Field suction variation with rainfall on cut slope in weathered sedimentary residual soil

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Field suction variation with rainfall on cut slope in weathered sedimentary residual soil

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ABSTRACT: Most residual soils especially in slopes are in unsaturated condition and therefore matric suction is an important factor to be considered in the design or analysis of slopes. The suction has an important bearing on water entry, structural stability, stiffness, shear strength and volume change. The soil matric suction, the water content and the solute content and how they vary with time are often the most important variables in soil engineering design. The field instrumentation for automatic continuous measurement of soil matric suction, rainfall and other slope instability related parameters are presented in this paper. Description of the selection, fabrication and installation of the instrumentation are discussed.

1 INTRODUCTION

Construction activities in hilly terrain covered by residual soil frequently confront geotechnical engineers with slope instability problems. Failures in both natural and cut slopes in residual soils of Peninsular Malaysia are usually brought about by rainfall during the monsoon season. The upper layer of the residual soil profile is always partially saturated , but invariably has a relatively high permeability to infiltrating rainwater. This obviously causes the pore water regime to be governed largely by rainfall pattern.

The mechanism of slope failure is that the infiltration of rainwater causes a reduction of matric suction in the unsaturated soil, resulting in a decrease in the effective stress. This in turn reduces the shear strength to a point where equilibrium can no longer sustained in the slope. Good correlations between rainfall intensity and frequency of landslides have been reported by some researcher from Hong Kong, Japan, United State and NewZealand.

The instrumentation is attempted to study the change of soil matric suction with the rainfall on a cut slope along the link road of The Kuala Lumpur International Airport (KLIA) Malaysia. The cut slope mainly consists of two types of weathered sedimentary residual soil, i.e., weathered sandstone and shale. These residual soils come in alternate bedding which is almost vertical. The weathered sandstone bed basically is the thicker bed and the study is concentrated in one of these beds. The soil consists of very fine sand and silt. The slope is covered by different types of synthetics (biodegradable) and non synthetic covers (poly-jute) after hydro-seeding to prevent erosion . Instrumentation is carried out on every berm with respect to different weathering grades of soil.

2 ROLE OF SUCTION IN SLOPE STABILITY

The principle of effective stress for unsaturated soil was first used by Terzaghi (1923) and proposed by him in the first International Conference on Soil mechanics in 1936. Numerous researchers have carried out work since then in order to confirm. But the validity of the principle for unsaturated soil mechanics has been questioned by Jennings and Burland (1962). Following an extensive research program on unsaturated soil conducted in Imperial College the shear strength of partially saturated soil was hypothesised (Bishop, 1959) to be a function of an effective stress defined as:-

$$\sigma' = (\sigma - u_a) + \chi (u_a - u_w) \quad [1]$$

where σ' and σ are the effective and total stresses respectively, u_a is the pore air pressure and u_w is the pore water pressure. χ is a function that depends on the saturation with value 1 at 100% saturation and 0 for completely dry soil.

Fredlund and Morgentern (1987) showed from a stress analysis that any two combination of the three possible stress variables $(\sigma - u_a)$, $(\sigma - u_w)$ and $(u_a - u_w)$ can be used to define unsaturated soil. The equation for unsaturated shear strength τ is written in terms of the stress state variables for an unsaturated soil and is an extension of the form of equation used for saturated soils

$$\tau = c' + (\sigma - u_a) \tan\phi + (u_a - u_w) \tan\phi^b \qquad [2]$$

where ,

c' = effective cohesion
σ = total stress
u_a = pore air pressure
u_w = pore water pressure
ϕ' = effective angle of friction
$(u_a - u_w)$ = matric suction
ϕ^b = gradient with respect to changes in $(u_a - u_w)$ when $(\sigma - u_a)$ is held constant.

The factor of safety for slope stability analysis using method of slices can be derived using shear strength equation [2] above. The shear force mobilised at the base of slice can be written as:-

$$S_m = \beta/F \{c' + (\sigma - u_a) \tan\phi + (u_a - u_w) \tan\phi^b\} \qquad [3]$$

Where
S_m = the shear force mobilised on the base of each slice.
F = the safety factor
β = the sliding surface of the slice.

