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RESEARCH ARTICLE ENGINEERING GEOLOGICAL INVESTIGATION ON KARAMBUNAI-LOK BUNUQ LANDSLIDES, KOTA KINABALU, SABAH

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ARTICLE DETAILS	ABSTRACT
Article History:	This paper describes landslide occurrences in debris materials, together with its engineering geological and geotechnical setting. The predictions from conventional geotechnical slope stability analyses, taking into account
Received 04 January 2019 Accepted 19 February 2019 Available Online 22 February 2019	topography, hydrological, geotechnical and engineering geological effects, are compared with the observed pattern of instability. Physical and mechanical properties of eight (8) soil samples indicated that the failure materials mainly consist of poorly graded materials of sandy clay soils and characterized by low to intermediate plasticity, containing of normal clay (0.42 to 0.95), very high degree of swelling (5.63 to 10.35), variable low to high water content (11.95 % to 19.92 %), specific gravity ranges from 2.60 to 2.68, low permeability (6.68 X 10 ⁻⁴ to 1.52 X 10 ⁻⁴ cm/s), friction angle (ϕ) ranges from 18.50° to 34.20° and cohesion (C) ranges from 3.36 kN/m ² to 19.50 kN/m ² with very soft to soft of undrained shear strength (9.47 kN/m ² to 32.30 kN/m ²). Geotechnical limit equilibrium stability analyses of entire slopes are rarely able to predict the smaller-scale initiation events leading to landslide occurrences, because these are controlled by local topography, water runoff and groundwater conditions, weathered materials and engineering geological setting. Slope stability analysis shows that the factor of safety value is ranges from 0.805 to 0.817 (unstable). It is concluded that the failures was debris flow and resulted from a combination of factors. Engineering geological evaluation should be prioritized and take into consideration in the initial step in all infrastructure program. Development planning has to consider the geohazard and geoenvironmental management program. This engineering geological study may play a vital role in slope stability assessment to ensure public safety.
	KEYWORDS
	topography, hydrological, geotechnical and engineering geological, Geotechnical limit equilibrium.

1. INTRODUCTION

The study area approximately located about twenty (20) km far from Kota Kinabalu City, Sabah (Figure 1). In 30^h June 2006, a large landslide occurred suddenly on embankment of road side at the Karambunai area, Kota Kinabalu. This landslide destroyed 3 residents and caused one fatality. After a few months from that incident, on 10th October 2006 a same large landslide occurred nearby (approximately one (1) kilometer from the Karambunai area) at hilly side of the Lok Bunuq area, Kota Kinabalu. This second landslide has been recorded occurred on previous year 2001, which destroyed 15 residents and caused 6 fatalities. And now today it's to be occurred again destroyed 7 residents received wide media coverage and raised concern from the authorities and local population over the stability of the surrounding slopes.



Figure 1: Location of the study area

The aims of this study are to analyses the physical and engineering properties of the local material, to evaluate the main factors contributing to landslide and to compute the factor of safety (FOS) of the slopes. Although little damage of any real consequence was caused, the slip is of geotechnical interest because of its geomorphological and geological setting, the speed with which the slip debris finally moved down slope, and the large number of potentially contributing factors in triggering the failure which were heavy rainfall event. The slope failures estimated to have involved approximately about 15 000 cubic meters of each slopes.

2. METHODOLOGY

The laboratory works such as classification tests (grain size, atterberg limit, shrinkage limit, specific gravity and water content), permeability test and consolidated isotropically undrained (CIU) test were carried out in compliance and accordance to British Standard Code of Practice BS 5930-1981 (*Site Investigation*) and British Standard Code of Practice BS

1377-1990 (Method of Test for Soils for Civil Engineering Purposes).

For the slopes stability analysis, using the "SLOPE/W" software through the Morgenstern and Price method was done successfully to determine susceptibility of the slopes to shallow non-circular slides based on the determination of factor of safety values, which are common in the study area [1]. The advantage of these methods is that in its limit equilibrium calculations, forces and moments on each slice is considered.

2.1 Climatic Setting

Evaluation of rainfall records in study area and it's surrounding for the year 2006 indicated that the average monthly rainfall is ranging 10 mm to 640 mm (Figure 2). The mean annual temperature for the same period is recorded ranges from 30°.9 C to 32.8° C, and the lowest from 23.2° C to 24.1° C.



