MODELING OF LOAD TRANSFER BEHAVIOR OF HELICAL PILE IN BANGKOK SUBSOILS

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ABSTRACT

A helical pile is a pile made of steel pipe with helix plate welded around the pipe, which can be installed and dismantled easily and rapidly. Henceforth, it is widely used in engineering applications as the foundation for structures like warehouses, transmission towers and residential buildings. The capacity of a helical pile depends on the surface friction between the pile and the bearing force, which is influenced by the size and number of steel helices. This varies the calculating principle from general piles. This paper proposes increasing the number of steel helices to study the load-bearing behavior of piles. By studying the behavior of the soil under the helix plate through the simulation from 3D finite element in order to understand the behavior of the soil. The simulation is compared with instrumented static pile load test. The pile used for testing has a pipe diameter of 15.24 centimeters and a length of 23.3 meters and are welded to steel helical plates with diameters of 40 and 50 centimeters. The efficiency of increasing the number of helix plates improves when they are placed in a stiff clay layer. Due to the properties of soft soil materials, they are more prone to shrinkage compared to stiff soil. This is evident in the collapse of Bangkok's soft clay over stiff clay soil.

Keywords: Pile, Helical Pile, Settlement, Static Pile Load Test

1.INTRODUCTION

Bangkok subsoils are topsoil found in the lower central plains, including the Bangkok Metropolitan Region. They are approximately 15-25 meters thick and play a crucial role in the livelihood of people in this region, where many large-scale buildings are located. However, Bangkok subsoils have unsuitable engineering properties for foundations due to their variability, which can lead to foundation damage.

Therefore, helical piles, a relatively new pile system in Thailand, present a promising alternative. Helical piles can penetrate the soft soil layer and effectively transfer loads to the underlying stiff soil layer. Although the load-bearing capacity of helical piles in Bangkok's subsoils is limited understanding, this knowledge gap has prompted the research team to study and improve helical piles to ensure their compatibility and efficiency in Bangkok's soft clay. The goal is to address construction needs while mitigating the challenges and potential issues associated with the subsoils.

However, when helical piles reach the stiff soil layer, they may impose additional load on it, potentially leading to excessive settlement. Therefore, it is crucial to study and understand the load-sharing and stress-strain behavior of the soil under the helix plate, which has not been thoroughly examined. Without a clear understanding of this behavior, accurately assessing settlement directly related to load-bearing capacity will be challenging.

2.RESEARCH SIGNIFICANCE

From the study of helical piles worldwide, it was found that there was a significant settlement problem. Therefore, we need to consider various methods to minimize pile settlement. This research aims to increase the number of helical plates on helical piles to reduce pile settlement. The study of soil mechanics analysis under helical plates using 3D finite element model (3D FEM) because 3D has more advantages than 2D FEM in terms of soil behavior study in 3D to enhance the comprehension of soil behavior. this study, the Mohr-Coulomb model is used in the study. The model results are compared with the field test results of helical piles.

3.METHODOLOGY

3.1 Study Area Conditions

Study Area Pathumtani Brewery Co., Ltd. Pathum Thani Province, located approximately 40 kilometers from Bangkok. Pathum Thani Province is one of five provinces in the Bangkok Metropolitan Region, Situated in the Chao Phraya River basin to the north of Bangkok. The soil in this study area is predominantly soft clay with low load-bearing capacity.

3.2 Helical Pile

3.2.1 Conventional Calculation Methods

Cylindrical shear method [1] and Individual bearing method [2] are used to estimate the maximum bearing capacity of helical pile.

The Cylindrical Shear Method, Initiated by Clemence and Mooney [3], this method is used to evaluate the axial capacity of helical piles in sand, clay and silt respectively. It assumes that cylindrical shear failure occurs between the top and bottom threads. Nasr [4] concluded that the ultimate load capacity is influenced by the number of helices, the shape of the pile, soil conditions, and the spacing of the helical plates. The ultimate load capacity is the sum of the resistance at the bottom tip of the lowest helix, the shear resistance along the cylindrical shear surface, and the shaft friction above the top helix. [4-6]

The Individual Bearing Method, Adams and Klym [7] reported that the bearing capacity of a helical pile can be estimated separately. If the spacing between each plate is large enough. Parameters influencing the load-bearing capacity include the bearing area of each helical plate and the undisturbed soil surrounding it. In addition, the equations for the Individual bearing method involve both helical plate and the resistance from the pile shaft. Therefore, the overall ultimate load capacity of a helical pile can be calculated from the sum of the capacity of each helical plate along with the shaft resistance [4-6].

