J-Researchers

Journal of Civil Engineering Researchers

Journal homepage: www.journals-researchers.com

Evaluation of High Capacity Helical Piles in Silty Clay

Farhad Nabizadeh,[a,*]

[a] Department of Civil Engineering, Cha.C., Islamic Azad University, Chalus, Iran

ABSTRACT

A new foundation system employing in situ grouting of helical screw piles has recently been developed. The paper discusses design considerations, installation procedures and results of full scale field load tests. This study assessed axial static loading tests on single, double and triple helix helical piles under grouted and un-grouted conditions. The field study was conducted to investigate the behavior of helical piles in silty clay soil. Also, the ultimate load capacity (Qu) for each pile test was predicted using six different interpretation methods. Also, the effect of post-grouting on the strength of these piles was assessed and the results of the piles load tests were interpreted using 6 methods presented in literature to predict the ultimate load capacity (Qu) for each pile. Results showed that the grouted helical piles are excellent foundation systems for the resistance of uplift, as well as, compressive loads and resistance against corrosion and less harmful to the environment than other types of piles especially in urban areas.

ARTICLE INFO

Received: April 16, 2026
Accepted: May 24, 2026

Keywords:
Capacity
Helical piles
Helical piles
Post Grouting
Silty Clay

DOI: 10.61186/JCER.8.2.71
DOR: 20.1001.1.22516530.1399.11.4.1.1

1. Introduction

Large design loads, poor soil at shallow depth, or site constraints like property lines are some of the most important reasons for using deep foundations. The use of helical pile as a kind of deep foundation has considerably increased in recent years. Currently, more than 50 manufacturers in the world produce a wide range of helical piles and anchors [1]. For the past 170 years, helical piles have been in use. Alexander Mitchell, an Irish civil engineer, is known as the inventor of the first helical piles which were used in the design of foundations for lighthouses [1–7]. A helical pile is a deep foundation system that consists of regularly spaced helical steel plates welded to a slender steel shaft. The central shaft can be square, round or a combination of square and round shafts, depending on the soil and loading conditions. The helices, which are typically fixed to a lead shaft section of up to 3 m length, can all have a common diameter or the helices may increase in diameter with distance above the tip of the pile. The pile is installed into the ground by applying torque to the shaft, causing the pile to screw through the soil. An axial compression force is applied to ensure that the pile advances through the soil [8–12].

Up to the year 2005, torque motors commonly used for helical pile installation produced a torque of 4500 to 80,000 ft—lb (6.1 to 108.5 kN.m) while new generation of torque motors that became available on the market in the late first decade of the 2000's offer torque up to 250,000 ft—lb (339 kN.m). Due to this development of powerful hydraulic rotary heads, helical piles have become more popular in recent years [13]. Helical piles have been used in the

* Corresponding author. Tel: +989113914437; Email: f.nabi799799@gmail.com

construction of structures subject to uplift forces such as buried pipelines, telecommunication and transmission towers, machine foundations, commercial and residential buildings [10,14]. They provide several construction and performance advantages over conventional concrete and steel piles including light weight, high compressive and uplift capacities, short installation time with minimal noise and vibration levels, suitability for construction in limited access conditions, installation in frozen or swamp soil conditions and their cost effectiveness and providing overturning and uplift stability immediately after installation due to the elimination of the curing that is encountered in concrete anchors [2,9]. Furthermore, helical piles don't have loud noise during installation so they are suitable for urban areas since they are not harmful to the environment.

Despite the many benefits of helical piles, the available literature provides only limited insight into their behavior compared to the other types of piles. Furthermore, the advantages of helical piles can be improved by some methods such as post-grouting, on which there are only few studies., Therefore, it is necessary to perform further studies on the behavior of helical piles.

Several studies have been conducted on the behavior of helical piles; Clemence; Mooney et al. Conducted field and laboratory testing; Hoyt, Hoyt et al., and Ghaly and Clemence conducted theoretical and experimental testing, Puri and Vijay, Huang et al., Perko, and Pack conducted theoretical analyses. Rao and Prasad, Prasad and Rao, conducted experimental testing; Vickars and Clemence studied the performance of helical piles with grouted shafts and discussed design considerations, installation procedures and results of full scale field load tests. It was noted that the grouted column significantly increases the anchor shaft's resistance to buckling and provides additional corrosion protection. It was also stated that the grouted shaft increases the stiffness of the column and bearing capacity of foundation [15].

Furthermore, few studies conducted on the performance of helical piles in full scale including a research by Mohammed Sakr showed that helical piles with double helixes provided about 40% higher resistance compared with piles with a single helix[14]. Therefore, the use of an additional helix, which adds only a minimal cost, is a very cost-effective method for increasing the capacity of helical piles.

In another research by Sakr in 2011, the first full-scale axial compression and tension (uplift) testing program executed on large capacity helical piles was presented, according to the author's claim. A total of thirteen tests were carried out, including nine axial compression tests and four tension (uplift) tests. The results of the axial compressive and tensile pile load tests and field monitoring of helical piles with either single helix or double helixes installed in either dense sand or very dense to very hard clay till soils showed that helical piles can develop significant resistance to axial compressive loads up to 2500 kN and tensile loads up to 2000 kN [13].

