The Effect of Installation Torque on The Behavior of Helical Piles under Tension Load Tested in Centrifuge Device

Jaafer A R Jabur[1], Saad F A Al-wakel [2]andMahmood R Mahmood[3]

[1]student PhD in Geotechnical Eng. Civil Eng. Dept. University of Technology Iraq. [2]Assit. Prof. Civil Eng. Dept. University of Technology-Iraq

[3]Prof. Dr. Civil Eng. Dept University of Technology-Iraq

Abstract. Screw piles have good compression and tension capacity and can be used for different soil strata under and over water. As well as to the screw pile has low cost and quick installation comparing with other piles. Screw pile foundations are also referred to as torque piles helical anchors, screw anchors, piers, or helical piles. To makethe behavior of stress-strain of the soil in the centrifuge similar to that exists in the sitea centrifuge modelling must be considered.New centrifuge device for installation and testing screw pile models is designed and manufactured with different velocities depending on the value of N (gravity scaling factor) and applying compression, uplift and inclined loads during rotation and control them electronically. The new installation system for helical piles used in this device is to install each pile with different torque from other depending on its capacity. The relative density (R.D) of sandy soil used in this study is 55% and the helical pile models with 40 mm diameter, the spacing ratio (S/D) of 1, 1.5, and 3 and different number of helices of (one and two helices). All tests of screw pile models are performed in centrifuge device at 10-g undertensionload. The installation torque causes a soil disturbance and this disturbance increases as the installation torque increases. For the cylindrical failure mechanism, the reduction percentages of the uplift capacity of the helical pile with double helix S/D =1 are 15% and 26 % while it is about 10% and 21% in the case of S/D =1 respectively.

Keywords: gearbox,helical pile, centrifuge device, installation torque

1. Introduction

Screw piles were used as foundations for bridges and buildings built on wet or weak soil. They had limited use in the 19th and early 20th century, where the installation of a screw pile was complicated without mechanical technique. During the 1960s, the technology of screw pile manufacturing and installation is developed. Thus, screw piles become very important to the designers and engineers due to high resistance for both tension and compression loads. Due to this evolution of technology, the use of a screw pile had increased widely.[1]. The uplift capacity of the helical pile is influenced bythe installation torque which is affected by number of factors such as diameter and number of helices, pile configuration,accuracy of torque measurements and soil conditions. Pile configurations such as pitch size, size and shapeof shaft are some parameters that affect the installation torque[2]. Inthe field, an empirical factor (kt) as proposed by [3] wasused to show the correlation between helical pile capacity and installation torque, which based on the shaft geometry only. Reference [4] presented a theoretical relationship to estimate theupliftcapacityof deep helical piles in cohesionless soil from the installation torque. Many studies have indicated that helical pile installation causes a disturbance in the soil.in this contest, Reference[5] confirmed that a significant disturbance occurs within the cylindrical failure zone of the helical pile; the disturbance influence can be predicted by relating the disturbed properties to the in-situ properties. The aim of this study is explaining the effect of installation torque on the uplift capacity of helical piles.

2. Previous study

Reference [4] performed centrifuge anchors model tests to validate a relationship between uplift capacity and installation torque of deep screw anchors in the sand. Besides, to explain the correlation between the installation process and the number of plates on the screw pile uplift capacity with multi-helix sand [6]. Twelve small-scale models were tested in dry NE34 Fontainebleau silica sand sample with a relative density equal to (56% and 85%). The wing ratio value used equal to 3 and the spacing ratio (space between any two helices) equal to 3. This model was tested at the "French Institute of Science and Technology for Transport, Development and Networks" (IFSTTAR) in France. The results indicate that the soil disturbance caused by the screw pile installation and effect on the uplift resistance of helical pile and the diameter of helix and sand relative density affects the efficiency of the third and second top plates of the triple-helix pile installed in sand.

