Adhesion Factor of Piles Embedded in Unsaturated Swelling Soil

Facteur d'adhérence des Piles intégrées dans insaturées sol Gonflement

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ABSTRACT: Expansive soil is one kind of unsaturated soils; it is spread over many areas in Iraq. The mechanical behavior of unsaturated soils differs from that of fully saturated soils. The main objective in this paper is to evaluate the clay-pile adhesion in unsaturated and saturated expansive clay. The present study involves a series of pull out tests conducted on a single pile 200 mm in length and 20 mm in square cross section. The expansive soil is composed of 70% bentonite and 30% sand. The soil water characteristic curve SWCC and initial soil suction were measured to study the influence of suction. It is revealed that the ultimate shaft capacity increases nonlinearly as the initial degree of saturation decreases and the initial matric suction increases. The ultimate skin resistance is increased about 49% when the initial degree of saturation decreases from 90 to 70%. The adhesion factor is found to increase as the undrained cohesion and the initial matric suction decreases. The maximum adhesion factor was 1.3. It is concluded that the suction in clay should be accounted for in calculating the pile skin resistance. The environmental conditions significantly influence the results; wetting the surface of the bed of soil produces a positive skin resistance while surface evaporation produces negative skin resistance.

RÉSUMÉ: Sol expansif est un type de sols non saturés; elle est répartie sur de nombreuses régions en Irak. Le comportement mécanique des sols non saturés est différente de celle des sols complètement saturés. La présente étude porte sur une série de tirer sur des tests effectués sur une seule pile de 200 mm de longueur et 20 mm de diamètre. La caractéristique SWCC de la courbe de l'eau du sol et l'aspiration initiale du sol ont été mesurés pour étudier l'influence de l'aspiration. Il est révélé que les capacités de l'arbre ultime augmente de façon non linéaire que le degré initial de saturation diminue et d'aspiration initiale augmente matriciels. La résistance ultime de la peau est augmentée d'environ 49% lorsque le degré initial de saturation diminue de 90 à 70%. Le facteur d'adhérence se trouve à augmenter lorsque la cohésion non drainée et les premières baisses de succion matricielle. Le facteur d'adhérence maximale était de 1,3. Il est conclu que l'aspiration dans l'argile doit être pris en compte dans le calcul de la résistance de la peau de velours. Les conditions environnementales influencent de manière significative les résultats; mouiller la surface du lit de sol produit une résistance positive de la peau tandis que l'évaporation de surface produit une résistance négative de la peau.

KEYWORDS: Pile, swelling soil, unsaturated soil, pullout, matric suction.

1 INTRODUCTION

Expansive soil is a natural, highly dispersed and plastic soil, which contains mainly clay minerals and is very sensitive to either drying or wetting (Li et al., 1992). Expansive soils will experience relatively large volumetric change when it absorbs water or when it dries. The expansive force will damage engineered structures when the volume of expansive soils changes. Hence it is of great significance to study the swelling behavior of expansive soil in engineering projects. Many factors have an effect on the characteristics of expansion and the magnitude of expansive force including composition of soil, water content, dry density and applied load (Yan and Wu, 2009).The study of this type of soil can be encompassed within the concept of unsaturated soils, whose mechanical behavior is to a large extent governed by the phenomenon of suction. The term ‘‘soil suction’’ was introduced by Schofield (1935) to explain the negative pressure to which the pore water in some soils is subject, meaning that such soils have the capacity to absorb water if they come into contact with water at atmospheric pressure . In some cases, this inflow of water may lead the soil to collapse (irrecoverable volumetric reduction), whereas in others it may lead to swell (increase in volume) (Yenes et al., 2012).

2 PILES IN EXPANSIVE SOILS

In highly expansive soils, it is generally advisable to design deep foundations employing piles that will transmit the pressure below the active layer (the surface zone of the terrain in which changes in the soil volume may occur as a result of changes in water content). Deep foundations are one of the solutions for swelling clay problems which includes methods of making the structure behavior independent of the expansive layers. The typical features of these solutions are those of a ‘palaphite’ which is a structure resting on piles going down until they reach deep and stable layers. A gap is provided between the structure and the swelling surface of the soil. Usually the piles are bored and cast in place, as the consistency of these clays makes the driving difficult (Ng and Menzies, 2007).

