International Journal of GEOMATE, July 2019, Vol.17, Issue 59, pp.166-172
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.59.38987
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

INFLUENCE OF CLAY CONTENTS ON DRAINED SHEAR STRENGTH PARAMETERS OF RESIDUAL SOIL FOR SLOPE STABILITY EVALUATION

*Asmaa Gheyath Salih[1] and Arez Mohammed Ismael[2]

[1]Faculty of Civil Engineering, University Technology Malaysia, Malaysia
[2]Faculty of Architecture Engineering, Cihan University, Sulaimaniya, Iraq

*Corresponding Author, Received: 29 Nov. 2018, Revised: 01 Jan. 2019, Accepted: 30 Jan. 2019

ABSTRACT: Consolidated drained triaxial compression tests (CD) were conducted to determine the compression properties of remolded samples collected from hillslope in residual soil. The test results showed that the effective drained shear strength of residual soil was primarily affected by the degree of weathering according to depth, parent rock material, and clay contents and also influenced by initial moisture content. These samples were classified as silt soils of high to low plasticity. CD tests were performed on samples prepared under 100 and 200 kPa remolding pressure with three different confining pressures of about 50, 100 and 150 kPa. Predicted results showed that the soil strength increased with increasing samples' density for those who prepared with a higher remolding pressure. According to the soil composition, a clear decrease in soil cohesion was observed for samples collected at a deeper depth, while a further increase in the effective internal friction angle was observed for samples collected with a lower depth. However, this explains the significant influence of clay contents that can be represented as a relevant relation. Therefore, the results indicated that the studied residual soils have physical and geotechnical properties that are highly dependent on the clay and initial water contents. Then, the concept of long-term stability analysis of hillslope of Balai Cerap area (in UTM/ Malaysia) was presented in the form of factors of safety as discussed later in this study by employing Geo-Studio program (SLOPE/W application) with Limit Equilibrium Method.

Keywords: Residual Soil, Triaxial Test, Drained Strength Parameters, Clay Content, Slope Stability

1. INTRODUCTION

Researchers are interested in determining the shear strength of soil that involved in embankment stability analysis, earth pressure calculations, and foundation design. In general, parent rock material properties and the environmental climate conditions are the main factors which play a significant role in the determination of residual soil characteristics in tropical areas.

As known, the variation in the geotechnical properties relays on the depth for the same geological formations in one site. Rahardjo et al., [1] indicated that the variation in the index and engineering properties, as well as microstructural characteristics of the residual soils with depth, can be related to the degree of weathering. Additionally, the variability of soil properties increases at higher levels of degradation and chemical alteration [2]. Actual, it is believed that the proposed weathering profile may contribute to engineering design and classification of weathered granitic rock in the tropical region as reported by [3].

Fundamentally, variety in foundation soil's properties; significantly affects the slope stability according to the impact of the failure mechanism on the slope slip surface. Many methods are adopted in numerical modeling of slope stability problems. Some analytical methods are satisfied for force equilibrium and others for both moment and force equilibrium; the rigorous and preferable methods are that integrate both force and moment equilibrium. Furthermore, results indicated by [4], described that the Limit Equilibrium slope stability analysis methods are simple and relatively fast can produce accurate and reliable results.

However, this study has extended a part of previous research by [5] about the residual soil of natural hillslope. Long-term stability has been evaluated based on the input parameters obtained from drained triaxial compression tests. The slope analyses have been performed using SLOPE/W with conventional Limit Equilibrium Method based on half sin function. Four methods have been employed: Morgenstern-Price's method (MP), Spencer's method (SM), Bishop's method (BM) and Janbu's method (JM).

2. LABORATORY TESTS

Experiments on the physical and geotechnical characteristics performed on remolded samples of residual soil that collected from Balai Cerap hills located in UTM area, Johor/ Malaysia. The first samples (S1) were collected from a depth between

1.5 m to 2.5 m below the ground surface [5], and the second samples (S2) were taken from a lower depth of 3.5 m.

