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RESEARCH ARTICLE

EFFECTS OF PHYSICAL AND MECHANICAL PROPERTIES OF RESIDUAL SOIL ON SLIDING AREA AT BUNDU TUHAN, SABAH, MALAYSIA

Rodeano Roslee[a,b,*]

[a] Universiti Malaysia Sabah, Natural Disaster Research Center (NDRC), Jalan UMS 88400 Kota Kinabalu, Sabah.
[b] Universiti Malaysia Sabah, Faculty of Science & Natural Resources, Jalan UMS 88400 Kota Kinabalu, Sabah.
**Corresponding Author Email: rodeano@ums.edu.my*

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ABSTRACT

The study of the earth mass movement has long been regarded as one of the most important and interesting aspect of engineering geology and geotechnical engineering, which the designers and planners from the private and public sectors address when implementing the initial stage of urban and rural development projects. This involves highways and infrastructures construction and land use planning among the others. Failure to appreciate the problems relating to mass movements of earth material could lead to damage of man made structures and even the loss of lives. These studies focused on the mass movement in Bundu Tuhan to Kundasang highway area approximately 84 km to 96 km from Kota Kinabalu city, Sabah, one of the most vulnerable to mass movements occurrence in west coast of Sabah. It is bounded by longitude line E 116° 31.592' to E 116° 36.183' and latitude line N 06° 00.269' to N 05° 57.610'. The main objectives of this study are; 1) to map and locate the landslides in the study area; and 2) to study the mechanism and the influence of geological factors causing the mass movement. Geology of the study area and its surrounding is hosted mainly by three sedimentary rock formations: Trusmadi Formation (Palaeocene to Eocene age), Crocker Formation (Late Eocene to Early Miocene age) and Pinousuk Gravel (Upper Pleistocene to Holocene age). These three geologic formations dissected by numerous geological lineaments structural produced by a complex tectonic history of multi phase folding and thrust, normal and reverse faulting. These tectonic setting reduce the physical and mechanical properties of the soil and produced intensive displacement in substrata resulting in intensive high degree of weathering processes. The weathered materials are weak and cause sinking, subsidence and sliding due to high pore pressure subjected by both shallow and deep groundwater. Evaluation 10 boreholes data in study area indicated that the groundwater table in study area is shallow and range 1.9 meter to about 11.3 meters. The groundwater in study area fluctuate drastically even within short period. Sand and gravel layer with variable thickness defined the major shallow aquifers within the top weathered materials while the highly fracture sedimentary rocks defined the major deep aquifers. Most of the aquifer within top unconsolidated weathered material is under unconfined condition. Most of significant aquifers within the sedimentary rocks are sandstones. The sandstones generally fracture and contain coarse sediments, which increase the permeability. Geologic and geotechnic evaluation of the study area indicates that the mass movement take place when slope materials are no longer able to resist the force of gravity. These decrease the shear resistance resulting mass movement, which is due to internal and external factors. Internal factors involve some change in either physical or chemical properties of the rock and soil. External factors involve increase of shear stress on slope, which usually involves a form of disturbance that is induced by man. The triggering mechanism in the study area most likely involves heavy rainfall causing water saturation of the slope material and loss of cohesion along rapture planes. The sheared shale, bedding and fault planes, and opening fractures are all structural weaknesses, which acting as pathways for water seepage, hastening the weakening and eventual mass movement in the study area. Development planning has to consider these hazards in order to counter their effect. An environmental management program should be implemented to prevent these losses. Geological and geotechnical studies will play a vital role in ground stability assessment that critical in public safety.

KEYWORDS

Mass Movement Hazard, Geotechnical Investigation, Geological Setting, and Bundu Tuhan.

