Soil suction and infiltration comparison between measured and computer prediction

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Soil suction and infiltration comparison between measured and computer prediction.

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ABSTRACT: Slope stability is an important aspect of man made or natural slope fringing human activities. Various expect of design need to consider before cost effective and stable slope is proposed. Tropical countries like Malaysia, which is exposed to heavy monsoon rainfall, slope failure is a common and serious event. Many researches have been carried out to study the slope failure mechanism to prevent catastrophic failures. Studies like risk and hazard mapping database analysis of slope failure with rainfall intensity and pattern, behavior of soil suctions etc. At University of Malaya, Kuala Lumpur research was carried out to study the influence of rainfall on soil matric suction. A full-scale model of rainfall simulation system was built at the field to conduct the study. The infiltration of rainwater into slope, reducing matric suction at the unsaturated zone was monitored in the research. Theoretically, the infiltrating rainwater into the slope reduces matric suction and increases pore pressure, resulting in gradual drop in shear strength to a point where stability can no longer sustained in the slope. This research was engineered to study the matric suction changes at the field and correlate the results with computer model.

1 INTRODUCTION

The research involves comparison study of field test data and computed results using engineering software with regards to rainfall and its influences on soil matric suction. In order to conduct this study a cut slope was utilized a long the link road to Kuala Lumpur International Airport with the assistance of Malaysian Public Works Department. The geological formation of the slope consists of various weathering grades, typical of Malaysian sedimentary residual soil. The 30m high cut slope exposed weathering grades ranging between II to VI. In this paper test results performed at grade V soil are presented. Figure 1.0 shows the description given by Geological Society of Engineering Group for residual soil weathering grades. Figure 2.0 indicates the geological map showing the subsoil stratification and zones of soil weathering grades of the said cut slope.

2 UNSATURATED SOILS

The mechanism of suction caused failure of slope is due to water infiltration that causes reduction of matric suction in soil under unsaturated state. This leads to decrease in effective stress of the soil strength to a point where equilibrium can no longer be sustained in the slope. The equation for unsaturated shear strength is written in terms of the stress state variables with an extension for saturated soils. (Fredlund D.G. et al , 1978).

$$\tau = c' + (\sigma - u_a) \tan \phi' + (u_a - u_w)\tan\phi^b \quad \text{----------(1)}$$

where:
c' = effective cohesion , σ = total stress ,
u_a = pore -air pressure, u_w = pore water pressure,
ϕ' = effective angle of internal friction ,
$(u_a - u_w)$ = matric suction,
ϕ^b = angle indicating the rate of increase in shear strength with respect to changes in $(u_a - u_w)$ when $(\sigma - u_a)$ is held constant.

The above equation assumes a planar failure envelope, the internal friction angle ϕ‘, remains constant under saturated and unsaturated condition. The angle ϕ^b , which quantifies the effect of suction is measured from the τ vs $(u_a - u_w)$ plot. The cohesion intercepts c_1, c_2 and c_3 due to the applied suction $(u_a - u_w)$ vary if the angle of internal friction ϕ' remains constant at different suction levels.

Figure 1 : Schematic representation of tropical soil weathering profiles.

Figure 2 : Geological map of the cut slope

3 SOIL SUCTION

Soil suction commonly called `total suction' can be subdivided into two component on the basis of forces responsible for the differences in energy between the water in question and the reference state. The two components are:

i) Matric Suction, ii) Osmotic Suction

The total matric, osmotic suction can be defined as follows (Aitchison, 1965), "Matric or capillary component of the free energy''. – In suction terms, it is the equivalent suction divided from the measurement of partial pressure of water vapor in equilibrium with soil water, relative to the partial pressure of water vapor in equilibrium with a solution identical in composition with soil water."

"Osmotic (suction) component of the free energy".- In suction terms, is the equivalent suction derived from the measured partial pressure of water vapor in equilibrium with a solution identical in composition with soil water, relative to the partial pressure of water vapor in equilibrium with free pure water'.

"Total suction of free energy of soil water". In suction terms the equivalent suction derived from the measured partial pressure of water vapor in equilibrium with a solution identical in composition with soil water, relative to partial pressure of water vapor in equilibrium with free pure water''.

The above definitions clearly state that the total suction corresponds to the free energy of soil water, while the matric and osmotic suction are the components of the free energy, Thus this can be written in an equation: -

$$\psi = (U_a - U_w) + \pi$$

ψ = Total Suction, $(U_a - U_w)$ = Matric Suction
U_a = Pure Air Pressure, U_w = Pure Water Pressure,
π = Osmotic Suction

However osmotic suction is related to the salt content in the pure water which is present in the both saturated and unsaturated soils. Hence changes in osmotic suction is less significant. In this research much attention was given in measuring matric suction at the field.

