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Physical Soil Characterization on Stable and Failed Slopes of the Ranau-Tambunan Road, Sabah, Malaysia

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ABSTRACT

In this study, an initiative has been taken to characterize soil physical properties of stable and failed soil slopes along the Ranau-Tambunan road in Sabah. A total of 26 samples consisting of 10 samples from stable slopes and another 16 samples from failed soil slopes were collected. Basic physical soil tests that were performed were particle size distribution, liquid limit, plastic limit and plasticity index. The Mann-Whitney test was used to determine the association between landslides and the physical properties of both slope groups. In addition, mean rank of physical properties for both slope groups were also computed. Based on the test, the particle size distribution, liquid and plasticity index for both groups were indicated as significantly associated with landslides with p values of 0.0305, 0.009 and 0.040 respectively. The plastic limit (p=0.667), however, did not show significant association with landslide occurrences. In terms of mean rank, failed slopes have higher value than stable slopes for fine grain materials comprising of silt and clay (15.94 vs 9.60), liquid limit (16.50 vs 8.70), plastic limit (14.03 vs 12.65) and plasticity index (16.69 vs 8.40).

INTRODUCTION

Although substantial landslide research involving geotechnical properties of failed soil slopes have been conducted globally, research using statistical analysis on studying soil properties and comparing these properties between failed and stable slopes are still lacking. Most past studies used statistical analysis to select influential landslide parameters that causes landslide (Carrara 1983, 1991, Gao 1993, Gritzner et al. 2010, Kojima & Obayashi 2010, Guthrie 2002, 2004, Ayalew & Yamagishi 2005, Knapen et al. 2006, Ghimire 2011). These statistical analyses range from basic techniques to identify association between landslides and landslide factors such as chi-square and *t*-test to a more complex multivariate modelling such as logistic regression, discriminant analysis, and neural network analysis.

The relationship between landslide occurrences and a landslide causal factor is reported based on the significance association between them. The level of significance is often based on 0.05 or 0.01 threshold probability values. These values are indicators to test whether or not the null hypothesis (there is no significance association) should be rejected (Knapen et al. 2006). For an example, if a chi-square significance value is below these thresholds, the relationship between the landslide occurrences and the causal factor is considered significant, and therefore, the null hypothesis is rejected (Ghimire 2011).

Very few studies have used statistical analysis to assess the differences of geotechnical properties of slope materials (e.g. particle size distribution, plastic limit, liquid limit, plasticity index, etc.) from failed and stable slopes and examine how these differences determine the stability of a slope. Studies on this subject are important especially to tropical countries such as Malaysia, where chemical weathering is the main factor that disintegrate slope materials (Tan 2004). This study attempts to test the hypothesis that stable and failed soil slopes in the same location have different material properties that determine the stability of a slope. This finding will explain on why some slopes are stable and others fail although they are located in the same geological formation and in the same stretch of slopes.

THE STUDY AREA

The study area is located along the 54 km stretch of the Ranau-Tambunan road in Sabah, Malaysia and is surrounded