1. INTRODUCTION

The study of the earth mass movement has long been regarded as one of the most important and interesting aspect of engineering geology and geotechnical engineering, which the designers and planners from the private and public sectors address when implementing the initial stage of urban and rural development projects (Abramson et al., 1995). This involves highways and infrastructures construction and land use planning

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among the others. Failure to appreciate the problems relating to mass movements of earth material could lead to damage of man made structures and even the loss of lives (Anderson and Richards, 1987). Mass movement is a general term for variety of earth processes by which large masses of rock and/or earth material spontaneously move downward, either slowly or quikly by gravitation. Other synonymous term are mass wasting and gravity movemnt. Such earth processes become geologic hazards when their interaction with the material environment is capable of causing significant negative impact on a human's well being (British Standard, 1975). These study focused on the mass movement in Bundu Tuhan to Kundasang highway area approximately 84 km to 96 km from Kota Kinabalu city, Sabah, one of the most vulnerable to mass movements occurrence in west coast of Sabah. The main objectives of this study are; 1) to map and locate the landslides in the study area; and 2) to study the mechanism and the influence of geological factors causing the mass movement.

2. Location of Study Area

Study area covered by 6 km². It is bounded by longitude line E 116° 31.592' to E 116° 36.183' and latitude line N 06° 00.269' to N 05° 57.610' (Figure 1).

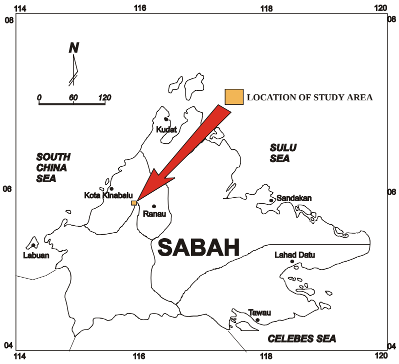


Figure 1: Location of Study Area

3. Topography and Drainage

The topography of the study area is more or less controlled by the underlying rock formation. The study area present physical morphology resulted from various geological and geomorphological processes acting under the climatic influences (British Standard, 1981). The study area can be divided into two contrasting physiographic features: 1) the highlands with elevation range from 3000 to 9000 ft (Figure 2). These highland is underlain by three sedimentary formation namely Trusmadi and Crocker Formation and Pinousuk Gravel and characterized by steep to rolling topography; and 2) the lowland portions underlain by alluvium, which are limited to narrow river valley with elevation ranging from 2500 to 3000 ft (Figure 2). The slopes within the highland are usually covered by secondary forest and produced the main catchments area (British Geological Survey, 1999). The region has a high drainage density being the cradle and origin of major rivers in Sabah (Figure 3). The watershed of the Mount Kinabalu region feed rivers like the Liwagu River, Kinasapian River, Kuaman River, Mesilau River and countless others, which flows to either the South China Sea or the Sulu Sea.

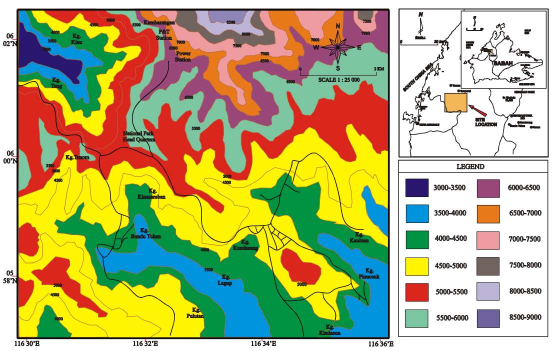


Figure 2: Topography Map

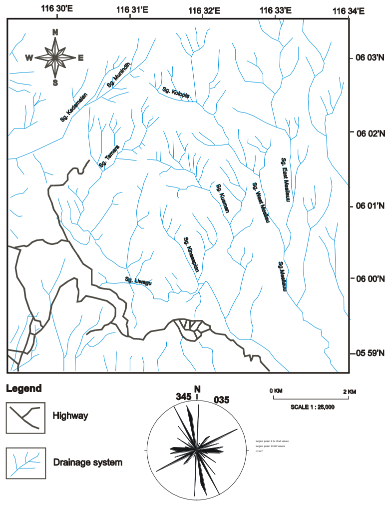


Figure 3: Drainage Map

4. Climatological

Heavy rain occurs in the study area where 80-100 inches a year are generally recorded (Figure 4). The driest seasons occurs during the northeast monsoon and the wettest season during the southwest monsoon (Collenette, 1958). The maximum temperature is 36° C and the minimum is 18.6 ° C, although usual range is from 23° C to 32° C. Rainfall provides the major source of inflow to the Kinabalu basin, while surface run-off, evapotranspiration, groundwater extraction, spring discharge and other constitute the out flow component. Evaluation of rainfall records in study area and it's surrounding for period 1990 to 2001 indicated that the total annual rainfall is ranging 1220.0 mm to 2688.5 mm (Figure 5).

