Plug Length Developed in Pipe Pile Embedded Within Partially Saturated Cohesionless Soils (Part 1)

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ABSTRACT:

This paper presents an experimental study to investigate the change of plug length for pipe pile under different state of saturation and investigate the effect of number of pipe piles on plug length. The influence of matric suction (i.e., capillary stresses) in unsaturated zone is typically considered on the plug length of pipe piles.

The experimental work consist of testing 20 models of pipe piles, these models divided into 4 different configuration of pipe piles; single pipe pile, group of double pipe piles, group of triple pipe piles and group of six pipe piles. All these models are loaded and tested under three different states; dry condition, fully saturated condition (i.e., matric suction equals to 0 kPa) and unsaturated conditions with three different matric suction values (6, 8 and 10 kPa), which are achieved by predetermined lowering of water table. The relationship between matric suction and depth of ground water table was measured in suction profile set by using three Tensiometers (IRROMETER). The soil, water characteristic curve (SWCC) was estimated by applying fitting methods through the program (Soil Vision).

The results of experimental work demonstrate that the values of plug length decreased with increase in value of matric suction for the same configuration of pipe piles, and the values of plug length decreased with increase in number of pipe piles.

Keywords: Partially saturated soil, SWCC, soil suction, pipe pile, soil plug.

INTRODUCTION:

Pipe piles have broadened their usage in the piling industry due to their relatively high strength of material and speed of installation. The load capacity of pipe pile is often considered to contain two major factors: the friction along pile shaft resistance and the end-bearing from pile tip resistance (Lu 1985; Smith et al. 1986; Paikowsky and Whitman 1990).

Open-ended piles cause less change in the soil state than closed-ended piles with the same diameter, but more than non-displacement piles with the same diameter. A major difference between closed- and open-ended piles is the possible formation of a "soil plug" inside the open-ended pile during driving. If no soil entered the pile during installation, open-ended piles would behave exactly as closed-ended piles. As the soil enters the pile, frictional resistance is mobilized between the soil and the inner surface of the pile. Until sufficient friction develops between the soil

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plug and the pile inner surface and the plug becomes sufficiently stiff, soil continues to enter the pile. The base resistance of open-ended piles is a combination of the soil plug resistance and the annulus resistance (Lee and Salgado 1999a, 2000).

Partially saturated soil is the most common material encountered in the field of geotechnical engineering. Yet, mechanics of partially saturated soil lags far behind that of saturated soil. A partially saturated soil is a complex multi-phase system consisting of air, water and solid material whose response is a function of the stress state, moisture condition and other internal variables present within the soil. Experimental and theoretical difficulties (e.g. direct measurement of suction, large number of influencing factors) delayed considerably the development of an understanding of the behavior of partially satur0ated soils. It is only during the last few decades that theoretical frameworks and constitutive models have been proposed to describe the mechanical behavior of such soils.

Paik et al. (2003) described the driving response and static bearing capacities of open-ended piles affected by the soil plug that forms inside the pile during pile driving. In order to investigate the effect of the soil plug on the static and dynamic responses of an open-ended pile and the load capacity of pipe piles, field pile load tests were performed on instrumented open-ended and closed ended piles driven into sand. For the open-ended pile, the soil plug length was continuously measured during pile driving, allowing calculation of the incremental filling ratio for the pile. The cumulative hammer blow count for the open-ended pile was 16% lower than that for the closed ended pile. The limit unit shaft resistance and the limit unit base resistance of the open-ended pile were 51% and 32% lower than those corresponding values for the closed-ended Pile. It was also observed, for the open-ended pile, that the unit soil plug resistance was only about 28% of the unit annulus resistance, and that the average unit of frictional resistance between the soil plug and the inner surface of the open-ended pile was 36% higher than its unit outside shaft resistance.

Lehane et al., (2005) showed that incorporated plugging into design practice in the ICP-05 and UWA-05 design approaches in sandy soil. The effect of plugging piles increase base resistance in pipe piles, from (five to seven) times the ultimate base resistance with piles moved from the coring to fully plugged condition. In general, for clay soil the amounts of base resistance are much less than total capacity of closed-ended piles. This may explain the historical lack of research examining the effects of plugging on the resistance of piles in clay.

Experimental Work:

Description and details of the material properties, foundation soil preparation, loading frame and apparatus, testing program techniques and manufacturing of the set-up required to perform the pressed model piles under static loading are presented in this section.

