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Helical Piles Embedded in Expansive Soil Overlaying Sandy Soil

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Abstract

In this study, the behavior of square helical piles models (5×5) mm^2 embedded in expansive soil bed overlaying a layer of sandy soil was investigated. The sand layer 200mm thickness was compacted into four sub layers in a steel container with diameter 400mm in size. Sandy soil layer was compacted into two relative densities 40% and 80%. The bed of expansive soil 300mm thickness was compacted into six sub layers on sandy soil layer. Model tests are performed with helical pile length 350mm, 400mm and 450mm and with helix diameter 15mm and 20mm. Also, one helix and double helix were used for these piles. Water was allowed to seep from bottom of sandy soil to reach surface of expansive soil through four sand drains around helical pile. This study revealed that the upward movement of helical piles decreases with increasing depth of embedment in the sandy layer, helix diameter and number of helix. The increase in these parameters provides anchorage against uplifting. Helical piles embedded in sandy soil of relative density (40%) have uplift movement more than helical piles of relative density (80%).

Keywords: *Helical piles, Expansive soil, Uplift movement.*

1. Introduction

Foundations on expansive clay are frequently subjected to severe movements arising from moisture changes within the clay with consequent cracking and damage due to distortion. Piles have been used extensively for foundations in swelling soils in order to anchor the structure down at a depth where change in moisture content are negligible, so that movements of the structure are minimized [8]. The modern square shaft helical piles has been refined in shape and size and adapted to high strength low alloy steels to produce the deep foundation system in use nowadays [7]. Helical piles are a factory-manufactured steel foundation system consisting of a central shaft with one or more helix–shaped bearing plate [11]. Any deep foundation, such as helical pile must embed and transfer load through the active zone to stable soil below. The active zone is defined as that zone or depth of seasonal moisture change, sometimes also called the depth of wetting. It is the depth or zone where soil expansion or shrinkage forces adversely affect deep [9]. Foundation is not sufficiently installed below the active zone, as moisture content changes, heave or shrinkage forces will be applied to the deep foundation which may cause it and the structure above to move. The present work aims is to investigate the behavior of model helical piles embedded in expansive soil overlaying a layer of sandy soil. The parameters investigated are the length of helical pile, relative density of sandy soil, number of helix and helix diameter.

2. Material Properties

2.1. Expansive Soil

The expansive soil used in this study was artificially prepared by mixing Iraqi bentonite from Al-Anbar Governorate / Bushayrah Valley, 35 kilometers southern Al-Waleed Military Base from a depth of three and a half meters from natural ground level, with sandy soil. In order to increase the permeability of prepared soil and to facilitate and accelerate saturation process, several trial mixes of bentonite-sand were performed. A ratio of expansive soil to sand of (4/1) was selected. At this ratio, the soil remains highly expansive and its permeability is increased**.** The results of laboratory tests are shown in Table (1). According to the ASTM standard soil classification, the soil is classified as (CH).

2.2. Sandy Soil

This soil is used beneath the expansive soil, which is used as a stable zone, is poorly graded fine clean sand obtained from site in Al-Khalis city. Prior to testing, the sandy soil is dried in laboratory by drying oven at 105 ^{o}C for 24 hr. then sieved on the sieve No.40 to remove the coarse particles. Laboratory tests were conducted on the sandy soil to determine the physical, mechanical, and chemical properties. The results of laboratory tests are shown in Table (2). It should necessary to mention here; that the direct shear test was performed at relative density of 80% which correspond to dry unit weight equal to (15.9) kN/m^3. According to the ASTM standard soil classification, the soil is classified as poorly graded sand (SP).

2.3 Model Piles

Thirty two of steel helical piles with length ranging from 300mm to 450mm and square solid section with dimension (5x5)mm^2 were manufactured from high resisting steel as shown in Plate (1). The experiment program is carried out on single pile with different length, helix diameter and number of helix. Two diameters of helix plate are used 15mm and 20 mm with thickness 3mm.

