Research on Engineering Structures & Materials
www.jresm.org
Research Group

Research Article

Model study on axial load-settlement response of helical piles in soft clay

Maysa Salem Al-Qaisi [1,a], Maki Jafar M. Al-Waily [*,2,b]

[1]*Department of Building and Construction, Al-Musaib Technical College, Al-Furat Al-Awsat Technical University, Kufa, Iraq*
[2]*Department of Civil Engineering, College of Engineering, AL-Nahrain University, Baghdad, Iraq*

Article Info

Article History:

Received 09 Sep 2026

Accepted 13 Oct 2026

Keywords:

Helical Piles;
Axial Load-settlement;
Soft clay;
Helix geometry;
Multi-helix piles;
Model testing;
Improvement ratio

Abstract

In this study, an experimental investigation is performed to characterize the axial load-settlement behavior of small-scale helical piles with different geometric configurations. A central shaft of 20 mm in diameter and 600 mm long was used, and the pile models prepared consisted of 10 piles that were tested. An experimental program was established to evaluate the impact of number (single, double, and triple) and diameter (40 mm, 50 mm, and 60 mm) of helices on bearing capacity as well as helical pile behavior through installation. It can be seen when comparing load-settlement curves established for different numbers of helices that the ultimate load increases and the total settlement decreases for all tested piles. Pioneering the design intent of this research, it was found that an extraordinary increase in bearing capacity could easily be achieved with a triple-helix configuration, where a 60 mm diameter model yielded an ultimate load of 815N at 50 mm settlement (an enhancement of 246.8% on plain shaft control basis). It is also indicated from these data that increasing the diameter, in addition to number of helices, improves helical pile capacity. These results show that increasing the helix diameter but keeping geometry proportional resulted in an improvement in soil-pile interaction and demonstrates a greater ultimate bearing capacity at adopted settlement, especially with larger helix-to-shaft (Dh/d) ratios. The results confirm that deep foundation systems used in engineering project applications should optimize helix geometry, as increasing the Dh/d ratio offers an improvement in both stability and bearing capacities.

© 2026 MIM Research Group. All rights reserved.

1. Introduction

Helical piles in soft clay exhibit a complex, primarily logarithmic axial load-settlement response that is not amenable to simple analytical modeling for structural serviceability [1]. Given their significantly low undrained shear strength and high compressibility, the accurate prediction of these settlement patterns is essential in geotechnical design in order to mitigate potential risk on structural safety [2]. In addition, the success of these systems is regulated through complex soil–pile interactions where load transfer primarily depends on clay undrained shear strength; geometry and layout of helical plates and relative spacing between adjacent helices [3,4]. In particular, shaft resistance and end-bearing capacity mobilization is extremely sensitive to installation-induced soil disturbance that can extend over a radial distance greater than one helix diameter [5]. In addition to those geometric controls, whether the failure mechanism is controlled by single plate bearing or an aggregate cylindrical shear mode [6] depends on inter-helical interaction as well. An elastoplastic load-transfer framework that incorporates the small-strain stiffness degradation in the elastic zone and is governed by plastic shear deformation on the shaft can achieve a better prediction of movement from an elastic-load-displacement response to

*Corresponding author: mkai.jafar@nahrainuniv.edu.iq
[a]orcid.org/0000-0003-3337-6074; [b]orcid.org/0000-0002-8906-2915
DOI: http://dx.doi.org/10.17515/resm2026-2325ic0909rs

