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# The Effect Of Tree Induce Suction On Slope Stabilization Analysis

M. F. Ishak[1*], N. Ali[2], A. Kassim[2]

[1]Faculty of Civil Engineering & Earth Resources, University Malaysia Pahang.
[2]Faculty Of Civil Engineering, Universiti Teknologi Malaysia.

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ABSTRACT

This research was conducted to study the effect of active root zone related to slope stabilization. The matric suction produced by mature tree was determined during high and moderated intensity of rainfall event condition, which related to significant changes on stability of the slope. The increasing of soil moisture and porewater pressure can significantly reduce shear strength of soil which lead to shallow slope failure. This study determined the active root zone of the tree near the toe of the slope which suctions have been generated within this section. In related with this, the effect it only focusing on hydrological aspect with soil moisture pattern near vicinity of the tree. The field monitoring result showed that there was a substantially increase in soil suction near the vicinity of tree. The effect of tree water uptake on soil suction profiles was applied for slope stability analysis. The findings indicate that the influence of rain fall event can cause variation to soil suction that is related to factor of safety. Furthermore, water uptake from root activity created dry condition that substantially increased the factor of safety against slope failure has improved up to 45.54%.

## 1. Introduction

The mass instability of soil slopes continue to affect large 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. In conjunction to that, shallow slope instability has become a common problem to man made and natural slopes. Hence, it is significantly important to find an economically and eco-friendly solution to rise how vegetation can be an element for sustainability of slope. So, to explore how vegetation might be selected as an approach to help maintaining and enhancing the soil strength by reducing moisture content and hence reduce 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 $d^{-1}$. A study on the water consumption of acacia mangium tree in the Malaysian state of Sabah, Borneo was reported by Cienciala (2000). Furthermore, *acacia mangium* tree is tolerance with a variety of tropical climate conditions (Adnan M., 2008). 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.

Prolonged antecedent rainfall would significantly alter the pore water pressure conditions prior to the main rainfall event, such that the initial pore water pressure distribution prior to the antecedent rainfall became all but irrelevant. The effects of rainfall on the stability of the slope seemed to relate by duration of the rainfall event, with the longer the rainfall period, the lower the slope factor of safety. 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 (N. Ali & Rees, 2008).

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 (Glendinning S. et al, 2009). Vegetation may prevent the collapse by reducing water pressure (increasing suction through water uptake) due to suction produced by vegetation will act to stabilize slopes by increasing effective stress and thus increasing soil shear strength. Simon and Collison (2001) 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 can 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 (Ali N. & Rees S.W., 2008)

The objectives of this study were 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. During no rainfall event, the soil becomes dry and the analysis of the changes soil suction at various depth and distance from tree trunk were conducted. 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.

## 2.0 Theoretical Background and Numerical

To assess mature tree effects on slope stability, hydrologic data (matric suction) were used in computer modelling. In these cases, it may be appropriate to perform slope stability analyses which include the shear strength contribution from the negative pore-water pressure. Matric suction (negative pore-water pressure) above the water table has the effect of increasing the apparent cohesion of a soil. A modified form of the Mohr-Coulomb equation can be used to link shear strength to soil suction. The use of theory of limit equilibrium of forces and moments was use to compute the FOS (Factor Of Safety) against failure.

This work aimed to explore the significance of soil suction change on shear strength and the water table is assumed to be below the zone of studies. It is also assumed that there were no interslice shear forces involved in the equation for both horizontal and vertical forces. This assumption has been made for the following reasons;

i. Vertical interslice forces can be assumed equal and opposite.
ii. The resultant of the interslice forces acting on a slice can be assumed to act parallel to the base of the slice. By resolving normal forces to the base of the slice, the interslice forces are eliminated.

The limit equilibrium method of slices is widely used for its simplicity particularly when compared to the finite element method (Fredlund and Rahardjo, 1993, Renaud et al.

2003). 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 Rees S.W. and Ali N. (2012) were used to calculate stability of a slope by performing divided the soil mass above the circular slip surface into vertical slices.

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

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 ($kNm^{-1}$), $\phi'$ = effective angle of internal friction (degrees), $\phi^b$ = an angle indicating the rate of increase in shear strength relative to matric suction, $W$ = weight of the slice (kN).