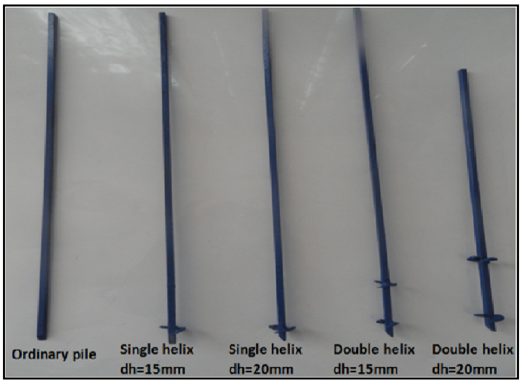

Plate. 1. Different Types of Helical Piles used in this Study.

2.4. Soil Container

Soil steel container was made using a 4mm thickness plate with internal diameter of 40cm and height of 60cm. The base of container is supported by four steel rigid legs and contains a hole of 2.5cm diameter in the center of the bed to connect the valve. This valve is connected to tank to perform the saturation process of soil from bottom to top of soil. The water level in the tank must be usually kept 10cm more than the surface of soil. The containers were painted with two coats of anti-rust paint and two layers leady base to resist corrosion during test period. Plate (2) shows the containers and frames used in testing models.

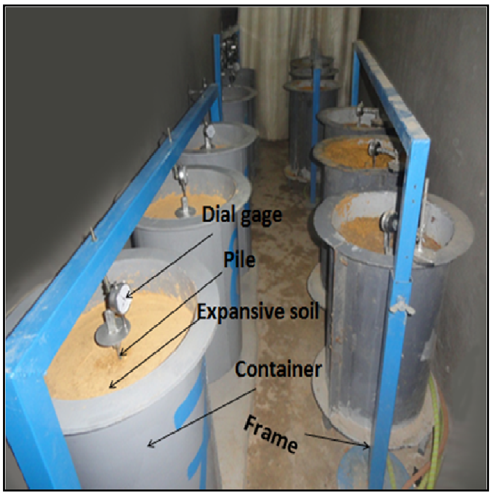

Plate. 2. Frames and Containers Tests.

Table 1,
Physical Properties of Expansive Soil.

Test Name	Standard	Soil Property	Value
Specific Gravity	(ASTM D-854)	Specific Gravity (Gs)	2.78
Atterbeg Limits	(ASTM D-4318)	Liquid limit (L.L)%	102
		Plastic Limit (P.L)%	43
		Plasticity Index (P.I)%	59
Grain size analysis	(ASTM D-422)	Clay %	53
		Silt%	27
		Sand%	20
		Gravel%	٠
		Unified Soil Classification System (USCS)	CH
Standard Compaction and (3/4) Energy of Standard	(ASTM D-1557)	Maximum Unit Weight (kN/m^3)	13.1-13.4
		Optimum Moisture Content (O.M.C)%	18-19
Swelling Pressure	(ASTM D-4526)	Swelling Pressure (kPa)	260

Table 2,
Summary of Sandy Soil Properties.

Test Name	Standard	Property	Value
Grain Size Analysis (Sieve Analysis)	(ASTM D-422)	Coefficient of Uniformity (Cu)	2.5
		Coefficient of Curvature (Cc)	1.23
		Unified Soil Classification System (USCS)	SP
Specific Gravity	(ASTM D-854)	Specific Gravity (Gs)	2.69
Direct shear	(ASTM D-3084)	Cohesion(kN/m^2)	0
		Angle of Internal Friction(φ°)	37

2.5. Testing Procedure

The soil bed was prepared on a dry density of 1.335gm/cm^3 which corresponds to a water content of 2% dry of optimum, from the compaction curve of 3/4 Standard Proctor for the expansive soil. Four sand drains were formed around the pile using thin walled steel tube (10 mm diameter and 300mm length). The sand drains were spaced 50mm from the pile (center to center). The required amount of the oven dried natural sandy soil passing sieve No.40 was prepared at two dry unit weight. The first unit weight is equal to 15.9 kN/m^3 to which represents the dense state. The second dry unit weight is equal to 14.5kN/m^3 which represents loose state. Torque is applied gradually to driven helical pile in the center of surface of expansive soil bed to required depth. Enough care and control should be taken to keep vertical line of helical pile.

