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Performance Assessment of Pile Embedded in Expansive Soil

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Abstract

An evaluation for the performance of model pile embedded in expansive soil was investigated. An extensive testing program was planned to achieve the purpose of this research. Therefore, special manufactured system was prepared for studying the behavior of model pile having different length to diameter ratios (L/D). Two types of piles were used in this research, straight shaft and under reamed piles. The effect of model pile type, L/D ratio and number of wetting drying cycles were studied. It is observed that significant reductions in pile movement when under reamed piles were considered. A proposed design charts was presented for straight shaft and under reamed piles to estimate the length of both types of piles that is required to exert minimized uplift pressure when the soil swells.

Keywords: *Expansive soil, pile model, reamed piles, wetting drying cycles, pile movement.*

1. Introduction

Although expansive soils are considered one of the problematic soils in the world and especially in Iraq, it represents serious problem when exist under the foundations, due to the volume change that exhibit when changes in moisture content were occurred. This behavior causes extensive damages to structures erected on these soils. In Iraq, expansive soils are found at northern and middle parts of the country, with different swelling tendencies Foundations on expansive soils pose a unique challenge to the geotechnical engineer. They usually cost more than construction of foundations on ordinary soils as well as the site investigation and the foundation design (Nelson et al., 2012).

One of the important issues is to insure the stability of the structure constructed on expansive soil, a conventional solution is to use piles as a foundation for the structure so it can reach a relatively stable zone in the deep layers of the soils especially when the swelling potential of the underneath expansive soil is so high that conventional soil treatment is considered not effective or not even economical. The using of piles as a practical foundation system in expansive soils has been recommended in practice by many researchers such as (Chen, 1975 and Arora, 2008).

Many researchers have conducted experimental, theoretical and field studies for the past five decades on piles embedded in expansive soils to make a better understanding of the behavior of the pile in such soil conditions. It was concluded from the literature that an investigation of the piles' movement and uplift force due to soil swelling when subjecting the surrounding soil to wetting-drying cycles for representing seasonal moisture content changes is needed to support the scientific and practical research.

Therefore, an extensive testing program was planned to investigate each of the following:

- Straight shaft and under reamed piles movement when subjecting the surrounding soil to wetting-drying cycles in order to represent seasonal moisture content changes.
- Exerted uplift force from straight shaft and under reamed piles due to soil swelling for different wetting-drying cycles.
- Comparison between the pullout capacity of straight shaft and under reamed piles for non-swelling and swelling soil conditions.

2. Material Properties
2.1. Expansive Soil

The expansive soil used in this research was artificially prepared by mixing Iraqi bentonite from Al-Anbar city / Bushayrah Valley, about 35 kilometers southern Al-Waleed Military Base from a depth of three and a half meters from natural ground level, with Karbala sand.

In order to increase the permeability of the 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 (9/1) was selected. At this ratio, the soil remains highly expansive and its permeability is increased.

2.2. Model Piles
2.2.1. Straight Shaft Piles

Nine straight shaft piles have been formed using solid aluminum rod with a diameter of 10mm and three different pile embedment lengths of 100mm, 150mm and 200mm that give L/D ratios of 10, 15 and 20 respectively. The dimensions are shown in Fig. 1 which illustrates that there is an extension of 20 mm in length of all piles for fixing and measurement.

Fig. 1. Dimensions of model straight shaft

2.2.2. Under-Reamed Piles

Nine under reamed piles with single bulb at the bottom of the pile were made using a solid aluminum rod with 200mm diameter and then formed to give the shape of an under reamed pile as shown in Fig. 2 with dimensions recommended by (Pumina, 2005) of stem diameter of 10mm, bulb diameter of 200mm and a bucket length of 10mm, the L/D ratios were 10, 15 and 20. There is an extension of 20 mm in length of all piles for fixing and measurement. The surface of the model piles has been textured to insure the interlock between the pile and the surrounding soil.

