



# ANALYSIS OF SLOPE STABILITY ON TROPICAL RESIDUAL SOIL

**M. F. Zolkepli**

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

**M. F. Ishak**

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

**M. S. I. Zaini**

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

## ABSTRACT

*Tropical residual soil is a product of chemical weathering, thus its characteristics are dependent upon environmental factors such as parent rocks, climate, topography and age. This type of soil can be found in many countries all over the world, especially in the tropical region. Since there are many accident happens due to slope failure, a comprehensive laboratory study need to be conducted in order to determine the properties of soil located at Pahang Matriculation College. Several experiments involving physical index and engineering properties of soil are conducted. The typical tropical residual properties are showed and can be considered as sandy SILT of high plasticity as suggested by previous researchers. The result from CIU testing give 9 kPa of cohesion and 25° of friction angle while unsaturated friction angle was assumed 21°. From the slope analysis at Pahang Matriculation College, for a saturated slope (0 kPa suction), the FOS value using Fellenius's method is 1.199 while Bishop's method give 1.262 which the difference is 5.25 %. For an unsaturated slope (20 kPa suction), the FOS using using Fellenius's method is 1.492 while Bishop's method give 1.550 which the difference is 3.89 %. The results concluded that FOS value of slope is always higher if calculated using Bishop's method compare to Fellenius's method.*

**Keywords:** Residual Soil, Index Properties, Unsaturated Soil, Fellenius's method, Bishop's method

**Cite this Article:** M. F. Zolkepli, M. F. Ishak and M. S. I. Zaini, Analysis of Slope Stability on Tropical Residual Soil, International Journal of Civil Engineering and Technology, 9(2), 2018, pp. 402–416.

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## 1. INTRODUCTION

Tropical residual soil can be defined as a soil weathered in-situ where the original rock structure is totally destroyed by weathering and has not been transported from its original location (Brand and Philipson, 1985; Blight, 2012; Public Work Institute Malaysia, 1996; Jia *et al.*, 2014; Rahardjo *et al.*, 2004) [6, 7, 20, 21, 22]. The definition of tropical residual soils varies from region to region and country to country. According to (Futai *et al.* 2004; Fourie *et al.* 2012) [11, 14], behaviour of residual soils do have structured soils bonding effect and can arise due to different conditions.

Townsend (1985) [29] and Salih (2012) [25] stated that residual soil is the result of chemical weathering and several factors like climatic factors, raw materials, topography, flow and age are the characteristics of engineering residual soil. These factors will include the engineering characteristic of residual soil. Ahmad *et al.* (2006) [2], the in-situ behaviour of soil is complex as it depends on many factors. Peninsular Malaysia was covered by more than three-quarters of residual soils (Taha *et al.*, 2000; Rahardjo *et al.*, 1995) [23, 28].

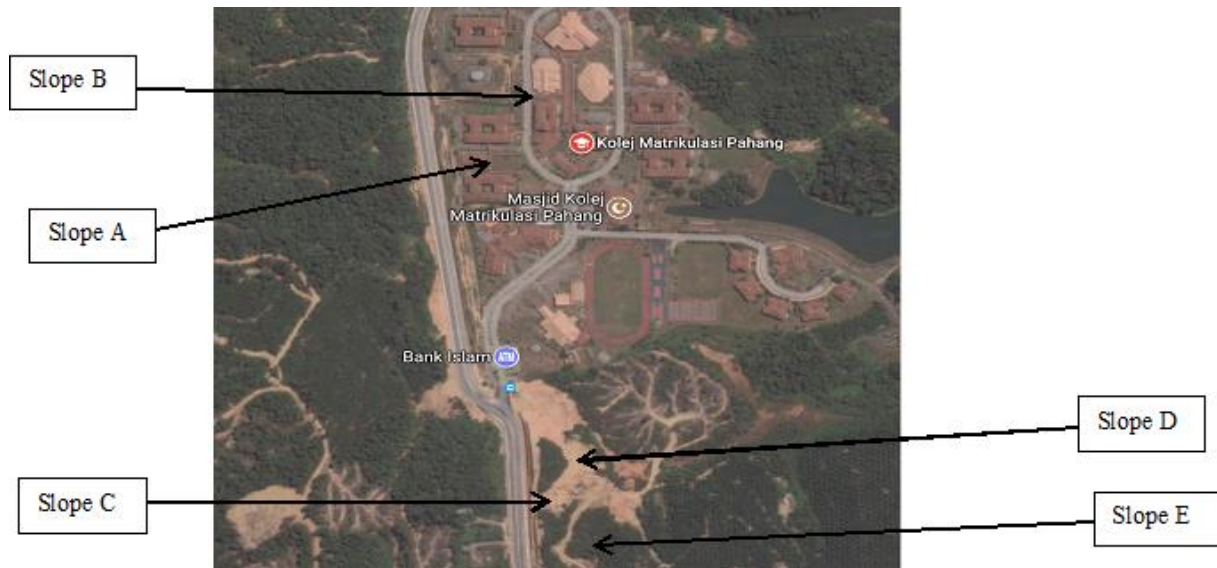
According to Sokhanvar and Kassim (2013) [27], many steep slopes in these residual soils often have a deep ground water table. (Zhai *et al.* 2016; Agus *et al.* 2005) [1, 31], residual soil covers most of the land in Singapore and found commonly unsaturated condition due to deep ground water table. Conceptually, residual soils are form at in-situ weathering and decomposition rock and remain at their original location. Physical and chemical processes of weathering leading to the formation of residual soils. Bland and Rolls (1998) [5] stated that, in humid tropical regions, physical and chemical breakdown can be categorized into decomposition that altering of soils.

