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Rainfall induced residual soil slope instability: building cracked and slope failure

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Abstract. Rainfall is one of the factors of slope failures due to the intensity of rainfall that will seep and increase the moisture content of geo-materials. One of the important role in slope stability is matric suction. This study present the relationship between rainfall and suction of soil which induced the slope instability and the slope stability analysis involving a building which may cause by instability due to suction variation. The slope had separated into three parts which are top of slope, middle of slope and toe of slope. Every part has been inserted with three tensiometer with 0.3 m, 0.45 m and 0.9 m depth. Suction of soil on slope was carried out by using tensiometer. Intensity of rainfall was collected by using rain gauge which placed at open area which to compare with matric suction of soil. Several site and laboratory tests were carried out to identify the soil properties. Stability of slope was analyzed using Slope/w and Manual Calculation via input parameters collected from laboratory test and field test. Fellenius' method was used to interpret the factor of safety for slope study. This includes the analysis of the factor of safety of slices at the selected area with its matric suction value. It was found that when the rainfall increased, the suction of soil decreased and affected to decrease of factor of safety. Hence, the constructed slope was suggested to be redesign to improve its safety factor.

1. Introduction

Slope instability can cause by three different factor or categories. Some of the main factors has being categorized by geological, climate change and human activities. From the geological perspective, soil layer and profile were crucial in influencing the slope instability. Intensity of rainfall, earthquake, flooding and those related disaster are some of the crucial factors of slope instability from the perspective of climate change. During the rainfall, rain water may distribute into two medium on surface and subsurface via surface runoff and infiltration/seepage phenomenon. Shallow failure of slope will occurred due to the less rainwater infiltration volume and surface runoff. Meanwhile, deep-seated slope failure will occurred due to the influence of the river and high groundwater level supplied by the excessive rainfall water.

Rainfall induced slope instability create a common geotechnical hazard in tropical region such as Malaysia [1]. The intensity of rainfall will affect the measurement of rain gauge and the suction of soil because of the measure amount of the rain that falls over time. Rainfall was one of the major cause of slope failures or slope instability when the area or region experience heavy rainfall. Therefore, the characteristic of the rainfall should be considered in the analysis of the slope instability.

Suction plays an important role in the stability of slope especially in tropical region. Hence, the evaluation on the measurement of suction in soil of slope stability is needed [1]. Rainfall which happening at the area will cause the moisture content increased, the matric suction is reduced which

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reduces the intergranular of the soil and the effective stress also reduced. Since the effective stress decreased so the shear strength also reduced [4]. Matric suction is forms at soil-air interface because of the surface tension which result in reduced vapor pressure in the water. Vapor pressure decrease or become negative, the matric suction pressure increases [3]. The reduction of matric suction occurred when the rainfall which cause wetting of influencing the reduction of unsaturated shear strength of soil slope. This is called rainfall infiltration [2].

The aim of this study is to determine matric suction of residual soil slope with building structures. Moreover, the study was able to demonstrate the slope instability due to the rainfall events.

2. Methodology

The data collection area was located at a slope with building which show in Figure 1 and 2. Visual Inspection is to contribute for an initial view of the natural and structural at surrounding of the study area.

Figure 1. Location of the study area from google maps view

Figure 2. Location of the study area from front view

In order to determine the soil type and soil sample for further testing, sample of soil was collected by boring machine and Trial Pits according to British Standard Code of Practice BS 5930: 1999 AND BS 1377: 1990.

2.1. Suction and Rainfall

The slope was divided into three parts which are top, middle and toe of slope for suction testing with three different tensiometer depth (0.3 m, 0.45 m and 0.9 m below the ground surface). The location of tensiometer was shown in Figure 3. Rain gauge was placed at the open area of the site or installed it at the centre of research area.

