IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

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To cite this article: M F Zolkepli *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **527** 012004

IOP Conf. Series: Materials Science and Engineering **527** (2019) 012004 doi:10.1088/1757-899X/527/1/012004

Slope stability analysis using modified Fellenius's and Bishop's method

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Abstract. Analysis of slope stability is very important as many structures in hilly areas failed due to instability of slope. The aim of this study is to determine the factor of safety (FOS) of slopes located at Pahang Matriculation College by using limit equilibrium method. Two methods known as modified Fellenius's method and modified Bishop's method are used in this study. Laboratory testing involving index and engineering properties are conducted to determine the properties of soil within the study area. The soil at Pahang Matriculation College can be classified as sandy SILT with high plasticity. From the analysis, the FOS values for two slopes in saturated soil conditions (0 kPa suction) are between 1.262-2.885 when using Bishop's method which are higher compare to 1.199-2.688 when using Fellenius's method. The percentage differences of FOS between these two methods are between 5.25% to 7.33%. For slopes in unsaturated conditions (20 kPa suctions), the FOS are between 1.550-3.702 when using modified Bishop's method which always higher compare to 1.492-3.507 when using modified Fellenius's method. The percentage differences of FOS are between 3.89% to 5.56%. The relative accuracy of Bishop's method is due to it consider only the vertical equilibrium of each slices and there is no need to consider the horizontal components of the interslice forces without introducing serious error in the FOS value.

Keywords: Bishop's method, Fellenius's method, engineering properties, unsaturated soil, factor of safety (FOS)

1. Introduction

Nowadays, rapid urbanisation, deforestation together with rapid growth of development have affected and destabilized soil surrounding it. The increasing number of development contributes to gradually weaken the earth structures. Several case studies that slope failure happened due to clearing of trees that vanished the reinforcement by roots of the soil [1,2].

Slope failure commonly occurs when shear strength of the soil is reduced due to decreasing of effective stress resulting from pore water pressure increment [3]. According to [4], several causes of slope failure are type of soil, precipitation and anthropogenic actions [5,6]. [7] suggested many statistical data that show most of slope failures usually occur during rainfall or after rainfall and happened in many countries like Japan, Hong Kong, and Southeast.

Many hill slope areas in Malaysia, both engineered slope and natural slope have high risk exposure to slope failure [8]. The increase of pore water pressure and soil moisture due to antecedent and prolonged rainfall contribute to the failure of a slope.

The aim of this study is to analyse the safety of two slopes located within the area of Pahang Matriculation College in order to determine the factor of safety (FOS) of both slopes. The analysis will be carried out using SLOPE/W and the results between FOS using modified [9] method and modified [10] method will later compared to determine the best method for slope analysis.

2. Methodology

This study was carried out at Pahang Matriculation College, Gambang, Pahang, Malaysia. Figure 1 show the study area. Figure 2 and Figure 3 show the clear view of the slopes.

Figure 1. Study Areas at Pahang Matriculation College [11].

Figure 2. Slope A [12].

Figure 3. Slope B [12].

Table 1 show the list of tests needed in order to determine the physical and engineering properties of soil at Pahang Matriculation College according to [13] while [14] was used for soil sample collection.

Table 1. List of Soil Test.

List of Tests	Function
Sieve Analysis and Hydrometer	To determine particle distribution of soil
Specific Gravity	To determine the ration of the weight of an equal volume of distilled water
Atterberg Limit	To determine the critical water contents of a fine-grained soil
Mositure Content	To determine the quantity of water contained in a soil
Consolidated Isotropic Undrained	The determine the shear strength of soil

3. Results and Discussion

Table 2 show the properties of the soil material in the study area. According to [11], the soil at Pahang Matriculation College can be considered as sandy SILT of high plasticity with average of specific gravity of 2.74

Table 2. Properties of the Soil Materials in the Study Area [11].

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
Specific Gravity (G_s)	2.74
Bulk Density, ρ_b (kg/mm^3)	1.99
Dry Density, ρ_d (kg/mm^3)	1.67

Figure 4 show the particle size distribution at Pahang Matriculation College.