As proposed by International Association of Engineering geology, IAEG (1981) [16] and International Society of Rock Mechanics, ISRM (1981) [19], residual soil is formed from weathering process leading to the formation that is highly complex cannot be used as a general guide to be relative of properties residual soils to its parent rocks. Normally, residual soils formed from parent rocks of igneous and metamorphic but residual soils formed from sedimentary rocks also widespread.

The aim of this study is to determine the physical and engineering properties of residual soil located within the area of Pahang Matriculation College. This paper also highlighted several testing procedures that are required to determine physical index properties (disturbed samples) and engineering properties (undisturbed samples) of soils.

## 2. METHODOLOGY

The study was carried out at Pahang Matriculation College, Gambang, Pahang, Malaysia. Figure 1 show the study area.



**Figure 1** Study Area

The soil profile of the study area was characterized in order to identify the thickness and various distributions of residual soils. Generally, the site investigation consisted of trial pit to the collection of disturbed samples and undisturbed samples. Two locations of trial pit were excavated, both at the toe of the slope. Both samples (disturbed and undisturbed) were collected during the excavation works as shown in Figure 2. The field investigation works (trial pit) are carried out accordance to the British Standard Code of Practice BS 5930: 1999 [9] and BS 1377: 1990 [8] was used to conduct the laboratory tests.



**Figure 2** Soil Samples

The main purposes of the data collections are to determine the characteristics of soil material by conducting the laboratory experiments. In addition of the soil properties, the saturated parameters (soil cohesion and friction angle) were determined through laboratory works while unsaturated friction angle was assumed. The laboratory testing were conducted by dividing the tests according the group of soils, i.e., (1) disturbed soil samples (for index

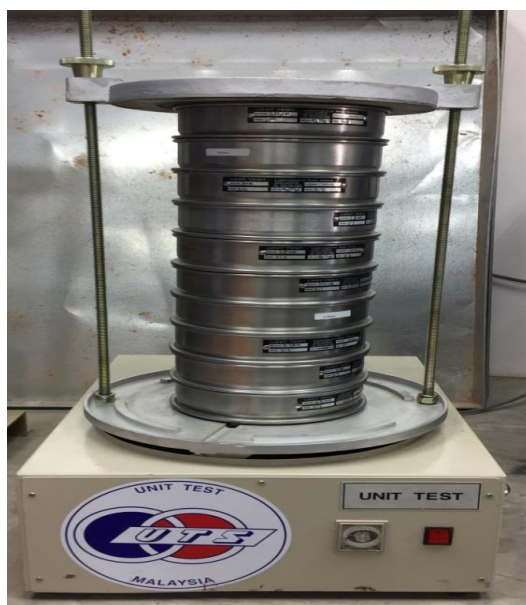
properties) and (2) undisturbed soil samples (for engineering properties). These samples were collected from field investigations at the ground surface (1 m depth) of the study area.

A series of laboratory testing to determine the soil properties, which can determine the index properties tests and also engineering properties tests were conducted. The main physical index properties tests conducted on the soils at this study area were particle size distribution, Atterberg Limit, specific gravity, and moisture content. To determine the engineering properties, Consolidation Isotropic Undrained (CIU) was applied for the soil of the study area. All experimental works were carried out according to the British Standard BS 1377: Part 1-9: 1990.

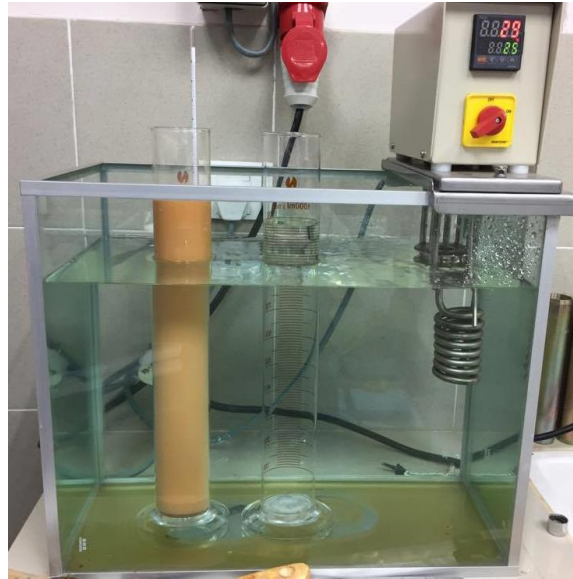
## 2.1. Index Properties Tests

Physical index properties test was conducted in order to determine the engineering characteristics of the soil. Overall, index properties tests were carried out based on recommended procedures stated in British Standard BS 1377: Part 1-9: 1990 which determine the particle size distribution, Atterberg limits, specific gravity and moisture content.

