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Moisture Implication on Landslide Occurrences of Lateritic Soil Slopes in Ranau, Sabah, Malaysia

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Study of engineering properties is vital in order to understand the relationship between the landslide occurrences with the soil moisture. A total of three soil samples were collected from Ranau lateritic soil for the engineering properties analysis. The result of analysis shows that the soil moisture content was in the range of 16.99% to 27.65%. The plasticity chart plot of soil found that the soil samples were classified as high plasticity to very high plasticity. The unconfined compression strength indicated that all samples are classified as very soft soils with value range from 3.20 – 3.86 kPa. Decrement of moisture percentage indicated that higher strength with increment soil strength from 3.24 kPa – 16.86 kPa. Increasing soil moisture resulted in the lower of soil strength with around 1.08 kPa for sample S1. Sample S2 and S3 were in slurry condition therefore not able to be measured for the soil strength. The increasing of soil moisture could decrease the soil strength and can cause the occurrence of landslide. This is due to water accumulation between the soil particle in the saturated condition and high adsorption of water by the secondary minerals. The result of XRD and SEM showed the kaolinite and iron oxide minerals such as ferrihydrate, antigorite, goethite, hematite, magnetite and maghemite appear as secondary minerals.

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I. INTRODUCTION

The study area is located at the Ranau Sport Complex to Kg. Libang Tanah Merah, in the district of Ranau, Sabah, Malaysia. The study area consists of lateritic soils originated from the weathering process of ultramafic rocks which can be found abundantly in the study area. Hutchison (2005) has described the ultrabasic rocks in Ranau are strongly serpentinized peridotite due to the metamorphism processes. Ultrabasic soil indicates high iron-oxide minerals such as goethite, hematite, magnetite and maghemite based on XRD and SEM analyses (Sahibin *et al.*, 1996). The study area has tropical climate which experience high rainfall intensity throughout the year. This caused high rate of chemical weathering and

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surface erosion which trigger continuous landslides occurrences (Bizimana & Sonmez, 2015). Friction strength of soil influenced by its mineral contents, shape of soil particles, pore ratio, organic materials content and soil grades (Braja, 2012). Oxide-hydroxide minerals became low plasticity and slurry when mixed with high percentages of water due to the formation of limonite minerals, therefore will trigger the landslide (Hossain, 2010; Jeans & Tommy, 2014). This condition shows how additional of water has increase the rate of adsorption and saturation especially on large-surface iron oxide mineral, thus reduce the cohesion to maintain the strength. Low plasticity makes it susceptible to failure due to reduction of soil shear strength. Most landslides are triggered by hydro climatic events such as prolonged or intensive rain (Jacob & Lambert, 2009; Syaran *et al.*, 2014). Understanding the engineering properties is vital in order to understand the relationship with the occurrences of landslide in this area.

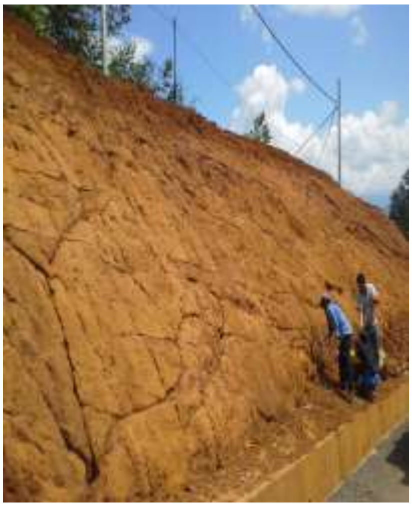
II. MATERIALS AND METHODS

Field investigations involved the study of lateritic soils distribution and sample collection. About three soil samples were collected from the slopes at Kg. Libang Tanah Merah and Ranau Sport Complex (Figure 1 and Figure 2). The samples were originated from ultrabasic soil of serpentinized peridotite. The serpetinization process occurred during regional metamorphism due to the existence of tectonism and seawater intrusion which resulted in the formation of chloritoid (blue color) and chlorite (green color). This parent rocks aged from Jurassic to Cretaceous were widely distributed in the study area resulted in thick profile of orange-reddish lateritic soils. The existence of iron concretion showed the abundance of iron oxide minerals such as magnetite, maghemite, hematite and goethite which can be identified through XRD analysis.

