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Monitoring soil slope of tropical residual soil by using tree water uptake method

M S I Zaini¹, M F Ishak^{1*} and M F Zolkepli¹

¹Faculty of Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Kuantan Pahang, Malaysia

*fakhrurrazi@ump.edu.my

Abstract. From years to years, the construction of residential buildings at hill-site in Malaysia will lead to various fatalities event. Cutting down of trees can vanish the reinforcement provided by the root of tree to the soil by means of weakening the soil shear strength due to the increasing value of pore water pressure and decreasing value of effective stress. Root of a tree plays an important part in preventing landslides event to occur either it is by modifying the soil moisture regime via evapotranspiration or providing root reinforcement within the soils. Water uptake by plant roots is fundamental in many applications agriculture. This study is conducted to explores the vegetation approach by using tropical mature tree and monitors the activeness of the root zone of a tree that lies at the top of the slope by which the data of the matric suction generated within this section of the slope is recorded by using Tensiometer and applied to the slope stability problem to increase the value of factor of safety (FOS). Based on the research conducted, it is proven that by using tree water uptake method can increase the FOS of the slope up to 57%. In retrospect, the method used in preventing the landslides event to occur at the slope is economical and eco-friendly which can be implemented globally as this is the most nature method to prevent landslide and required low cost compared to other methods.

1. Introduction

Over the past few years, the consequences and frequency related to the human activities and natural event around the whole world has increased rapidly with continuous trend. Due to the losses of economic resulting from landslides and slope failures, increases of cases in injury and loss of life also occurred especially resulted from catastrophic events. had presented a data published by the World Health Organization (WHO) in 1992 related to the number of people killed, injured or displaced globally due to the natural hazards during the 20th century is presented [1]. Based on the data presented, for most categories, the fatalities are considerable and it is significant that the country that are less developed recorded the highest number of consequence events. It is very important to highlight that the number per million of the population along with the total number of deaths are both higher for most of the undeveloped parts of the world. The increase in elements at risk and their vulnerability as well as the increase in the frequency of hazards became the main reasons that lead to the rapid increasing in the number of deaths due to the landslide events. Lack of adequate planning for development and hilly areas and marginal lands, inadequate management of hazards and the rapid growth or urbanization become the main contributions factor that cause the landslide disaster to occur. From time to time the need for landslide risk management and the assessment of landslide susceptibility and hazard recognition continuously increasing [2].



2. Literature review

2.1. Tropical residual soil

Like other soils, residual soils are used in construction as a construction material or as a build upon. When the rate of rock weathering is more rapid than the transportation of the weather particles such as wind, water and gravity which results in a large share of the soils formed are how the residual soils are formed. Residual soils often retain more than one characteristics of the parent rock. Residual soils layers can be very thick in a tropical region where sometimes it extends to more than hundred meters before reaching the un-weathered rock [3]. The engineering properties and behaviour of the tropical residual soils may widely vary from place to place depending on the local climate and the rock of origin during their formation and are more difficult to model and predict mathematically unlike the more familiar transported sediment of soil. Residual soils are not as extensive as that of transported sediment oil despite of their significance and abundance of the understanding and knowledge of these soils [3].

Theoretically, residual soils are form at in-situ decomposition and weathering of rock which remain at their original location. The entire of transported soils are having distinctly different characteristics. Weathering included chemical and physical processes leading to the formation of residual soils to be formed. Chemical and physical breakdown can be categorized into decomposition that altered the soils especially in tropical regions that exposed to the humidity [4]. The solid phase of residual soil is constituted not only from the products of the interaction of the agents of surface processes but also from the origin of unaltered terrestrial material. In addition, it also consists gaseous and water phases. The upper portion which supports the plants that live in this area also includes organic matter between both dead and living [3].

2.2. Rainfall infiltration

Interception (rainfall that is held by the vegetation), runoff, evapotranspiration and infiltration are the components of the cycle of hydrological condition of rainfall. When categorising the rainfall components, the amounts of evapotranspiration cannot be neglected because they indicate a small amount of the total rainfall [5]. These generalizations leave the infiltration and runoff equal to the estimated rainfall.

When rainfall infiltrates into the zone of phreatic surface, the moisture content will reduce or rise the suction for the soil above the phreatic surface as the water flows downward that can resulted in the rise of phreatic surface zone. Some instability to the slope may occur due to the increasing of this area that has been proved by [6] and compared to rising groundwater, failure may be induced by the direct rainfall.

2.3. Tree water uptake

For over a hundred year, there have been a subject in international research on related to the amount of water used by the trees [7]. In the fields such as geotechnical engineering, hydraulic environmental engineering, building management, ecology, geo-environmental engineering and agricultural take interests in the aspect of the behaviour of the amount of water used by the trees.