3 EXPERIMENTAL WORK

The experimental work includes a series of laboratory model tests to investigate the behavior of single pile in saturated and unsaturated expansive soil. The influence of different degrees of saturation on a single pile behavior is investigated. A mix of soil of 70% bentonite and 30% sand is employed in this research. Bentonite Ca-base and silica sand were brought from a site west of Iraq. Standard tests were performed to determine the physical and chemical properties of the soil; details are given in Table 1. This mixture of bentonite and sand provides more workability and less expansion than that of pure bentonite and then save time to be fully saturated and dried.

All piles used in the model tests are made of hollow square cross section aluminum bar 2 mm thick, 200 mm long and 20 mm wide. The length to width ratio (L/D) is 10. All piles used in tests are closed at the tip using an Aluminum plate with appropriate dimensions. The container was manufactured for studying the load-displacement behavior of a single pile. The container is made of steel plates of thickness 4 mm. It has dimensions of (220 x 220 x350) mm. The dimensions of container have been chosen to fulfill the requirements of stress bulb not been in contact with sides of container. The axial loading system used in this experimental work is a compression machine with strain controlled system to control the rate of loading on a single pile to study the load–displacement behavior. The applied pressure is measured by a load cell of 50 kN capacity connected to the digital load indicator. Figure 1 shows the container filled with soil and placed in the loading machine.

Figure 1. Soil container in the compression machine.

4 PREPARATION FOR MODEL TEST

Earlier to the stage of preparation of the bed of soil, many trial tests were performed to control the efficiency of the preparation method. Control tests were carried out to check main points of significant importance regarding the preparation of the homogeneous bed of soil and determine the variation of shear strength, dry density, swelling percent and swelling pressure with different water contents. Several trails were made since samples are placed in ten layers inside CBR moulds. Each layer was pressed by a hydraulic jack. The samples were then covered with polythen sheet and left for 24 hours. The undrained shear strength was measured by a portable vane shear device. Samples were taken to obtain dry density and degree of saturation and then measure swelling percent and swelling pressure for each sample, typical results are presented in Figures 2 to 4.

Three soil samples were selected of different initial degrees of saturation namely; 70, 87 and 91% to carry out the one dimensional consolidation test, since the two others were so hard and of low degree of saturation which required a lot of effort and time to be in fully saturated condition. Swelling test was performed by the oedometer to the end of the swelling pressure value. The test was carried out according to the ASTM D 2435–96. The soil sample that has Sr = 70%, c_u = 99.5 kPa, γ_d = 12.75 kN/m^3, swelling percent of 66.5% and a swelling pressure of 240 kPa is chosen for the preparation of bed of soil, since it is considered as a very high swelling soil according to the criterion proposed by Chen (1975) and Al-Rawas and Goosen (2006).

Different degrees of saturation are then obtained when adding sufficient amount of water to this sample to achieve the selected desired degree of saturation. Table 2 shows the values of the unconsolidated undrained shear strength of soil measured by performing the unconsolidated undrained triaxial compression test according to ASTM D2850-03a (2007) for each particular degree of saturation.

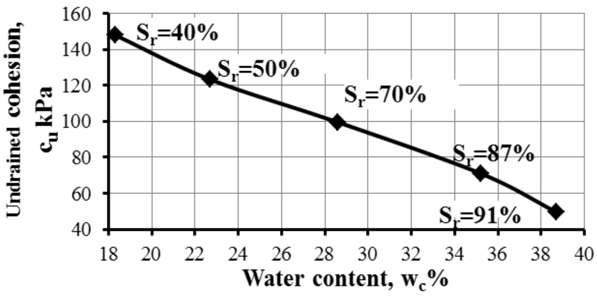

Figure 2. Variation of the undrained shear strength with water content.