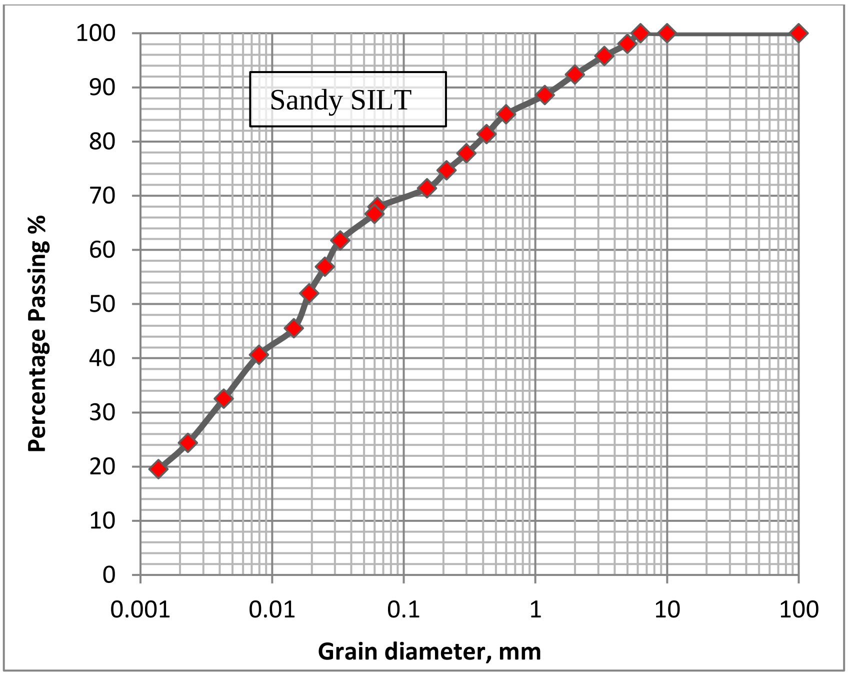

Figure 4. Particle Size Distribution of Tropical Residual Soil [11].

Table 3 shows experimental shear strength values of soil at study area with value of ϕ^b angle. The effective saturated shear strength parameters (c' and ϕ') 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, ϕ^b was assumed lower than saturated friction angle, ϕ' based on previous literature from other researchers. According to [15; 16; 17] the new parameter introduced which is the unsaturated friction angle, ϕ^b is always less than or equal to saturated friction angle, ϕ'. [18] assume the shear strength of soil is linearly proportional to matric suction, where ϕ^b is equal to ϕ' when matric suction lower that air-entry value. From the stated literature, the value of unsaturated friction angle, ϕ^b was assumed 21° which is lower than the saturated friction angle, ϕ' because no experiment has been conducted to obtain this parameter.

Table 3. Experimental Values of Shear Strength with Values of ϕ^b of Residual Soil [11]

Researcher	Location	c', (kPa)	ϕ', (°)	ϕ^b, (°)
[11]	Pahang Matriculation College	9	25	21 (assumed)

4. Analysis of Slope

The analysis of slope in this study was based on two formulas known as modified [9] method and also modified [10] method. [19] suggested an equation which was the modification of [9] method (1936) in order for the formula applicable to calculate FOS of unsaturated soil slope.

$$F = \frac{(\Sigma\ c'lR + (W\cos\beta)R\tan\phi' + SRl\tan\phi^b)}{\Sigma WR\sin\beta} \tag{1}$$

The final modification of [10] method (1955) were proposed by [20] and is applicable to calculate FOS of slope influenced by both saturated ad unsaturated soil.

$$F = \frac{\sum\left[\left(c'b + (W + \Delta X - \mu_a b)\tan\phi' + Mb\tan\phi^b\right)\left(\frac{\sec\alpha}{m_a}\right)\right]}{\sum W\sin\alpha} \tag{2}$$

i. Slope A

The critical slip surface for slope A was presented in Figure 5. This slope was divided into 20 slices to calculate weight of soil bounded implement to equation (1).

