



OPEN ACCESS INTERNATIONAL JOURNAL OF SCIENCE & ENGINEERING

Behavioral Study of Helical Piles Subjected to Ground Movement

R. K. Madhumathi¹, M. Ashni², A. Anushiya³

¹Associate Professor, Department of Civil Engineering, Stella Mary's College of Engineering, Tamil Nadu, India

²Assistant Professor, Department of Civil Engineering, Stella Mary's College of Engineering, Tamil Nadu, India

³Department of Civil Engineering, Stella Mary's College of Engineering, Tamil Nadu, India
madhumathi17@gmail.com¹

Abstract: Helical piles are increasingly adopted as deep foundation elements where rapid installation, limited site disturbance, and resistance to axial and lateral actions are required. Their response can, however, be affected by nearby excavation because removal of soil changes the stress field and produces lateral ground deformation. This study experimentally examines the response of model helical piles subjected to excavation-induced ground movement. Laboratory tests were performed in a $1\text{ m} \times 1\text{ m} \times 0.75\text{ m}$ steel tank containing poorly graded sand. Model piles were positioned at clear distances of $2d$, $3d$, and $4d$ from a simulated retaining wall, and excavation was carried out incrementally. Pile-head movement was monitored using a dial gauge. Single-, double-, and triple-helix configurations were considered, together with H/D ratios of 2.5 and 3.5. The observations indicate that pile-head deflection increases as excavation progresses and becomes more pronounced when the pile is positioned closer to the excavation boundary. Increasing the pile-to-excavation distance reduces the imposed lateral movement, while greater embedment and multiple helices improve resistance to ground deformation. The results demonstrate the combined influence of pile geometry and excavation proximity and provide practical guidance for preliminary assessment of helical pile foundations adjacent to excavation works.

Keywords— helical piles, ground movement, excavation, pile deflection, H/D ratio, retaining wall, lateral soil movement, foundation engineering

I. Introduction

Helical piles, also referred to as screw piles, are deep foundation elements consisting of a central shaft fitted with one or more helical plates. During installation, the shaft is advanced into the ground by rotation, allowing the helices to penetrate the soil with comparatively low vibration and limited spoil generation. These characteristics make the system attractive for retrofit works, restricted-access sites, temporary structures, and projects where rapid installation is desirable.

The response of a helical pile is governed by the interaction between shaft, helix plates, and surrounding soil. Soil density, strength, stiffness, installation depth, helix diameter, shaft diameter, and the arrangement of helices can influence the resulting axial and lateral resistance. Although considerable attention has been given to the axial capacity of helical piles, their behavior when the surrounding ground is forced to move laterally remains an important design issue.

Excavation adjacent to an existing pile foundation can cause unloading, stress redistribution, and lateral soil displacement. The pile may therefore experience bending, rotation, and additional lateral demand even when the supported structure is not subjected to a corresponding external horizontal load. The magnitude of this interaction depends not only on excavation depth and soil properties but also on the distance between the pile and excavation,

pile stiffness, embedment, and the characteristics of the retaining system.

Previous investigations have emphasized soil–structure interaction, settlement response, lateral displacement, cyclic behavior, and the effects of excavation on pile foundations [1]–[5]. These studies collectively indicate that excavation-induced deformation should be considered when foundations are located within the zone influenced by ground movement. However, the combined effect of helix number, embedment ratio, and pile position relative to an excavation is less frequently illustrated through simple laboratory model tests.

Accordingly, the objective of the present study is to examine the qualitative and comparative response of single-, double-, and triple-helical model piles subjected to staged excavation in sand. The study specifically evaluates the influence of pile-to-wall distance and H/D ratio on pile-head deflection. The experimental observations are intended to support preliminary understanding of pile–soil interaction and to identify configurations that are less vulnerable to excavation-induced lateral movement.

II. Experimental Program

2.1 Model Tank and Soil

The model tests were conducted in a rigid steel tank measuring $1\text{ m} \times 1\text{ m} \times 0.75\text{ m}$, with a wall thickness of 6 mm. Locally obtained

sand was used as the model soil. Basic characterization included specific gravity, particle-size distribution, and direct shear testing. Based on the particle-size characteristics, the material was classified as poorly graded sand (SP) according to the Unified Soil Classification System. The sand bed was placed in successive layers using a sand-raining technique to obtain a reasonably uniform state of deposition and to reduce variability between tests.

