Tree Water Uptake And Suction Distribution On Tropical Residual Soil Slope

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Abstract. This paper present an exploration of soil matric suction effected by water uptake via tree root at toe of slope on various condition between wet condition (high rainfall) and dry condition (prolonged no rainfall). Matric suction generated by active root tree has substantial influence soil moisture content on residual soil slope. A field monitoring was carried out to collect matric suction data at slope in two conditions; with a tree located at toe of slope and absent of a tree. The installations of instruments particularly at slope with tree at toe were placed within vicinity of the tree with certain depths and distances. The matric suction data from field monitoring was influence by the rainfall events that lead to the instability of soils slope. Analysis of soil matric suction distribution pattern indicates that the highest matric suction value was at shallower depth and proximity of tree. The matric suction profiles obtained from field monitoring are applied as an input data to develop soil matric suction contour. The effect of transpiration driven by active root zone generated matric suction on soil at vicinity of tree may create dry soil to increase soil shear strength.

1. Introduction

The studies on the side slopes of a railway embankment that began to fail after several years of construction due to the gradual loss of stability resulted from a decrease in the strength of the soil with time has been done by Krahn *et al*. (1989). Slope failures commonly occur when the shear strength of the soil is reduced through a decrease in effective stress due to pore water pressure increment (Glendinning *et al*., 2009). The field measurements showed that there was a decrease in suction near slope surface. There is evidence that the suction may have been at or near zero at the point of instability.

This study illustrates the important role of matric suction that play in the stability of slopes, particularly in the near surface stability. Related to that, matric suction produced by vegetation plays an important parts for slope stability by providing immediate shear strength enhancement and modifying the saturated soil water regime, which is turn causes a variation in soil suction or pore pressure (Simon & Collison, 2002). Vegetation also can enhance the stability of a slope by root reinforcement.

Many researchers (Thorne, 1990; Ali, 2010; Normaniza *et al.*, 2007) have discovered the effect of mechanical on tree root that can benefit in preventing shallow slope failure but only a few studies to quantify the hydrological effect for the potential benefit stabilization of slope. Apart from providing natural mechanical soil reinforcement, tree roots dissipate excess pore water pressure and produce sufficient matric suction to increase the shear strength of the surrounding soil. The hydrological effect is related much closed to soil moisture variation and can be directed through transpiration. This effect is found to be important as mechanical effect provides significant increase in soil strength that will definitely improve slope stability in certain conditions. It must be considerate before cutting and felling down the trees without understanding the hydrological condition that have a great impact on the stabilization of slope and soil surrounding it.

Lim *et al.* (1996) and Hossain (2010) has stated that, variations in matric suction profile have been caused by changes in climatic conditions with time. However, the presence of vegetation has shown a significant increase in the in situ matric suction and changes the total head profile and soil in that area (Lim *et al.*, 1996). The hydrological effect is related much closed to soil moisture variation and can be directed through transpiration.

The field measurements of matric suction changes were observed at slope with and without tree at toe to provide useful data for analysis of study area at Faculty Electrical Engineering, Universiti Teknologi Malaysia. The objective of this study is to analysis the effect of tree induced suction at various conditions from wet condition (high rainfall) as an initial condition to dry condition (prolonged no rain). The soil suction results were adopted to develop soil suction contour influence by tree at toe of the slope. This study focuses on the pattern of soil suction that generate within the vicinity of a single representative mature tropical tree.

2. Material And Method

This study was carried out during field monitoring period from 4th February 2012 to 15th February 2012. The tree located at the toe of slope in front of P16 at Faculty of Electrical Engineering, Universiti Teknologi Malaysia as showed in Figure 1. The *acacia mangium* tree was preserved at toe of the slope and no irrigated during this study period to avoid complication of water wetting to soil proximity of the tree.

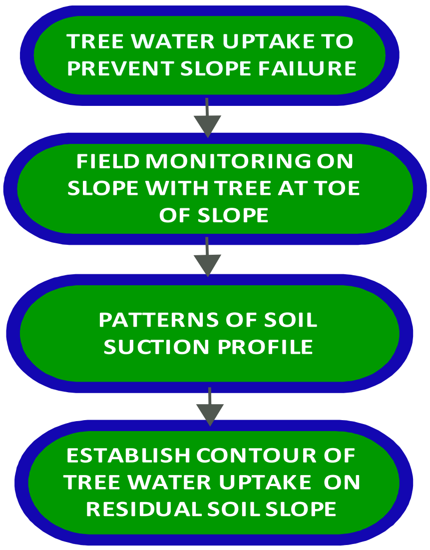

Figure 1. Flow chart of research stages

Field monitoring was carried out to determine the in-situ matric suction on the slope with and without tree at toe. Throughout this field monitoring, the matric suction measurements were taken manually. The installed instruments are concentrated at single mature tree at toe of slope. Two types of soil suction measurement instruments were used in the study, i.e. tensiometer and gypsum block. These combinations of instrumentations were placed at Slope Station and Flat Station as shows in Figure 1 and 2, respectively. Each station of tensiometers were placed at distance of 0.1*h*, 0.2*h*, 0.4*h* etc (where *h* is the height of the tree), according to Biddle (1998). Then, the instruments were installed according to arrangement of 1m, 2m and 4m distance from tree trunk with depth of 0.5m, 1.0m, 1.5m and 2.0m.