3 INSTRUMENTATION

20 numbers of tensiometer and 20 numbers of moisture block and a rain gauge are installed on the slope to monitor the changes of matric suction with respect to rainfall. The tensiometers and moisture blocks are installed at different depths. At each berm, 4 numbers of tensiometers and moisture block are installed i.e., with depth of 0.5m, 1m, 3m and 3m. An automatic data acquisition system is designed to record the output from tensiometers and moisture blocks. Automatic data acquisition system solves the problems of reliability, access and safety which are difficulties associated with manual data recording and allows continuous monitoring. The data acquisition system is supported by a solar powered set and specifically designed for low power consumption. The logging intervals are achieved by prescribing the appropriate interval during the set-up process. Two time intervals are adopted in this study, i.e., 30 minutes interval and 10 minutes. The system is set in such that when there are rapid changes (in terms of percentage change of suction value) the 10 minutes interval would be utilised, or else, the 30 minutes interval is used. The recorded data are downloaded from the data logger direct to a portable notebook computer through an RS232 interface .

An automatic logging tipping bucket rain gauge is installed at the study site. The rain gauge records rainfall events on a real time basis. The clock of the data logger for the tensiometers and moisture blocks and the rain gauge recorder are always synchronised. Figure 1 shows the schematic arrangement of the instrumentation at the study site.

The infiltration characteristics of the soil are deduced by using a sprinkler system installed at the site. A V- Notch fixed with a flow meter is used to measure the surface run-off in a control section in the study (refer to Figure 2). Besides, an infiltrometer P-88 from Geonor (refer to Figure 3) is used to obtained the infiltration capacity at the site for the comparison with the sprinkler system.

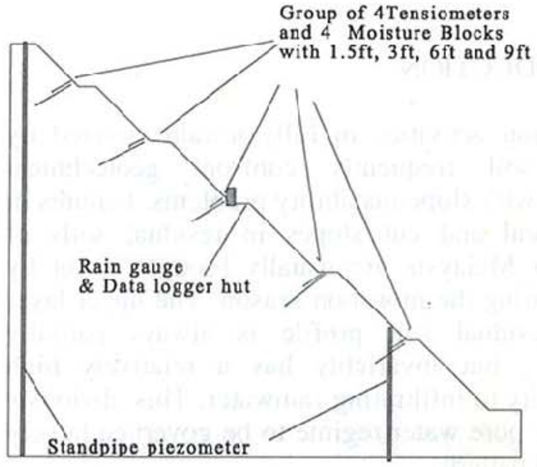

Figure 1. Instrumentation Layout of the study Site.

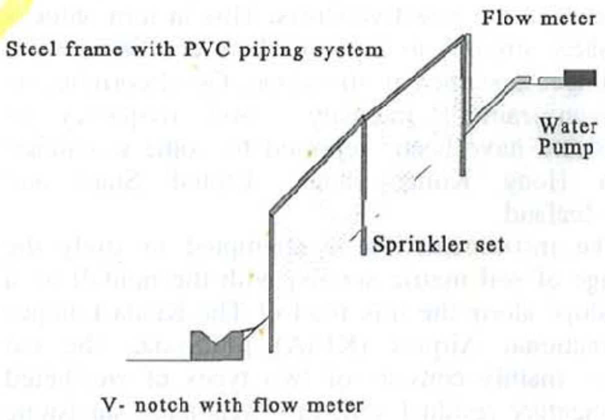

Figure 2. Field Infiltration Sprinkler System

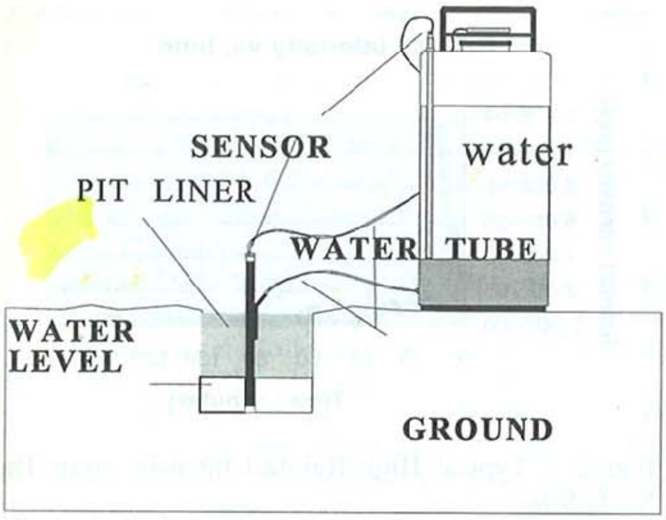

Figure 3. Infiltrometer

4 MATRIC SUCTION MEASUREMENT

In this study, matric suction of the soil is measured using jet-fill tensiometer and moisture block (Soil Moisture Corporation U.S.A). Moisture blocks are used because tensiometer can only measure matric suction below 1 bar of negative pressure while moisture block can measure more than 4 bar. The matric suction obtained from the tensiometer is the difference between the gauge reading and the head of the water in the stamp. The longer the tensiometer, the lower the suction it can measure.

