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Wetting-Drying Cycles Effect on Piles Embedded in a Very High Expansive Soil

Bushra Suhale Al-Busoda, Laith Kadim Al-Anbarry

Abstract**—**The behavior of model piles embedded in a very high expansive soil was investigated, a specially manufactured saturation-drying tank was used to apply three cycles of wetting and drying to the expansive soil surrounding the model straight shaft and under reamed piles, the relative movement of the piles with respect to the soil surface was recorded with time, also the exerted uplift pressure of the piles due to soil swelling was recorded. The behavior of unloaded straight shaft and under reamed piles was investigated. Two design charts were presented for straight shaft and under reamed piles one for the required pile depth for zero upward movement due to soil swelling, while the other for the required pile depth to exert zero uplift pressure when the soil swells. Under reamed piles showed a decrease in upward movement of 20% to 30%, and an uplift pressure decrease of 10% to 30%.

Keywords**—**Expansive Soil, Piles, under reamed, wetting drying cycles.

I. Introduction

EXPANSIVE soils and rocks undergo volumetric changes upon wetting and drying, thereby causing ground heave and settlement problems, these characteristics cause considerable defects if not adequately taken care of, for swelling to occur, these soils must be initially unsaturated at some water content, if the unsaturated soil gains water content, it swells, on the other hand, if a decrease in water content occurs the soil will shrink [1].

It is widely distributed around the world, the deformation of structure above an expansive soil is caused by apparent swelling-shrinkage behavior of the soils with changes in water content, which is different from the common foundation systems whose settlement are controlled by soil compressibility and strength. For engineering construction on the area of expansive soil, piles are commonly used to be digged into deeper soil layers which may greatly decrease the upward movement of the structure. Since piles are inserted into expansive soils, it must be pulled by upward shear force transmitted from the soil to the piles. If the upward shear force is great enough, the pile may even be broken by such great tension [2].Therefore, a more comprehensive investigation of tension-resistant foundations such as under reamed piles should be done with comparing to the conventional straight shaft piles.

Many researchers had recommended studying the effect of cycles of wetting and drying on behavior of piles embedded in expansive soil.

Bushra Suhale Al-Busoda is Assistant Professor, College of Civil Engineering, Baghdad University, Iraq (e-mail: albusoda@yahoo.com).
Laith Kadim is Geotechnical Engineering M.Sc. Student, College of Civil Engineering, Baghdad University, Iraq (e-mail: laith.anbarry@gmail.com).

II. Material Properties

A. Expansive Soil

The expansive soil used in this research is brought from Al-Anbar region western Iraq, 300 km west of the capital Baghdad, the expansive soil covers large regions of that area and they are mainly bentonite soils with high percentage of montmorillonite mineral. To shorten the period of soil saturation, the soil had been mixed with 10% sand. The final mix produced a very high expansive soil with swelling pressure of (312 kPa); the following table gives the physical properties of the used expansive soil:

TABLE I
PHYSICAL PROPERTIES OF EXPANSIVE SOIL

Soil Property	Test Specification	Value
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	2.805
Liquid Limit		102 %
Plastic Limit	ASTM D4318 - 10	45 %
Plasticity Index		57
Swelling Pressure	Standard 6.9kPaOedometer	312 kPa

B. Soil Containers

Fifteen steel containers of 4mm thickness with dimensions of 25cm * 25cm *35cm were manufactured to contain the expansive soil and the piles within. These containers were perforated with 25 holes on each side, the hole diameter was 3mm, to allow water seeping through them.

C. Model Piles

Six straight shaft piles and six under reamed piles with one bulb were formed from solid aluminum with a diameter of 10mm and embedment length to depth ratio (L/D) of 10, 15 and 20 respectively.

D. Saturation-Drying Tank

Two saturation-drying systems were manufactured with dimensions of 150 cm* 80cm *40cm to apply cycles of wetting and drying to eight soil containers at the same time. One tank is dedicated for piles movement monitoring due to soil swelling and shrinkage, the other is to determine the exerted uplift pressure due to soil swelling for different wetting-drying cycles. Fig. 1 shows the saturation-drying tank for pile uplift pressure determination during saturation period and Fig. 2 shows saturation-drying tank during drying process.

Fig. 1 Saturation-Drying Tank for Piles Uplift Pressure

Fig. 2 Saturation-Drying System

III. Test Methodology

A. Introduction

The experimental test consists of modeling straight shaft and under reamed piles with L/D ratios of 10, 15 and 20. The piles are fully embedded in a very high expansive soil, the effect of soil swelling and shrinkage on the behavior of model piles due to wetting-drying cycles will be investigated

B. Soil Bed Preparation

The inside surface of soil containers were lubricated with petroleum jelly to minimize friction between soil and containers through test period. Dense sand bed was placed in the bottom of the soil container with 2 cm thickness. The soil was compacted inside the container with specially manufactured square hand hammer (weighted 5 Kg) with five layers to the maximum dry density and 2% water content dry of optimum moisture content, the required amount of soil layer was placed into the container and compacted with the square hand hammer, the number of blows was controlled by the final thickness of the soil layer, this method of compaction was recommended by many researchers such as Chao [3]. The piles were placed during compaction process according to their required depth. At the end of compaction process, the final thickness of soil bed was 25cm.Four sand drains were formed around each pile with 25cm depth to reduce soil saturation period.

