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GEOTECHNICAL BEHAVIOR OF HELICAL PILES VIA PHYSICAL MODELING BY FRUSTUM CONFINING VESSEL (FCV)

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ABSTRACT

Helical piles including central shaft and helices performance depends on soil properties, soil-pile interaction and the pile geometry. Failure due to helical piles axial loading can occur either in individual helix vicinity or cylindrical shear surface. So, the failure type can affect on piles behavior and also their capacity. Static analysis, in-situ testing records and also static or dynamic tests can be used for calculating of helical piles capacity. In this study we focused on an experimental method that carried out by frustum confining vessel (FCV) to investigate geotechnical behavior of helical piles. The FCV has been used because of its special geometry that makes a linear distribution of vertical and lateral stresses along its vertical line. Thus, it can simulate field conditions as well. Accordingly, several tests performed on small scale helical piles are made of 4 mm thick steel plate with 750 mm length, 32 mm shaft diameter and 64 to 89 mm helices diameter. According to the achievements, helical piles behavior essentially depends on pile geometric characteristics and in addition test results demonstrated the bearing capacity of helical model piles depends on spacing ratio, S/D, and helices diameter. Results also, indicated helical model piles can bear axial uplift loads about equal of usual steel model piles that have the helices diameter and in compression their bearing capacity is too sufficient to act as a medium pile.

Keywords: Helical pile, Frustum confining vessel (FCV), Physical modeling, Bearing capacity, Geotechnical behavior, Deep foundation.

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1. INTRODUCTION

Many research works have been performed to find the suitable type of piles for various geotechnical and structural conditions. Firstly, the pile shape was a simple shaft, then developed to complex forms over time similar to these now used, including Omega piles, Franki piles, Atlas piles, Fundex piles, cast flight auger (CFA) piles, screw piles, helical piles and etc. (Basu and Prezzi, 2009). As Vito and Cook (2011) presented, helical piles and anchors have been used to support boardwalks in environmentally sensitive areas, to support tower foundations (new and retrofit), to support and lift existing structures, to augment existing foundations, soil nailing applications, heavily loaded piles in new construction, and retaining wall support and tiebacks (new and retrofit). Kurian and Shah (2009) reported that recently helical piles are used as deep foundations to bear both compression and uplift loads up to 3000 kN. Thus, it can be used as a deep foundation in usual structures. Although, helical piles have been used as supports and anchors for a long time, there is little information available on their performance in compare to other piling industry. Hence, they are not well-known to be used commonly. It is required to run more studies on the pile characteristics and compile records of helical piles behavior and performance.

A helical pile as Davis (2009) described, is defined as a foundation element consisting of a central shaft with at least one helix or more helices plates on the shaft with its axis positioned parallel to the shaft's length. Also Kurian

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and Shah (2009) and Perko (2003) confirmed the shaft shape can be square or circular and its diameter is not a constant or normal diameter, recorded data in various studies indicated it varies between 50 to 965 mm, while helix diameter varies between 150 to 1219 mm. Fig. 1 shows schematic of a helical pile and its components.

Fig-1. Schematic of helical piles; a) Helical pile details (Tappenden, 2006) b) A single helical pile components (Pack, 2009)

According to Kurian and Shah (2009) and Sakr (2011) the helical pile is an old type of foundation which has staged a comeback recently and becoming common more and more. It is being used in a variety of situations. However, Perko (2009) have regarded some exceptions that in the past, helical piles were barely mentioned in undergraduate and graduate civil engineering studies. They were considered an alternative in a way that geotechnical engineers would take it into consideration in some special cases. Recently, as Perko (2009) and Pack (2009) indicated, helical piles are widely known by most practicing engineers and can be used as an essential part of deep foundations. Now at the time being, there are over 50 helical pile manufacturing companies in at least twelve countries and there may be more than 2,000 helical pile installation contractors in the United States alone. Helical piles are installed by a torque motor as indicated in Fig. 2.

Fig-2. A multi helical pile installation (Pack, 2009)

Helical piles have advantages that make them considerable for geotechnical and practicing engineers. Some of them include, short installation time with minimal noise and vibration levels, suitability in difficult soils, ease of installation in limited accessibility, light weight, hazard reduction of excavations, on site quality control by measurement of installation torque, less environmental hazards (reuse possibility). Consequently, for the major advantages of normal size, workability and cost efficiency, it is expected that helical pile applicability increases. In this research helical piles behavior and the differences between them and ordinary piles are studied to evaluate using them in current constructions.

2. BACKGROUND ON BEARING CAPACITY

Several investigations have been done to determine helical piles bearing capacity. It is tried to find relationships between bearing capacity and torque installation, helix diameter, helices depth and the spacing ratio. Various numerical analyses also were carried out to investigate the capacity of helical piles under axial loads. For example, Liu *et al.* (2007) reported an equation, based on their Finite-Element analysis in frozen ground, that the helix capacity is determined by calculating the soil's unit-bearing capacity and applying it to the individual helix areas. In this theory, the helices should be spaced far enough apart.

$$Q_t = \sum Q_h \quad (1)$$

Where:

Q_t = helical pile capacity

Q_h = individual helix bearing capacity resulted from Eq. 2.

$$Q_h = A_h(9C + qN_q) < Q_s \quad (2)$$

Where:

A_h = projected helix area

C = soil cohesion

q = effective overburden pressure

N_q = bearing capacity factor

Q_s = upper limit determined by pile material strength

As Sakr (2009) and other researchers illustrated, the axial capacity of helical piles depends mainly on the soil type and spacing ratio, S/D, where S and D are the average spacing and diameter of helices, respectively. Failure can either occur at each individual helix as seen in Fig. 3a or in cylindrical shear surface indicated in Fig. 3b. In the first state, total capacity of helical pile in compression or tension is the sum of the capacities of the individual helices plus shaft resistance (Meyerhof and Adams (1968); Vesic (1971); Canadian Geotechnical Society (2006). In the second state a cylindrical shear failure surface is formed with the connecting uppermost to lowermost helices. Hence, the axial capacity is derived mainly from the shear resistance along the cylindrical surface and bearing resistance above the top helix for uplift loading. In compression loading, the axial capacity is derived from the bearing resistance below the bottom helix and the shear resistance along the cylindrical surface as mentioned above (Vesic (1971); Mitsch and Clemence (1985); Das (1990); Zhang (1999); CGS (2006); Tappenden *et al.* (2009).