Figure 2: Total annual rainfall for 2006 (Source from Climatological Services Department of Sabah)

2.2 Topography and Drainage Systems

The study area lies between the South China Sea and the Crocker Range. The area consists of swamps, coastal plains, valleys, small isolated foothills and a linear belt of hills parallel to the Crocker Range towards the east (Figure 3). The coastal plains and valleys vary from 2 to 5 km in width while the linear belt of hills is about a kilometre wide. The height of the hills range from 6 to 45 m; rising to over 60 m towards the east at the foot of the Crocker Range, which rises about 180 m. The complexity of the overall geomorphology of the study area is a combination of erosion, weathering process, faulting, folding and mass movement. The watershed lies in the Crocker Formation and river flows westward into the South China Sea. Most of the rivers flow through mangrove swamp before discharging towards the South China Sea (Figure 3). Structurally, a number of linear river segments that different watershed systems indicate the existence of major fractures. This structural control of many of the tributary streams is evident in the areas of sedimentary rocks; faults and less competent shale beds are preferentially eroded. The sedimentary rocks are intensely dissected and form a trellis and parallel drainage patterns.



Figure 3: Topography and drainage map with their sampling locations

2.3 Geology and Tectonic Setting

Borneo forms an extension of Sundaland, a cratonic core built of accreted continental fragments, which stabilized towards the end of Mesozoic. Throughout the Late Mesozoic and Tertiary additional terrains where added to this core, by subduction of oceanic sea floor. This subduction is believed to be the result of the expansion of this region, which was related to the collision of India with the southern margin of the Asian continent during Early Tertiary and to spreading in the Indian and Pacific Oceans [2].

The geology of the study area is made up of two sedimentary rock formations: the Crocker Formation (Miocene to Late Eocene age) and Quaternary Alluvium (Recent age) (Figure 4). The effect of faulting and folding activities can be observed on the lithologies in the study area (Figure 5). This was confirmed by the existence of transformed faulted material consisting of angular to sub angular sandstone fragments, with fine recrystallined quartz along the joint planes, poorly sorted sheared materials and marked by the occurrence of fault gouge with fragments of slickensided surfaces. Breaks and fractures were developed by shearing stresses that caused the rapid disintegration and weathering of the rocks into relatively thick soil deposit. As a corollary to this, in rock bodies, the surface roughness of joint are generally smooth to rough planar. A relatively smooth surface decreases the frictional resistance to expose the fractures, therefore effected the possibility of landslide occurrences in



Figure 4: Geological map of the study area



Figure 5: The presence of faulting and folding activities on the lithologies (a: Telipok & b: Kastam quarters)

2.4 Groundwater Conditions

The study area consists mainly of beach deposits along the beach area, alluvial deposit mostly in the valley and swamp area and sedimentary rocks of the Crocker Formation. Based on the field observation, the study area is located within the area of sedimentary rocks which has a locally significant occurrence of groundwater, while some area are of unconsolidated sediment (beach deposit and alluvial deposit) and areas with no significant occurrence of groundwater. These sedimentary rocks are made up principally of interbedded sandstone-shale sequences, occasional breccias units and alluvial deposit that have limited primary porosity and moderately well-developed secondary porosity. The areas where there are no significant occurrences of groundwater are made up principally of shale unit sequences. On the others view, it is indicated that the spring flowing follow the topography from highland toward the road and the valley sides (Figure 6). The weathered materials are weak and caused landslide due to high fractured porosity and high pore pressure subjected by both shallow and deep groundwater.



Figure 6: The surface water shows that it's flowing strongly into the road drain and local villages (a: Karambunai landslide & b: Lok Bunuq landslide)

2.5 Geotechnical Properties and Stability Analysis

Table 1: Laboratories analysis results of soil materials

Type of failure	Rotational Slide							
Location	Karambunai				Lok Bunuq			
Geological Formation	Crocker Formation			Crocker Formation				
Lithology	Sedimentary rock				Sedimentary rock			
Weathering grade	IV to VI				IV to VI			
Volume (1)	Large				Large			
Boreholes	AH 1	AH 2	AH 3	AH4	AH 5	AH 6	AH 7	AH 8
Sand (%)	34.75	50.27	34.98	45.57	35.56	49.41	51.79	46.26
Silt (%)	32.50	19.11	41.91	33.06	20.36	27.82	27.25	30.49
Clay (%)	32.75	30.62	23.11	21.37	41.90	22.76	20.96	23.25
Liquid limit (%)	40	36	30	40	30	28	34	33
Plastic limit (%)	22	22	19	26	19	20	20	19
Plasticity index (%)	18	14	11	14	11	8	14	14
Liquidity index (%)	- 0.14	- 0.13	- 0.72	- 0.52	- 0.27	- 0.66	- 0.25	- 0.62
Clay activity	0.95	0.89	0.56	0.65	0.60	0.42	0.66	0.68
Shrinkage limit (%)	10.35	7.14	8.09	7.86	8.57	8.70	9.16	5.63
Moisture content (%)	19.60	16.48	17.53	18.98	16.05	11.95	19.92	18.87
Specific gravity	2.61	2.65	2.63	2.62	2.68	2.60	2.64	2.62
Permeability (cm/s)	1.52 X 10-4	4.83 X 10-4	1.40 X 10-4	1.57 X 10-4	4.08 X 10 ⁻⁴	6.68 X 10 ⁻⁴	6.59 X 10 ⁻⁴	$4.34 \mathrm{X} 10^{-4}$
Unit Weight (kN/m³)	17.36	22.83	17.85	18.05	17.46	17.95	21.58	18.25
Cohesion, C (kN/m ²) (Ave.)	7.20	3.40	6.78	6.27	7.31	19.50	8.29	3.36
Friction angle (°) (Ave.)	26.30	34.20	28.90	32.90	29.20	35.50	20.76	18.50
Undrained shear strength (τ) (kN/m²)	15.78	18.91	16.63	17.95	17.07	32.30	16.47	9.47
Factor of safety	0.817				0.805			
Main factors causing failures (2)	SA, W, V, GWL, M, C, G and AC							

