Engineering Properties of Soil from Unstable Slopes in Ranau-Kundasang, Sabah, Malaysia

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ABSTRACT: A total of five soil samples were collected from different sedimentary rock units namely Trusmadi Formation, Crocker Formation and Pinosouk Gravel in order to analysis the engineering properties of the soils. The soil samples were collected from unstable soil slopes in Ranau-Kundasang, Sabah. The result of analysis shows that the soil moisture content was in the range of 6.94% to 22.70%, the soil organic content range from 0.60% to 1.79%, and the soil specific gravity in the range of 2.49 to 2.65. All samples show the acidity to low alkaline in pH. The average liquid limit of soil samples were from 20.93% to 65.00%, while the plasticity indexes were in the range of 5.67% to 20.98%. The plasticity chart plot of soil found that soils from Trumadi and Crocker Formation were classified as low plasticity soil, while Pinosouk Gravel samples were classified as intermediate to high plasticity. Clay activity analysis showed the existence of illite and kaolinite in soil of Trusmadi and Crocker Formation, while kaolinite and Ca-montmorillonite appeared in soil of Pinosouk Gravel. The result shows that the optimum moisture contents range from 11.50% to 21.13%, while the maximum dry density was within a range from 1.52 Mg/m3 to 1.90 Mg/m3. The unconfined compression strength indicated that all samples are classified as soft soil where soil samples of Pinosouk Gravel showed the lowest strength. The permeability of all soil samples is best classified as very low permeability to impermeable. The porosity analysis showed that Trusmadi and Crocker Formation are sandy-dominated soil with 61.73% to 69.08%, while Gravel Pinosouk samples are poorly-sorted soil with 42.90% to 61.50%.

KEYWORDS: Engineering properties of soil; Unstable slopes; Sedimentary rock units; Pinosouk Gravel; Crocker Formation; Trusmadi Formation

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INTRODUCTION

The study area is located at Ranau-Kundasang, Sabah, Malaysia (Figure 1) with often occurrence of slope failure and soil creep. The study area consists of three different sedimentary rocks units namely: the Trusmadi Formation aged Paleocene to Middle Eocene, the Crocker Formation (Late Eocene to Middle Miocene) and the Pinosouk Gravel (Pliocene) (Sanudin & Baba, 2007). The Crocker Formation is characterized as mudstone, sandstone and shale, whereas the Trusmadi Formation consists of argillite, mudstone and sub-phyllite with tuff (Collenette, 1958). Meanwhile, the Pinosouk Gravel is stated by Jacobson (1969) as tilloid deposit due to Mount Kinabalu glacial transportation and deposition.

Different soil has different strength, depending on its parent material and mineral contents. Friction strength of soil is influenced by the mineral contents, organic materials content, shape and size of soil particles, soil grades and pore ratio (Braja, 2012). Besides geological factors, weather also influences the rate of soil weathering to contribute to the soil stability (Allen *et al*., 2011). Fine grain soil become low plasticity and slurry when mixed with high percentages of water which affects the slope failure due to the reduction of soil shear strength (Jeans & Tommy, 2014). This situation is probably due to the type of sedimentary rocks which consist of single grained with different arrangement, either is in-contact or to fill-up voids, which produced pore ratio. This study is to justify the engineering properties of soil from unstable slopes among sedimentary rock units in the study area in order to understand the relationship of slope failure.