Reference [7] present a series of tests on single-helix anchors under tension loading in the IFSTTAR “French Institute of Science and Technology for Transport, Development and Networks” geotechnical centrifuge device. The centrifuge modeling experiments were performed in dry sand (reconstituted HN38 Houston) samples, with a relative density equal to 99%. This paper aims to investigate: (i) the anchor installation process caused the disturbance of the soil; (ii) the grain size of soil effect on the joined behavior of the plate bearing capacity and the shaft frictional resistance of screw anchor models in the sand.

3. Centrifuge modelling system

The centrifuge system used in this study consists of two axes as shown in figure 1; the first axis represents a shaft with a fixed base and restricted by a steel beam from the top to ensure the stability of rotation. The second axis represents the arm of the centrifuge system whichis connected to the first axis and rotated by the main gearbox of type SEW with different velocities depend on the value of the scaling factor (N). The second axis consists of two parts; the first part with a length of 1.70 m permits passing the wires that used to supply the electricity to the indicator of the load cell, first and second gearboxes.

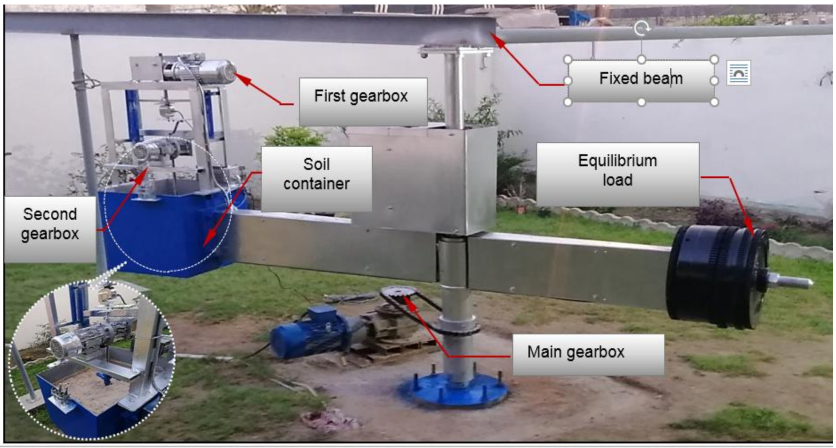

Figure 1. The centrifuge system.

The second part has a length of 1.70 m and used for the equilibrium purpose during rotation of the centrifuge system. The main gearbox rotational speed is 200 rpm which controlled by an AC Drive via control board. During the installation stage, the helical pile rotates by the second gearbox, while the vertical load is applied to the helical pile via the first gearbox. The control board transfers the orders to the centrifuge system, and consists of; the AC Drive which is used to control the velocity rate of rotation of the centrifuge system, and the electrical relays which is used to transfer the signal to the first gearbox to apply the compressive loads.

4. Scaling Laws

The object of scaling laws used to ensure stress similarity between the model and corresponding prototype. If the soil in prototype with density ρ, at depth h_p, the vertical stress σ_{vp} is (p: refers to prototype):

$\sigma_{vp} = \rho\ g\ h_p$ … (1)

Therefore, if the density of the soil in the prototype is the same as that in the model according to the theory of centrifuge modeling then, the vertical stress (σ_{vm}) in the model acting at depth h_m is given by (m: refers to model):

$\sigma_{vm} = \rho\ N\ g\ h_m$ ...(2)

Thus:

$\rho\ N\ g\ h_m = \rho\ g\ h_p$… (3)

$h_m / h_p = 1/N$ ...(4)

The scale factor N (model to prototype) for linear dimensions is (1: N). Since the model is a linear scale representation of the prototype, then displacements will also have a scale factor of 1: N. therefore, that strains have a scale factor of 1:1 and so the part of the soil stress strain curve mobilized in the model will be identical to the prototype. The scaling relation explains in table 1.