The key to successful growth is the interaction between soil water and plant roots [8]. Quality and quantity of infiltration recharge to groundwater systems as well as reducing in plan growth, and affecting the crop yield is the effect of the shortage of water in the root zone [3]. During this period, the depth and distribution of its root system will become the dependent factors to the capability of crop roots to extract soil water. Hence, modelling plant growth under those conditions becomes crucial when predicting the water uptake. The tree water uptake is measured by using a Jet-Fill Tensiometer that were planted at the study area.

2.3.1. Root water uptake process. Water used for metabolism in plant tissues and water transpired to the atmosphere is categorized from the loss of moisture from the soil. The water uptake from the root zone can be assumed the same as total water transpiration. Hence, the change in the soil moisture within vicinity of the tree is influenced by the soil suction exert from water uptake by tree [3]. It is

mainly being considered in this study the water uptake by plant root which is treated as a sink term distributed in the root zone and the matric suction generated by the tree was measured. Different adaptations by the tree and strategies to acquire water to photosynthesize and undergo transpiration process was developed by the trees [7]. The adaptations such as water storage, deep water uptake, stomata closure, etc. were developed by the trees to acquire water for photosynthesis and transpiration process.

2.3.2. Transpiration. The vegetation at the slope which demand the cycle of the water are met by the roots that extracted the moisture of the soil. Within the vicinity of the tree the moisture is lowered directly by the extraction of the moisture. Transpiration is the rate at which plant consumes the moisture of the soil. It became one of the important values that were employed in the water uptake process. Strength of daylight, length of daylight, root volume, soil moisture availability, soil type, wind speed, xylem volume, temperature, canopy volume, weather condition, size and tree species are among the factors that influenced the rate of transpiration [9].

2.4. Slope stability

Methods of geotechnical engineering for slopes have been transformed since the first ASCE conference on stability and performance of slopes and embankments in 1966, largely because computers have changed so many aspects of geotechnical engineering and geo-construction. While the new tools available for shear strength evaluation, computation, communication, construction, and monitoring have revolutionized the way we work, the need for judgment and the value of experience have not diminished [10]. Computer programs for slope stability analysis have been developed that can perform analyses and provide results in figures of professional report-quality, in very little time. However, as pointed out many times by Steve Wright, results should not be accepted at face value. They should be checked thoroughly. Because the computer programs now available are so complex, it is virtually impossible to check the results using hand calculations. The only feasible way of checking the results is by using a second computer program to analyse the problem. Wright has shown the value of thorough checking through many examples [10].

2.4.1. Slope stability analysis. In most applications, the primary and the main purpose of slope stability analysis is to contribute to the safe and economic design of excavations, embankments, earth dams, landfills, and spoil heaps. Slope stability evaluations are concerned with identifying critical geological, material, environmental, and economic parameters that will affect the project, as well as to understand the nature, magnitude, and frequency of the potential slope problems. When dealing with the slope stability analysis in particular, previous geological and geotechnical experience in an area is valuable [3].

2.4.2. Type of Slope Stability Analysis. Slope stability analysis is very important in order to perform and to assess the safe design of human made or natural slopes. The analysis such as analytical techniques (method of slices), limit analysis, stereographic and kinematic analysis, rock fall simulators and numerical methods of analysis were all being practiced in the industry especially for the geotechnical engineers and geologist [4].

3. Methodology

The project methodology is a method or process of a study done from the search data up to the stage of data analysis. It is also forms the basis of a study. The methodology can also enhance the ability of researchers to evaluate and comment on existing issues. Case study research excels at bringing to an understanding of a complex issue and cases which can extend experience or add strength to what is already known through previous research. Case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships. Researchers have used the case study research method for many years across a variety of disciplines. Social scientists, in particular, have made a wide use of this qualitative research method to examine contemporary real-life situations and

provide the basis for the application of ideas and extension of methods. For this research the case study was conducted at Pahang Matriculation College (KMPH).