According to Ishak *et al.* (2013) [17], the determination of particle size distribution from 20 mm down to clay fraction (0.002 mm) will involving sieve analysis test with the addition of hydrometer test was conducted. Figure 3 show mechanical sieve analysis. In this procedure, 0.5 kg bags of natural disturbed soil were broken down that passed 20 mm sieve. 100 g of soil sample was placed in the container together with 100 ml of dispersant solution with the addition of 35 g sodium polyphosphate and 7 g sodium carbonate in 1 L of distilled water added into it. Later, the treated soil was washed through a 2 mm nested in a 63  $\mu\text{m}$  sieve and the retained soil particles were dried for dry sieving. For sedimentation test using hydrometer, the fine fraction was collected from the wet sieving. Figure 4 show the hydrometer test. To obtain full reading particle distribution curves, the results obtained from the two sets of procedure of dry sieving and hydrometer test were combined.



**Figure 3** Mechanical Sieve Analysis



**Figure 4** Hydrometer Test

The Atterberg limit test was defined as water that mixed with soil and determines water content which corresponds to condition of fine soil with different behavior (Ishak, 2014) [18]. To determine in term of plasticity that applied to fine soils such as silt and clay portion of 100 g fine soil indicated an ability to be rolled down to the diameter of 3 mm without breaking apart. The combination of Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) were known as Atterberg Limit. Figure 5 show the Atterberg Limit test.



**Figure 5** Atterberg Limit Test

To determine the specific gravity (also known as density of solid particles), a small portion of soil which about 5 g was placed in a small pycnometer with water (Ishak, 2014). Specific gravity was applied in determining porosity and void ratio of the soil. In-situ density (bulk density,  $\rho_b$  and dry density  $\rho_d$ ) of tropical residual soil were obtained by weighing and measuring the volume of undisturbed sample. The simplest test but give a very important result is moisture content. The ratio of the mass of water removed from the wet soil against the dry soil is called moisture content. In this research, 50 g of soil was weighted and placed in the oven under the temperature of 105° Celsius until the soil dried. The mass of the dry soil was calculated later to determine the moisture content in the form of percentage (%).

## 2.2. Engineering Properties Tests

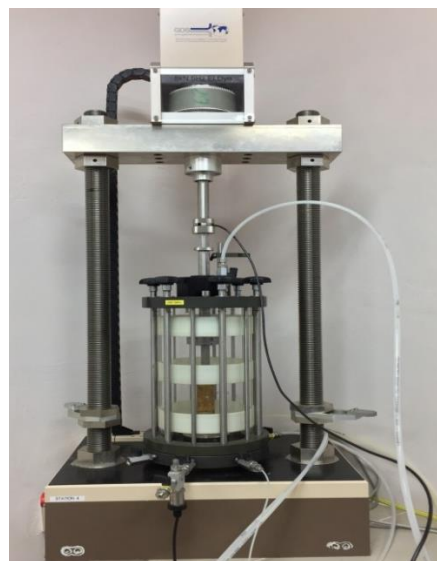
It is vital to specify the input density of the undisturbed soils in the laboratory experiments as soil density and void ratio governing the behaviour of the soil permeability. The determination of bulk and dry density ( $\rho_b$  &  $\rho_d$ ) together with moisture content ( $w$ ) of the soil samples were conducted before conducting a series of Consolidation Isotropic Undrained (CIU) test.

Three soil samples (38 mm diameter with 76 mm height) must be prepared in order to conduct the CIU testing. Figure 6 show samples of undisturbed soil for CIU testing. These soil samples were prepared by using soil sample splitter.



**Figure 6** Undisturbed Soil Samples for CIU Testing

A series of CIU testing were conducted under different cell pressures (100, 150, 200 kPa) to determine saturated ( $c', \phi'$ ) shear strength parameters, while the unsaturated ( $\phi^b$ ) parameter will be assumed based on works from previous researchers. CIU testing were conducted using triaxial machine model GDS Lab. Figure 7 show the sample been prepared in triaxial machine.



**Figure 7** Consolidated Isotropic Undrained (CIU) Testing

### 3. RESULTS AND DISCUSSION

#### 3.1. Properties of Soil

The summary of laboratory test result for soil properties of residual soil materials at Pahang Matriculation College is as shown in Table 1. The following section will discuss further about the soil properties.