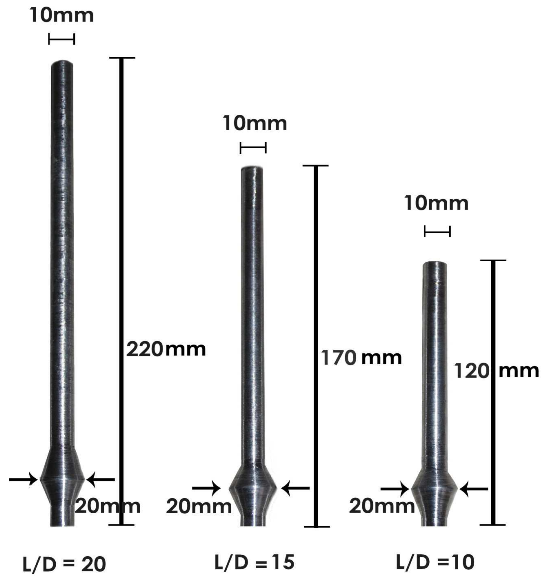


Fig. 2. Dimensions of model reamed pile

2.2.3. Soil Container

Twenty five soil steel containers were made using a 4mm thickness steel plate with the dimensions of (25cm × 25cm ×35cm). The sides of the containers were perforated with 25 holes each with 3mm diameter to decrease soil saturation period, the containers were painted with two coats of anti-rust paint and then two layers of gray base paint to resist the corrosion during test period. Fig. 3 shows the dimensions of the soil container

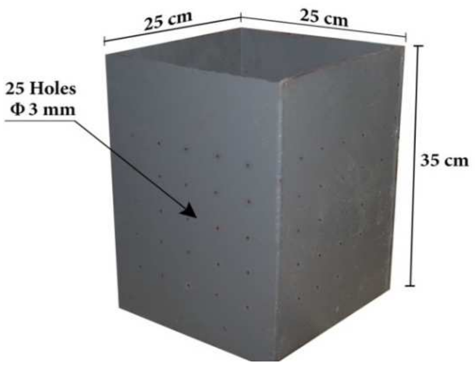


Fig. 3. Soil Container Dimensions.

2.2.4. Manufactured Apparatuses

The main goal of this research is to investigate the effect of wetting and drying cycles on the movement and uplift force of piles embedded in expansive soil which will consume too much time to cover different L/D ratios and types of model piles, for that reason, manufacturing of special devices and apparatuses was needed to shorten test period as will be discussed in details in the following sections.

2.2.5. Saturation-Drying Model for Pile Upward Movement

The basic idea here is to manufacture a saturation-drying model for the soil containers; that is large enough to contain eight containers at one time, and to be the same model that the drying process would take place in, instead of transferring the soil containers to a suitable oven. For that purpose, a large tank was made of galvanized steel plate of 2mm thickness and dimensions of (150cm X 80cm X 40cm). A flange was then attached to the side of the model to use it when conducting drying process. In addition, a drainage valve was then fixed at the bottom of the model. Fig. 4 illustrates the dimensions and the shape of the saturation model.

Fig. 4. The saturation-drying model

A cap for saturation-drying model was also made using galvanized steel plate of 2mm thickness and dimensions of (160cm X 80cm X 40cm). This cap is used only when drying process is performed.

For the purpose of soil drying, many researchers used electrical heaters around the soil; the defect here is that the heaters provide heat only for the vicinity area around the heaters which will cause a large gradient in the temperature between the core and the outside of the soil (especially for large soil samples). To overcome this defect, a specially designed heating source was manufactured using three rows of electrical heaters each with 7 KW capacity and a fan, all assembled in a thermally isolated aluminum box to give what is called a heating duct as shown in Fig. 5, also a thermometer was provided to the heating duct to control the temperature of soil drying which was fixed to 50^{o} Celsius. The whole system for heating (drying process) can be shown in Fig. 6.

Fig. 5. Heating Duct Details.

