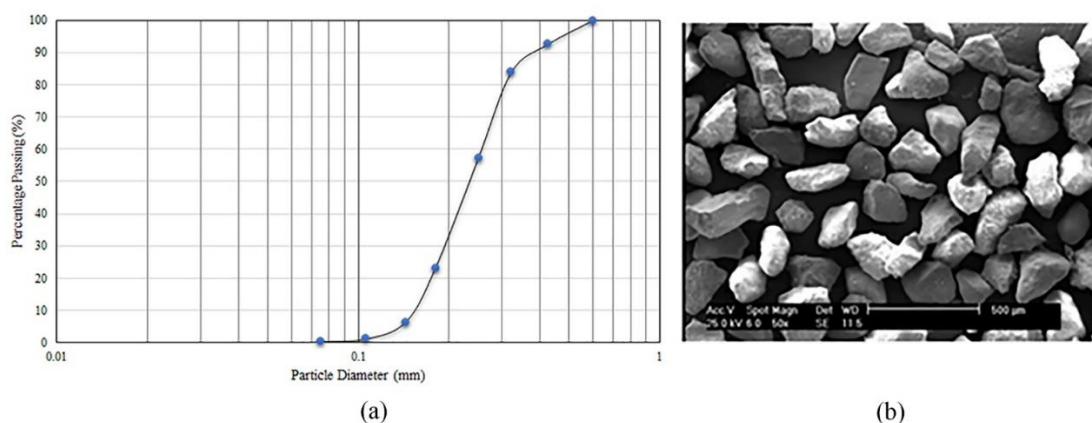


Fig. 1. (a) Particle Size Distribution Curve, (b) SEM Image of the soil.

Table 1. Soil properties.

Parameters	$D_{50}(mm)$	e_{max}	e_{min}	$\gamma_{d,max}(kN/m^3)$	$\gamma_{d,min}(kN/m^3)$	G_s	C_u	C_c	W_{opt}	ϕ	C (kg/cm ²)
Value	0.18	0.876	0.637	17.0	14.82	2.78	1.22	1.67	11	32	0.08

3.2. AUT-FCV device

In this study, experiments were performed using the large-scale AUT-FCV device at Amirkabir University. This advanced apparatus is designed to simulate actual-world stress and loading conditions on piles at various depths. The Frustum Confined Vessel of Amirkabir University (AUT-FCV), constructed from steel with a height of 130 cm, features a two-part separable structure to facilitate sample preparation.

The upper section is connected to the lower section at a height of 70 cm from the base. The lower section has a diameter of 135 cm, while the upper section has a diameter of 30 cm. Loading is applied from the base using rubber membranes and hydraulic pressure to simulate in-situ stress conditions. The system comprises a 75-liter air-water tank, a 110-liter compressor with a pressure capacity of 10 bar, pressure regulators, and a set of hydraulic jacks capable of applying static, tensile, and compressive loads of up to 15 tons.

This apparatus, designed to minimize scale and boundary effects, enables precise and controlled testing. It is particularly effective in simulating stress distribution from the chamber base and generating realistic linear stress distributions. A schematic and an actual image of the AUT-FCV device are presented in Figure 2.

3.3. Soil preparation inside AUT-FCV

The target relative densities—20–25% for loose sand and 40–45% for medium-dense sand—were established based on the known volume of the AUT-FCV tank and the corresponding dry unit weights necessary to achieve these relative densities. The required quantity of dry sand was calculated accordingly. The sand was deposited in the tank in multiple layers, with each layer being gently compacted through manual tamping to ensure uniform density throughout the tank's height. Mechanical vibration was not employed to maintain controlled and repeatable conditions. To verify the achieved densities, sand samples were collected from within the tank after full placement using a calibrated cylindrical sampler. The in-situ dry density was determined from the mass and known internal volume of the sampler. The measured values closely aligned with the target density ranges, thereby confirming the reliability of the compaction method employed.

3.4. Tested piles

The selection of helix spacing ratios of 1.5D and 3D in this study is grounded in previous experimental and analytical research that underscores the impact of spacing on the load transfer mechanism of helical piles. To distinctly capture and compare the contrasting behaviors of the two primary mechanisms—cylindrical and individual—this study concentrates on the two bounding conditions of 1.5D and 3D. This choice is intended to isolate the fundamental differences in pile-soil interaction, thereby avoiding the ambiguity that may arise in the transitional zone.

The piles were subjected to loading under three distinct configurations:

1. Single-helix
2. Dual-helix with helix spacings of 1.5 and 3 times the helix diameter

The study systematically evaluates the influence of four primary parameters on the bearing capacity of helical piles under various loading conditions:

- Helix spacing
- Soil layer characteristics, considering low compaction (20–25%) and medium compaction (40–45%)
- Number of helices
- Loading type, including compressive and tensile loading

In this study, similitude principles grounded in Buckingham's π -theorem were employed to validate the experimental results for field-scale helical piles. The experiments were conducted using the AUT-FCV, a large-scale physical modeling apparatus designed to replicate stress conditions while minimizing the boundary effects. To ensure mechanical similarity between the model and prototype, key dimensionless parameters, such as the stress ratio ($\lambda\sigma = 1$), density ratio ($\lambda\rho = 1$), and geometric scale ratio ($\lambda L = L_m / L_p$), were controlled in accordance with the recommendations of Sedran and Garnier et al. [31,32]. The dimensions of the scaled pile (30 cm in diameter and 110 cm in length) corresponded to a 1:4 prototype ratio. The force and displacement were scaled using factors of 19.36 and 4.4, respectively, derived from the similitude analysis and corroborated by the field data.

The helical piles utilized in this study are fabricated from steel and possess the following specifications:

- Pile Diameter: 30 cm
- Pile Length: 110 cm
- Embedment Depth: 75 cm
- Helix Diameter: 90 mm

Figure 3 presents schematic representations and actual images of the tested piles, while Table 2 provides detailed specifications of the piles and the corresponding test conditions.