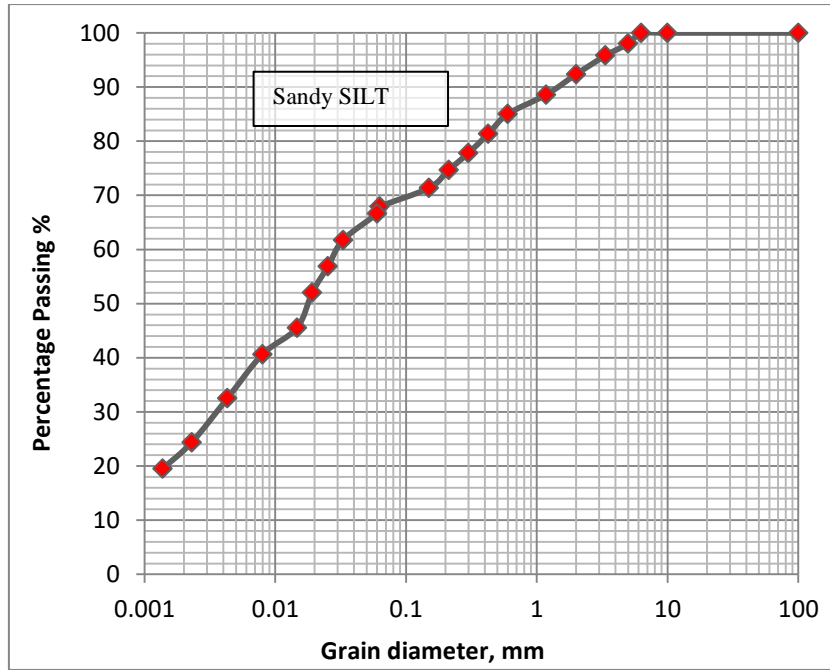
**Table 1** Properties of the Soil Materials in the Study Area

Composition	Sandy SILT
Natural Moisture Content (%)	17.95
Gravel (%)	4.2
Sand (%)	27.9
Silt (%)	45.1
Clay (%)	22.8
Liquid Limit, LL (%)	70.0
Plastic Limit, PL (%)	31.0
Plasticity Index, PI (%)	39.0
Soil Classification BSCS	MVS
Specific Gravity ( $G_s$ )	2.74
Void Ratio ( $e$ )	0.69
Porosity ( $n$ )	0.41
Bulk Density, $\rho_b$ ( $\text{kg/mm}^3$ )	1.99
Dry Density, $\rho_d$ ( $\text{kg/mm}^3$ )	1.67

##### 3.1.1. Index Properties of Soil and Soil Classifications

A series of laboratory testing for index properties has been conducted on residual soils at Pahang Matriculation College. Soil classification is the main physical index properties, which depends on several factors such as, Atterberg limits, moisture content, specific gravity, and particle size distribution.

Figure 8 show the particle size distribution at Pahang Matriculation College. Based on British Soil Classification System (BSCS), the tropical residual soil was classified as sandy SILT of high plasticity (MVS). The result of particle size distribution for a portion 100 g of soil sample consisted of 4.2 % larger than 2 mm (gravel), 27.9 % between size of 2 mm to 0.063 mm (sand), 45.1 % between 0.063 mm to 0.002 mm (silt), and 22.8 % is smaller than 0.002 mm (clay). From several origin of residual soil formation at Pahang Matriculation College, the distinct particle size distributions were observed and the average was presented in Figure 8.



**Figure 8** Particle Size Distribution of Tropical Residual Soil (sandy SILT)

Table 1, shown the Atterberg Limit of residual soils from Pahang Matriculation College indicated that the liquid limit (LL) of the soil was 70.0 %, plastic limit (PL) was 31.0 % and Plastic Index, (PI) = LL-PL = 39.0 %. Based on the British Soil Classification System (BSCS), the soil at the field study can be classified as SILT of high plasticity (MHS). The average specific gravity is 2.74 of residual soils from Pahang Matriculation College.

**3.1.2. Engineering Properties**

According to (Fredlund *et al.* 1978; Fredlund *et al.* 1996; Ali, 2007) [12, 13, 3], the new parameter introduced which is the unsaturated friction angle,  $\phi^b$  is always less than or equal to saturated friction angle,  $\phi'$ . Vanapalli and Fredlund (1997) [30] stated that the unsaturated angle of friction ( $\phi^b$ ) was estimated from her study based on previous researchers. Goh *et al.* (2010) [15] assume the shear strength of soil is linearly proportional to matric suction, where  $\phi^b$  is equal to  $\phi'$  when matric suction lower that air-entry value.

