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Experimental Modelling of Helical Piles Subjected to Axial Loading

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***Abstract*- In the construction sector, axial loads have traditionally been supported by piles. There hasn't been sufficient comparative study related to the economics and viability aspects of conventional and helical piles up to this point in natural soil condition. The current study was conducted to test the behavior of helical piles subjected to axial loading and the results were compared with the conventional pile counterpart. For this, a total of eighteen experiments were performed with varying number of helical piles either single or multi helical piles in a raft. Helical piles were penetrated into ground, vertical load of 512 kg was applied and the settlements were recorded with the gauges installed. The reduction in settlement was found to increase due to increasing the number of piles, inter distance between the piles and increasing the number of helices. Nine double helical piles were observed to reduce settlement by 80.5% when compared to nine conventional piles. Due to the smaller number of piles needed to support the applied axial load when employing helical piles as opposed to conventional piles, the cost was greatly lowered.**

***Index Terms*—Helical Pile, Bearing capacity, Compression and uplift, Settlement**

I. INTRODUCTION

Piles are structural components that are frequently required to maintain the safety of buildings. In some cases, pile foundations are necessary, and depending on the situation, piles may be changed to screw piles or helical piles. A square or circular shaft and one or more helices attached to the shaft make up the helical pile deep foundation system. Helical piles are driven into the earth by a mechanical torque applied by a driving head. As long as the soil is tolerable and the pile is constructed to withstand the torque that an appropriate driving head will provide, these piles can be implanted at any depth and at any angle, which is shown in the Fig. 1. Helical piles have been used in innumerable projects across the world. Helical piles, in particular, can be used in poor soil because of their ability to compress existing soil and apply tension to it thus ensuring that it does not shift. Pile raft with the conventional pile system performs exceptionally well in dense soil under axial and lateral loading, but the number of piles in piled raft may be more, which will result uneconomical. Therefore, the performance of pile raft with piles modified to helical piles in the natural ground surface in the natural field conditions need to be investigated.

Figure 1: Installation of Helical piles with hydraulic machine

Under axial and lateral loading, a pile raft with a conventional pile system works remarkably well; but, if there are more piles than necessary, the raft will not be economically viable. Therefore, it is necessary to evaluate how well a pile raft with helical piles performs on a natural ground surface under field conditions. To assess the structural and economic performance of the helical piles different tests are needed to be performed. These include the testing of the piles for different number of piles, helices, and also conducting the test for the conventional type of piles for the same number of piles used in the testing of the helical piles [1-5].

Jamil et al [1] conducted the experimental test for the measurement of the response of the small scale combined pile raft foundation (CPRF) by applying the vertical load as well as the lateral load and it was discovered that pile raft effectively contributed to vertical and lateral load resistance. It was concluded that the contribution of the pile raft decreases and that of the piles increases when the lateral loads are increased. Similarly, as the number of piles is increased, the contribution of the pile raft towards the vertical loading is significantly reduced. According to the study carried by Safdar et al. [2], adding more helical piles will boost their ability for bearing and lifting. Pullout pressures for the screw pile of double helices plates are 1.10–1.50 times more than for single helix. Furthermore, it was found that increasing the helix diameter will increase the compressive and tensile strengths of helical piles. Similar results were also derived from other researchers [6-10].

Perko et al. [11] discovered the behavior of the soil toward the inter spacing of the piles. It was concluded that to prevent group action, piles must be set far enough apart and influence zones of a helical pile may overlap if it is placed too tightly, leading to group behavior. For piles in compression and tension, respectively, helical piles should be spaced at least 4 and 5 diameters apart to prevent this. Results from the experimental set-up using multi-helix anchors revealed that the number of helical plates, reduced soil moisture content, and soil consistency index rise pile ultimate uplift capacity [12, 13].

Using theoretical formulations, Tappenden et al. [10] calculated the friction and bearing capacities in compression and tension of the helical piles. It was demonstrated that friction resistance increases with the amount of soil that is occupied between two helices.