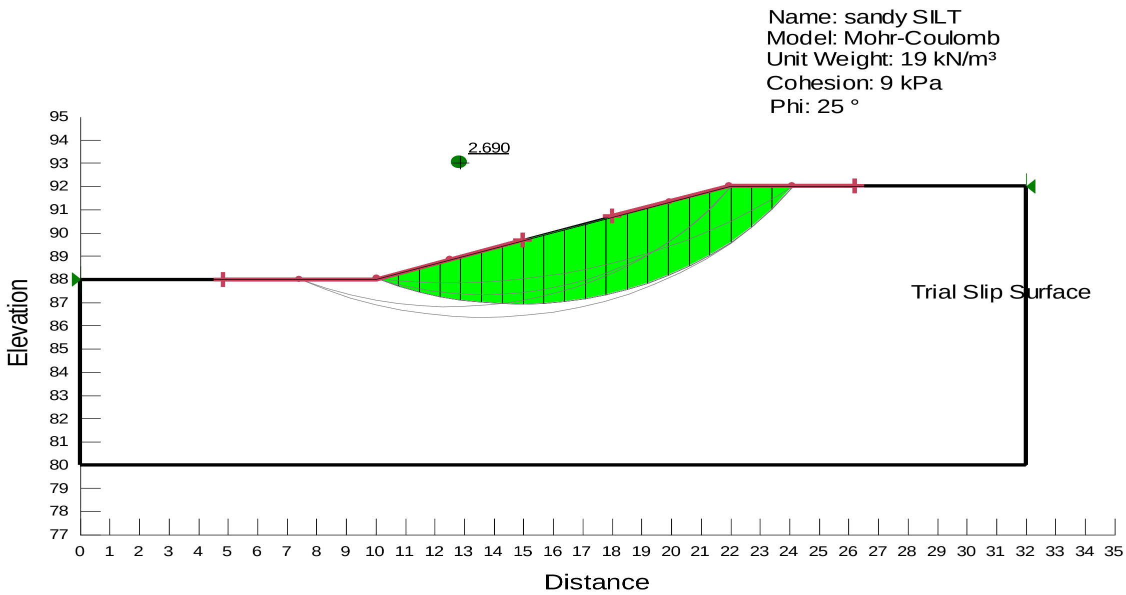

Figure 5. Identification of the critical slip surface using commercial software (SLOPE/W) for slope A using equation (1).

A minimum FOS of 2.690 was calculated from SLOPE/W using conventional method of slices. To determine the difference and percentage difference of FOS of slope A with other methods, this value is used as a controlled value. This particular slip surface corresponded with a radius of 11.04 m and origin of x = 14.827 m, y = 97.975 m from benchmark point marked at Pahang Matriculation College. Figure 6 show the critical slip surface for slope A with the implementation of equation (2).

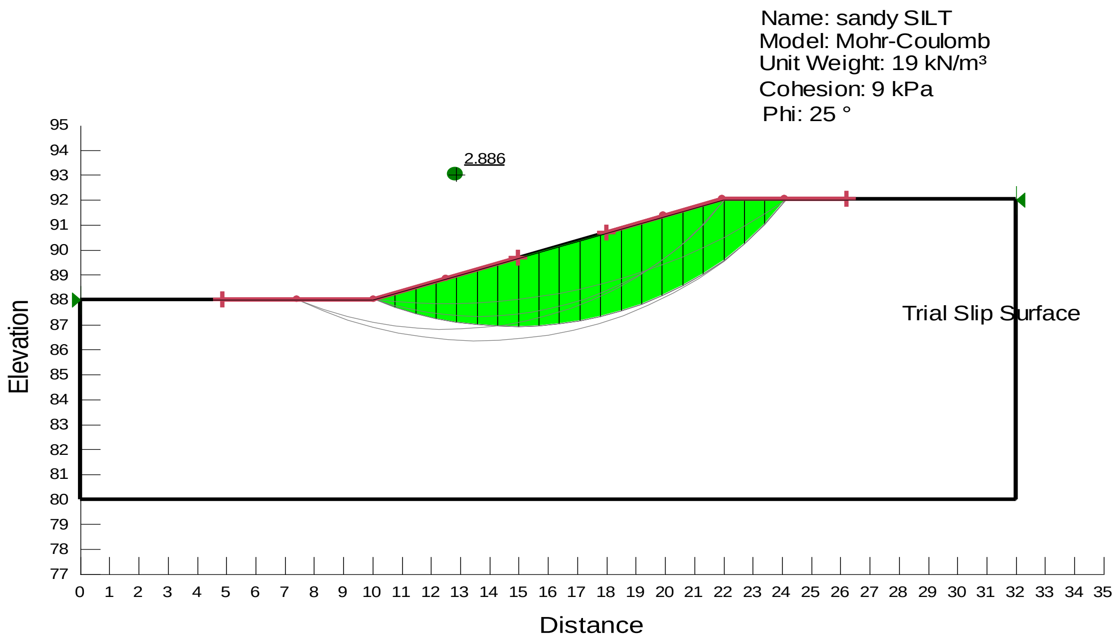

Figure 6. Identification of the critical slip surface using commercial software (SLOPE/W) for slope A using equation (2).