2.1 Soil Physical Characteristics

2.1.1 Moisture content and specific gravity

As with any soil investigation tests, determination of soil moisture content is very important especially for the lands that they have a high fines percentage; irrespective of the weathering degree or the depth, it increases with increasing clay content due to the ability of clay particles to absorb the water [6]. The natural moisture content of the collected soil was 18.24% and 26.48% for samples S1 and S2 respectively.

Essentially, residual soil value of the specific gravity does not vary much with depth but it decreases with increasing of the initial void ratio in the soil, and the values were 2.59 and 2.62 for samples S1 and S2 respectively. Total unit weight for samples S1 was18 kN/m^{3}and 19 kN/m^3 for samples S2; thus, the unit weight generally increased with depth.

2.1.2 Particle size distribution

Soil characteristics and properties are largely affected by the grain sizes and the distribution of the particle size through the mass of the soil. Accordingly, grain size distribution analyses for representative soil samples were investigated. The results show that samples S2 (depth of 3.5 m) have 12.93 % clay, 38.04% silt, 11.34% sand, and 37.69% Gravel. These results show a clear variation from previously published results in [5] for samples S1 (depth from 1.5 to 2.5 m) as shown in Fig. 1 and summarized in Table 1. Generally, clay contents increase with the decrease in depth or with the increase in weathering degree since weathering degree is higher near the ground surface.

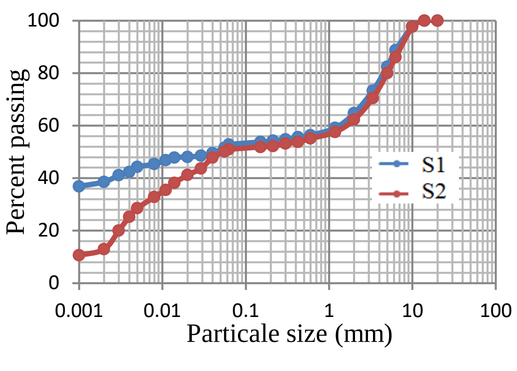

Fig.1 Grain size distribution of residual soil for samples S1 and S2

Table 1 Depth and physical index characteristics of residual soil

Description		S1	S2
Depth (m)		1.5-2.5	3.5
WC (%)		26.48	18.24
Specific gravity Gs		2.59	2.62
Total density (KN/m^3)		18	19
Grain size %	Clay (%)	38.6	12.93
	Silt (%)	14.21	38.04
	Sand (%)	11.93	11.34
	Gravel (%)	35.26	37.69

2.1.3 Atterberg limits

Atterberg limits for samples (S2) were determined and compared with results indicated for samples (S1) as presented in Table 2. However, it can be noted that liquid limit and plastic limit increase with the degree of the soil weathering.

Table 2 Atterberg Limits and residual soil classifications for different depths

Sample		S1	S2
Depth (m)		1.5-2.5	3.5
Atterberg Limits	LL (%)	68.4	47.8
	PL (%)	42.8	27.5
	PI (%)	25.6	20.3
Classification (USCS)		MH	ML

Residual soil samples from the studied area at depth of 3.5 m showed low plasticity (Liquid Limit, LL < 48 % and Plasticity Index, PI=20.3%). Thus, the soil is classified based on plasticity chart by Unified Soil Classification System as (ML) Low plasticity silt as clarified in Fig.2. Furthermore, soil at depth of 1.5-2.5 m has been classified as (MH) High plasticity silt [5], whereas both types of soils are plotted below A-line.