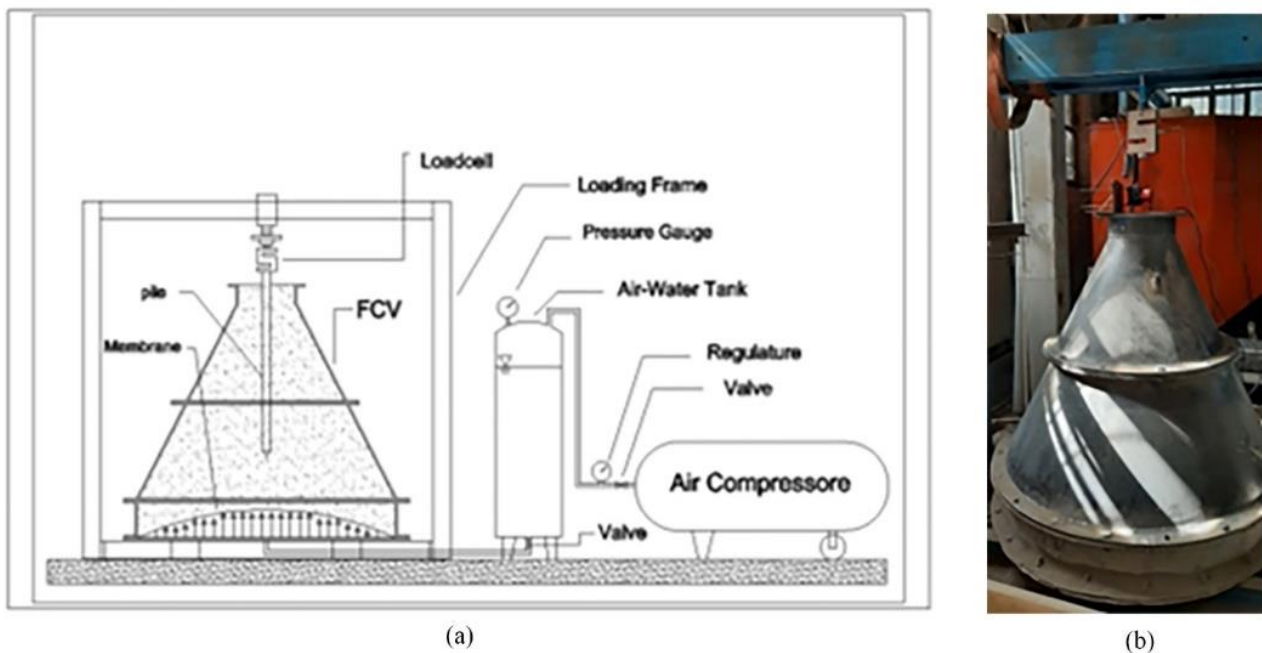


Fig. 2. (a) Schematic image (b) Actual image of the AUT-FCV.

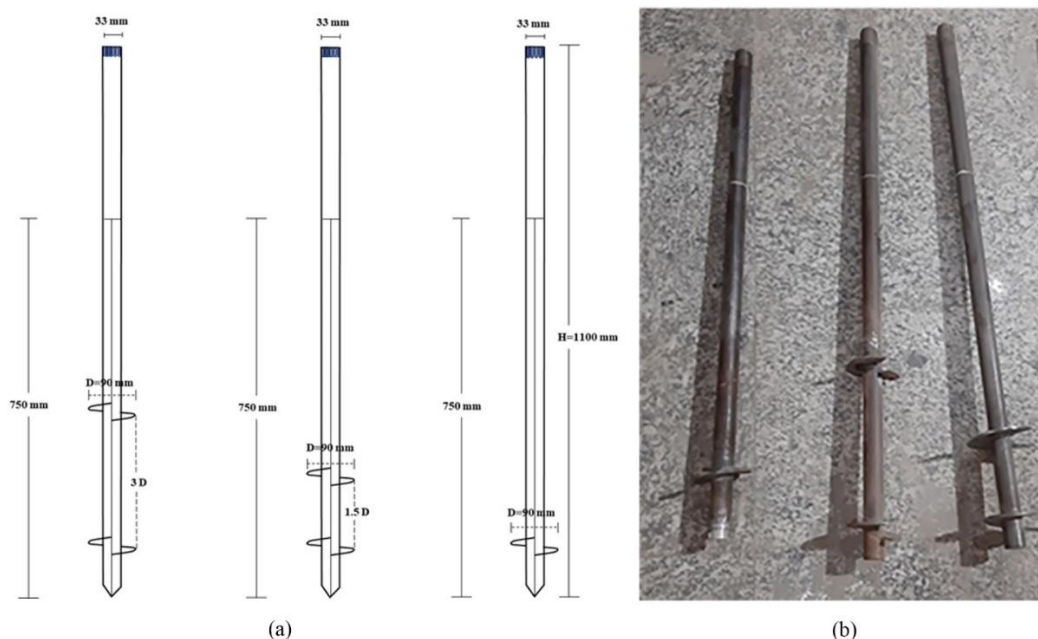


Fig. 3. (a) Schematic image (b) Actual image of helical piles.

Table 2. Geometric and mechanical properties of helical piles under compressive and tensile loading tests.

Test Type	Buried pile length (mm)	Helix Number	Distance Ratio (S/D)	Helix Diameter (mm)	Shaft Diameter (mm)	Density (%)	Loading Type
1H,90-Loose	750	1	-	90	33	20-25	Compressive
1H,90-Loose	750	1	-	90	33	20-25	Tensile
2H,90, S/D=1.5-Loose	750	2	1.5	90	33	20-25	Compressive
2H,90, S/D=1.5-Loose	750	2	1.5	90	33	20-25	Tensile
2H,90, S/D=3-Loose	750	2	3	90	33	20-25	Compressive
2H,90, S/D=3-Loose	750	2	3	90	33	20-25	Tensile
1H,90-Medium	750	1	-	90	33	40-45	Compressive
1H,90- Medium	750	1	-	90	33	40-45	Tensile
2H,90, S/D=1.5-Medium	750	2	1.5	90	33	40-45	Compressive
2H,90, S/D=1.5-Medium	750	2	1.5	90	33	40-45	Tensile
2H,90, S/D=3- Medium	750	2	3	90	33	40-45	Compressive
2H,90, S/D=3- Medium	750	2	3	90	33	40-45	Tensile

3.5. Experimental procedure

The experiments were performed under two loading conditions: compressive and tensile, with each test conducted in three sequential phases:

1. Pile Installation
2. Loading
3. Displacement Measurement

Key parameters, including the number of helices, helix spacing, and soil compaction, were recorded for each test. To evaluate the bearing capacity, the modified Davisson method was applied. According to this approach, the bearing capacity of the pile was defined as the maximum applied load corresponding to a displacement equal to 10% of the pile diameter.