localized plastic failure state [7]. In addition to these site-specific consolidation effects, experimental field data show that group interaction and pile-to-pile spacing greatly influence how much total shaft resistance is mobilized when compared with isolated single-pile behavior [8]. Emerging results show that performance for discrete helix capacity is strongly influenced by cohesive soil nature, and that larger-capacity systems can provide greater resistance in the form of deep-seated end bearing/shaft friction transfer [9]. Additionally, 3D numerical analyses have highlighted the necessity for optimizing these geometric parameters to address embankment stability and long-term consolidation settlement of soft clay deposits [10]. To improve the predictive accuracy beyond conventional empirical boundaries, machine learning algorithms used previous mechanical data (i.e. load-displacement) to improve settlement estimates [11]. Recognizing that the excess pore-water pressure generated during loading reaches critical limits at certain displacement ratios is also important to successfully replicate the non-linear transition from active to ultimate resistance. In such environments, the actual pile capacity corresponding to installation torque remains extremely heterogeneous and needs to be site-specific calibrated rather than approached with generic correlation factors [12]. In summary, a well-defined and clearly interpretable serviceability criterion—such as a certain percentage of the helix diameter—is important for assessing whether a foundation has structural adequacy under short-term loading and postconstruction secondary compression [13]. This reading would necessitate integrating the average excess pore pressure dissipation observed during installation with later axial load-displacement trajectories in subsequent loading, limiting confidence that the anticipated serviceability limits are met [14]. In addition, the creation of strict relationships among installed torque and vertical capacity enables to systematically optimize foundation layout for different cohesive profiles [15]. It is crucial to accurately estimate these parameters, since it is well known that available analytical methods typically do not capture the complexity of tensile capacity in each layer in an arbitrary soil profile [16]. Developments in coupled Eulerian-Lagrangian modelling offer significantly greater clarity and have the potential for quantifying the response under undrained tensile loading by directly modelling large deformations during an installation. These sophisticated frameworks account for strain rate and softening effects that are essential to estimate the reduction of clay resistance during both the installation and loading stages [17]. Furthermore, performing these numerical simulations enables a parametric study on the ratios of helix pitch and diameter, which is fundamental to improving the empirical models needed for offshore/bridge foundation design. This was evident in these numerical frameworks as disturbed cylindrical hydromechanical behavior is responsible for most of the effective stress state (and therefore long-term settlement trajectory) through 0.7H time [18]. Modeling the transition from independent plate bearing to cylindrical shear envelope failure correctly in soft clay environments is important for developing realistic design capacities [19]. The ultimate resistance during such loading conditions is rather related to a full assessment (time-dependent) of the undrained shear strength since soil thixotropy and pore-pressure dissipation play crucial roles [20]. It still remains important to be able to predict these performance metrics because current design approaches, for example those that are torque-based capacities, do not explicitly account for the likely future complex settlement trajectories under service loads [21]. Within geotechnical engineering, the performance of screw and helical piles has been extensively investigated in research studies featuring complex soil conditions and load cases in recent years. For example, physical soil-pile interaction tests of screw piles in soft clayey soils subjected to uplift forces [22]. In addition, numerical modelling has been increasingly used to assess the performance of screw piles in soft and layered soils under static and seismic loading [23]. In addition to the soft clay cases, both structural resistance and settlement of screw piles have been examined in fields of challenging geotechnical soil conditions including gypseous deposits [24]. Expanding on these previous studies, this work targets the compressive axial behavior of multi-helix configurations.

Although earlier works have separately characterized the influence of helix parameters, the simultaneous effect of helix number, diameter, and pitch remains elusive to some extent. This research overcomes this limitation by studying how such parameters jointly influence installation disturbance and subsequent load transfer mechanisms.

2. Experimental Works

2.1 Materials

The clay soil used in this study was obtained from the Al-Hamza Al-Gharbi district, Babylon Governorate, locality (about 135 km south of Baghdad, near the Euphrates River). The material is a lean clay per the Unified Soil Classification System (Geotechnical evaluation). All tests were conducted in accordance with ASTM standards to ensure reproducible results. Hydrometer analyses and Atterberg limit tests were also performed which indicated that the soil type is low plasticity clay (CL) according to USCS system, (Table 1). Even though the clay soil was sourced from a natural deposit, the experimental procedure involved air-drying, crushing and sieving of the sample, followed by mixing with water and re-compaction using the procedure described in the next paragraphs.

Table 1. Physical properties and particle-size distribution of the soil sample

Property	Value	Specifications
Specific (G_s)	2.66	ASTM D854
Liquid Limit (LL)	45%	
Plastic Limit(PL)	18%	ASTM D4318
Plasticity Index (PI)	27%	
Clay Content	53%	ASTM D6913
Silt Content	46%	ASTM D7928
Sand Content	2%	
Maximum Dry Unit Weight $\gamma_{d(max)}$	18.8 kN/m^3	ASTM D1557
Optimum Moisture Content (OMC)	17%	
Soil Classification (USCS)	Lean Clay (CL)	ASTM D2487

2.2 Undrained Shear Strength Correlation

ASTM D2166 (6) unconfined compression apparatus measures cu. Undrained shear strength, cu (from 5 to 100 kPa) versus liquidity index (L.I=(PL-w)/(L.L-P.L)) of soil sample in varied liquidity indices (from 1 to 0.1) is shown in Figure 1. An undrained shear strength of 18 kPa was selected, as it is common for sensitive alluvial deposits such as those found along sections of the Euphrates. In undrained conditions, soil remolding can be used to study the pile-soil interaction characteristics. For this test, a value of 18 kPa was chosen to represent the undrained shear strength of soft-to-medium clay conditions; however, extensive vane shear tests (VST) were performed across the tank before forming the piles for spatial density and uniformity. Measurements were taken from different depths [100, 300 and 500] mm at several locations. The tests showed an average cu of 17.9 kPa with minimum and maximum individual measures of 17.0 kPa and 18.5 kPa, respectively. A low standard deviation of 0.55 kPa combined with a coefficient of variation equal to 3.1% allows for its characterization, and the representativeness of this value as a uniform shear strength along depth to provide a reliable experimental baseline at 18kPa for the models used.