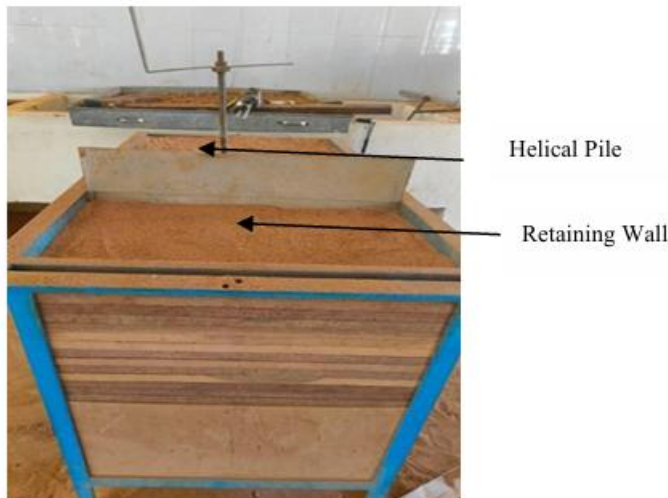


Figure 1: The Model Setup

The use of a controlled laboratory bed provides a convenient means of comparing pile configurations under similar boundary and soil-placement conditions. Nevertheless, the finite dimensions of the tank represent a model boundary condition and should be considered when extending the observations to field-scale foundations.

2.2 Model Helical Piles

The model piles were fabricated from mild-steel rods having a length of 381 mm and a shaft diameter of 19 mm. Helical plates were attached to the shaft to form single-, double-, and triple-helix configurations. Two H/D ratios, 2.5 and 3.5, were considered to investigate the influence of relative embedment. Here, H denotes the effective embedded length considered in the model and D represents the relevant helix diameter used for the H/D comparison.

The different helix configurations were selected to examine how the distribution of bearing surfaces along the pile shaft modifies resistance to lateral ground movement. A greater number of helices increases the interaction area between the pile and surrounding soil and can also modify the deformation mechanism around the pile.

2.3 Simulation of Excavation and Measurement

A thin aluminium plate was used to represent the retaining boundary. Excavation was simulated by progressively removing wooden planks placed along one side of the soil mass. The staged removal produced a controlled change in the boundary condition and induced lateral movement toward the excavation. This approach enabled the pile response to be monitored as excavation depth increased.

Piles were installed at distances of 2d, 3d, and 4d from the retaining wall, where d denotes the reference pile/helix diameter used for

positioning. Pile-head displacement was measured with a dial gauge having a least count of 0.002 mm. The same general sequence of soil preparation, pile positioning, instrumentation, and staged excavation was maintained for the comparative tests. The measured displacement was recorded after each excavation stage and used to establish the relationship between excavation depth and pile-head deflection.

2.4 Test Variables

The principal variables considered in the experimental program were: (i) pile configuration—single, double, and triple helix; (ii) H/D ratio—2.5 and 3.5; (iii) pile-to-retaining-wall distance—2d, 3d, and 4d; and (iv) excavation depth. The response parameter used for comparison was pile-head deflection.

III. Results and Discussion

3.1 Single-Helix Pile With H/D = 2.5

For the single-helix pile with H/D = 2.5, pile-head deflection increased progressively with excavation depth. The pile installed at 2d from the retaining wall displayed the greatest movement, indicating that the pile was located within a more strongly disturbed zone adjacent to the excavation. Moving the pile to 3d and 4d reduced the measured response. The trend confirms that excavation proximity is a major factor controlling pile movement.

The observed behavior can be interpreted through the progressive development of an excavation influence zone. As soil is removed, the remaining ground tends to deform toward the excavation. A pile positioned close to the excavation is consequently subjected to greater lateral soil movement and larger interaction forces. At greater separation, the magnitude of ground deformation reaching the pile decreases, resulting in smaller pile-head displacement.

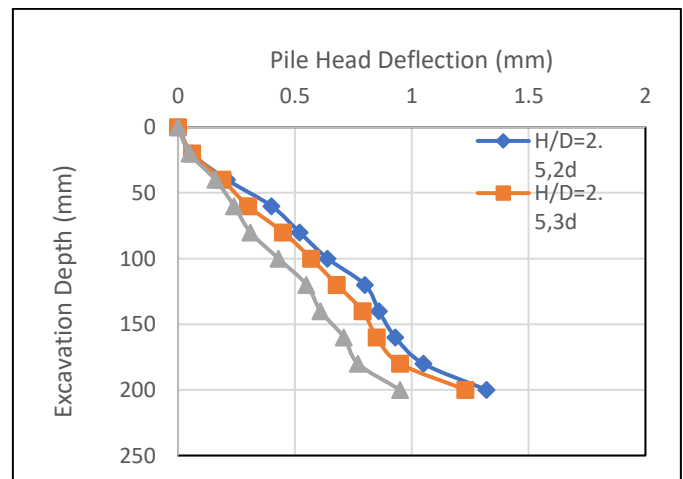


Figure 2: Deflection of Pile vs. Excavation Depth for H/D = 2.5

3.2 Double-Helix Pile With H/D = 2.5

The double-helix configuration exhibited the same general relationship between excavation depth and pile-head movement. The response was greatest at 2d and decreased as the pile was shifted to 3d and 4d. Compared with the single-helix arrangement, the additional helix provided increased interaction with the surrounding soil and improved resistance against lateral movement.