Also Weech and Howie presented the results of observations of pore pressures during and after installation of helical piles and interpreted the results of load test on these piles in a soft, sensitive clayey silt. The results showed that the capacity mobilized by the helices with cylindrical bearing failure increases substantially with time as the shear strength of the soil surrounding the piles recovers after pile installation. Conversely, the capacity of the helices with individual bearing failure does not appear to increase significantly with time after installation and so the effect of installation disturbance is less [12].

In this research, field study was conducted on piles with various numbers of helixes to investigate the behavior of helical piles in silty clay. Also, the effect of post-grouting on the strength of these piles was assessed and the results of the piles load tests were interpreted using 6 methods presented in literature.

2. Testing Procedure

2.1. Test Site (Geotechnical Condition)

The pile test was performed in a site in the city of Sari located in the north of Iran. The site location is shown in Figure 1.

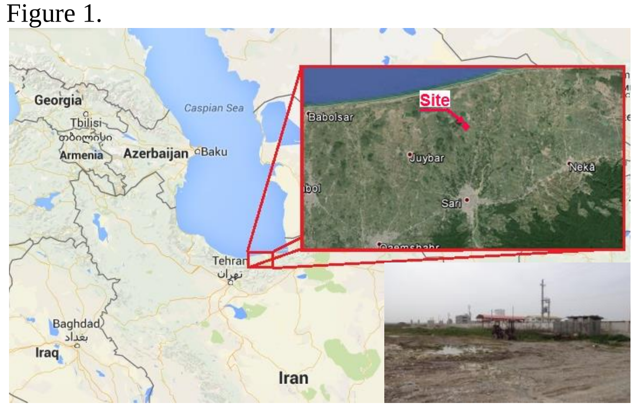


Figure 1. Location of the pile test site

Geotechnical study was conducted at the site and standard penetration (SPT) and cone penetration (CPT) tests were carried out. Soil stratigraphy at the test site consists of silty clay layers with middle layers of sand that extended to a depth of 30 m underlain by stiff layers of silt and clay that extended to a depth of 40 m. A rock layer ranging from sandstone to soft siltstone was encountered at depths greater than 40 m. Ground water level was 0.5 m below existing ground surface. Soil properties are summarized in Table 1.

Table 1.
summary of soil properties site 1

Depth(m)	Soil description	STP blow count per 300 mm	Total unit weight (gr/cm^3)	Undrained Shear Strength (Kg/cm^2)	Frictional resistance angle (°)
0-10	silty clay layers with middle layers of sand	22	1.45~1.55	0.12~0.20	18~20
10-20	silty clay layers with middle layers of sand	24	1.50~1.60	0.15~0.25	18~20
20-30	Silty clay	17	1.60~1.70	0.20~0.30	15~17
30-40	Silty clay	30	1.65~1.75	0.25~0.35	15~17
> 40	Silty clay	> 50	1.70~1.80	0.40~0.60	16~20

Based on test results, which was up to 28 m depth, number of SPT blow counts per 300 mm of penetration was 20 and afterward reached 30. Also, CPT results showed that in depths greater than 20 m, pile point resistance was about 60 kg/cm2 and pile friction resistance ranged between 2 and 4 kg/cm2.

2.2. Pile Configuration

Field behavior of helical piles was studied by assessing the piles with one, two and three helixes and with 6m length. Also, effect of post-grouting on the behavior of piles was evaluated using piles with shaft diameter of 117 mm and helix diameter of 250 mm. The configurations for different piles considered for the helical pile load test program are summarized in Table 2. Typical test helical piles configurations and the double helix pile used in this study are shown in Figures 3&4, respectively.

Table 2.
Summary of pile configurations

	No. of helices	Shaft diameter, (mm)	Helix diameter (mm)	Prototype anchor depth (m)
pile	1	117	250	6

2.3. Pile Installation and Test Set-up

The helical pile shaft is turned into the ground by application of torsion using a truck mounted auger or hydraulic torque motor attached to a hydraulic machine. The principal component of the equipment is the hydraulic torque motor, which is used to apply torsion (or rotational force) to the top of the helical pile. Helical piles should be installed with high-torque, low-speed torque motors, which allow the helical bearing plates to advance with minimal soil disturbance. Torque motors commonly used for helical pile installation produce a torque of 6,000 to 100,000 Nm or higher. The connection between the torque motor and helical pile should be in-line, straight, and rigid, and should consist of a hexagonal, square, or round adapter and helical shaft socket. This is typically accomplished using a manufactured drive tool. The central shaft of the helical pile is best attached to the drive tool by a high-strength, smooth tapered pin with average diameter equal to the helical pile bolt hole size. A very basic, convenient and useful aspect of most helical piles is that the capacity can be verified from the installation torque. The relationship between capacity and torque is experimentally and theoretically well-established. A torque indicator should be used to measure torque during installation. Most torque indicators are capable of measurements in increments with a precision of 500 to 1,000 Nm. A photograph showing installation equipment is shown in Figure 5.