2.3 Soil Tank

Tank dimensions were then chosen to quantitatively limit the effects of rigid boundary conditions during installation and loading. Accordingly, the pile was placed in the center of the 800 mm x 800 mm plan area with a minimum radial distance of 400 mm from the stack to the side walls. At the largest tested helix diameter (D_h = 60 mm) this radial clearance correlates with 6.67 Dh, which is well above the widely recognized geotechnical limit of lateral boundary interference at approximately 5 D_h . The pile is installed into a space of 700 mm depth soil bed with an allowable clearance below the tip of piles as 200 mm. This clearance below the bottom boundary directly relates to a value of 3.33 D_h (and 10 times the shaft diameter of 20 mm) that is more than enough to envelope the localized vertical stress distribution and pressure bulbs activated underneath the lowermost helix without significant stresses being transferred to rigid tank floor.

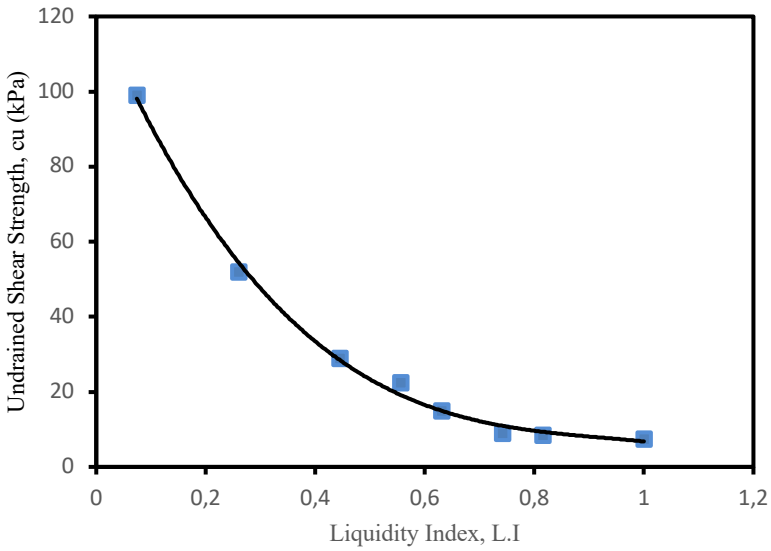


Fig. 1. Experimental relationship between liquidity index and undrained shear strength, derived from UCS test

2.4 Loading Frame

A manually operated hydraulic jack with a maximum capacity of 5 tons was utilized to exert vertical loads. The apparatus comprised two high-precision linear variable differential transformers capable of measuring axial settlement with a resolution of 0.01 mm, in addition to a calibrated load cell for real-time measurement of reaction forces during pile loading (Figure 2) .

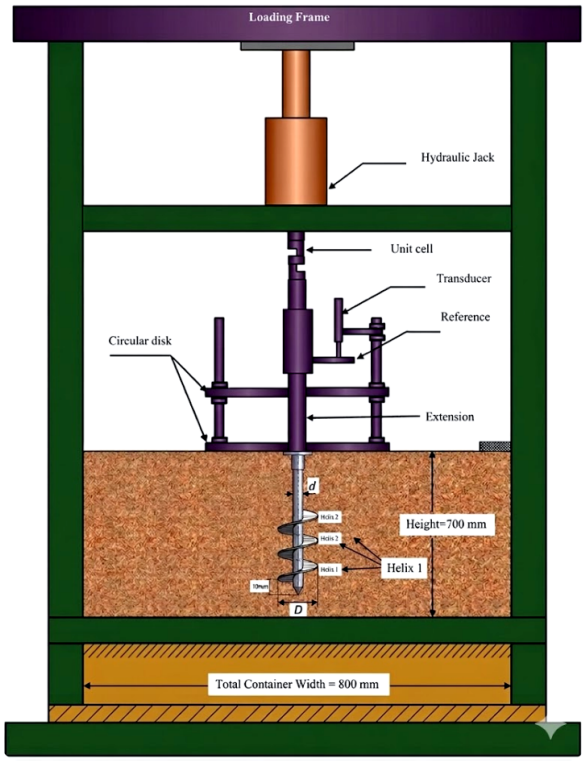


Fig. 2. Sketch of the loading frame with soil tank

2.5 Preparing the Soil and Constructing the Model

Soil bed preparation was performed in two systematic stages for uniformity and to reach the prescribed undrained shear strength (cu). First, the clay sample was air-dried, crushed, and sieved to eliminate contaminants and obtain a homogenous particle size distribution. In phase two, the

treated material was mixed with pre-measured distilled water to reach 33% final moisture content. Soil was then compacted in the test tank with a manual wood rammer. To create an even mass, the soil was put into the 700 mm deep tank in seven equal layers of compacted thickness 100 mm. This stage of compaction produced a dry density value of 13.90 kN/m3, an initial void ratio of 0.88, and a degree of saturation equal to 100% (completely saturated state). Finally, the soil bed was allowed to equilibrate chemically and hydrologically for about 48 h. In addition, vane shear tests were performed before pile installation in multiple locations and at different depths to ensure spatial uniformity throughout the tank. The undrained shear strengths measured ranged from a minimum of 17 kPa to maximum of 18.5 kPa, confirming an average target strength value around 18 kPa.