There has been research on conventional calculation before, used in considering what kind of load bearing behavior the pile will have. From the research of Srijaroen [8] , it is research using calculation formulas to compare with field test, which has been used for trial and error to see if it is consistent with the calculations. But from the research above, it is not possible to know the behavior of the soil under the helix.

3.2.2 3D finite element model (3D FEM)

Numerical simulation is an effective method to study and predict the behavior of helical piles under different conditions. This simulation is often performed using finite element method such as PLAXIS and ABAQUS to analyze the bearing capacity, deformation and failure mechanisms of helical piles.

Single helical pile simulations are often used to study the loading and deformation behavior trends. Studies such as by Akl [9] have shown that helical piles have a higher bearing capacity compared to conventional piles.
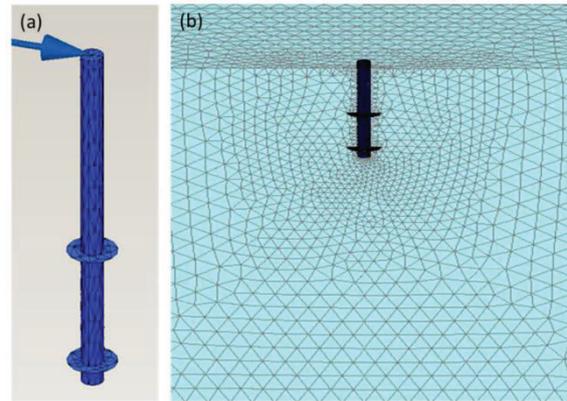

Fig. 1 PLAXIS 3D Analysis of helical Pile [9]

Naggar and Elsherbiny [10] used ABAQUS to model helical pile groups. They found that the spacing between the piles affected the bearing capacity of the piles. The simulations showed that placing helical piles in groups could increase the bearing capacity.
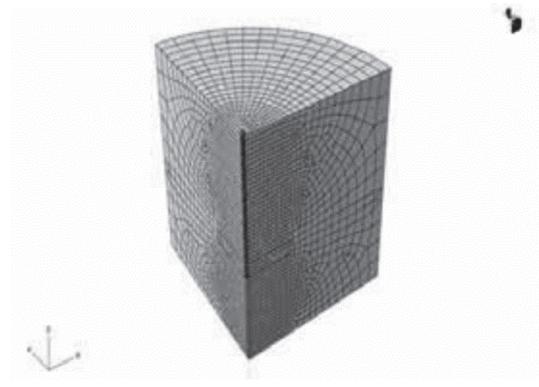

Fig. 2 Numerically Model helical Pile subjected to axial load using ABAQUS [10]

Alwalan and Naggar [11] used PLAXIS 3D to study the effect of dynamic loading on helical piles. The study showed that helical piles exhibited greater resistance to deformation as compared to single piles.

From the above research, it can be seen that numerical simulation an important role in the study and design of helical piles, enabling researchers and engineers to accurately predict the behavior of helical piles under various conditions. In addition, simulation helps to develop more efficient and resource-saving design guidelines. However, from the above research, we cannot know the behavior of the soil under the helix.

3.3 Field Testing and Pile instrumentation

Soil investigation were conducted using wash boring, Screw Driving Sounding test (SDS) and Standard Penetration Test (SPT). Instrumented static pile load test was performed strain gauges were installed along the length of the piles to assess load distribution during the testing process.

The helical pile used in the study has a length of 23.3 meters and 1.826 centimeters thick and is made from a hollow circular steel pipe with a diameter of 15.24 centimeters. The helix plates are spaced every 2 meters on the bottom 3 plates and spaced 2.5 meters on the upper plates. The helix plates have diameters of 40 and 50 centimeters as show in table 1. Strain gauges are installed along the length of the helical pile to assess load distribution, as shown in Fig.3.

The static load test was performed in accordance with Modified ASTM D 1142/D 1143M-07; the loading was applied incrementally on the piles, and the corresponding settlement was measured to produce the load–settlement curves. using a standard loading procedure based on the design load at 60 tons Two cycles of tests were performed

Cycle 1 (Maximum 100% of Design Load).
0%, 25%, 50%, 75%, 100%, 50%, 0%

Cycle 2 (Maximum 200% of Design Load).
0%, 25%, 50%, 75%, 100%, 125%, 150%, 175%, 200%, 150%, 100%, 50%, 0%

1. In each step of loading in rounds 1 and 2, the load shall be maintained for 1 hour with a settlement rate not exceeding 0.25 mm/hr. Otherwise, the test load shall be maintained for another 1 hour before proceeding to the next loading step.