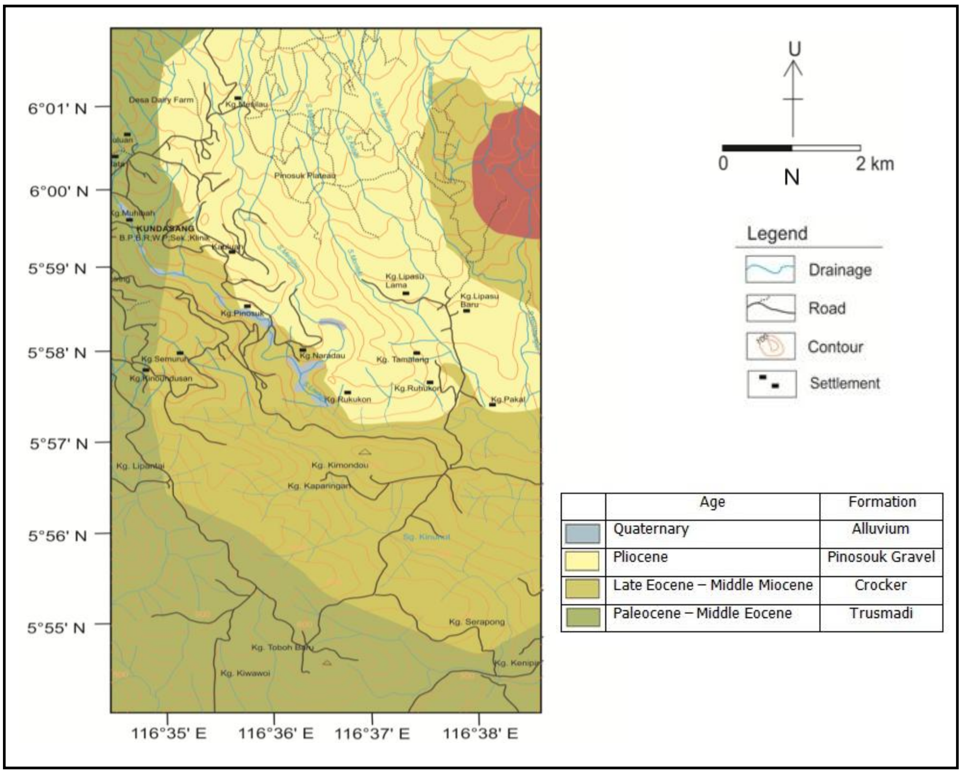

Figure 1. Geological map of Ranau-Kundasang, the study area

METHODOLOGY

Five soil samples were collected from three different sedimentary rock units namely Trusmadi Formation (S1), Crocker Formation (S2 and S3) and Pinosouk Gravel (S4 and S5). All samples were collected from unstable soil slopes to determine the engineering properties of soils to occur slope failure or landslides. The laboratory analysis involved the physico-chemical analysis and engineering properties 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 analysis followed BS1377:1990 methods (British Standard, 1990). The Atterberg's limits were used to identify the type of soil plasticity based on plastic limit, liquid limit and linear shrinkage index. Engineering properties consist of Proctor compaction test, unconfined compression test (UCT), porosity analysis and permeability test.

RESULT AND DISCUSSION

Physico-chemical properties

Table 1 shows the results of analysis for moisture content, organic matter content, specific gravity, and pH for five soil samples collected from different sedimentary rocks in Ranau-Kundasang, Sabah. Based on the table below, the soil moisture content was in the range of 6.94% to 22.70%; the soil organic content range from 0.60% to 1.79%; the soil specific gravity was in the range of 2.49 to 2.65, and the average pH value was from pH 4.80 to pH 7.60. All samples show the acidity of soil except S5 shows low alkalinity (pH 7.47) due to the production of sodium carbonate during weathering process (Oosterbaan, 2003). Sample S4 and S5 (Pinosouk gravel) show the highest moisture content, whereas sample S2 and S3 (Crocker Formation) show the highest soil organic content (0.79% to 1.72%) and highest specific gravity (2.63 – 2.65) to indicate the existence of quartz. The specific gravity tests were conducted to determine the density of each soil sample by calculating the ratio between the mass of dry soil and distilled water.