4. Results and Discussion

Models tests are performed on steel piles without helix plates and have the same square cross section (5×5) mm^2 of helical piles to assess the degree of efficiency gained after introducing helical piles. Figures (1) and (2) shows the effect of the length of helical piles on its maximum uplift movement. In general, the maximum uplift movement of piles decreases with increasing its length. When full mobilization of the uplift movement is achieved, the deeper soil will tend to restrain the upper movement and increase the anchorage resistance of the pile. It can be seen from Figures (1) and (2) that helical piles embedded in sandy soil of relative density equals (40%) have uplift movement more than helical piles embedded in sandy soil of relative density equals (80%). The efficiency of helical piles embedded to sandy soil decrease with the increase of the relative density. The installation of helical piles in loose sandy soil leads to be denser and increases shear strength. On the contrary, if helical pile is installed in dense sandy soil lead the soil to be disturbed and decrease shear strength.

Also, it can be noticed from Figures (1) and (2) that the maximum uplift movement decreases with increasing helix diameter. This behavior may be attributed to the increase the surface area of part of helical pile embedded in sandy soil that causes increasing in anchorage resistance.

It can be noticed also from Figures (1) and (2), the maximum uplift movement decreases with increasing number of helix. Figures (3) and (4) illustrates the dimensionless ratio of the maximum uplift movement of pile to the maximum uplift movement of soil surface (Sp_{max}/Ss_{max}) plotted against L_s/H ratio (depth of embedment of the pile in sandy soil layer to the thickness of expansive soil) for two relative densities 40%,80% of sandy soil. The relationship is for helical piles with single and double helix with two ratios of diameter of helix plate/ equivalent diameter of square cross section of shaft of helical pile (d_h/d_{pe}) 2.68 and 3.57. A unique relationship was observed within a limited number of model tests performed and for specified soil. Extrapolating the results indicate the ratio(Sp_{max}/Ss_{max})=0 at different ratios of (L_s/H) according to helix diameter and number of helix as shown in Table (3). To reflect the required anchorage the required anchorage depth to field conditions, the model test would be more conservative since the applied load was not included in the model tests. However, this depth may be proposed for determining a safe anchorage depth.

Table 3,
Analysis of Results for Required (Ls) of Case no Upward Movement of Helical Piles.

No.of Helix	d_h/d_{pe}	(R.D.) %	Ls/H	Required Ls (mm)
Single	2.68	40	1.02	306
	3.57		0.97	291
Single	2.68	80	0.68	204
	3.57		0.67	201
Double	2.68	40	0.78	234
	3.57		0.70	210
Double	2.68	80	0.58	174
	3.57		0.53	159

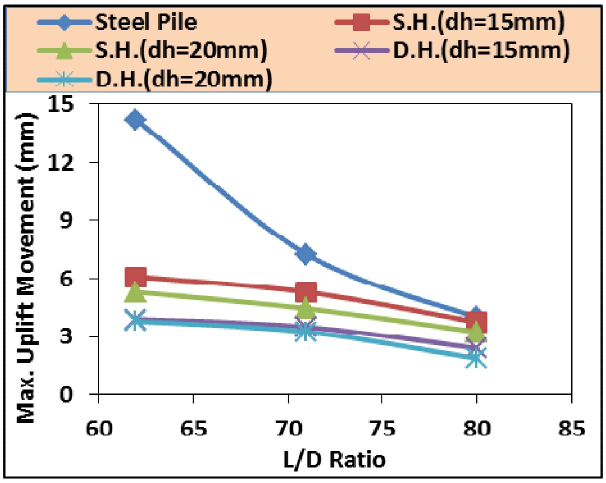

Fig. 1. Variation of Maximum Uplift Movement of Helical Pile with L/D Ratio for Different Lengths and Helix Diameters (Relative Density =40%).