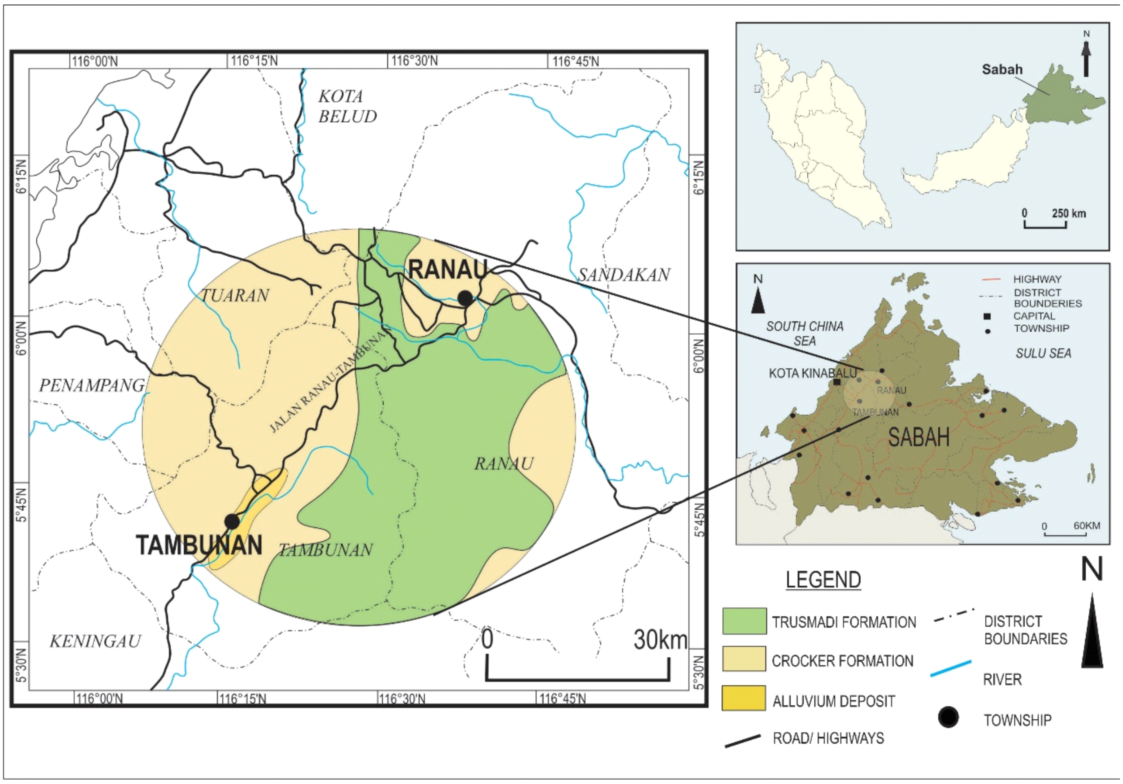

Fig. 1: Location of the study area with its lithological boundary.

by highlands and mountains reaching 4000 m in altitude (Fig. 1). The Tambunan area which is located in the SW of Ranau is dominated by lowland paddy field and agricultural areas. Landslides are very common in this area and can be observed clearly along the Ranau-Tambunan road. The landslide distribution occurred either on the slope, road embankment or on the road itself. Ground subsidence on roads with signs of circular failure is common and large, indicating deep seated landslides may occur. Most materials in the slope are either composed of rocks, soil or both. Hence, it is difficult to find soil slopes which are important for this study.

The study area is located in the Crocker and Trusmadi Formations, which are well known for their instability. Both formations were deposited around the Paleocene to Eocene with the latter deposited during the Late Eocene (Jacobson 1970). The Crocker Formation consists of four lithological units, namely; thick bedded sandstone, thinly bedded sandstone and siltstone, red and dark shale and slumped deposits (Jacobson 1970). The sandstone and shale units are highly fractured and sheared due to tectonic activity in the past (Roslee et al. 2006). The Trusmadi on the other hand has different lithologies that have experienced low grade metamorphism such as slate, phyllite, and quartzite. The lithologies in the Trusmadi Formation can be divided into interbedded sequences (turbidites), argillaceous rocks, cataclasites and massive sandstones (Jacobson 1970). Other materials that are present are Quarternary alluvium deposits that can be found in the lowland area and ultrabasic and granite igneous rocks in the vicinity of the Ranau district.

MATERIALS AND METHODS

In order to achieve the aim of this study, only slopes that are categorized as soil slopes are considered for sampling. Soil slope in this context refers to all rock materials that were converted to soil, which means the mass structure and material fabric are destroyed. In this case, soil taken can be classified as grade VI in the weathering scale (IAEG 1981). Twenty six (26) soil samples weighing around three to four kilograms were collected from two slope conditions; stable and failed (Fig. 2). On the stable slope condition, samples were taken about 50-60 cm below the soil surface; on the failed slopes samples were also taken from 50-60 cm from the failure plane. Samples were put inside a plastic sampling bag with a seal. The soil physical tests were carried out not more than three days after the sampling to avoid excessive moisture loss.

Several laboratory tests have been determined and car-

Table 1: Description on each slope examined in this study.