2. The maximum test load shall be maintained in rounds 1 and 2 for 12 hours or, if the settlement rate is greater than 25 mm/hr., for at least 24 hours.

3. The load shall be reduced every 1 hour in rounds 1 and 2 until it reaches zero and the test load shall be maintained until the rate of recovery is constant, but not exceeding 12 hours.

4. Record the settlement and recovery data in rounds 1 and 2 at 0, 1, 5, 10, 15, 20, 30, 40, 60 minutes and every 1 hour for the next 10 hours and every 2 hours thereafter.

The static load capacity of piles typically changes as time elapses after pile installation, possibly increasing or decreasing, depending on the soil properties and the pore water pressure and soil structure disturbance induced by installation. This behavior may affect both driven piles and cast-in-place piles. The engineer may specify a waiting period between pile installation and static testing to investigate time effects. The waiting period may range from 3 to 30 days or longer, based on testing (for example, redriving piles) or prior experience. For this test, we waited 14 days.

Table 1 Helix plates information.

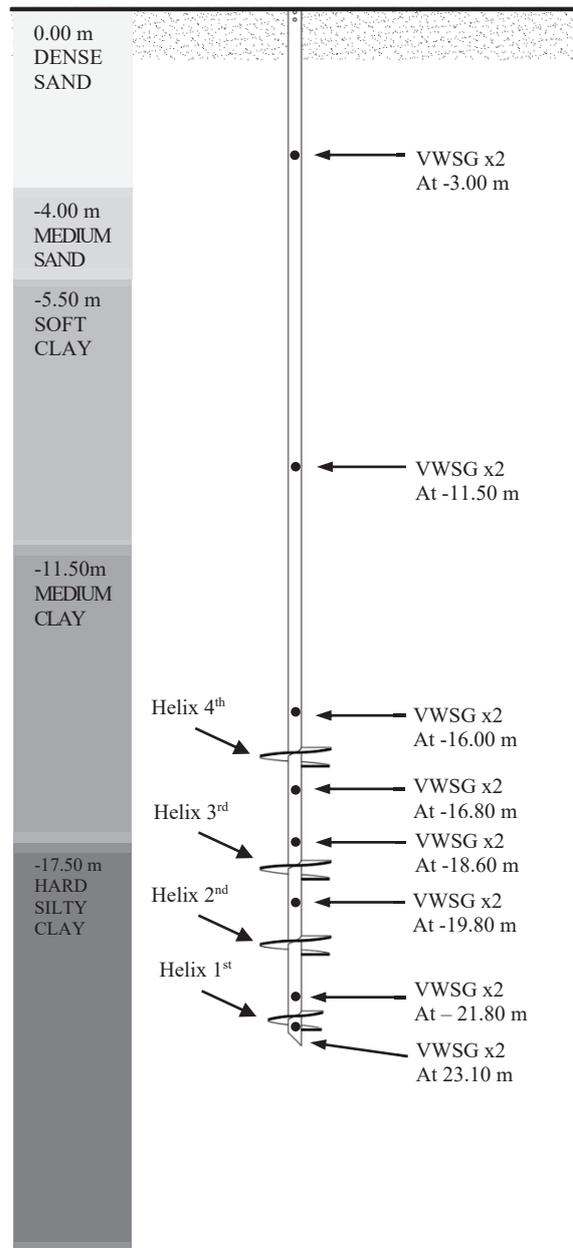| Depth (m)	Information	Diameter (m)
-16.60	Helix 4th	0.50
-19.10	Helix 3rd	0.50
-21.10	Helix 2nd	0.50
-23.10	Helix 1st	0.40

Fig. 3 Strain gauges installation location.

3.4 Simulation Modelling

Interpretation of soil investigation

The 3D FEM analysis was performed using MIDAS GTS NX 3D model software, as shown in Fig. 4 . The model size area is 10m x 10m, and the depth is 25m. The water table was set at 1.00 m below the ground surface. Soil modeling using Mohr-Coulomb was used for the analysis, along with the appropriate soil parameters.

For the modeling, soil data were obtained from the site survey using wash boring, Screw driving sounding test and Standard Penetration Test.

The soil types were classified, and the SPT values were converted into other parameters using Eqs. (4-5), as shown in Table 3.