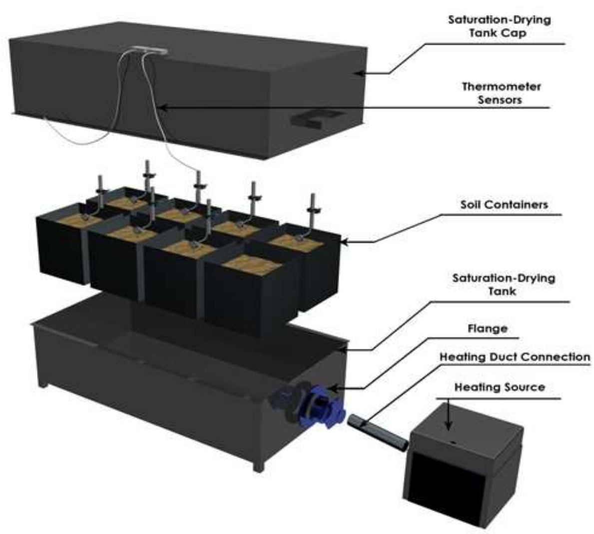


Fig. 6. Heating system for drying process.

2.2.6. Saturation-Drying Model for Pile Uplift Force Measurement

Another saturation-drying model was manufactured with the same dimensions for the purpose of measuring pile upward movement. This model is similar to that illustrated in previous section with one difference that this model was provided with a rectangular steel tube frame fixed above it to hold on the proving rings installed above the piles as shown in Fig. 7. The rectangular steel frame was provided with adjustable screws for adjusting the distance between the proving rings and the piles.

Fig. 7. Saturation-drying tank for pile uplift force measurement.

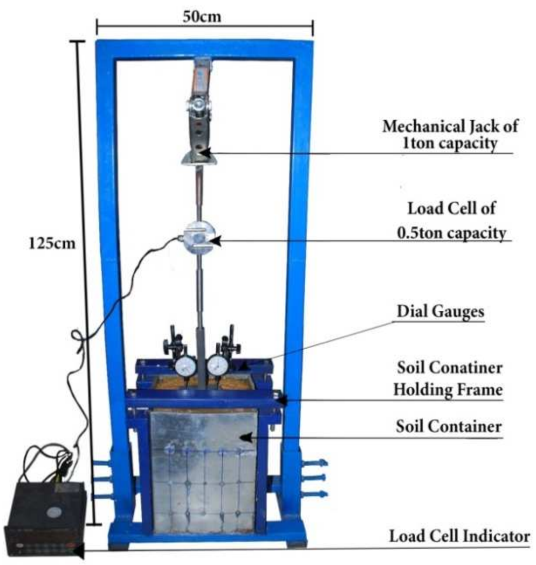


Fig. 8. Details of pile pull-out loading frame.

2.2.7. Pile Pull-out Loading Frame

Special pull-out loading frame was manufactured for measuring pile pull-out capacity as illustrated in Fig. 8. A load cell with its indicator was attached to measure the applied tension force on the pile, and two dial gauges were fixed above the pile cap using two magnetic holders to indicate the upward displacement of the pile due to applied force.

2.3. Testing Program

The testing program consists mainly of two series. The first series include the physical properties tests. The second series comprises the pile model tests on both straight shaft and under reamed piles. The pile model tests consist of pile movement test due to wetting-drying cycles which consumed 153 days (58 days for the first cycle, 49 days for the second cycle and 46 days for the third cycle) as shown in Fig. 9.