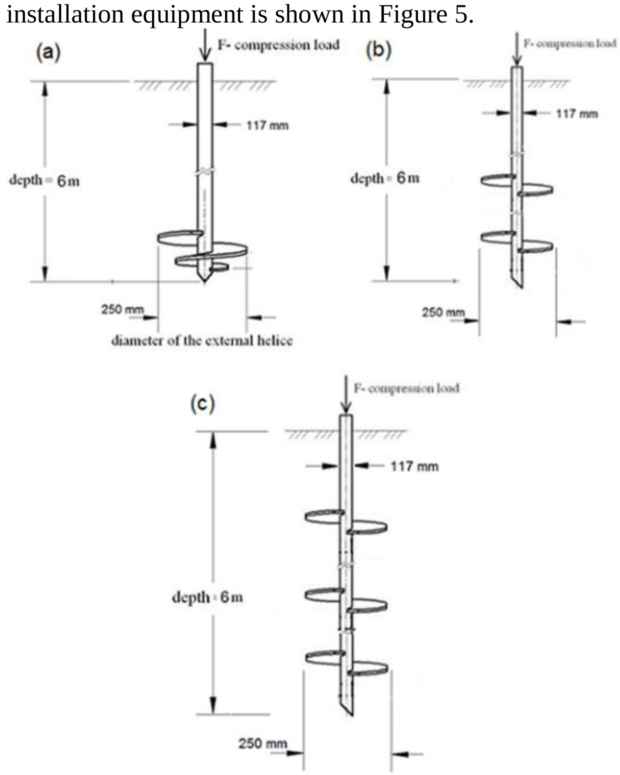


Figure 3. Typical test helical piles configurations, a) single helix pile; b) double helix pile; c) triple helix pile

Installation begins by attaching the helical pile lead section to the torque motor using a drive tool and drive pin. The lead section should be positioned and aligned at the desired location and inclination. Next, axial force should be applied to push the pilot point into the ground, then plumpness and alignment of the torque motor should be checked before rotation begins then the pile should be advanced into the soil in a smooth, continuous manner at a rate of rotation typically less than 30 rpm. Installation torque and depth should be recorded at selected intervals. Constant axial force should be applied while rotating helical piles into the ground. Helical piles are generally advanced until the termination criteria are satisfied. Termination criteria for helical piles involve achieving the required final installation torque and obtaining the minimum depth [3].

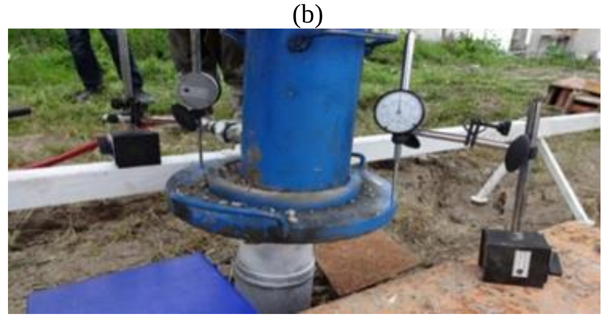
Figure 4. The double helix pile used in this study

Figure 5. Helical pile installation equipment

The axial compression load tests were carried out in accordance with ASTM standards D 1143-07. Since the main objective of the load tests was to determine the ultimate bearing capacity of the pile, Procedure A (Quick Test) was adopted for all tests wherein numerous small load increments were applied and maintained constant over short period of time intervals[16]. A photograph showing axial compression load test is shown in Figure 6(a,b&c).

(a)

(b)



(c)

Figure 6. Test Set-up(a,b,c)

2.4. Post Grouting

The primary purpose of grouting is compaction of the soil under and around the pile point. In grouting procedure, cement grout is placed around the shaft to fill the annulus created by the anchor connection couplings while being screwed into the soil to make the shaft connecting the anchors more stiffer [17]. Grout is the most important component in grouted helical piles.

Ideal grout have a fine aggregate, such as silica fume (5-20% by weight), to increase the density and flow ability of the grout and is liquid enough to flow down around the pile shaft and should bonds to the anchor shaft so that skin friction capacity can be achieved. Also, the grout should be compatible with the soil chemistry with regards to acidity, conductivity and the presence of sulfates and chlorides.

In order to perform grouting, holes were made on the pile body. Using several separate grout flow paths provide a system that does not stop grouting operation. The grout is usually a mixture of water and cement with a water to cement ratio (W/C) of 0.4 to 0.55. Portland cement type II was thoroughly mixed with water in a colloidal mixer. Grout was compressed using simple pump. In a condition that the pile provides an adequate reaction for the frictional resistance, pressure at the top of the pile can be achieved at 311 psi. A typical view of grouting operation is shown in Figure 7.