Table (1). Described scaling relation

Quantity	Prototype	Model
Length	N	1
Area	N^2	1
Volume	N^3	1
Velocity	1	1
Acceleration	1	N
Mass	N^3	1
Force	N^2	1
Energy	N^3	1
Stress	1	1
strain	1	1
Mass density	1	1

5. Soil characteristic

The soil used in this study is nature silica sand with poorly graded according to USCS (unified soil classification system) withrelative density of 55% (dry unit weight of 17.0kN/m^3).The sieve analysis according to standard test method for the analysis of the practice-size of soil according to (ASTM D422-02) Specifications is performed. The mechanical and physical properties of the sand used in the centrifuge tests are shown in table 2.

6.Screw pile models

The screw pile model is manufactured from central steelshaft with (20mm) diameter and (1.5mm) thickness. This shaft is welded with plate (helix) with 40mm diameter and (2mm) thickness. The plate helix is welded on a steel shaft with different distances depending on the spacing ratio (the percent of the space between two helicestohelix diameter).The value of pitch distance equal to 6 mm (0.3d). The dimensions and configurations of screw pile modelsare shown in figure 2.

Table 2. The mechanical and physical properties of the soil used

Index property	Sandy soil	Specification
Grain size analysis		ASTM D422-2001[8]
D10(mm)	0.12	
D30(mm)	0.17	
D60(mm)	0.27	
Cu(Coefficientof uniformity)	2.25	
Cc(Coefficientof curvature)	0.89	
Maximum dry unit weight (kN\m^3)	19.5	ASTM D4253-00[9]
Minimum dry unit weight (kN\m^3)	14.4	ASTM D4254-00[10]
(ϕ peak)^0	41	
(ϕ critical)^0	31	
Specific gravity	2.65	ASTM D854-00[11]

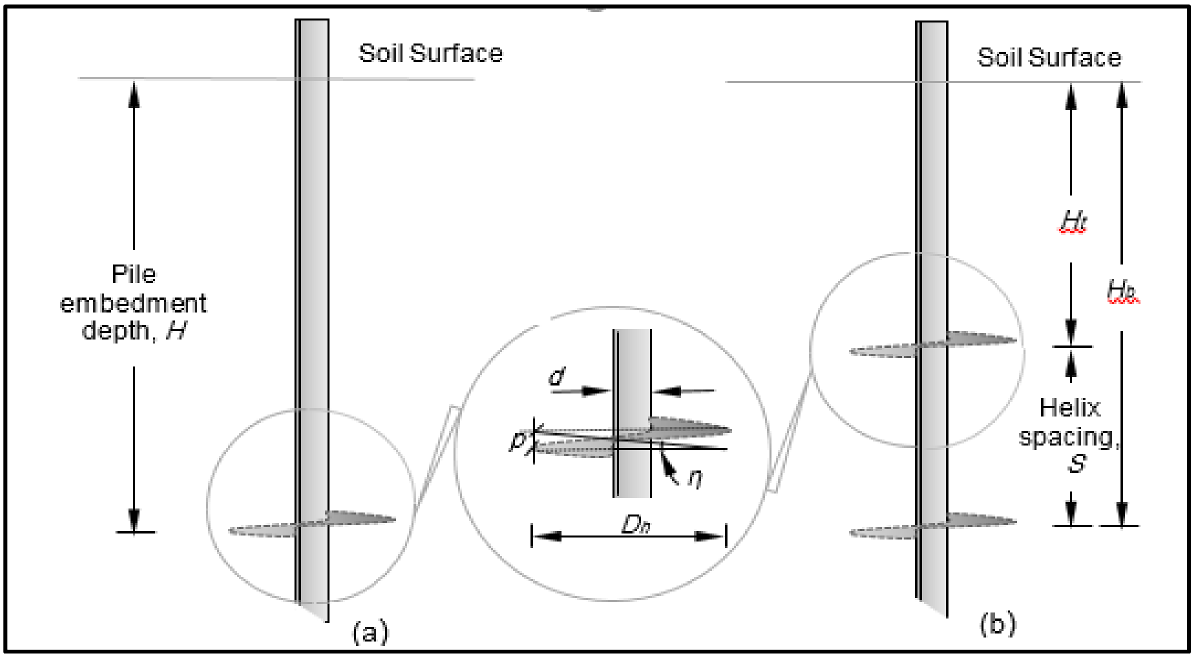

Figure 2. The dimensions and configurations of screw piles models.