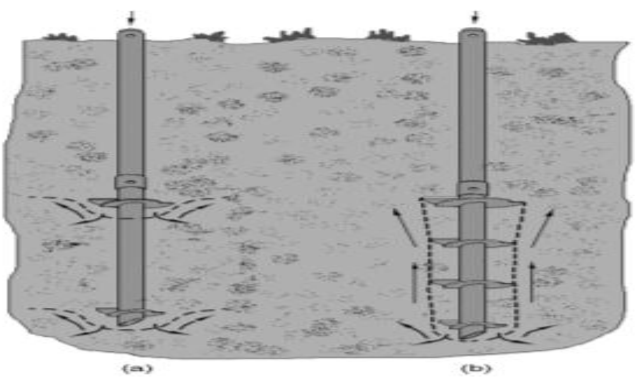


Fig-3. Two Common models for helical pile failures: a) Individual shear method, **b)** Cylindrical shear method (Perko, 2009)

At the time being, almost all researchers have expressed that helical pile bearing capacity can be computed by the equation 3 as follows:

$$Q_c = (Q_{hf} + Q_{hb}) + Q_s \quad (3)$$

The major problem in various methods are estimating Q_{hf} (helix friction), Q_{hb} (helix bearing) and Q_s (shaft friction). Hence, effect of pile configuration variances on bearing capacity is the most important subject that several studies have been carried out on it. Kurian and Shah (2009) have done a numerical study by finite element method on helical piles. They compared helical piles performance with that of prismatic piles. In that study the finite element analysis is eminently suited for analyzing helical piles as it can incorporate the geometrical details of the helical blades at the micro level. They presented in a quantitative form, the bearing capacity increases with increasing the helix diameter. Moreover, when the helix surface varies from smooth to rough, an increase is also reported. Sprince and Pakrastinsh (2010) reported a considerable increasing in pile capacity when helix diameter and its depth increase.

Di Bernardo (2012) carried out a field test program in various soils between years 2009 to 2012 and indicated that helical piles can be used not only in fine grained deposits but also in all soil types even frozen areas and rocky sites. Sakr (2011) reported that uplift capacity of helical piles is about 80% of compressive capacity, but, Livneh and El Naggar (2008) had reported fewer values of uplift capacities. They proposed a failure criterion to predict the ultimate load for the helical piles. The ultimate load is defined as the load associated with deflection equal to 8% of the diameter of the largest helix plus the elastic deflection of the pile.

3. PHYSICAL MODELING FOR STUDYING HELICAL PILE PERFORMANCE

Physical modeling has been recognized as a proper tool to study the pile behavior. It has an important advantage that allows one to carry out many tests that are not expensive in compare to field programs. In this approach, pile testing is not difficult in various soil types. In fact, physical modeling offers the possibility of studying both theoretical and practical viewpoints.

Common small scale sets including simple chambers (1g), calibration chambers (CC), and centrifuge apparatus (ng), have some limitations and difficulties. For instance a limitation of simple chambers is low stress level in compare to real condition surrounding pile in the field. A major limitation of the calibration chambers is uniformity of lateral stresses in all over the chamber and centrifuge apparatus tests are so complex and costly as indicated in Sedran (1999) and Zare and Eslami (2014).

In recent years, Frustum Confining Vessels (FCV) have been developed for physical modeling of penetrometers and piles. This device is a truncated cone shape that applies a steady pressure on its bottom. So, a linear stress distribution is created along its vertical central core. This specification can be the most important advantage of Frustum Confining Vessels (FCV), because it simulates field real overburden and lateral stress conditions. The vertical stress in the soil at the top is zero and it increases with depth to the stress value that applied in the bottom by pressure system. Several model piles in various void ratios and base pressures were tested via FCV by Horvath and Stolle (1996) and it has been illustrated that there is a linear stress distribution via depth in FCV. Fig. 4a show schematic form of the first FCV having been built in McMaster University. Stress distribution along vertical center line of FCV has been drawn in fig. 4b.Scaling factors using for FCV, can be calculated by simulation theories, depending on the degree to which it is pressurized. Sedran (1999) reported the factors relevant to FCV in his research.

The FCV used in the current study has been built in AmirKabir University of Technology (AUT) by Zare and Eslami in 2011 named FCV-AUT. It has a height of 1200 mm, with top and bottom diameters of 300 and 1350 mm, respectively as presented in Fig. 5a. Through the application of a bottom pressure range from 100 to 400 kPa, the in-situ overburden stress conditions equivalent up 10 to 40 m soil deposits almost consistent to the embedment depth of commonly used piles.

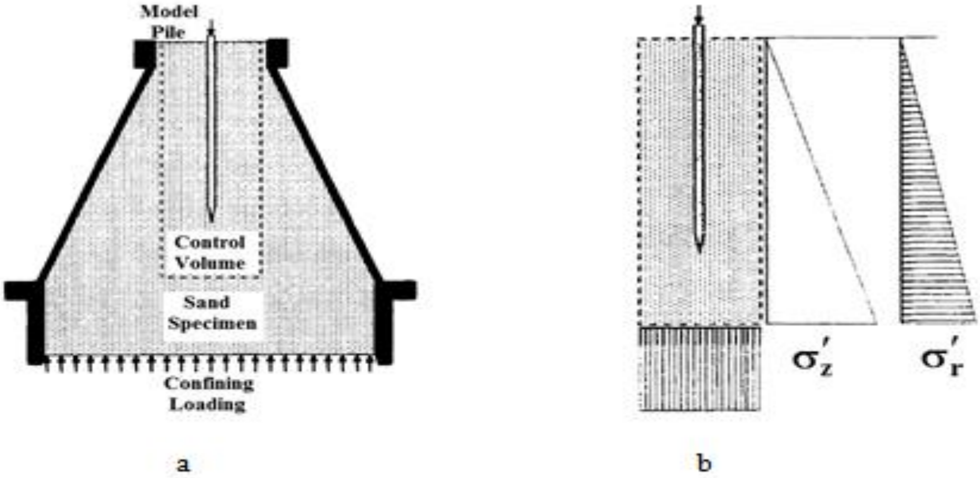


Fig.4- a) Schematic of the FCV, **b)** Idealized distribution of stresses within control volume, Sedran (1999)

Axial compression and tension tests focusing on load-movement behavior were conducted to evaluate the performance of the FCV for model piles. Tested model piles confirmed that there is approximately a linear trend of stress distribution and this device can create realistically overburden stress in the desired control volume along the central core.