The loading tests were conducted in accordance with ASTM D1143 (for compression) and ASTM D3689 (for tension), using a load-controlled method. Loading was applied in twenty incremental steps, each equal to 5% of the estimated ultimate load, and held constant for 10 minutes per step. Both compression and pullout tests followed this stepwise procedure until failure was observed. A reciprocating hydraulic jack (capacity: 150 kN, stroke: 150 mm) applied the axial loads, and the pile head displacement was continuously recorded using a 100 mm-stroke LVDT with 0.01 mm accuracy.

Data from the LVDT and a 100 kN S-type load cell were logged every 5 seconds using a 16-channel datalogger (Figure 3). This setup ensured precise monitoring of the pile response under both compressive and tensile loading conditions.

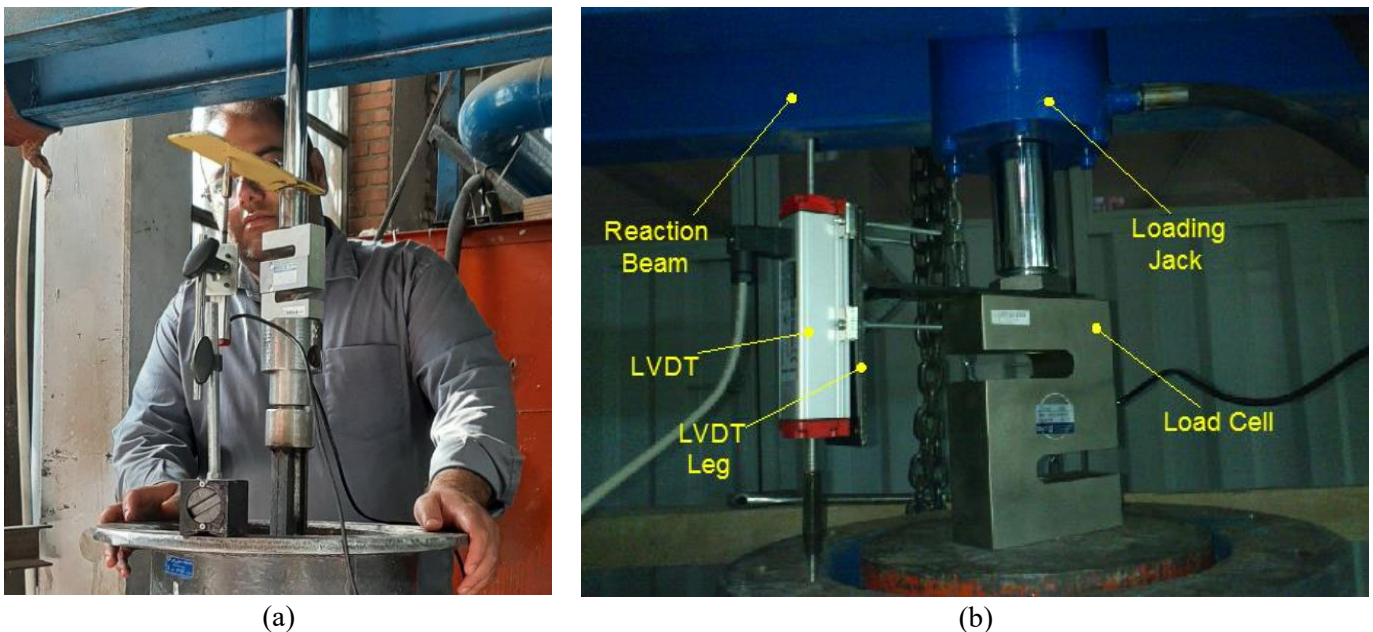


Fig.4. Installation and loading setup of the model pile in the FCV device: (a) Installation apparatus; (b) Loading system.

3.6. Repeatability

Separate compression and tension (pull-out) tests were performed on helical piles using the FCV apparatus. The goal was to verify the consistency and reliability of the results. As shown in Figure 5, the load-displacement curves obtained from these tests exhibit a high degree of similarity in both loading paths, confirming the repeatability of the setup.

4. Data analysis

4.1. Effect of soil compaction on the performance of helical piles under compressive and tensile loading

The results indicate that an increase in soil compaction significantly enhances the bearing capacity of the piles while reducing displacement. Figure 6 illustrates the load-displacement curves, categorized based on the number of helices and helix spacing. Specifically, increasing soil compaction from a loose to a

medium-compacted state resulted in an increase in the compressive bearing capacity of the piles up to 290%.

A similar trend was observed under tensile loading, where increased soil compaction led to improved pile performance. Notably, transitioning from a loose to a medium-compacted state enhanced the tensile bearing capacity by up to 320%. This optimal improvement was most evident in dual-helix piles with a 3-times helix spacing ratio (Figure 7).

These findings are consistent with previous studies by Khazaei et al. (2014) and Hosseinpour et al. (2024), which also demonstrated a positive correlation between soil compaction and bearing capacity enhancement (Figure 8).

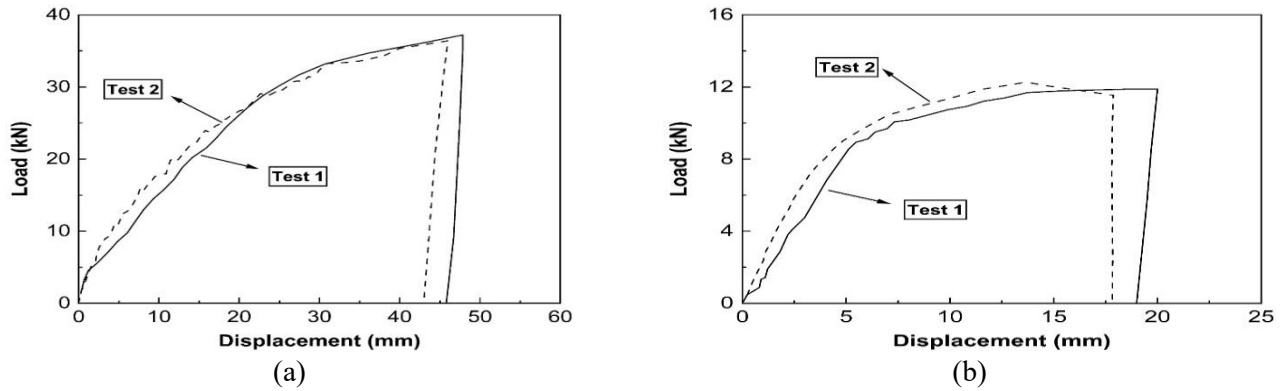


Fig.5. Repeatability of load-displacement curves for two-helix helical piles with a spacing ratio of 3 tested in the FCV device: (a) Compression; (b) Pullout.