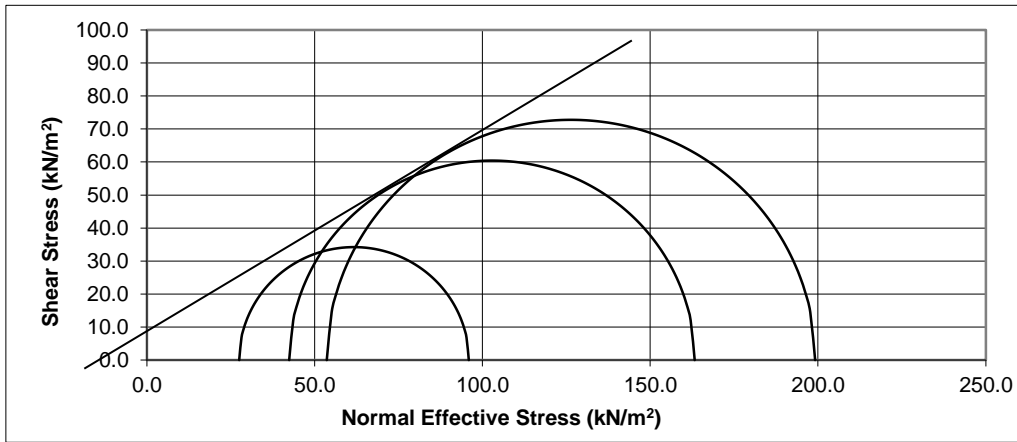
Table 2 show experimental shear strength values of soil at study area with value of  $\phi^b$  angle. The effective saturated shear strength parameters ( $c'$  and  $\phi'$ ) for the soil at Pahang Matriculation College were determined by performing the consolidated isotropic undrained (CIU) tests on three undisturbed soil samples. The unsaturated friction angle,  $\phi^b$  was assumed lower than saturated friction angle,  $\phi'$  based on previous literature from other researchers.

**Table 2** Experimental Values of Shear Strength with Values of  $\phi^b$  of Residual Soil

Researcher	Location	$c'$ , (kPa)	$\phi'$ , (°)	$\phi^b$ , (°)
Author	Pahang Matriculation College	9	25	21 (assumed)



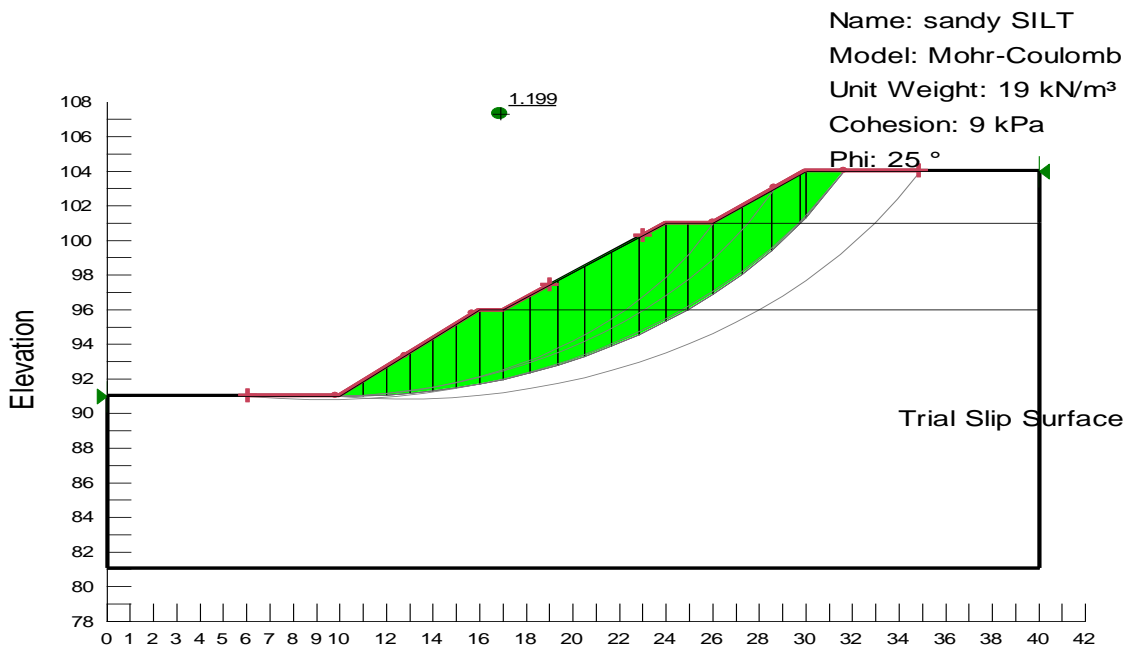
Based on the Mohr's Circle and the effective stress failure envelope for specimens 1,2, and 3 illustrated in Figure 9, the effective cohesion ( $c'$ ), is 9 kPa and the effective friction angle ( $\phi'$ ) is 25°.