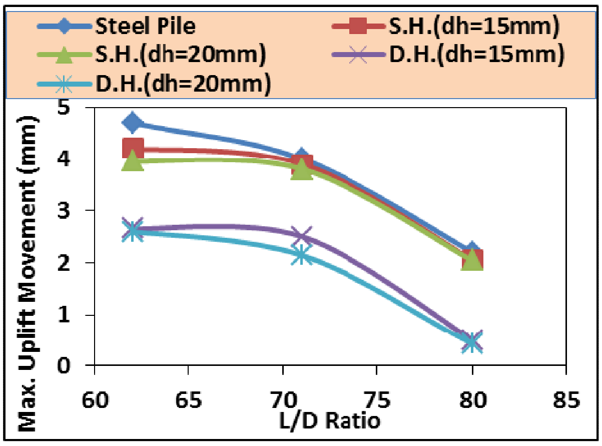

Fig. 2. Variation of Maximum Uplift Movement of Helical Pile with L/D Ratio for Different Lengths and Helix Diameters (Relative Density = 80%).

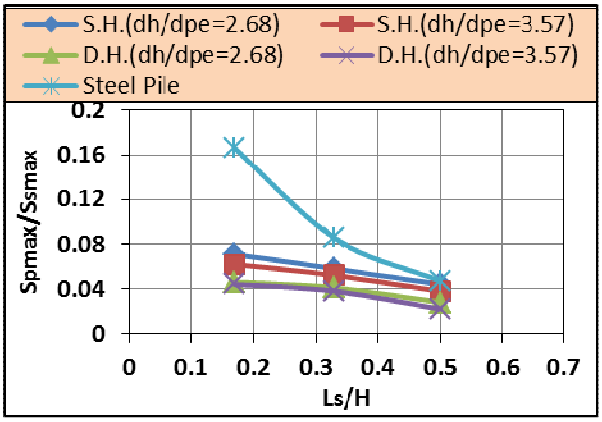

Fig. 3. Design Chart for Steel and Helical Piles in Expansive Soil Embedded in Sandy Soil with R.D. = 40 %.

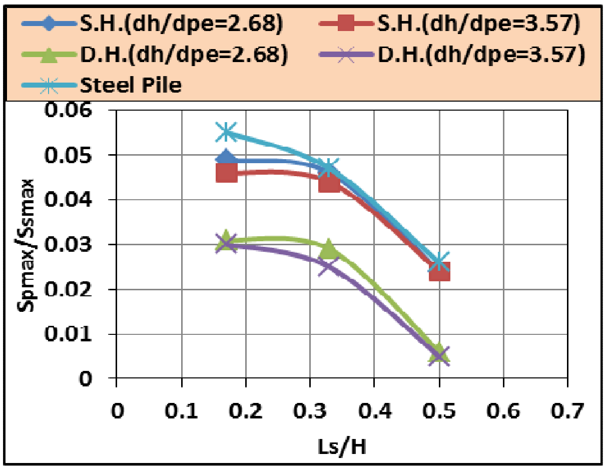

Fig. 4. Design Chart for Steel and Helical Piles in Expansive Soil Embedded in Sandy Soil with R.D. =80 %.