4 FIELD MEASUREMENT

For field suction measurement three type of tensiometer were used, namely:

i. Jet fill tensiometer,
ii. Small tip tensiometer
iii. Quick draw tensiometer

Jet fill and small tip tensiometer were installed on to the slope to monitor the soil suction changes with rainfall. Quickdraw tensiometer was used to study the soil-water characteristic at various weathering Grades. The schematic drawing of the above tensiometer is shown in Figure 3.0

As part of the computer model requirement, insitu soil infiltration rate was investigated. Infiltrometer P-88 from Geonor was used to obtain the infiltration capacity of the soil. Figure 4.0 shows the infiltrometer used.

5 SOIL-WATER CHARACTERICTIC

The energy / soil matric suction relationship for water is an important physical properties of unsaturated soil. The soil – water characteristic curve describes the relationship between the amount of water held / moisture in soil as a function of suction to serve the basis of much more important consideration, the magnitude and engineering behavior of soils. It has long been recognized, as energy relation (suction moisture content relationship) of soil for water in multiple value functions (hysteresis effect) that depends upon the moisture history of the sample. The data for the soil – water characteristic is a combination of soil suction measurement with moisture content at both laboratory and filed. Modified Rowe Cell with suction measurement was used to study the soil moisture content at various suction values in the laboratory. Likewise quickdraw tensiometer was used to measure matric suction with various soil moisture content in the field. Figure 5.0 and 6.0 illustrates the modification Rowe Cell and a plot of soil water characteristic curve obtained at study location. The data of soil-water characteristic curve was used as an input in the computer model to simulate the change in suction with given infiltration rate, time and rainfall intensity.

6 FIELD TEST METHOLOGY

An artificial rainfall simulation sprinkler system was set up at the field using steel frame parallel to the slope. The frame was sized at 15 feet by 15 feet with four rows of PVC host fitted with six sprinkler heads on each row. The schematic diagram of the frame and sprinkle head location is shown in Figure 7.0. The required intensity of artificial rainfall was calculated based on the highest rainfall recorded in Malaysia. The inlet water supply was measured and monitored to be constant during the test using a flow meter. Whereby the surface run off water was collected using V-notch collecting drain and measured periodically.

To monitor the suction changes 7 numbers of small tip tensiometer and 4 numbers of jet fill tensiometers were installed. The small tip tensiometers were installed at 10 inches depth perpendicular to the slope surface within the sprinkling frame.Wherelse jet fill tensiometers were installed at 0.5m, 1.0m, 2.0m and 3.0m near to the slope toe and perpendicular to the slope surface. The schematic layout of the installed tensiometer positions with respect to the sprinkling frame and slope shown in Figure 8.0.

The test was performed at constant volume of water supply with artificial rainfall intensity of $2.66m^{-5}$ m/s. The soil suction and surface run off data were measured at 10 minutes intervals. The artificial rainfall was maintained for two and half-hours. And the subsequent time, the suction data were monitored till no further changes in reading.

Figure 3.0 : Schematic drawing of Jet Fill, Small Tip and Quick draw Tensiometer.

7 COMPUTER MODEL

The computer simulation was performed using finite element, seepage analysis software, “SEEP-W” developed by Geo-Slope International Ltd. The field experiment data shown in Figure 6.0 is converted into input parameter of Soil Conductivity and Volume Water Content Function with respect to soil matric suction as shown in Figure 9 and 10 respectively. Figure 11.0 shows the developed computer model to simulate the site condition. Finer messes were given at the location where small tip and jet fill tensiometers were installed. Hence, relative comparison between field data and computed results can be analysed. The field recorded permeability rate of 2.31 X 10^{-6} m/s has also incorporated in the model. The analysis was executed using transient control mode with total run time of 2 hours 30 minutes.