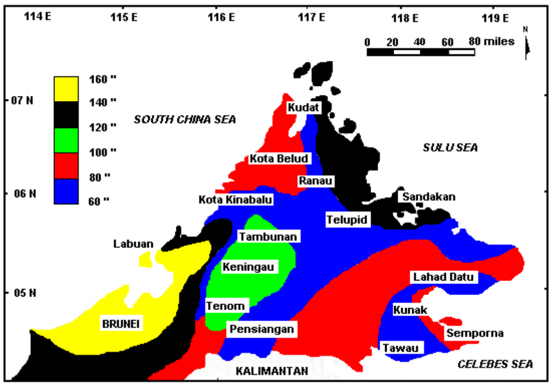


Figure 4: Distribution of Sabah Mean Annual Rainfall

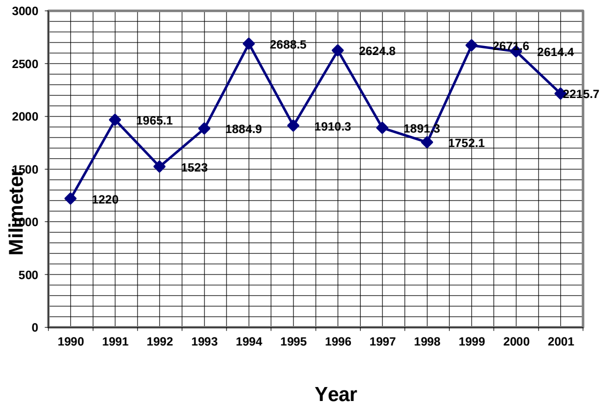


Figure 5: Total Annual Rainfall Data

5. Geology and Hydrogeology Setting

Geology of the study area is covered by three sedimentary rock formations: Trusmadi Formation (Palaeocene to Eocene age), Crocker

Formation (Late Eocene to Early Miocene age) and Pinousuk Gravel (Upper Pleistocene to Holocene age). Figure 6 and Table 1 shows the geological map and local stratigraphy column of the rock units exposed in the study area and their water-bearing characteristic (Davis, 1984). The three geologic formations in the study area exhibit a high degree of weathering. It covered by residual soil, which extends to more than 20 meters in thickness. The weathered materials are weak and may cause sinking, subsidence and sliding due to high pore pressure subjected by both shallow and deep groundwater. Most weathered products also have high clay content, which may lower the rock strength.

The study area is dissected by numerous geological structural (Figure 7) produced by a complex tectonic history of multi phase folding and thrust, normal and wrench faulting, and compression (Das Braja, 1983). The rocks within the vicinity of faults and lineaments were highly fractures, highly jointed and highly weathered The occurrence of groundwater in study area is greatly influenced by structures because of faulting or fracturing control to large extent, the occurrence and movement of groundwater influenced by enhancing the secondary porosity and permeability (Eckel and Edwin, 1958). The occurrence of mass movement (sliding and subsidence) are highly influence by structures and pore water pressures.

Evaluation of more than 60 boreholes drilled (Figure 8) and the cross-section constructed from those boreholes in study area indicated that the groundwater table in study area is shallow and range 1.9 meter to about 11.2 meters (Figure 9). It is also indicated that the water table following the topography from highland toward the road and the valley side (Hoek and Bray, 1996). This situation caused the slope to be subjected to great pore water pressure and causing intensive mass movement and road subsidence in study area. The groundwater in study area was fluctuation drastically even within short period. Sand and gravel layer with variable thickness defined the major shallow aquifers while the highly fracture sedimentary rocks defined the major deep aquifers (Tija, 1974). Most of the aquifers within top unconsolidated weathered material are under unconfined condition. Most of significant aquifers within the sedimentary rocks are sandstones. The sandstones generally fracture and contain coarse sediments, which increase the permeability. Even though the diagenetic changes may have locally reduce the porosity and permeability of the sandstone, fracturing related to fault zones may have enhance the secondary porosity and permeability (Jacobson, 1970). The shell bed or lenses locally occurring within the sandstone might be extensive enough to separate the sandstone into several aquifers. Aquifers system within the deep aquifer produced unconfined to semi-confined aquifers.