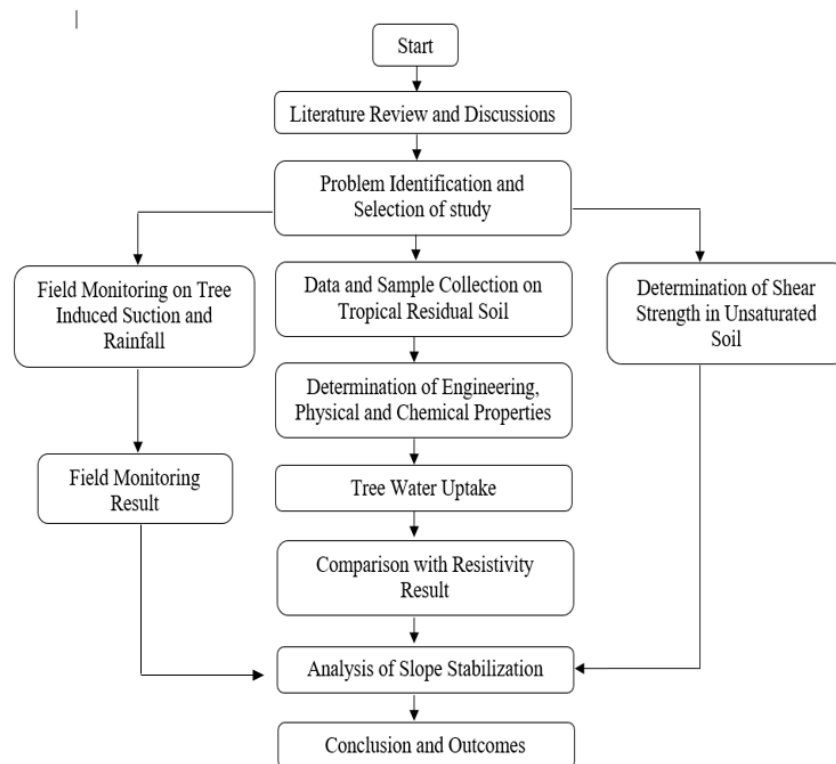


Figure 1. Flow chart of research methodology.

The methodology for the research as shown in figure 1 involves field works, field monitoring procedures and laboratory testing and experiments for the study which will be conducted. For the first stage, the research started with reviewing materials and published works by the previous researchers through books, journal, database, internet and many more with related to the topic of research such as the influence of mature tree to induce moisture that affect the slope stability of in the unsaturated soil. Besides, personal consultation with the experts in geotechnical engineering was conducted with related to the matric suction of the tree on the slope stability in order to form a strong background for the research that will be conducted.

For the second stages, the study involves data collection that can be attributed from laboratory testing and field monitoring works. Two main sets of data that were collected and monitored, i.e., the response to rainfall within the tree on a residual soil slope and the response changes in matric suction influenced by tree water uptake. Rainfall distribution and matric suction data was acquired through instrumented field monitoring works during the course of six months, starting from January 2018 until June 2018. In the means time, to gain data related to the soil characteristics governing their physical, hydrological and chemical behaviours, a series of engineering laboratory tests on mineralogy, hydrology and index were conducted on residual soil samples. The matric suction together with the rainfall events data were statistically analysed during no rainfall which considered as a tree water uptake period.

Finally, the shear strength parameter of unsaturated soil (in terms of ϕ_b) was determined through Unconsolidated Undrained (UU) test using the Triaxial testing apparatus. The unsaturated soil specimen was tested at its initial water content or suction, i.e. at the initial matric suction to the maximum matric suction encountered during field monitoring. Moreover, the testing that was conducted by replacing the porous stone with metal or plastic discs on both top and bottom part of the specimen and covered the specimen with rubber membrane during the test as an alternative method.

Despite of the fact that the suction may decrease due to the increase of pore-water pressure during shearing stage of the soil sample, it is assumed that the variation is negligible.

It was considered that tree water uptake in certain condition would alter hydrological condition of slope in the study area. Furthermore, the matric suction generated by tree can be a significant attribute to replicate the condition of soil strength in the laboratory. The laboratory shear strength test results with variant matric suction were used as the basis model for shear strength of unsaturated soil mechanic. The shear strength responds to matric suction was extended to determine factor of safety of monitored slope. The final results of this study were to examine the matric suction distributions as a response to water uptake driven by active root tree (transpiration). Both of this method were compared based on the genuine result obtained through field monitoring and field testing.

4. Result and discussion

The sections present the engineering properties of the tropical residual soil, matric suction change due to climax condition such as local rainfall intensity and the slope stability analysis influenced by the matric suction.

4.1. Shear strength

The summary of shear strength parameters of the tropical residual soils employed from the study area is shown in table 1. The saturated consolidated isotropic undrained (CIU) triaxial tests was performed on undisturbed soil samples resulted in effective cohesion (c'), effective friction angle (ϕ') and unsaturated friction angle (ϕ_b) of 9 kPa, 25° and 21°, respectively. Table 1 shows the shear strength parameter that were used in Geo-Studio Software to find the factor of safety value for slope stability analysis.

Table 1. Shear strength properties of study area.

Shear Strength Parameter	Sandy SILT
Effective Cohesion, c' (kPa)	9
Effective Friction Angle, ϕ' (°)	25
Unsaturated Friction Angle, ϕ^b (°)	21

4.2. Field monitoring result

Field measurement results presented in this study were recorded from February 2018 until July 2018. The data collected during the course of monitoring consisted of matric suction response to the annual trend of rainfall events together with the effect on water uptake via transpiration of tropical mature tree on residual soil slope. In addition, the data plays important role in demonstrating the mechanism of rainfall infiltration together with the data on the matric suction generated by the tree water uptake which were used in establishing a dependable condition of soil materials for unsaturated shear strength test at low moisture (high matric suction) in the laboratory. Field suction envelopes measured at 0.25 m, 0.5 m, 1.5 m and 2.0 m without tree (Flat Area 3) functioning as controlled matric suction in soil slope at the study area were shown in figure 2.