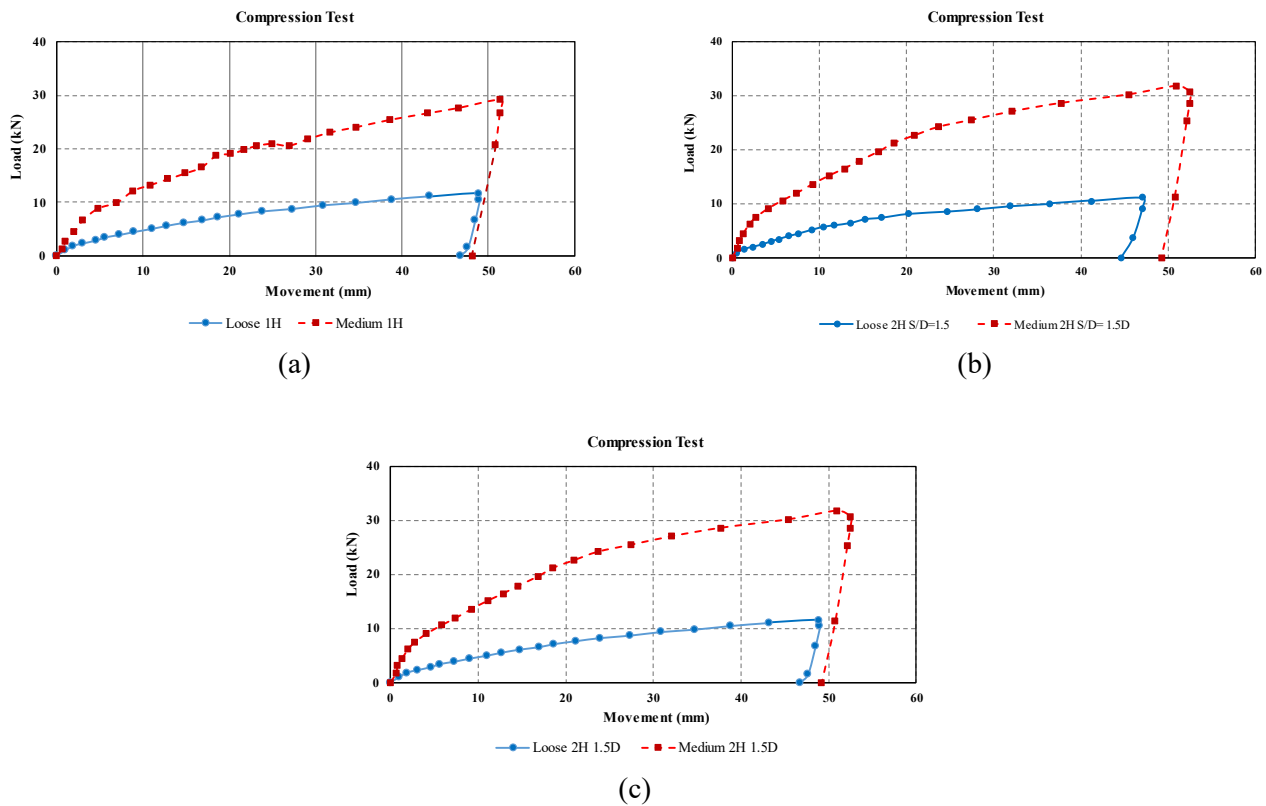


Fig. 6. Displacement variations of helical piles under compressive loading in soils with low and medium density. a) Single-helix pile. b) Dual-helix pile with a helix spacing ratio of 1.5. c) Dual-helix pile with a helix spacing ratio of 3.