Kurniawan et al [11] showed the effect of helix diameter on the ultimate axial compressive capacity from the static loading test. The ultimate axial compressive capacity increased by 43.13% to 60% along with the increasing size of the helix from 15cm to 25 cm. Similar conclusions were derived regarding the effect of sizes and the spacing of the helixes on the bearing capacities [7-9]. Researchers also investigated the feasibility of circular shaft helical piles in oil sand as deep foundation choice and concluded that such piles can resist substantial number of loads [12].

The purpose of this study is to conduct an experimental investigation of the axial capacity of helical piles. The following goals have been established for this study to accomplish:

- To assess the effectiveness of helical piles under axial loading.
- To compare the results with the results from traditional piles.

II. METHODOLOGY

A. GENERAL

Experimental piles constructed as helical or screw types were loaded axially and the reaction to the loading were monitored and plotted. To test cheaply and simply, the piles were of small-scaled or model-scaled, and the interpreted results were applied to full-scale piles in terms of economy and efficiency. To see how the modelling compares to the results in cohesive and cohesionless soil, the axial capacity of the helical pile was evaluated in real-world conditions and on a natural soil sample. To get the best outcomes in particular for their installation, the helical piles, whether single or double helix, are modified to have a pinned tip along their pilot point.

B. TEST SPECIMEN

Small scale models of helical piles were created and constructed in accordance with the dimensions listed in Table 1 in order to test the axial capacity of the helical piles. Additionally, to fabricate a pile raft, a raft with a thickness of one inch and a dimension of one square foot was constructed. The nature of the soil sample used in this test was a silty clayey soil of low plasticity.

Table 1 – Dimensions of the helical piles

Length (in)	External shaft diameter (in)	Internal shaft diameter (in)	Helix diameter (in)	Thickness of helix (in)	Pitch of helix (in)	the bottom of the pile	Spacing between two helices (in)
18	0.75	0.5	2	0.1	0.3	1.5	3.7

Table 2 – Soil properties of the testing soil

Cohesion (KPa)	Angle of internal friction (ϕ)	Liquid limit	Plastic limit	Plasticity index	Unit weight of soil (psf)	Specific gravity
40	22.25	40.64	20.21	20.43	114	2.62

Sieve analysis was also conducted to measure the particle size. The sieve analysis test results are given in the Table 3.

Table 3 – Sieve analysis results

Particle	Grave (%)	Sand (%)	Fines (%)	D10 (mm)	D60 (%)	D30 (%)
Percentage	8	27.82	64.18	0.0014	0.0700	0.0140

C. PRACTICAL TESTING OF SMALL-SCALE COMBINE PILE RAFT FOUNDATION (CPRF)

The lawn area of Civil Engineering Department, University of Engineering and Technology, Peshawar. Khyber-Pakhtunkhwa, Pakistan was used to construct and test a small-scale CPRF using pre-fabricated helical piles and a raft. On the set up, a vertical load of 512 kg was used. Helical piles both as single and double helix were fabricated and used to test with the designed raft. The schematic of the typical pile is shown in Fig. 2(a) and the fabricated pile with single and double helices are shown in the fig. 2(b).