Data collections from Flat Area of 1, 2 and 3 and Slope Area of 1, 2 and 3 for half year (6 months) period were used for analyses of this study. The matric suction for Flat Area of 1, 2 and 3 and Slope Area of 1, 2 and 3 were shown in figure 3 and figure 4, respectively. In this field monitoring results, the measurements are taken from tensiometer and gypsum block readings from February 2018 until July 2018 with the daily rainfall data. The five lines in that were shown in the graph represents the readings from the instruments at five different depth as indicated in the legend which are 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m. The bar graph represents the rainfall data in which it shows the occurrence of the rainfall during 6 months period of monitoring.

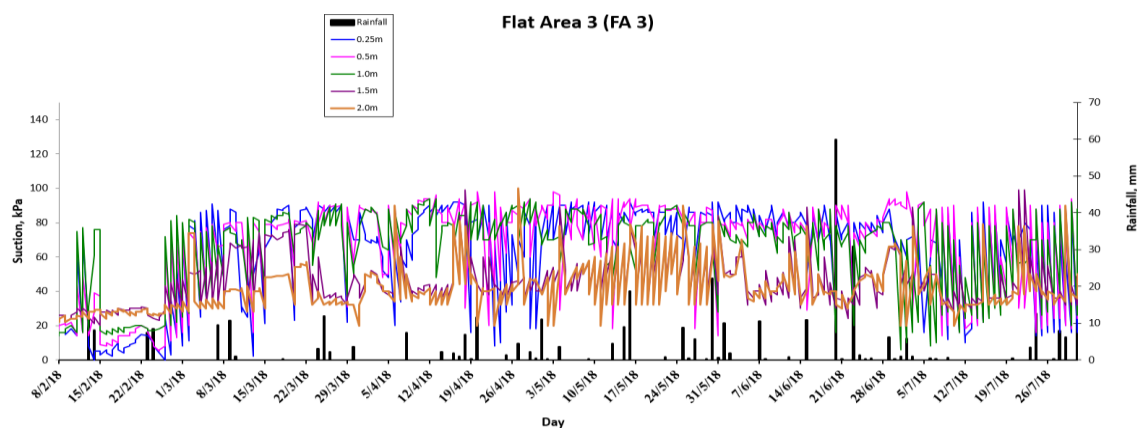


Figure 2. Field Matric Suction in response to the rainfall distribution at slope without tree during monitoring period starting from February 2018 until July 2018.

From 15th February 2018 to 22nd February 2018, 1st March 2018 to 6th March 2018, 11th March 2018 to 23rd March 2018, 1st April 2018 to 15th April 2018, 17th May 2018 to 24th May 2018 and 3rd June 2018 to 6th June 2018 the matric suction increased during no rainfall event as water in soil was removed from the soil via transpiration. The effect of transpiration on matric suction were revealed significantly at Flat Area 1 (FA 1) and Slope Area 2 (SA 2), which were then gradually decreases at Flat Area 2 (FA 2) and Slope Area 2 (SA 2) with much more lesser effects toward Flat Area 3 (FA 3) and Slope Area 3 (SA 3) as shown in figure 3 and figure 4.