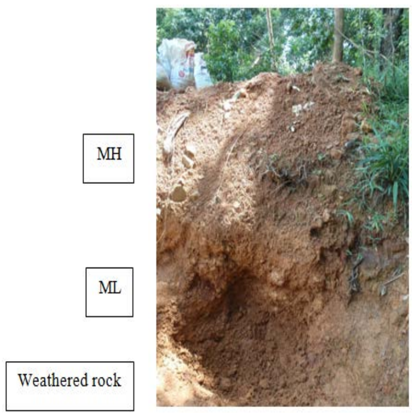

Fig.2 Soil profile and classification

2.2 Soil Drained Shear Strength

Drained triaxial tests were conducted to obtain the compression properties of the soil samples. The drained shear strength is commonly used in slope and embankment stability analysis, earth pressure calculations, and foundation design. Soil shear strength is affected by moisture content, pore pressure, disturbance of the soil structure, the groundwater level fluctuations, stress history, time and environmental conditions [7]. Ideally, for slope analysis; effective stress (drained or long-term condition) is more critical than total stress (undrained condition). Furthermore, CD test gives more reliable data that idealize the soil behavior in the real situation of freely draining state comparing to other tests' type but; CD test is more expensive and also needs longer time to perform. In this research, samples were remolded under two different consolidation pressure (100 and 200 kPa). CD test was carried out with confining pressures of about 50, 100 and 150 kPa. The following figures: Fig. 3, 4, 5 and 6 present the relations of effective stress failure envelope (Mohr-Coulomb circle), deviator stress versus axial strain and volumetric strain versus axial strain respectively.

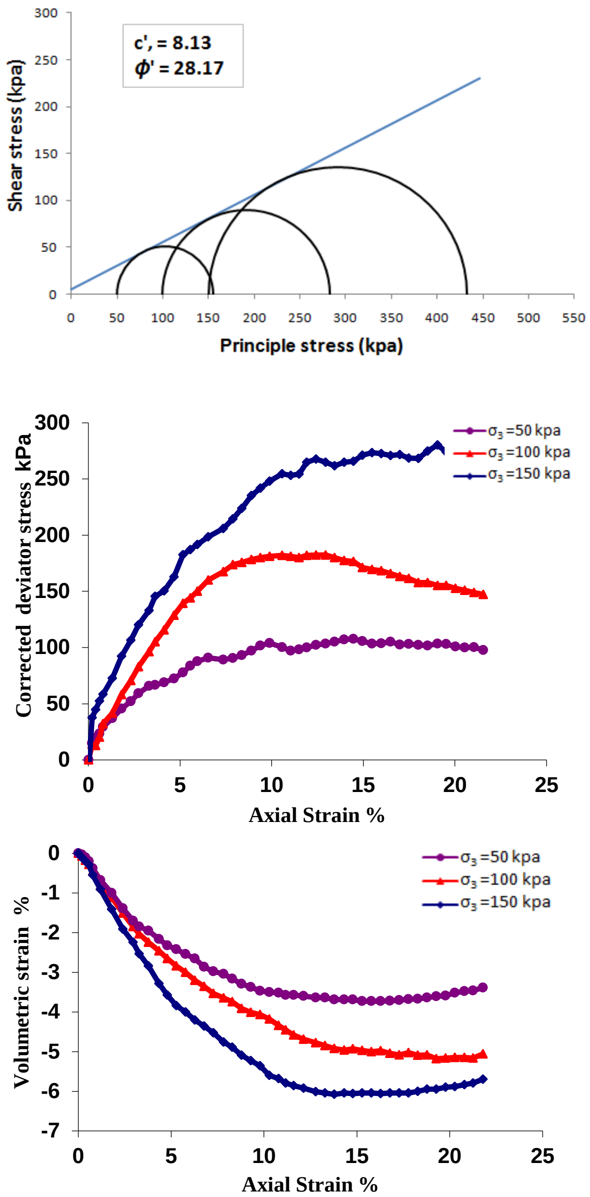

Fig. 3 Relations of effective stress failure envelope of CD test (for samples S1 that remolded with 100 kPa pressure, depth of 1.5-2.5 m), deviator stress vs. axial strain and pore water pressure vs. axial strain [5]