Sample	Slope condition	Slope component			km from Ranau Township	Failure type	Failure Dimension (m^3)	Slope Grade (%)
		Top	Mid	Foot				
T05	F	N	N	A	4.9	Translational slide	360	567
T01	F	N	A	A	0.8	Translational slide	4800	100
T16	F	N	A	A	10.4	Translational slide	60	173
T60	F	N	A	A	7.6	Flow, translational slide	30	275
T14	F	A	N	N	9.0	Translational slide	20	373
T59	F	N	A	A	10.1	Flow	53	111
C32	F	A	N	N	33.7	Rotational slide	360	275
C34	F	A	N	N	34.4	Rotational slide	600	215
C07	F	N	N	A	6.4	Flow	150	173
C01	F	N	A	A	0.8	Flow, translational slide	4800	100
C47	F	N	N	A	44.8	Translational slide	108	142
C31	F	A	N	N	31.2	Rotational slide	200	275
C42	F	N	A	A	40.3	Translational slide	400	128
C44	F	N	N	A	40.7	Translational slide	90	119
C51	F	N	A	A	46.1	Flow	240	173
C46	F	N	N	A	41.5	Translational slide	160	160
T15	S	N	A	A	9.4	-	-	119
T55	S	N	A	A	21.0	-	-	119
T58	S	N	A	A	12.1	-	-	143
T02	S	A	A	A	1.3	-	-	100
T19	S	N	A	A	10.8	-	-	100
C49	S	N	N	N	45.8	-	-	111
C52	S	N	A	A	46.7	-	-	119
C39	S	A	N	N	38.0	-	-	275
C20	S	N	A	A	18.1	-	-	119
C38	S	N	N	A	36.5	-	-	111

F = failed, S = stable, A = Artificial, N = Natural

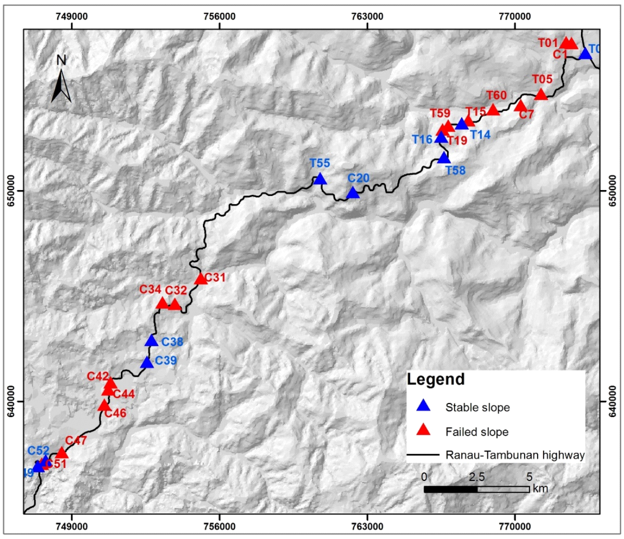

Fig. 2: Locations of sampling along the Ranau-Tambunan road.

ried out. The particle size distribution was the first test conducted on the samples. This test was conducted based on the British Standard (1998), to determine the grain size distribution of soil slopes. Wet sieving using mesh #200 is used for the separation of coarser and finer materials (Kez'di 1974). Dry sieving analysis was conducted on coarse grained (>63 µm) and test for silt and clay fractions (<63 µm) was measured using a hydrometer test. Before the tests were performed, a few sample preparations were needed. For each of the samples, a 100 g soil was weighted and subsequently was put in a glass beaker together with 100 mL of H_2O_2 to remove any organic materials. Later, the sample was soaked with 60 mL of 5% $NaPO_3$ for four hours to disperse the soil particles.

The Atterberg limit, which includes liquid limit (LL), plastic limit (PL) and plasticity index (PI) was measured based on the procedure described in ASTM-D4318 (2010). These tests were conducted to identify the plasticity behaviour of the soil slope materials. Casagrande method is used for LL determination. PL values were obtained by doing a threading method. All samples analysed were replicated to 2-3 samples to obtain the average value and PI values were calculated by subtraction of LL and PL values.

In this study the Mann-Whitney non-parametric test was used to test the association between landslide occurrences

Table 2: Particle size distribution and type of soil for each slope.

Sample	Slope condition	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Coarse grain (Grav. + sand)	Fine grain (Silt + clay)	Texture
T05	F	27	38	35	0	65	35	SML
T01	F	5	38	45	12	43	57	MLS
T16	F	37	27	28	8	64	36	MLG
T60	F	42	39	19	0	81	19	GML
T14	F	51	25	24	0	76	24	GML
T59	F	25	27	40	8	52	48	MLS
C32	F	13	39	30	18	52	48	MLS
C34	F	10	28	62	0	38	62	MIS
C07	F	50	39	11	0	89	11	GWM
C01	F	9	20	46	25	29	71	MI
C47	F	2	33	42	23	35	65	ML
C31	F	18	37	35	10	55	45	MLS
C42	F	23	33	33	11	56	44	MLS
C44	F	13	23	38	26	36	64	MLS
C51	F	9	35	45	11	44	56	MLS
C46	F	5	45	35	15	50	50	MLS
T15	S	46	32	22	0	78	22	GML
T55	S	49	27	22	2	76	24	GML
T58	S	43	31	24	2	74	26	GML
T02	S	20	49	27	4	69	31	SML
T19	S	52	26	20	2	78	22	GML
C49	S	3	53	36	8	56	44	MLS
C52	S	15	49	29	7	64	36	MLS
C39	S	0	43	37	20	43	57	MLS
C20	S	48	30	18	4	78	22	GML
C38	S	19	38	36	7	57	43	MIS