6. ENGINEERING CHARACTERISTIC

Engineering characteristic study of the sliding materials was conducted for 24 locations (Figure 10). Completed grain size analysis, atterberg limits test, specific gravity test and moisture content test was conducted to classified the sliding material (Faisal, 1997). While one-dimensional consolidation test, triaxial compression test and point load test was conducted to study the engineering characteristic of the soils and rocks in the study area. All these laboratory tests were carried out in accordance with the test procedures recommended in BS 1377 and soil were classified according to the Unified Soil Classification System (USCS) and BS 5930. The result of the analyses shows in table 2 (Faisal, 1998). Data analysis indicated that the sliding material is representing of clayey soil types and moderately weak of rocks, which are the main causes of mass movement especially during rainy seasons.

7. FACTORS AFFECTING MASS MOVEMENT

Several factors contribute to occurrence of mass movement in study area and these are categorized into geological, geomorphological, climatological and anthropological. Included in the geological factors are the dense occurrence of geological faults and joints providing zones of weakness and presence of clayey material within the sliding area (Kirkby, 1987). Geomorphological factor includes steepness of slopes, relief, elevation, valley configuration and ridge form. Climatological factor includes deep tropical weathering, lack of tropical forest and high rainfall (Tongkul, 1987). While the anthropological factors are those that result from man-made activities such as steeping of natural slopes due to road building, distability of slope toes due to road cutting and removal of vegetation protection. Consideration of these hazards must be put in development to counter their disruptive effects.

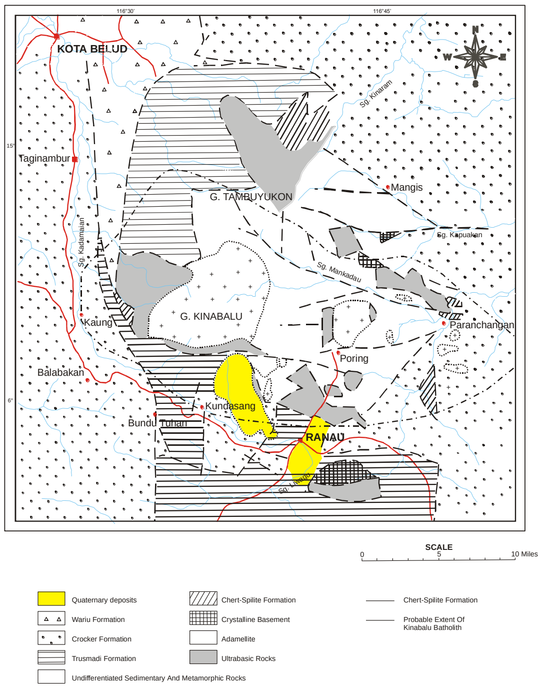


Figure 6: Regional Geology Map (Modified from Jacobson, 1970)

Table 1: Local Stratigraphic Column and their Water Bearing and Engineering Properties

Age	**Rock Formation**	**Unit**	**General Character**	**Water-Bearing Properties**	Engineering Properties
Quaternary	Alluvium	-	Unconsolidated gravel, sand and silt with minor amounts of clay deposited along the rivers or streams and their tributaries. Includes natural levee and flood plain deposit.	Gravelly and sandy, portions are highly permeable and yield large quantities of water. Important to groundwater development.	Generally poorly consolidated. Hence not suitable for heavy structures and subsidence under heavy load.
Upper Pleistocene to Holocene	Pinousuk Gravel	-	Poorly consolidated tilloid deposits. Unconformable overlie ultrabasic granitic and Tertiary sedimentary rocks.	Good aquifer present in poorly fractures consolidated deposit.	Poorly consolidated. Not suitable for heavy structure. Born to be heavy sliding.
Late Eocene to Early Miocene	Crocker Formation	Shale	This unit composed two types of shale red and grey. It is a sequence of alteration of shale with siltstone of very fine.	It has no significant to groundwater development due to its impermeable characteristic.	Very dangerous site for heavy structures and the main causes of mass movement.
			It is a sequence of interlayering of permeable sediment sandstone with impermeable sediment of shale. The permeability of this unit is quite	Little importance to groundwater provides some water but not enough for groundwater development.	Dangerous site for heavy structures and high potential for mass movement.