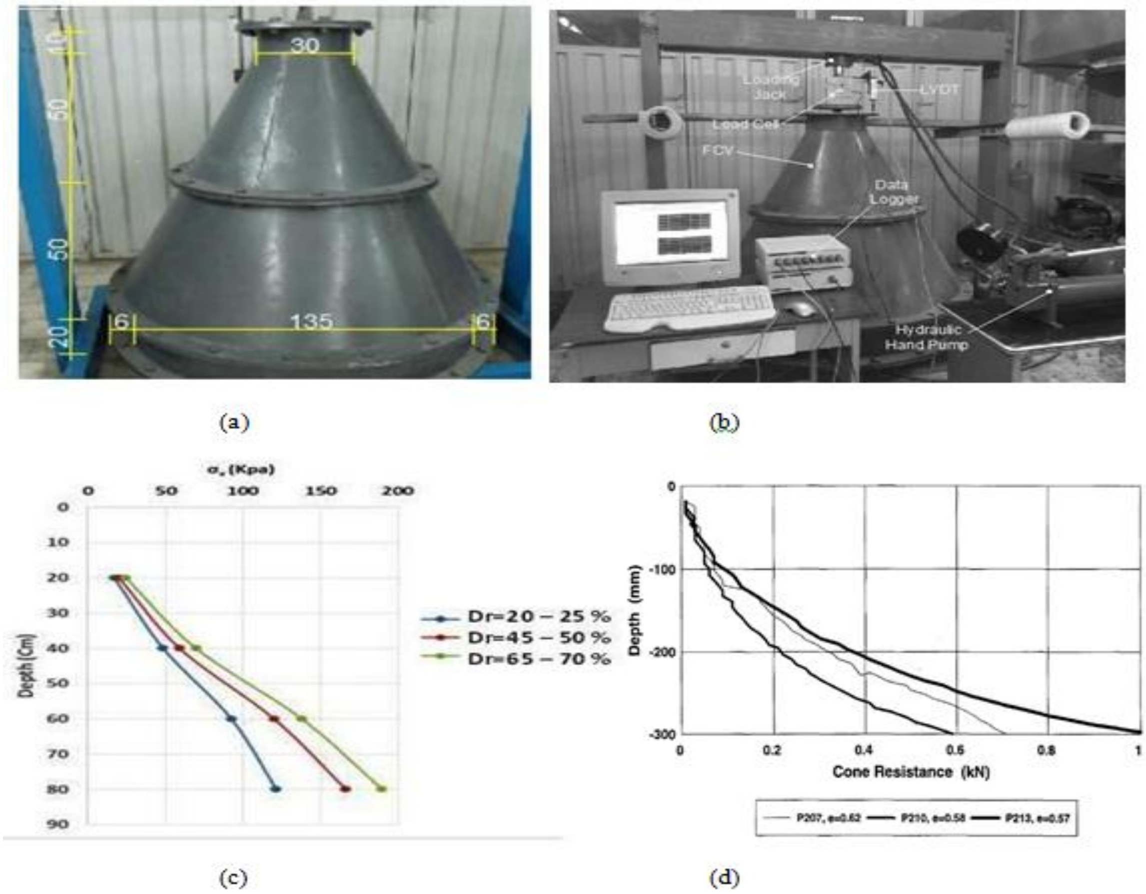
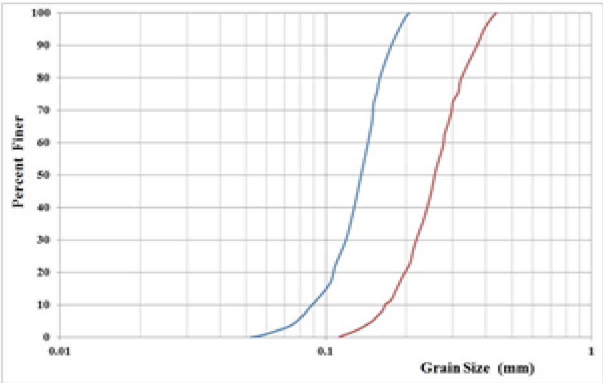


Fig-5.a) FCV-AUT and its dimensions (cm), b) Overview of FCV at AUT and its accessories, c)Stress distribution in FCV-AUT by Zare *et al.* (2013) d) Lateral stress distribution in FCV by Sedran (1999)

Sedran (1999) demonstrated that the stress distributions along the centerline obtained by membrane loading were smoother than in the case of piston loading. Hence, in the AUT- FCV, a membrane to apply bottom pressure has been installed. This device consists of four major parts such as the frustum body, bottom pressure system, loading system and instrumentation system. Hydraulic jack designed and made to apply tension and pressure load. Maximum load is 15 tons and maximum displacement is 150 mm. Power of jack, which is designed to apply hydraulic pressure up to 300 bars which is provided by a hydraulic hand pump with a switch valve.

4. EXPERIMENTAL STUDY BY FCV-AUT

Babolsar is a coastal city in northern area of Mazandaran province in Iran. In this experimental study Babolsar sand was used as surrounding soil of model piles. The sand was approximately uniform soil and has a grain size distribution curve as shown in Fig. 6a. So, the sand is categorized as SP in Unified Soil Classification System (USCS). The sand properties due to the laboratory tests are given in Fig. 6b.



a

Relative density (D_r) %	$\gamma_{d(min)}$ (kN/m^3)	$\gamma_{d(max)}$ (kN/m^3)	Cohesion (kPa)	Internal Friction Angle
25-30	14.85	17.99	1	29.9
45-50	14.85	17.99	2	32.2
65-70	14.85	17.99	2	35

b

Fig-6. Grain size distribution of Babolsar sand and its properties

For testing, first, the sand prepared and placed in FCV-AUT in loose state by air raining method and leveled by a wooden pallet in each 50 mm depth. In this filling method relative density is about 20% to 25%. In the second state, which relative density is about 45% to 50%, the sand placed in FCV and each 50 mm layers height compacted by body vibration. Hammer compaction in layers is used to achieve 65% to 70% relative density. The tests were applied on short rigid model piles in vertical compressive and pullout tests in the FCV-AUT. As indicated in Table 1 all fourteen model piles tested in this study have 750 mm embedment depth and were made from 4 mm thick steel plate. Shaft diameters of three usual and eleven helical model piles are 89 mm and 32 mm, respectively. Helix diameters varied from 64 to 89 mm and spacing ratios are assumed 1 to 4. Some model piles are shown in Fig. 7.

Table-1. Model Piles Characteristics

Model Number	Pile Type			Installation Method	Average Diameter (mm)		Thicknes s (mm)	Length (mm)
1	Closed-end			Jacking	89		4	750
2	Closed-end			Hammer Knocking	89		4	750
3	Open-end			Hammer Knocking	89		4	750
	Helical Piles	Helixes	Spacing Ratio (S/D)	Torque motor	Shaft Diameter	Helix Diameter	4	750
4		1	-	Torque motor	32 mm	64 mm	4	750
5		1	-	Torque motor	32 mm	89 mm	4	750
6		2	1	Torque motor	32 mm	89 mm	4	750
7		2	2	Torque motor	32 mm	89 mm	4	750
8		2	3	Torque motor	32 mm	89 mm	4	750
9		2	4	Torque motor	32 mm	89 mm	4	750
10		2	5	Torque motor	32 mm	89 mm	4	750
11		2	3	Torque motor	32 mm	64 , 89 mm	4	750
12		2	3	Torque motor	32 mm	89 , 64 mm	4	750
13		3	2-3	Torque motor	32 mm	89 mm	4	750
14		3	3-2	Torque motor	32 mm	89 mm	4	750

a b c d e

Fig-7. Model piles used in current study: a) Steel pile, b) Open ended steel pile, c) Single helix pile, d) Double helices pile, **e)** Multi helices piles,

Common piles include open and closed- end models were driven vertically by hammer knocking and jacking. The jacking pile was a closed-end model. The helical model piles were driven by torque implementation. All compressive and tensile loading tests were carried out on every model pile. The vertical load was applied in a stepwise manner by a hydraulic system. A load cell and linear vertical displacement transducers (LVDT) with high precision of 0.001 mm were mounted on the loading piston to measure the total vertical imposed loads and corresponding displacement of pile head. After driving pile, FCV-AUT base pressure was set on 200 kPa. The loading starts and continued till the pile head displacement goes up and reaches 30% of pile diameter. According to Horvath and Stolle (1996) there are a few number of failure criteria used to interpret the axial piles capacities from pile load test results. It should be pointed out that in many situations the design loads of deep foundations is controlled by the allowable structural displacements at foundation level. In experimental studies the head pile displacement which pile capacity is measured, varies between 5 to 30% of average pile diameter. Therefore, pile loading is continued to 30% of pile diameter in present study but the major criterion was focused on 15% of average pile diameter.