- Soil material

The soil used in this study is dry sand obtained from Baghdad city (Abu Nawas) site. The standard tests are performed to determine the physical properties of the soil as follows:

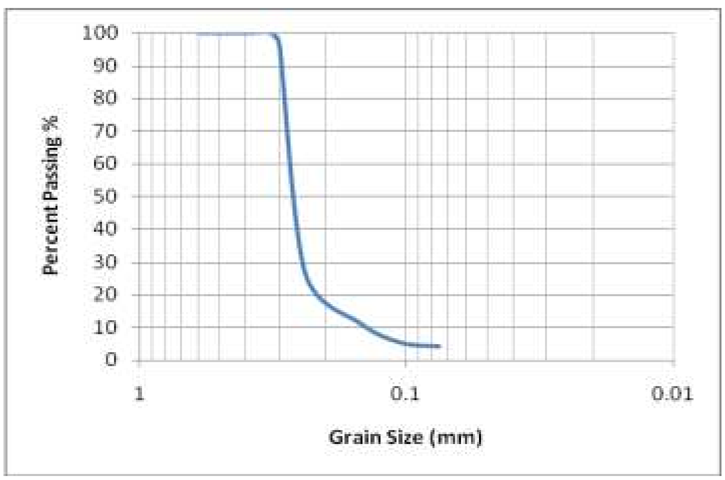
1. Specific gravity.
2. Grain size distribution.
3. Maximum and minimum dry unit weight, and
4. Direct shear test.

The grain size distribution of the sand used is shown in figure (1), and the testing result is shown in table (1). The soil bed is prepared by adopting raining fall technique with relative density of (65%).

Table (1): Physical properties of the sand used in present study.

Property	Value	Specification
Effective size, D_{10}	0.14	
Coefficient of uniformity, C_u	1.98	
Coefficient of curvature, C_c	1.60	
Classification (USCS)	SP	
Specific gravity, G_s	2.685	
Maximum unit weight, $\gamma_{d(max)}$, kN/m^3	16.16	ASTM D854- 02
Minimum unit weight, $\gamma_{d\,(min)}$, kN/m^3	13.34	ASTM D4253-00
Maximum void ratio, e_{max}	0.97	
Minimum void ratio, e_{min}	0.63	

Figure (1): Grain size distribution.



- Model set-up formulation:

All the model tests were conducted using the setup shown in Plate (1), which consists of steel frame, steel soil tank, pipe pile models, pile cap model and apparatus of applied vertical load on the pile models of 10 ton capacity (hydraulic compression handle jack). During all the experimental tests, the loading rate is kept approximately the same. The applied load is measured using a load cell with 2 ton capacity. A digital weighing indicator is used to read and display the load value. Two deformation dial gages with 0.01 mm sensitivity have been used for measuring the displacements of the pipe pile model and three Tenseometer were used to measure the matric suction within the soil.

Plate (1): The loading and measuring system assembly

- Pipe piles model and pile cup:

The pipe pile models used in this study are steel hollow pipes each of circular cross section with (23mm inner diameter and 26mm outer diameter and 500mm length) as shown in plate (2). The pile caps used for pile groups were made of steel plate with smooth surface having a thickness of 14 mm. Four steel caps with smooth surface of (80×75) mm, (160×75) mm, (220.5×75) mm and (230.5×150) mm for (1×1), (1×2), (1×3), and (2×3) pile groups respectively were used. These dimensions were chosen to fit in configuration with pile groups. Circular groves of 27 mm diameter were made in each cap for fixing and aliment the piled during installation, these groves were distributed according to the dimension and spacing of piles as shown in plate (3).

Plate (2): Pipe piles

Plate (3): Caps of pile

Direct Measurement of Soil Suction (Tensiometer Method):

A Tensiometer is used for measuring the negative pore water pressure. This method depends on placing the Tensiometer in contact with the soil. A good contact, by forcing the probe into the soil, is necessary to ensure that there is a continuation of the water phase from the soil to the Tensiometer"s filter. The principle of this method is that the water pressure in the high air entry material will come to equilibrium to the water pressure of the soil making it possible to measure the pore water pressure. Since a true semi permeable membrane is not available, only the matric suction will be measured by this technique and not the osmotic suction (Take and Bolton-2003).