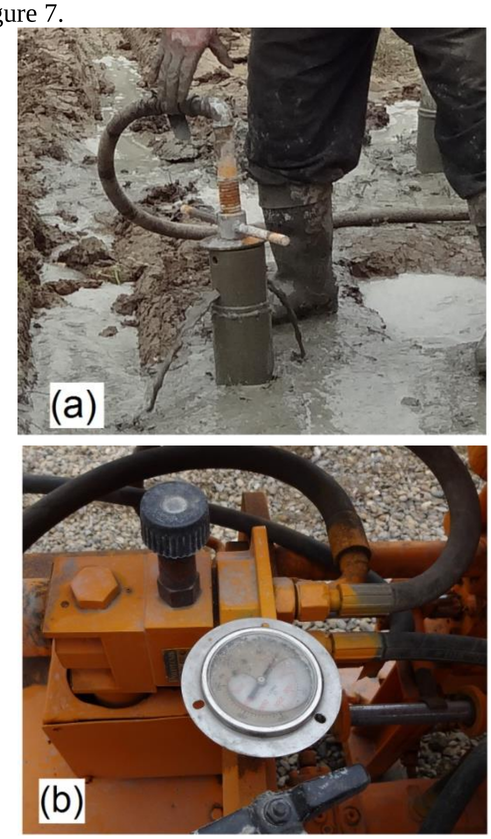


Figure 7. a) Helical piles grouting operation b) Grouting pump

3. Review of methods of interpretation of the load test results

The methods of interpretation of the load test results depend on the limit or ultimate load which can be predicted by mathematical or graphical techniques. So determining the limit or ultimate load as accurate as possible is very important. There are six methods that can be used to predict the pile capacity from load-movement records of static loading tests. A summary of these methods is presented in this section.

1-Davisson Offset Limit method: Based on a method proposed by Davisson in 1972, the pile load settlement curve is drawn to a suitable scale, so that the line shows the relationship between the load and shortening of an elastic free axially loaded column.

The offset limit load straight line is plotted parallel to the elastic line to intersect the load movement curve. Where OC is given by:

$$\text{Offset}=4+b/120 \qquad (1)$$

Where, b is the pile diameter in mm.

A basic benefit of this method is that the actual limit line can be plotted on the load movement diagram before beginning the test

2-Brinch Hansen's method: The load that gives four times the movement of the pile head as achieved at 80% of that load can be predicted directly from the load-movement curve, but it is more accurately determined in a plot of the square root of each movement value divided by its load value and drawn against the movement.

After calculating the slope C1, and y-intercept C2 of the drawn line, the ultimate failure load Qu is obtained as follows:

$$Qu = 1 / (2\sqrt{C1C2}) \qquad (2)$$

In many cases, the calculated 0.8 Qu doesn't intersect the observed curve, because it is more than the test load. The 80% criterion determines the load-movement curve for which the Hansen plot is a straight line throughout.

The equation for this calculated curve is shown in Eq. 4 which gives the relation for the calculated curve.

$$Q = \sqrt{S} / [C1\ S + C2] \qquad (3)$$

Where: Q = applied load, and S = movement. When using the Hansen 80%-criterion, it is important to check that the point (0.80 Qu, and 0.25 S) lies on or near the measured load-movement curve.

3-Chin-Kondner and Modified Chin Methods: Chin assumes that the relationship between load and settlement is hyperbolic. In this method, each settlement value is divided by its corresponding load value in vertical axis and the settlement in the horizontal axis. The plotted values almost lie on a straight line. The inverse slope of the straight line indicates Chin–Kondener Extrapolation Limits. This method was used to determine the load-movement curve for which the Chin-Kondner plot is a straight line throughout. The calculated curve is given by the following equation:

$$Q_u = \frac{1}{C_1} \qquad (4)$$

Where:

Q_u = Limit load

C_1= the inverse slope of the straight line

The Chin-Kondner limit load is useful when assessing the results of static loading tests, particularly in conjunction with the values determined according to Davisson's and Hansen's methods.

4-Mazurkiewicz's Method: In this method, the relationship between load and settlement is almost parabolic. A series of equal settlement lines were chosen using equal intervals and the corresponding loads were marked on the abscissa. For the marked loads on the load axis, a 45°line is plotted to intersect with the next vertical line running through the next load point. These intersections almost fall on a single straight line, the intersection of this line with the load axis defines the ultimate load.

5-De Beer's method: In this method, the load–settlement value is drawn on a double logarithmic chart. When the values fall on two approximately straight lines, the intersection of these lines determine the ultimate load.

6-Decourt's Extrapolation Method: This method is applied by dividing each load by its corresponding settlement and plotting the resulting values against the applied load. Slope C1 and y- intercept C2 constants are obtained by linear regression over the apparent straight-line.Decourt's ultimate load is the value at the intersection with the load axis, Decourt's ultimate load Qu can be accurately calculated as the ratio between the y- intercept and the slope of the line as given in Eq. 5.

$$Qu = C2 / C1 \quad (5)$$

4. Results and Discussion

As it is mentioned 6 single- helix, double - helix and triple - helix piles are executed at two sites including clay-silt and sand soil which 3 of these 6 piles were used without grouting and 3 of them were used with grouting. The helix spacing to diameter ratio (S/D) is 1.5 and 3 for double and triple helix piles, respectively. The load displacement curves are shown in Figures 8 to 12 compare the axial compressive load capacities of the piles tested under grouted and un-grouted conditions. The results show that in single- helix pile in silty clay compressive capacity has increased approximately 8% after grouting. Like single-helix piles, pile resistance has increased about 10% in double - helix. But in triple - helix piles the final load has increased about 28% after grouting. The reason is vast disturbance of the soil around the triple - helix piles which showed an increase after grouting due to the influence of slurry in the soil around resistance. Generally load-displacement curves can be divided into three main sections. . The first part is done with displacement of about 2 mm linearly and after that a non-linear components that varied from 35 to 55 mm can be observed.