In this study the tensiometer is installed perpendicular to the slope surface to reduce the head of water (refer to Figure 4)

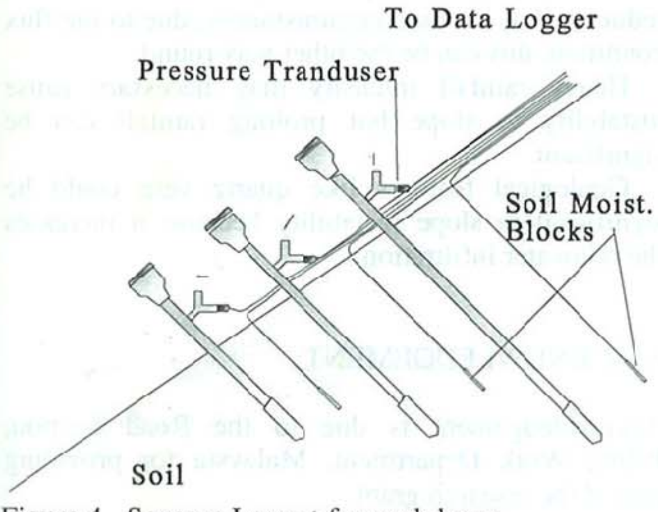

Figure 4. Sensors Layout for each berm.

The accuracy of the moisture block when the suction is below 1 bar is not as good as tensiometer. To overcome the limitation of both the devices, both the tensiometer and moisture block are installed at the same depth for comparison and cross checking purposes.

5 INSTALLATION OF INSTRUMENT SENSORS

In this study, normal coring tools cannot be used because the soil is brittle and hard (various weathering grades of weathered sandstone). A special in-house designed motorised auger is fabricated for the installation purposes. The motorised auger consists of two motors with ½ and ¼ horse power. The quarter horse power motor is fitted at the top of the machine to push the auger into the slope as the half horse power motor is used to rotate the auger. Both the motors are fitted with a speed controller. During installation, four sand bags are placed at the base of the augering machine and the speed of the motors are properly controlled to prevent the auger machine from being pushed up when drilling through hard layers. The set-up is shown in Figure 5.

The auger used in this study is designed to suit the soil condition at the study site. The most suitable distance between the flights is determined to be 25mm in order to ease the process of augering. Due to the difficulty in fabricating long auger, 2 or 3 lengths of short extension flights are jointed together.

After the hole has been augered, a special tool is used to remove the residual from the hole. Precaution needs to be taken because an intimate contact with the soil is necessary in order for the tensiometer and moisture block to function properly.

Moisture blocks are inserted into the bored hole using a fabricated tool in the form of a long rod with a modified tip. The soil is tamped firmly after placing the blocks and bentonite is placed at the surface of the hole in order to prevent the hole from becoming an abnormal water passage.

All the wire leads are inserted into a poly-pipe and are buried in a shallow trench in the ground. The wires are connected to the data logger situated at the midway between the berms. The adverse tropical climate and vandalism are major concerns in the installation. The tensiometers and moisture blocks installation are protected by lockable steel security cages grouted to the slope. The data acquisition system is contained in a lockable steel hut. All the transducers for the tensiometers are protected from sunlight by wrapping them with a double layered foam rubber on the inside and aluminium foil on the out side.

6 DISCUSSION

Figure 6 shows a typical suction variation with rainfall (one month duration) for one of the berm at the study site. It is clearly shows that as the depth increases, the matric suction reduces.