The Tensiometer (IRROMETER) is able to measure the soil suction in kilopascals in a range between 0-100. It is able to detect the changes in the soil moisture content with several hours after installation, in the case of poor drainage soil; it may take longer time (IRROMETER Manual Book, the IRROMETER Company Inc.). The hand vacuum pump supplied with the Tensiometer will apply a vacuum pressure between (80-85 kPa) to release the air entrapped in the ceramic disc, Plate (4) shows the details of Tensiometer used with its accessories.

Plate (4): IRROMETER (IRROMETER Manual Book, IRROMETER company, Inc.)

Results of Suction Profile Set:

In this study three Tensiometers installed at different depths below the soil surface to measure the suction in the sand (plate 5) and the period to achieve equilibrium conditions was 24 hours.

The suction values of the soil for the suction profile set are determined using three Tensiometers. The first Tensiometer was installed at 7.5 cm below the soil surface, the second was installed at 22.5 cm below the soil surface and the third was installed at 37.5 cm below the soil surface. The soil was initially saturated by raising the water level in the container from bottom to ensure fully saturation and escape air from soil .The water table was then lowered to 15cm below the soil surface (i.e. first stage) for a period of 24 hours to let capillary suctions reached the equilibrium conditions .

Plate (5): Inserting three Tenseometers for profile set suction

This procedure was repeated by varying depth of water table below the soil surface to another different levels (30 cm and 45 cm) (i.e. second stage and third stage) respectively. Then the matric suction is measured after 24 hours. Figure (2) summarizes the measured suction values above the water table for the three stages.

The suction profile of the soil used shows that the matric suction increases with the lowering of water table .The soil suction near soil surface (7.5 cm below the soil surface) increases steeply as the depth of water table increases. According to (Li, 2008) and (Sun, 2011) the rapid increase of matric suction values at the soil surface of sand may be attributed to evaporation of water from soil surface. Table (2) shows the results of the corresponding average matric suction for lowering water table suction profile set.

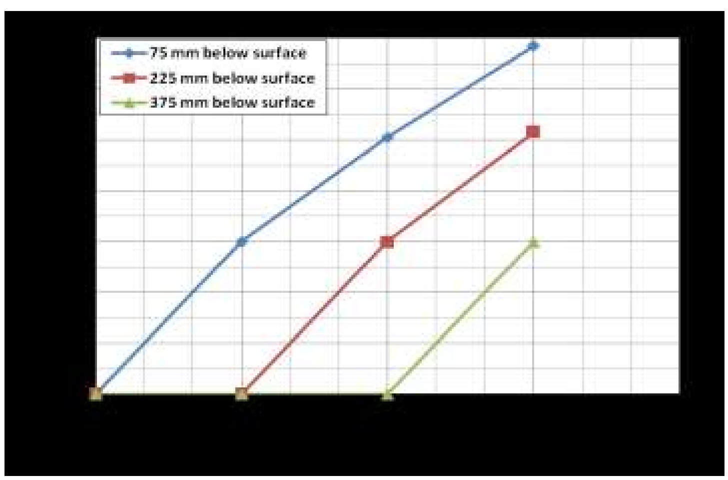


Figure (2): Matric suction values for three stages of water table below soil surface.

Table (2): Summarized results of the corresponding average matric suction for lowering water table suction profile set.

Corresponding average Matric suction in (kPa)	Lowering of Water table From soil surface in (cm)	Soil conditions
0	0	Fully saturated
6	15	Partially Saturation
8	30	
10	45	

SWCC Estimated by Tensiometer:

The SWCC for this soil was measured by using Tensiometers which were inserted in the suction profile model at different depth (i.e. 7.5 cm, 22.5 cm and 37.5 cm).

Figures (3) and (4) show the SWCC for the soil as estimated by the Fredlund and Xing and Van Genuchten equations respectively with the aid of Soil Vision program

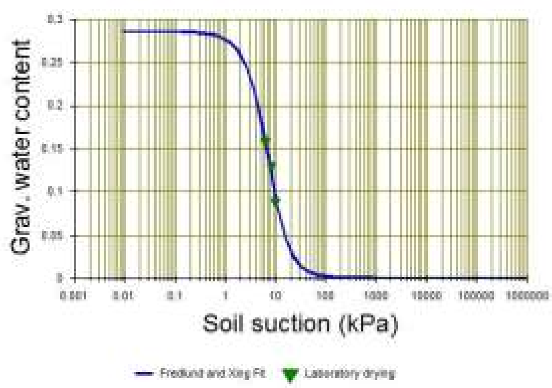


Figure (3): Relationships between the gravitational water content and the matric suction obtained by the program soil Vision. by using Fredlund and Xing