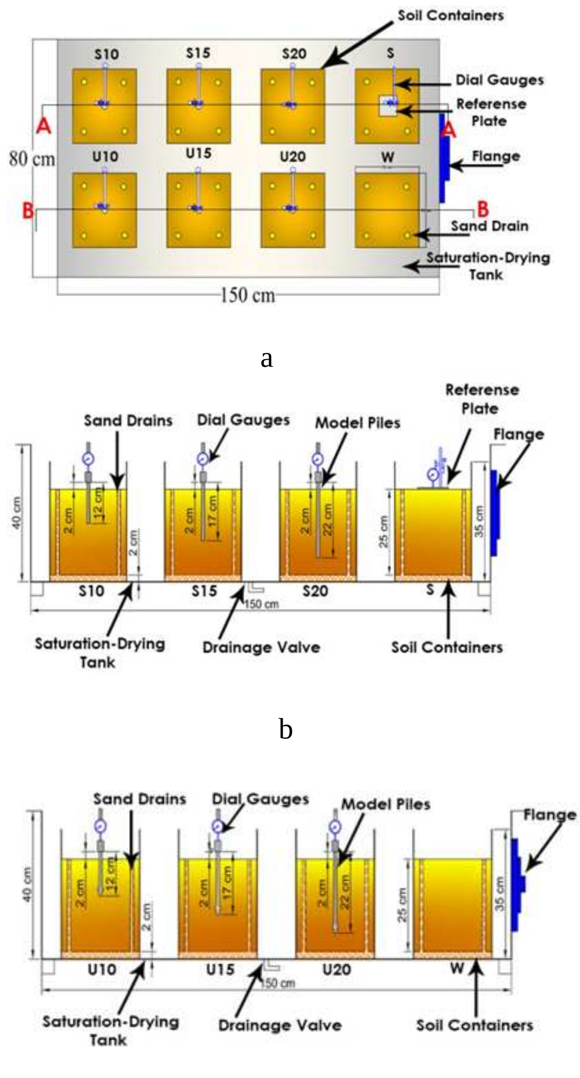
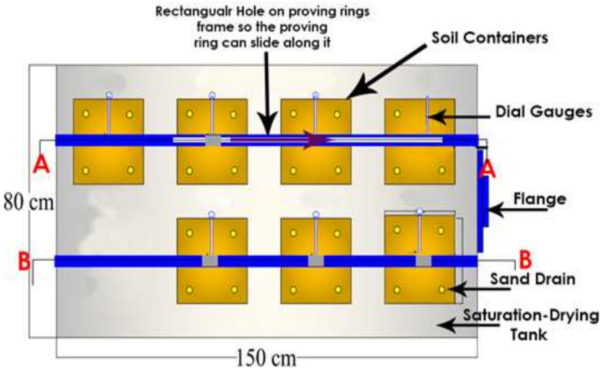


Fig. 9. Schematic view for pile movement model test a:top view, b: sec A-A, c: sec B-B

The pile uplift force test through wetting-drying(six pile models were tested on three wetting-drying cycles which consumed an average period of 45) as shown in Fig. 10.



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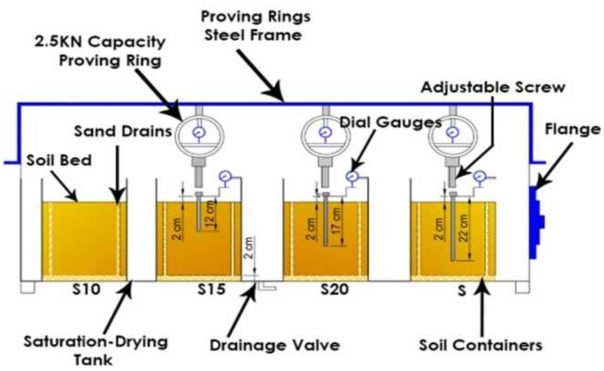

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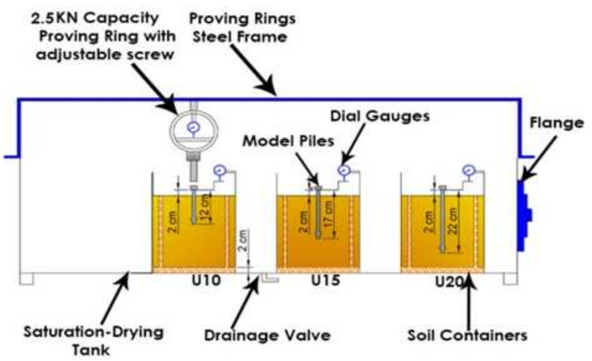


c

Fig. 10. Uplift force saturation-drying tank a: top view of the tank, b: section A-A, c: section B-B

The pull-out capacity test was performed according to ASTM D3689-07 (Section 8.1.2 quick test procedure) on six model straight shaft piles, three of them were embedded in an expansive soil prepared at initial water content of 2% dry of optimum and the other piles were embedded in expansive soil at the same initial water content but exposed to wetting that consumes 40 days for each model. Another six pile model tests were conducted on under reamed piles to determine the pull out capacity of these piles, three of them when the soil was wetted, and the other three model tests when the soil was prepared at initial water content without wetting, see Fig. 11. It is important to note that each test is conducted on three different L/D ratios (10, 15, and 20).