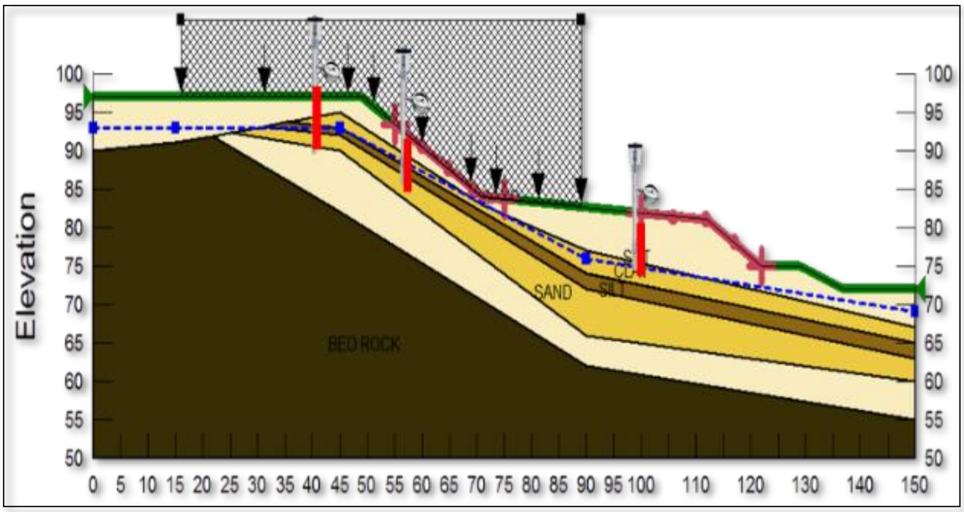


Figure 3. Location of tensiometer

2.1.1. Apparatus used for in situ test. Jet fill tensiometer was used in this study to measure the soil suction. The reading of suction was taken from dial gauge at tensiometer daily from 9 a.m. to 10 a.m. If the soil is too dried, water is added and make sure the water added is enough for to saturate the soil completely. If the soil had completely saturated, the gauge reading on tensiometer will drop to zero. Tensiometer used in the study was shown in Figure 4. Rain gauge is an instrument to collect rainfall. The decision of rain gauge installation location was due to the suitable open area, offset from buildings and free form above obstacles (trees, roof, etc.). This is because the overhead will cause the inaccuracy of the measurement. The reading was recorded daily. The example of the rain gauge is show in Figure 5.

Figure 4. Tensiometer

Figure 5. Rain gauge

2.2. Laboratory test

The laboratory test is carry out to measure the soil properties. Some of the soil tests measure direct properties of the soil, while others measure "index properties" which provide useful information about the soil without directly measuring the property desired. Five (5) laboratory soil testing were performed via particle size distribution, Atterberg limit, standard proctor, unconsolidated undrained triaxial and consolidated drained triaxial (see Table 1). Unified Soil Classification (USCS) with American Society for Testing and Materials (ASTM) standards was used to classify the soil type at slope studied.

Table 1. Laboratory test

No.	Type of Laboratory Test	Function	Standard
1	Particle Size Distribution (PSD)	To determine the size range of the soil and the apparatus used for this test is sieve shaker	ASTM
2	Atterberg Limit Test (AL)	To categorised soil into types and provide their engineering properties such as permeability, strength and compressibility	ASTM D41318
3	Standard Proctor Test	To determine the optimum moisture and maximum dry unit weight of the sample	ASTM 698
4	Unconsolidated Undrained Triaxial Test (UU)	To obtain shear strength parameters for a variety of soil types under undrained soil	ASTM D2850
5	Consolidated Drained Triaxial Test (CD)	To obtain shear strength parameters for a variety of soil types under drained soil	ASTM D7181

2.3. Data analysis

2.3.1. Stability analysis method: SLOPE/W. Geo-Studio Software or SLOPE/W (2004) was performed to determine the stability of soil slope with input parameters from Mohr Coulomb in site investigation (SI) report. The soil input parameters used are cohesion c' and effective friction angle Φ'. Particular research, ordinary method is used in analyse the slope with the direction of movement, left to right and slip surface option which is entry and exit. Figure 6 shows the SLOPE/W analysis of the study area.