		Shale-Sandstone Inter bedded	variable. Groundwater in this unit tends to be under semi-confine to confine system.		
		Sandstone	Light grey to cream colour, medium to coarse -grained and some time pebbly. It is highly folded, faulted, jointed, fractured occasionally cavernous, surfically oxidized and exhibit spheriodal weathering.	Importance to groundwater.	Good site for heavy structures with careful investigation. Stable from mass movement and provide some modification like closing of continuous structure.
Paleocene to Eocene	Trusmadi Formation	Trusmadi Slate and Trusmadi Phylites	Comprise of dark colored argillaceous rock either in thick bedded or interbedded with thin sandstone beds reported along with isolated exposures of volcanic rock is a common feature of this formation.	Fracture bed of sandstone has significant to groundwater.	Dangerous site for heavy structure. Improvement should be conducted before any project.

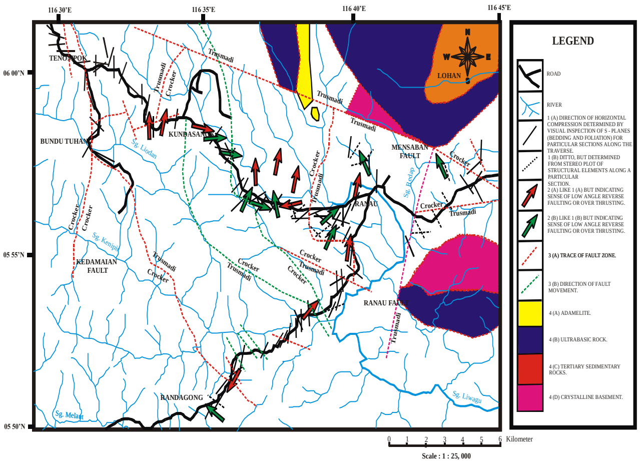


Figure 7: Structural Map (Modified from Tjia, 1974)