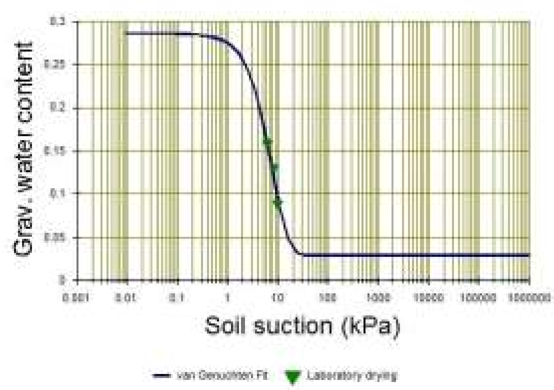


Figure (4): Relationships between the gravitational water content and the matric suction obtained by the program soil Vision. by using Van Genuchten equation

The changes in slope defined two points that are pivotal to describe the SWCC (Fredlund et al 2011). The first point termed "air-entry value" is the matric suction where air starts to enter the largest pores in the soil. The second point is defined as "Residual water content" which is the water content where a large suction change is required to remove additional water from the soil. Fredlund and Xing 1994 distinct three zones that can be illustrated from the SWCC by the changes in slope, namely, the "boundary effect zone". In the lower suction range, the "transition zone" is adopted between the air- entry value and the residual value.

From the soil water characteristics curve, figures (3) and (4), fitting curves proposed by

Fredlund and Xing 1994 and Van Genuchten 1980, the air–entry value $(u_a - u_w)_b$ (kPa) was 2.37 kPa and 2.4 kPa respectively.
In general, the shape of the curves is not affected by the different parameters in each equation; however, the parameters show large variations in value depending on the number of data points used for the curve fit (E.C.Leong-1997). For this reason there is no large difference between these curves and no observed change in the slope of the curves.

Test procedure:
1- Soil Bed Preparation: A layer of filter material placed at the base of the soil container which was designed according to soil used to prevent corrosion of soil particle during dewatering and prevent excess pore water pressure. This filter layer compacted to the same density of the soil samples to have the same resistance. A double layer of Geo-mesh was placed above this layer to prevent the mixing between the soil and the filter material. After that the sand was placed in the container according to the raining technique, i.e. maintaining the dropping height constant for controlled density. After conducting each test, the sand at the container removed to a depth of the filter layer. During the process of sand raining, the piles were placed at the center of the container by using steel plates to fix the model piles vertically, and then the raining was continued to the level of the lower surface of the raft. The final layer of the sand is leveled by a sharp edge ruler then the raft model is placed carefully above the piles to be in touch with the soil and piles at same time.
2- Soil saturation: Water supplier was connected to the lower valve of soil container using a thin plastic tube. This valve fixed at the base of the soil container to provide access of water to the prepared sand in the container under a controlled head of water. Water flows through a filter soil layer in container base and rises up from bottom slowly until the sand is fully saturated (i.e. the water table reaches the sand surface in the container).This technique facilitated escape of air from bottom to the surface layers of the sand in the container gradually to ensure a fully saturated condition.
3- Tests under fully saturated condition: The adjustments of the water level were inspected periodically in the Piezometers. The supplier valve was closed once the water level reached the soil surface in the tank. Then all the model tests were conducted at the fully saturated state under zero suction value.
4- Tests under unsaturated conditions: The water table was then lowered down (using drainage valves) to a different levels below the soil surface (i.e.,15 cm , 30 cm and 45 cm) to achieve different suction values. Equilibrium conditions with respect to suction value in the soil were typically achieved at a period of 24 hours. Then bearing capacity of pipe piles in unsaturated soil was measured by loading test under different average suction values.
5- Measurement of plug length and Incremental Filing Ratios (IFR): Formation of a soil plug in an open-ended pile is a very important factor in determining pile behavior during insertion of the pipe. The degree of soil plugging can be represented by the incremental filling ratio (IFR), which defined by Iskander (2010), as the increase in soil plug length inside pipe pile per unit increase of penetration depth of pile in soil.
IFR was measured during pile instillation by steel measure tape every 2.0cm insertion of pipe piles and by using the following relationship IFR was determined.
$IFR\% = (L_2 - L_1) / (D_2 - D_1) \times 100$