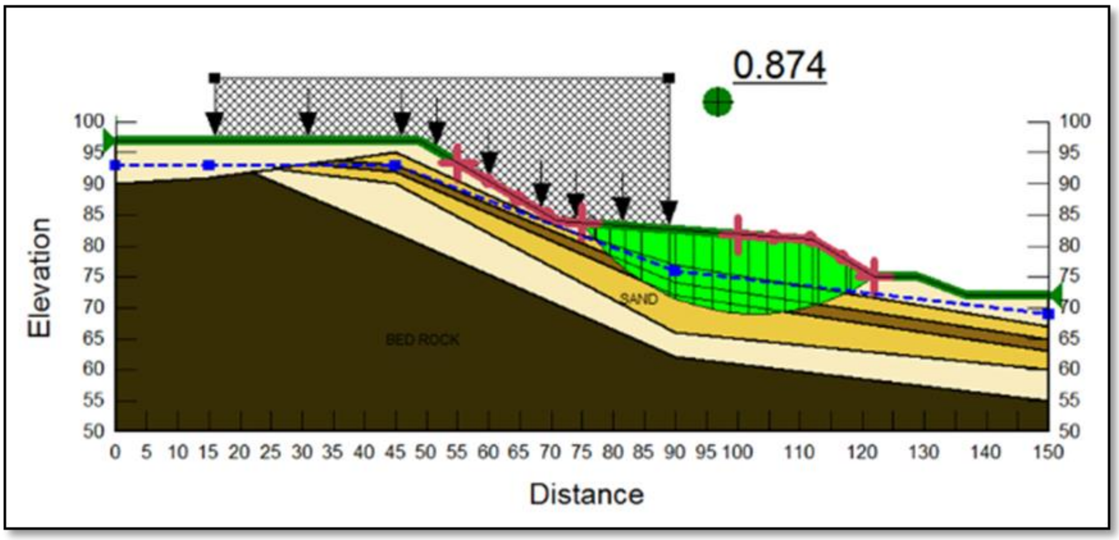


Figure 6. SLOPE/W analysis

2.4. Stability analysis: Fellenius Method

The parameters (cohesion c', effective friction angle Φ', suction and etc.) carried out from laboratory test was calculated using in the formula with the slices selected in each part of the slope studied. The Fellenius' method of Slices was calculated via Microsoft Excel with the formula in table to define the factor of safety (FOS) at each part of slope. The Fellenius' Method formula was shown below:

$$F = \frac{\sum c'l + (W\cos\alpha - ul)\tan\varphi'}{\sum W\sin\alpha} \quad (1)$$

3. Results and Analysis

3.1. Consolidated drained triaxial test (CD)

Three (3) specimens from trial pits sample were used to determine the shear parameters which useful for input parameters for Geo-Slope (SLOPE/W) software analysis.