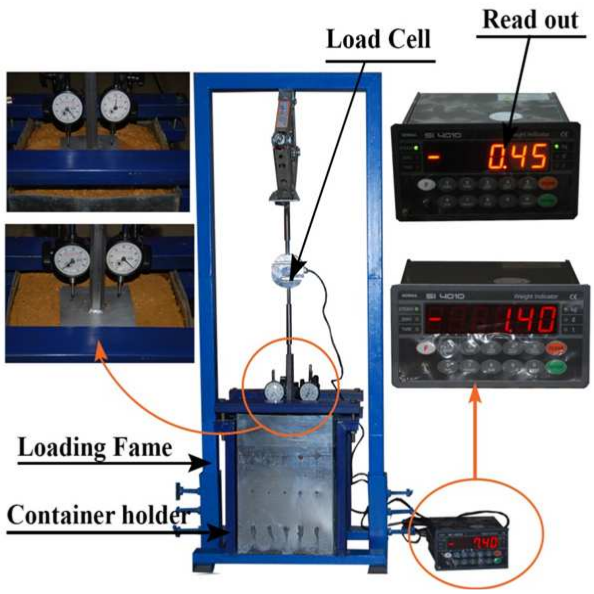


Fig. 11. Model pile pull-out test system during testing.

2.4. Physical Properties Tests

The following table gives the physical properties of the used expansive soil, (Table 1).

Table 1,
Physical Properties of Expansive Soil.

Test	Standards	Results
Soil Classification	USCS	CH
Maximum Dry Density (MDD)	ASTM D698-12	1.23 g/cm^3
Optimum Moisture Content (OMC)		34 %
Specific Gravity Gs	ASTM D854-10	2.52
Liquid Limit	ASTM D4318-10	102 %
Plastic Limit		45 %
Plasticity Index		57
Swelling Pressure	Standard Oedometer Test	312 kPa

2.5. Soil Bed Preparation

The soil bed is prepared in the container to be ready for performing model tests. Two trial mixes were carried out on sand mixing percentages of 5% and 10% with the soil. The two percentages of mixing reduced the swelling pressure of the soil and certainly increased the permeability. Fig. 12 shows the variation of swelling pressure with the sand mixing percentages.

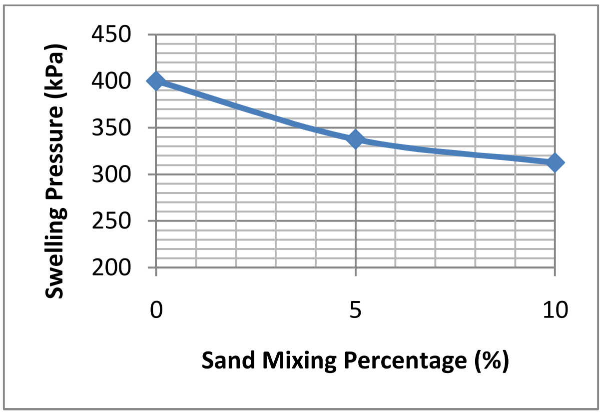
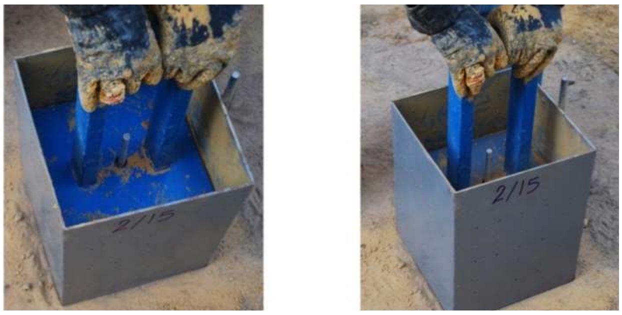


Fig. 12. Relationship between sand-soil mixing percentage and the resulting swelling pressure y.

The soil bed was prepared on a dry density of 1.225 g/cm3, which corresponds to a water content of 2% dry of optimum. The required amount of expansive soil was placed inside the container to one fifth of the final thickness of the bed of the soil and compacted using a hand hammer with a square base of the same internal dimensions of the soil container and a hole centered on its base in order not to let the pile be affected during soil compaction as shown in Fig. 13.