7. Installation of screw piles

Most previous studies about screw pile installation used a similar installation process for helical piles despite being small scale model or in field helical pile, and this way of installation is not logical because each helical pile has different installation torque depends on its bearing capacity, therefore a different procedure is done in the present study through sequential theoretical calculations.The model of piles is installed into the soil with a procedure that involves the advancing the helical pile through the utilization of a hydraulic motor [12]. The penetration of helical pile into the soil via rotation occurs through applied the torque at the top of the pile shaft[13]. Reference [14] stated that, in the absence of precise installation procedure, the installation torque readings should be used with caution and may only be used to assess the installation qualitatively. Therefore, the present study adopted a precise procedure for the installation process considers all aspects of the helical pile geometry and soil properties. Initially, the ultimate capacity of the helical pile is predicted theoretically by [15] equation. The parameters of the equation used were according to the failure mechanism (cylindrical shear failure or individual bearing failure) and failure condition (shallow or deep foundation). The followed step the screw pile capacity as a direct correlation with installation torque for a 1-g model of equation (5) as suggested by [16], used as a guide for the preliminary determination of installation torque from capacity

$$\left[\frac{Q_u}{\gamma AH}\right] = 2\left[\frac{T}{\gamma AHp}\right]^{(1.1)} \ldots. (5)$$

where Q_u is the value of helical pile bearing capacity (kN), γ is the soil unit weight(KN/m^3), A is the surface area of helix(m^2), H is the embedment depth of screw pile (m), T is the value of installation torque (kN.m) and p is the value of pitch distance of helix (m). Based on the mechanical properties of the second gearbox as given in figure 3, the installation speed rate of rotation is specified according to the counterpart torque at 10-g for some models of piles, as shown in table 2. The speed rate of rotation was kept constant during the installation process of helical pile to be consistent with a vertical movement of one time the value of pitch of the helical pile helix per revolution, this methodology recommended by previous researchers [14] and [6]. The vertical movement rate of helical pile per revolution should be higher than 0.85 times the pitch to reduce ground disturbances during installation [14]. The penetration rate of helical pile is different with the different values of pitch. For example, the helical piles with a pitch of 6 mm penetrate the soil at a vertical movement rate of 6.0 mm/revolution.The details of first and second gearboxes used in installation processare shown in table 3(a),(b). Figures 4 and 5display the first and second gearboxes respectively.

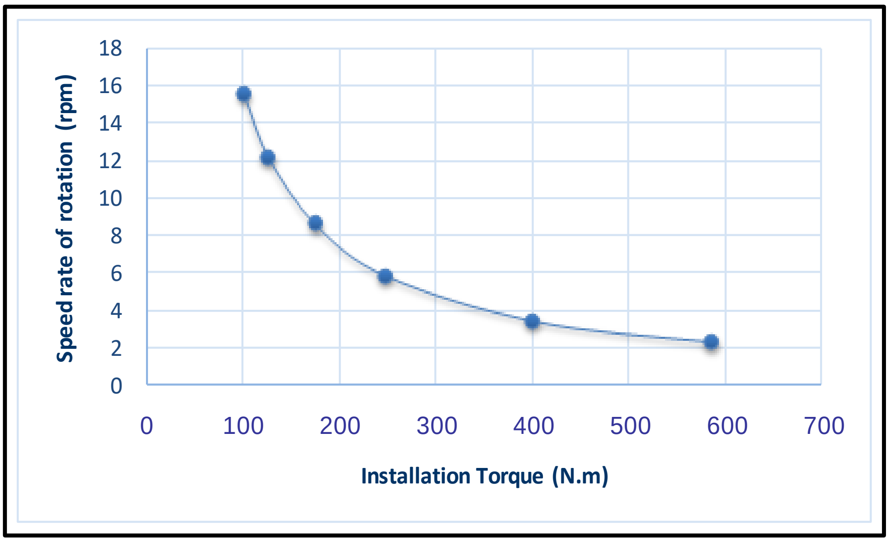

Figure 3. The relationship between speed rate of rotation - torque.