For Elastic Modulus based on Bowles [12]

$$Es = 500(N + 15) \text{ for Sand} \quad (4)$$
$$Es = 300(N + 6) \quad \text{for Clay} \quad (5)$$

Create a homogeneous or heterogeneous material interface where slip or isolation can happen. It is used to simulate the interface behavior between ground and structural members with a large relative stiffness difference. The interface generation method is classified by the work environment and the target. The properties must be defined in order to create an interface element. The properties can be directly entered, or can be automatically calculated from the properties of adjacent elements using Wizard.

Table 2 Suggested Reduction Factors based on Brinkgreeve and Shen [13]

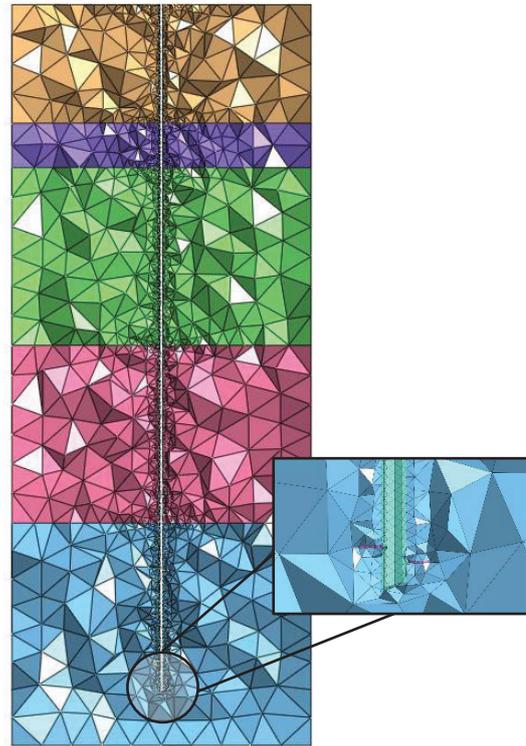| Type of material	Reduction Factors (R)
Interaction sand/steel	0.6 – 0.7
Interaction clay/steel	0.5

Fig. 4 Model for simulation by MIDAS GTS NX

4. THE RESULT AND DISCUSSION

4.1 Soil Investigation

Based on the borehole data at the test site, it was found that the soil data in all three boreholes were very similar, thus reducing the possibility of errors.

Results of Standard Penetration Test (SPT) and soil testing in the laboratory. The depth of the drill hole is 30.45 meters. The soil layer can be divided into 4 layers with the following details:

The 1st layer, is a sand mixed with silt (SM); The 2nd layer, is a sand layers (CH, CL), soft to medium.; The 3rd layer, is a layer of clay mixed with silt (CH) and a very hard layer (Hard).; The 4th layer, is a very dense sand and silt (SM) layer.

Table 3 Soil parameters for the modelling.

Depth (m) From	To	Type of material	Thickness (m)	γ_t (t/m³)	E (t/m²)	ν	c (t/m²)	ϕ (°)	Reduction (R)
0.0	4.0	Dense Sand	4.0	1.80	2295	0.25	0	34	0.90
4.0	5.5	Medium Sand	1.5	1.70	969	0.15	0.31	29	0.90
5.5	11.5	Soft Clay	6	1.60	1292	0.30	2.55	22	0.50
11.5	17.5	Medium Clay	6	1.75	1866	0.30	2.55	22	0.50
17.5	25	Hard Sand	7.5	2.00	2421	0.25	2.55	22	0.50
-	-	Steel	-	7.85	21,414,040	0.25	-	-	-

4.2 Pile Load Test results.

Graph showing the relationship between load and settlement from pile load test as shown in Fig.5, Load transfer graphs analyzed from strain gauge are shown in Fig.6. From the test, the friction resistance was 30.27 tons. The ultimate load capacity predicted as show in table 4.

Table 4 The ultimate load capacity predicted.