Where:
L_1 = Length of Plug before pressing, L_2 = Length of Plug after pressing

D_1 = embedded depth of pipe pile before pressing, D2 = embedded depth of pipe pile after pressing

Soil plugging:

During installation of pipe pile, a soil column is formed inside the pile. For small depths, the height of the soil column typically equals to the penetration depth (full coring state). As the penetration depth increases, the developed internal shear stresses become larger and reduce the amount of soil to penetrate. At the same time, the soil in pile at the bottom is compacted. This will continue for a short time, and then the soil column forms a plug, and does not move relative to the pile. This is because the shear stresses developed in the interior pile are greater than the load-bearing capacity of the soil. An open-ended pipe pile is said to be plugged when the soil inside the pile moves down with the pile, resulting in the pile becoming effectively closed-ended. Plugging is believed to result in an increase in horizontal stresses between the pile and the surrounding soil, which results in an increase in skin friction.

Under static conditions, both theoretical analyses and experiments have shown that plugging occurs with only a small pile penetration (Murff et al., 1990).

Table (3) illustrates the variation of plug length values for different soil conditions (dry, fully saturated and unsaturated with matric suction 6, 8 and 10kPa) for different configurations of pile groups (1x1, 2x1, 3x1 and 2x3).

Table (3): Variation of plug length values at the end of pressing of pipe piles for different soil conditions and different configuration of pile groups.

Soil Condition	Configuration	Average Plug Length (cm)
Dry state	1×1	7.0
	2×1	6.6
	3×1	6.2
	2×3	5.4
Full saturation 0 kPa	1×1	9.0
	2×1	8.7
	3×1	8.1
	2×3	7.3
Unsaturated 6 kPa	1×1	8.5
	2×1	8.0
	3×1	7.8
	2×3	7.0
Unsaturated 8 kPa	1×1	8.2
	2×1	7.7
	3×1	7.4
	2×3	6.8
Unsaturated 10 kPa	1×1	7.6
	2×1	7.3
	3×1	7.1
	2×3	6.4

From table (3) it can be seen that the average values of plug length decreases with increasing the number of pipe piles, for example the value of plug length decrease from (9 cm) in single pipe pile to the (8.7 cm), (8.1 cm) and (7.3 cm) in (2×1), (3×1) and (2×3) configuration respectively in full saturation state, and that due to the group effect which tend to the amplify the displacement on stresses and soil densification during pressing the piles. Also it shows that average values of plug length decreases with increasing the average value of matric suction after fully saturated condition and the lowest plug pile length is at dry condition. This occurs due to the increase in effective stress of soil during lowering the water table. In another word, during the lowering of water table, the friction resistance along the pile shaft will increase due to the

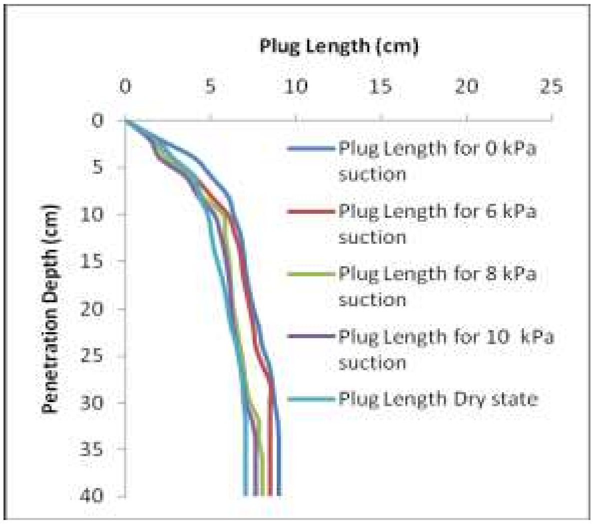


Figure (5): Average soil plug length for single pipe pile of 40 cm long pressed in different state soil (dry, full saturation and unsaturation with average matric suction (6, 8 and 10 kPa).