Table 3(a),(b): The details of first and second gearboxes respectively.

a

Description	value
Power	0.5 HP
rpm (angular velocity)	16
I (conversion ratio)	1/100

b

Description	value
Power	0.25 HP
rpm (angular velocity)	25
I (conversion ratio)	1/80

Figure 4. The first gearbox.**Figure 5.**The second gearbox.

8. Preparation bed of soil

Preparation of soil process inside container is done by dividing the container into five layers with thickness equal to 100 mm for each layer. The required amount of soil for a predetermined thickness is placed in the container and compacted by using a vibration tool to satisfy a dry density equal to 17.0 kN/m^3 with relative density 55% according to the test. Thedimensions of container are 0.5m length, 0.5 m width, and 0.6 m height

9. Testing procedure

The following steps can be described the procedure of testing for screw pile models:

- Preparation of soil inside container in technique which is shown previously in this study with density depends on the RD of the soil.
- The screw pile model is fixed using the shaft of the second gearbox to ensure that the screw pile model is staying vertical during the penetration of the soil
- Operating the second gearbox with a specific value of rotation speed (the range of rpm is 3 to 20) depends on the value of the screw pile torque.

- The horizontal shaft of the first gearbox goes down with vertical movement, v of (0.85 pitch < v < 1.15 pitch) per revolution according to the British Standards Institution Code of Practice (BS 5918:1980) until it become in contact with the shaft of the second gearbox. The whole operation (rotation of second gearbox and descent of the first gearbox will make the screw pile models penetrate the soil).
- After finishing the screw pile installation process, the horizontal shaft of the first gearbox is lifted to put load cell between this shaft and the shaft of the second gearbox.
- Fixing all the units (i.e. load cell, dial gauge and electronic devices) in the required place (load cell is placed between the horizontal shaft of the first gearbox and the shaft of the second gearbox).

- The edges of the cover plate (square steel plate) are painted with siliconto ensure that the soil is not going out from the container during the rotation process of the centrifuge system.
- Rotating the centrifuge device with a specific value of velocity depends on the N value (scaling factor) and controlling this process by a control board.
- Applying load and the direction of movement of the first gearbox which is controlled by a timer relay in the control board.
- Monitoring the test and record the results of the applied load and the settlement of the helical pile by an external electronic device.

10. The Analysis of results and discussion

Many tests of helical pile models are performed to explain the effect of installation torque on the behavior of the helical pile under tension load. Thehelical pile models are tested in centrifuge device at 10-g with diameter of 40 mm, spacing ratio of 1, 1.5, 3 and different number of helices (single helix and double helix) embedded in sand with R.D of 55% are shown in figures below. Each helical pile model is installed with different three value of the installation torque and different value of r.p.m.

In this paper,to predict the uplift capacity of helical piles from the load- displacement curve a5% failure criterion approach is used. A5% failure criterion provides a more reasonable estimationof the uplift capacity of screw piles at practical displacement levels since in many cases, the design controlled by allowable vertical displacement [17].