5. RESULTS AND DISCUSSION

As explained, several model piles were tested by FCV-AUT in this study and the applying base pressure of system, pressurized on 200 kPa. It simulates a full scale pile with about 10 to 15 m embedment depth in Babolsar sand. The rate of pile loading was set in such a manner that in each loading step, pile head displacement approximately be fixed. The penetration was about 2.5 kN in each 2 minutes, i.e. 20 N/sec.

This study was performed to investigate geotechnical model piles behavior. Hence, in all model piles effect of soil densification and also difference in compression and tension were studied. Effect of spacing ratio, size and number of helices were studied only in helical models. The test results are presented as load-displacement curves.

As expressed before, criterion load was based on corresponding load with head pile displacement of 15% of pile diameter. Due to this norm, as seen in Fig. 8, the maximum of compression applied loads in open-end model piles varied between 9.4 to 50 kN for loose to dense sands, while the head pile displacements up to 15% of pile average diameter. The maximum of tension applied loads, also, are about 1.3 to 14 kN. Results of closed-end models, indicated in Fig. 9, show that this model pile can bear 11 to 65 kN compressive loads and 2.2 to 14 kN tensile loads. In addition, compression and tension capacity of open end models were installed by jacking, varied from 16 to 89 kN and 1.5 to 14.3 kN, respectively as shown in Fig. 10.

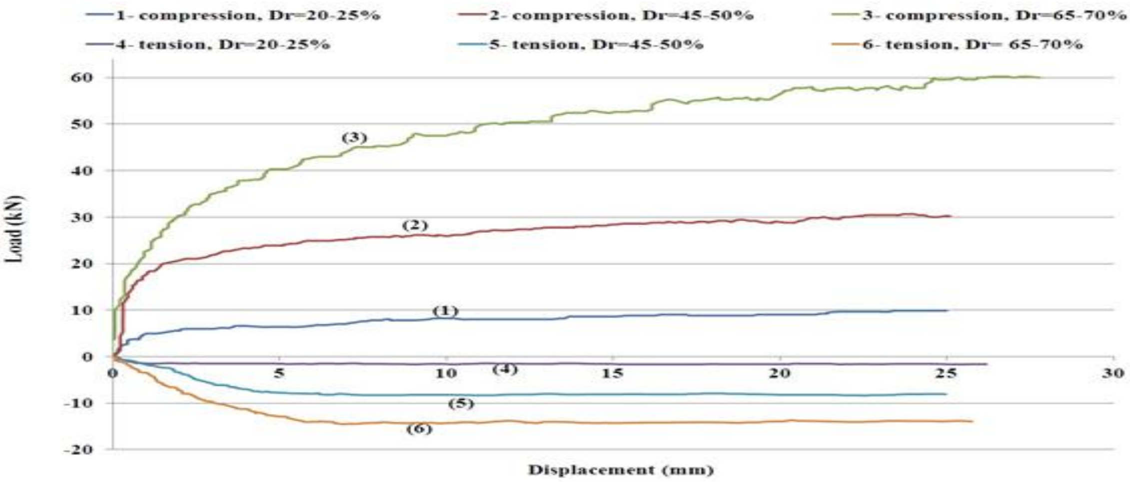


Fig-8. Load-Displacement diagrams in open end model piles in three various relative densities

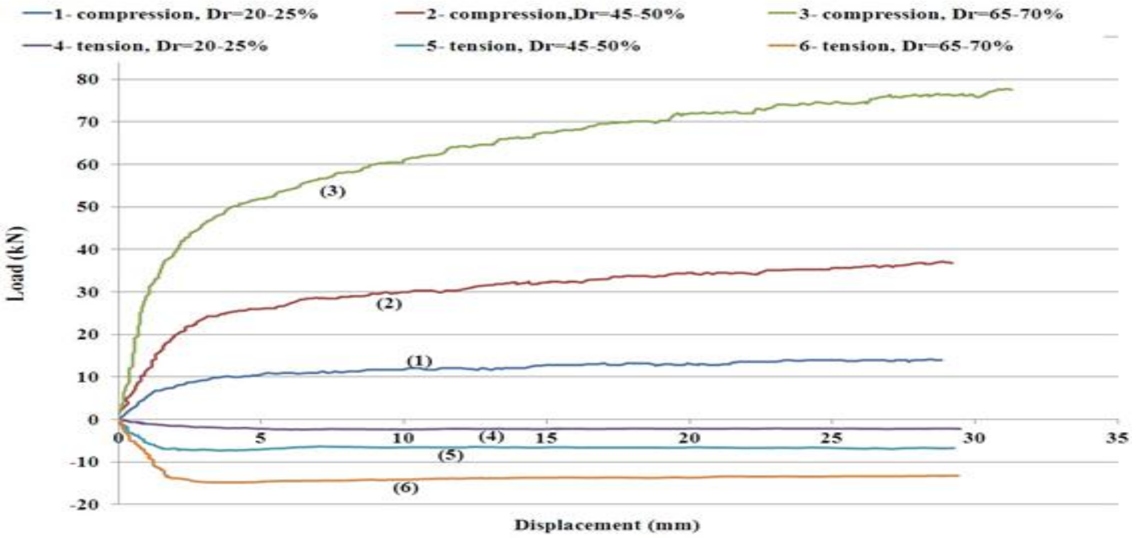


Fig-9. Load-Displacement in closed-end model piles

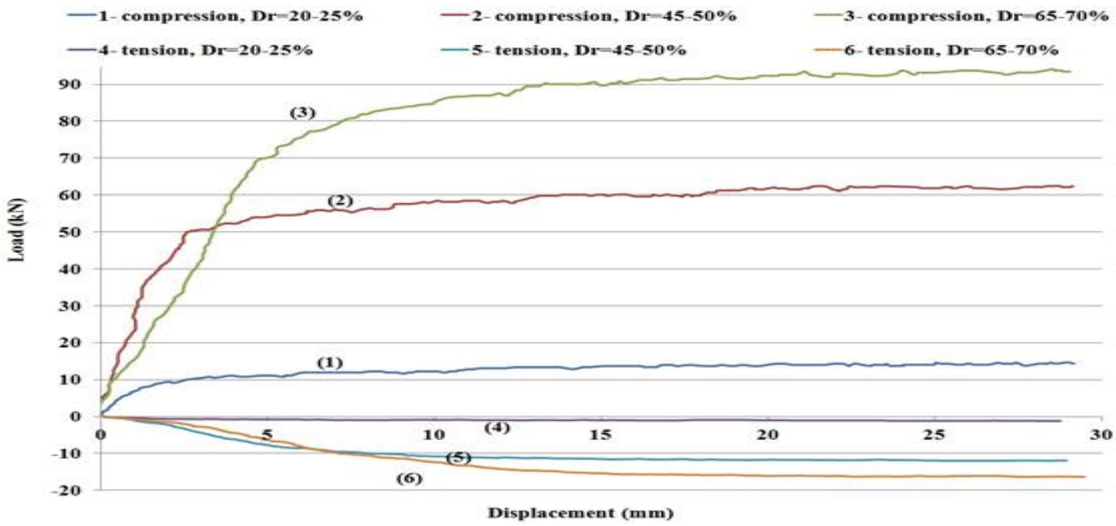


Fig-10. Load-Displacement curve in Jacking model piles

For these model piles, there is a low applied compressive load growth after displacement of 10% pile diameter and also, a low growth in tensile load after displacement of 5% pile diameter. So, the criterion of displacement 15% can be reasonably accepted from the viewpoint of ultimate pile capacity as well. The results also illustrate that about