To monitor soil suction changes of low suction value at slope with *acacia manggium* tree at toe, Jet-fill tensiometers were used. Soil suction range between 0 kPa to 100 kPa is measured directly by Jet-fill tensiometer. A tensiometer comprises of a tube with a porous ceramic tip on the bottom, a vacuum gauge near the top and a sealing cap.

To measure the high suction value beyond 100kPa up to 1000kPa, the Gypsum block with a measuring capacity range of 10kPa to 1500kPa was introduced. The Gypsum block is cylindrical having a diameter of 22 mm and a length of 24 mm. This instrument consists of two parts; the gypsum soil blocks (sensor) and the measuring instrument Moisture Tester. At this study area, the gypsum blocks and tensiometer were installed with same arrangement throughout both Station (Slope Station and Flat Station).

2.1. Residual Soil Profile

In this study, the subsurface investigation was conducted to determine and identify the thickness and various distribution materials of weathering zones in residual soils at Faculty of Electrical Engineering. Data collected from the trial pit with maximum depth of 1.5 m was analysed to produce the generalized soil profile characteristics of the residual soil at the study area.

Through this site investigation, it is indicated that the soil was formed in-situ by the decomposition of parent material, which the trace of uplifted and transportation marks cannot be found in this study area.

3. Results And Discussion

3.1. Soil Properties

The disturbed and undisturbed soil samples were collected at 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 as presented in Table 1. 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, particle size distribution, porosity and void ratio. This soil formed in-situ under tropical weathering condition as defined by The Public Work Institute Of Malaysia (1996). Based on BSCS classification, the soil is classified as in grouped of sandy SILT (MVS)

Table 1. The properties of the soil material in this study area

Composition	Sandy SILT
Gravel (%)	5.1
Sand (%)	20.9
Silt (%)	48.7
Clay (%)	25.3
Specific Gravity (G_s)	2.62
Void Ratio (*e*)	1.44
Porosity (*n*)	0.59
Permeability (k_{sat} (m/s))	4.1×10^{-7}
Effective Cohesion (*c'*)	9
Effective Friction Angle (ϕ')	23
Unsaturated Friction Angle (ϕ^b)	20

3.2. 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 3. 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 2.

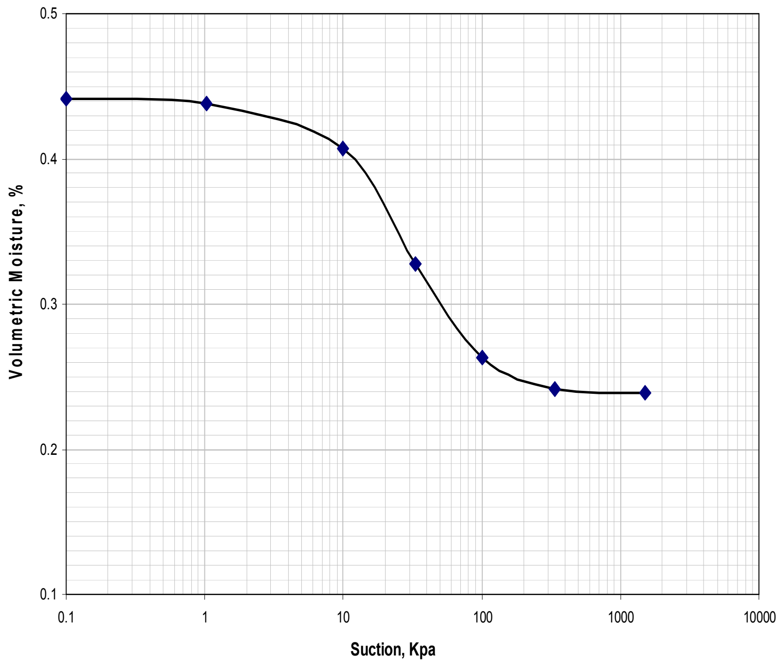

Figure 2. Soil Water Characteristic Curve (SWCC)

3.3. Soil Suction Profile

Soil suction profiles related to soil depth at Slope Station and Flat Station on 4th February 2012 and 15th February 2012, are shows in Figure 3,4, 5 and 6, respectively. During this field monitoring, dry period was occurred of 9day without rainfall was selected to represent condition of suction profile due to tree water uptake. First of all, Figure 3 and 4 shows the matric suction profiles right after prolonged and antecedent rainfall on both slopes (slope with and without tree at toe). Also, soil suction profile on 4th February 2012 was identify as lowest value regarding to antecedent rainfall occurred for 4days and indicate as an initial condition for the analysis.

