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TREE INDUCED SUCTION ON SLOPE STABILIZATION ANALYSIS

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ABSTRACT

This research explores the effect of active root zone related to slope stabilization. The matric suction produced by mature tree was determined with high and moderated intensity of rainfall event condition. The increasing of soil moisture and pour water pressure can significantly reduce shear strength of soil, which leads to shallow slope failure. This exploration is concentrate at active root zone of the tree at toe of the slope. The effect only focused on hydrological aspect with soil suction pattern within vicinity of the tree. The monitoring result show a substantially increase in soil suction at slope with tree at toe. The effect of tree water uptake on soil suction distribution is applied for slope stability analysis that significantly changes stability of the slope. The rainfall events also lead to variation on soil suction and factor of safety of the slope. The influence of water uptake from root activity at the toe of slope created a dry condition and substantially increased the factor of safety against slope failure up to 63%.

Keywords: matric suction, tree induce suction, field monitoring, slope stability.

1. INTRODUCTION

The mass instability of soil slopes continue to affect Malaysian populations for each year, in particular at the areas of steep terrain that experience prolonged hot and dry periods followed by intense rainfall events. Related to that, shallow slope instability has become a common problem to manmade and natural slopes. Hence, it is significantly important to find an economically and eco-friendly solution to rise on how vegetation can be an element for sustainability of slope. An exploration on how vegetation might be selected as an approach to help maintain and enhancing the soil strength by reducing moisture content thus reducing the risk of slope failure.

Acacia mangium tree was first introduced in the state of Sabah in 1967 and then planted in peninsular Malaysia as the main species compensation plantation forest project. This plant species grow between 4m to 5m a year, medium-sized, growing up to 20 m high. *Acacia mangium* tree is a fast-transpiring tree species with high daily water consumption reaching an average up to 4.6 mm d^{-1}. [6] Reported a study on the water consumption of acacia mangium tree in the Malaysian state of Sabah, Borneo. Furthermore, *acacia mangium* tree is tolerance with a variety of tropical climate conditions [1]. These include tropical dry to moist conditions and subtropical dry zones to wet forest zones. Therefore, this tree has been selected and suitable preserved for this research.

Slope failure commonly occurs when the shear strength of the soil is reduced through a decrease in effective stress due to pore water pressure increment [12]. Vegetation may prevent collapse by reducing water pressure (increasing suction through water uptake) due to suction produced by vegetation will act to stabilise slopes by increasing effective stress and thus increasing soil shear strength. According to [11] claimed as a key finding that the hydrologic effect is as important as mechanical effect, which can bring beneficial by increasing FOS up to 71%. It should also be noted that if trees are cut down, failure could be the result when pore water pressures recover because strain softening has already occurred (due to previous seasonal cyclic loading effects). This is important in the management of vegetation and engineers must be wary of felling trees without understanding the hydrology condition. Importantly, Preserve of a mature tree can readily increase the factor of safety against slope failure due to tree water uptake in relation to soil slope [13].

The objectives of this study are to determine matric suction soil moisture on the slope with mature tropical tree (*acacia mangium*) preserved at the toe of the slope, which suction have been generated within this area. The equipment was installed at certain depth and distance to measure soil suction. Therefore, it is just considering the main factor of drying influenced by mature tree. In associated with this, effect of tree induced suction was used to perform a stability analysis at active root tree. In this scope of this research, the mechanical aspect of tree root such as tensile strength and bonding between root and soil which can lead to increasing soil strength are assumed negligible in this study.

2. THEORETICAL BACKGROUND AND NUMERICAL STABILITY

The limit equilibrium method of slices is widely used for its simplicity particularly when compared to the finite element method [8]. The FOS is defined as that factor by which the shear strength of the soil must be reduced in order to bring the mass of soil into a state of limiting equilibrium along a selected slip surface. The equation (1) produced by [2] was used to calculate stability of a slope by performing divided the soil mass above the circular slip surface into vertical slices.

$$F=\frac{\sum c' lR + NR \tan \phi' + SRl \tan \phi^{b}}{\sum W_x} \tag{1}$$

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The equation was define as, where c' = effective cohesion (kPa), l = length of the slice (m), N = total normal force on the base of the slice (kN), R = the radius for a circular slip surface (m), S = force produced by matric suction on the unsaturated part (kNm^{-1}), ϕ' = effective angle of internal friction (degrees), ϕ^b = an angle indicating the rate of increase in shear strength relative to matric suction, W = weight of the slice (kN).

3. MATERIALS AND METHODS

3.1. Study area

The study was carried out at slope with the existence of mature tropical tree *Acacia mangium* situated at latitude (+1°33' 32.03") and longitude (+103° 38' 38.04"). The tree was located at the toe of slope at Faculty of Electrical Engineering University Technology Malaysia.