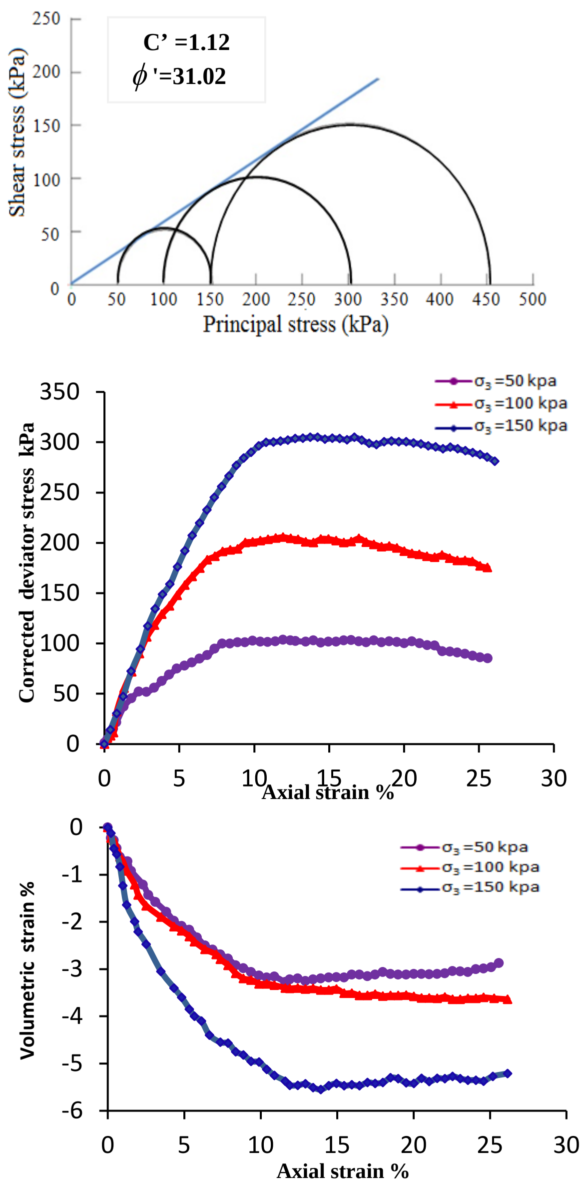

Fig. 4 Relations of effective stress failure envelope of CD test (for samples S1 that remolded with 100 kPa pressure, depth of 3.5 m), deviator stress vs. axial strain and pore water pressure vs. axial strain

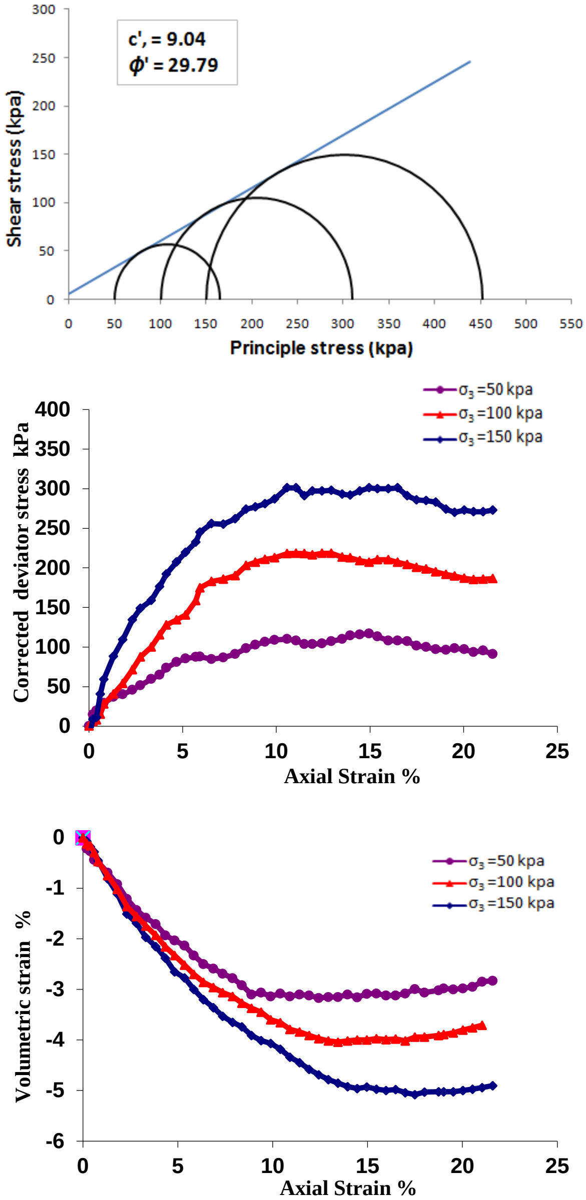

Fig. 5 Relations of effective stress failure envelope of CD test (for samples S1 that remolded with 200 kPa pressure, depth of 1.5-2.5 m), deviator stress vs. axial strain and pore water pressure vs. axial strain [5]