The reduction in displacement with increasing distance was particularly important during the later excavation stages. This suggests that pile position can be as significant as pile configuration when a foundation is located near an excavation. Consequently, increasing the setback distance should be considered as an effective method of reducing excavation-induced pile deformation whenever site constraints permit.

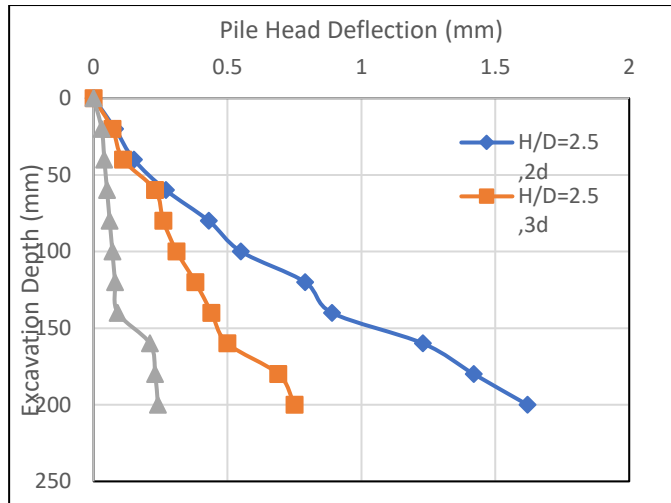


Figure 3: Pile deflection vs. excavation depth for double helical pile ($H/D = 2.5$).

3.3 Triple-Helix Pile With $H/D = 2.5$

The triple-helix model showed the smallest qualitative response among the configurations considered at the same H/D ratio. Piles placed at 3d and 4d exhibited very small measured movements. The improved behavior is attributed to the increased soil-helix interaction and the greater resistance offered by multiple bearing surfaces along the embedded portion of the pile.

The results also indicate that the benefit of additional helices should not be considered independently of excavation distance. A pile with multiple helices located very close to an excavation can still be exposed to substantial ground movement. Hence, an appropriate combination of pile geometry and setback distance is necessary for controlling deformation.

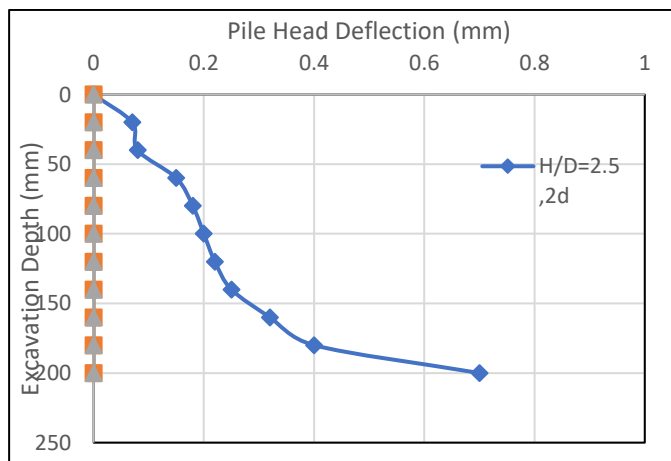


Figure 4: Pile deflection vs. excavation depth for triple helical pile ($H/D = 2.5$).

3.4 Influence Of H/D Ratio

Increasing the H/D ratio from 2.5 to 3.5 produced a reduction in pile-head deflection under the investigated excavation conditions. A larger embedment provides a greater length of pile-soil interaction and increases the depth over which lateral resistance can be mobilized. The effect was more evident for piles positioned away from the retaining wall, where the imposed ground movement was already smaller.

The results therefore suggest that embedment depth is an important design variable for helical piles subjected to lateral ground movement. However, the experimental trends should be interpreted comparatively rather than as direct field design values because model-scale effects, tank boundaries, installation effects, and differences between laboratory and field soil conditions can influence the measured response.