Table 2. Summary of CD's result for TP-1

Shear Strength	
Cohesion, c_u	Angle Resistance (˚)
C' = 9 kPa	ϕ' = 32˚

Table 3. Summary of CD's result for TP-2

Shear Strength	
Cohesion, c_u	Angle Resistance (˚)
C' = 8 kPa	ϕ' = 35˚

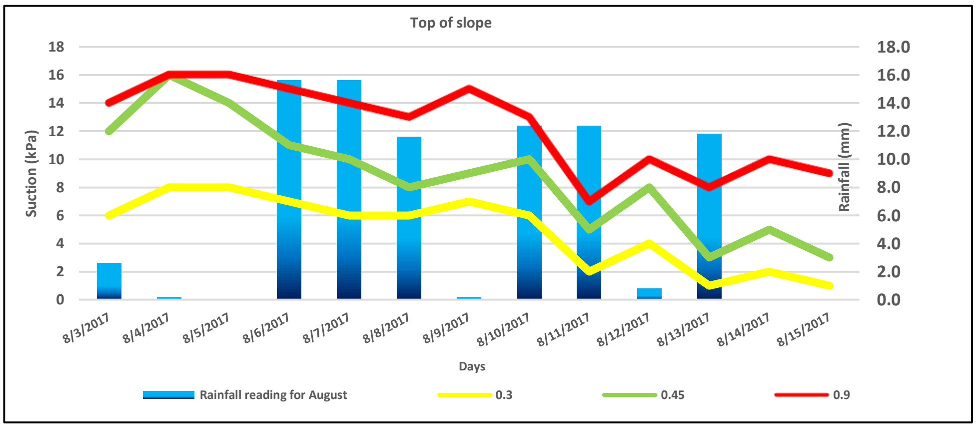
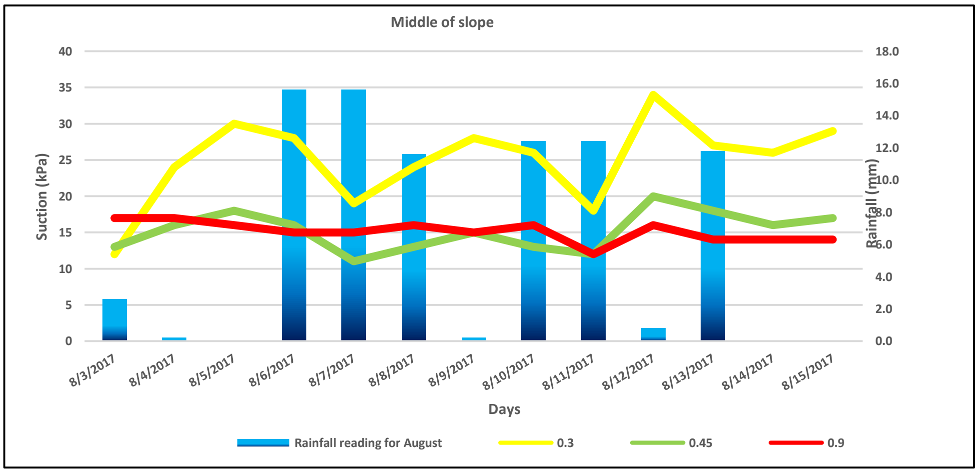
Table 2 and 3 shows the result of (CD) at the study area that were used in analysis for slope stability.

3.2. Relationship between rainfall and suction

Rainfall intensity has influence on the potential failure of slope due to the water content and shear stress developed along the surface. The result and relationship between two parameters are shown in Table 4.

According to Table 4, it was found that the suction value decreased due to increase of water content in soil during the high rainfall and number of precipitation.

Table 4. Relationship between rainfall and suction at different location

<table>
<tr><th>Slope</th><th>Relationship between Rainfall and Suction</th></tr>
<tr><td>Top</td><td>
</td></tr>
<tr><td>Middle</td><td>
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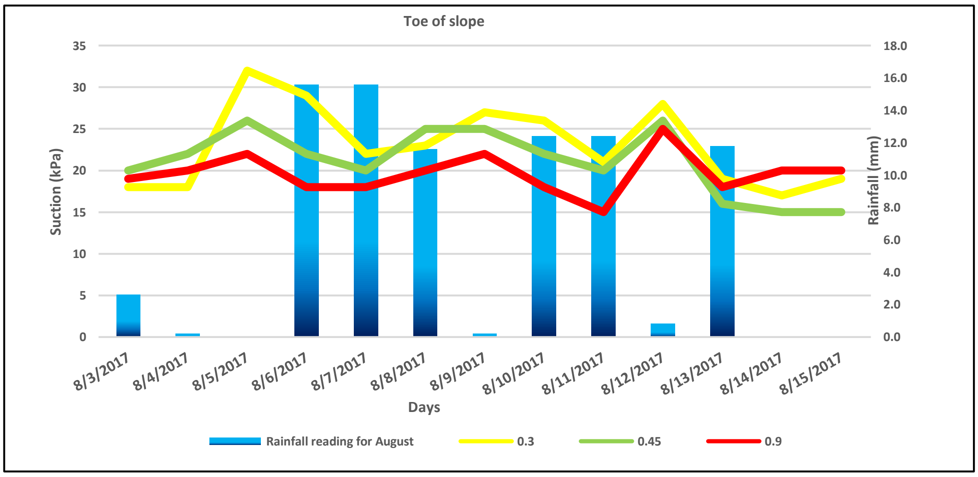
<tr><td>Toe</td><td>
</td></tr>
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3.3. Slope stability analysis