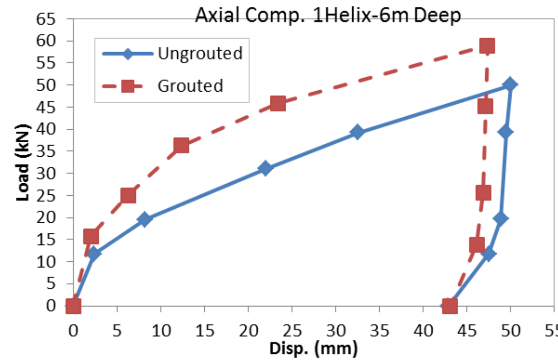


Figure 8. Axial compression load test on piles with one helix in cilty-clay

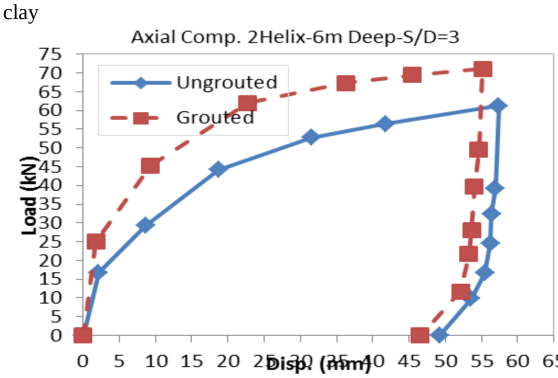


Figure 9. Axial compression load test on piles with two helix in cilty-clay

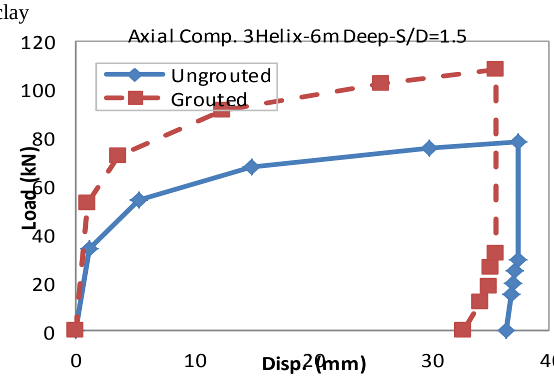


Figure 10. Axial compression load test on piles with three helix in silty - clay

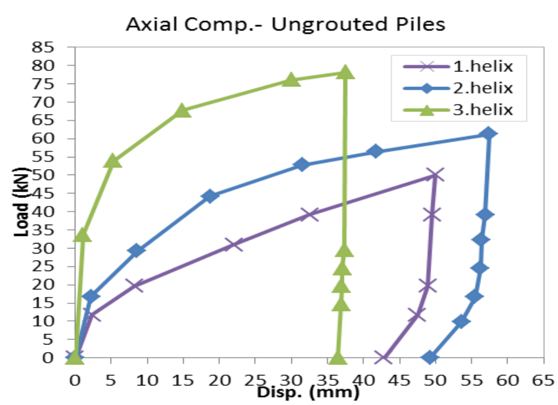


Figure 11. Axial compression load test on ungrouted in silty-clay

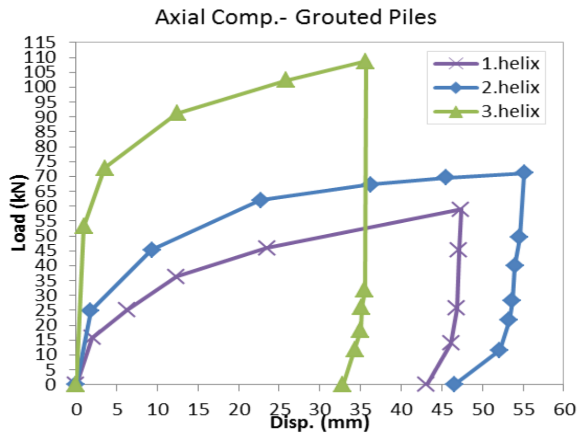


Figure 12. Axial compression load test on grouted piles in cilty-clay

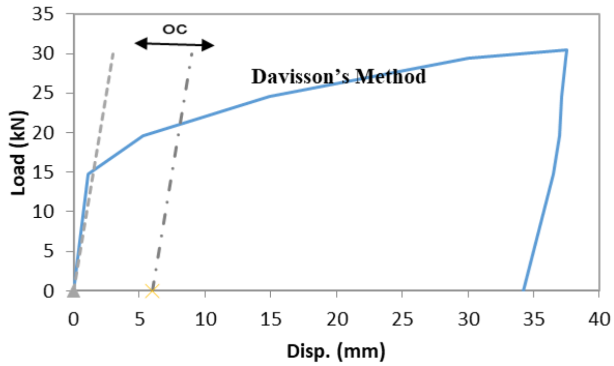


Figure 13. Ultimate failure load according to Davisson For pile no. 5

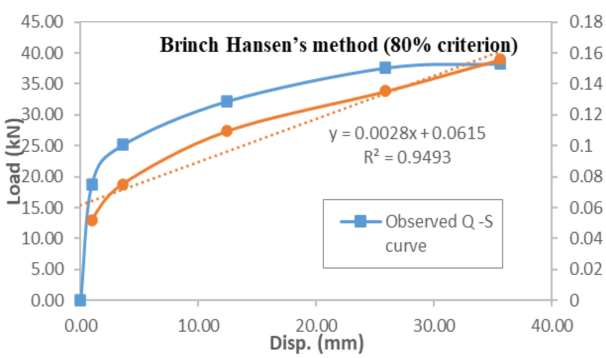


Figure 14. Ultimate failure load according to Brinch Hansen 80% criterion for pile no. 6

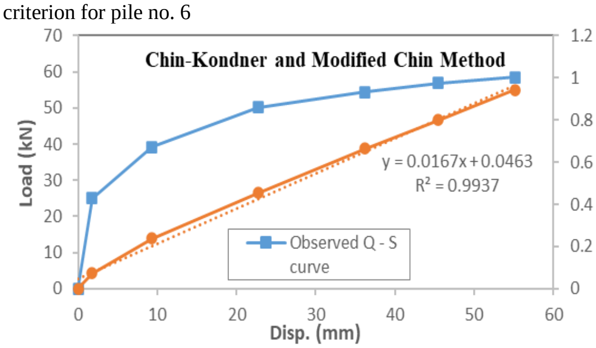


Figure 15. Ultimate failure load according to Chin- Kondner's extrapolation for pile no. 4

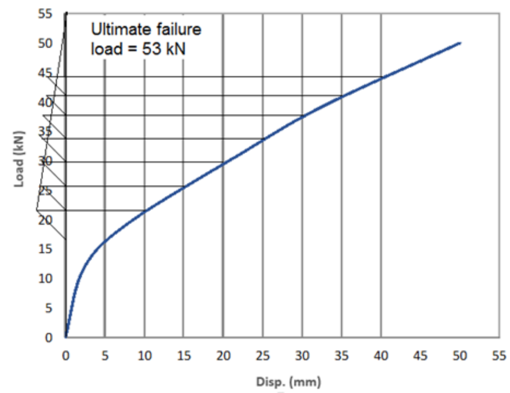


Figure 16. Ultimate failure load according to Mazurkiewicz for pile no. 1

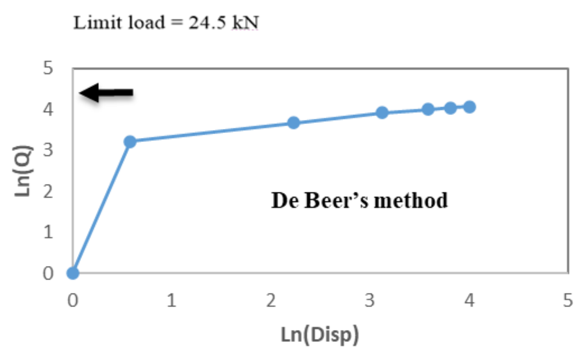


Figure 17. Yielding limit load for pile no. 3

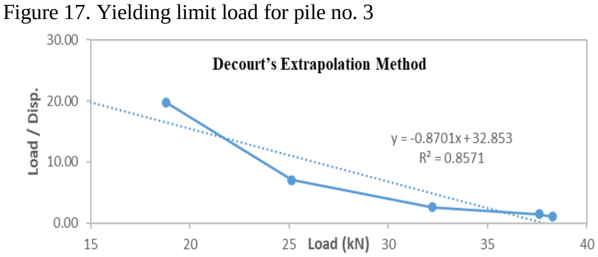


Figure 18. Decourt's Extrapolation Method for pile no. 6

It can be seen from the curves that in grouted piles in clay soil have less place shift than piles without grouting that shows grouting operation has caused an increase in pile resistance. In clayey soil none - grouting triple-helix piles bearing capacity is more than single- helix piles and double - helix piles, the reason is the cylindrical performance of triple-helix piles and single- helix piles and double - helix piles have single performance that this reason caused this that increasing the number of helix results to increase the loading capacity and stiffness of the pile. In piles due to shallow depth and low levels of tension there is no expected pile frictional resistance impact but when the grouting is done the resistance increases due to adhesion increase. Among grouted piles, grouting was more effective in triple-helix piles because the soil of the upper part is more scrabbled and grouting has filled the cracks and with a further adhesion increase gives greater load capacity. Generally it can be said that grouting operation in clay has dense performance and due to lack of penetration in clay loading capacity did not increase.