70% of capacity is obtained before pile displacement exceeds 5% pile diameter, especially when relative density is over 50%. In displacement equal to 10% pile diameter, it will be more than 80% of ultimate pile capacity. About 90% of ultimate pile capacity is achieved before the jacking model displacements reach to 10% of pile average diameter. It should be noticed that the uplift capacities are about 25% of compressive loads. Thus, in three model piles as mentioned, definition of concerned load with 5% head pile displacement is a logic decision when relative density is less than about 50%. The displacement will be 10% of pile diameter while relative density is more than 50%, if movement considerations allow. It is proposed to have a criterion that in these piles the design loads be assumed the loads related to displacements of 5% pile diameter when soil relative density is less than 50%. If not, pile displacement of 10% pile diameter in compression and 5% pile diameter in tension is the criterion.

As explained, in loose, medium and dense conditions, the model piles load-displacement behavior is similar, although in loose condition maximum load is obtained in lower pile displacements. Hence, it can be resulted that soil densification is not much effective on pile behavior. In models installed by hammer knocking, bearing increase is upper when relative density varies from medium to dense and in jacking models bearing loads have more increase when relative density varies from loose to medium.

Helical pile test results are shown in Table 2. It is observed that a single helix pile with 32 mm shaft diameter and 64 mm helix diameter can bear 3.7 to 15.1 kN compressive load and 0.94 to 4 kN tensile load as indicated in figs. 11 to 13. If the helix diameter increases to 89 mm, the compressive and tensile loads will raise to 5.5 to 26 kN and 1.4 to 7.3 kN, respectively. So, axial helical capacity increases while helix diameter increases. In this condition weight of helical pile grows up only 4% but compressive and tensile capacities in dense sand increase about 70% and 80%, respectively. This increase in loose sand is about 49% in both compression and tension tests.

Table-2. Loads in Displacement 15% of Pile Diameter for Multi Helixes Piles

Model Number	Dr= 20-25% (kN)		Dr= 45-50% (kN)		Dr= 65-70% (kN)	
	compression	tension	compression	tension	compression	tension
1	16	1.5	60	11.1	89	14.3
2	11	2.2	32.5	6.2	65	14
3	9.4	1.3	29.1	6.9	50	14
4	3.7	0.94	7.5	2.92	15.1	4
5	5.5	1.4	15.6	5.1	26.2	7.3
6	4.9	2	15.9	5.2	26.8	8.2
7	7.5	3	18.2	6.1	33.1	11.5
8	8.4	2.3	22.1	7	36.8	11.9
9	10	2	28.1	6.2	42.1	9.7
10	8.9	-	25.1	-	40	-
11	4.1	1.75	14.2	4	23.8	7
12	5	2	15.5	5.1	27	10
13	10.2	2.6	25.1	7.1	48.3	12.6
14	10.1	2.6	28.6	6.9	44	12.2

Therefore, adding helix diameter will be very effective to enhance helical pile capacity and in higher relative density, this can be more pronounced, if the helix materials do not buckle.

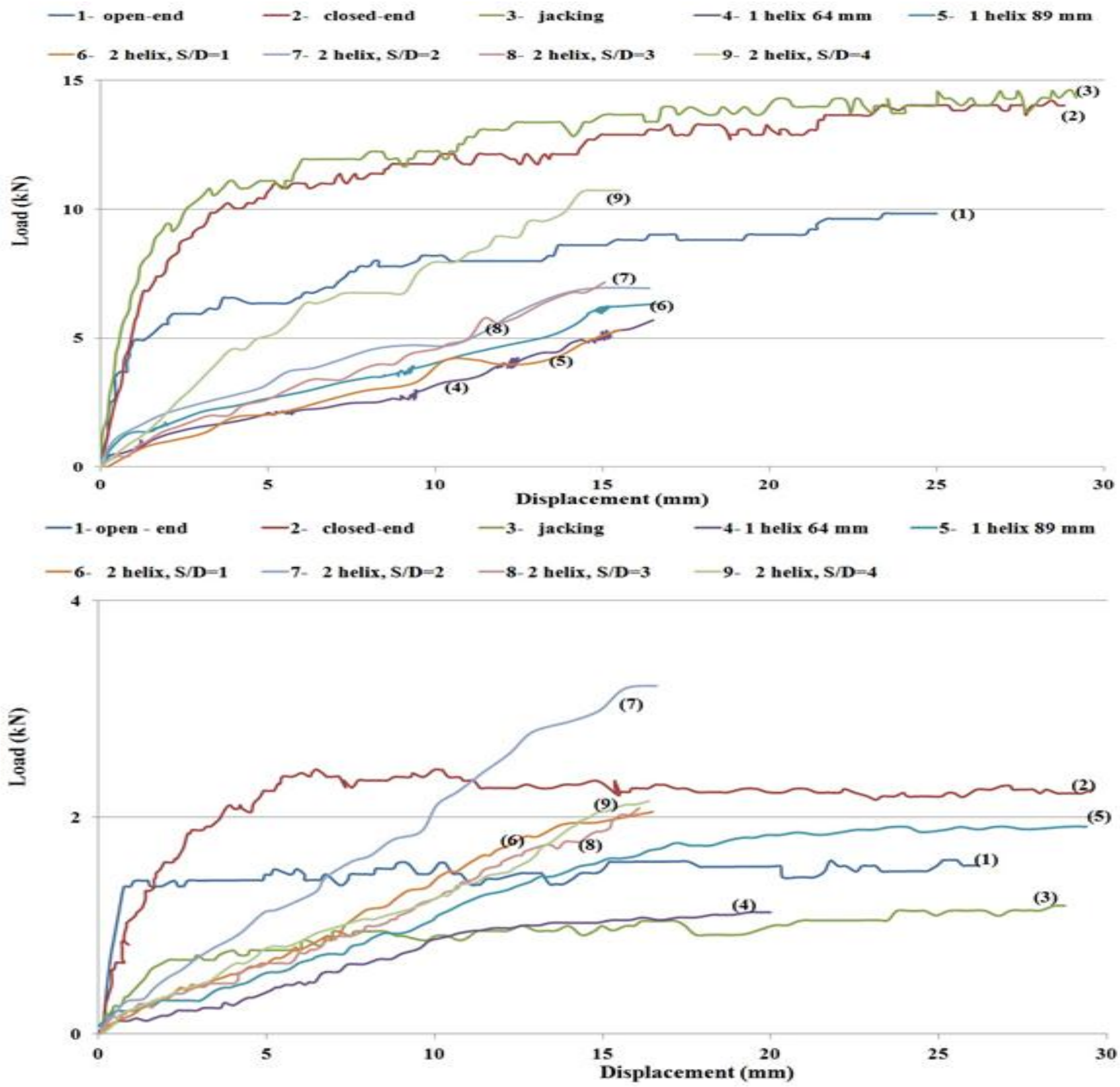
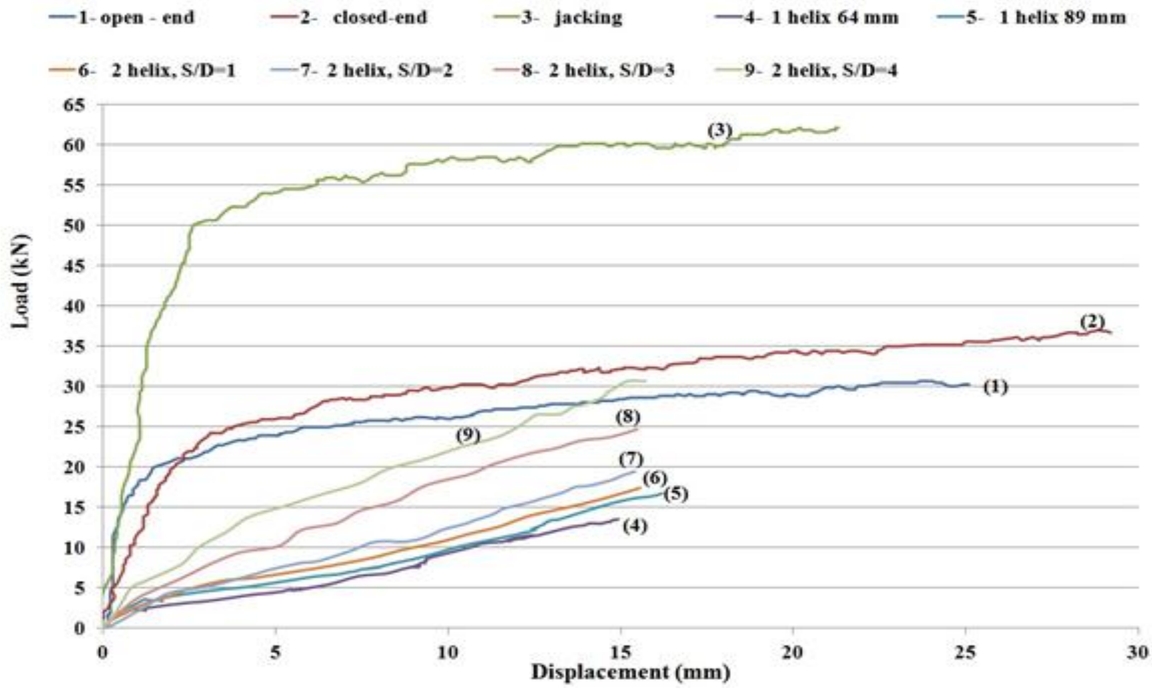