Note: F = failed, S = stable, SML = very silty Sand of low plasticity, MLS = sandy SILT of low plasticity, MLG = gravelly SILT of low plasticity, MIS = sandy SILT of intermediate plasticity, GML = very silty GRAVEL of low plasticity, GWM = well graded, silty Gravel, MI = SILT with intermediate plasticity, ML = SILT of low plasticity

and the condition of slopes based on the soil physical properties tested. The Mann-Whitney test was used instead of the chi-square and *t*-test because the dataset in this study is a non-categorical type and also with this test, the dataset does not need to be normally distributed (Fowler 1998). The association between slope condition based on soil physical properties and landslide occurrences is based on the $p < 0.05$ confidence level. To compare the soil properties from stable and failed slopes, a mean rank is computed for each slope condition based on the soil properties.

RESULTS AND DISCUSSION

Landslide inventory mapping: There are 26 sites comprising of stable and failed slopes that were assessed in this study. The distance of each site from Ranau Township and their information is given in Table 1. Based on the assessment, translational slide dominates the types of failure followed by flow and rotational slides. The dimensions of failure range from the smallest 20 m^3 to largest 4800 m^3. Most slides occurred on modified slopes, but natural slopes are still observable at the top of most slopes. The depth of failures recorded during the fieldwork is from 1 m to 3 m.

Laboratory analysis: Soil samples from the stable and failed slopes were analysed together using Mann-Whitney non-parametric test. The normality of the data distributions was tested by Shapiro-Wilk normality test. The results of the statistical analysis for each of the physical properties are as follows:

***Particle Size Distribution*:** Soils from the failed and stable slopes are generally coarse grain with more than 50% can be classified as gravel and sand. Fine grain soil, which is mainly silt; do occurred dominantly in samples such as T01, C34, C39, C44, C46, C47 and C51. Clay material on the other hand only occurred around 20% of the samples. The particle size distribution analysis is divided into two categories; gravel and sand are categorized as coarse-grain and the fine-grain group consists of silt and clay. The grain sizes were divided into these groups because the different texture (coarse and fine) plays different roles in causing failure to the slopes (Montgomery et al. 1997). Table 2 shows the amount of coarse and fine grains in each of the samples together with their soil classification.

The relationship between landslide and grain size is related to slope angle, hydrology and cohesiveness (Eyles et

Table 3: Atterberg limit of soil samples taken from stable and failed slopes.

	Stable Slope					Failed Slope			
Sample	LL	PL	PI	Plasticity*	Sample	LL	PL	PI	Plasticity*
T15	23	22	1	Low	T05	18	16	2	Low
T55	26	24	2	Low	T01	27	21	6	Low
T58	26	23	3	Low	T16	29	23	6	Low
T02	27	24	3	Low	T60	22	20	2	Low
T19	21	19	2	Low	T14	27	22	5	Low
C49	25	20	5	Low	T59	29	20	9	Low
C52	25	22	3	Low	C32	29	21	8	Low
C39	26	22	4	Low	C34	35	27	8	Moderate
C20	26	24	2	Low	C07	21	20	1	Low
C38	28	24	4	Low	C01	44	30	14	Moderate
					C47	29	23	6	Low
					C31	28	23	5	Low
					C42	31	26	5	Low
					C44	32	27	5	Low
					C51	30	25	5	Low
					C46	29	25	4	Low

Note: Classification of plasticity based on Bell 1992.

Table 4: Particle size has significant association with landslide occurrences as indicated by the Mann-Whitney test. The mean rank shows coarse grain are more abundant in the stable slope and the failed slope contains higher amount of fine grain soil.

Texture	Condition	Shapiro-Wilk	Mann-Whitney	
			Mean Rank	Sig. (p)
Coarse – grains	Stable	0.417**	17.40	0.039*
	Failed		11.06	
Fine – grains	Stable	0.417**	9.60	0.039*
	Failed		15.94	

*Value below 0.05 indicates significance association; **Value higher 0.05 indicates that the data is normally distributed.

al. 1978, Sidle et al. 1985, Crozier 1986, Pachauri & Pant 1992, Coe et al. 2004, Atkinson & Massari 1998). The grain size of soil influence the angle of repose of a slope, which determines its steepness threshold before it fails. A slope with a higher percentage of coarser grain material is more stable than a slope with a higher fine grain material if other factors are constant (Montgomery 1997). Higher content of fine grain material may cause landslides in a slope with angle as low as 10° to 20° (Barredo et al. 2000, Temesgen et al. 2001).