Method	Q_{ult} (tons)	Displacement (mm)
Butler and Hoy's method	108	22.8
Davisson's method	95	21.0
Mazurkiewicz's method	125	32.0
Static load test	106	22.6

From Table 4, it can be seen that Butler and Hoy's method is the closest when compared with the results of the static load test.
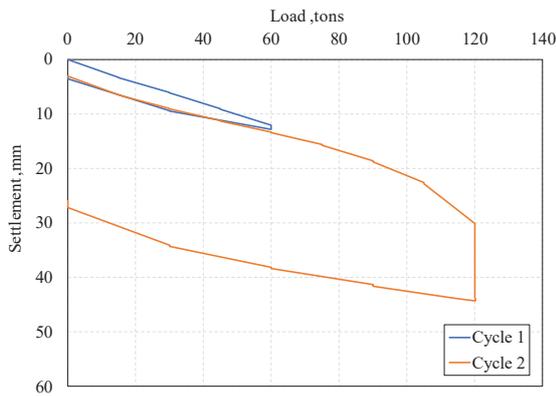
Fig. 5 Pile Load Test result.
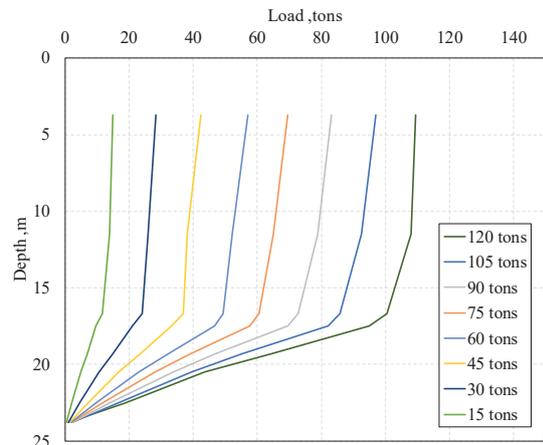
Fig. 6 Load transfer graphs.

4.4 Computation Result

4.4.1 Comparison of Results between full scale load test and 3D FEM

The comparison between the 3D FEM simulation results and the static load test results indicates that the analyzed pile head displacement shows excellent agreement between the simulation and the actual test results, as shown in Fig.7, The load transfer curves obtained from the tests closely approximates the final values.

The recommended R_{inter} value from [12] for each type of soils is in the range of 0.5 - 0.7. However, in term of the skin friction response results obtained from the model to be similar to the field results, The R_{inter} was adjusted by using the R_{inter} of each type of soils in the range of 0.5 – 0.9 as shown in Table 2. Therefore, the simulation using the load transfer method demonstrates high accuracy and reliability.
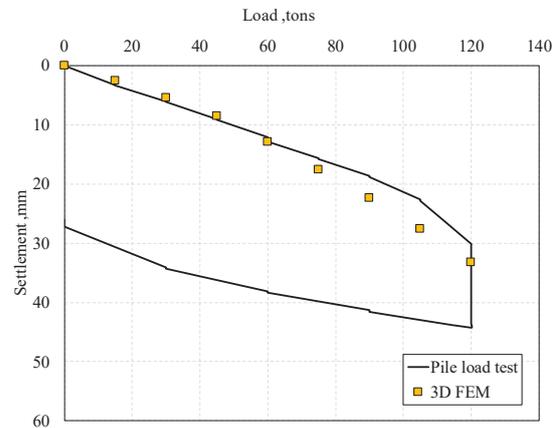

Fig. 7 Comparison of Results between static load test and 3D FEM.

4.4.2 The results of the model evaluation

According to 3D FEM the simulation results show that it can support a weight of 115.37 tons, divided into a friction resistance of 21.67 tons and a bearing resistance of 93.70 tons. Load transfer is shown in comparison with the static load test results as shown in Fig.8 and the bar graph comparing the load transfer behavior between the 3D FEM and the static load test can be displayed as a bar graph, as shown in Fig. 9.

From Fig.9 shows the development of bearing capacity and skin friction simultaneously. However, it can be seen that the development of skin friction on the pile shaft gradually decreases. As a result, some of the weight is supported by the bearing capacity of the Helix plate. It can be observed that the 4th Helix plate (the top plate) is still developing its bearing capacity. The development of bearing capacity and skin friction shows a similar trend according to field test results.
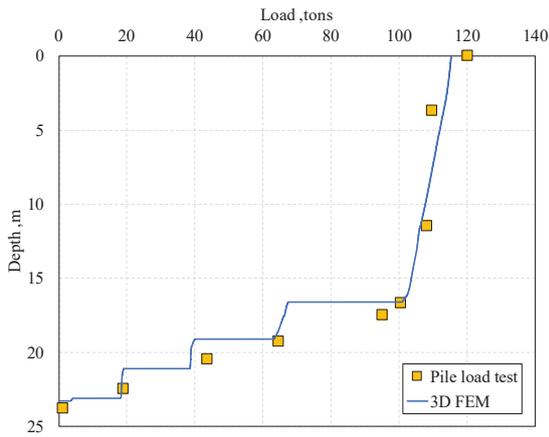
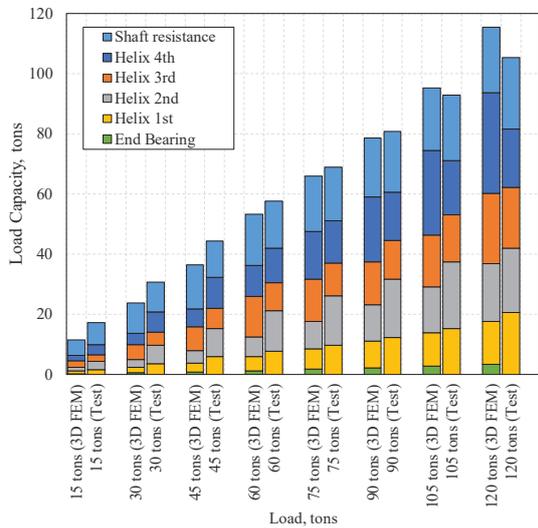Fig. 8 Comparison of load distribution results with 3D FEM.