The laboratory analysis involved the physico-chemical analysis, engineering properties analysis, and mineral content analysis. The parameters in physico-chemical analysis are natural moisture content, organic content, pH value, particle size distributions and specific gravity of soil. The physico-chemical analyses were followed BS1377:1990 methods (British Standards, 1990). The Atterberg's limits were analyzed to identify the type of soil plasticity. Engineering properties consist of Proctor compaction test, unconfined compression test (UCT) and permeability test. The increment or decrement of moisture content percentage will then be used to determine the effect of moisture (rainfall volume) on the soil's strength value. The microstructures of the soil samples were observed using SEM analysis and identification of soil minerals were analyzed using XRD. The identification of minerals from X-Ray Diffractograms was based on Moore & Reynolds (1997).

(a) S1

(b) S2



(c) S3

Figure 1. Lateritic soil slopes of the study area

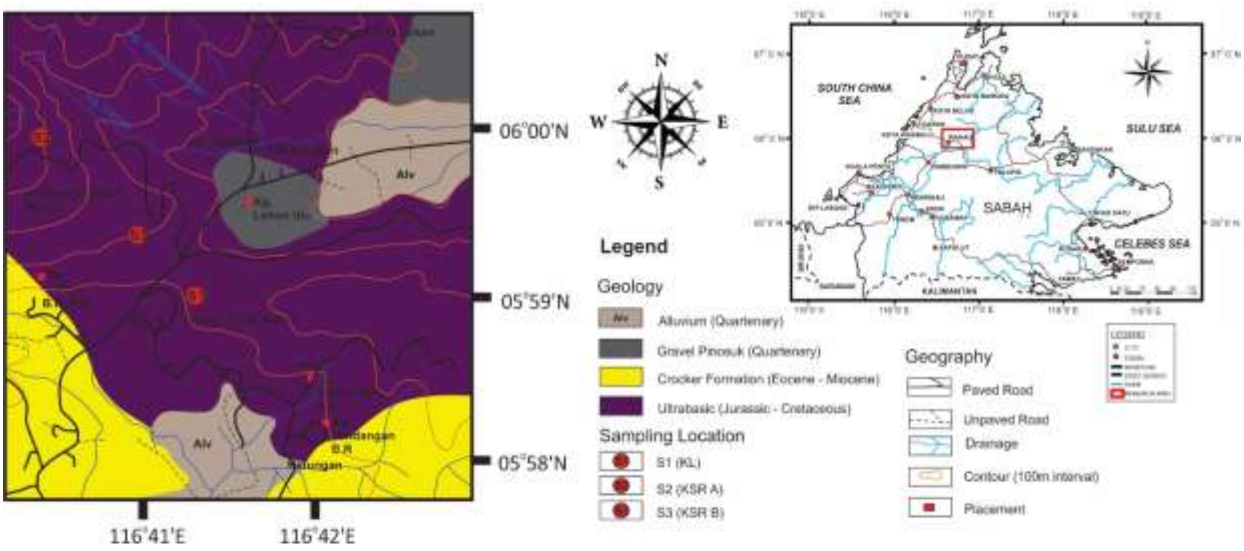


Figure 2. Geological map of the study area based on Sanudin & Baba (2007)

III. RESULTS AND DISCUSSIONS

Table 1 shows the results of analysis for physico-chemical properties including analysis of moisture content, organic matter content, specific gravity, pH and particle size distribution for three soil samples collected from lateritic slopes from Ranau, Sabah. Based on the table, the soil moisture content is at the range of 16.99% to 27.65%; the soil organic content ranges from 13.79% to 14.81%; the soil specific gravity at the range from 2.74 to 2.95, and the average pH value is from pH 5.34 to pH 5.67. All samples show the acidity value with sample S1 shows the highest moisture content which was 27.65%, while S2 shows the highest soil organic content (17.46%) and highest specific gravity (2.95). The specific gravity tests are conducted to determine the density of each soil sample by calculating the ratio between the mass of dry soil and distilled water. The value of specific gravity of ultrabasic soils is in range from 2.77 to 3.00, but could be higher. This is due to the existence of iron oxide minerals such as goethite, hematite, magnetite and maghemite, similarly observed in soil samples. Based on particle size percentages, all soil samples are classified as sandy and silty clay (Head, 2008). The uniformity coefficient (Cu) and curvature coefficient (Cc) (Figure 3) results with range of 13.64 – 24.00 and 1.25 – 1.72 respectively, indicated all samples are well graded.