The pullout load test carried out on helical piles in expansive soil embedded to sand soil to measure the ultimate pullout load capacity with swelling effect. After complete saturation and the swelling of expansive soil is stopped, pullout load is applied on helical piles models and the upward movement is measured. The failure occurs when observing a certain maximum value of pullout load or a large upward movement happened due to small increment of applied load, this load is called failure pullout load. The results of pullout load tests of 32 models are tabulated in Table (4). Figures (5) to (8) show the variation of pullout load with upward movement for three different ratios of (L/D) 62, 71, 80 and two relative densities of sandy soil 40%, 80%. The pullout load upward movement relations are nonlinear and show similar trend of behavior. The failure pullout load increased with the increasing length, helix diameter, number of helix of helical piles and relative density of sandy soil. This may be attributed to the effect of anchorage action of helical piles and shear resistance mobilized along the cylindrical helical pile soil interface. Also, when sandy soil is dense the friction force between helical pile and soil increased which caused high resistance. A comparison between steel piles and helical piles in term of failure pullout load is shown in Table (4) It can be seen clearly that the value of failure pullout load of helical piles is approximately (4.7-10.6) times higher than that of steel piles when R.D. of sandy soil 40% and (2.8-8.1) times when R.D. of sandy soil 80%.The results obtained were coinciding with that obtained by [10] and [12].

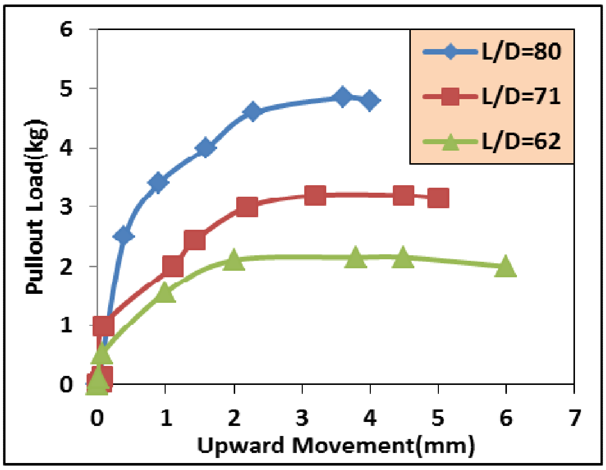

Fig. 5. Pullout Load -Upward Movement Curves for Steel Pile without Helix (R.D= 40%).

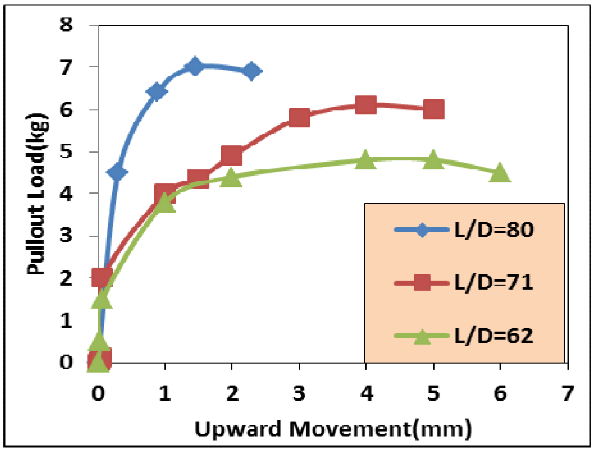

Fig. 6. Pullout Load -Upward Movement Curves for Helical Pile with Single Helix (dh=20mm, R.D= 40%).

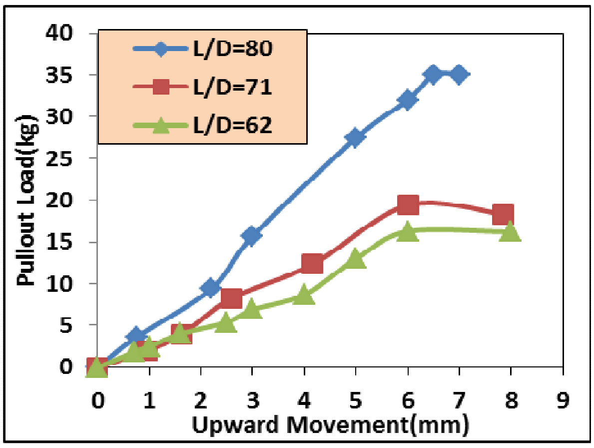

Fig. 7. Pullout Load -Upward Movement Curves for Steel Pile without Helix (R.D= 80%).