The minimum FOS calculated using SLOPE/W was 2.886 using [10] Simplified method. This value is used as a controlled value to determine the percentage difference of FOS of other methods from SLOPE/W. This particular slip surface corresponded with a radius of 11.04 m and origin of x = 14.827 m, y = 97.975 m from benchmark point marked at Pahang Matriculation College. The results obtained for this particular slip surface employed from equation (1) in comparison with the various methods available using SLOPE/W was presented in Table 4. This comparison had been made to see the differences between factor of safety (FOS) of the slope as provided in SLOPE/W.

Table 4. Comparison of FOS by various methods of analysis (Slope A, equation (1)).

Type of Analysis	FOS	Percentage Difference (%)
Manual calculation using equation (1)- Ordinary method ([9] method)	2.688	0
SLOPE/W using [9] method	2.690	0.07
SLOPE/W using [10] method	2.886	7.37
SLOPE/W using [21] method	2.630	2.16
SLOPE/W using [22] method	2.883	7.25
SLOPE/W using [23] method	2.883	7.25

Table 4 shows the differences between methods range from 0.07 % to 7.37 % when compared to manual calculation. Table 5 show the comparison of particular slip surface employed from equation (2) with various method from SLOPE/W.

Table 5. Comparison of FOS by various methods of analysis (Slope A, equation (2)).

Type of Analysis	FOS	Percentage Difference (%)
Manual calculation using equation (2)- [10] method	2.880	0
SLOPE/W using [9] method	2.690	6.60
SLOPE/W using [10] method	2.886	0.21
SLOPE/W using [21] method	2.630	8.68
SLOPE/W using [22] method	2.883	0.1
SLOPE/W using [23] method	2.883	0.1

Table 5 shows the differences between methods range from 0.1 % to 8.68 % when compared to manual calculation. The difference between the use of equation (1) with the Ordinary method ([9] method- SLOPE/W) and equation (2) with ([10] method – SLOPE/W) are small, due to the fact that these two methods (manual calculation and SLOPE/W), when applied to analyse a saturated slope at study area, was adopted from a very similar formula in equation and approach. The small differences between FOS values between SLOPE/W and manual calculation may due to the decimal places use when calculating the formula.

Since equation (2) have two FOS in the left (real) and the right (assumed) hand side, two FOS values need to be assumed first before obtaining the real FOS. Table 6 show the assumed and real FOS values calculated using equation (2) for saturated soil slope (i.e. ($\mu_a - \mu_w$) = 0, ϕ^b = 0).

Table 6. Assumed and real FOS values using equation (2) for saturated soil (0 kPa suction) of slope A.

Type of Analysis	Assumed FOS	Real FOS
Manual calculation using equation (2)- [10] method	(1) 2.800	2.880
	(2) 2.900	2.885

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 equation (2). Figure 7 show the graph of [10] Simplified method for 0 kPa suction.