2.6 Suggested models of helical piles

Since the axial capacity and load transfer mechanisms of helical piles in cohesive soils are inherently related to the initial undrained shear strength and stress history of the clay matrix, documenting these physical state parameters is crucial.

Table 2 provides laboratory model geometrical and technical parameters of 10 helical piles. The study aims to investigate how changing the blade diameter and number of helices affects pile efficiency.

The pipe length 600 mm model, outer diameter 20 mm, thickness 1.5 mm, helix (2 mm thick)

There are three types of models based on helix diameter and pitch spacing.

- Group 1 (40 mm Diameter). Pitch 30 mm, single, double or triple helices.
- Group 2 (50 mm Diameter) with a pitch of 38 mm. Also in this group are Helices 1, 2, or 3 variants.
- Group 3 (60 mm Diameter) has a pitch of 45 mm. That group carries one or two or three helices.

Table 2. Helical pile models of geometric properties

Model Type Control Model	Configuration Plain pipe shaft	Helix Dia. (D_h) -	Pitch (p)=0.75 D_h -
Single Helix	1 Helix	40, 50 and 60 mm	
Double Helix	2 Helices	40, 50 and 60 mm	30 mm, 38 mm and 45 mm
Triple Helix	3 Helices	40, 50 and 60 mm	30mm, 38 mm and 45 mm
Model Type	Configuration	Helix Dia. (Dh)	Pitch (p)=0.75 Dh

2.7 Helix Configuration and Spacing

As mentioned before, the experimental program employed 10 model helical piles with different geometric configurations (Figure 3). Three helix diameters (D_h), 40, 50 and 60 mm were examined as shown in table 2 and were attached to the same length of steel shaft with a diameter of d =20 mm, which was 600 mm long. Helix pitches of 30, 38 and 45 mm were chosen respectively for the pitch-to-diameter ratio (p/Dh) to be around a constant value of 0.75. For multi-helix models (double and triple), the center-to-center spacing (S) between helices was applied as a fixed absolute value of 40 mm. Correction of this spacing is possible, however it is recognized that normalized spacing ratio (S/D_h) changes naturally with changing helix diameter, taking the ratios 1.00, 0.80 and 0.67 respectively for the diameters of 40, 50 and 60 mm. This is why geometric similarity is not exactly satisfied in the three diameter groups. In this case, and because for all considered configurations all calculated S/D_h ratios are ≤ 1.0 the inter-helical spacing is small enough in all configurations tested that the foundation operates largely within a regime of multi-plate peripheral bearing with little risk of switching from overlapped stress areas to separate plate bearing behavior. It is essential for standardization of evaluation for overlapped stress areas and soil-pile interaction at axial load. To reduce soil disturbance while installing and limit excess pore-water pressure development in the soft clay matrix, all models were installed using a controlled advance ratio. Such methodological rigor guarantees that the observed capacity improvements result purely

from changes in the helix geometry and given that we transitioned from shaft friction to multi-plate peripheral bearing.

The embedment depth and positions of the helices were strictly controlled to define the overburden stress conditions. The specimen shaft length was 600 mm in total, but the depth of each pile embedded into soil during testing was equal to 500 mm and the remaining 100 mm present above ground for load application. In this configuration, the bottom helix was located at a depth of 500 mm measured from the soil surface directly below the pile tip for all configurations.



Fig. 3. Photograph of the fabricated helical pile models

2.8 Tools and Equipment for Installation and Configuration

A primitive mechanical guide had been designed and deployed to help the helical pile vertical throughout penetration. It consisted of the following components (Figure 4):

- T-Handle: This is done at the top of the piling shaft – has a handle which permits constant torque to be applied by hand, without overloading the soil matrix in axial loading as an end-state criterion.
- Frame: A heavy steel frame fitted onto the upper part of the soil containment tank. Bushing with a 21mm internal diameter prevents the piles from getting bent or deviating during installation.



Fig. 4. Installation of helical pile model

2.9 Procedures for Installation

The installation was done as per the official order of the following:

The apex of the helical pile was first geometrically aligned directly above the desired test locus on the soil surface and thence referenced within a frame of reference externally generally directed via the guide. Screw Propagation: The screw was rotated in a clockwise manner, at low and constant angular velocity to produce axial penetration equal to helix pitch per twist. This approach simulated ideal screw-in kinematics, eliminating the auguring effects that decrease soil resistance.

Plumbness Monitoring: An automatic digital inclinometer recorded whether the pile was vertical at all times during insertion, permitting only movements that stayed within acceptable limits relative to the total length of the pile. The helical pile models were installed in the prepared clay bed using a vertical force and a constant rate of rotation simultaneously down through the length of the shaft.

Reaching the target depth: The rotation process continues until a predefined embedment depth is reached (accounting for the shaft length remaining above the ground surface).