Fig-11. Load-Displacement results in helical model piles with relative density equal 20-25%, a) Compression, b) Tension



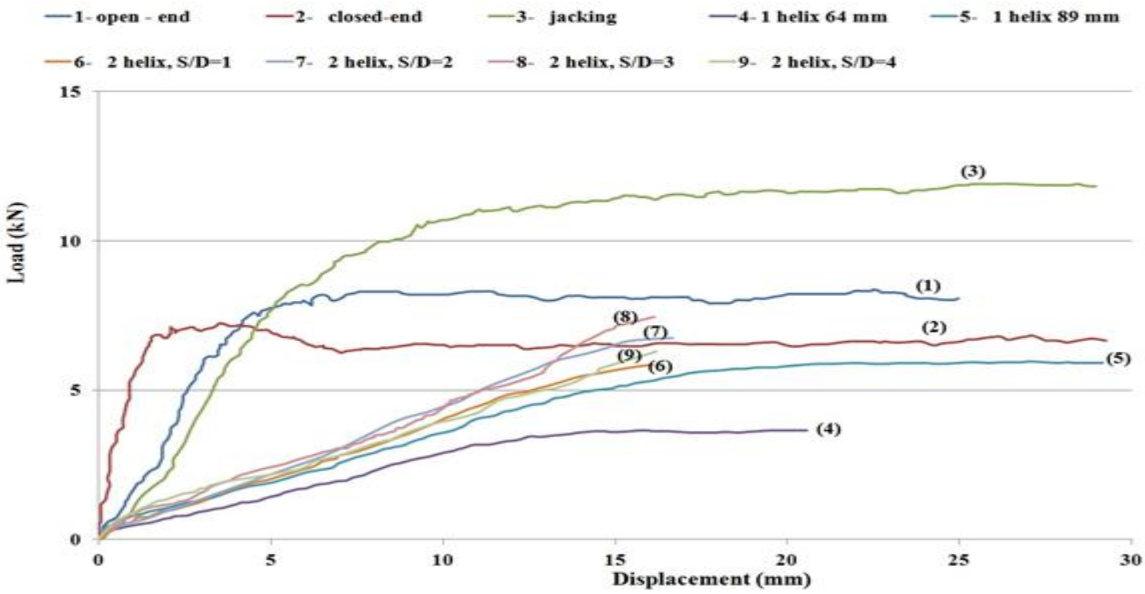


Fig-12. Load-Displacement results in helical model piles with relative density equal 45-50%, a) compression, b) tension