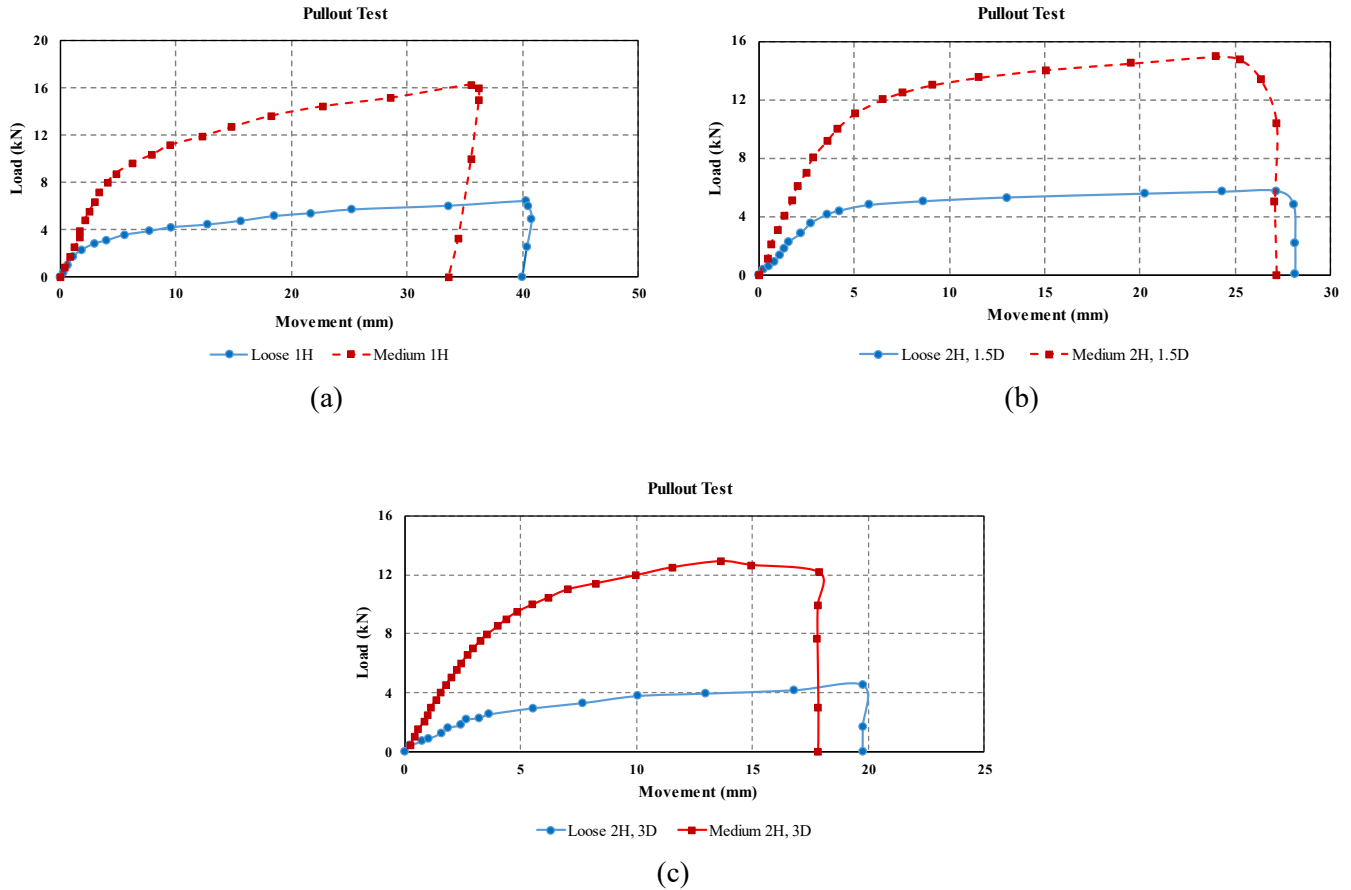


Fig. 7. Displacement variations of helical piles under tensile loading in soils with low and medium density. a) Single-helix pile. b) Dual-helix pile with a helix spacing ratio of 1.5. c) Dual-helix pile with a helix spacing ratio of 3.

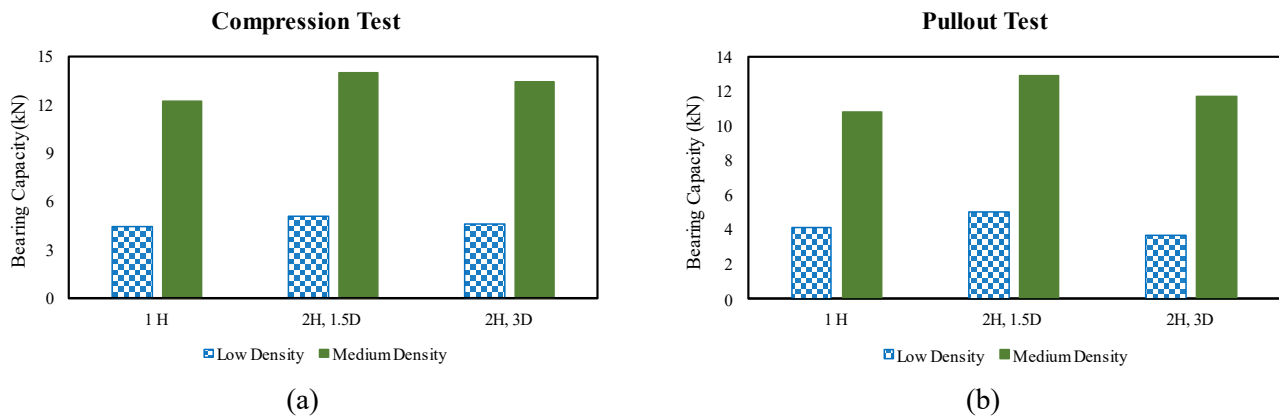


Fig. 8. Effect of increasing density on the bearing capacity of helical piles a) Tension b) Compression.

4.2. The effect of the number and spacing of helix on the bearing capacity of helical piles

The results suggest that in loose sandy soil under compressive loading, adding a helix to a helical pile—with a helix spacing of 1.5 times the helix diameter—leads to a 14% increase in bearing capacity. Under tensile loading, the same pile configuration exhibits an 18% increase in bearing capacity compared to a single-helix pile. However the loading tests indicate that an increase in the number of helices enhances bearing capacity only when the optimal spacing is maintained. If the helix spacing exceeds this optimal

range, the bearing capacity does not exhibit a significant improvement. The results show increasing the helix spacing to three times the helix diameter under compressive loading results in only a 4% increase in bearing capacity. Under tensile loading, this configuration not only fails to enhance bearing capacity but instead leads to an 11% reduction compared to the single-helix pile (Figure 9,10 & Table 3).

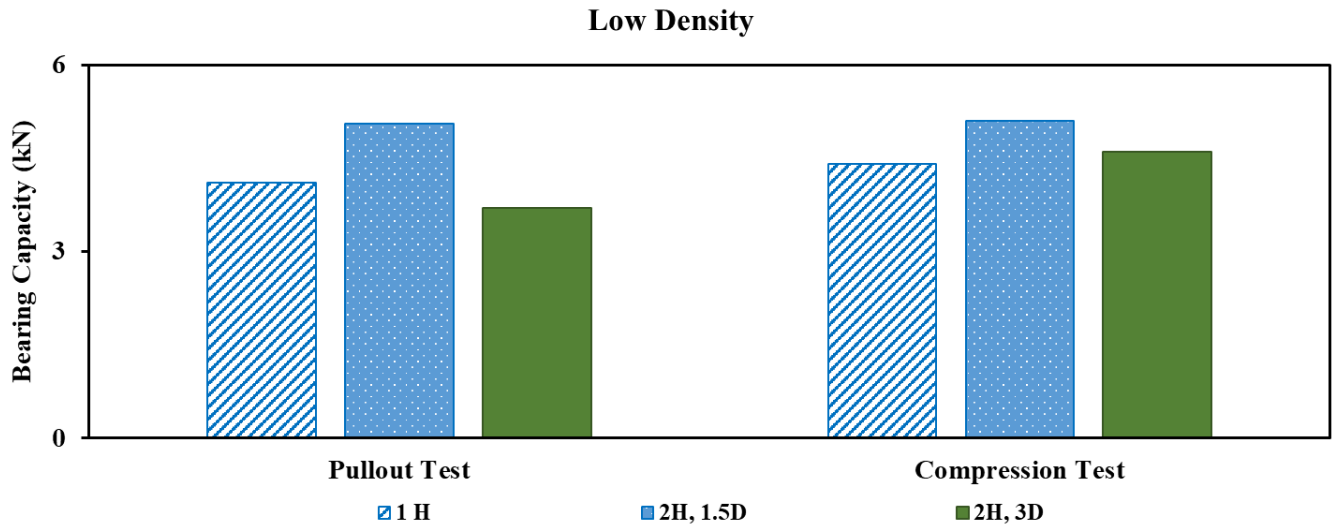


Fig. 9. Effect of increasing the number of helices on the bearing capacity of helical piles in loose sandy soil.