**Figure 9** Effective Stress Failure Envelopes and Mohr's Circles for Sample 1,2 and 3

#### 4. SLOPE ANALYSIS

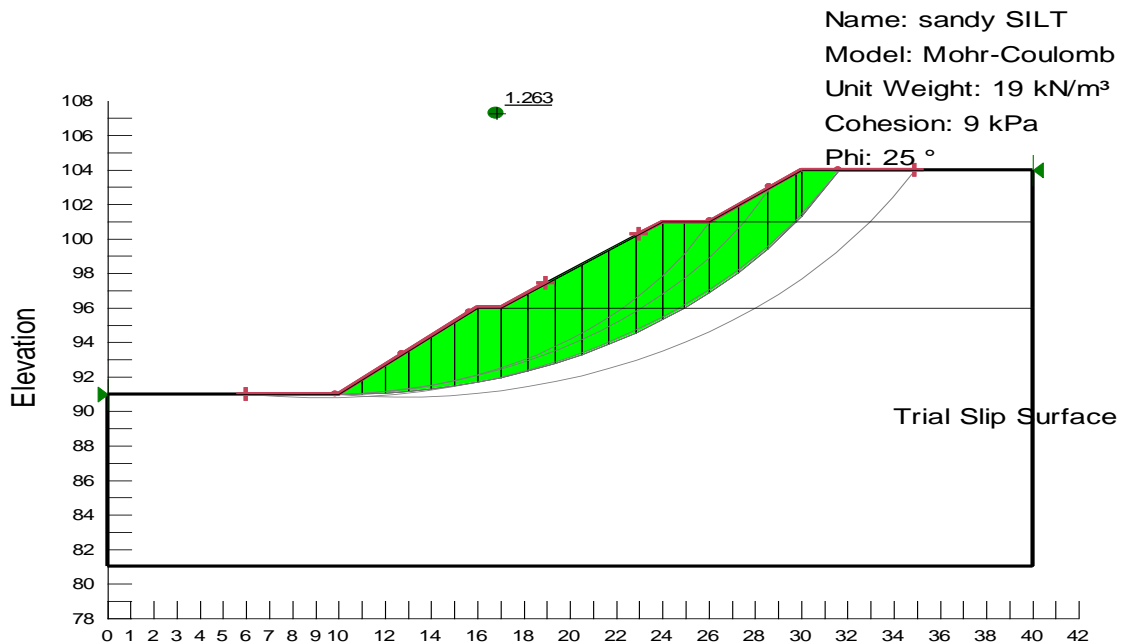
The analysis of slope in this study was based on two formulas known as modified Fellenius's method [10] and also modified Bishop's method [4]. The critical slip surface for a slope measured within the area of Pahang Matriculation College was presented in Figure 10. This slope was divided into 21 slices to calculate weight of soil bounded implement using Fellenius's method.



**Figure 10** Identification of the critical slip surface using commercial software (SLOPE/W) for slope using Fellenius's method

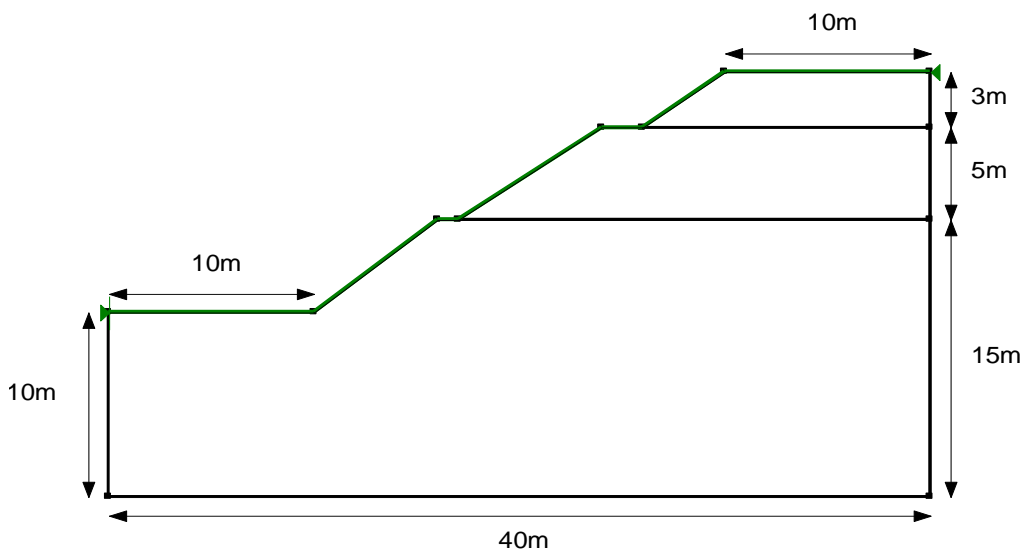
A minimum FOS of 1.199 was calculated from SLOPE/W using conventional method of slices. To determine the difference and percentage difference of FOS for slope with other methods, this value was used as a controlled value. This particular slip surface corresponded

with a radius of 24.14 m and of origin of  $x = 10.199$  m,  $y = 115.137$  m from benchmark point marked at Pahang Matriculation College. Figure 11 show the critical slip surface for slope with the implementation of Bishop's method.



