Preliminary Analysis on Matric Suction for Barren Soil

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Abstract. Most research conducted on slope failures can broadly be attributed to the convergence of three factors, i.e. rainfall, steepness of slope, and soil geological profile. The mechanism of the failures is mainly due to the loss of matric suction of soils by rainwater. When rainwater infiltrates into the slopes, it will start to saturate the soil, i.e., reduce the matric suction. A good understanding of landslide mechanisms and the characteristics of unsaturated soil and rock in tropical areas is crucial in landslide hazard formulation. Most of the slope failures in unsaturated tropical residual soil in Malaysia are mainly due to infiltration, especially during intense and prolonged rainfall, which reduces the soil matric suction and hence decreases the stability of the slope. Therefore, the aim of this research is to determine the matric suction for barren soil and to model an unsaturated slope with natural rainfall to evaluate the effects of matric suction on rainfall intensity. A field test was carried out using the Watermark Soil Moisture Sensor to determine the matric suction. The sensor was connected to a program called SpecWare 9 Basic which also used Data Logging Rain gauge Watermark 1120 to measure the intensity and duration of rainfall. This study was conducted at the Research Centre for Soft Soil which is a new Research and Development (R & D) initiative by Universiti Tun Hussein Onn Malaysia, Parit Raja. Field observation showed that the highest daily suction was recorded during noon while the lowest suction was obtained at night and early morning. The highest matric suction for loose condition was 31.0 kPa while the highest matric suction for compacted condition was 32.4 kPa. The results implied that the field suction variation was not only governed by the rainfall, but also the cyclic evaporation process. The findings clearly indicated that the changes in soil suction distribution patterns occurred due to different weather conditions.

Keywords: matric suction, barren, slope, rainfall.

1.0 Introduction

Slope failures can broadly be attributed to the convergence of three factors, i.e. rainfall, steepness of slope, and soil geological profile. Rainfall infiltration in unsaturated soils is a complex process which seriously affects slope stability conditions [1]. The mechanism of the failures is mainly due to the loss of matric suction of soils by rainwater. When the rainwater infiltrates into the slopes, it will start to saturate the soil, i.e., reduce the matric suction [2].
phenomena) are triggered which cause, in turn, different flow-like mass movements [1]. Movement of the wetting front stops when an equilibrium or steady state condition is achieved. Basically, it is well known that infiltration impairs slope stability, but since it is often not measured off directly from the field, its assessment often relies on vague correlation with rainfalls and runoff [3]. Some of these factors, such as rainfall duration and intensity, slope surface cover, degree of saturation, slope angle, permeability ratios and perched water table are extremely difficult to evaluate. Matric suction is one of the primary stress variables in unsaturated soil hypothesis [4,5].

An understanding of landslide mechanisms and the characteristics of unsaturated soil and rock in tropical areas is crucial for landslide hazard formulation. Most of the slope failures in unsaturated tropical residual soil in Malaysia are mainly due to infiltration, especially during intense and prolonged rainfall, which reduces the soil matric suction and hence decreases the stability of the slope [6,7]. The conventional practice in slope design usually ignores the existence of matric suction in unsaturated soil and assumes that the effect of matric suction will be destroyed completely after heavy rainfall. Therefore, it is important to seek confirmation using lab or field tests.

2.0 Materials and Methods

2.1 Site Description
The embankment is located at the Research Centre for Soft Soil which is a new Research and Development (R & D) initiative by Universiti Tun Hussein Onn Malaysia. The soil sample, which consists of barren acidic soil, was collected from Ayer Hitam [8]. The soil was used to make an embankment measuring 10 m in length and 10 m in width from the bottom. Meanwhile, the top sections measuring 2 m in length and 2 m in width were selected for installing instrumentation.

![Figure 1. Cross sectional view of the position instrument (Watermark Soil Moisture Sensor)](image)

2.2 Field Instrumentation Monitoring Program
To monitor the soil suction changes in the slope, the Watermark Soil Moisture Sensor was installed (Figure 2 and Figure 3). The Watermark Soil Moisture Sensor is used since it can directly measure the matric suction that ranges between 0 kPa to 200 kPa. Figure 1 shows the layout of the instrument installed in the area. Each station consists of a Watermark Soil Moisture Sensor which was installed at a depth of 20 cm. The stations were named Slope 1, Slope 2, Slope 3 and Slope 4 with a gap of 1 m between each other. The readings to measure the matric suction change and volumetric water content using a soil water characteristic curve were taken daily. Since rain gauges were used in this study, rainfall data were monitored using a Data-Logging Rain Gauge called Watch Dog 1120. Field monitoring of in-situ matric suction in slopes has been conducted by a number of researchers, e.g. Krahn et. al. [9], Lim et. al. [10] and Mofiz et. al. [11]. In most of the studies, Tensiometers are...
generally utilized as a part of the field instrumentation to measure matric suction in soil, as long as the
suctions are less than 100 kPa.