Atterberg limit: The liquid limit (LL), plastic limit (PL) and plasticity index (PI) were calculated to gain understanding of the behaviour of soil in response to water (Muggaga et al. 2012). It is a set of index tests conducted on fine-grained soils to measure their relationship to moisture content and relative activity (Diko et al. 2014). The calculated LL, PL and PI are given in Table 3. Based on the test, the measurement for the LL, PL and PI of samples for the stable and failed slopes are similar with moderate to low plasticity. However, there are few samples in the failed slopes with higher LL, PL and PI than other samples in the same group. For example, sample C01 has very high LL and PL which resulted in a high PI compared to other samples. Similar results were also observed in samples C34, C42, C44 and C50. The PI values for soils in the stable group are generally lower than the values in the failed slope group.

The presence of higher percentage of fine grain material in a slope will increase the plastic limit, liquid limit and plasticity index of a slope. Based on a statistical analysis using logistic regression, Hosseini et al. (2013) reported that landslide dimensions increase as a result of increasing liquid and plastic limit of slope materials. Although results in Table 3 show that the soils taken from the study area fall into the moderate to low plasticity class, failure can still occur for slopes with material consisting of silt with low plasticity (Jotisankasa & Vathananukij 2008). Furthermore, slopes in the study area are exposed to intense weathering and this condition may affect the grain condition over time (Diko et al. 2014).

Statistical analysis: The soil physical properties which were divided into stable and failed slope groups were analysed

Table 5: The LL and PI exhibit significant association with landslide occurrences. Mean ranks of LL, PL, and PI of the failed slope group are higher than the stable slope group.

Atterberg Limit Test	Condition	Shapiro-Wilk	Mann-Whitney	
			Mean Rank	Sig. (p)
Liquid limit (LL)	Stable	0.17	8.70	0.009*
	Failed		16.50	
Plastic limit (PL)	Stable	0.819	12.65	0.667
	Failed		14.03	
Plasticity index (PI)	Stable	0.006	8.40	0.040*
	Failed		16.69	

* Value below 0.05 indicates significance association

to determine their significance on landslide occurrences using the Mann-Whitney non-parametric test. The discussions on each of the physical properties analysed using the Mann-Whitney test are as follows:

***Particle size distribution*:** The statistical test indicates that there is a significant association between landslide occurrences with grain size of soils in the stable and failed slope groups. Both coarse- and fine-grained soils have p value of 0.039 indicating significant association with the slopes' state of stability (Table 4). In terms of grain size distribution, sharp differences were observed between the stable and failed slopes. The stable slope group has higher content of coarse-grain material (mean rank = 17.40) than the failed slope group (mean rank = 11.06). On the contrary, the failed slope group has higher fine-grain material with the mean rank of 15.94 compared to 9.60 of the stable slope group.

***Atterberg limit*:** The Mann-Whitney test on the Atterberg limit for the stable and failed slopes suggest that the liquid limit and plasticity index of the soil has a significant association with slope stability with p-values of 0.009 and 0.040 respectively (Table 5). In addition, the mean rank difference for both LL and PI for the stable and failed slopes is striking. The mean rank of the failed slopes for both LL (16.50) and PI (16.69) is higher than the stable slope group, which has mean ranks of 8.70 for LL and 8.40 for PI. This clearly indicates that the soil materials in the failed group are tending to be finer. Although the plastic limit exhibits no significant association with the slope stability in the study area, the PL mean rank for failed slopes evidently indicates that the plastic limit is higher in the failed slope than the more stable slope group.

CONCLUSION

The analyses indicate that landslide occurrences in the study area are influenced by soil physical properties as presented by the different mean rank for both, stable and failed slopes and significant association values. The results suggest that the presence of fine texture soil with higher liquid limit and plasticity index are highly associated with landslide occurrences as indicated by the Mann-Whitney non-parametric test. On the basis of mean rank comparison between the stable and failed slope groups, the mean rank of fine texture soil and Atterberg limit, soil samples from the failed slope group are inherently higher than the soil samples in the stable slope group. Therefore, based on these findings, the hypothesis that, the soil physical properties in both, stable and failed slopes located in the same area are different and influence the landslide occurrences, can be generally accepted.

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