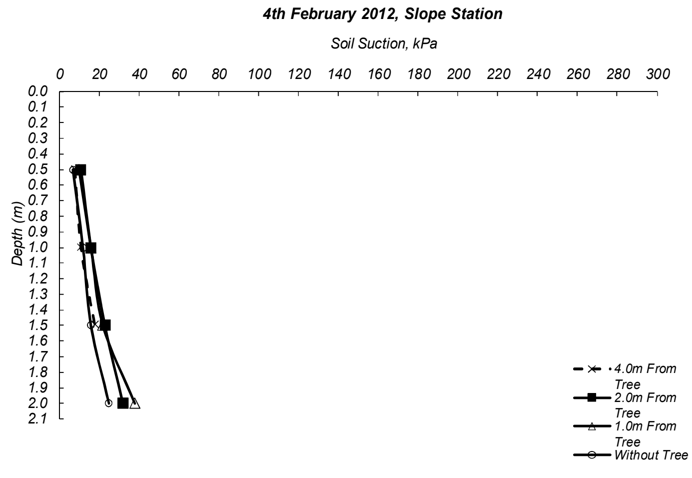

Figure 3 Soil suction profiles on 4th February 2012 at Slope Station

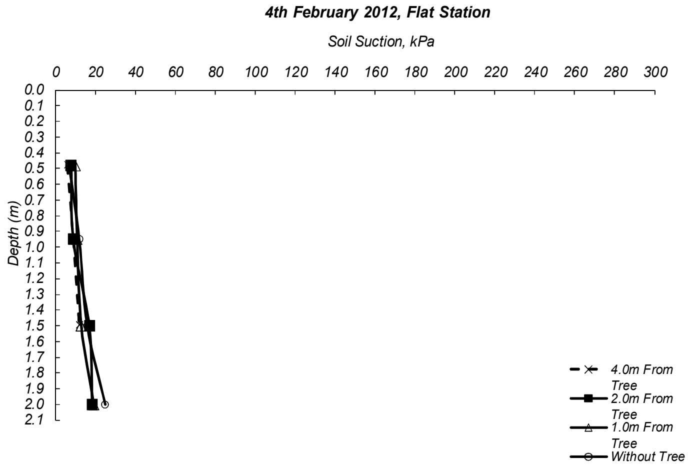

Figure 4 Soil suction profiles on 4th February 2012 at Flat Station

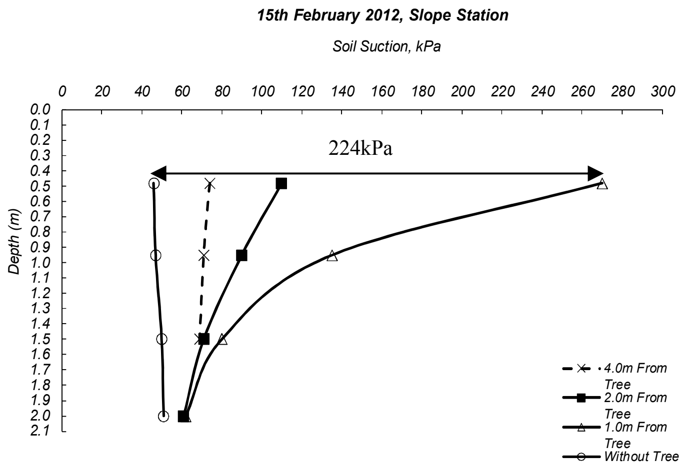

Figure 5 Soil suction profiles on 15th February 2012 at Slope Station

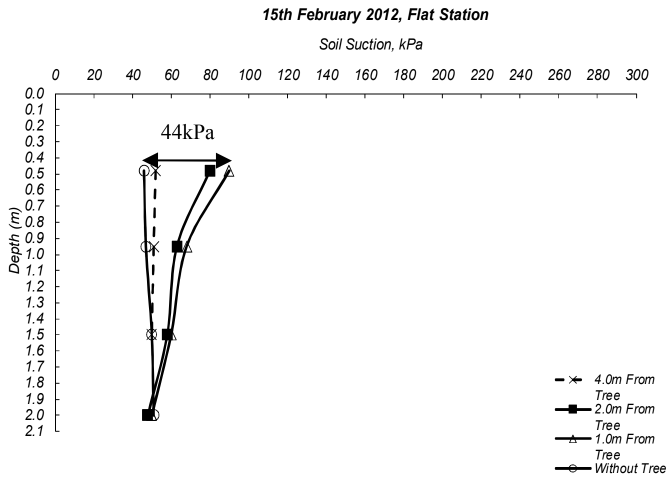

Figure 6 Soil suction profiles on 15th February 2012 at Flat Station

Soil suction value at Slope Station with and without tree at toe on 4th February 2012 and 15th February 2012 was shows in Figure 4 and 6 respectively, has revealed a significant increase in matric suction. This similar pattern of suction was showed at Flat Station in Figure 5 and 6. While, the highest suction value was encounter on 15th February 2012, the maximum value was occurred at both Stations due to absent of rainfall for 9days. Furthermore, suction was gradually decreased at distance of 2.0m and continues to decrease at distance of 4m from tree. The soil suction distribution patterns of changes were developed with different condition or weather can be clearly seen. The matric suction at near surface particularly at 0.5m depth increase gradually to the right as showed in Figure 6 and 7. These figures also indicate that the matric suction at 1m from tree (at Station Slope and Station Flat), particularly at depth of 0.5m, which higher than at slope without tree up to 244 kPa and 44 kPa, respectively.

It can be concluded, the soil suction value was significantly increase within vicinity of tree and decrease subject to distance from tree. It also discover that suction value was significantly difference occur at particularly swallow depth of tree. This is owed by active *acacia mangium* tree root zone that produce sufficient suction on soil compared to the soil suction without tree (Biddle, 1998).

3.4. Soil Suction Contour

The result variation of the soil suction encounter during field monitoring was show in Figure 5 and 6 are applied as an input data to develop soil suction contour. Figure 7 show the soil suction contour on 15th February 2012, the highest suction value of 240kPa was generated at the base of tree near the toe of slope and the lowest suction value of 42kPa as suction without influence by tree. The effect of tree induced suction on soil was concentrated at preserved tree, while the suction depleted when distance away from tree.