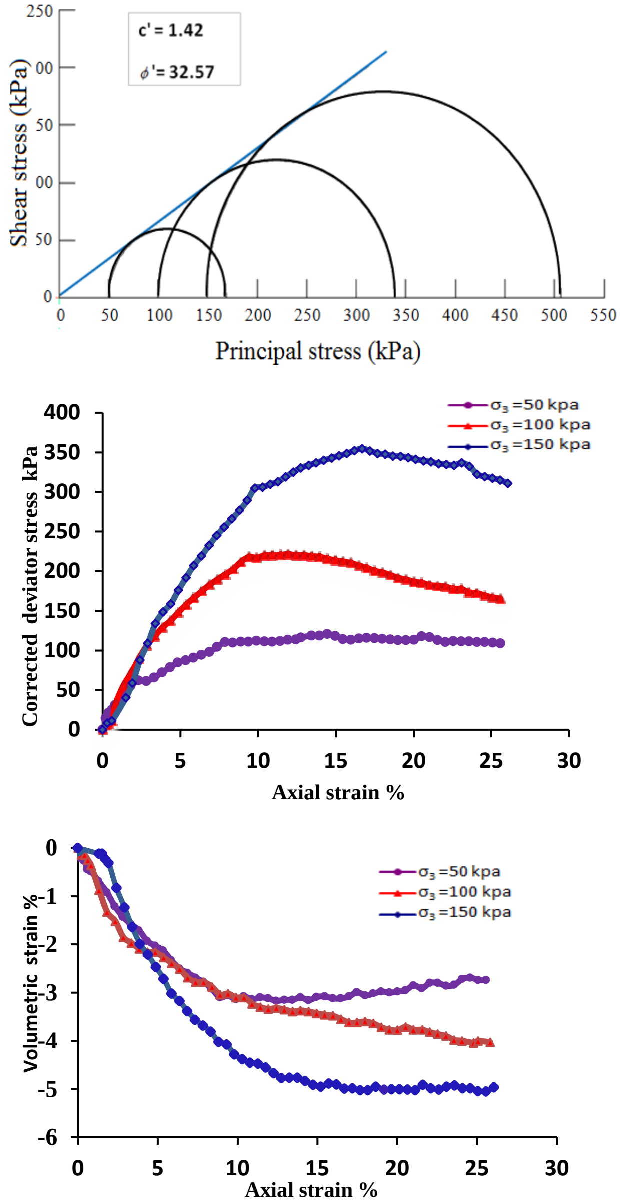

Fig. 6 Relations of effective stress failure envelope of CD test (for samples S1 that remolded with 200 kPa pressure, depth of 3.5 m), deviator stress vs. axial strain and pore water pressure vs. axial strain

As noted from the preceding results of the drained triaxial test; the soil cohesion varies significantly with respect to the clay contents according to the degree of weathering for residual soil, as well as for moisture content change.

According to the reduction in clay contents due to the increase in depth, soil effective cohesion decreased in a range of 84.3% to 86.2%. Unlike for effective internal friction angle which increased in a range of 9.3% to 10.2%. Thus, soil drained strength can be associated with the weathering degree, which is directly related to the depth.

Furthermore, with respect to the moisture content reduction when remoulding the samples with a higher pressure (200 kPa); the rate of soil effective cohesion increased in a range of 11.2% to 26.8%, while the rate for the effective internal angle of friction increased in a range of 5% to 5.8% (by comparing with results of samples that remolded with 100 kPa pressure). In other words, the soil strength decrease with increasing the moisture content and this can be explained due to surface tension disturbance that occurs while increasing in water volume. Table 3 summarizes the effective shear strength parameters of residual soils from the drained triaxial test.

Table 3 Summary of effective shear strength parameters of residual soils from drained triaxial test

Sample remolding pressure	Sample Depth (m)			
	1.5 -.2.5		about 3.5	
	c' (kPa)	ϕ'^{o}	c' (kPa)	ϕ'^{o}
100 kpa	8.13	28.17	1.12	31.02
200 kpa	9.04	29.79	1.42	32.57

3. SOIL SLOPE STABILITY ANALYSES

Geotechnical results of this research depended mainly on parent rock characteristic, the degree of weathering process, climate change and rainy seasons in this tropical area, depth of collected samples and sampling method.