Table 1. Physical properties of the used mixed soil

Property	Value	Standards
Liquid limit	110	B.S. 1377 (1990)
Plastic limit	40	ASTM D4318
Plasticity index	70	
Specific gravity	2.805	ASTM D854
Maximum dry unit weight, γ_{dmax}kN/m^3	13.6	ASTM D1557
Optimum moisture content, OMC %	28.3	

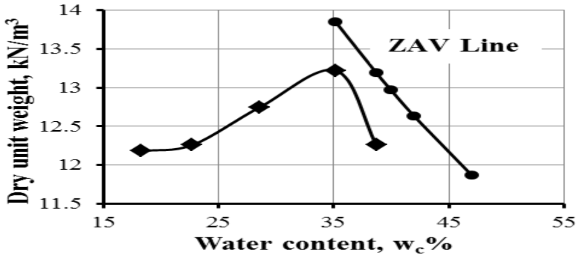

Figure 3.Dry unit weight- water content relationship from static compaction test.

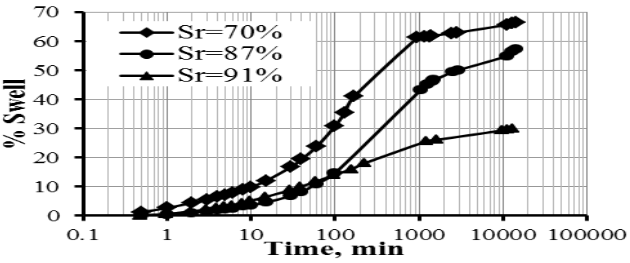

Figure 4. Swelling - time relationship for samples prepared at different initial degrees of saturation.

Table 2. Values of the undrained cohesion c_u for samples prepared at different initial degrees of saturation.

Initial degree of saturation, S_r %	Undrained cohesion, c_u, kPa
100	36
90	66
80	85
70	149

5 SUCTION VALUES OF DIFFERENT INITIAL DEGREES OF SATURATION

The filter paper technique was used in this study according to ASTM D5298-03 to measure the suction values (total and matric) of different initial water contents and hence different initial degrees of saturation. Samples are compacted individually at the same dry unit weight of 12.75 kN/m^3 but at different initial water contents. Figure 5 shows the values of suction (total and matric) for different initial degrees of saturation.

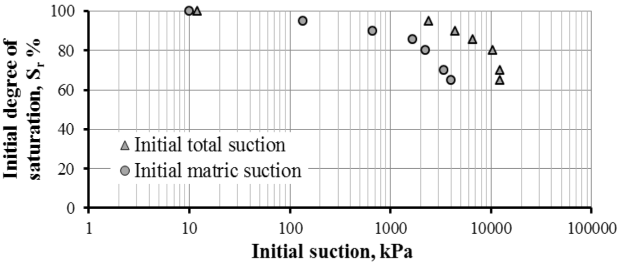

Figure 5. Relationship between the initial degree of saturation and the initial suction (total and matric) measured by the filter paper technique.

6 PULL OUT TEST

Four pull out tests have been carried out on a single pile embedded in soil compacted individually at the same dry unit weight of 12.75 kN/m^3 but at different initial degrees of saturation namely; 100, 90, 80, and 70% as shown in Figure 6. The ultimate uplift load (skin resistance) is taken as the maximum value of the load on the load–displacement curve. According to BSI Code of Practice for Foundation No.4, (1954), the ultimate load capacity is that load at which the rate of settlement continues at a constant rate without increasing of the applied load. It is apparent that the skin resistance arrived to the peak value and then dropped to the residual. Figure 6 demonstrates that there is an increase in the pile uplift capacity (shaft capacity) with the decreasing in the individual degree of saturation and increase in the initial matric suction. This is due to the increase in shear strength of soil with the increase in matric suction. This behavior was also observed by Vanapalli and Taylan (2012) who measured the ultimate shaft bearing capacities of model piles embedded individually in soil having different initial water contents and matric suctions. Fredlund and Rahardjo (1993) stated that the shear strength of soil reaches a maximum before it begins to reduce with further increase in suction.

The ultimate shaft capacity increases about 49% when the initial degree of saturation of the soil decreases from 90 to 70%.

The ultimate uplift stress (skin resistance) is calculated at different initial degrees of saturation by dividing the ultimate load by the surface area of the pile. Figure 7 shows the relationship between the ultimate uplift skin stress (skin resistance) with the initial degree of saturation. It is obvious that the ultimate uplift skin stress decreases with the increase in the initial degree of saturation. This behavior is due to the increase in the unconsolidated undrained cohesion and the initial matric suction with the decrease in the initial degree of saturation and that will affect the adhesion factor α which decreases with the increasing of the undrained shear cohesion c_u as will be given later. Figure 8 shows the relationship between the ultimate uplift skin stress (skin resistance) and the initial matric suction. It is obvious from this figure that the uplift stress capacity increases as the initial matric suction increases.