This method of compaction was performed by many researchers such as (Al-Ani, 1993, Al-Maamoury, 1994 and Chao, 2007). Four sand drains were formed around the pile using thin walled steel tube (10 mm diameter and 250 mm length). The sand drains were spaced 100 mm from the pile (center to center). The sand used was passing sieve No.8 and prepared at a relative density equal to 82% to decrease soil saturation period.

Required amount of expansive soil is poured onto the soil container



Compaction of soil to the required level by using the specially manufactured hand hammer

Fig. 13. Placing of expansive soi bed layers and compaction.

3. Model Test Results
3.1. Pile Movement Model Test
3.1.1 Experimental Model Test Results

The upward movement of the piles due to soil swelling and the downward movement due to soil shrinkage were recorded with time for straight shaft and under reamed piles with L/D ratios of 10, 15 and 20. Fig. 14 illustrates the recorded results.

3.1.2. Proposed Design Chart

Based on the experimental model test, a design chart is presented in Fig. 15 to determine the required depth of the pile to resist the tension forces exerted by the swelling soil and produce zero or allowable upward movement. The concept of the following design chart is that the soil swelling decreases with deeper soil layers. This design chart provides values for unloaded piles so in the case of loaded piles it will be in the safe conservative side.

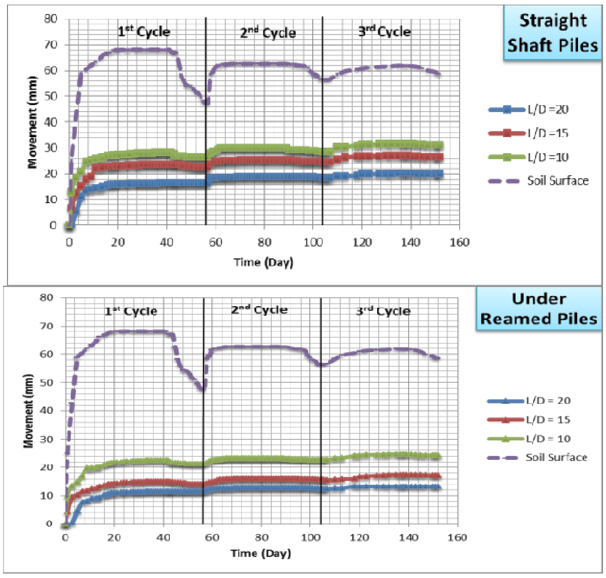


Fig. 14. Pile movement compared to soil surface movement due to wetting-drying cycles for straight shaft and under reamed piles.

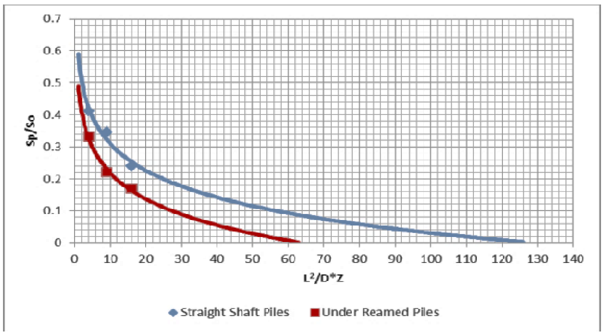


Fig. 15. proposed relationship for determining required pile dimensions to resist upward movement due to soil swelling at the end of the first wetting-drying cycle

3.2. Pile Uplift Pressure Model Test Results

3.2.1. Experimental Model Tests

When the soil swelling is happened, the shear strength of the soil is reduced, maximum swelling occurs in the top layers of the soil which surrounds shallower piles , thus, the maximum loss in soil shear strength during swelling occurs in the top soil layers. Therefore, shallower piles exerts less uplift forces due to soil swelling and more upward movement comparing to deeper piles which are anchoraged in the relatively deeper soil layers that have less tendency to swelling. The magnitude of uplift resistance from straight shaft and under reamed piles due to soil swelling in the first cycle is illustrated in Fig. 16.