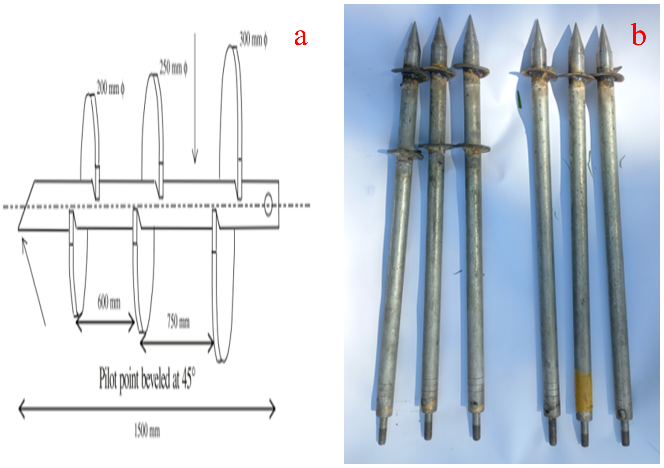


Figure 2: Helical piles, (a) Schematic, (b) Fabricated

D. TEST SETUP

1) Installation of testing component

The piles were erected in the ground by giving a twisting moment using a drill machine that was brought from the local market in Peshawar as shown in Fig. 3 (a). and the installed pile is shown in Fig. 3(b). The 1-inch-thick raft of square dimension 1 sq. ft. was attached to the pile by screwing nuts as shown in Fig. 3(c). On top of the pile raft, below the vertical load, a load cell with an 8-ton capacity was erected. It was connected to a data logger to record the applied load and to four LVDTs to measure settlement shown in Fig. 4(a) and (b).

Figure 3:Test setup, (a) drill machine, (b) installation of piles, (c) screwing of pile.

2) Connection to data logger

A data logger of 30 channels was used for data acquisition during the testing. Using MATLAB software, loading and settlement data from load cells and LVDTs connected to the data logger through data cables were saved and examined on the laptop screen (also connected to the data logger). These connections are shown in the Fig. 4.

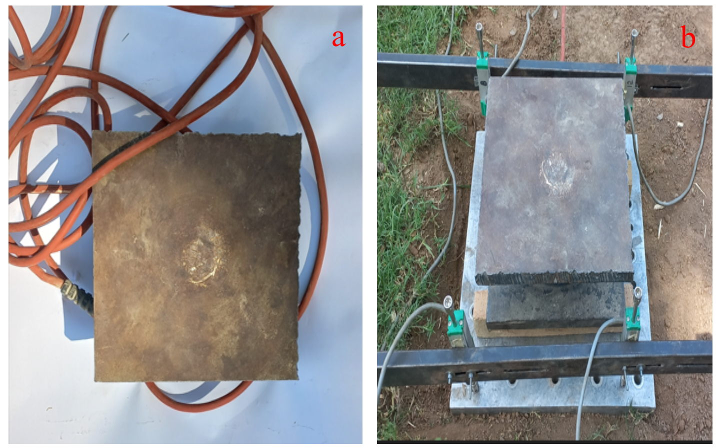


Figure 4: Setup of data acquisition system, (a) connection of load cell to data logger, (b) connection LVDTs to data logger.

3) Application of axial loads

A vertical load weighing 512 kg was purchased from Peshawar Market. With the use of a standing rod, the weights were statically imposed one at a time. Static axial load applied to the pile raft system is shown in the Fig. 5.

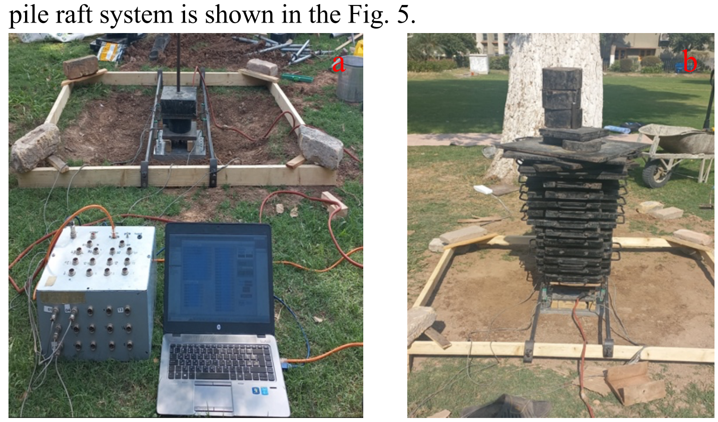


Figure 5: Application of load, (a) view 1, (b) view 2

E. TESTING CONFIGERATIONS

In this work, total 18 numbers of tests were performed on the six different configurations of piles. For each configuration three type of test were performed which include the test for conventional pile, single helical pile and double helical pile. The plane view of different configurations of test is shown in the Fig. 6.