2.9.1 Time for Relaxation and Dissipation of Pore Pressure

The cohesive clay is sensitive and generates additional pore pressures during the installation of an embedded pile, thus the test for this pile was commenced 24 hours after the embedding was done without applying any stresses. It proved possible to partially restore shear strength thixotropically and stabilize circumferential stresses in the area adjacent to the helical bearing plates so that reconstitution could take place. The reason this rest period is so important: dissipation of positive excess porewater pressure dampens effective stress loss due to remolding of the clay matrix around the pile during penetration. In this small (d = 20 mm) laboratory model, a duration of 24 hours was considered sufficient time for primary load stabilization since the radial drainage paths in the soil bed are exceptionally short. Nonetheless, it must be emphasized that in field installations at full scale much longer rest periods would generally be necessary to achieve complete excess pore water pressure dissipation and full gain of thixotropic strength.

2.10 Load Capacity Criterion

Axially loaded helical piles in soft clay environments do not usually display a distinct, sudden plunging failure mechanism and develop either a continuous or non-linear load-settlement response. This study uses a comparative criterion (rather than definition of a standard code-based limit, such as 10% of the helix diameter) to evaluate pile load-settlement curves since true geotechnical failure load could not be unequivocally recognized from the diaphragm wall's experimental load-settlement curves. Comparative load capacity was defined as the load resulting in a settlement equivalent to 50 mm of measured experimental ground settlement. A large displacement threshold was chosen as a technical convention to fully mobilize the soil's passive resistance and compare the multi-plate peripheral bearing mechanism in all configurations. A common experimental technique for comparing performance in cohesive soil where plunging failure does not occur is to use a predetermined settlement limit (e.g. Elsherbiny and El Naggar, 2013).

2.11 Experimental Limitation

It should also be emphasized that only one load test was conducted for each geometry because of the considerable preparation time required for the cohesive soil bed, and the long consolidation times. Therefore, duplicate tests were not performed and there was no ability to calculate standard deviation or coefficient of variation for each model. This is recognized by the authors as a limitation of the experiment, but we believe that the consistent and believable trend of improvement in terms of capacity over all tested configurations strengthens our general comparative findings.

3. Results and Discussion

As presented in Figures 5 to 7, the experimental results demonstrate that the ultimate load increases significantly with an increasing number of helices. The results show that for a 40 mm

diameter configuration the ultimate capacity increased from 350 N (single helix) as additional helices were added, and a maximum load of 815 N at 50 mm settlement was attained for the triple-helix model with a diameter of 60 mm. These results also confirmed that the initial stiffness increased and the total settlement decreased with the increment of helices number.

All those trends observed are completely consistent with the existing literature. The proportional increase in capacity is consistent with the work by [3] and [6]. Moreover, the high Improvement Ratios (IRs) observed here also support [6] theory about a shifting from dominant shaft friction to multi-plate peripheral bearing behavior. This improvement in initial stiffness agrees with the laboratory data of [1] associated with the establishment of a stable pressure bulb within the soil matrix. As noted by [19], therefore, the potential for non-linear behavior on sensitive clays has to be considered during optimization and design. Besides, the effect of helix geometry on the dissipation behavior of porewater pressure [14] remains a central parameter affecting the long-term strength properties of the clay matrix.