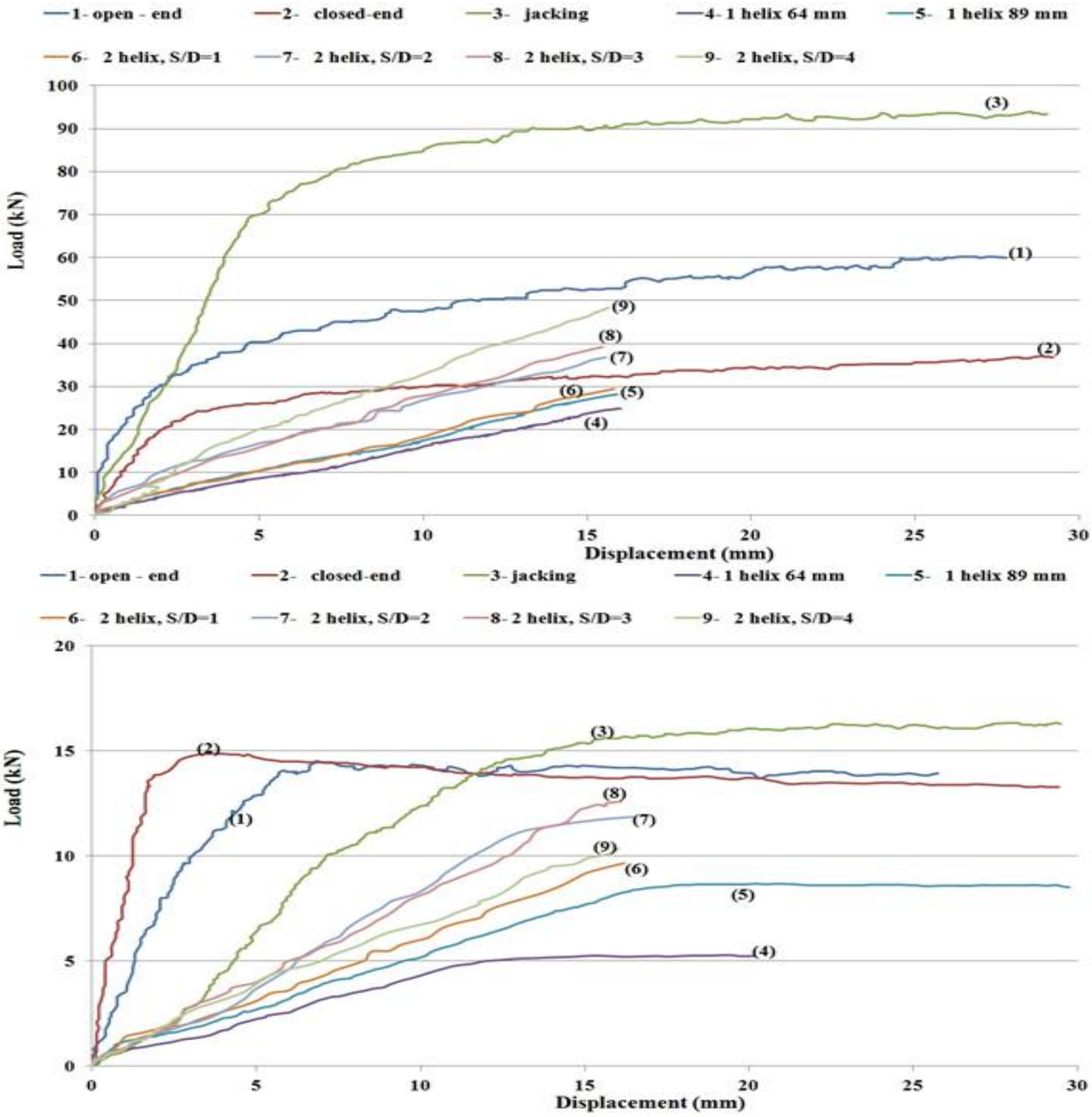


Fig-13. Load-Displacement results in helical model piles with relative density equal 65-70%, a) compression, b) tension

If two various sizes of helixes use in one helical pile, better results will be achieved when the larger helix is put on the top. When a helix with 89 mm diameter is positioned on top of a 64 mm diameter helix on one helical pile, the compression and tension loads in displacement of 15% average diameter are about 5 kN to 27 kN and 2 kN to 10 kN in loose to dense sand, respectively as shown in Fig. 14. If the smaller helix put on the top, these values will vary to 4.1 kN to 23.8 kN in compression and 1.75 kN to 7 kN in tension with the spacing ratio equal to three.

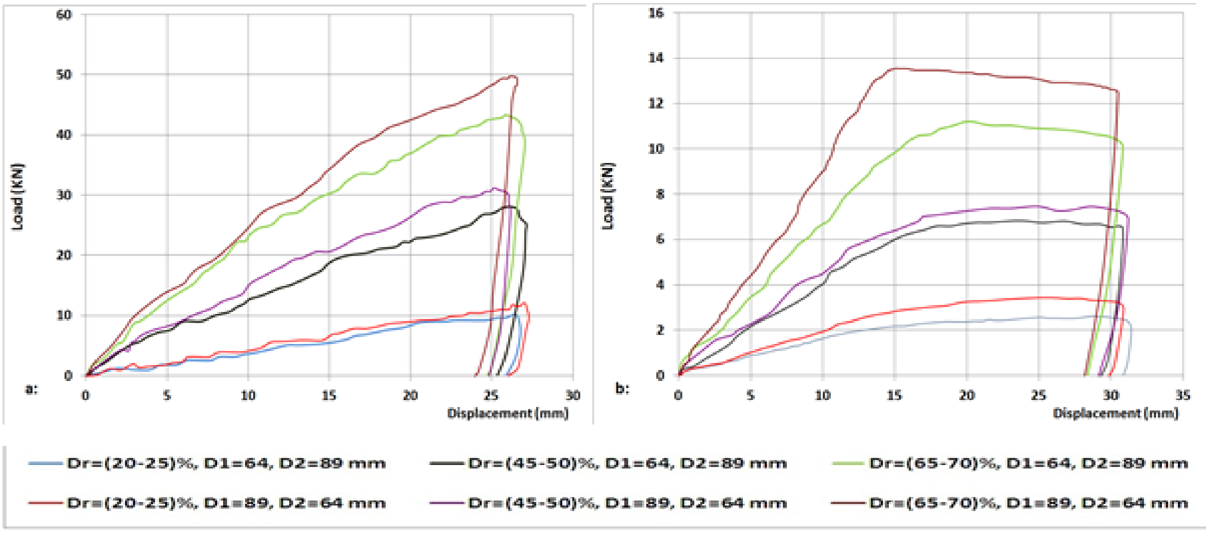


Fig-14. Load-Displacement curve in double helices pile (various helices diameter), a) compression test b)tension test

According to the results, in double helices model piles, axial capacity mainly depends on spacing ratio, S/D. So, in this study, helical piles by various spacing ratios were tested. The spacing ratios varied from 1 to 5. Fig. 15 showed the optimum value of spacing ratio in compression and tension tests which the value of S/D equals to 4 and 3 determined respectively. This can be noticed in dense sand helical pile compressive capacity decrease from 42.1 kN to 40 kN when S/D increases from 4 to 5, also, in loose and medium conditions. Tensile loads are reduced while S/D varies from 3 to 4. Loose sand is more sensitive to spacing ratio and reduction is obtained when S/D varies from 2 to 3. The reason may be more potential of loose soils displacement. Hence, a constraint like of a helix should be positioned in shorter distances. Sakr (2009) and Merifield (2011) had proposed the value of 3 for spacing ratio (S/D) but in this study the results showed that the spacing ratio can be different in compression and tensile loadings. It can differ in loose and dense states, too. Based on FCV-AUT tests the spacing ratio in dense sand and compression state is higher, about 4, than loose sand and tension state, approximately 3. Consequently, the proposed optimum value of the spacing ratio is designated 4 and 3 for compression and tension loading conditions, respectively.

Experimental study and observations in the field and modeling denote helical piles involve a main difference in comparison with other piles. Results showed axial capacity in open and closed-end model piles installed by either hammer knocking or jacking, rises rapidly and in low pile displacements reaches to about 70% ultimate capacity. Thus, a considerable increase in axial capacities is not expected anymore, when displacements exceed 10% of pile diameter. In helical piles the axial loads increase versus displacement, progressively. This increase continues till the test ends while displacements up and reach to 30% pile diameter and no soil failure is occurred. In this state further bearing resulted to resist higher loads up to the end of testing. Hence, no plunging failure was observed on helical model piles, tested in FCV-AUT. Therefore, design loads for helical piles can be determined by settlement limitations. Consequently, there are two design load criteria, in ordinary piles it can be the load value concerned to displacement of 5% of pile diameter in loose and medium state, and 10% in dense condition. In helical piles, displacement of 15% of pile diameter is proposed for design loads. It can be limited by structural allowable movements.