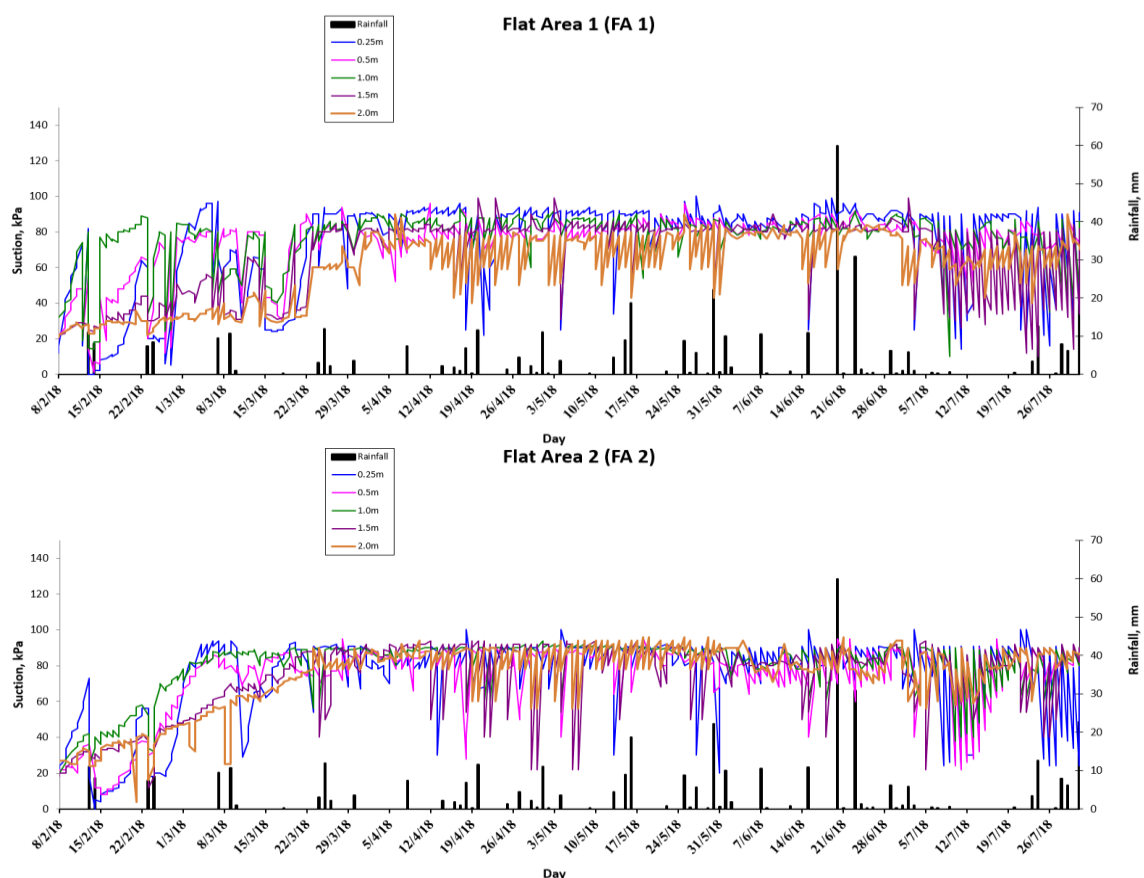


Figure 3. Field Matric Suction in response to the rainfall distribution at Flat Area of 1 and 2 during monitoring period starting from February 2018 until July 2018.

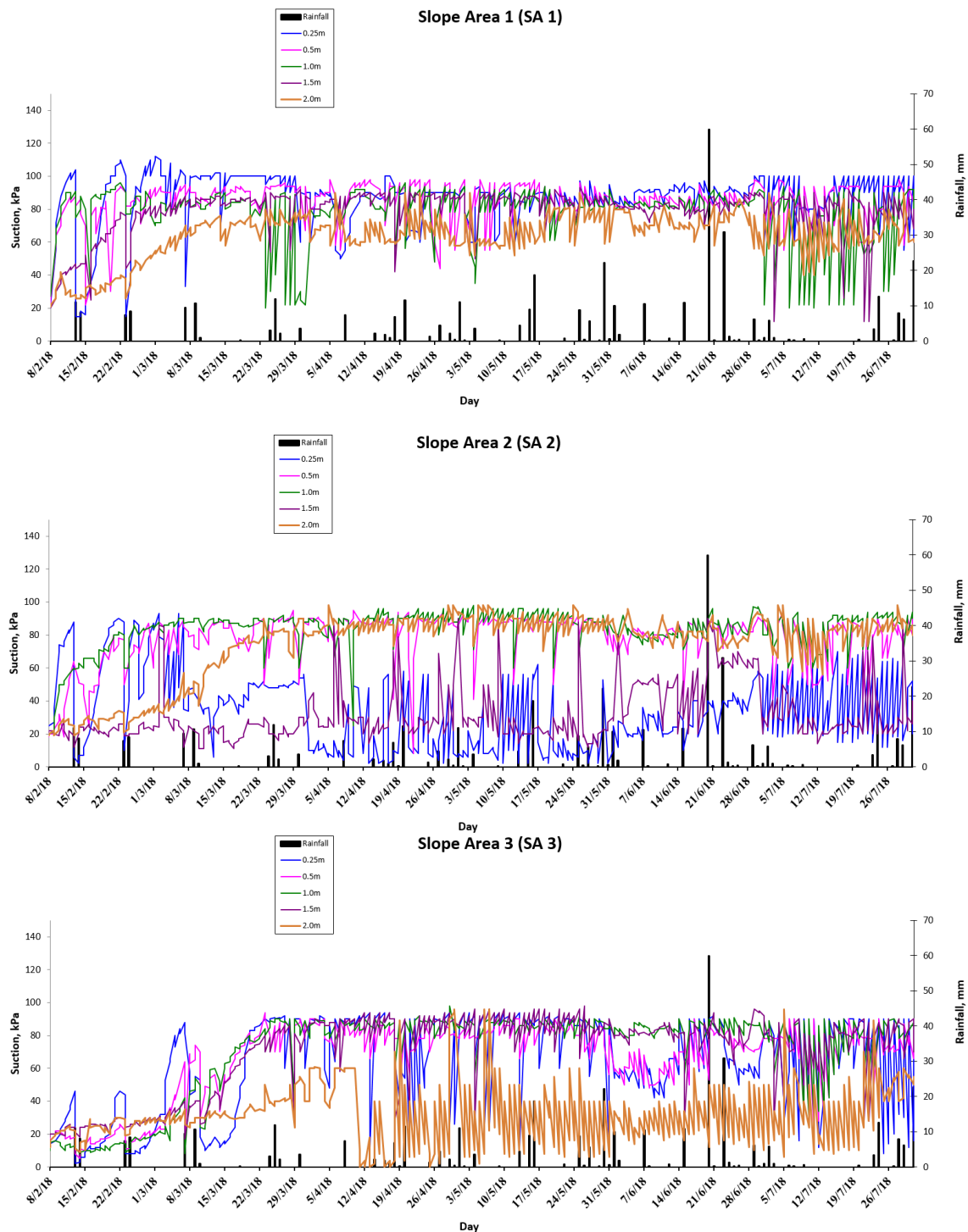


Figure 4. Field Matrix Suction in responds to the rainfall distribution at Slope Area of 1, 2 and 3 during monitoring period starting from February 2018 until July 2018.