## 3.0 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 Universiti Teknologi Malaysia as shown in Figure 1.

**Figure 1** Acacia mangium tree located at the toe of slope

*3.2 Jet-fill Tensiometer*

To develop soil moisture profile due to influence of *acacia manggium* tree, Jet-fill tensiometer (Figure 2) was use. Jet-fill tensiometer (Soilmoisture Equipment Corp. CA) is used since it can measure directly the soil suction that range between 0 kPa to 100 kPa. 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 named as Flat 1, Flat 2 & Flat 3 (Figure 3) and Slope 1, Slope 2 & Slope 3 (Figure 4). Each station consisted of three tensiometer installed which is consider as top, middle and bottom of the root zone according to Biddle, (1998) and it was assumed that the active root zone was extended to the depth of 2m.

**Figure 2** Tensiometer

**Figure 3** Tensiometer installed at slope

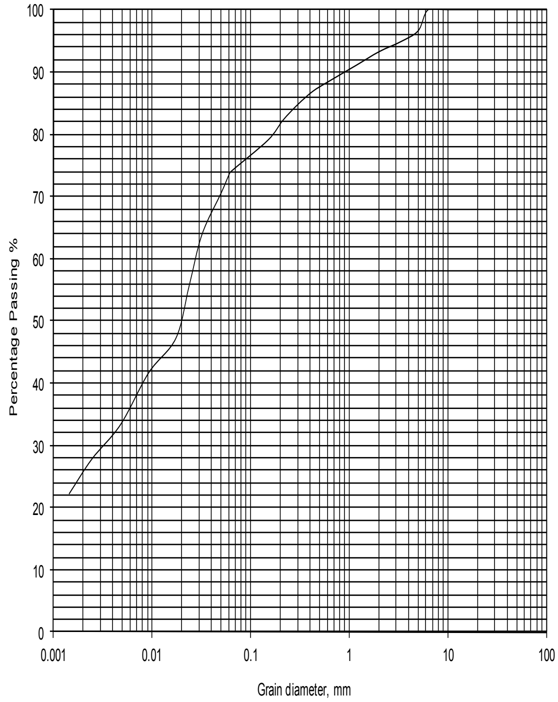


**Figure 4** Particle size distribution curve

## 4.0 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, the result in graph figure 4 show 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 (Craig, 2004) which is the range of silty 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.

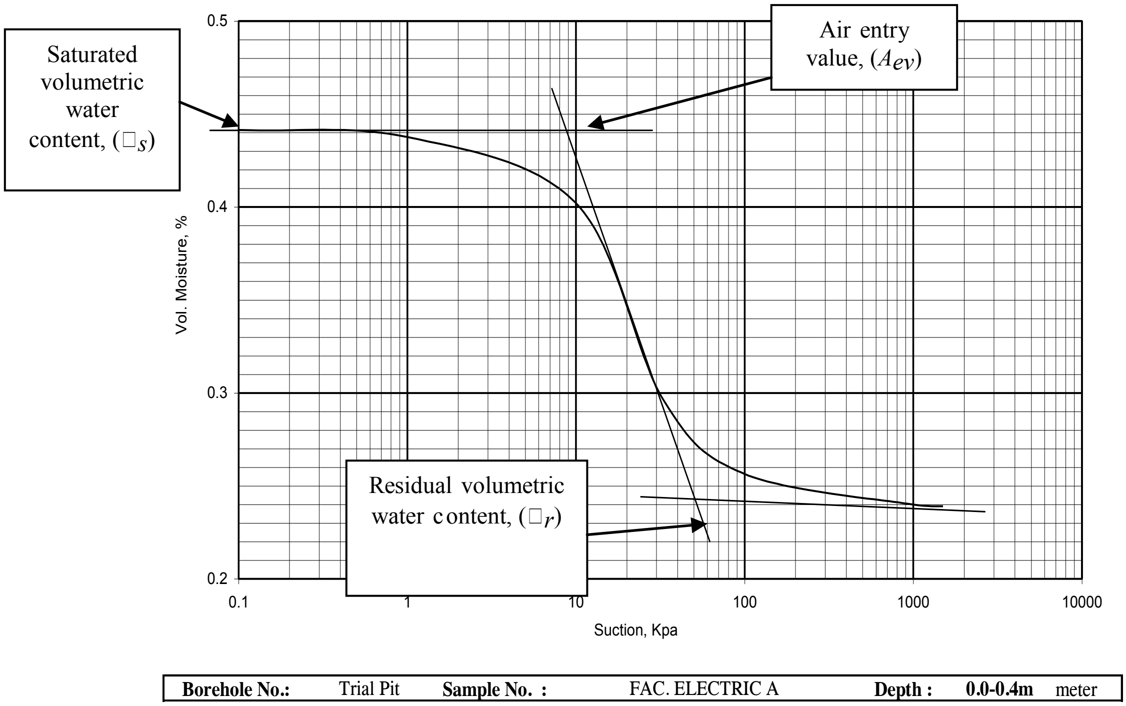


**Figure 5** Soil Water Characteristic Curve (SWCC)

*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 5. 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 ($\square_s$), air entry value ($A_{ev}$) and residual volumetric water content ($\square_r$) of the soils can be identified and shown in Figure 6.