**Figure 11** Identification of the critical slip surface using commercial software (SLOPE/W) for slope using Bishop's method

The minimum FOS calculated using SLOPE/W was 1.263 using Bishop's Simplified method. This value is used as a controlled value to determine the difference and percentage difference of FOS for slope with other methods. This particular slip surface corresponded with a radius of 24.14 m and of origin of  $x = 10.199$  m,  $y = 115.137$  m from benchmark point marked at Pahang Matriculation College. The actual slope geometry completed with slope elevation, critical slip surface passed through the toe of the slope and the location of each slices are shown in Figure 12. The results obtained for this particular slip surface employed from Fellenius's method in comparison with the various methods available using SLOPE/W was presented in Table 3.



**Figure 12** Detail of slope geometry

**Table 3** Comparison of FOS by various methods of analysis Fellenius’s method

Type of Analysis	FOS	Percentage Difference (%)
Manual calculation - Ordinary method (Fellenius’s method)	1.199	0
SLOPE/W using Ordinary method	1.199	0
SLOPE/W using Bishop method	1.263	5.34
SLOPE/W using Janbu’s method	1.184	1.25
SLOPE/W using Morgenstern- Price’s method	1.259	5.00
SLOPE/W using Spencer’s method	1.259	5.00

Table 3 shows the differences between methods range from 0 % to 5.34 % when compared to manual calculation. Table 4 show the comparison of particular slip surface employed from Bishop’s method with various method from SLOPE/W.

**Table 4** Comparison of FOS by various methods of analysis Bishop’s method

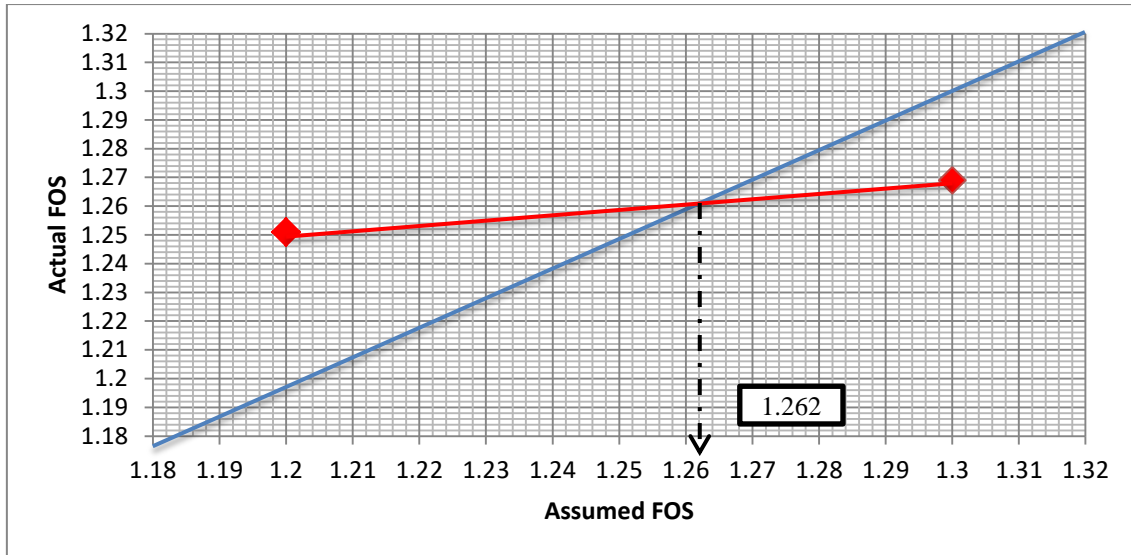
Type of Analysis	FOS	Percentage Difference (%)
Manual calculation - Bishop’s method	1.251	0
SLOPE/W using Ordinary method	1.199	4.16
SLOPE/W using Bishop method	1.263	0.96
SLOPE/W using Janbu’s method	1.184	5.36
SLOPE/W using Morgenstern- Price’s method	1.259	0.64
SLOPE/W using Spencer’s method	1.259	0.64

Table 4 shows the differences between methods range from 0.64 % to 5.36 % when compared to manual calculation. Table 5 show the assumed and real FOS values calculated using Bishop’s method for saturated soil slope (i.e.  $(\mu_a - \mu_w) = 0, \phi^b = 0$ ).

**Table 5** Assumed and real FOS values using Bishop’s method For saturated soil (0 kPa)

Type of Analysis	Assumed FOS	Real FOS
Manual calculation - Bishop’s method	(1) 1.200	1.251
	(2) 1.300	1.269

Since there is two FOS values obtained from the assumptions, a graph need to be plot in order to obtain one real FOS when calculating using Bishop’s method. Figure 13 show the graph of Bishop’s Simplified method for 0 kPa suction.



**Figure 13** Graph of Bishop's Simplified method for saturated (0 kPa)

The graph indicates that, the actual FOS value calculated using Bishop's method with 0 kPa suction is 1.262. Since the FOS is greater than 1, therefore it is safe. Table 6 show the percentage differences of FOS between Bishop's Simplified method with Fellenius's method of 0 kPa suction.