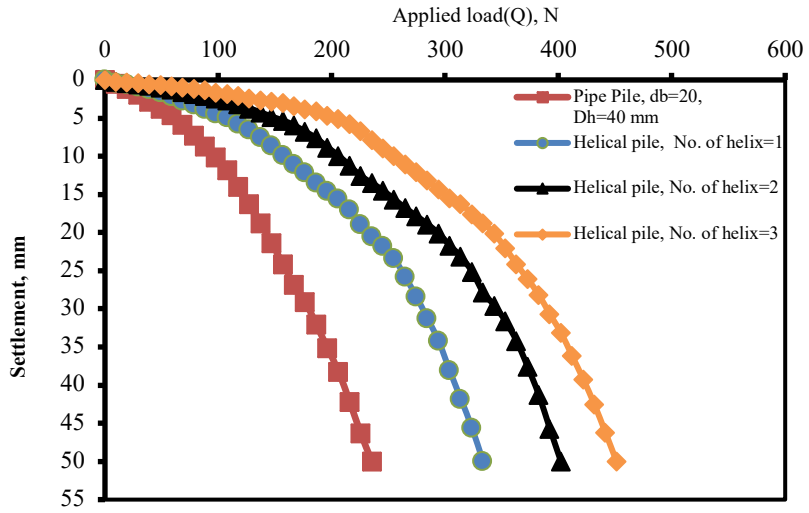


Fig. 5. Load-Settlement Curves for Various Helix Configurations, D_h = 40 mm

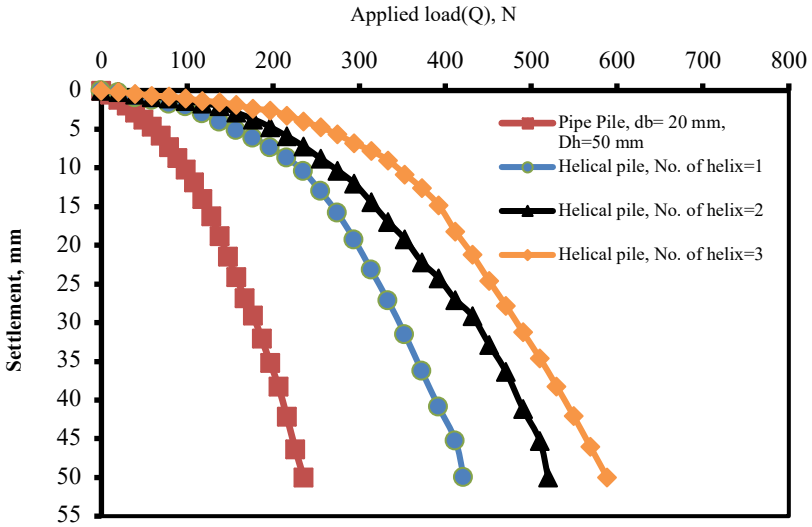


Fig. 6. Load-Settlement Curves for Various Helix Configurations, D_h = 50 mm

In addition, there is a significant increase in capacity when the helix diameter (Dh) increases from 40 mm to 60 mm, confirming further structural efficiency of helical piles. The optimal improvement ratio (IR) compared with the plain shaft control value of 235 N increases with triple-helix geometry, rises from 104.3% for the 40 mm diameter to reach a maximum value of 246.8% in the case of 60 mm model and IR = 159,6% for the 50 mm model. The current results are consistent with those of [9] who found that individual helix contributions dominate larger Dh/d ratios where higher diameters transfer passive soil resistance more effectively between helices. The interaction of the

number of helices with the diameter of the helix is important to ensure a stable foundation system. Nevertheless, at high D_h/d ratios it has a considerable impact on surrounding clay morphology that may affect the maximum undrained shear strength caused by installation effects. [5] showed that the failure mechanisms can be modified by disturbances to the installation process, implying a trade-off between geometry and site. In addition, the capacity of individual helices may be reduced by those already installed because they disturb the previously placed ones. Hence efficiency factors must be included in the design to capture these disturbances even when the inter-helix spacing is sub-optimal, as discussed by [8].

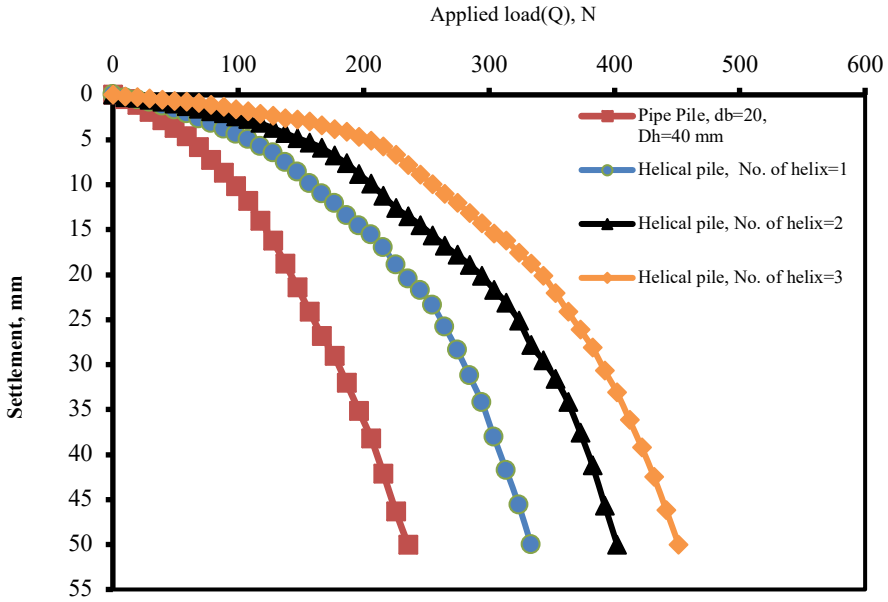


Fig. 7. Load-Settlement Curves for Various Helix Configurations, D_h = 60 mm

Load-settlement response of the helical piles with 60 mm diameter plates are shown in Figure 7. This further supports the well-known trend that more helical plates result in a much greater than linear increase to the final bearing capacity. The control pipe pile reached a capacity of about 235 N at a settlement of 50 mm, while the triple-helix variant sustained a top load of approximately 815 N. The degree of improvement was almost 246.8%, well above the ratios for the 40 mm (104.3%) and 50 mm (159.5%) diameter configurations.

The nonlinear efficiency increases when the helix diameter changes from 50 mm to 60 mm agrees with [3] showing that as D_h/d (helix diameter to shaft diameter) increases, the contribution of each helix towards the total capacity rises. This enhancement in the efficiency noted for the 60 mm triple-helix configuration is supported by analyzing “interacting bearing” theory which states that decreased blade area provides more efficient activation of passive soil resistance. As shown in Figure 7, the first stiffness increases, indicating that the triple-helix model is more stable under initial loading. Based on Lutenegger data, the durability of a pressure bulb is significantly improved with an increased number and diameter of the helix [1] vs small model or single-helix design. The experimental test cases evidently reveal that an optimal center-to-center spacing is cost-effective as well as maintains optimum foundation stability. This method enables a larger helix diameter without using isolated shear failures while obtaining satisfactory performance ratios.