2.3 Soil Properties
A series of laboratory tests were conducted to determine the properties of soil. The soil type and its
geotechnical properties are presented in Table 1. The main physical index property of the soil
investigated in this study was soil classification according to British Standard such as the moisture
content, permeability test, in-situ density test (Core Cutter Method), specific gravity, particle size
distribution (see result in Figure 4), and Atterberg Limits of the soil.

| Composition                  | Loose  | Compacted       |
|------------------------------|--------|-----------------|
| Moisture content (%)         | 28     | 25              |
| Permeability (m/s)           | 1.33x10^{-6} | 1.43x10^{-7} |
| Bulk density, \( \rho_b \) (Mg/m³) | 1.517  | 1.810           |
| Dry density, \( \rho_d \) (Mg/m³) | 1.426  | 1.450           |
| Specific gravity, \( G_s \)  | 2.70   | 2.70            |
| Liquid Limit, LL             | 46     | 46              |
| Plastic Limit, PL            | 27     | 27              |
| Plasticity Index, PI         | 19     | 19              |
| Void Ratio, \( e \)          | 0.756  | 0.675           |
| Porosity, \( n \)            | 63%    | 43%             |
| Dry unit weight, \( y_d \) (kN/m³) | 15.08  | 15.81           |
| Saturated unit weight, \( y_{sat} \) (kN/m³) | 19.3  | 19.8            |

Figure 2. Watermark Soil Moisture Sensor before installed
Figure 3. Watermark Soil Moisture Sensor after installed
3.0 Results and Discussions

Field measurement results of rainfall distribution with days for Loose Slope Condition (from 13th to 18th Oct. 2015), rainfall distribution with hours (on 14 Oct. 2015) and matric suction with hours for Loose Slope Condition (on 14 Oct. 2015) are presented in the Figure 5, Figure 6 and Figure 7, respectively. The changes in matric suction as well as the matric suction profiles influenced by response to rainfall are then investigated.

Figure 5. The rainfall distribution for Loose Slope Condition.
Field monitoring data collection of matric suction on the slope are named Slope 1, 2, 3 and 4. The data were collected at one-hour intervals. During this field monitoring period, the maximum suction occurred at Slope 1, followed by Slope 2, Slope 3 and Slope 4. The results presented for the other method agree with the findings from past research done by Ishak et al., [12]. The sudden increase of matric suction at the beginning of rainfall and sudden drop in matric suction after rainfall are believed to be caused by the laminar flow of rainwater at the slope surface [13].

Figure 5 shows the bar graph representing rainfall data as well as the rainfall which occurred during this monitoring period. From 13th Oct. 2015 until 18th Oct. 2015, rainfall occurred on one day only, which was on 14th Oct. 2015. Figure 6 shows the rainfall distribution from 6.50 p.m. until 7.50 p.m and the rainfall prolonged for an hour. The range of rainfall distribution was between 0.02 inch to 0.27 inch (see Figure 6) and recorded the highest reading of 0.27 inch at 7.20 p.m. The values are dropped significantly until the rain has stopped. The lowest reading was 0.02 inch at the beginning and the end of the rainfall. Figure 7 shows that the matric suction values drop from certain values (13 to 27 kPa) to 0 kPa (suction is disappeared) at 6.50 p.m. for all slopes. Matric suction close to the ground surface were the first to be influenced by changes in climatic condition and some delays in matric
suction changes were exhibited at greater depths. A similar conclusion was also discussed by Lim et. al.[10].

Field measurement results of rainfall distribution with days for Compact ed Slope Condition (from 23rd to 29th Oct. 2015), rainfall distribution with hours (on 26th Oct. 2015) and matric suction with hours for Compacted Slope Condition (on 26th Oct. 2015) are presented in the Figure 8, Figure 9 and Figure 10, respectively. Figure 10 shows that the matric suctions at Slope 1 are dropped dramatically from 32.4 kPa at 3.00 a.m to 0 kPa at 4.00 a.m. The rainfall intensity started with 0.09 inch at 2.50 a.m. and continued until 4.30 a.m which took about one and a half hours of rain duration (see Figure 9). As seen in Figure 10, the matric suction for all slopes are dropped drastically to 0 kPa from 4.00 a.m until 6.00 p.m. Slope 1 has recorded the highest value at the beginning (33 kPa), followed by Slope 2 (25 kPa), Slope 4 (3 kPa) and Slope 3 (0 kPa). It is clear that the changes in soil suction distribution patterns occurred due to different weather conditions or rainfall intensity [14] and also variables along the slope profiles (from top to bottom of the slopes).

![Figure 8](image1.png)

**Figure 8.** The rainfall distribution for Compacted Slope Condition.

![Figure 9](image2.png)

**Figure 9.** The rainfall distribution on 26th October 2015 for Compacted Slope Condition.
4.0 Conclusion
A field monitoring program was established to quantify the hydrological impact on the slopes. Field monitoring was measured under various weather conditions and significant changes in matric suctions were found. This statement complies with a study by Ishak et al., [12] which mentioned that weather condition is one of the factors that influences soil suction variations in their study area. In overall, the results of matric suctions have greatly influenced by the rainfall intensity.

The maximum changes in soil suction occurred on the top slope and the changes in soil suction decreased gradually at the bottom slopes. However, suction is more affected by climatic conditions instead of loading conditions as the case of positive pore water pressure in saturated soils [15]. This is due to the uncertainty of the climatic conditions and the suctions are variable with time. Evaporation is an important factor that causes the daily fluctuation of soil suction, particularly during dry periods [16]. Therefore, the evaporation needs to be taken into consideration for future investigation in this study. The suction distributions during the dry season is affected by evaporation, which is in turn governed by a number of environmental factors [17], the type of unsaturated soil such as barren soil [8,18,19] and other tropical residual soils [7].

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