C. Pile Movement Due to Wetting-Drying Cycles

Eight soil containers were placed into saturation-drying tank, three for under reamed piles, three for straight shaft piles one for soil surface movement and the last one for water content checking with time. Dial gauges were fixed above each pile and dial gage and reference plate for soil surface movement were fixed too. The water has been added equally on the top of each soil container in addition to the main tank, the relative movement of the piles with respect to the soil surface were recorded with time till reaching the state of full soil saturation, after that, a cap were placed upon the tank, a heating source is attached to apply hot air with temperature of 50^{o} Celsius to the soil containers, the drying process is started there, also, the downward movement of the piles and soil surface were recorded with time, after reaching the state of full soil shrinkage, the saturation is repeated and so on till we had three cycles of wetting and drying.

D. Pile Uplift Pressure

Seven soil containers were placed inside the second saturation-drying tank, three for under reamed piles, other three for straight shaft piles and the seventh one for water content determination during test period. Four proving rings of 2.5kNcapacities with a base adjustable screw were placed vertically above the piles. Soil inundation was made in the same manner as in the pile upward movement saturation-drying tank, whenever the piles had an upward movement due to soil swelling the adjustable screw of the proving ring was turned to apply a vertical pressure on the piles letting them to return to their initial place. The proving rings readings correspond to zero upward movement of the piles were recorded with time. The stress registered by the proving rings represents the true uplifting pressure of the pile [4].

Three wetting-drying cycles were applied to the expansive soil and the uplift pressure of the piles was recorded with time for each pile and for different L/D ratios.

IV. Model Test Results

A. Pile Movement Model test

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. 3 illustrates the recorded results.

2. Proposed Design Chart

A design chart is presented in Fig. 4 based on the experimental model test 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.

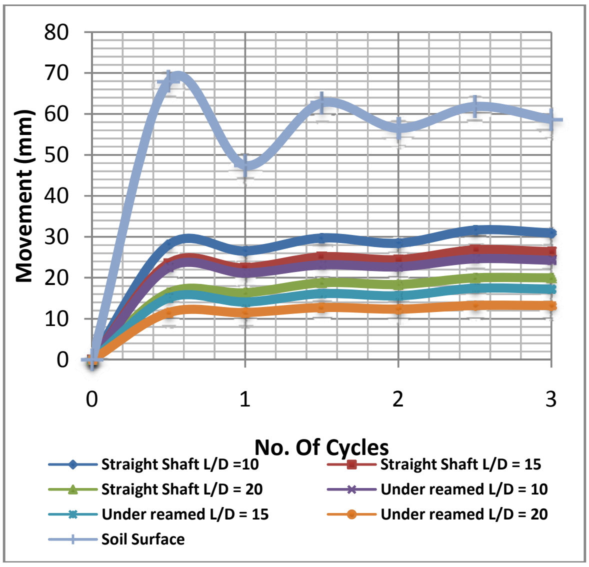

Fig. 3 Pile Movement Due To Soil Swelling and Shrinkage

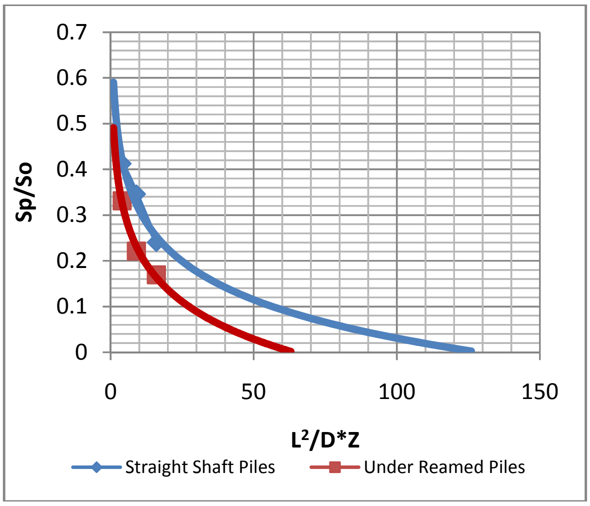

Fig. 4 Design Chart for Pile Movement

B. Pile Uplift Pressure Model Test Results

1. Experimental Model Test

The exerted uplift pressure from the piles due to soil swelling was recorded with time for different cycles [4]. Chen stated that the uplift pressure of the pile is a direct function of soil swelling. It is observed that, on each cycle the uplift pressure exerted by the piles is reduced due to expansive soil fatigue, the following figure shows the reduction of uplift pressure of straight shaft and under reamed piles with the increase in number of cycles.