The adhesion factor was calculated for each model by dividing the shear stress of the clay mobilized as a skin friction on the pile shaft (ultimate skin uplift stress) by the shear strength of the soil as stated by Tomlinson and Woodward (2015).

Figure 9 indicates the relationship between the adhesion factor and the unconsolidated undrained cohesion c_u. It is shown from this figure that there is a non-linear decrease in the adhesion factor as the unconsolidated undrained cohesion increases. This trend of the relationship is also observed by Peck et al. (1974), Wealtman and Healy (1978) and Bowles (1996) as illustrated in Figure 10 which shows a good agreement between the present experimental results and past works. Further discussions may be consulted in a thesis by Fadhil (2015).

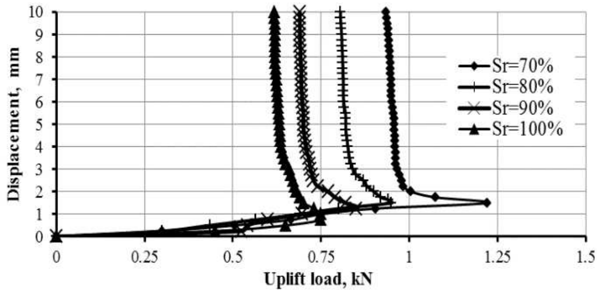

Figure 6. Uplift tension load-displacement behavior of a single pile embedded in soil compacted individually at different initial degrees of saturation.

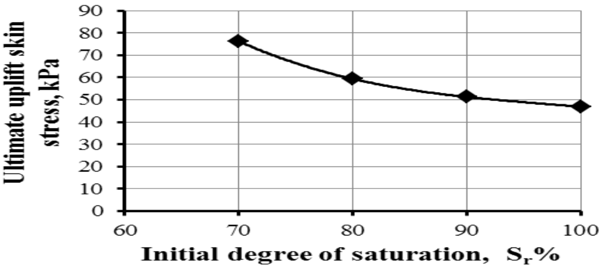

Figure7 . Relationship between the ultimate uplift skin stress and the initial degree of saturation.

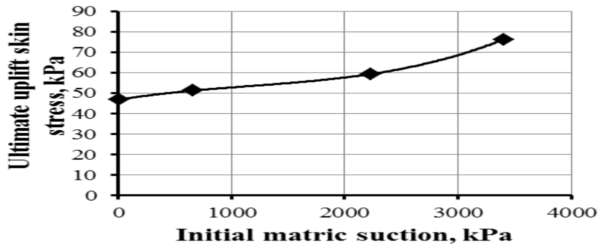

Figure 8. Relationship between the ultimate uplift skin stress and the initial matric suction.

Murthy (2003) stated that it is possible that the value of the adhesion factor under a swelling condition be equal to 1.0 or more according to the swelling type and environmental conditions of the soil. Furthermore, Bowles (1996) mentioned that the adhesion factor α can be larger than 1 when c_u is less than about 50 kPa, this is appeared in the present experimental results, when c_u = 36 kPa, the adhesion factor α is found to be 1.3.

Another relationship can be presented between the adhesion factor and the initial matric suction as shown in Figure 11 which shows that the adhesion factor decreases as the initial matric suction increases. This behavior was also concluded by Vanapalli and Taylan (2012) who measured the adhesion factor on model piles embedded individually in soil having different initial water contents and matric suctions. Figures 12 and 13 show the relationship between the adhesion factor α with the ultimate uplift skin stress and the initial degree of saturation, respectively. It is shown that the adhesion factor α decreases with the increase in the ultimate uplift stress while it increases with the increase in the initial degree of saturation. This is due to the fact that the undarained cohesion c_u and the initial matric suction decrease with the increase in the initial degree of saturation and this is reflected on the ultimate up-lift stress as shown in Figure 7.