The result of Atterberg's limits tests for three soil samples are given in Table 2. Atterberg's limits consist of plastic limit test, liquid limit test, soil plasticity index and linear shrinkage. Soil conditions can be divided into four phases, namely solid, semi-solid, plastic and liquid (Head, 2008). Based on the analysis, average liquid limit of soil samples are from 53.00 to 74.00%. Average plastic limit ranged from 47.29% to 60.37%, while the plasticity indexes are in the range from 5.71% to 13.78%. The plasticity chart shows that S1 and S2 are classified as high plasticity soil, while S3 soil was classified as very high plasticity (Figure 4). Based on the clay activity analysis it is found that all soil samples are classified as inactive clay with the value range of 0.22 – 0.61. The analysis results show the linear shrinkage percentage is at the range of 7.14% to 12.14%.

The engineering properties consist of Proctor compaction test, unconfined compression test (UCT) and Falling Head permeability test. Proctor compaction test were conducted to determine the maximum dry density and optimum moisture content of the soil samples. This test is intended to increase the density of the soil samples by reducing the volume of the air space between the soil particles through compaction methods. The result shows that the optimum moisture contents ranged from 32.99% to 44.26%, while the maximum dry density is within range from 1.27 Mg/m^3 to 1.35 Mg/m^3 (Table 3).

To determine the influence of climate change on soil samples of the study area, suggested amount of percentage of moisture content will be added or reduced. In this study, increment and decrement of 0.5% to 2.5% from the optimum moisture content is applied to simulate the rainfall volume received on the soil samples. The mixture of soil and particular percentage of moisture is then tested for its compression strength value (Table 4). Addition of more than 0.5% moisture could not been conducted due to resulted slurry condition.

Unconfined compression test (UCT) was conducted to determine the strength of the soil samples when subjected to compressive forces. Stress resistance strength is the maximum power per soil area that can be produced by a soil sample to prevent failure or slide along its plane. From Table 4, the result of the UCT shows that all samples are classified as very soft soil (Terzaghi *et al.*, 1996) with range of 3.22 kPa to 3.86 kPa on natural condition. Decrement of moisture percentage up to 2.5% indicates less water added which increase the strength value for each samples from 3.26 kPa to 16.86 kPa. However, the increment of 0.5% of moisture has resulted to lower strength of 1.08 kPa for sample S1. This indicates 72% lesser in strength compared to optimum moisture condition. Figure 5 shows compression curve for all soil samples. Only sample S1 is able to proceed with permeability test which contributed to 9.2×10^{-10} m/s and is classified as impermeable soil (Terzaghi & Peck, 1948). Other samples are not able to perform this analysis due to over-saturated condition of soil (Figure 6).

Analysis of mineral content in the soil samples shows that the main mineral content in the soil samples are quartz (Q), goethite (G), hematite (H), antigorite (A), magnetite (Mg), maghemite (Mh) and kaolinite (K). The micro morphology and micro structure of soil from SEM images show the appearance of antigorite with its layer and platy habit and needle-like magnetite.

The X-ray diffractograms and electron microscopic images for sample S1, S2 and S3 in normal conditions are given in Figure 7.

Table 1. Physico-chemical properties of soil samples

Samples	Moisture content (%)	Organic matter content (%)	pH	Specific Gravity	*Clay*	*Silt*	*Sand*	Soil Classification	Grade
S1	27.65	14.81	5.67	2.74	27.86	37.31	34.83	Sandy & Silty Clay	Well graded
S2	24.80	17.46	5.58	2.95	25.62	35.86	38.52		
S3	16.99	13.79	5.34	2.83	22.29	47.17	30.54		

Table 2. Results of the Atterberg's Limit of soil samples

Sample	Average liquid limit, L_L (%)	Average plastic limit, P_L (%)	Plasticity index, I_P (%)	Linear shrinkage, L_S (%)
S1	62.00	48.22	13.78	11.43
S2	53.00	47.29	5.71	7.14
S3	74.00	60.37	13.63	12.14

Table 3. Optimum moisture content and maximum dry density of soil samples

Sample	Optimum Moisture content, W_{opt} (%)	Maximum Dry density, p_D (Mg/m^3)
S1	32.99	1.32
S2	39.45	1.35
S3	44.26	1.27

Table 4. Compression strength and permeability of different moisture percentage

Sample	UCT (kPa)			Permeability (m/s)		
% Moisture	S1	S2	S3	S1	S2	S3
-2.5%	16.86	3.98	10.10	Not applicable		
-1.5%	10.20	3.67	7.64			
-0.5%	7.93	3.26	6.89			
0%	3.86	3.22	3.54	9.2×10^{-10}	-	-
+0.5%	1.08	-	-	-	-	-
+1.5%	-	-	-	-	-	-