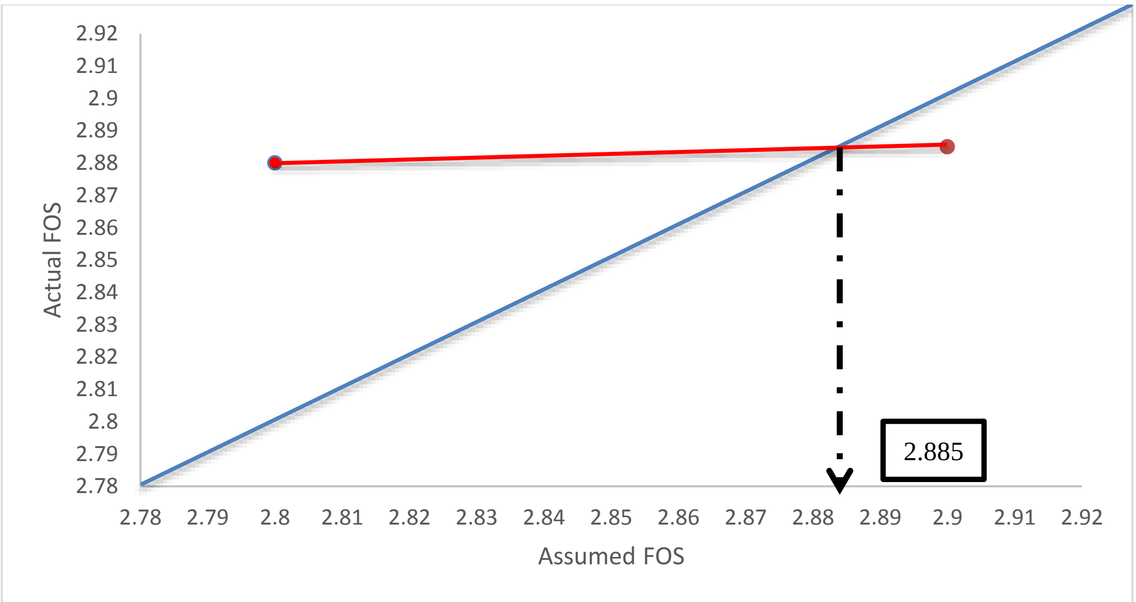

Figure 7. Graph of [10] Simplified method (equation (2)) for saturated (0 kPa) slope A.

The graph indicates that, the actual FOS value calculated using equation (2) with 0 kPa suction is 2.885. Since the FOS is greater than 1, therefore it is safe. Table 7 show the percentage differences of FOS between [10] Simplified method (equation 2) with [9] method (equation 1) of 0 kPa suction.

Table 7. Differences of FOS values for saturated soil (0 kPa suction) of slope A.

Type of Analysis	FOS	Percentage Difference (%)
Manual calculation using equation (1)- [9] method	2.688	0
Manual calculation using equation (2)- [10] method	2.885	7.33

The results suggested that, calculation by using [10] Simplified method gave higher FOS value compare to ordinary [9] method by 7.33 % for 0 kPa suction. To compare the FOS value of unsaturated soil slope between equations (1) and (2), the matric suction was assumed 20 kPa. This assumption has been made just to differentiate the state of the soil whether the soil was in saturated or unsaturated condition without introducing any error in this study. Table 8 shows the assumed FOS and the real FOS values calculated using equation (2) for unsaturated soil (i.e. ($\mu_a - \mu_w$) = 20, ϕ^b = 21).

Table 8. Assumed and real FOS values using equation (2) for unsaturated soil (20 kPa suction) of slope A.

Type of Analysis	Assumed FOS	Real FOS
Manual calculation using equation (2)- [10] method	(1) 3.650	3.699
	(2) 3.750	3.703

Figure 8 show the graph of [10] Simplified method for 20 kPa suction.

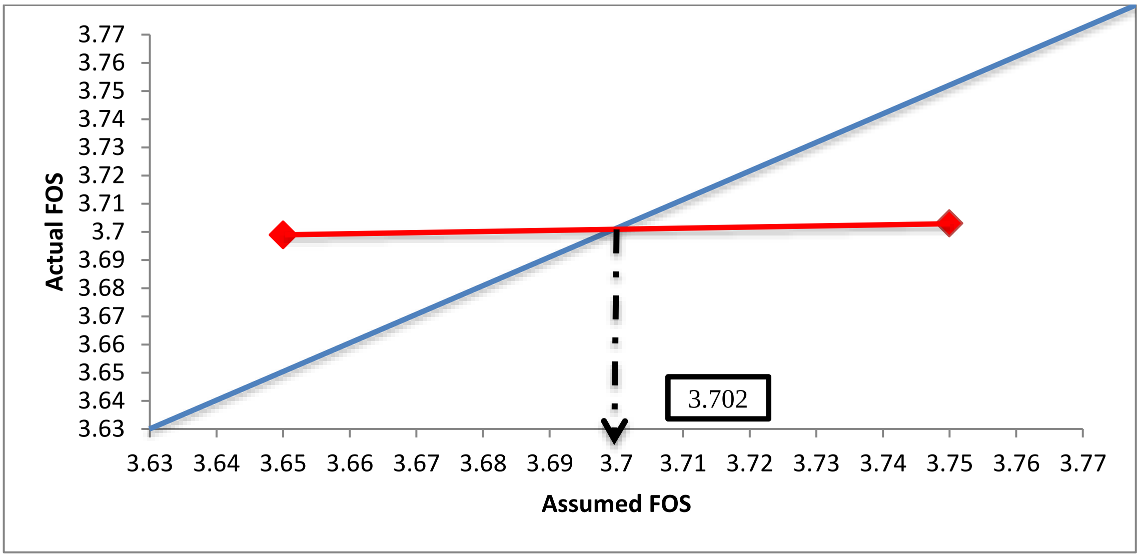

Figure 8. Graph of [10] Simplified method (equation (2)) for unsaturated (20 kPa) slope A.