Specifically, Table 3 presents an especially strong and clear case for synergism between helix number and size." For instance, the higher diameter of a triple–helix structure increased the improvement ratio from 2.04 to 3.47 by increasing its diameter from 40 mm to 60 mm. The combined increase in total ultimate load at 50 mm settlement, estimated at approximately 247% above that of the solid pipe control suggests not only that a larger nominal blade area can provide greater vertical bearing pressure surface, but it also enables effective and seamless transfer to a multi-plate peripheral bearing system which has the effect of activating and mobilizing a larger soil bulb within the soft clay matrix.

Table 3. Summary of ultimate load capacity (Q_{ult}) at 50 mm settlement and improvement ratio (IR)

D_h, (mm)	No. of Helices	Ultimate Load, Q_{50} (N) at settlement = 50 mm	Improvement Ratio, $(IR)=Q_{(helical\ pile)}/Q_{(pipe\ pile)}$
Pipe pile	-	235	1
40	1/2/3	350, 430, 480	1.49, 1.83, 2.04
50	1/2/3	440, 540, 610	1.87, 2.30, 2.60
60	1/2/3	500, 660, 815	2.13, 2.81, 3.47

5. Conclusions

- This study presents an investigation of the effects of number and dimensions of helices on vertical settlement response of small-scale helical piles subjected to axial load. The analysis results demonstrate that these geometric effects greatly improve the load-carrying capacity prescribed settlement and stiffness of the foundation system.
- More helices correlate with increased load-bearing ability for all annuli measured. This configuration showed approximately 6% to 40% greater resistance compared to the single- and double-helix piles. A significantly larger blade diameter meant a proportionally greater load-bearing capacity due to the broader surface in contact between soil and helix.
- The ratio of helix-to-shaft diameter is a significant determinant in the foundation's strength. Helix with 60mm diameter increases the improvement ratios significantly in comparison to helix with 40 mm. The 40 mm triple-helix pile showed a 104.3% increase in load capacity compared to the plain shaft, and the 60 mm triple-helix pile showed a 246.8% improvement.
- Including helices, especially in the configuration of triple helix, decreased total settlement and increased initial stiffness of the piles. Notice the gentler slopes in all of the diagrams during the beginning loading zones.
- Comparative performance of reference pipe pile (235 N) against helical versions demonstrates a successful transfer from the shaft friction mechanism to the more efficient multi-plate end-bearing mechanism.
- The relative motion of the multiplate peripheral bearing mechanism across all configurations is also mobilized due to the fact that a fixed center-to-center spacing of 40 mm always resulted in S/Dh ratios ≤1.0 for each diameter tested. Nevertheless, since this parameter was kept fixed another study is required to separate the effect of different spacing-to-diameter ratios on pile global behavior and to suggest an explicit provision for optimum spacing considering soil properties.
- In short, helical piles are more stable with a higher number of helices and larger diameters. Based on the findings, design guidelines should focus on large Dh/d ratios and triple-helix structure when working on projects where it is necessary to support high loads with significant settlement.
- The Improvement Ratio (IR) yielded a nonlinear improvement in pile capacity, where the increase of helix diameter was more beneficial than the increase of number of helices. An example of this is the triple-helix model with competitive IR = 3.47, among all diameter combinations (Dh/d) ratio optimizing load transfer through the multiple plate peripheral bearing mechanism in soft clay.
- The relationship maintained between pitch and diameter was geometric (p = 0.75 Dh), which enabled comparable soil–pile interaction. The capacity improvements, however, are dominated more by the helix diameter than by the pitch — this variable was not studied independently for this experiment

Acknowledgement

The authors acknowledge that this study is supported by Eng. Abdulrahman H. Hussain

References

[1] Karami M, Basack S, Das G, Bhadra D, Karakouzian M. Experimental and numerical evaluations of load settlement response of helical piles in soft clay. Marine Georesources & Geotechnology. 2024;42(9):1146-63. https://doi.org/10.1080/1064119X.2023.2254790

[2] Ali OK, Abbas HO. Performance assessment of screw piles embedded in soft clay. Civil Engineering Journal. 2019;5(8):1788-98. https://doi.org/10.28991/cej-2019-03091371

[3] Elsherbiny ZH, El Naggar MH. Axial compressive capacity of helical piles from field tests and numerical study. Canadian Geotechnical Journal. 2013;50(12):1191-203. https://doi.org/10.1139/cgj-2012-0487

[4] Stanier SA, Black JA, Hird CC. Modelling helical screw piles in soft clay and design implications. Proceedings of the Institution of Civil Engineers - Geotechnical Engineering. 2014;167(5):447-60. https://doi.org/10.1680/geng.13.00021