Note: (1) Volume: small (10 – 50 m3), Medium (50 – 500 m3) and Large (> 500 m3) and (2) Slope angle (SA), Weathering (W), Vegetation (V), Groundwater level (GWL), Material characteristics (M), Climatological setting (C), Geological characteristics (G), Over burden or vibration (OBV), Drainage system (DS), Embankment construction (EC) and Artificial changing (AC)

Results of laboratory analyses for the soil materials are presented in Table 1. The failure volume scale involved generally large in size for each slopes (15 000 cubic meters) endangering road users and villagers. In term of weathering grades, the materials that underwent failure were in the ranges from grade IV to VI (Figures 7 to 9). Climatic setting is the main factors causing failure with the depth of intensive weathering influencing the volume of material that fails. It appears that grade IV to grade V materials actually failed with the overlying grade VI material sliding or flowing down together with this debris materials during failure. Physical

and engineering properties of eight (8) soil samples indicated that the failure materials mainly consist of poorly graded materials of sandy clay soils, which characterized by low to intermediate plasticity, containing of normal clay (0.42 to 0.95), very high degree of swelling (5.63 to 10.35), variable low to high water content (11.95 % to 19.92 %), specific gravity ranges from 2.60 to 2.68, low permeability (6.68 X 10⁻⁴ to 1.52 X 10⁻⁴ cm/s), friction angle (ϕ) ranges from 18.50° to 34.20° and cohesion (C) ranges from 3.36 kN/m² to 19.50 kN/m² with very soft to soft of undrained shear strength (9.47 kN/m² to 32.30 kN/m²). Slope stability analysis shows that the factor of safety value is ranges from 0.805 to 0.817 (unstable) (Figures 10 & 11). The presence of ground water, slope angle, removal of vegetation cover, lack of proper drainage system, artificial changing, intensive weathering process and geological characteristics are additional factors contributing to the failures.



Figure 7: Landslides generally consisting of fine texture, cohesive materials, completely weathered to residual soil materials (a: Karambunai landslide & b: Lok Bunuq landslide)



Figure 8: Rotational Slide showing the failure movement are starting from the hill side to the road and/or village sides through the development of water runoff (a: Karambunai landslide & b: Lok Bunuq landslide)



Figure 9: Failure materials which containing of clayey soil materials (a: Karambunai landslide & b: Lok Bunuq landslide)



No.	Description	Minimum Factor of Safety			
	Analysis method	Moment	Force		
1	Ordinary	0.749	-		
2	Bishop	0.826	-		
3	Janbu	-	0.741		
4	Morgenstern – Price	0.819	0.817		
Slip surface # = 17 576 of 17 576					

Figure 10: The results of slope stability analysis (Location: Karambunai landslide)



No.	Description	Minimum Factor of Safety			
	Analysis method	Moment	Force		
1	Ordinary	0.785	-		
2	Bishop	0.819	-		
3	Janbu	-	0.781		
4	Morgenstern – Price	0.812	0.805		
Slip surface $\# = 9261$ of 9261					

Figure 11: The results of slope stability analysis (Location: Lok Bunuq landslide)

3. DISCUSSIONS

It is clear from records existing before the landslide occurred that the study area was one of the pre-existing instability. The slope stability analysis shows the area of the eventual slip as being underlain by brecciated rock with the sandy clay soil (debris materials) of the Crocker Formation. It seems likely that fracturing associated with faulting is a controlling mechanism in the production of the debris materials that is found intermittently on these hillsides [3]. The aerial photograph clearly shows the location of a number of areas of previous instability, one which coincides with and is slightly larger than the eventual area that slipped.