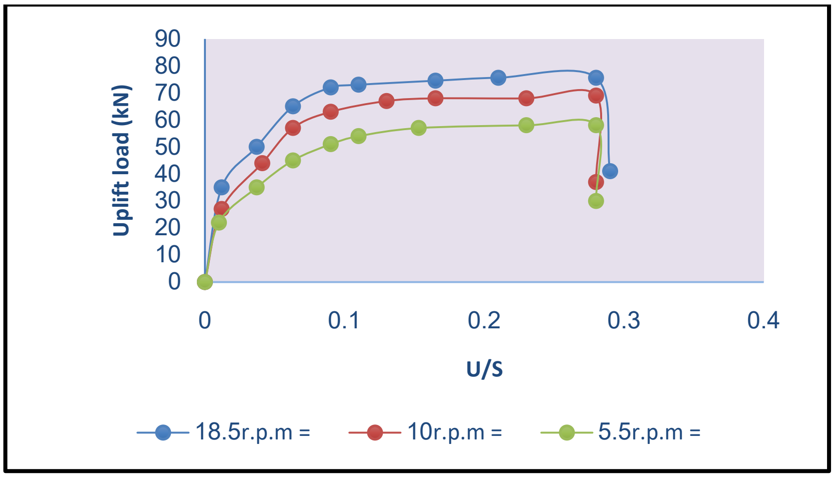

Figure 6. Normalized displacement-load curve for helical piles (2HD40S3).

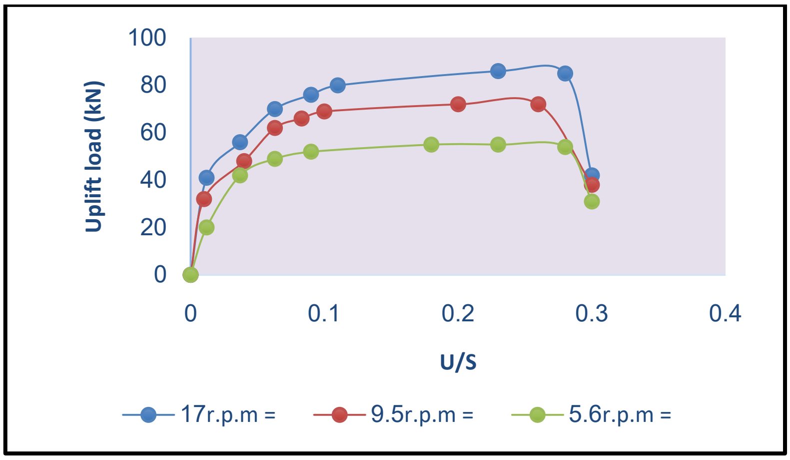

Figure 7. Normalized displacement-load curve for helical piles (2HD40S1).

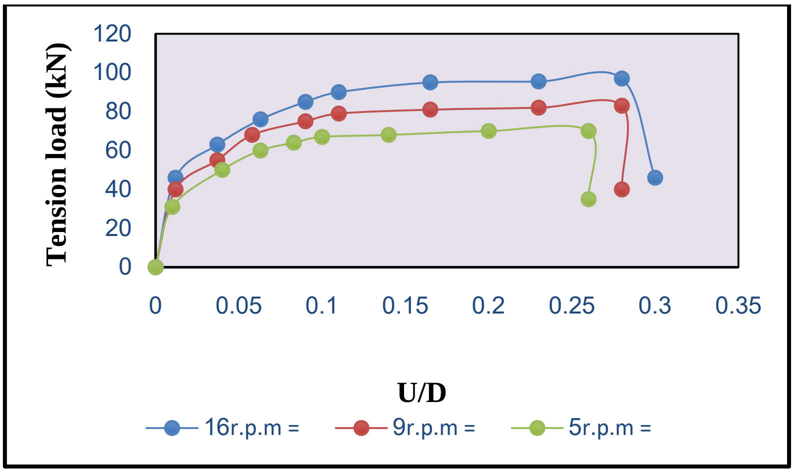

Figure 8. Normalized displacement-load curve for helical piles (2HD40S1.5).