Table 5 shows the soil properties for slope design which all the parameters stated in Table 5 were used to analyse the slope stability in SLOPE/W software as shown in Figure 7.

Table 5. Soil properties for slope design

Parameters Adopted in Slope Stability Analysis				
Region	Slope Description	Unit Weight (Kn/M^3)	Cohesion,C' (Kpa)	Friction Angle, Φ (˚)
1	Sandy CLAY	19.4	9	32
2	Sandy SILT	22.2	9	34
3	Silty SAND	19.9	8	35
4	GRANITE (Bedrock)		-	

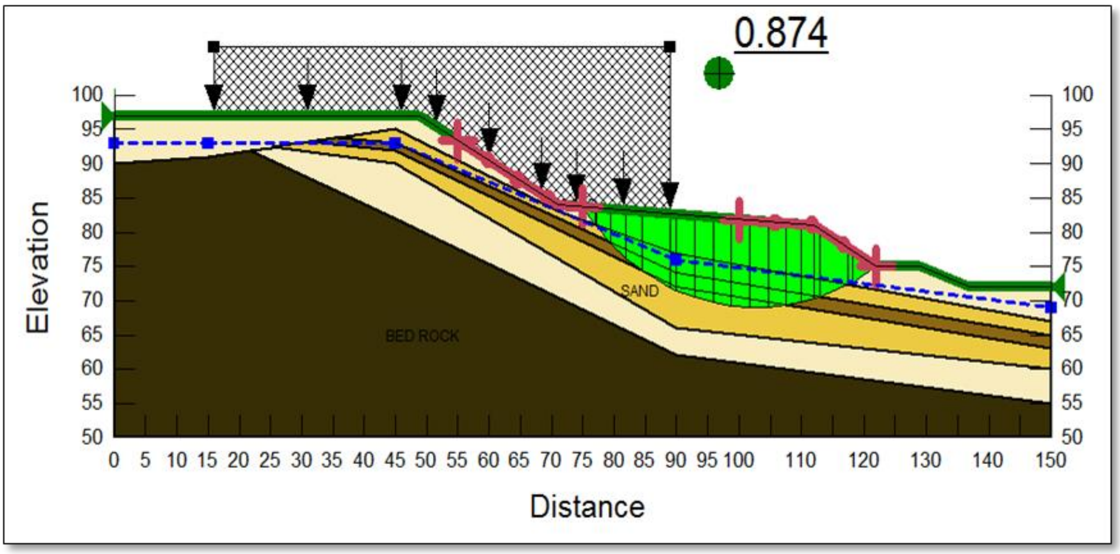


Figure 7. Analysis result of critical FOS with building surcharged on toe of slope

3.4. Comparison value of factor of safety from slope/w and Microsoft Excel

Table 6. Comparison value of factor of safety

Slope	Factor of Safety		Percentage Different (%)
	Slope/W	Excel	
Top	2.04	2.4	15
Middle	1.963	2.65	25.92
Toe	0.874	2.3	49.62

From the analysis by using Slope/w software, on top of slope, the factor of safety on the top of the slope is higher than factor of safety at middle and toe of slope. It was found that slope was not stable due to the factor of safety value of less than 1.3 at toe of the slope studied. This may happen Due to the seepage force in the sloping alignment together with the gravity force thus promoting to the slope instability. The factor of safety at middle of slope was determine by 1.963 via Slope/W analysis. Since at the middle of slope present a building structure the factor of safety may higher than expected factor of safety due to the disturbance of soil structure via earthwork (cut, fill and compaction of soil).