**Table 6** Differences of FOS values for saturated soil (0 kPa suction)

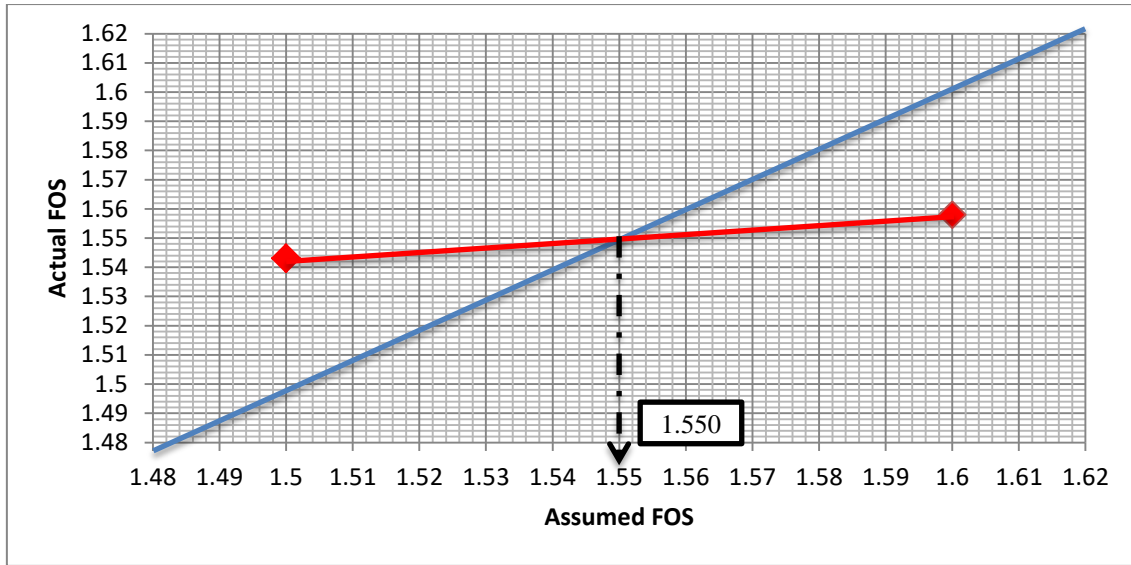
Type of Analysis	FOS	Percentage Difference (%)
Manual calculation - Fellenius's method	1.199	0
Manual calculation - Bishop's method	1.262	5.25

The results suggested that, calculation by using Bishop's Simplified method gave higher FOS value compare to ordinary Fellenius's method by 5.25 % for 0 kPa suction. Table 7 shows the assumed FOS and the real FOS values calculated using Bishop's method for unsaturated soil (i.e.  $(\mu_a - \mu_w) = 20$ ,  $\phi^b = 21$ ).

**Table 7** Assumed and real FOS values using for unsaturated soil (20 kPa)

Type of Analysis	Assumed FOS	Real FOS
Manual calculation - Bishop's method	(1) 1.500	1.543
	(2) 1.600	1.558

Figure 14 show the graph of Bishop's Simplified method for 20 kPa suction.



**Figure 14** Graph of Bishop’s Simplified method for unsaturated (20 kPa)

The graph shows that, the actual FOS value calculated using Bishop’s method with 20 kPa suction is 1.550. Since the FOS is greater than 1, therefore it is safe. Table 8 show the percentage differences of FOS between Bishop’s Simplified method with Fellenius’s method of 20 kPa suction.

**Table 8** Differences of FOS values for unsaturated soil (20 kPa suction)

Type of Analysis	FOS	Percentage Difference (%)
Manual calculation - Fellenius’s method	1.492	0
Manual calculation - Bishop’s method	1.550	3.89

The results suggested that, calculation by using Bishop’s Simplified method) gave higher FOS value compare to ordinary Fellenius’s method by 3.89 % for 20 kPa suction.

### 5. CONCLUSION

The experimental results from soil testing can be used to classify types of soil. Based on physical index properties results, the soil consisted of 4.2 % gravel, 27.9 % sand, 45.1 % silt, and 22.8 % clay with plasticity index of 39 %. The specific gravity of the soil is 2.74 with natural moisture content of 17.95 %. The engineering properties of the soil gives 9 kPa of cohesion ( $c'$ ), 25° of saturated friction angle ( $\phi'$ ), and the assumed unsaturated friction angle ( $\phi^b$ ) is 21°. The type of tropical residual soil at Pahang Matriculation College can be considered as sandy SILT of high plasticity as suggested by previous researchers. From the slope analysis at Pahang Matriculation College, for a saturated slope (0 kPa suction), the FOS value using Fellenius’s method is 1.199 while Bishop’s method give 1.262 which the difference is 5.25 %. For an unsaturated slope (20 kPa suction), the FOS using using Fellenius’s method is 1.492 while Bishop’s method give 1.550 which the difference is 3.89 %. The results concluded that FOS value of slope is always higher if calculated using Bishop’s method compare to Fellenius’s method.

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