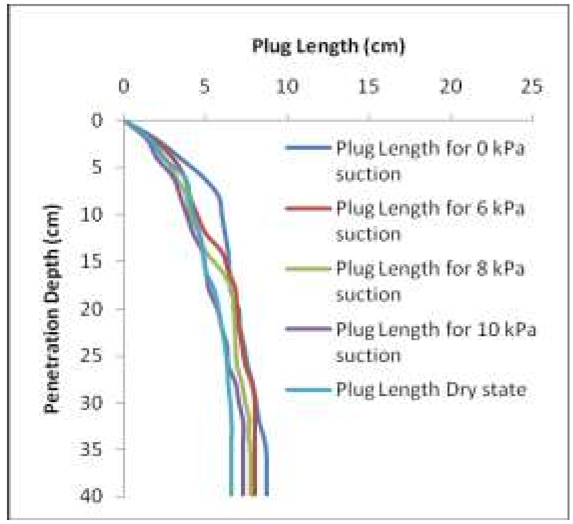


Figure (6): Average soil plug length for group of double pipe piles of 40 cm long pressed in different state soil (dry, full saturation and unsaturation with average matric suction 6 , 8 and 10 kPa).

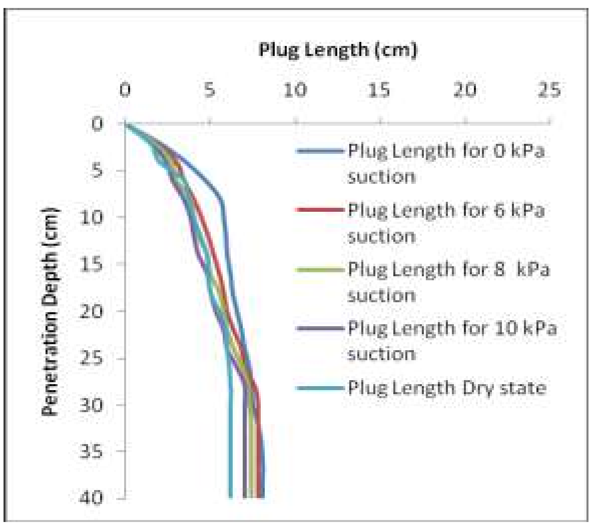


Figure (7): Average soil plug length for group of triple pipe piles of 40 cm long pressed in different state soil (dry, full saturation and unsaturation with average matric suction 6 , 8 and 10 kPa).

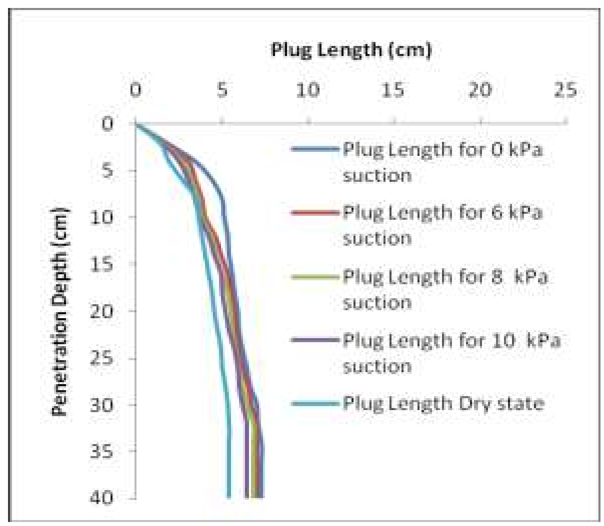


Figure (8): Average soil plug length for group of six pipe piles of 40 cm long pressed in different state soil (dry, full saturation and unsaturation with average matric suction 6 , 8 and 10 kPa).

increase in effective stress which agreed with Escrio and Juca (1989), who shows that shear strength for such soil increases where the degree of saturation approaches to zero value (which is the maximum increment of the soil suction).

Figures (5) to (8) shows the relationship between average soil plug lengths for different configurations of pile groups (single , double, triple and six pipe pile group) pressed in different soil conditions (dry, full saturation and unsaturation with average matric suction 6, 8 and 10 kPa). The figures show that a marginal increase in plug length with increasing soil suction accompanied with a little discrepancy during insertion, and this attribute to the small scale model used in testing. Table (3) shows clearly in numbers the difference in plug length for different pipe pile group configurations inserted within different soil state conditions of different soil suctions.