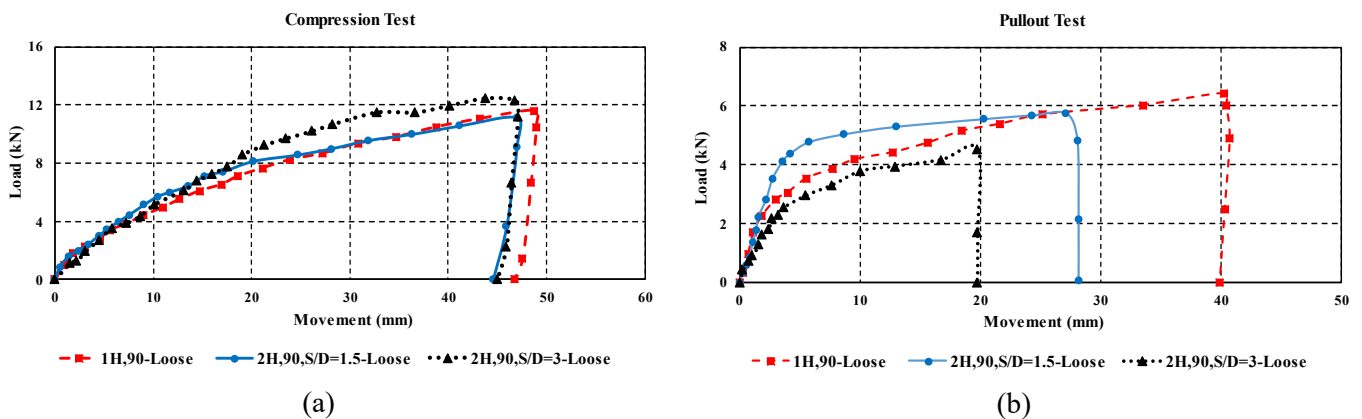


Fig. 10. Load-displacement behavior of helical piles in loose sandy soil: (a) Under compressive loading, (b) Under tensile loading.

Table 3. Bearing capacity of helical piles under compressive load in loose sandy soil.

Pile	Pile Bearing Capacity (kN)	
	Tensile	Compressive
Single Helix	4.1	4.4
Dual-helix pile with a helix spacing of 1.5 times the helix diameter.	5.05	5.1
Dual-helix pile with a helix spacing of 3 times the helix diameter.	3.7	4.6

In medium-dense sandy soils, increasing the number of helices under compressive loading results in a 13% increase in bearing capacity for a helix spacing of 1.5 times the helix diameter and a 9% increase for a spacing of 3 times the helix diameter. Under tensile loading, the corresponding increases in bearing capacity are 16% and 8%, respectively (Figures 11, 12 & Table 4).

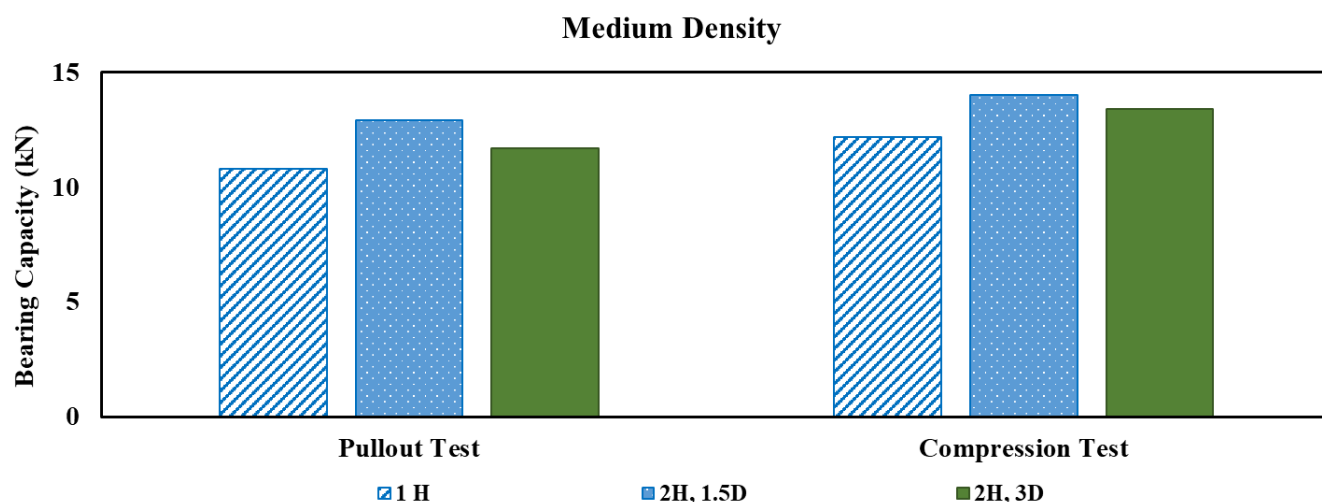


Fig. 11. Effect of increasing the number of helices on the bearing capacity of helical piles in sandy soil with medium density.

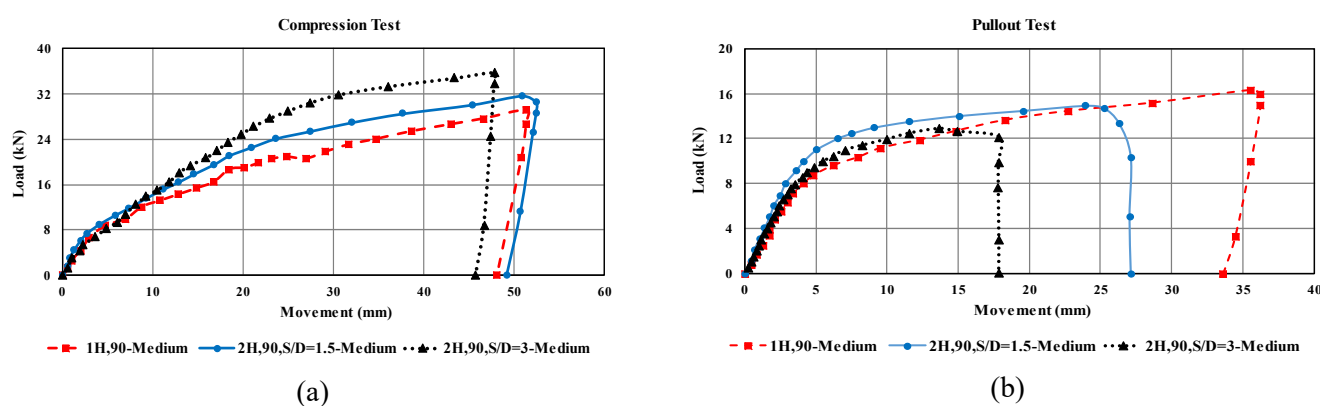


Fig. 12. Load-displacement behavior of helical piles in medium-density soil: (a) Under compressive loading, (b) Under tensile loading.