On 29th June 2018 the suction variation was considerably large as the matric suction at 0.25 m depth at Flat Area (FA 1) reached a value of approximately 92 kPa, while the changes in matric suction was approximately 91 kPa. The matric suction at 0.5 m, 1.0 m, 1.5 m and 2.0 m depth reached approximately 80 kPa, 88 kPa, 88 kPa and 80 kPa respectively, while the changes of the matric suction were 78 kPa, 87 kPa, 86 kPa and 78 kPa respectively. For Slope Area 1 (SA 1), the matric suction was approximately reaching 100 kPa while the changes in the matric suction was approximately 96 kPa. The matric suction at 0.5 m, 1.0 m, 1.5 m and 2.0 m depth approaching to 98 kPa, 88 kPa, 90 kPa and

78 kPa respectively and the changes in matric suction was 96 kPa, 86 kPa, 88 kPa and 56 kPa respectively.

At Flat Area 2 (FA 2), the matric suction at 0.25 m depth reached a value of approximately 92 kPa while the changes in matric suction was approximately 84 kPa. The matric suction at 0.5 m, 1.0 m, 1.5 m and 2.0 m depth reached approximately 90 kPa, 90 kPa, 90 kPa and 90 kPa respectively while the changes of the matric suction were 88 kPa, 88 kPa, 88 kPa and 88 kPa respectively which are much more lowered compared to the matric suction at Flat Area 1 (FA 1). For Slope Area 2 (SA 2), the matric suction was approximately reaching 58 kPa while the changes in the matric suction was approximately 56 kPa. The matric suction at 0.5 m, 1.0 m, 1.5 m and 2.0 m depth approaching to 84 kPa, 97 kPa, 66 kPa and 90 kPa respectively and the changes in matric suction was 83 kPa, 96 kPa, 65 kPa and 88 kPa respectively which concluded to the same phenomenon occurred where at this area (SA 2) the value of the matric suction are lower compared to the first area (SA 1).

The minimum effect of tree induced suction was encountered at Slope Area 3 (SA 3) at depth of 0.25 m, 0.5 m, 1.0m, 1.5 m and 2.0 m were recorded as 55 kPa, 71 kPa, 86 kPa, 56 kPa and 50 kPa respectively. The field data in figure 2, figure 3 and figure 4 are matric suctions plotted with respect to the depth of instruments installed and rainfall intensity to allow uncomplicated comparison and configuration between the field data covering the area of the slope, flat and area without tree. The slope of the study area were presented in figure 5 and figure 6.

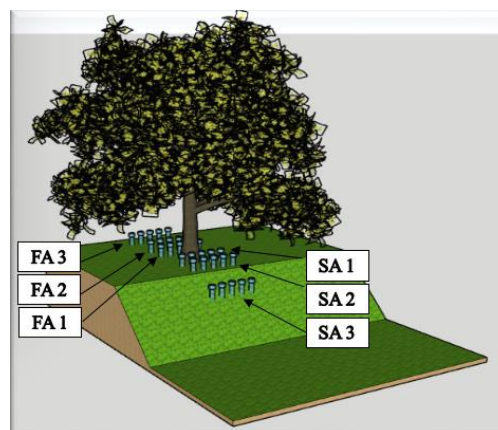


Figure 5. Jet-Fill Tensiometers installed at Slope Area and Flat Area.