The graph shows that, the actual FOS value calculated using equation (2) with 20 kPa suction is 3.702. Since the FOS is greater than 1, therefore it is safe. Table 9 show the percentage differences of FOS between [10] Simplified method (equation 2) with [9] method (equation 1) of 20 kPa suction.

Table 9. Differences of FOS values for unsaturated soil (20 kPa suction) of slope A.

Type of Analysis	FOS	Percentage Difference (%)
Manual calculation using equation (1)- [9] method	3.507	0
Manual calculation using equation (2)- [10] method	3.702	5.56

The results suggested that, calculation by using [10] Simplified method gave higher FOS value compare to ordinary [9] method by 5.56 % for 20 kPa suction. Table 10 show the summary of FOS values for both slopes at Pahang Matriculation College (study area). The calculations of FOS of Slope B are not shown since it is the same way of calculation as previous FOS calculation of Slope A.

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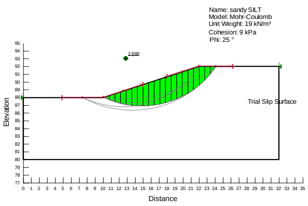
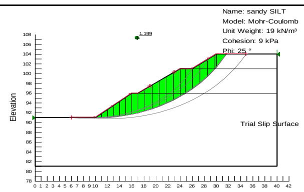
Table 10. Summary of FOS values of research slopes.

Type of Slopes	FOS for Saturated Soil Slope			FOS for Unsaturated Soil Slope		
	[9]	[10]	Percentage Difference (%)	[9]	[10]	Percentage Difference (%)
 Slope A	2.688	2.885	7.33	3.507	3.702	5.56
 Slope B	1.199	1.262	5.25	1.492	1.550	3.89

Slope A give 2.688 FOS value when calculating using [9] method and 2.885 when using [10] method for saturated soil slope and give a percentage difference of 7.33 %. For unsaturated condition, 3.507 was the FOS calculated using [9] method while 3.702 when using [10] method. These give the percentage difference of 5.56 %.

For Slope B, the FOS calculated give 1.199 when calculating using [9] method while 1.262 using [10] method for saturated condition. These contribute to 5.25 % difference of FOS between both methods. Manual calculation also gives 1.492 of FOS value when calculating using [9] method and 1.550 when using [10] method. These give percentage difference of 3.89 %.

5. Conclusion

The result of FOS values for both slopes at study area show that the FOS values, when calculated using [10] Simplified method always higher compare to FOS calculated using [9] method. This is due to [10] method consider moment of equilibrium of forces and also vertical forces which is different from [9] method which only consider moment of equilibrium only. This contributes to the analysis of a slope was more accurate when using [10] method compare to [9] method. According to [24] the relative accuracy of [10] method is due to it consider only the vertical equilibrium of each slices and there is no need to consider the horizontal components of the interslice forces without introducing serious error in the FOS value.

6. References

[1] Wu, T.H. (1995). Slope Stabilization. Slope Stabilization and Erosion Control: A Bioengineering Approach*. E & FN Spon, 2-6 Boundary Row, London*. 221-264.

[2] Jamaluddin, T.A., Sian L.C. and Komoo, I. (2011). Laporan Terbuka Penyiasatan Geobencana Tanah Runtuh Madrasah Al-Taqwa, Felcra Sungai Semungkis, Batu 14, Hulu Langat, Selangor. *Institut Kajian Bencana Asia Tenggara (SEADPRI) Universiti Kebangsaan Malaysia. 31.*

[3] Gledinning, S., Loveridge, F., Starr-Keddle, R.E., Bransby, M.F. and Hughes P.N. (2009). Role of Vegetation in Sustainability of Infrastructure Slopes. *Geotech. Eng., Proc. Inst. Civil Eng.,* 162, 101-110.

[4] da Costa Teixeira, E.K., de Azevedo, R.F., Ribeiro, A.G.C., de Azevedo, I.C.d.A.D. and Candido, E.S. (2015). Influence of Rainfall Infiltration on the Stability of a Residual Soil Slope. *Electronic Journal of Geotechnical Engineering*. 20. 13321-13336.