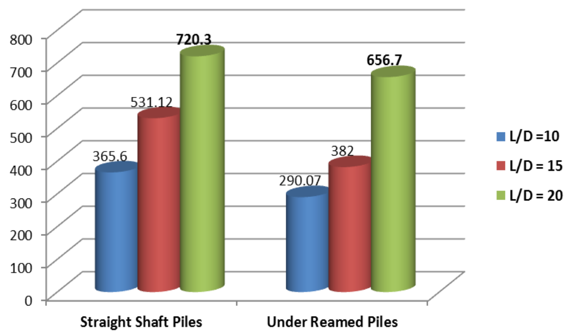


Fig. 16. Effect of L/D ratio on straight shaft and under reamed piles uplift resistance by soil swelling.

3.2.2. Piles Pull-Out Capacity Model Test

The model test results for piles pull-out load - upward movement behavior was presented through Table 2. For straight shaft and under reamed piles it was noticed that deeper piles with higher L/D ratios showed greater pull out capacity comparing to the shallower piles for wetted and unwetted soil states. Also, the under reamed piles showed more resistance to the applied uplift forces than the stra

ight shaft piles because of the presence of the base bulb which provides extra anchorage in deep soil layers and thus more pull out force resistance for the under reamed piles.

Table 2,
Increment in pile pull-out capacity.

L/D	Unwetted State Straight Shaft Piles	Unwetted State Under reamed Piles	Increment Ratio%
10	18.46 N	20.77 N	12.50
15	30.45 N	39.15 N	28.57
20	56.14 N	91.23 N	38.46
L/D	**Wetted State Straight Shaft Piles**	**Wetted State Under reamed Piles**	**Increment Ratio%**
10	16.156 N	18.46 N	14.26
15	26.10 N	34.80 N	33.33
20	35.00 N	63.00 N	80.00

4. Conclusion

One of the challenges in geotechnical engineering is how to construct a stable foundation system to resist tension forces exerted by expansive soils and produce a safe building under this condition. The thought of this study was to examine the suitability of using under reamed with one base bulb as an alternative for straight shaft pile and study the behavior of both types of piles under seasonal moisture changes by applying successive cycles of wetting and drying to the soil that piles embedded in, the following points were concluded:

1- Pile upward movement due to soil swelling is reduced to about (20%-30%) when using under reamed pile with one base bulb instead of conventional straight shaft pile, deeper piles showed more resistance to upward and downward movement than shallower piles.

2- A relationship is obtained for the piles upward movement that provides the required dimensions of any unloaded pile fully embedded in a very high expansive soil for zero upward movement or any recommended tolerable movements. For loaded piles, the results obtained from this relationship will be on the safe conservative side.

3- Pile uplift force due to soil swelling is reduced to about (10%-20%) when using under reamed piles instead of conventional straight shaft piles

4- The use of under reamed piles instead of straight shaft piles for the same L/D ratio increases the pull out capacity of the piles by (12.5% -38.46%) for unwetted soil state, and about (14.26% - 80%) for wetted soil state.

Notation

D	Pile Diameter
CH	Fat Clay
L	Pile Length

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تقييم اداء ركيزة في ترب انتفاخية

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الخلاصة

تم تقييم اداء انموذج لركيزه مغروسة في تربة انتفاخية من خلال برنامج فحص تم التخطيط له لتحقيق هدف هذه الدراسة.لذلك تم تصنيع نظام خاص لدراسة خواص انموذج الركيزة باطوال مختلفة اي بنسب طول الى قطر مختلفة.نوعين من الركائز تم اعتمادها في هذا البحث، الركائز الأعتيادية والركائز ذات التوسع.تم دراسة تأثير نوع الركيزة،نسبة طول الركيزة الى قطرها وعدد دورات الترطيب التجفيف على تصرف الركائز.لوحظ نقصان واضح في حركة الركيزة الى اعلى عند استخدام الركائز ذات التوسع. مخطط تصميم تم اقتراحه للركائز الأعتيادية والركائز ذات التوسع لتخمين طول الركيزة المطلوب بحيث ينتج عنه اقل مايمكن من ضغط الأصعاد عند انتفاخ التربة.