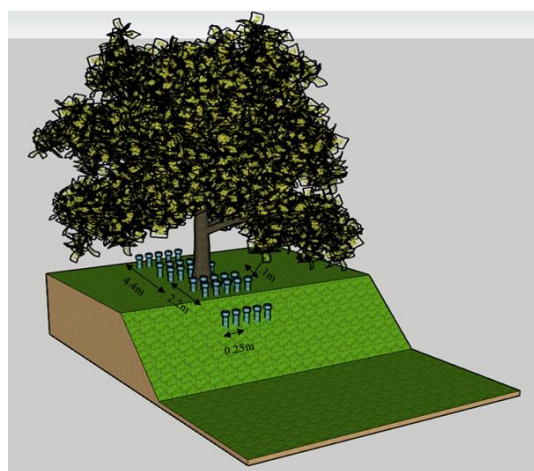
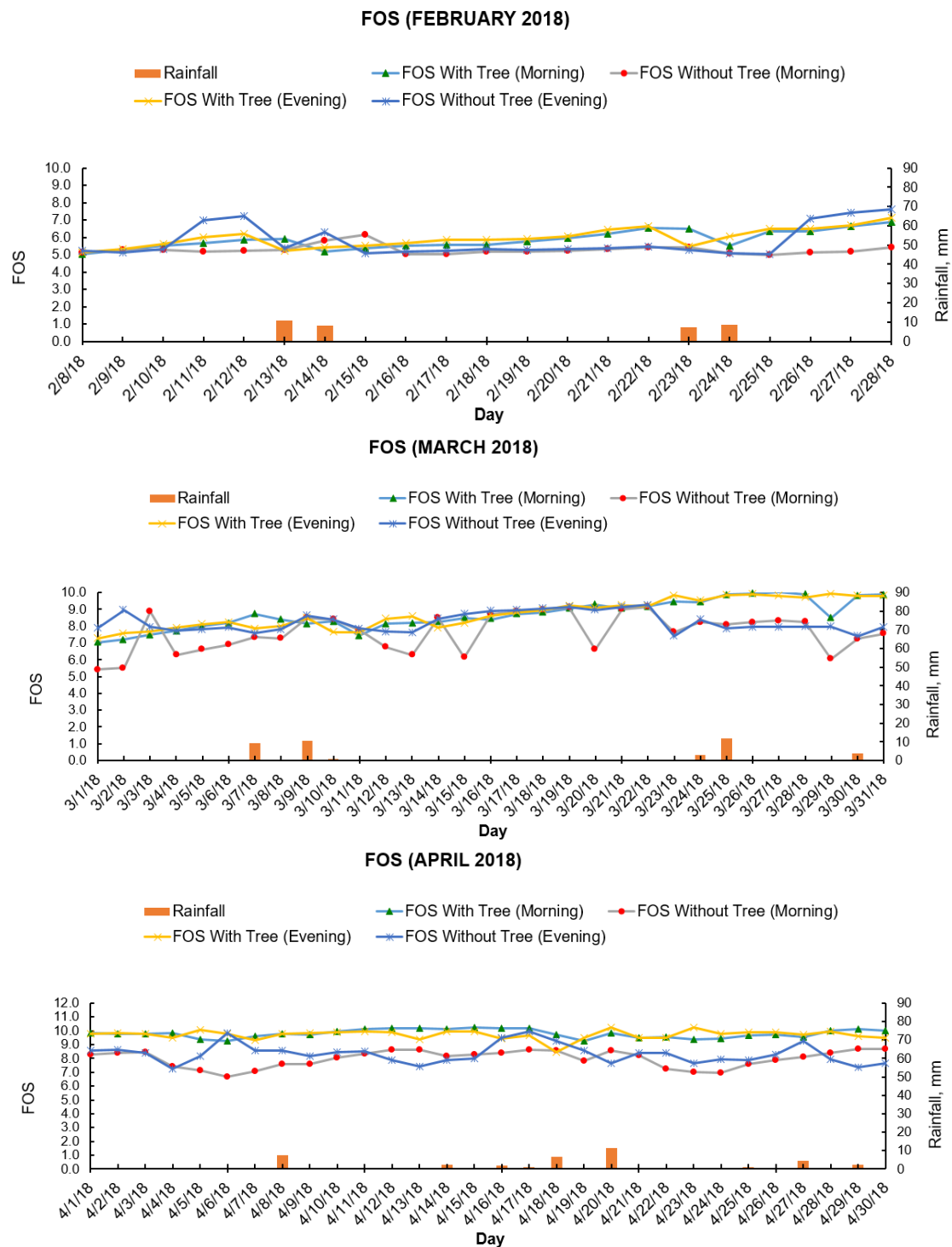


Figure 6. Alstonia Angustiloba tree located at the top of the slope with position of instruments.

4.3. Slope Stability Analysis

The matric suction distributions from field monitoring were applied to Terzaqi's equation for slope stability analyses. Figure 7 shows the changes in results of the FOS against failure during 6 months period of slope monitoring. The graph also presented in combination with the rainfall data for the half year period which also covered the value of FOS for slope with tree and without tree between two different time (morning and evening). The initial FOS of saturated slope is 3.64 which is lower than unsaturated slope with absence of tree and the FOS varies with soil matric suction and time.