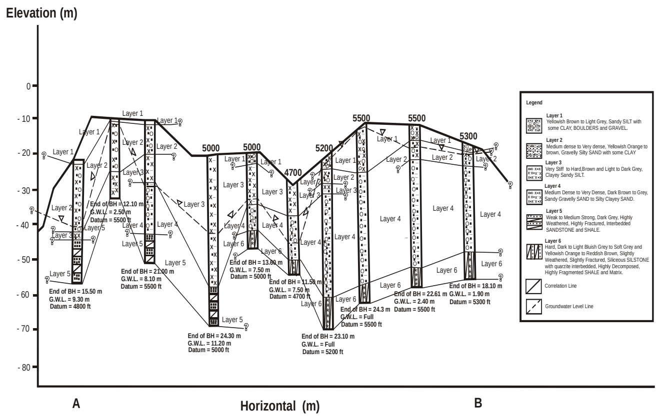


Figure 9: Cross-Sectional of Groundwater Table

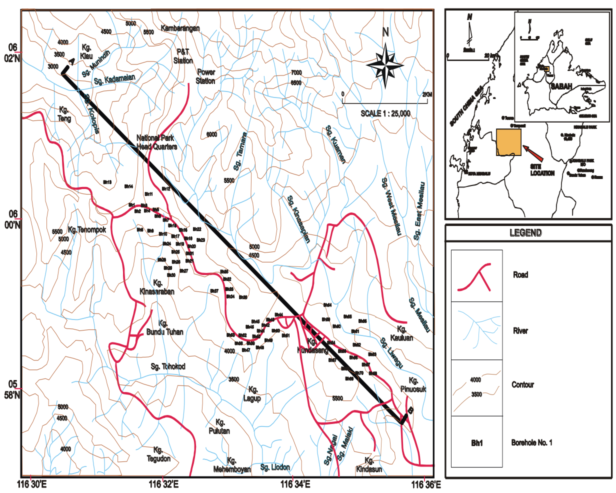


Figure 8: Location of Borehole

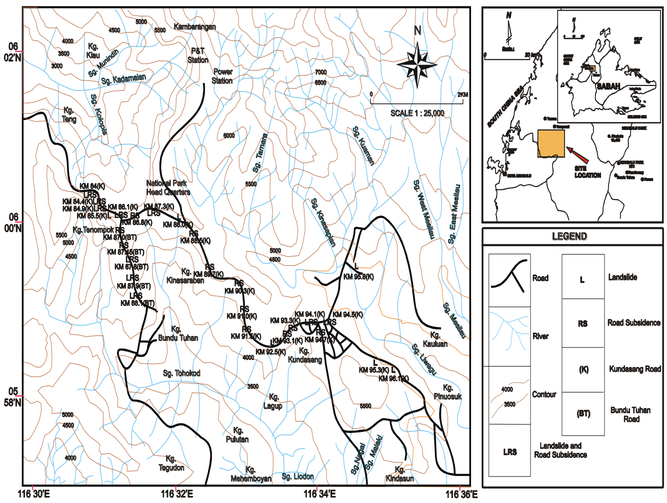
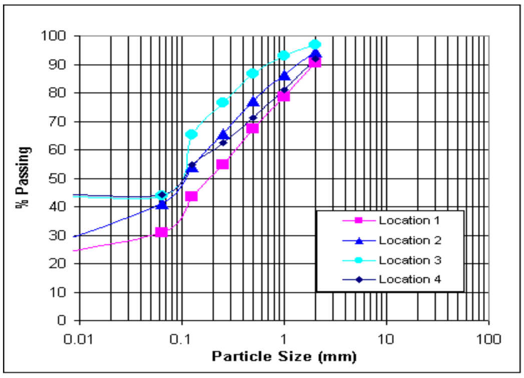


Figure 10: Mass Movement Location Map

Table 2: Result of laboratory analysis for physical and mechanical properties with their engineering characteristic (Cont.)

Location			KM 84.0 (K)	KM 84.4 (K)	KM 84.9 (K)	KM 85.5 (K)	KM 86.1 (K)	KM 87.0 (BT)	KM87.45 (BT)	KM 87.8 (K)
Depth (m)			**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**
Sample No.			**L1/BH1/UD 5**	**L2/BH1/UD 5**	**L3/BH1/UD 5**	**L4/BH1/UD 5**	**L5/BH1/UD 5**	**L6/BH1/UD 5**	**L7/BH1/UD 5**	**L8/BH1/UD 5**
Classification		BS 5930	SCI	SMI	SCI	SCH	SCI	SCI	CIG	CIG
Clay 0.002 mm		%	17.99	17.56	40.788	40.26	20.8	4.37	31.068	42.556
Silt 0.002 - 0.0063 mm		%	12.85	23.51	3.105	3.98	15.35	33.38	26.223	13.059
Sand 0.0063 - 2 mm		%	69.16	58.93	56.108	55.76	63.85	62.25	42.709	44.385
Gravel		%	0	0	0	0	0	0	0	0
Particle Size	20	mm								
Distribution	14	mm								
(% Passing)	10	mm								
	6.3	mm								
	5	mm								
	3.35	mm	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	2	mm	90.38	94.452	97	91.756	87.76	96.75	96.654	98.624