*4.3 Soil Suction Profile*

The suction distribution responded to several rainfall patterns in the month of December was used for analysis and observation in a certain interval of time. The isolation of data toward the effect of tree induce suction during the monitoring at slope can be denoted as pattern A (December 4) in figure 6 influenced by heavy rainfall occurred, pattern B (December 10) in figure 7 with moderate rainfall occurred and pattern C (December 16) in figure 8 after 6days without rainfall.

Figure 6 shows pattern A of suction distribution through the soil profile after 54mm/day rainfall event on December, 4. The respond showed that suction at all depth dropped dramatically at lowest value was recorded. The lowest suction was encountered at distance of 4m from tree trunk at depth 0.5m, 1.0m and 1.5m were 2kpa, 4kpa and 12kpa respectively. The suction recorded at depth 0.5m, 1.0m and 1.5m without tree are much lower than at distance of 4m from tree trunk. However for this high rainfall event the pore-water pressure at all depth did not achieve saturated condition (0kpa suction value).

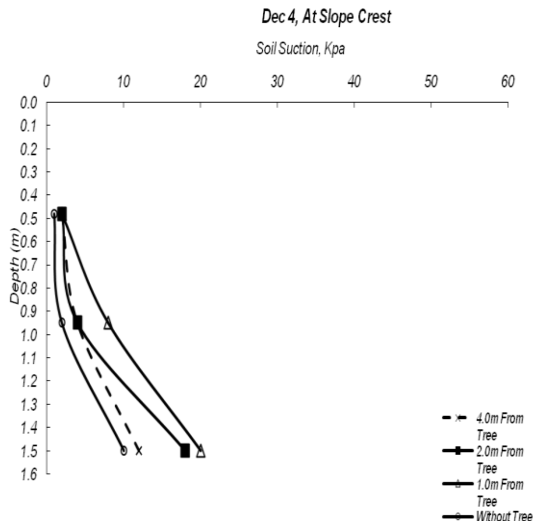


**Figure 6:** Soil suction profile pattern A on 4 December

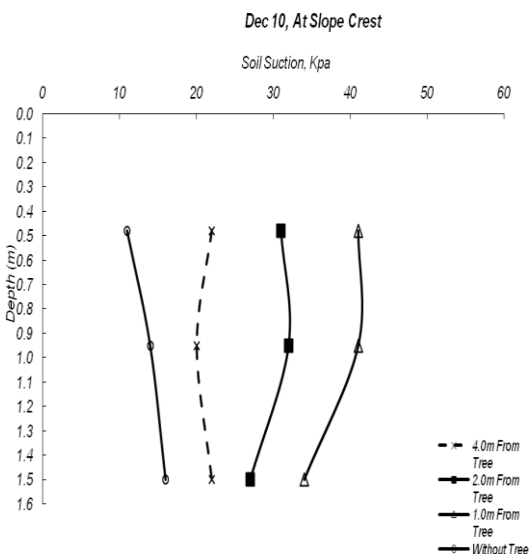


**Figure 7** soil suction profile pattern B on 10 December

Figure 7 show soil suction profiles on December 10, matric suction increased significantly due to effect of tree induce suction. It is indicated that, after 6 day without rainfall event the pattern of soil suction substantially increased at depth 0.5m until 1.0m. Although, the slope was subjected to receive moderated rainfall amount (14mm/day) but soil suction profile distribution was still high compare to December 4. This is due to tree water water uptake that contributed to induce suction through soil appreciable only at the shallow depth and near the trunk. Still, suction profile distribution without tree is much lower at all depth compared to at the distance of 4m from tree trunk.