During the time interval of 14000 to 24000

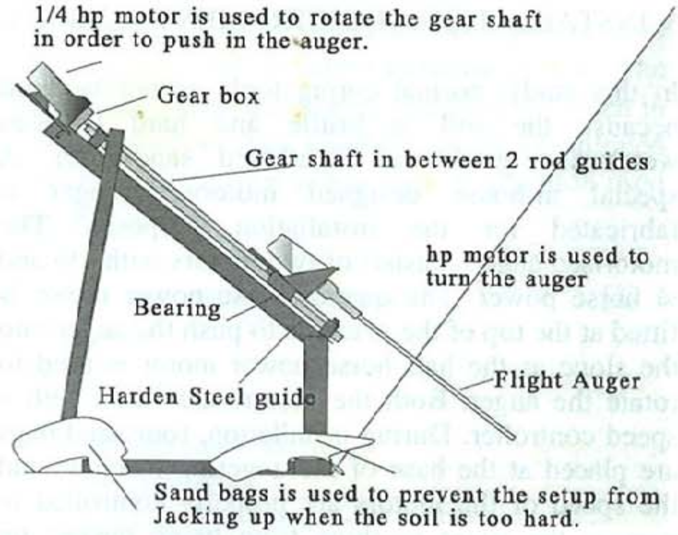

Figure 5. Special Fabricated Augering Machine

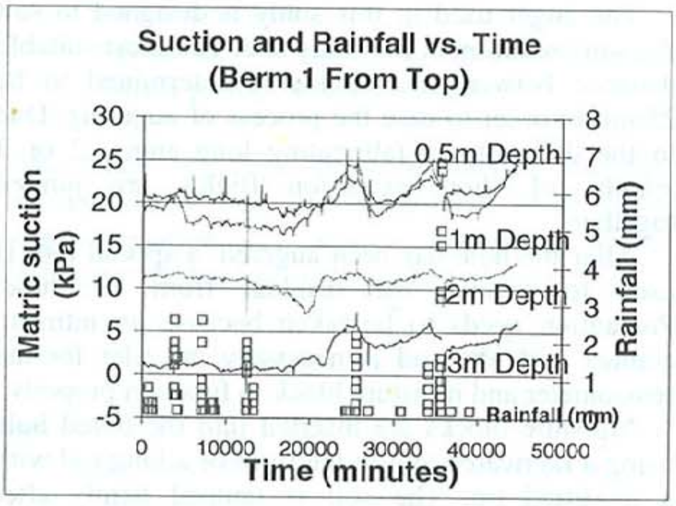

Figure 6. Typical suction variation with rainfall for one-month duration.

minutes, there was no rainfall occurred. All the four tensiometers experiencing increments in matric suction. When the rain started to fall, matric suction did not reduce immediately. Due to the infiltration of rain water into the ground after rainfall, the matric suction reduced slowly for all depths even without any rainfall after the rainstorm.

From Figure 6 , the time interval of 0 to 13000 minutes, suction of the 3.0m depth tensiometer gives very low suction values. This is mainly due to the cumulative rain water during the raining period.

From the field infiltration test, the water infiltration rate is 2.31 x10^{-6}m/s. From Figure 6, it is clearly shown that during heavy rainstorm, the suction drops very fast and also recovers fast. One of the reasons is that the rainwater infiltrate into the slope through quartz veins in the soil.

Figure 7 shows one of the typical high rainfall intensity patterns at the study site. The rainfall intensity at the site can be very high, i.e., 1.13 x 10^{-4}m/s.

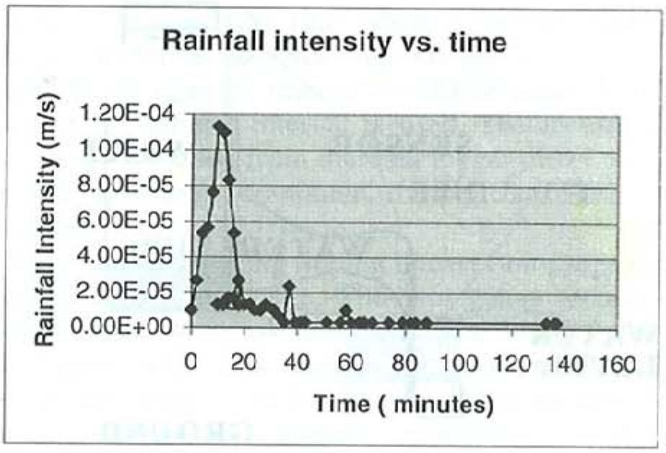

Figure 7. Typical High Rainfall Intensity from The Study Site

As shown in Figure 6, high rainfall intensity with short duration may not play an important role in the instability of slope. Prolong rainfall even with low intensity could be significant.

7 CONCLUSIONS

The automatic data logging system for monitoring tensiometers, moisture blocks and other devices has been detailed. The desired attributes of the system have been reasonably achieved and the advantages of a fully electrical installation are credited to its flexibility and continuity of data obtained. Installation method which creates much less disturbance helps to obtain more accurate data from the instruments.

Generally as the depth increases, matric suction reduces. But, in some circumstances, due to the flux condition, this can be the other way round.

Heavy rainfall intensity may necessary cause instability to slope but prolong rainfall can be significant.

Geological features like quartz vein could be significant in slope instability because it increases the rainwater infiltration.

8 ACKNOWLEDGEMENT

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