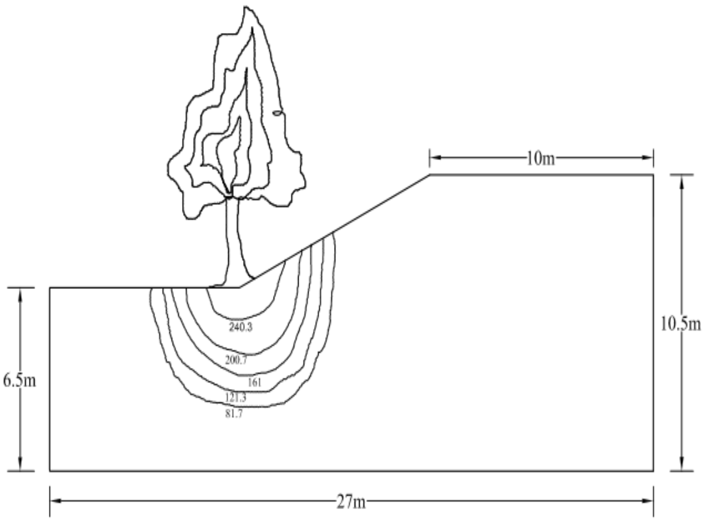

Figure 7 Matric suction (kPa) contour on 15th February 2012

The comparison of matric suction between with and without trees was done by previous researcher such as Pollen-Bankhead *et al.*, (2010) and Woon *et al.*, (2011). In their comparison of matric suction developed in vegetated and bare soil columns in the field and physical model in the laboratory, it was found that almost 100% of matric suction generated in the vegetated column higher than bare soil columns. In relation to that, the measured matric suction at slope without tree is attributed by evaporation which is lower than at slope with tree at the toe, as it was induced by transpiration. The soil suction contour as show in Figure 8 exposed the soil suction at the toe is higher than other section. This contributed by *acacia mangium* tree and helps enhance the soil matric suction to pull out water from soil via active root tree in that area.

4. Conclusion

Weather condition is one of factors that influence soil suction variation at this study area. From the overall profiles results showed that tree water uptake influence soil suction distribution on slope with tree at toe and can be summaries as follow:

i. The results showed that water uptake by tree root mostly influenced by the weather of antecedent rainfall and dry period. The soil suction near the ground surface is more sensitive to the variation of weather, followed by those at greater depths.

ii. The results disclose that tree water uptake caused soil suction increased significantly at vicinity of tree and reach high soil suction value than soil suction without tree. Maximum changes in suction occur at close proximity to tree trunk and near to ground surface but the changes in soil suction decreases gradually with depth and distance from tree. It shows that, increased of soil suction was driven by tree water uptake at active root tree zone.

iii. This study revealed the matric suction generated by root tree has significantly increased values that presented in soil matric suction contour for vertical and radial direction from the tree between 9days of this analysis. Contribution of single mature tree has significantly altered the soil suction or soil moisture distribution trigger by transpiration on unsaturated soil slope.

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