Factor of safety at middle of slope which calculate by Fellenius' Method is higher than top and toe of slope due to the surcharge load. Since the existing of the present buildings, the stability should higher but the soil at middle of slope may influences by the instability of soil at toe of slope. Furthermore, the building had cracked and the road at toe of slope collapsed. The suction value had assumed as 0 to define the factor of safety where suction of soil is zero.

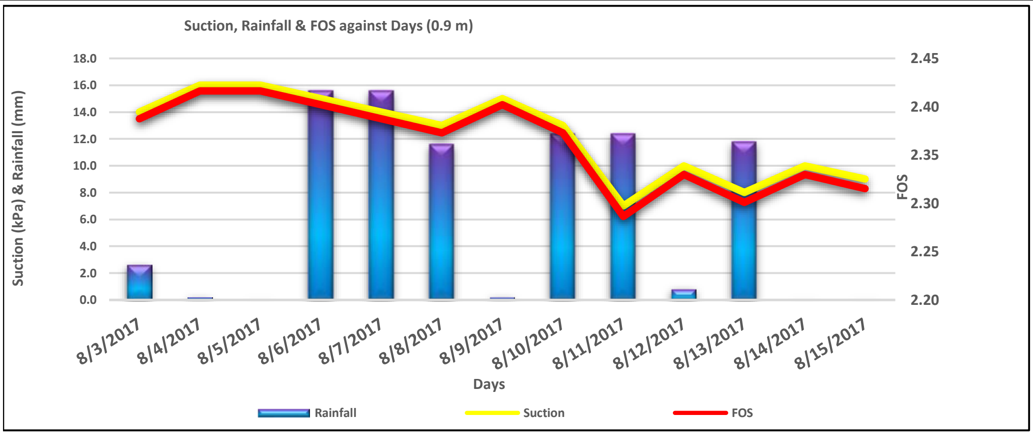
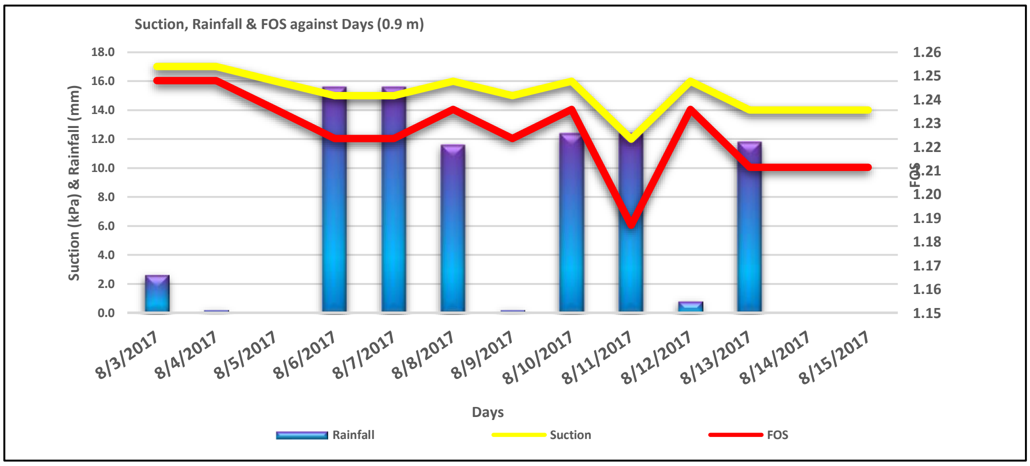
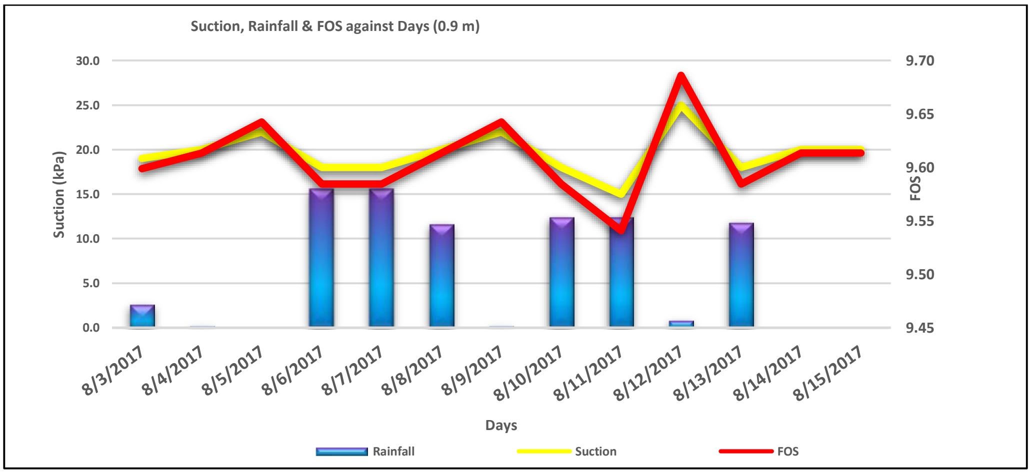
According to Table 6, there is a huge different between these two methods. The result may occurred due to the influence of soil layer. The different layer of soil had substituted into software to analyse the factor of safety. As a result, the analysis has contained different type of soil but Fellenius' method used slices method to analyse the factor of safety. Every slice may contain different type of soil but in Table 6 every slice can only be considered having one type of soil despite of every slice had different type of soil. It was found that the different soil type has shown different shear strength properties which had affected the factor of safety of the slope studied.