Fig. 9 Bar graph showing the amount of load transferred with 3D FEM.

When showing the stress-strain values under the Helix plate, considering the underside of the Helix plate as shown in Fig. 10, it is plotted in graph form, it can be seen that the stress-strain graphs for Helix plates 1st, 2nd, and 3rd show a similar trend. However, the graph for Helix plate 4th differs from the three lower plates because the Helix plates are located in different soil layers, as shown in Fig. 11.

Where the strain with a positive value is deformed due to tension and the strain with a negative value is deformed due to compression.
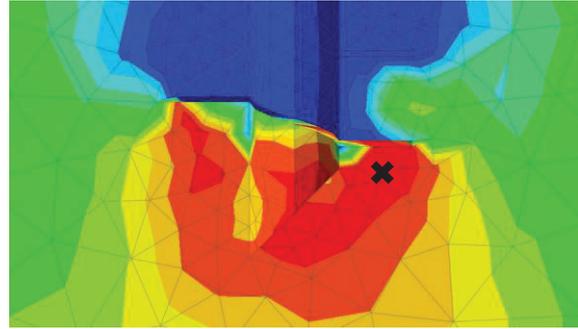

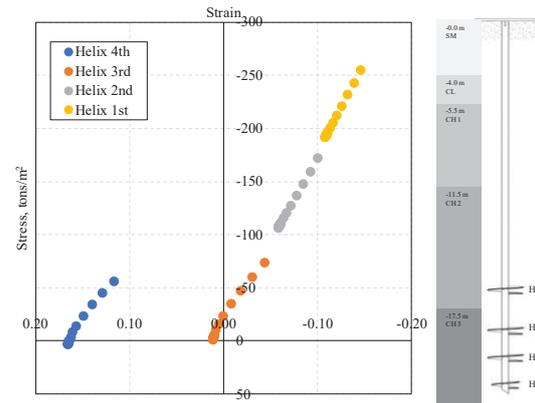Fig. 10 Result normal stress under the helix.

Fig. 11 Stress-Strain graph under the helix plate.

5. CONCLUSIONS

This research analyzes the maximum load capacity when added the helix plate. The R_{inter} in the model was adjusted to be close to the field results. The R_{inter} was adjusted using the R_{inter} between clay/steel to be 0.9 and the R_{inter} between clay/steel remained at 0.5. The study evaluates the ultimate load capacity of the helical pile through static load tests and compares these results with 3D FEM. It is observed that the load-bearing behavior closely resembles natural conditions. The bearing capacity behavior of each helix plate closely matches the static load test results, and the load transfer behavior simulated by the model also aligns closely with the field test results. From this analysis, the following conclusions can be drawn:

1) The relationship between the load-bearing capacity of piles and subsidence at the pile head, analyzed using the 3D FEM, showed values similar to the field test results.
2) The efficiency of increasing the number of helix plates improves when they are placed in a stiff clay layer. Due to the properties of soft soil materials, they are more prone to shrinkage compared to stiff soil. This is evident in the collapse of Bangkok's soft clay over stiff clay soil.

3) Soil movement influence zones are proposed and described, determined from the deviation stress obtained from the 3D FEM analysis.

The findings of this study were based on 3D FEM analysis, which was validated using field tests. However, further research is needed to confirm the conclusions drawn from this study. Can these findings be applied and validated under full field conditions in the real world.

6. ACKNOWLEDGMENTS

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