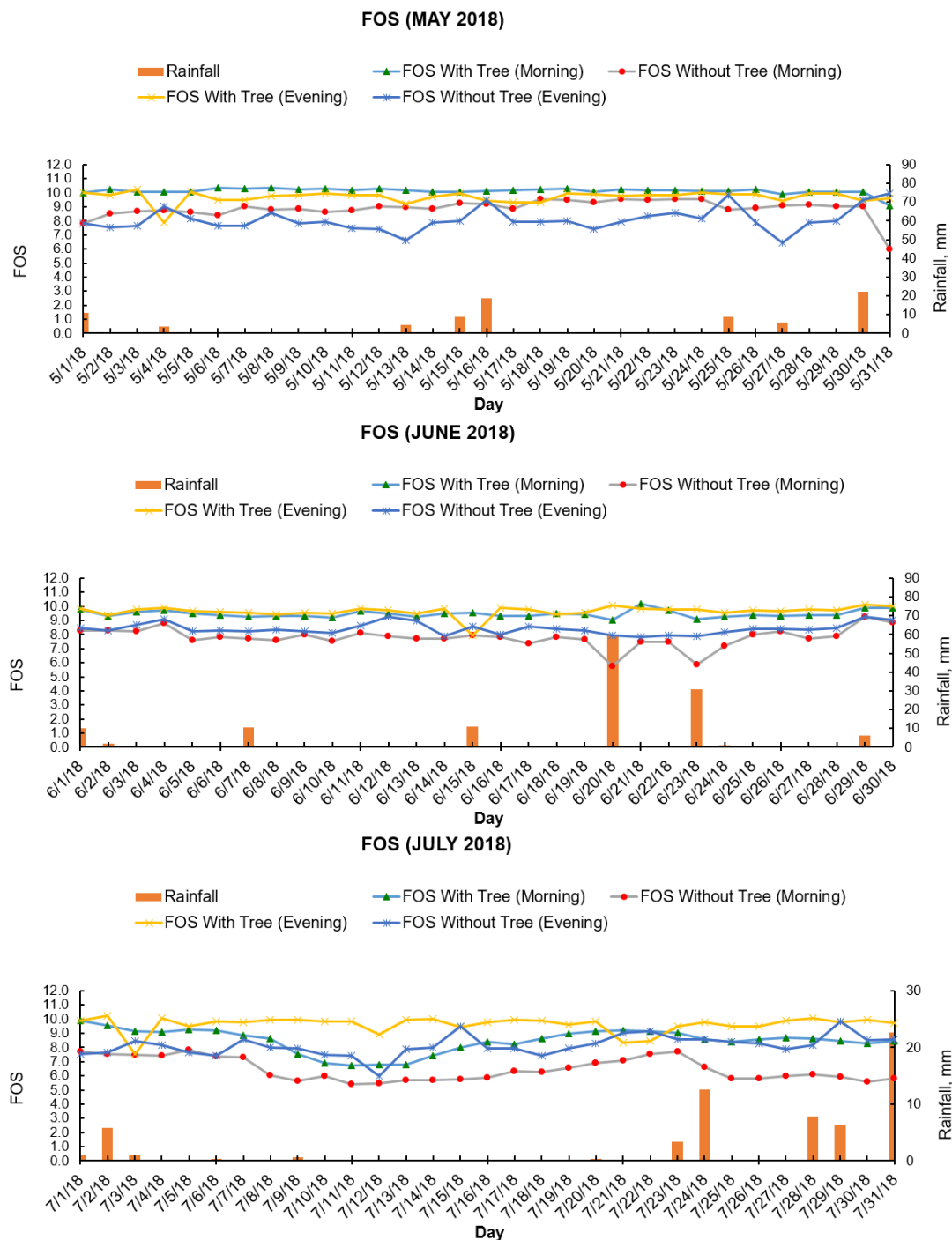


Figure 7. Factor of Safety versus Time for Slopes with and without Tree at Top of the Slope (February 2018 – July 2018)

Figure 7 clearly shows an increasing value of FOS due to the lower value of rainfall during drying period. These patterns of drying were isolated to several events starting from February 2018 to mid-June 2018 and end-June 2018 to mid-July 2018. During these periods, soil moisture deficit has occurred on soil in order to maintain high matric suction. As matric suction suddenly decreases owing to the rainfall event that reduce the value of FOS because of infiltration, it took only 15 days to make it occur. However, it took nearly 1 to 2 week for FOS to increase through evaporation as shown in figure 5 (FOS without tree). In addition, preservation of mature tree rapidly increase the value matric

suction and it took only one day for FOS to gradually increase. In 20th June 2018, the FOS of the slope with tree at the top reached up to 57% higher than FOS of slope without tree existing at the slope area. The increases on matric suction on slope with tree at the top basically improved the slope stability compared to a slope without preservation of the tree. The presence of the tree has a remarkable influence to accelerate the matric suction after rainfall and as a virtual tool to remove water from tropical residual soil and stabilize slope against slope failure.

5. Conclusion

This study explores the influence of mature tropical tree at top of slope to the matric suction distributions on tropical residual soil. The matric suction profiles pattern in soil mass subjected to decrease by rainfall and increase due to tree water uptakes. The changes in matric suction, particularly on slope with tree at top are significantly differing with slope without tree. This exploration provides the contribution of single mature tree significantly alter the matric suction or moisture variation distribution in tropical residual soils slope. Based on the research conducted, it is proven that by using tree water uptake method can increase the value of FOS of the slope up to 57%. With hindsight, the method used in preventing the landslides event to occur at the slope is economical and eco-friendly which can be implemented globally as the disasters caused by nature can be prevented by nature approach.

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