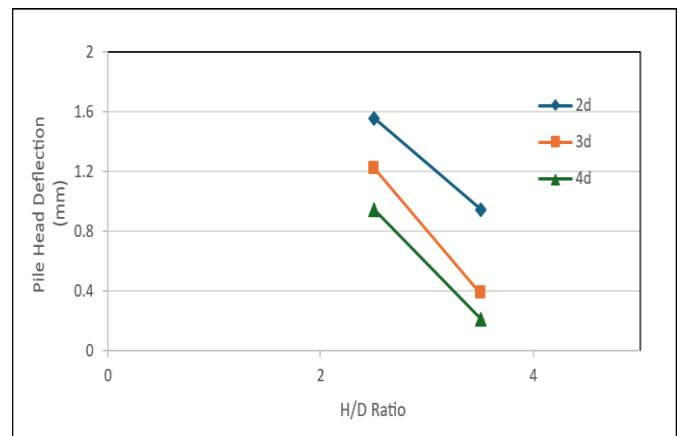


Figure 5: Comparison of helical piles on pile head deflection for different spacing

3.5 Comparative Effect of Pile Position and Helix Number

The combined observations demonstrate a consistent reduction in pile-head movement when the pile is moved from 2d toward 4d. At the same time, increasing the number of helices generally improved resistance to lateral deformation. Among the tested arrangements, the triple-helix piles positioned at 3d and 4d provided the most favorable response, with very small pile-head movements.

From a soil-structure interaction perspective, the results emphasize that pile design near excavations cannot be based solely on axial capacity. Lateral ground deformation can impose additional demand on the pile, and the resulting response depends on both structural characteristics and the spatial distribution of soil movement. Therefore, excavation sequence and foundation location should be considered together during preliminary design.

IV. Engineering Implications

The experimental observations have several practical implications. First, maintaining an adequate horizontal setback between a helical pile and an excavation can substantially reduce pile movement. Second, where geometric constraints prevent a large setback, increased embedment and a suitable multi-helix arrangement may improve lateral resistance. Third, staged excavation should be considered in construction planning because the pile response can increase progressively as excavation advances.

For field applications, the laboratory trends should be complemented by site-specific soil investigation, excavation-induced ground-movement prediction, pile stiffness assessment, and structural checks for bending and connection capacity. Numerical analysis or field instrumentation may be required for deep excavations, soft or layered soils, high-value structures, and situations where pile movement tolerances are stringent.

V. Limitations of the Study

The investigation was conducted using a finite-size laboratory tank and a model sand bed. The retaining wall and excavation process were simplified to provide repeatable comparative conditions. The study also focused primarily on pile-head deflection rather than directly measuring bending moment, soil displacement profiles, interface stresses, or pore-pressure response. In addition, scale effects and differences between model pile installation and full-scale construction may influence the observed magnitudes.

Accordingly, the findings should be used to identify trends and relative performance rather than as direct numerical design criteria. Further work involving instrumented model piles, different soil densities, varying excavation geometries, and numerical back-analysis would strengthen the applicability of the results.

VI. Conclusion

This experimental study examined the response of model helical piles subjected to excavation-induced ground movement. The principal conclusions are as follows:

1. Pile-head deflection increased with excavation depth, demonstrating the progressive influence of ground movement on the pile.
2. Piles located at 2d from the retaining wall experienced greater displacement than piles placed at 3d and 4d, confirming the importance of excavation proximity.
3. Increasing the H/D ratio from 2.5 to 3.5 reduced the observed pile-head movement, indicating the beneficial role of greater embedment under the investigated conditions.
4. Multi-helix configurations showed improved resistance to lateral ground movement compared with the corresponding single-helix arrangement.
5. The triple-helix piles positioned at 3d and 4d exhibited the most favorable qualitative response, with very small measured deflections.
6. For practical design, pile geometry, embedment, excavation sequence, and setback distance should be considered together rather than treating axial pile capacity as the only governing criterion.

VII. References

- [1] J. Smith and A. Williams, "Soil Structure Interaction in Helical Piles," *International Journal of Geomechanics*, vol. 20, no. 12, Art. no. 04020228, 2018.
- [2] M. Johnson and R. Patel, "Effects of Settlement on Helical Piles," *Soil Dynamics and Earthquake Engineering*, vol. 151, Art. no. 106994, 2021.

[3] S. Williams and C. Brown, "Lateral Displacement and Helical Pile Performance," *Journal of Deep Foundation Institute*, vol. 12, no. 1, pp. 1–14, 2020.

[4] K. Lee and K. Garcia, "Response of Helical Piles to Cyclic Loading," *Engineering and Technology Journal*, vol. 40, no. 11, pp. 1–7, 2021.

[5] P. Anderson and D. Kim, "Numerical Modeling of Helical Piles Under Ground Movement," *Technical Journal*, vol. 28, no. 3, pp. 1–8, 2022.