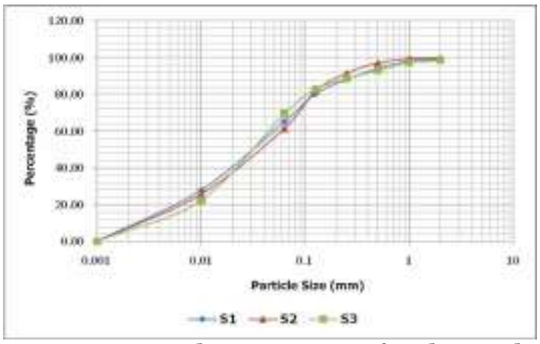
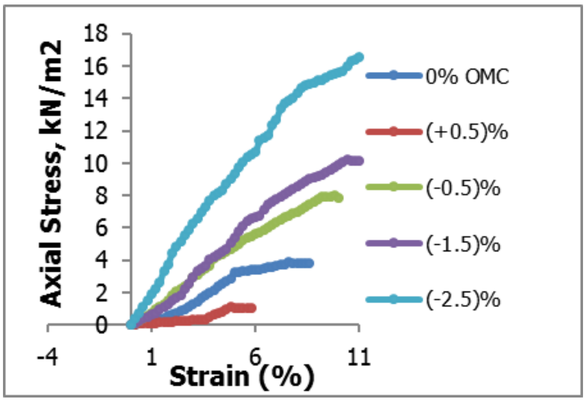


Figure 3. Particle size curve of soil samples



S1

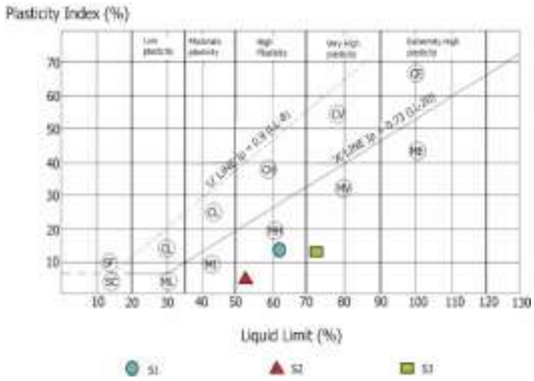
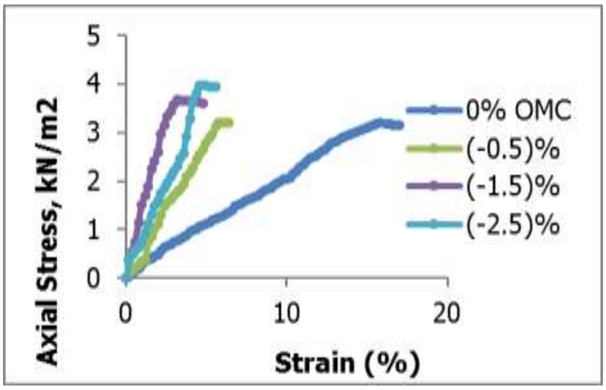
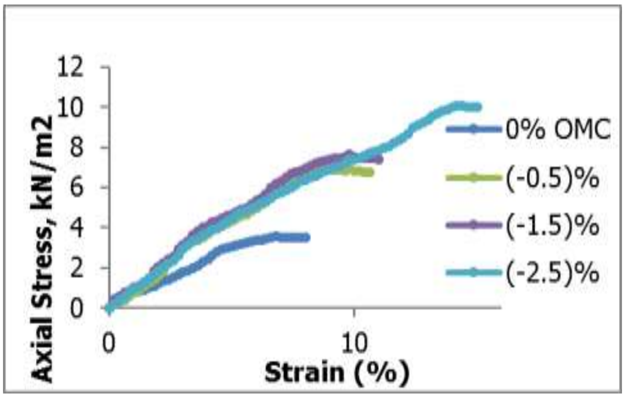


Figure 4. Plasticity chart of soil samples



S2

Figure 6. Water saturated for permeability test for sample S1. Other samples do not able to proceed due to its slurry condition when added with more water