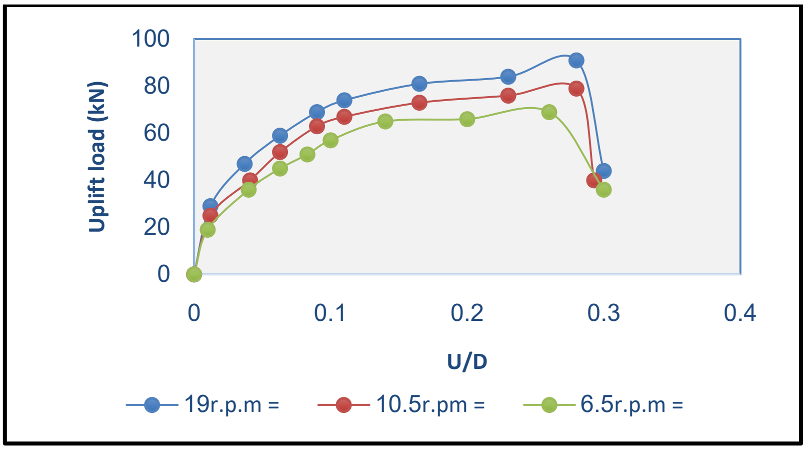

Figure 9. Normalized displacement-load curve for helical piles (1HD40).

Table 4 (a), (b), (c). The results of helical pile(D=40 mm) with different properties under tension load in centrifuge case at 10-g.

a

Model helical pile designation	Failure mechanism	Failure condition	Speed rate of rotation(r.p.m)	Installation torque(N.m)	Load test5% failure criterionQ_u(kN)
2HD40S3	Individual	shallow	18.5	96	59
2HD40S1	cylindrical	deep	17	92	64
2HD40S1.5	cylindrical	deep	16	96	70
1HD40	Individual	deep	19	84	53

b

Model helical pile designation	Failure mechanism	Failure condition	Speed rate of rotation(r.p.m)	Installation torque (N.m)	Load test5% failure criterionQ_u(kN)
2HD40S3	Individual	shallow	10	150	50
2HD40S1	cylindrical	deep	9.5	160	54
2HD40S1.5	cylindrical	deep	9	170	63
1HD40	Individual	deep	10.5	145	48

c

Model helical pile designation	Failure mechanism	Failure condition	Speed rate of rotation(r.p.m)	Installation torque (N.m)	Load test5% failure criterionQ_u(kN)
2HD40S3	Individual	shallow	5.5	250	40
2HD40S1	cylindrical	deep	5.6	260	47
2HD40S1.5	cylindrical	deep	5	270	55
1HD40	Individual	deep	6.5	230	44

The results of the figures (6-9) are shown in table (4 a, b, c). It can be seen that the uplift capacity is influenced by the installation torque of helical pile, where the helical pile capacity decreases as installation torque increases. The reduction percentages of the uplift capacity of the helical pile with double helix S/D =1 (cylindricalfailure mechanism) and diameter of 40 mm due to the increasing the installation torque are 15% and 26 % while the reduction percentages of the helical pile with double helix (S/D =1.5) are 10% and 21% respectively.

The reduction percentages of the uplift capacity of screw pile with single helix (individualfailure mechanism) are 9% and 16% while it is about 15% and 30% in the case of screw pile with double helix (S/D = 3) respectively. Thescrew pile with two helices is affected by installation torque more than the screw pile with one helixbecause the helical pile with single helix causes a low disturbance in soil as compared with double helices. The reason behind the decreasing in the uplift capacity because the increasing in the value of installation torque which causes a disturbance in the soil and this leads to decreasing the uplift capacity of screw pile

11. Conclusions

- Each helical pile has different installation torque depends on its uplift capacity, where theinstallation torque increases by increasing the uplift capacity.
- The behavior of helical pile models is influenced by the installation torque (the upliftcapacity decreases as installation torque increases).
- For the cylindricalfailure mechanism, the reduction percentages of the uplift capacity of the helical pile with double helix S/D =1 are 15% and 26 % while it is about 10% and 21% in the case of S/D =1 respectively.
- For the individualfailure mechanism,the effect of installation torque on the screw pile capacity with double helicesis more than that with single helix,wherethe reduction percentages of the uplift capacity of screw pile with single helix are 9% and 16% while it is about 15% and 30%in the case of double helix respectively**.**