Slope stability analysis reveals that most of it occurring in sandy clay soil. Low to intermediate plasticity, high elasticity, friability and shrink - swell nature of the soil are just some properties, which characterized the sandy clay soils. The relatively high liquid limit and water content lead to a decrease in strength during rainy period when the limiting condition is reached, the material tends to behave like viscous liquid, which then easily slides. The sandy clay soils with a low permeability of inert particles in the study area have a high porosity and more porous. Porous soils allow for rapid infiltration of surface water to the lower layers. Additionally, the surface water was found flowing strongly into the road drain and local villages [4]. This limits the destabilizing effect of accumulated water on the upper soil layer. The draw back here is that clayey soils tend to be very weak, friable and easily transported by flowing surface water and this would seriously weaken the shear strength of the soils slopes, causing high chance for slope failure to occur. Slope stability analysis shows that the factor of safety value for the soil slope failures ranges from 0.805 to 0.817 (Unstable).

The compositions of the slip mass, the speed of slope movement, the manner in which it moved, and the lobate form of its toe, classify the major movement as a debris flow. Rotational slide occur when poorly sorted brecciated and clayey materials, saturated with water, surge down slopes under gravitational action and characterized by the sudden collapse and extensive, very to extremely rapid run-out of a mass of debris material following some disturbance [5]. An essential feature is that the material involved has unstable, loose or high porosity structure. As a result of disturbance this collapses, transferring the overburden load wholly or partly onto the pore fluid, in which excess pore pressures are generated. The consequent sudden loss of strength gives the failing The consequent sudden loss of strength gives the failing material, briefly a semi-fluid character and allows a debris flow to develop.

In understanding the geology of the region is of paramount importance in tackling problems associated with slopes and slope development. Local geological details such geometry of the sub-surface; soil properties and groundwater have a considerable influence on the performance of individual slopes. The slope stability evolution is an interdisciplinary endeavour requiring concepts and knowledge from engineering geology [6]. Any slope stability method of analysis must give due consideration to significant geological features. Awareness of geology is necessary for appropriate idealization of ground conditions and the subsequent development of realistic geotechnical model. In order to understand the relationship between slope failure and geology, it is prerequisite to have knowledge on the types, characteristics and features of geological materials (soil and rock). Besides that, geological structures of the slope forming materials are a dominant feature in slope behaviour. The succession, thickness and attitude of beds are direct relevance to consideration of potential instability especially in sedimentary rock of the Crocker Formation. These geological structures play an important role in understanding slope development processes, formation of valleys, ridges and the development of residual soil. In order to predict slope stability

accurately, it is essential to recognize features such as a sequence of weak beds, thin marker beds, old surfaces, fault or shear zones and hydro geological effects.

4. CONCLUSIONS

A rotational slide has been described involving the flow of a large mass of failure materials in the study area. The Karambunai-Lok Bunuq landslides occurred in an area of previous instability, on a steep slope, and involved a large mass of debris material flowing rapidly down slope. Climatic setting is the main factor causing soil slope failures. Physical and engineering properties of eight (8) soil samples indicated that the failure materials mainly consist of poorly graded materials of clayey soils, which characterized by low to intermediate plasticity, containing of normal clay (0.42 to 0.95), very high degree of swelling (5.63 to 10.35), variable low to high water content (11.95 % to 19.92 %), specific gravity ranges from 2.60 to 2.68, low permeability (6.68 X 10-4 to 1.52 X 10-4 cm/s), friction angle (ϕ) ranges from 18.50° to 34.20° and cohesion (C) ranges from 3.36 kN/m² to 19.50 kN/m² with very soft to soft of undrained shear strength (9.47 kN/m² to 32.30 kN/m²). Slope stability analysis shows that the factor of safety value is ranges from 0.805 to 0.817 (unstable).

5. RECOMMENDATION

To correct or prevent the mass movement in the study area, the following recommendations are proposed:

1. Installation of piezometric and clinometers to monitor seasonal build -ups of pore water pressure and creep movement respectively.

2. Surface drainage, which include:

- a) Sealing off of the cracks;
- b) Shot Crete or other means of reducing erosive action of rainwater runoff.
- c) Retaining wall with bore piles.
- d) Subsurface drainage, i.e. horizontal drainage method.

REFERENCES

[1] Morgenstern, N., Price, V.E. 1965. The analysis of the stability of the stability of generalized slip surfaces.

[2] Hamilton, W. 1979. Tectonics of the Indonesian region. U.S. Geol. Survey Prof. Paper 1078.

[3] Roslee, R., Tahir, S., Omang, S.A.K.S. 2006. Engineering Geology of the Kota Kinabalu Area, Sabah, Malaysia. Bull. of Geol. Soc. of Malaysia, 52, 17-25.

[4] Nelson, P.H. 1997. Monte Carlo Simulation (on-line) http://www.circle4.com/pww/mc.index.html

[5] British Standard BS 5930. 1981. Site Investigation. London: British Standard Institution.

[6] British Standard BS 1377. 1990. Methods of Test for Soils for Civil Engineering Purposes. London: British Standard Institution.