3.5. Relationship between factor of safety, suction and rainfall

Factor of safety (FOS) is directly proportional to suction of soil. Table 7 shows the graph of FOS calculated with suction of soil in specific slices against suction at toe of slope that had been plotted to show the relationship between factor of safety, suction and rainfall.

It was found that the trend line for suction and FOS at toe of slope is most critical compared to FOS at middle and top of slope shown in Table 7. The trend line for suction and FOS in these three graphs are having same extent. On 11th August, the volume of the rainfall is same as 10th August for three locations and the FOS and Suction had dropped gradually. While on 12th August, value of FOS and suction at toe of slope had rose rapidly compared to FOS and suction at middle and top of slope. Different location and depth of soil had different suction and FOS due to infiltrate of rainwater with different type of soil and groundwater. In conclusion, the rainfall had influenced the changes of suction and FOS. The suction of soil and FOS are interrelated affect each other.

Table 7. Relationship between factor of safety, suction and rainfall at three different location with 0.9m depth

Slope	Relationship Between Three Parameters at 0.9m Depth from Ground
Top	
Middle	
Toe	

4. Conclusion

The paper had shown the relationship between suction, rainfall and FOS. FOS was determined using SLOPE/W and Fellenius' Method with Microsoft Excel formula. Matric suction was influenced by rainfall because when rainfall intensity increased, matric suction of soil decreased. Factor of safety is interrelated with rainfall and suction of soil. Suction of soil increased and thus influence the increasing of the factor of safety. The factor of safety at specific slice was analysed using the suction which affected by rainfall. Finally, the changes of rainfall intensity caused the factor of safety to reduce, the lower factor of safety had caused the instability of slope. Hence, the constructed slope was suggested to be redesign to improve its safety factor.

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[5] ASTM
[6] ASTM D41318
[7] ASTM 698
[8] ASTM D2850
[9] ASTM D7181
[10] USCS

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