Determination of suction distribution on soil due to *acacia manggium* tree, Jet-fill tensiometer (Figure 2) was used. Jet-fill tensiometer is installed to the soil and it can measure directly the soil suction at range between 0kPa to 100kPa. A tensiometer comprises of a tube with a porous ceramic tip on the bottom, a vacuum gauge near the top, and a sealing cap. As the soil dries and water moves out of the tensiometer, it create vacuum inside the tensiometer that is indicated on the gauge. When the vacuum created just equals the "soil suction", water will stop flowing out of the tensiometer. The dial gauge reading is a direct measure of the force required in removing water from the soil. The tensiometers installed at the depth of 0.5m, 1.0m and 1.5m and the distance from tree for the insertion of tensiometer were measured according to 0.1*h*, 0.2*h*, 0.4*h* etc (where *h* is the height of the tree) making up a 'station' or 'nest'. Six station were placed at the flat and slope area (Figure-1 and 2). Each station consisted of three tensiometer installed which is consider as top, middle and bottom of the root zone according to [5] and it was assumed that the active root zone was extended to the depth of 2m.

Figure-1. Tensiometer installed at toe of slope.

Figure-2. Tensiometer installed at slope.

4. RESULT AND DISCUSSION

4.1. Soil properties

The disturbed and undisturbed soil samples were collected from near the ground surface up to 1.5 m depth of the study area. A series of laboratory testing were conducted to determined soil properties, which can determine the soil type and geotechnical properties. The main physical index property of the soils investigated in this study was soil classification, which depends on several factors such as the Atterberg limits, specific gravity, and particle size distribution. From 100g of soil sample, it is consists of 5.1% larger than 2mm which is gravel, 20.9% are between sizes of 0.063mm to 2mm which is sand. 48.7% are between 0.063mm to 0.002mm, which is silt, 25.3% is smaller than 0.002mm. The liquid limit (LL) of the soil was 71%, plastic limit (PL) 39% and Plastic Index, (PI) = LL – PL = 32%. Based on the British Soil Classification System (BSCS), the soil at the field study can be classified as Sandy Silt of high plasticity (MHS). Moreover, the plasticity index of the two residual soils was plotted below the A line [7] which is the range of salty materials. The specific gravity depends on the mineralogy of a soil and it can reflect the history of weathering. In this study area, the specific gravity of the soil was 2.65.

4.2. Soil water characteristic curve (SWCC)

The soil-water characteristic curves (SWCC) of residual soils at Faculty of Electrical Engineering Universiti Teknologi Malaysia are shown in Figure-6. The SWCC for low suctions (less than 1500kPa) was determined by fitting the average value from a series of pressure plate extractor tests. Based on this SWCC, the parameters such as saturated volumetric water content (θ_s), air entry value (A_{ev}) and residual volumetric water content (θ_r) of the soils can be identified and shown in Figure-6.

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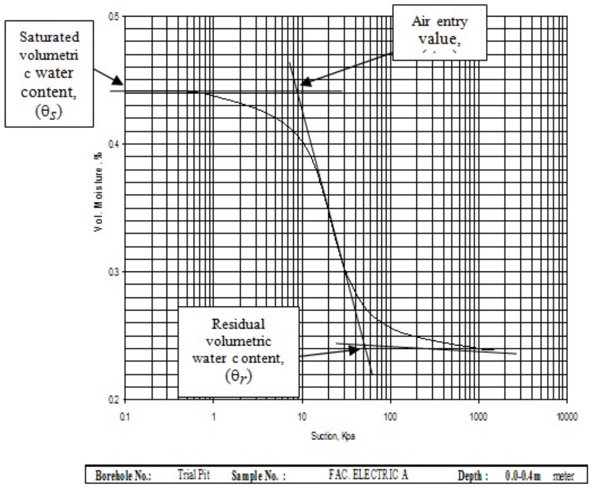

Figure-3. Soil water characteristic curve (SWCC).

4.3. Soil suction distributions

Field measurements results are presented here from 1st December 2012 to 28th February 2012. This period falls under the wet season northeast monsoon blows from east part across peninsular Malaysia from November 2011 to dry season in March 2012. The changes in matric suction influence by tree water uptake and response to rainfall within vicinity of tree are investigated.

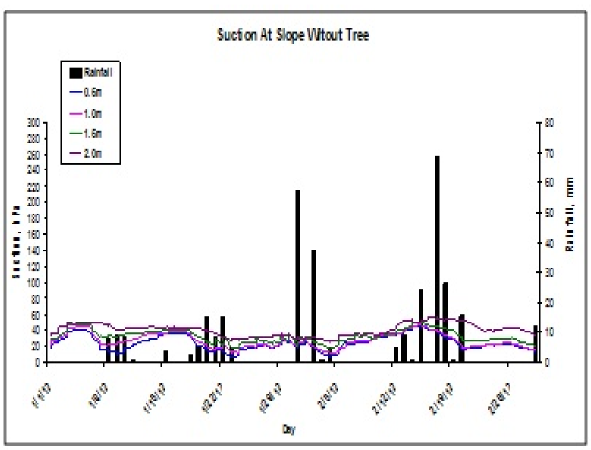

Figure-4. Field matric suction with depth responds to rainfall distribution at slope without tree.

Figure-6 show field monitoring suction envelopes measured at 0.5m, 1.0m and 1.5m without tree at the toe of the slope and can be a function as control matric suction in soil. During this field monitoring period, the suction at 1.0m and 1.5m have never reached 0kPa (suction disappeared). However, the suction at 0.5m depth deceased to 0kPa after several of long and intense rainfall event.