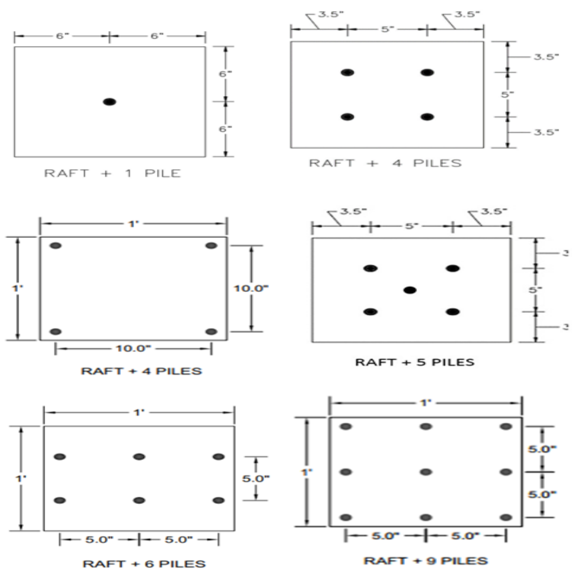


Figure 6: Six different configurations of piles for testing purpose.

III. RESULTS AND DISCUSSIONS

A. TEST RESULTS FOR DIFFERENT CONFIGERATIONS

The Figure 8 shows the load versus settlement for the various testing scenarios indicated in section II (E). The settlements for applied load of 512kg in conventional, single, and double helical piles have been demonstrated in each test. The graphical plots make it clear that the double helical piles' settlements are substantially smaller than those of their competing single helical piles and conventional piles. In the single pile test the settlements in the conventional pile are 13.33% and 38.24% larger for the single helical pile and the double helical pile respectively. Settlements are reduced in conventional piles as 35.54, 35.48%, 38.12%, 41.09%, and 70% as compared to the single helical piles in four (5 and 10 inch spacing), five, six and nine piles respectively. Similarly, the settlements are reduced 51.95%, 53.63%, 66.38%, 74.75%, and 80.55% for as compared to double helical piles of four (5 and 10 inch spacing), five, six and nine piles respectively.

Table 4: Maximum settlements for the 18 different tests

No. of Piles	Test Type	Settlement in mm
	Conventional	2.85
Single Pile	Single Helical	1.762
	Double Helical	.47
	Conventional	2.47
Four Piles	Single Helical	1.60
	Double Helical	1.15
	Conventional	2.23
Five Piles	Single Helical	1.38
	Double Helical	0.75
	Conventional	2.02
Six Piles	Single Helical	1.19
	Double Helical	0.50
	Conventional	1.80
Nine Piles	Single Helical	0.54
	Double Helical	0.35

The overall result of settlement for conventional, single helical and double helical piles have been shown in the Figure 7.

B. PILES NUMBER EQUIVALENCY IN TERMS OF SETTELEMENT

As compared to single-helical and double-helical piles, the overall changes (reduction in settlement) seen in conventional piles when advancing from 1 pile test to 9 pile tests are not as significant. The settlement changes in the conventional pile when moving from 1 pile to 9 piles is 1.05mm. This change in the single and double helical piles are 1.41mm and 1.93 mm respectively. This higher change in the settlement of double helical piles as compared to the single helical piles and conventional piles represents higher tendency of the double helical piles to the settlement at small number of piles. From the results obtained in experiments, it can be concluded that the response of 1 single helical pile in terms of settlement is almost equivalent to 4 conventional piles (spacing). Also, 1 double helical pile is equivalent to 4 single helical piles, 4 double helical piles is equivalent to 6 single helical piles and 6 double helical piles are equivalent to 9 single helical piles. The designed axial strength of soil required in a project can be achieved by smaller number of helical piles as compared to conventional piles.