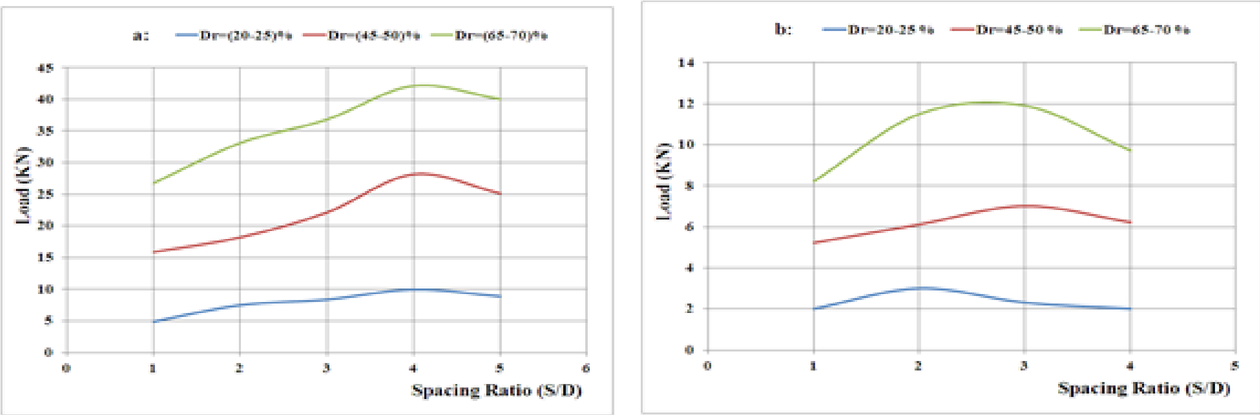


Fig-15. Comparison in axial pile capacities versus relative Spacing Ratio (S/D), a) compression test, b) tension test, (Displacement is about 15% of pile diameter)

Comparing between the load displacement curves for helical piles with single helix and more helixes showed that helical piles have a similar behavior. Hence, the behavior is not dependent to soil densification, but helical piles have a better performance in dense sands. The reason might be the higher restraint between sand and helixes. It is important to note the soil should move and have a minimum displacement to occur a proper interlocking in loose conditions. In helical models tensile loads vary from 30% to 40% of compressive loads.

FCV test results indicated that helical piles can bear tensile loads almost equal to steel piles with the same diameter of helices. Comparing pile weights showed that maximum weight of double helices pile is about 42% of a usual steel pile. Therefore, helical pile is an economic choice to bear uplift loads. Results also revealed that helical pile compressive capacity is about 65% of a common pile. This provided capability for using them to bear compression loads. According to present results, in all tests the axial uplift capacity seldom exceeds 40% of axial compressive capacity. Paying attention to pile size, it is noticed that in model piles the pile embedment depth on diameter ratio (L/D) is about 8.4. Model piles are categorized as short rigid piles, so, the friction resistance which is the most important section to resist reverse uplift loads still is low.

Based on FCV test results, adding a helix to a single helix pile, depending on soil densification and spacing ratio, causing increased tensile capacity about 30% to 50%. However, maximum rise in compressive capacity is limited to 20%. When three helices are used, results showed similar behavior to usual piles (without any helices) as shown in Fig. 16. Results show the larger S/D in lower level of piles is more effective. In both tension and compression states, more increase resulted while relative density increased.

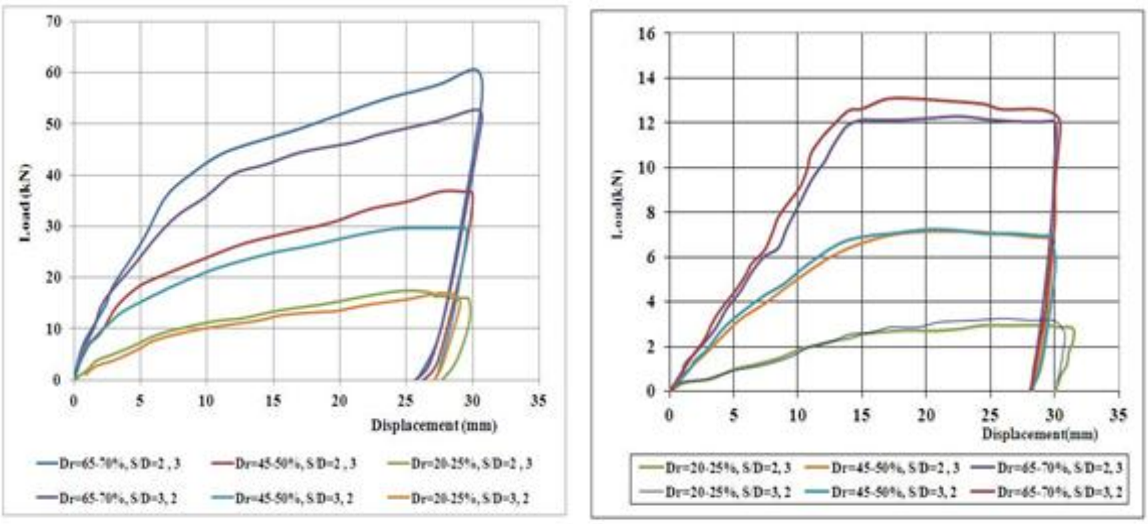


Fig-16. Load-Displacement curve in three helixes pile (various S/D), a) compression test, b) tension test

6. CONCLUSIONS

Helical piles have some advantages that have made them very reasonable choice for using in offshore structures, building supports and crowded urban sites. Some of these advantages include ease of installation, safety piling because of pre-drilling elimination, short installation time. Helical piles also are economical and environment-friendly pile types.

FCV-AUT is used to test small scale model piles due to its configuration (lateral stresses vary almost linear from zero at the top soil to system applied pressure at the bottom). The FCV device presents a practical and economical alternative to chambers and centrifuge devices. Furthermore, the most limitations associated with simple 1g and CC devices can be eliminated when model piles are tested in FCV. The results of stress tests have shown clearly that FCV can simulate the stress gradient in reality where the full scale piles are instrumented.

According to test results, displacement of 5% pile diameter in loose and medium, and 10% in dense conditions are assumed as criteria in usual piles. In helical piles, 15% of pile diameter is proposed as a criterion if structural movements allow.

Helical piles have a suitable performance to bear tension loads. A helical pile with two helixes can function approximately, equal to a steel pile when the steel pile diameter is the same as the helix diameter. The helical pile weight is less than 45% of steel pile in these conditions. In compression, helical piles with two helixes can bear about 47% to 65% of a common steel pile capacity with the helixes diameter. Therefore, helical piles are reasonable choices in where there are uplift loads, especially in marine projects.

Adding a helix to a single helix pile in tension is more effective than compression loading. Uplift loads can be enhanced about 30% and higher. However, it is limited to 20% in compression. If two helices used in one helical pile, have various sizes, better results can be achieved when the larger helix is put on top.

When the number of helices becomes up to three, helical piles behavior is closer to common piles behavior. Uplift loads in this state are equal to ordinary piles or more. Compressive loads increment is about 10-15% in compare with two helixes piles. Helical piles with three or more helixes have a better performance when the spacing ratio in down is larger than the pile top, i.e. S/D be 2 in top and 3 in down.

Due to the results, helical piles have a better performance when the relative density of site soil increases; this is because of more restraint between soil and pile helices.

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