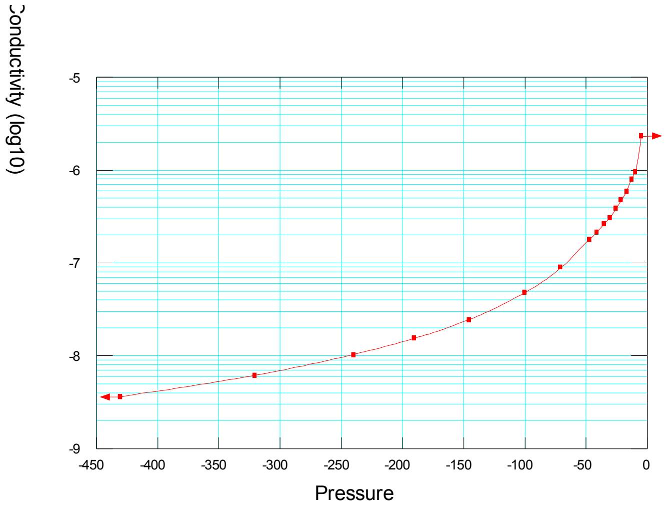

Figure 6 : Soil water characteristic curve obtained at test location

Figure 4.0 : Infiltrometer

Figure 5 : Modified Rowe Cell

Figure 7: Diagram of the sprinkling system

Figure 8 : Tensiometer layout

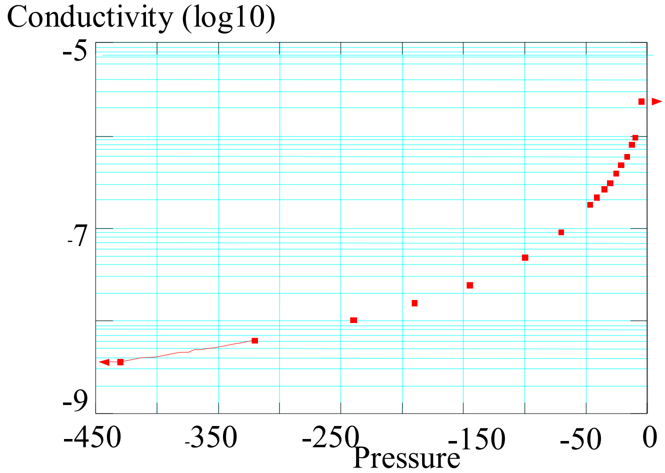

Figure 9 : Soil conductivity function

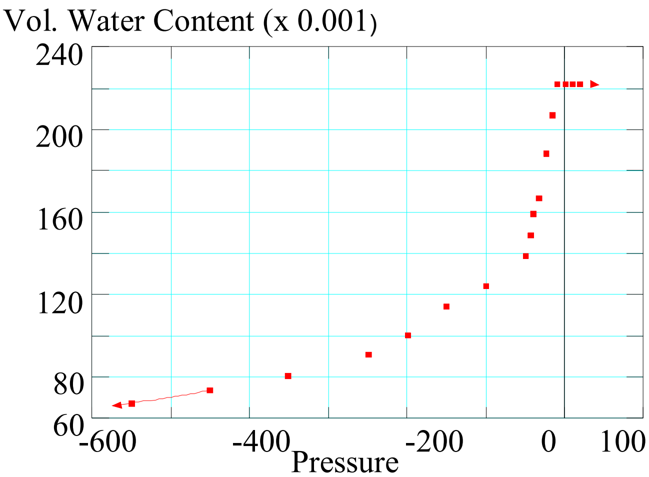

Figure 10 : Volume Water Content Function

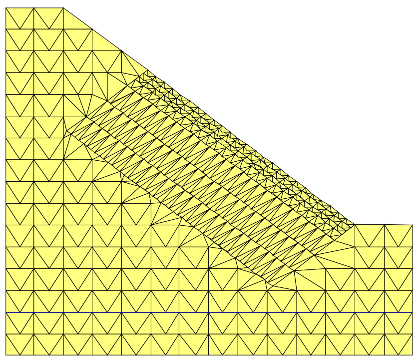

Figure 11 : Computer model of the site

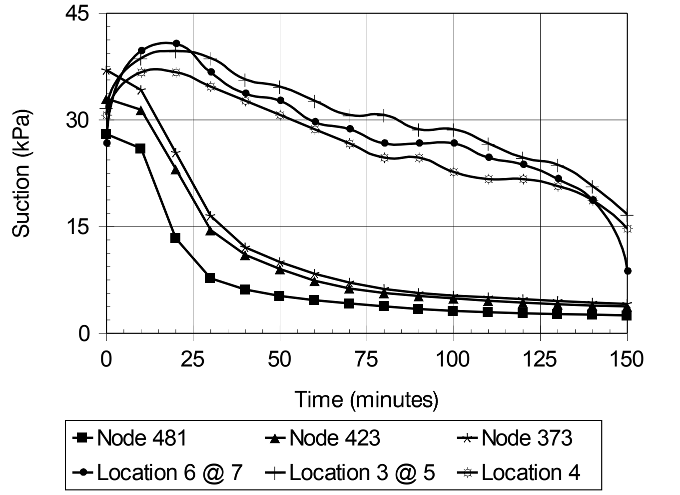

Figure 12 : Comparison plot between field and computed data

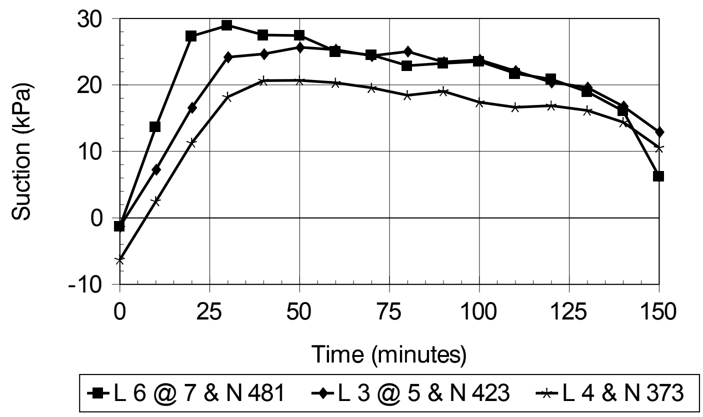

Figure 13 : Plot of net differences between field and computed data

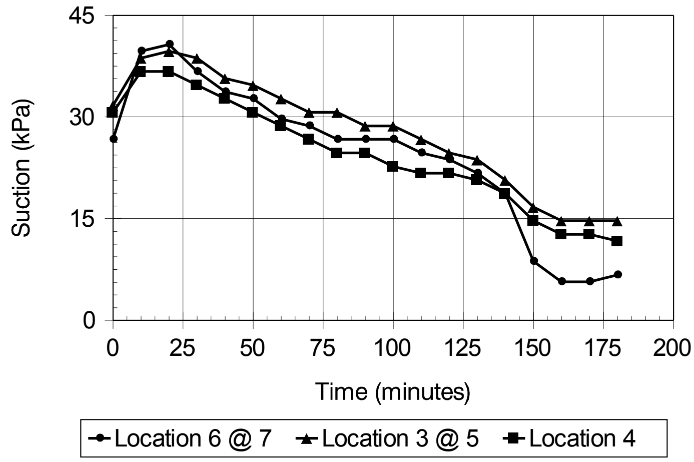

Figure 14 : Plot of continous monitoring of soil suction at the field

8 COMPARISON BETWEEN FIELD AND COMPUTED RESULTS

Relative comparison between field tensiometers data and the computed results were made by plotting the changes in matric suction with time. Figure 12.0 shows the plot of field and computed matric suctions with time for some selected points. Figure 13.0 illustrates the net differences of soil suction between field and computed data. Based on the plot, rate of suction changes with time after 30 minutes of rainfall is more the less same.

However a phenomena of sudden increase of matric suction in the first 20 minutes of rainfall is recorded in every tensiometers. The software did not compute this effect. Figure 14.0 shows the plot of continuos monitoring of suction after rainfall. The figure shows that when the rainfall is stopped at 150 minutes a sudden drop in matric suction takes place. In addition to the sudden drop in suction after 150 minutes, the rate of suction reduction is also recorded high for the next 30 minutes before stabilization take place and drying process begins. The sudden increase of matric suction in the beginning of rainfall, and sudden drop in matric suction after rainfall, believed to be caused by lamina flow of rainwater at the slope surface. The flow creates lower pressure zone at the surface, which respectively increases matric suction. However a sudden drop of rainwater flow, releases the lower pressure zone at the surface, causing an quick drop in soil suction and increase in water infiltration rate into the slope. The sudden drop in suction after a heavy rainfall is commonly not taken into consideration in a slope stability analysis. Hence, a new mechanism or algorithm need to be developed considering the above mention phenomena in the slope stability analysis methodology.

9 CONCLUSION

The test results obtained from this experiment have indicated some differences between theoretical and measured data. The different could have derived from:

1. Much higher surface runoff at site.
2. Less water infiltration due to surface cover.

However the intermediate values have shown that the rate of suction changes with time is more the less same for both field and computer prediction.

Currently continuos research are being conducted at both field and laboratory to understand the infiltration pattern of rainwater. The present infiltration algorithm used in computer software may require to be improved further by considering the influences of soil capillary and lamina flow of rainwater at the surface.

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