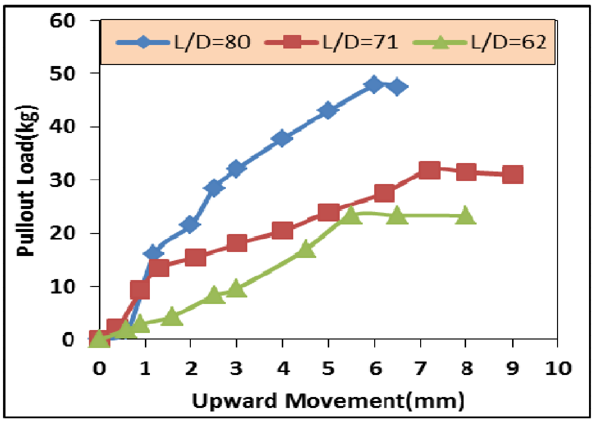

Fig. 8. Pullout Load -Upward Movement Curves for Helical Pile with Single Helix (d_h=20mm, R.D= 80%).

5. Conclusions

1. The upward movement of helical piles for piles embedded in expansive soil overlaying a sandy soil layer decreases with increasing depth of embedment in the sandy layer, helix diameter and number of helix those provide anchorage against uplifting. 2. Helical piles embedded in sandy soil of relative density (40%) have uplift movement more than helical piles of relative density (80%). The increase in efficiency of helical piles embedded to sandy soil decrease with the increasing of the relative density.
3. The helical piles resist the soil volume changes more than steel piles.
4. The failure pullout load increased with the increasing length, helix diameter, number of helix of helical piles and relative density of sandy soil.
5. The value of failure pullout load of helical piles is approximately (4.7-10.6) times higher than that of steel piles when R.D. of sandy soil 40% and (2.8-8.1) times when R.D. of sandy soil 80%.
6. For the specified soil used, there is a unique relationship between dimensionless ratio of the maximum uplift movement of pile to the maximum uplift movement of soil surface (Spmax/Ssmax) and ratio of depth of embedment of the pile in sandy soil layer to the thickness of expansive soil (Ls/H) for loose and dense state of sandy soil. This relationship may be used for determining the safe depth required to provide provide a sufficient anchorage**.**

Notation

D diameter of pile
d_h diameter of helix plate
d_{pe} equivalent diameter of square pile
H thickness of expansive soil
L length of pile
L_s embedment length of pile in sandy soil
R.D. relative density of soil

6. References

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الركائز اللولبية المغروسة فى تربة انتفاخية تستند على طبقة رملية

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الخلاصة

فى هذه الدراسة تم دراسة تصرف الركائز اللولبية ذات مقطع مربع بابعاد (٥x٥) ملم مربع مغروسة بتربة انتفاخية تستند على طبقة من الرمل. التربة الرملية بسمك ٢٠٠ ملم حدلت باربع طبقات فى اناء حديدى بقطر ٤٠٠ ملم وتم حدلها بكثافة نسبية ٤٠%و ٨٠%. التربة الانتفاخية بسمك ٣٠٠ملم تم حدلها بست طبقات فوق التربة الرملية. استخدمت ركائز لولبية باطوال ٣٥٠ ملم و ٤٠٠ ملم و ٤٥٠ ملم وصفائح لولبية دائرية بقطر ١٥ملم و ٢٠ ملم واستخدمت بصورة احادية وثنائية لكل ركيزة. الماء اضيف الى التربة من الاسفل عن طريق التربة الرملية ويرتفع للاعلى عن طريق اربع مبازل رملية حول الركيزة. وجد من خلال هذه الدراسة ان حركة الركائز اللولبية للاعلى تقل بازدياد العمق فى التربة الرملية وزيادة قطر الصفيحة وعددها. الركائز اللولبية المغروسة فى التربة الرملية ذات الكثافة النسبية ٤٠% تكون حركتها للاعلى اكثر من المغروسة فى ذات الكثافة النسبية ٨٠% .