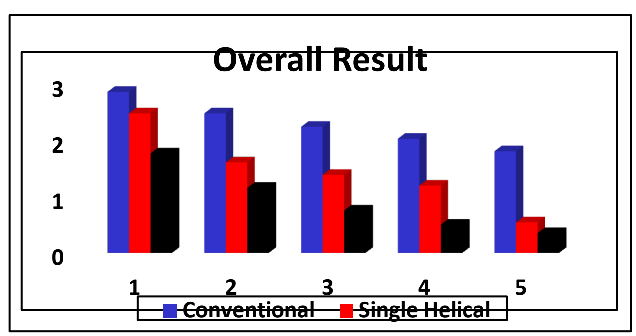
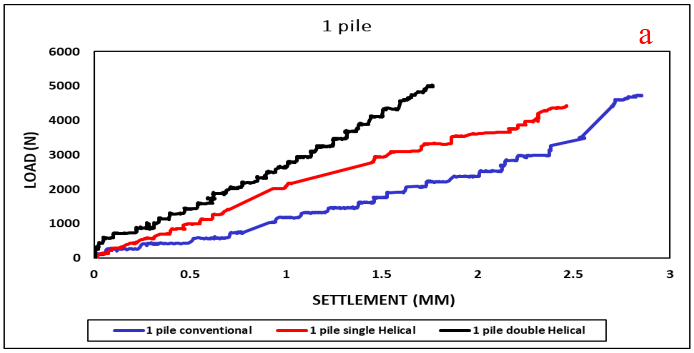
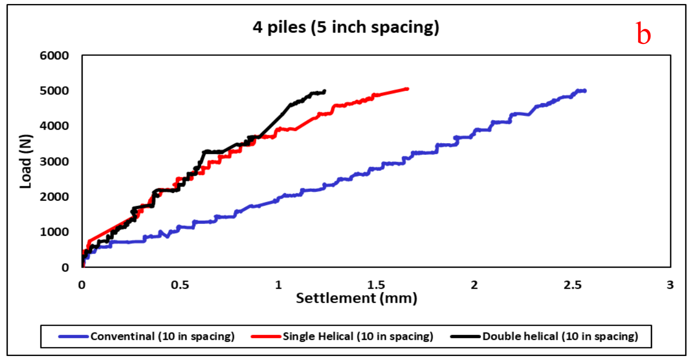
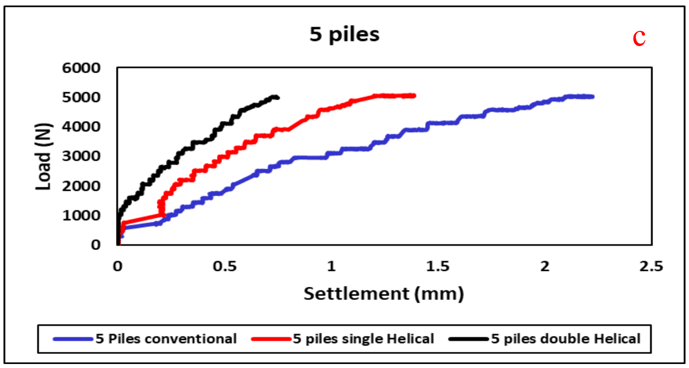


Figure 7: Overall result and comparison of settlements of different piles







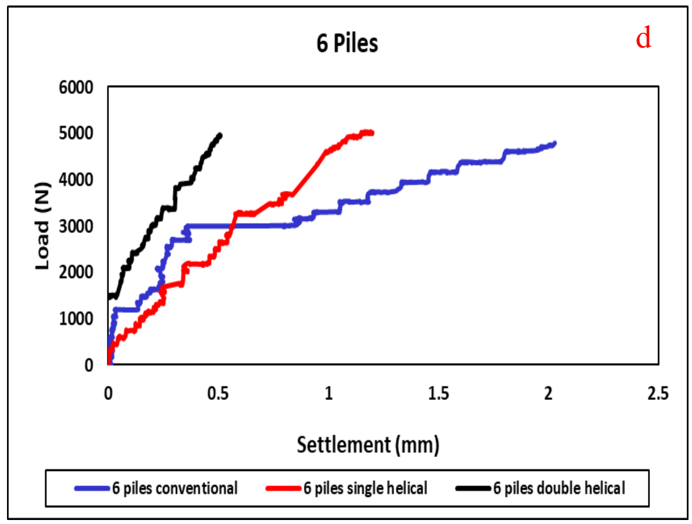


Figure 8: The load versus settlement for the various testing scenarios, (a) 1 Pile, (b) 4 Piles (5 inch spacing), (c) 5 Piles, (d) 6 Piles, (e) 9 Piles