	1	mm	78.66	86.284	92.867	80.971	79.99	93.81	91.706	94.912
	0.5	mm	67.21	77.037	86.631	71.115	71.63	89.82	85.549	88.979
	0.25	mm	54.91	65.728	76.414	62.368	61.38	83.24	76.987	79.763
	0.125	mm	43.45	54.125	65.399	54.72	50.99	70.1	68.733	68.601
	0.063	mm	30.84	41.07	43.892	44.233	36.16	37.74	57.292	55.615
	0.001	mm	17.99	17.564	40.788	40.25	20.81	4.36	31.068	42.556
	0.0001	mm	0	0	0	0	0	0	0	0
Liquid Limit (L.L)		%	36	39	42	52	43	45	47	49
Plastic Limit (P.L)		%	22	31	20	29	15	25	23	23
Plastic Index (Ip)		%	14	8	22	23	28	20	24	26
Natural Moisture Content		%	18.00	19.00	22.00	25.00	20.00	23.00	23.00	24.00
Specific Gravity			2.64	2.670	2.650	2.650	2.64	2.640	2.58	2.62
Permeability		K cm/s	0.0149	0.767	0.254	0.799	0.0116	0.101	0.00955	0.00915
One Dimensional		M_v (m²/MN)	0.003-0.412	0.003-0.22	0.0-0.017	0.008-0.822	0.0-0.011	0.006-0.474	0.001-0.778	0.007-0.818
Consolidation Test		C_v (m²/Year)	79.28-94.54	81.13-100.11	93.97-100.39	76.062-94.653	88.47-96.47	78.07-96.34	70.82-90.83	74.92-90.64
Trixial Compression Test										
Saturated Unconsolidated Undrained		S_u kN/m²	64.94	75.35	79.06	139.4-166.31	39.99-72.09	43.13-65.89	24.52-35.25	83.09
		φ								
Consolidated Isotropic		c' kN/m²	7.26	7.27	6.81	19.23	6.33	0.18	25.13	12.22
Undrained		φ'	26.25	29.12	28.97	35.48	32.92	18.41	7.72	17.29
Unconfined Compression		c kN/m²	20.2	26.83	66.95	161.65-187.02	35.1	23.87	15.63	40.34
Rock Strength Tests										
Unconfined Compressive		kN/m²	11.04	10.08	11.28	6.48	12.24	-	-	8.64
Point Load Strength Index		kN/m²	0.46	0.42	0.47	0.27	0.51	-	-	0.36
Chemical Test										
pH										
Sulphate content		%								
Chloride content		%								
Organic content		%								



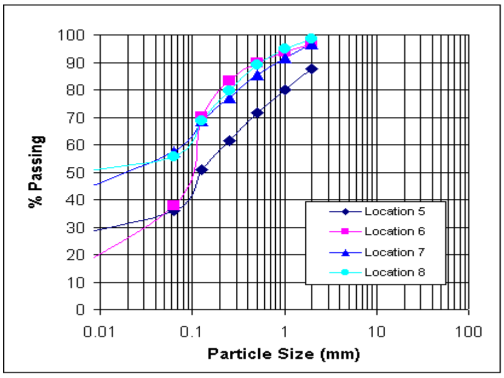
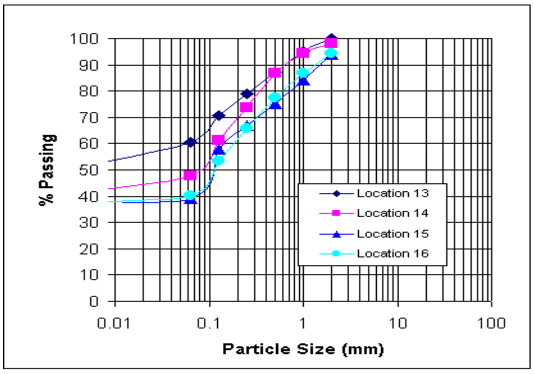


Table 2: Result of laboratory analysis for physical and mechanical properties with their engineering characteristic (Cont.)