Furthermore, as it can be seen, when comparing between the load-displacement curves for grouted and un-grouted helical piles, the data showed that both types of piles had a similar performance and the trends of both types of grouted and un-grouted axial compression load tests curves are the same but grouted piles show greater axial compressive strength.

The grouted helical piles deflected less at the failure load than the ungrouted helical piles. This stiffer response is also very useful in structural support applications.

4.1. Estimation of Ultimate Load from Pile Load Test

A database of six axial static loading tests on single, double and triple helix helical piles under grouted and un-grouted conditions was compiled. The ultimate load capacity Qu for each pile test was predicted using the six different interpretation methods stated in section 2.5 that are used in the evaluation of the pile load test. Figures 13 to 18 show typical ultimate failure load predictions according to these methods. A summary of predicted ultimate failure loads is presented in Table 3 and Figures 19 to 20.

4.2. Choice of evaluation method

Choosing the best criteria for pile axial load capacity is quiet complicated since this is mostly depended on engineer's experiences and mechanism of failure. One of the conservative methods is Davisson's method.

Brinch-Hansen method is in good agreements with real ultimate resistance of pile which gives about 80% of ultimate load calculated based on static loading test.

Chin-Kondner and Decourt methods both are using extrapolation for determination limit load values, hence, the ultimate load gained from both is asymptotically.

As a straight engineering rule never to interpret static loading test result to gain ultimate load larger than the test load. Therefor allowable load should not calculate by dividing the limit loads obtained from Chin-Kondner's and Decourt's methods by a factor of safety.

The most conservative method is Mazurkiewicz method which its results are less than others methods including Davisson, Hansen, Chin, and Decourt methods. This method is easy to use and is more reliable especially for piles loaded near failure.

Table 3.
Summary of predicted ultimate failure loads

		Davisson	Hansen	Chin	Mazur	De Beer	Decourt	Test Site Load
		Qu(kN)	Qu(kN)	Qu(kN)	Qu(kN)	Qu(kN)	Qu(kN)	Qu(kN)
1 Helix	Ungrouted	22.5	54.55	53.19	53	12.18	53.7	50
	Grouted	32.5	73.7	63.7	61	16.44	61.98	58.9
2 Helix	Ungrouted	19.5	49.5	50.5	47.5	9.97	49.65	47.09
	Grouted	38	58.15	59.9	59	24.5	58.43	58.44
3 Helix	Ungrouted	21	29.5	31.05	31	14.8	29.8	30.4
	Grouted	28.5	38.1	39.22	39.5	18.17	37.75	38.29

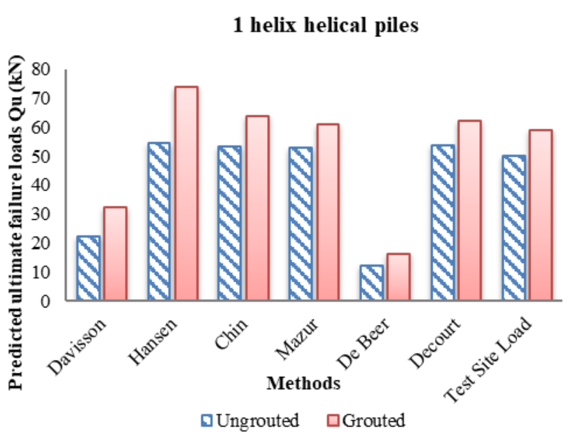


Figure 19. Summary of predicted ultimate failure loads for 1 helix helical piles

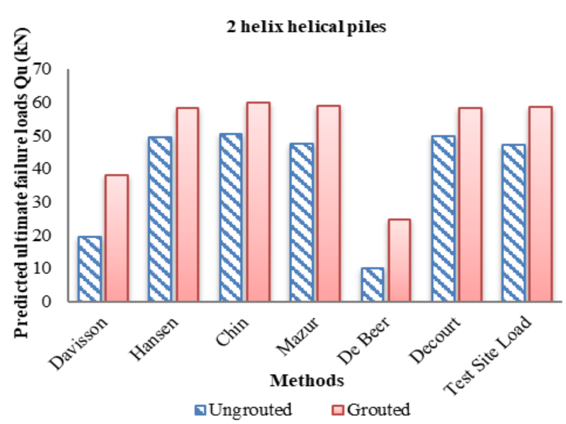


Figure 20. Summary of predicted ultimate failure loads for 2 helix helical piles

Shortcomings of De Beer's method are mentioned earlier. Hansen's 80%-criterion, Chin's and Decourt's extrapolation methods using the latter part of the load-movement curve and could extrapolated beyond the maximum load applied.

One of the advantages of Decourt's method is that a plot can be drawn while the static loading test is performing which allow the user to eyeball the projected capacity directly once a straight line plot starts to develop.

While in Chin-Kondner's method, if during the static loading test, a weakness in the pile develops, the curve would deviate from straight line. Hence it is significantly desirable plotting the readings as per Decourt's method as the test progresses. Finally these two methods estimate ultimate failure load reasonably.

5. Conclusions

In this study, helical piles behavior was evaluated. Furthermore, the effect of grouting on the load capacity of these piles was assessed and finally the limit load was obtained using methods presented. The results showed that:

For single, double and triple helix piles with various lengths, the ultimate load at the site was 50, 47.09 and 30.4, respectively.