Table 1. Physico-chemical properties of soil samples

No. Sample	Moisture content Wo (%)	Soil organic matter content, OM (%)	pH	Specific Gravity SG
S1	6.94	0.60	6.90	2.53
S2	19.36	1.72	4.63	2.63
S3	15.56	0.79	5.39	2.65
S4	22.70	1.07	6.55	2.50
S5	22.08	1.22	7.47	2.49

Table 2 shows the percentage of clay, silt and sand for all five soil samples. Based on Head (2008) classification, sample S1, S2 and S5 were classified as clayey sand, whereas sample S3 and S4 were classified as slightly clayey sand and clayey and sandy silt soil respectively. The uniformity coefficient (Cu) and curvature coefficient (Cc) results indicated all samples were poorly graded except sample S4 and S5 (Pinosouk gravel) which were well graded. This shows that soils from Trusmadi and Crocker Formation were dominated by sandy grains due to high percentage of quartz in the sandstones. While Pinosouk gravel soil samples consist of larger range of particle size due to the mixture of gravel, sand, silt, mud and blocky material (Siong *et al*., 2001).

Table 2. Grain size distributions of soil samples

Sample	Percentages of Grain size (%)			Soil Classification	Grade
	Clay	*Silt*	*Sand*		
S1	12.33	7.31	80.36	Clayey sand	Poorly graded
S2	15.63	8.53	75.84	Clayey sand	Poorly graded
S3	9.53	12.13	78.34	Slightly clayey sand	Poorly graded
S4	12.23	35.16	52.61	Clayey & sandy silt	Well graded
S5	11.09	20.17	68.78	Clayey sand	Well graded

The result of Atterberg Limit tests for soil samples are given in Table 3 below. 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).

Table 3. Atterberg limit analysis of soil samples

Sample	Average liquid limit, L_L (%)	Average plastic limit, P_L (%)	Plasticity index, I_P (%)	Linear shrinkage, L_S (%)
S1	21.57	14.82	6.75	2.86
S2	20.93	13.62	7.31	7.14
S3	31.27	22.35	8.92	9.28
S4	37.80	32.13	5.67	5.71
S5	65.00	44.02	20.98	19.86

Based on the analysis, average liquid limit of soil samples were from 20.93% to 65.00%. Average plastic limit ranged from 13.62% to 44.02%, while the plasticity indexes were in range of 5.67% to 20.98%. The plasticity chart based on Sowers (1979) has classified sample S1, S2 and S3 as low plasticity soil, while S4 and S5 were classified as intermediate and high plasticity respectively (Figure 2). Clay activity analysis shows that sample S1 and S3 indicated the existence of illite, sample S2 and S4 with kaolinite, whereas sampel S5 with Ca-montmorillonite for its clay mineral content (Skempton, 1953) (Table 4).

Engineering properties

The engineering properties consist of compaction test, unconfined compression test, permeability test and porosity analysis. 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. Table 5 shows the optimum optimum soil moisture content and maximum dry density. The result shows that the optimum moisture contents ranged from 11.50% to 21.13%, while the maximum dry density is within a range from 1.52 Mg/m^3 to 1.90 Mg/m^3.

Table 4. Clay activity analysis for soil samples

Sample	Clay activity	Classification	Mineral Existence (Skempton, 1953)
S1	0.54	Non-active clay	Illite
S2	0.46	Non-active clay	Kaolinite
S3	0.93	Normal clay	Illite
S4	0.46	Non-active clay	Kaolinite
S5	1.89	Active clay	Ca-montmorillonite