In general, parameters of the effective drained shear strength of residual soil that presented in this study can be utilized in presenting an accurate and representative slope stability model in order to calculate the factor of safety in long-term stability analyses. Normally, most slope failures related to the reductions in effective stress associated with groundwater and seepage. In slope stability modeling, considering pore water pressure and seepage regime within and beneath the slope can demonstrate the critical condition. Furthermore, as the factor of safety evaluates, the designer should be aware of the critical features and parameters that can have a significant impact on the analysis results with respect to the limitations and risks associated in the modeling process. Many factors affect the stability of the slope and mainly depend on hydrology (e.g., rainfall characteristics), soil properties (e.g., unit weight, angle of friction, cohesion of soil), hydrogeology (e.g., hydraulic conductivity, moisture content, groundwater table), and others such as vegetation cover [8].

3.1 Limit Equilibrium Analysis with (SLOPE/W) Software

The sloping geometry assumed that contained two soil layers model with variable strength parameters as indicated in Table 3, and the upper layer thickness was 3m. The groundwater table was selected as shown in Figures 7, 8 and 9 to represent the most critical and rainy conditions. The computed FOS values are presented in Tables 4 and 5 for different land inclinations and slopes heights. Typically, the slope stability (along with a potential failure surface) could be achieved when FOS ≥1, where the relative stability of the slope is represented by the ratio of actual shear strengths to the equilibrium shear strengths (the ratio is the factor of safety) [9].

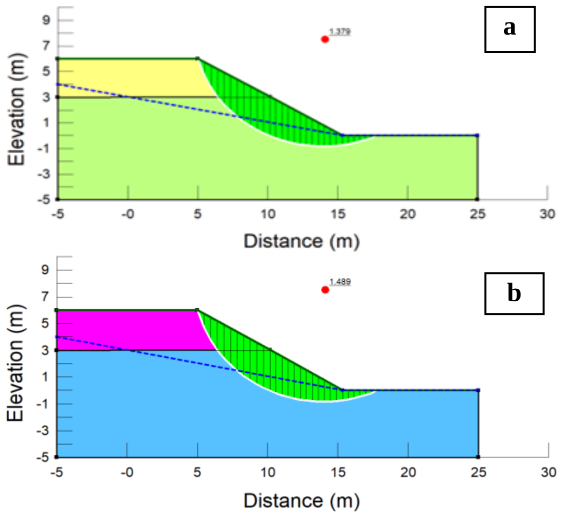

Fig.7 Failure slips surfaces for slope model with H = 6m and β = 30° for (a) sample S1 and (b) sample S2 (Bishop)

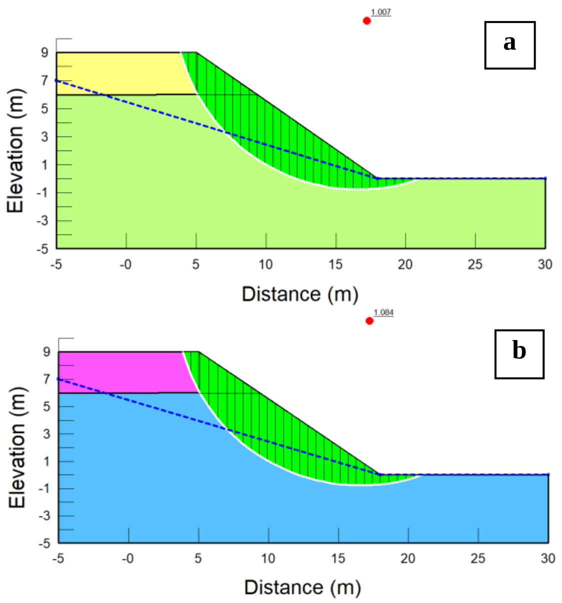

Fig.8 Failure slips surfaces for slope model with H = 9m and β = 35° for (a) sample S1 and (b) sample S2 (Janbu)