CONCLUSIONS:

1. From the test results it can be noticed that there is an influence of matric suction on the plug length of all the tested models. These results show that there is a relationship between the SWCC and the plug length for pipe piles.
2. From the results of pipe pile models test it can be notice that the values of plug length decreased with increase in value of matric suction for the same configuration of pipe piles, and the plug length ratio decreased with increase in number of pipe piles.
3. The soil plug length with penetration depth changed during press of the open-ended pipe pile until the pile reached a fully plugged state (for which plug length would be constant value).
4. The steeply increase in soil suction near soil surface is attributed to evaporation of water from soil surface.
5. The SWCC was drawn with the aid of Soil Vision program and the experimental results obtained from the Tensiometer apparatus. The suction tends to decrease with the increase in soil initial water content because increasing the water content will increase radius of meniscus and that will decrease the soil suction.

REFERENCES:

[1] Abdullah I, Al-Mhaidib A. (1999). “Bearing capacity of a model pile in sand under different loading rates”. Int Soc Offshore Polar Eng. 1:724–730.

[2] Berney E. S., Peter J.F., and Smith D.M (2003), "The Thermodynamics of Three-Phase Partially Saturated Soil". 16th ASCE Engineering Mechanics Conference. University of Washington, Seattle, USA, PP. 3-21.

[3] Carter, J.P, Randolph, M.F., and Wroth, C.P (1979), “Some Aspects of the Performance of Open and Closed – Ended Piles”, Numerical Method in Offshore Piling, London, pp.165-170.

[4] Escario, v., and Juca, J., (1989), "Strength and Deformation of Partly Saturated Soils", Procceding of 12 th International Conference on Soil Mechanics and foundation Engineering, Roi de Janeiro, Vol. 3, pp. 43-46, (Cited by Vanapalli, et al., 1996).

[5] Fredlund, D.G., and Xing, A. (1994), "Equations for the Soil Water Characteristic Curve". Civil Engineering Department, University of Saskatchewan, Canada Geotechnical Engineering Journal, Vol. 31, pp. 521 – 532.

[6] Fredlund, D.G., Sheng, D. and Zhao, J., (2011), "Estimation of soil suction from the soil-water characteristic curve", Canadian. Geotechnical Journal Vol.48, pp. 186–198.

[7] Iskander, M. (2010), “Behavior of Pipe Piles in Sand Plugging and Pore-Water Pressure Generation During Installation and Loading”, Springer Series in Geomechanics and Geoengineering.

[8] Lehane, B. M., Schneider, J. A. & Xu, X., (2005), “The UWA-05 Method for Prediction of Axial Capacity of Driven Piles in Sand. Perth, Taylor & Francis, pp. 683-689.

[9] Leong, E.C., He, L., Rahardjo, H., (1997), "Review of Soil- Water Characteristic Curve Equation", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 123(12), pp. 1106-1117.

[10] Li, X., (2008), "Laboratory Studies on the Bearing Capacity of Unsaturated Sands ", MSc. Thesis, University of Ottawa.

[11] Murff, J. D., Raines, R. D., and Randolph, M. F. (1990), "Soil Plug Behavior of Piles in Sand", Proceedings of the 22nd Offshore Technology Conference, Houston, OTC 6421, pp. 25 –32.

[12] Paik K, Salgado R, Lee J, Kim B. (2003). "Behavior of open- and closed-ended piles driven into sands". Journal of Geotechnical Engineering,Vol. 129(4):296–306.

[13] Pan, H., Qing, Y., and Pei – Yong, L., (2010), "Direct and Indirect Measurement of Soil Suction inthe Laboratory", Electronic Journal of Geotechnical Engineering, Vol.15, Bund. A.

[14] Sun, R. (2010), "Bearing Capacity and Settlement Behavior of Unsaturated Soils from Model Footing Tests ", M. Sc. Thesis, University of Ottawa, Canada.

[15] Szechy, C. (1958), " Test of Tubular Pile", Acta Technical, Hungarian Academy of Science, 24, pp. 181-219.

[16] Szechy, C. (1961), " The Effect of Vibration and Driving Upon the Voids in Granular Soil Surrounding a Pile", Proceedings of the 5th International Conference on Soil Mechanics and Foundation Engineering, 2, pp.161-164.

[17] Take, W. A. and Bolton, M. D. (2003), "Tensiometer Saturation and the Reliable Measurement of Soil Suction", Geotechnique, Vol. 53, No. 2, pp. 159-172.

[18] Van Genucten, M. T., (1980), "A Closed-Form Equation for Prediction They Hydraulic Conductivity of Unsaturated Soils", Soil Science Society America Journal, Vol 44, pp. 892 – 898.