Table 4. Bearing capacity of helical piles in sandy soil with medium density.

Pile	Pile Bearing Capacity (kN)	
	Tensile	Compressive
Single Helix	10.8	12.2
Dual-helix pile with a helix spacing of 1.5 times the helix diameter.	12.9	14.0
Dual-helix pile with a helix spacing of 3 times the helix diameter.	11.7	13.4

4.3. Impact of loading type on the bearing capacity of helical piles

A comparison of helical piles under compressive and tensile loading reveals that, in addition to their notable compressive capacity, helical piles exhibit a considerable tensile capacity. The tensile bearing capacity ranges from 80% to 99% of their compressive bearing capacity, indicating their suitability for applications in tensile structures such as transmission towers.

A single-helix pile exhibits different behavior under tensile and compressive loading, with its tensile bearing capacity ranging from 88% to 93% of its compressive bearing capacity. The most effective performance under tensile loading is observed in dual-helix piles with a helix spacing of 1.5 times the helix diameter. These piles demonstrate a tensile bearing capacity ranging from 92% to 99% of their compressive bearing capacity, effectively withstanding higher tensile loads with reduced displacement.

In dual-helix piles with a helix spacing of 3 times the helix diameter, the tensile bearing capacity ranges from 80% to 87% of the compressive bearing capacity. Figures 13-16 and table 5 present a comparison of the bearing capacity and load-displacement of each pile under compressive and tensile loading.

These results may be attributed to the influence of helices on the tensile bearing capacity of piles, as demonstrated in previous studies, including Esmailzadeh and Eslami (2025). Their research indicates that the presence of helices significantly enhances the tensile capacity of piles. Furthermore, comparisons between the bearing capacities of torsional (helical) and conventional piles under both compression and tension loading conditions reveal that the tensile bearing capacity of helical piles is substantially higher than that of conventional piles [33].

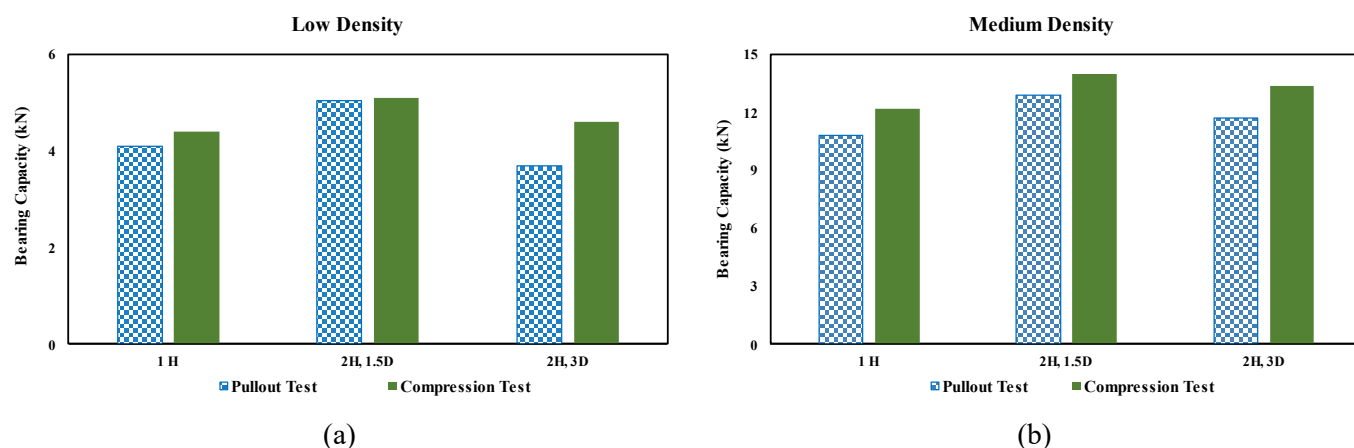


Fig. 13. Comparison of the compressive and tensile bearing capacities of helical piles in sandy soils: (a) Low-density soil, (b) Medium-density soil.

Table 5. Bearing Capacity of Helical Piles Under Compressive and Tensile Loading.

Pile	Density	Pile Bearing Capacity (kN)	
		Tensile	Compressive
Single Helix	20%-25%	4.1	4.4
	40%-45%	10.8	12.2
Dual-helix with helix spacings of 1.5 times the helix diameter	20%-25%	5.05	5.1
	40%-45%	12.9	14.0
Dual-helix with helix spacings of 3 times the helix diameter	20%-25%	3.7	4.6
	40%-45%	11.7	13.4

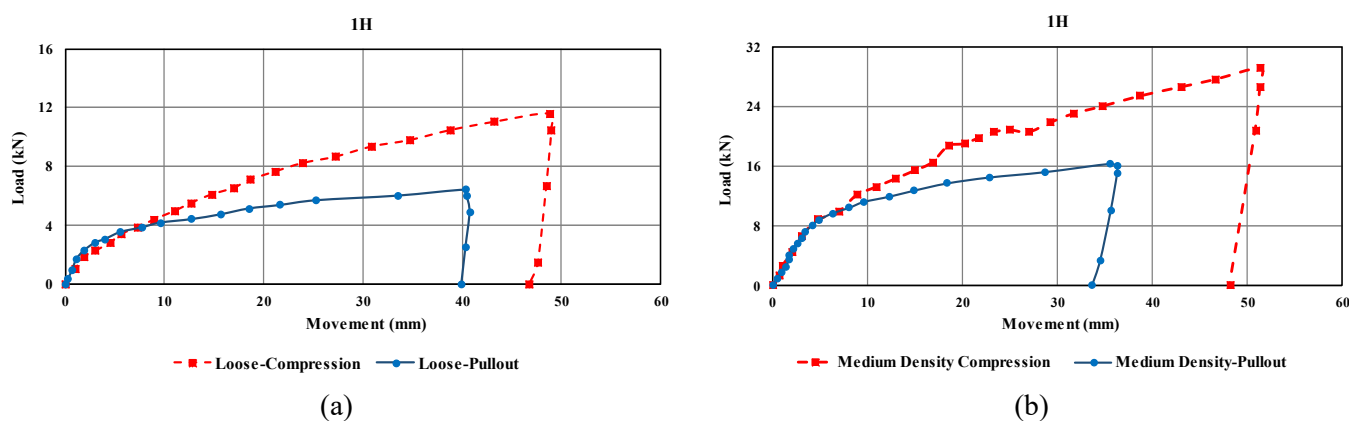


Fig. 14. Displacement behavior of a single-helix helical pile under tensile and compressive loading in sandy soil (a) low density (loose) and (b) medium density.