The previous studies correlated the adhesion factor, α with either undrained cohesion, c_u or the depth of the soil layer, in this study correlation of the adhesion factor with the initial degree of saturation, S_r, is presented in the following equation and as shown in Figure 13.

$$\alpha=3-0.017\ S_r^{1.5}+0.00153\ S_r^2 \qquad 70\leq S_r\leq 100 \qquad (1)$$

This relation is obtained with a coefficient of determination (R^2) of 0.96.

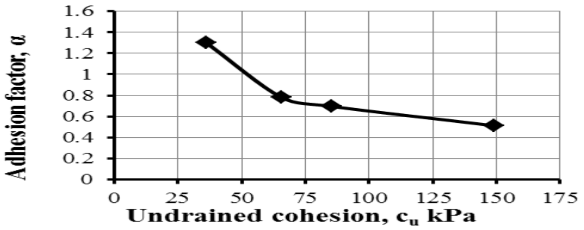

Figure 9. Relationship between the adhesion factor and the unconsolidated undrained cohesion.

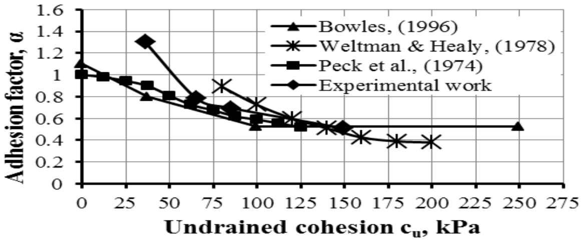

Figure 10. Comparison of the relationships between the adhesion factor and the unconsolidated undrained cohesion.

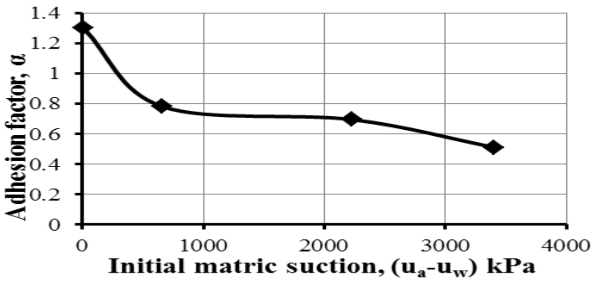

Figure 11. Relationship between the adhesion factor and the initial matric suction.

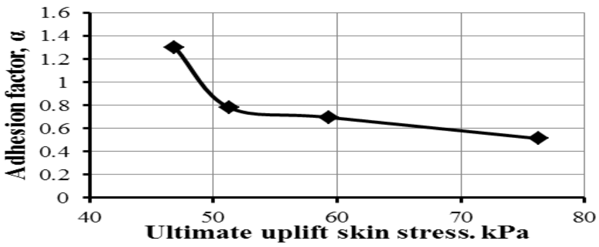

Figure 12. Relationship between the adhesion factor and the ultimate uplift skin stress.

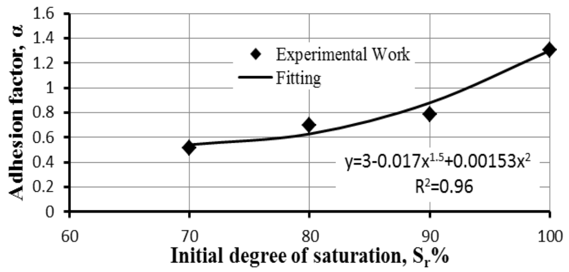

Figure 13. Relationship between the adhesion factor and the initial degree of saturation.

7 CONCLUSIONS

1. The results of the pull out test conducted on a single pile embedded in soil compacted individually at different initial degrees of saturation reveal that the ultimate shaft capacity (skin resistance) increases nonlinearly as the initial degree of saturation decreases and the initial matric suction increases. This is due to the increase of shear resistance as the matric suction increases. The ultimate skin resistance is increased about 49% when the initial degree of saturation decreases from 90 to 70%.
2. The adhesion factor obtained from the experimental work increases as the unconsolidated undrained cohesion decreased and as the initial matric suction decreased. The adhesion factor reached a value of 1.3 when the undrained cohesion is 36 kPa, initial degree of saturation of 100% and initial matric suction of 10 kPa. A good agreement is noted between the results of the adhesion factor obtained in the present work and that obtained in past works as given in Fig. 10.
3. A correlation was obtained between the adhesion factor and the initial degree of saturation as presented in equation (1).

8 ACKNOWLEDGMENTS

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