[5] Sun, D., Li, X., Feng, P. and Zang, Y. (2016). Stability Analysis of Unsaturated Soil Slope During Rainfall Infiltration Using Coupled Liquid-Gas-Soli Three-Phase Model. *Water Science and Engineering*. 9(3). 183-194.

[6] Nazir, R., Ghareh, S., Mosallanezhad, M. and Moayedi, H. (2016) The Influence of Rainfall Intensity on Soil Mass from Cellular Confined Slopes. *Journal of Measurement*. 81. 13-25.

[7] Zhang, G., Qian, Y., Wang, Z. and Zhao, B. (2014). Analysis of rainfall Infiltration Law in Unsaturated Soil Slope. *The Scientific World Journal*. 1-7.

[8] Ishak, M.F. (2014). *Tree Water Uptake on Suction Distribution in Unsaturated Tropical Residual Soil Slope.* Doctor Philosophy. Universiti Teknologi Malaysia, Skudai.

[9] Fellenius, W. (1936). Calculation of the Stability of Earth Dams. *Trans. 2nd Int. Cong. Large Dams, Washington*, 445-459.

[10] Bishop, A.W. (1955). The Use of the Slip Circle in the Stability Analysis of Earth Slopes. *Geotechnique*, *5* (1), 7-17.

[11] Ishak, M.F., Zolkepli, M.F. and Affendy, M. (2017). Tropical Residual Soil Properties on Slopes. *International Journal of Engineering Technology and Sciences (IJETS)*. 8 (1).

[12] Zolkepli, M.F. (2018). *Slope Stabilization Influenced by Unsaturated Soil.* Master Thesis. Universiti Malaysia Pahang, Kuantan.

[13] BS, (1990). *Methods of Tests for Soils for Civil Engineering Purposes, (BS 1377: Part 1-9).* London: British Standard Institution.

[14] BSI, (1999). *Code of Practice for Site Investigations, (BS 5930).* London: British Standard Institution.

[15] Fredlund, D.G., Morgenstern, N.R. and Widger, R.A. (1978). The Shear Strength of Unsaturated Soil. *Canadian Geotechnical Journal*, *15*: 313-321.

[16] Fredlund, D.G., Xing, A., Fredlund, M.D. and Barbour, S.L. (1996). The Relationship of the Unsaturated Shear Strength to the Soil-Water Characteristic Curve. *Canadian Geotechnical Journal*, 33(3): 440-448.

[17] Ali, N. (2007). *The Influence of Vegetation Induced Moisture Transfer on Unsaturated Soils.* Doctor Philosophy. University of Cardiff, United Kingdom.

[18] Goh, S.G., Rahardjo, H. and Leong, E.C. (2010). Shear Strength Equations for Unsaturated Soil Under Drying and Wetting. *Journal of Geotechnical and Geoenviromental Engineering*. April, 136(4), 594-606.

[19] Rees, S.W. and Ali, N. (2012). Tree Induced Soil Suction and Slope Stability. *Geomechanics and Geoengineering: An International Journal*. Taylor & Francis Group, London, Uk., 7, 103-113.

[20] Zolkepli, M.F. and Ishak, M.F. (2017). Exploration of Methods for Slope Stabilization Influenced by Unsaturated Soil, *Malaysian Journal of Civil Engineering*, 29(2), 121-131.

[21] Janbu, N. (1968). Slope Stability Computations. *Soil Mech. Found. Engg. Report, Trondheim Technical University of Norway*.

IOP Conf. Series: Materials Science and Engineering **527** (2019) 012004 doi:10.1088/1757-899X/527/1/012004

[22] Morgenstern, N.R. and Price, V.E. (1965). The Analysis of the Stability of General Slip Surfaces. *Geotechnique*, 15(1), 70-93.
[23] Spencer, E. (1967). A Method of Analysis of the Stability of Enbakments Assuming Parallel Interslice Forces. *Geotechnique,* 17(1), 11-26.
[24] Chowdhury, R., Flentje, P. and Bhattacharya, G. (2010). Geotechnical Slope Analysis. *CRC Press, Taylor & Francis Group, London, Uk*.

Acknowledgement
The authors would like to express their deepest appreciation to Universiti Malaysia Pahang Malaysia for supporting this research. This research was funded by UMP under grant (ID- RDU1703205)