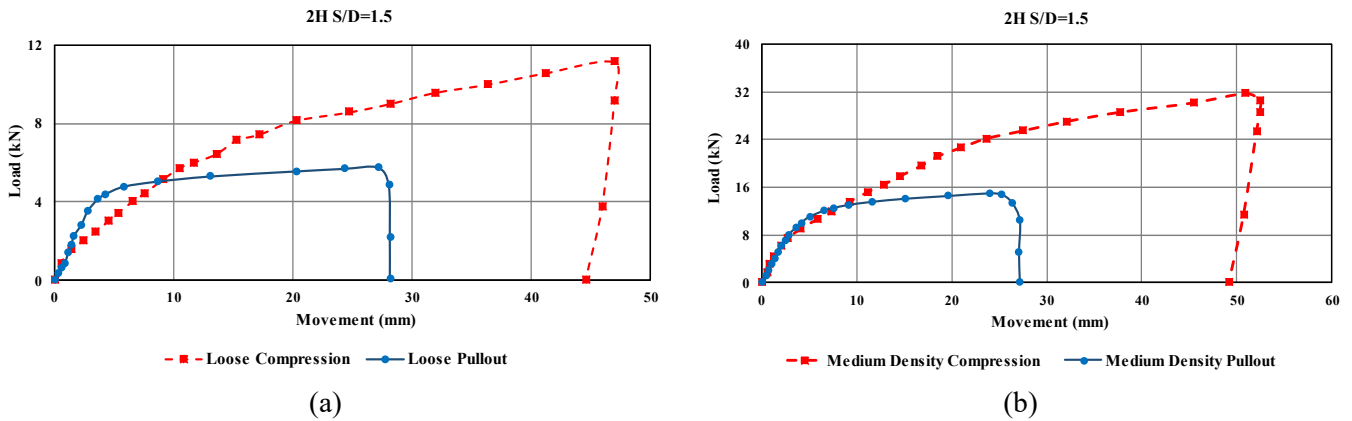


Fig. 15. Displacement behavior of Dual-helix with helix spacings of 1.5 times the helix diameter under tensile and compressive loading in sandy soil (a) low density (loose) and (b) medium density.

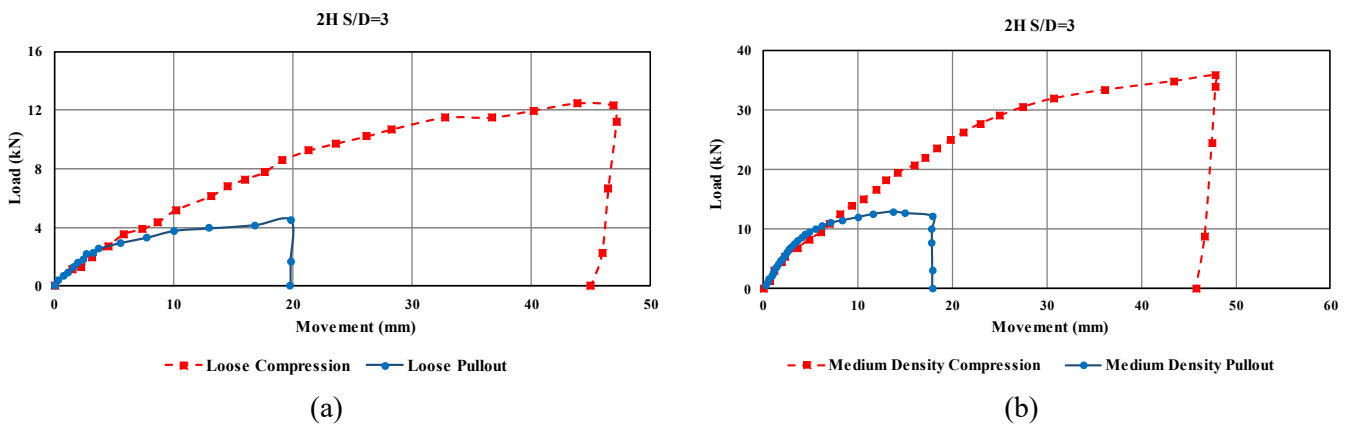


Fig. 16. Displacement behavior of Dual-helix with helix spacings of 3 times the helix diameter under tensile and compressive loading in sandy soil (a) low density (loose) and (b) medium density.

5. Conclusions

This study aimed to evaluate the factors influencing the bearing capacity of helical piles under compressive and tensile loading in sandy soil sourced from Babolsar. The combined effect of four key parameters — soil compaction, number of helices, helix spacing, and loading type — on the bearing capacity of helical piles was systematically investigated.

The findings of this study demonstrate that soil compaction is a critical factor in improving pile performance. Increasing the soil compaction from a loose to a medium state enhances the bearing capacity of the pile by up to 290% under compressive loading and 320% under tensile loading.

The results indicate that the optimal helix spacing has a more significant impact on bearing capacity than the number of helices. In both loose and compacted soils, dual-helix piles with a spacing of 1.5 times the helix diameter exhibit the highest bearing capacity, particularly under tensile loading. Conversely, increasing the spacing ratio to 3 times the helix diameter adversely affects the tensile bearing capacity.

The findings further indicate that helical piles exhibit not only high compressive resistance but also considerable tensile strength, with their tensile bearing capacity ranging from 80% to 99% of their compressive capacity. This characteristic makes them suitable for use as supports for tensile members in structures such as transmission towers.

While the experiments were conducted under monotonic axial loading, the findings offer baseline insight into pile behavior. The study acknowledges the need for further research to evaluate pile response under cyclic, lateral, and dynamic loading, especially in urban or coastal environments where such conditions are prevalent.

Despite the absence of formal statistical modeling, the interaction effects between parameters—particularly between helix configuration and soil density—were systematically analyzed, highlighting their coupled influence on load-bearing behavior.

This study provides practical recommendations for optimizing helical pile design in sandy soils, particularly emphasizing the effectiveness of a 1.5D helix spacing for improving load transfer and minimizing displacement.

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Conflicts of Interest

The authors declare there are no conflicts of interest.

Authors' Contribution Statement

Hamed Bahrami: Writing original draft, Methodology, Investigation, Conceptualization.

Soheil Ghareh: Writing, reviewing & editing, Visualization, Validation, Supervision, Investigation.

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