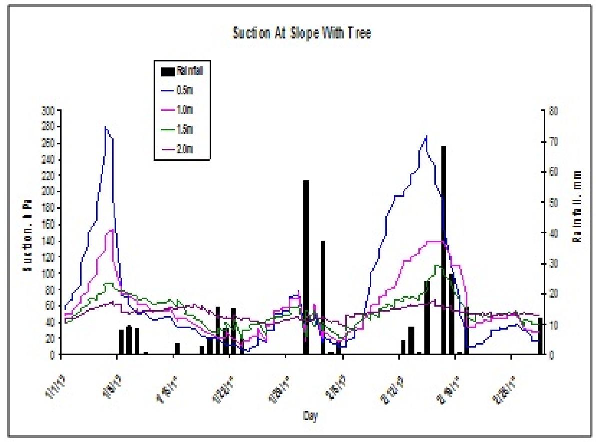

Figure-5. Field matric suction with depth respond to rainfall distribution at slope with tree at toe.

Field monitoring data collections from the slope name as Station slope are applied for analyses in this study. Figure-7 shows the matric suction were measured by combination of tensiometer and gypsum with depth and daily rainfall data. The four lines shown on the graph represents readings from the instruments (matric suction) at depth as indicated in the legend. The bar graph represents the rainfall data and shows that rainfall occurred during this period of monitoring.

The suction variation was considerably large, on 6th January 2012 after twelve day without rainfall, the matric suction at 0.5m reached value approximately 280kPa, while the changes in the matric suction was approximately 278kPa.

Field monitoring data shows in Figure-7 were plotted, matric suction with respect to depth and rainfall were allow easier configuration and comparison between the field monitoring slope with tree at toe and without tree. However, during this field monitoring, the suction at 0.5m, 1.0m and 1.5m have never reached 0kPa (suction disappeared) at slope with tree at toe despite received several long and intense rainfall event.

4.4. Effect of tree induce suction in stabilty analysis

The lowest FOS (Factor Of Safety) for the critical slip failure was encounter using limit equlibrium method (LE) model (slope/w) in saturated condition was 1.70. This value was used as controled value to determine the percentage difference of FOS for other conditions. The FOS after numerical stability analysis was performed at various conditions considered from 1st January 2012 to 28th February 2012. The difference are compared on unsaturated slope with and without tree at toe of slope. Still, FOS for unsaturated slope with tree at toe (4.1) much higher than FOS without tree (2.6), with significanly different up to 63%. This analysis reveal the key finding that changes in matric suction due to the effect of tree induced suction substantially increase the FOS.

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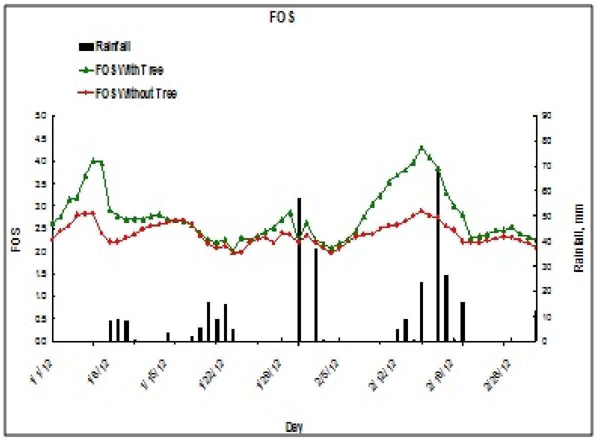

Figure-6. The Variation of FOS in time with and without tree at toe of slope.

Figure-10 reveals the result and change in the FOS after analysis of monitored data. It shows that FOS can rise up with various times in 12 day of analysis period in the conditions of moderate and high intensity rainfall. This figure shows that FOS varies with time and increases with matric suction in soil with and without tree at toe of slope.

5. CONCLUSIONS

Based on field monitoring result it is expected that the established pattern of root water uptake is likely to happen. A root tree zone could help to reinforce the soil by increasing matric suction and FOS. This study indicated that matric suction generated caused by the presence of mature tropical tree (*acacia mangium*) at toe of the slope can readily increase the FOS against slope failure up to 63%.

The FOS calculation presented here considered only hydrological effects which are related to soil matric suction generated by active root zone driven by transpiration. Mechanical effect that arised from the tensile strength of root and bonding between root and soil are assumed beyond the scope of this study. A part from provided a ‘free’ refreshment condition or acoustic screen, it can also help in strengthening the slope via active root zone to absorb water from soil. Consideration is needed for practical cases when cutting down and felling the trees without understanding the hydrological condition can increased the risk of landslide and erosion on slope.

The effect of *acacia mangium* tree can be acceptable as low cost solution to problem of erosion and slope instability that can increase the factor of safety of slope. From this study, suggest more consideration is given to the hydrologic influence, which also can bring increment to soil shear strength. In fact, this research has also revealed that *acacia mangium* planted is beneficial in producing suction via root and in stabilizing the soil.

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