It was seen that in all three kinds of piles, grouting increased the load capacity of piles. This increase was 17, 24 and 26 for single, double and triple helix piles, respectively.

The increase of load capacity due to grouting for double helix piles was more than other piles. Increase of resistance of triple helix piles was less than double helix piles due to soil disturbance around helixes in triple helix piles. Compression capacity in grouted helical piles increases due to the mobilization of skin friction at the grout/soil interface.

According to various limit load methods evaluation, it was concluded that the values for three methods of Chin, Decourt and Mazurkiewicz were close to the site values.

In summary, the grouted helical pile is a creative new development in anchored helical piles, which provides a great improvement in compressive load resistance further resistance against corrosion. It provides the design engineer with an excellent new foundation system for the resistance of uplift, as well as, compressive loads.

Furthermore, it is difficult to make a choice of the best axial load capacity criterion to use, because the preferred criterion depends heavily on one's experience and conception of what constitutes the ultimate resistance of a pile to failure. The most convenient methods that were applied and gave reasonable results are Chin's, Mazurkiewicz's, Decourt's, and Brinch Hansens methods. However, Davisson's, and DeBeer's methods needs the pile to be loaded for failure to be applicable.

References

[1] Perlow, J. M. (2011). Helical pile acceptance criteria, design guidelines, and load test verification. In *Geo-Frontiers 2011: Advances in Geotechnical Engineering* (pp. 94–102).

[2] Sakr, M. (2010). High capacity helical piles – A new dimension for bridge foundations. In Proceedings of the 8th International Conference on Short and Medium Span Bridges, Niagara Falls, Canada.

[3] Perko, H. A. (2009). Helical piles: A practical guide to design and installation. John Wiley & Sons.

[4] Zhang, D. J. Y., Chalaturnyk, R., Robertson, P. K., Sego, D. C., & Cyre, G. (n.d.). Screw anchor test program (Part I): Instrumentation, site characterization and installation. Edmonton, AB.

[5] Zhang, D. J. Y., Chalaturnyk, R., Robertson, P. K., Sego, D. C., & Cyre, G. (n.d.). Screw anchor test program (Part II): Field test results and design implication. Edmonton, AB.

[6] Merifield, R. S. (2011). Ultimate uplift capacity of multiplate helical type anchors in clay. Journal of Geotechnical and Geoenvironmental Engineering, 137(7), 704–716. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000478

[7] Basu, P., & Prezzi, M. (1969). Design and applications of drilled displacement (screw) piles. https://doi.org/10.5703/1288284314278

[8] Rao, S. N., & Prasad, Y. V. S. N. (1991). Behavior of a helical anchor under vertical repetitive loading. Marine Geotechnology, 10(3–4), 203–228. https://doi.org/10.1080/10641199109379892

[9] Cerato, A. B., & Victor, R. (2009). Effects of long-term dynamic loading and fluctuating water table on helical anchor performance for small wind tower foundations. Journal of Performance of Constructed Facilities, 23(4), 251–261. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000013

[10] El Sharnouby, M. M., & El Naggar, M. H. (2012). Field investigation of axial monotonic and cyclic performance of reinforced helical pulldown micropiles. Canadian Geotechnical Journal, 49(5), 560–573. https://doi.org/10.1139/t2012-017

[11] Liu, H., Zubeck, H. K., & Schubert, D. H. (n.d.). Finite-element analysis of helical piers in frozen ground. Journal of Cold Regions Engineering, 21(3), 92–106.

[12] Weech, C., & Howie, J. A. (2012). Helical piles in soft sensitive soils – a field study of disturbance effects on pile capacity. In VGS Symposium on Soft Ground Engineering.

[13] Sakr, M. (2011). Installation and performance characteristics of high capacity helical piles in cohesionless soils. DFI Journal: The Journal of the Deep Foundations Institute, 5(1), 39–57. https://doi.org/10.1179/dfi.2011.004

[14] Tsuha, C. H. C., Aoki, N., Rault, G., Thorel, L., & Garnier, J. (2012). Evaluation of the efficiencies of helical anchor plates in sand by centrifuge model tests. Canadian Geotechnical Journal, 49(9), 1102–1114. https://doi.org/10.1139/t2012-064

[15] Abdelghany, Y., & El Naggar, M. (2014). Full-scale field investigations and numerical analyses of innovative seismic composite fiber-reinforced polymer and reinforced grouted helical screw instrumented piles under axial and lateral monotonic and cyclic loadings. In Advances in Soil Dynamics and Foundation Engineering (pp. 414–424). https://doi.org/10.1061/9780784413425.042

[16] American Society for Testing and Materials. (2013). Standard test methods for deep foundations under static axial compressive load

(ASTM D1143/D1143M-07). Annual Book of ASTM Standards, 04.08. https://doi.org/10.1520/D1143_D1143M

[17] Vickars, R., & Clemence, S. (2000). Performance of helical piles with grouted shafts. In New Technological and Design Developments in Deep Foundations (pp. 327–341).