S3

Figure 5. UCT test with different moisture content for all soil samples

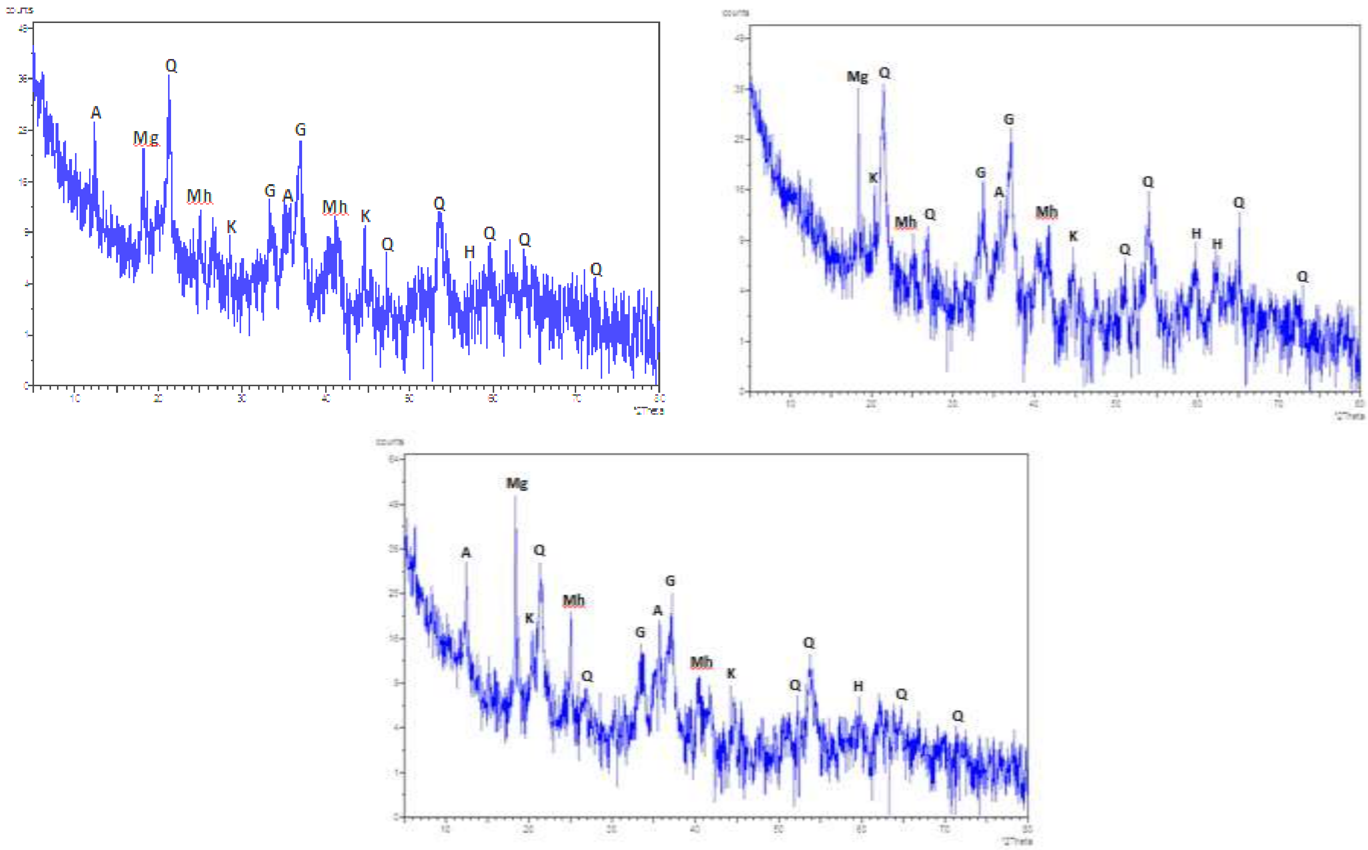


Figure 7. X-ray diffractograms and electron microscope image

IV. SUMMARY

In conclusion, this study shows the implication of moisture on landslide occurrences based on its engineering properties. All samples are classified as very soft soils from 3.22 – 3.86 kPa on natural condition. Increment of moisture reduces the strength for S1 with value of 1.08 kPa. All samples show higher strength value range from 3.26 kPa to 16.86 kPa when the moisture content is reduced to 0.5%, 1.5% and 2.5%. For permeability test, only S1 was able to be tested and was classified as impermeable soil. Both S2 and S3 could not been tested with any additional moisture due to its slurry of water saturation condition. XRD analysis shows the mineral content of quartz, ferryhydrite, goethite, hematite, antigorite, magnetite, maghemite and kaolinite.

ACKNOWLEDGEMENT

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