[5] Yu H, Zhou H, Sheil B, Liu H. Finite element modelling of helical pile installation and its influence on uplift capacity in strain softening clay. Canadian Geotechnical Journal. 2022;59(12):2050-66. https://doi.org/10.1139/cgj-2021-0527

[6] Lanyi-Bennett SA, Deng L. Effects of inter-helix spacing and short-term soil setup on the behaviour of axially loaded helical piles in cohesive soil. Soils and Foundations. 2019;59(2):337-50. https://doi.org/10.1016/j.sandf.2018.12.002

[7] Xiu Y, Liu H, Zhang D, Han X, Li L. An elastoplastic theory-based load-transfer model for axially loaded pile in soft soils. Buildings. 2025;15(23):4300. https://doi.org/10.3390/buildings15234300

[8] Lanyi-Bennett SA, Deng L. Axial load testing of helical pile groups in glaciolacustrine clay. Canadian Geotechnical Journal. 2019;56(2):187-97. https://doi.org/10.1139/cgj-2017-0425

[9] Elkasabgy M, El Naggar MH. Axial compressive response of large-capacity helical and driven steel piles in cohesive soil. Canadian Geotechnical Journal. 2015;52(2):224-43. https://doi.org/10.1139/cgj-2012-0331

[10] Mashayekhi MA, Khanmohammadi M. Numerical studies on performance of helical pile-supported embankments over soft clay. 2024. https://doi.org/10.5829/IJE.2024.37.04A.03

[11] Shuman NM, Khan MS, Amini F. Efficient machine learning model for settlement prediction of large diameter helical pile in c-Φ soil. AI in Civil Engineering. 2024;3(1):10. https://doi.org/10.1007/s43503-024-00028-4

[12] Verumandy K, Arulrajah A, Mirzababaei M, Rajeev P. Static load testing of instrumented screw piles in soft soil deposits. International Journal of Geosynthetics and Ground Engineering. 2024;10(1):10. https://doi.org/10.1007/s40891-023-00519-x

[13] Livneh B, El Naggar MH. Axial testing and numerical modeling of square shaft helical piles under compressive and tensile loading. Canadian Geotechnical Journal. 2008;45(8):1142-55. https://doi.org/10.1139/T08-044

[14] Li W, Deng L, Chalaturnyk R. Centrifuge modeling of the behaviour of helical piles in cohesive soils from installation and axial loading. Soils and Foundations. 2022;62(3):101141. https://doi.org/10.1016/j.sandf.2022.101141

[15] Mahmoudi-Mehrizi ME, Ghanbari A. A review of the advancement of helical foundations from 1990-2020 and the barriers to their expansion in developing countries. Journal of Engineering Geology. 2021;14(5):37-84. https://doi.org/10.52547/jeg.14.5.37

[16] Davidson C, Brown MJ, Cerfontaine B, Al-Baghdadi T, Knappett J, Brennan A, et al. Physical modelling to demonstrate the feasibility of screw piles for offshore jacket-supported wind energy structures. Géotechnique. 2022;72(2):108-26. https://doi.org/10.1680/jgeot.18.P.311

[17] Ullah SN, Hu Y. Discussion: A review on the behaviour of helical piles as a potential offshore foundation system. Marine Georesources & Geotechnology. 2020;38(9):1121-7. https://doi.org/10.1080/1064119X.2020.1793040

[18] Zhang L, Zhou H, Xu W, Chen Y. Numerical analysis of installation performance and uplift bearing capacity of helical piles in clay. International Journal of Geomechanics. 2025;25(2):04024334. https://doi.org/10.1061/IJGNAI.GMENG-10565

[19] Houlsby GT. Interactions in offshore foundation design. Géotechnique. 2016;66(10):791-825. https://doi.org/10.1680/jgeot.15.RL.001

[20] Ullah SN, O'Loughlin C, Hu Y, Hou LF. Torsional installation and vertical tensile capacity of helical piles in clay. Géotechnique. 2024;74(12):1360-76. https://doi.org/10.1680/jgeot.22.00014

[21] Shuman NM, Khan S, Amini F. Settlement based load capacity curve for single helix helical pile in c-ϕ soil. Soils and Foundations. 2023;63(1):101265. https://doi.org/10.1016/j.sandf.2022.101265

[22] Hussein AA, Karkush MO. Experimental investigation of pullout capacity of screw piles in soft clayey soil. In: Geotechnical Engineering and Sustainable Construction: Sustainable Geotechnical Engineering. Singapore: Springer; 2022. p. 315-27. https://doi.org/10.1007/978-981-16-6277-5_25

[23] Karkush MO, Alkaby AD. Numerical modeling of pullout capacity of screw piles under seismic loading in layered soil. Transportation Infrastructure Geotechnology. 2023;10(1):125-46. https://doi.org/10.1007/s40515-021-00211-5
[24] Mukhlef OJ, Karkush MO, Zhussupbekov A. Strength and compressibility of screw piles constructed in gypseous soil. IOP Conference Series: Materials Science and Engineering. 2020;901(1):012006. https://doi.org/10.1088/1757-899X/901/1/012006