C. COST COMPARISION

Comparative cost analysis of the conventional and helical piles can be easily done if the mechanism of piling process is thoroughly known and associated cost of each component and processes are well identified. Extract the casing: Extracting the casing involves removing the temporary steel or PVC pipe that is used to stabilize the borehole during the drilling process.

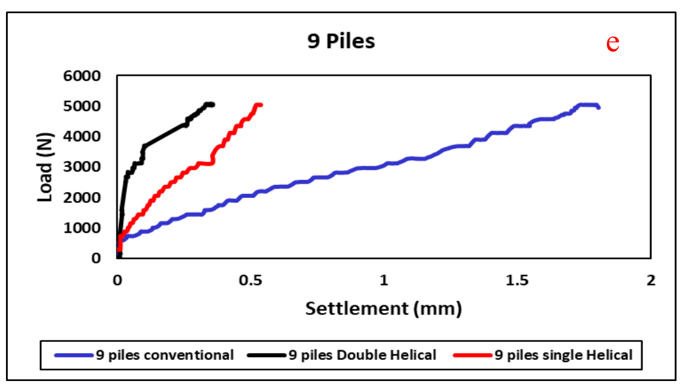
1) Conventional piling:

Drilling: Drilling a pile involves using a drilling rig to bore a hole into the soil or rock to the required depth. The reinforcement cage, also known as a rebar cage, is typically Casing:

The casing is installed initially which involves installing a steel or concrete casing before driving into the ground. The casing is typically driven into the ground using a pile driver.

Pouring concrete:

made of steel bars that are placed inside the drilled hole and securely tied together to form a cage-like structure.



The cage is then filled with concrete, which solidifies around the bars to create a reinforced concrete pile.

Extract the casing:

It involves removing the temporary steel or PVC pipe that is used to stabilize the borehole during the drilling process.

2) Helical piling:

Fabrication of steel helical pile:

The fabrication of steel helical piles involves cutting of steel coils to the desired length and then formed into a helix shape with help of pile forming machine. Then, the helices are welded onto a steel pipe shaft, creating the pile. Finally, the pile is coated with a protective coating to protect it from corrosion.

Installation of Helical piles into the grounds:

The installation of helical piles into the ground is done using torque motor or helical pile driver. The pile driver attaches to the pile and rotates it as it is driven into the ground. The helix on the pile acts as a screw, allowing it to be easily installed into the soil. The following associated cost was found in the conventional and helical piling during the prototype piles.

IV. CONCLUSIONS

This research was focused on the axial behavior of the helical piles by experimental study. The conventional piles were tested first and the result was interpreted, then the piles were modified into the helical by fabrication of the steel blades attached to their shaft. Also, the pilot point i.e., the bottom tip of the piles was made pin type into 45 degrees. The following conclusions are made from this research study:

- A substantial reduction in the settlement has been noticed while going from conventional pile to that of single helical to multi helical pile. Increasing the number of piles in a single raft and increasing the number of helices in a pile both increases the response to loading.
- The capacity of double helical pile is 1 to 1.5 times that of single helical pile. For example, the capacity of double helical pile is 1.311 times more than that of single helical pile.
- Piles placed closed to each other have less resistance to the settlement because the friction imparted by the soil on the shaft is reduced as compared to that of the piles placed apart.
- The reactivity of helical piles varies depending on the kind of soil. The reaction obtained for silty soil like in this research scenario is not the same as that for pure clay and pure sand.

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