12. Notation

D pile helix diameter
H Embedded depth of helical pile
H_pDepth from surface to bottom helix
H_tEmbedded depth of helical pile
dpile shaft diameter
N scaling factor
P pitch distance
S spacing between two helices
R.D relative density of soil
η The helix angle
1HD40 screw pile with single helix and diameter equal 40 mm
2HD40S3 screw pile with double helix, diameter equal 40mm and spacing ratio equal 3
2HD40S1 screw pile with double helix, diameter equal 40mm and spacing ratio equal 1
2HD40S1.5 screw pile with double helix, diameter equal 40mm and spacing ratio equal 1.5
2HD50S3 screw pile with double helix, diameter equal 50mm and spacing ratio equal 3
2HD50S1.5 screw pile with double helix, diameter equal 50mm and spacing ratio equal 1.5

13. References

[1] Mohajerani, A., Bosnjak, D. and Bromwich, D. (2016) 'Analysis and design methods of screw piles: A review', Soils and Foundations. Elsevier, ***56(1)****, pp. 115–128. doi: 10.1016/j.sandf.2016.01.009.*
[2] Harnish, Jared Louis, "Helical Pile Installation Torque and Capacity Correlations" (2015). Electronic Thesis and Dissertation Repository. 2855.
[3] Hoyt, R. M. &Clemence, S. P. 1989. Uplift capacity of helical anchors in soil. Proc. 12th Int. Conf.Soil Mechanics and Foundation Engineering, Rio de Janeiro, Brazil, ***Vol. 2****: 1019-1022.*
[4] Tsuha, C.H.C. 2007. Theoretical model to control on site the uplift capacity of helical screw piles embedded in sandy soil. Ph.D. thesis, Department of Geotechnics, São Carlos School of Engineering, University of São Paulo, São Car-los, Brazil. [In Portuguese.]
[5] Nagata, M. & Hirata, H. 2005. Study on uplift resistance of screwed pile. Nippon Steel Technical Report, ***(92)****, 73-78.*
[6] Tsuha, C. H. C. et al. (2012) 'Evaluation of the efficiencies of helical anchor plates in sand by centrifuge model tests', Canadian Geotechnical Journal. doi: 10.1139/T2012-064.

[7] Schiavon, J.A., Tsuha, C.H.C., Neel, A. &Thorel, L. 2016b. "Physical modelling of cyclic loading on a single-helix an-chor in sand". to be published in the Proceedings of EuroFuge 2016, Nantes, France.

*[8] ASTM D 422-2002***,** *"Standard Test Method for Particle-Size Analysis of Soils", Reprinted from the Annual Book of ASTM Standards. CopyrightASTM,* ***Vol.4****, No.8.*

[9] ASTM D4253-2000, "Standard Test Method for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table", American Society for Testing and Materials.

[10]ASTM D4254-2000, "Standard Test Method for Minimum IndexDensity and Unit Weight of Soils and Calculation of Relative Density", American Society for Testing and Materials.

[11] ASTM D854-2005, "Standard Test Method for Specific Gravity of Soil Solids by Water Pycnometer", American Society for Testing and Materials.

[12]Aydin, M., Bradka, T. D. and Kort, D. A. (2011) 'Osterberg cell load testing on helical piles', in Geotechnical Special Publication. doi: 10.1061/41165(397)8.

[13]Tappenden, K. M. (2007). "Predicting the Axial Capacity of Screw Piles Installaed in Western Canadian Soils". Edmonton: The University of Alberta.

[14] Perko, H. A. (2009). Helical piles: "A practical guide to design and installation". Hoboken, N.J.: J. Wiley.

[15] Mitsch, M. P., and Clemence, S. P. 1985. "The uplift capacity of helix anchors in sand". Uplift behavior of anchor foundations in soil. Proc, ASCE, New York, N.Y., 26-47

[16] Ghaly, A., and Hanna, A. 1991. "Experimental and theoretical studies on installation torque of screw anchors". Canadian Geotechnical Journal, ***28(3)****: 353-364.*

*[17]Sakr, M., 2011."Installation and performance characteristics of high capacity helical piles in cohesion-less soils". Deep Found. J.(DFI)***5(1)***,39–57.*