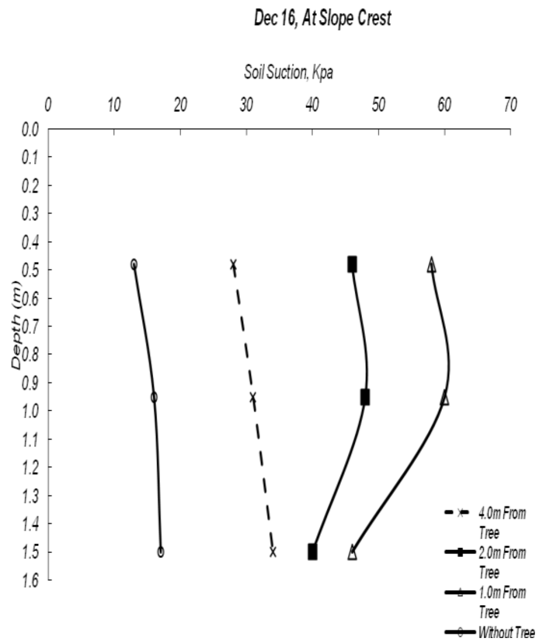


**Figure 8**: Soil suction profile pattern C on 16 December

Lastly, soil suction profile pattern C (December 16) in figure 8 shows substantial increment after 6 day without rainfall. The highest suction profile was encountered at depth 0.5m, 1.0m and 1.5m with 58kpa, 60kpa and 46kpa respectively at distance of 1m from tree trunk. The minimum effect of tree induce suction was encounter at distance of 4m from tree trunk, which recorded the lowest value were 28kpa, 31kpa and 34kpa at depth 0.5m, 1.0m and 1.5m. As mention before and still, suction profile distribution without tree was much lower at all depths compared to the distance of 4m from tree trunk.

**5.0 Effect Of Tree Induce Suction In Stabilty Analysis**

The lowest FOS 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. Table 1 shows the comparison of FOS after numerical stability analysis was performed at various conditions considered on December 4 and December 16 the percentage difference when compare to unsaturated slope with and without tree at toe of slope. In table 1, the lowest FOS on December 4 was encountered due to the high intensity of rainfall event (54mm/day). However, the FOS for unsaturated slope with trees at the toe (1.88) was much higher than FOS without tree (1.73), which significantly different from 8.84%. On December 16, FOS as shown in table 1 substantially increased due to the increasing matric suction was recorded. Still, FOS for unsaturated slope with trees at the toe (3.08) was much higher than FOS without tree (2.12), with significantly different from 45.54%. From the results, it can be seen that changes in matric suction due to the effect of tree induce suction substantially increase the FOS by 8.84% from 1.73 to 1.88 on December 4 and increase the FOS by 45.54% from 2.12 to 3.08 on 16 December.

**Table 1:** Comparison Of FOS on December 4 and 16

The other FOS comparison has been made on 4 and 16 December due to effect of tree water uptake is shown in table 2. From the results for tree water uptake cases consideration it can be seen that changes in matric suction due to tree induce suction at active root zone after moderate and high intensity rainfall (which suction have been generated within this area) can substantially increase the FOS by 38.96% from 1.88 to 3.08.

**Table 2:** Comparison Of FOS on 4 & 16 December For Slope With Tree At Toe

| | Unsaturated Slope With Tree at Toe on 4 December | Unsaturated Slope With Tree at Toe on 16 Decemeber | Percentage Increase, (%) |
|---|---|---|---|
| FOS | **1.88** | **3.08** | 38.96 |

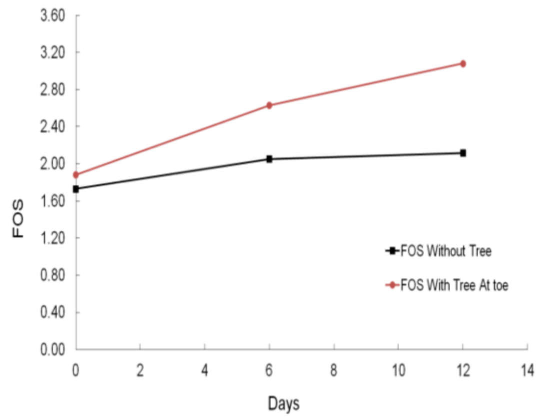


**Figure 9** The Variation Of FOS In Time Due To Tree Induce Suction

Figure 9 reveal 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.

## 6.0 Conclusion

Based on the finding on field monitoring result it is expected that the established pattern of root water uptake is likely to happen when condition is high, moderately rainfall was occurring. A root tree zone could help to reinforce the soil by increasing matric suction related to increasing 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 45.54%.

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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