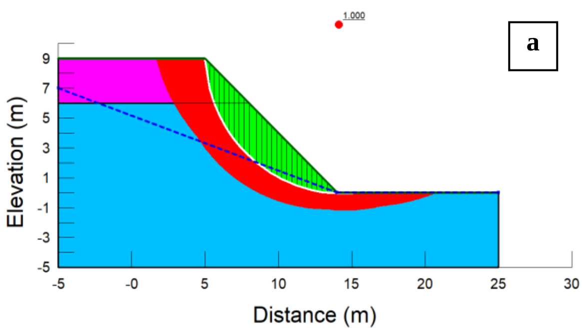

Fig.9 (a) Failure slip surface and safety map for slope model with H = 9m and β = 45° for sample S2 (Morgenstern-Price)

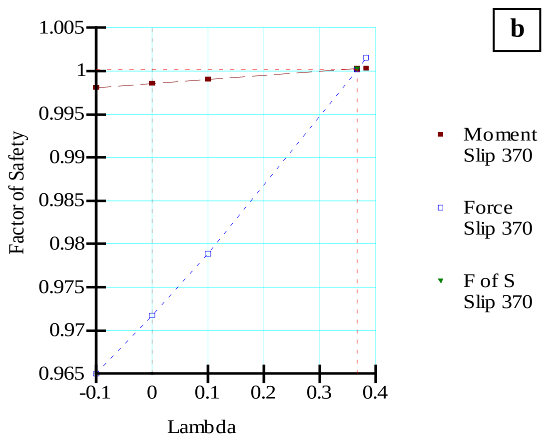

Fig.9 (b) Factor of safety vs. lambda; FOS=1.000

3.2 Result Discussion

Results demonstrate that the slope stability affected mainly by soil properties, the slope height, the angle of the land inclination and even the pore-water pressure conditions. Whereas for the cases with higher H and β values; the stability analysis results illustrated that the slopes were more unsafe since the factor of safety decrease.

Where H is the slope height and β is the slope angle.

For the lower values of soil shear strength parameters; the critical inclination (β) were 45°, 40°, 30° for the heights of 6m, 9m and 12m respectively as shown in Table (4), nevertheless the slope failure could occur even with smaller inclinations according to other complex and combined causes.

By comparing the results in both Table 4 and 5; the variation in soil strength parameters influenced extremely the calculated FOS. In other words; the change in the soil cohesion can influence considerably the calculated FOS. Accordingly, when the influence of cohesion decreases; the importance of friction angle increases. As a result, the soil friction angle has a significant impact on slope stability.

Beside different conditions of slope geometry; remolding (consolidation) pressure is another important concept that can significantly affect the results of the calculation. Thus, according to the presented results; samples with a higher remolding (consolidation) pressure gave bigger FOS than those of a lower remolding pressure due to increasing the soil density and decreasing the initial water content.

3.3 Comparisons of FOS That Computed by Different Methods

FOS values computed by the MP and the SM were the same for all slope inclinations and different foundation soil properties and it's vital to notice that the two methods are satisfying both the force and moment requirements for static equilibrium. By comparing BM with the previous two methods; results from BM were almost the same with slight differences. Unlike for JM, that gave lower FOS values comparing to the above-mentioned methods. These varieties significantly come as a result of respect to the assumptions included and the limitations for every adopted method.

Table 4 FOS values of slope models for samples remolded with 100 kPa pressure

Slope	H	6m					9m					12m				
geometry	β	25°	30°	35°	40°	45°	25°	30°	35°	40°	45°	25°	30°	35°	40°	45°
LEM	MP	1.552	1.384	1.270	1.154	1.041	1.335	1.206	1.098	1.007	0.927	1.226	1.106	0.988	0.910	0.845
	SM	1.553	1.386	1.271	1.156	1.071	1.335	1.207	1.099	1.007	0.932	1.225	1.106	0.989	0.910	0.846
	BM	1.549	1.379	1.264	1.152	1.040	1.331	1.200	1.094	1.003	0.926	1.220	1.096	0,982	0.905	0.840
	JM	1.416	1.269	1.175	1.099	1.042	1.214	1.089	1.007	0.938	0.878	1.114	0.986	0,899	0.831	0.775