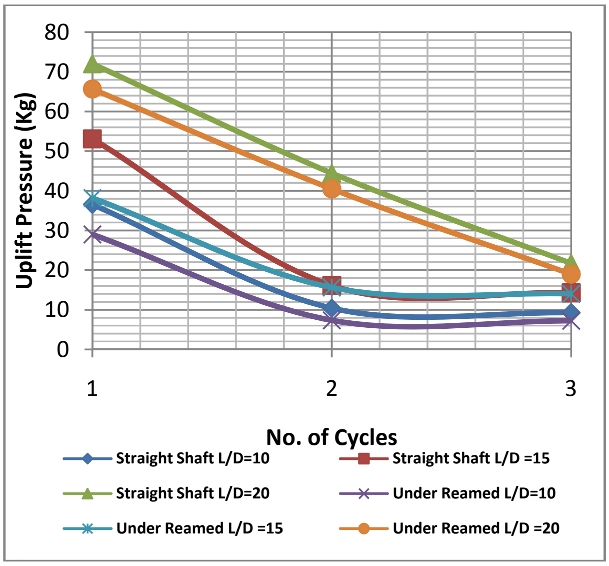

Fig. 5 Pile Uplift Pressure Reduction through Wetting-Drying Cycles

2. Proposed Design Chart

A design chart is presented to determine the amount of uplift pressure exerted by straight shaft and under reamed piles when the expansive soil swells depending on pile embedment length (L), Active zone depth (Z), pile diameter (D).

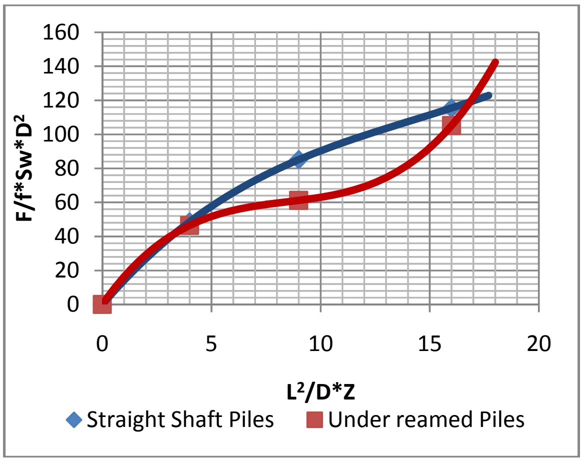

Fig. 6 Design Chart for Piles Uplift Pressure

III. Conclusion

One of the most challenging issues in geotechnical engineering is that constructing a foundation system that is stable enough to resist tension forces exerted by the expansive soil and produce a safe building under swelling and shrinkage conditions. The main idea of this study was to investigate the eligibility of using under reamed pile with one base bulb as a alternative solution for conventional straight shaft pile and study the behavior of straight shaft and under reamed pile under seasonal moisture content changes by applying cycles of wetting and drying to the soil surrounding the piles, the following points were concluded:

i. 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 movement and downward movement than shallower piles because of the anchorage in deep soil layer which is more stable comparing to the surface soil layer.
ii. Pile uplift pressure due to soil swelling is reduced to about (10%-20%) when using under reamed piles instead of conventional straight shaft pile
iii. The piles takes the pattern of soil upward and downward movement when the soil swells or shrinks but with percentages depending on the pile depth and anchorage in the stable zone, deeper piles have the same movement of the soil but with less percentage comparing to the shallower piles which moves with the surrounding soil but with higher percentages. For example, straight shaft piles had an upward movement percentage comparing to soil surface upward movement of 23% for deep piles but the percentage get higher in shallower piles to 40%, for under reamed piles deeper piles had a movement percentage of 16% and shallower piles 32%.
iv. When applying cycles of wetting and drying to the soil surrounding the pile, the uplift pressure exerted by the piles due to soil swelling is reduced in the range of (40%-70%), deeper piles showed smaller percentage. The straight shaft and under reamed piles showed the same reduction.

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Dr. Bushra Suhale born in Baghdad, 1974. B.Sc Civil Engineering, University of Baghdad, Baghdad, Iraq, 1996. M.Sc. Soil Mechanics and Foundation Engineering, University of Baghdad,Baghdad,Iraq,1999.Ph.D. Soil Mechanics and Foundation Engineering, University of Baghdad, Baghdad, Iraq, 2004.

Laith Kadim B.Sc. Civil Engineering, University of Al-Mustanseryuah, Baghdad, Iraq.M.Sc.in Geotechnical Engineering (Currently a student), Baghdad University.