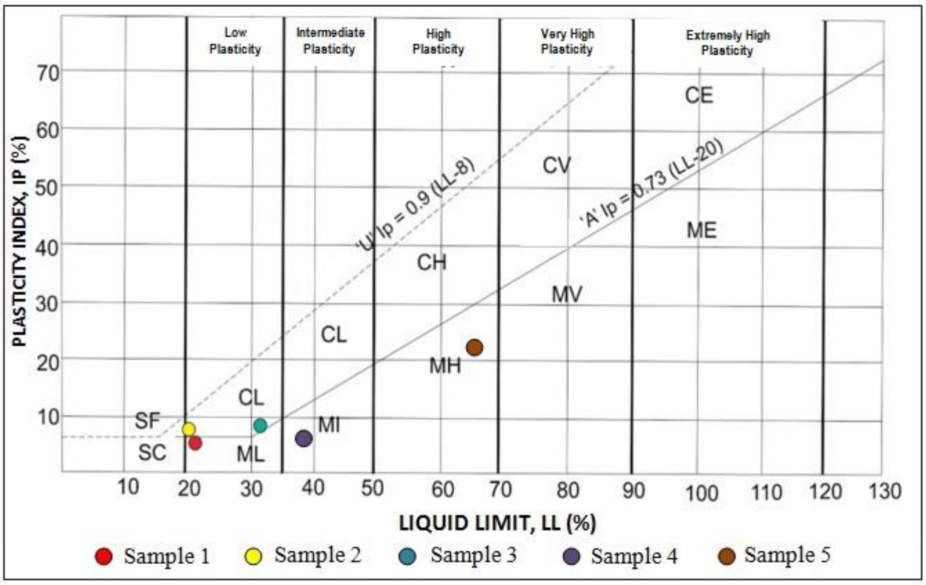

Figure 2. Plasticity chart of soil samples

Unconfined compression test was conducted to determine the stress strength of the soil samples when subjected to compressive forces. Stress resistance strength is the maximum power per area that can be produced by a soil sample to hold the stress to prevent failure or slide along its plane. The unconfined compressive strength based on Terzaghi & Peck (1996) where all samples are classified as soft soil except for sample S5 is very soft soil (Table 5). The permeability tests were conducted to determine the permeability of the soil to drain water between its pore spaces. The result shows that the permeability of all soil samples is best classified as very low permeability except for sample S3 which is impermeability soil.

Table 5. Engineering properties of soil

Sample	Optimum Moisture content, Wopt (%)	Maximum Dry density, ρ_D (Mg/m³)	Unconfined compression test (kPa)	Permeability value, k (m/s)	Porosity, n (%)
S1	11.50	1.90	32.33	1.84×10^{-9}	69.08
S2	16.50	1.70	50.33	1.60×10^{-9}	62.07
S3	21.00	1.56	52.67	4.62×10^{-10}	61.73
S4	18.50	1.52	27.76	5.68×10^{-9}	61.50
S5	21.13	1.56	11.76	1.60×10^{-9}	42.90

Based on Table 5, sand-dominated soil samples (S1, S2 and S3) show higher strength (32.33 kPa to 52.67 kPa) and porosity value (61.73% to 69.08%) compared to sample S4 and S5 (Pinosouk gravel) which were well-graded and poorly-sorted soil due to wide range of various particle sizes. This also contributed to low permeability to impermeable where finer grains has filled spaces among bigger grains thus minimizing the interconnected pores to allow water to flow (Zulfahmi *et al*, 2009).

CONCLUSION

The soil samples from different sedimentary rocks unit show that the moisture content, organic matter and specific gravity were 6.94% - 22.70; 0.60% - 1.72%; and 2.49 – 2.65 respectively.

The pH value was acidic for all samples (pH 4.63 – 6.90) to low alkaline (pH 7.47). The average liquid limit was 20.93% - 65.00%, while the plasticity index was 5.67% to 20.98%. The plasticity chart of soil shows that soils from Trusmadi and Crocker Formation were classified as low plasticity soil, while Pinosouk Gravel samples were classified as intermediate to high plasticity soils. Clay activity analysis shows that the existence of illite and kaolinite in soil of Trusmadi and Crocker Formation, while kaolinite and Ca-montmorillonite appeared in Pinosouk Gravel soil samples. Particle size distribution indicates Trusmadi and Crocker Fromation soils as poorly-graded with dominance of sand, while Pinosouk Gravels soils are well-graded with wider variety of grain sizes.

The result of engineering properties shows that the optimum moisture contents ranged from 11.50% to 21.13%, while the maximum dry density is within a range from 1.52 Mg/m3 to 1.90 Mg/m3. The unconfined compression strength indicated that all samples are classified as soft soil to very soft soil. The permeability of all soil samples is classified as very low permeability to impermeable classification. The porosity analysis shows that Trusmadi and Crocker Formations are sandy dominated soil samples with 61.73% to 69.08%, while Pinosouk Gravel samples are poorly-sorted soil contributed to lower strength and permeability.

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