Table 5 FOS values of slope models for samples remolded with 200 kPa pressure

Slope	H	6m					9m					12m				
geometry	β	25°	30°	35°	40°	45°	25°	30°	35°	40°	45°	25°	30°	35°	40°	45°
LEM	MP	1.674	1.493	1.369	1.242	1.129	1.435	1.296	1.183	1.084	1.000	1.314	1.186	1.061	0.977	0.908
	SM	1.674	1.496	1.371	1.243	1.157	1.435	1.297	1.184	1.084	1.005	1.313	1.187	1.062	0.978	0.910
	BM	1.670	1.489	1.363	1.242	1.130	1.431	1.289	1.178	1.081	0.999	1.308	1.175	1.055	0.973	0.904
	JM	1.523	1.368	1.270	1.192	1.130	1.302	1.170	1.084	1.009	0.947	1.193	1.058	0,966	0.892	0.834

4. CONCLUSIONS

A considerable amount of studies showed that residual soils characteristics are a function of the weathering degree of the parent rock. Consequently, changes in the geotechnical characteristics with depth are related to different degrees of weathering. Specifically, effective internal friction angle and soil cohesion are significantly influenced by clay content that can be represented as a relevant relation. Moreover, a variety of initial water content has a noticeable effect on soil strength. Therefore, the variability of soil properties increases at a higher level of weathering process in tropical climate condition. As a result, soil strength characteristics play important role in the trend of slope stability with consideration to the importance of the soil moisture content. In addition, the slope geometry conditions control the pattern of the failure mechanism that considered as a significant predictor of slope failure. Furthermore, it is important to adopt drainage conditions to simulate the occurrence of slope failure. Eventually, since there is no concept to estimate the time, shape and location of the failure surface for the real slopes failure that would occur; thus all previous studies remain as a prediction tools to evaluate the failure mechanism for diverse slope failure cases and that comes due to the complexity of the soil behavior.

5. ACKNOWLEDGMENTS

The authors would like to acknowledge the staff of Geotechnical Engineering Lab in University Technology Malaysia for their support of this research project.

6. REFERENCES

[1] Rahardjo, H., Aung, K.K, Leong, E.C. and Rezaur, R.B. Characteristics of Residual Soils in Singapore as Formed by Weathering, Engineering Geology, 73, 2004, 157-169.

[2] Gustavo O. Bogado, Hugo O. Reinert and Franco M. Francisca, Geotechnical properties of residual soils from the North-east of Argentina, International Journal of Geotechnical Engineering, (2017), DOI: 10.1080/19386362.2017.1326682.

[3] Alavi Nezhad Khalil Abad, S.V., Mohamad, E.T., Komoo, I. Kalatehjari, R., A Typical Weathering Profile of Granitic Rock in Johor, Malaysia Based on Joint Characterization. Arab J Geosci. 8 (4), 2015, 2191–2201.

[4] Zein, A., M., and Abdel Karim, W., Stability of Slopes on Clays of Variable Strength by Limit Equilibrium and Finite Element Analysis Methods, International Journal of GEOMATE, Vol.13, Issue 38, 2017, pp.157-164.

[5] Salih, A. G., and Kassim, K. A., Effective Shear Strength Parameters of Remoulded Residual Soil, EJGE, Vol. 17, 2012, pp 243-253, Bund C.

[6] Salih, A. G., Review on Granitic Residual Soils' Geotechnical Properties, EJGE, Vol., 2012, pp 2645-2658, Bund T.

[7] Cernica, John N., 1995, Geotechnical Engineering: Soil Mechanics, University of California, Wiley.

[8] Tung Y. K. and Chan G. C. C., Stochastic Analysis of Slope Stability Considering Uncertainty of Soil-Water Retention Characteristics, Proceeding of The International Conference on Applications of Statistics and Probability in Civil Engineering, Vol.1and 2, 2003, pp.1409–1414.

[9] Geo-environmental section Oregon, department of transportation, chapter 7, Slope Stability Analysis, 2018, geotechnical design manual, version 2.0, U.S.