Location			**KM 87.9 (BT)**	**KM 88.1 (BT)**	**KM 86.8 (K)**	**KM 87.3 (K)**	**KM 88.0 (K)**	**KM 88.5 (K)**	**KM 89.7 (K)**	**KM 90.3 (K)**
Depth (m)			**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**
Sample No.			**L9/BH1/UD 5**	**L10/BH1/UD 5**	**L11/BH1/UD 5**	**L12/BH1/UD 5**	**L13/BH1/UD 5**	**L14/BH1/UD 5**	**L15/BH1/UD 5**	**L16/BH1/UD 5**
Classification		BS 5930	CIG	SCI	SF	SCI	CIG	CLG	CLG	CLG
Clay 0.002 mm		%	37.222	22.68	9.553	25.01	42.3	34.832	34.748	32.991
Silt 0.002 - 0.0063 mm		%	16.066	19.061	17.247	16.74	18.4	23.042	24.457	17.281
Sand 0.0063 - 2 mm		%	46.712	58.259	73.2	58.25	19.3	42.122	40.795	49.728
Gravel		%	0	0	0	0	0	0	0	0
Particle Size	20	mm								
Distribution	14	mm								
(% Passing)	10	mm								
	6.3	mm								
	5	mm								
	3.35	mm	100.00	100.00	100.00	100.00		100.00	100.00	100.00
	2	mm	96.74	98.465	93.345	98.918	100.00	98.12	93.982	94.335
	1	mm	92.62	93.408	79.717	96.672	95.018	94.196	84.176	86.768
	0.5	mm	86.424	87.111	62.179	90.127	87.289	86.69	75.247	77.349
	0.25	mm	76.878	75.481	50.839	73.748	79.027	73.705	66.74	65.95
	0.125	mm	67.28	62.312	38.782	57.772	70.512	61.362	57.973	53.423
	0.063	mm	53.287	41.741	26.799	41.747	60.701	47.878	39.204	40.272
	0.001	mm	37.221	22.68	9.552	25.009	42.298	34.832	34.748	32.991
	0.0001	mm	0	0	0	0	0	0	0	0
Liquid Limit (L.L)		%	41	39		37	36	38	31	34
Plastic Limit (P.L)		%	23	11	Non-Plastic	20	21	23	16	20
Plastic Index (Ip)		%	18	28		17	15	15	15	14
Natural Moisture Content		%	20.00	20.00	22.00	18.00	18.50	19.00	16.00	17.00
Specific Gravity			2.62	2.560	2.880	2.630	2.64	2.620	2.61	2.58

Permeability	K cm/s	0.00833	0.142	3.72	0.0112	0.00433	0.00566	0.00643	0.00511
One Dimensional	M_v (m²/MN)	0.0-0.01	0.0-0.021	0.003-0.198	0.008-0.822	0.008-0.594	0.005-0.3	0.002-0.282	0.002-0.206
Consolidation Test	C_v (m²/year)	90.30-100.90	88.311-98.57	80.59-93.93	76.06-92.60	76.59-95.76	78.63-97.19	79.43-96.26	81.11-97.72
Trixial Compression Test									
Saturated Unconsolidated	S_u kN/m²	66.65-91.27	60.72	58.55-70.99	36.22	99.92-120.43	103.6	68.06-139.69	97.9-107.35
Undrained	⍰								
Consolidated Isotropic	c' kN/m²	12.55	11.3	14.03	6.42	16.92	7.16	7.53	12.8
Undrained	⍰'	9.13	11.04	24.66	31.64	32.95	31.83	32.5	31.61
Unconfined Compression	c kN/m²	29.68	8.16	51.04	72.88	247.27-427.01	122.27	335.74-404.66	189.84-197.21
Rock Strength Tests									
Unconfined Compressive	kN/m²	11.52	11.28	-	90.96	9.60	-	-	-
Point Load Strength Index	kN/m²	0.48	0.47	-	3.79	0.40	-	-	-
Chemical Test									
pH									
Sulphate content	%								
Chloride content	%								
Organic content	%								



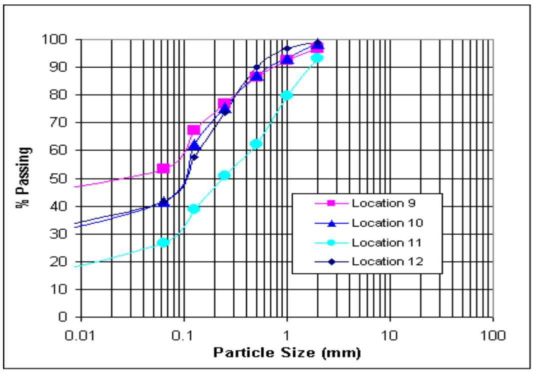
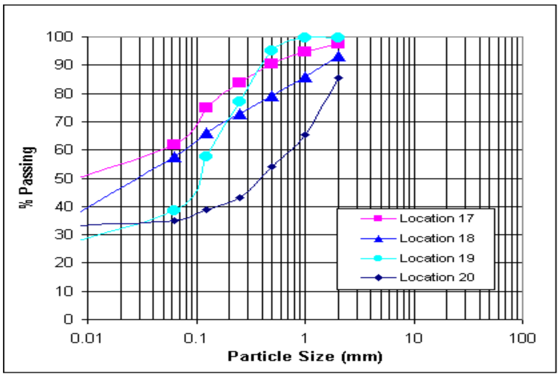
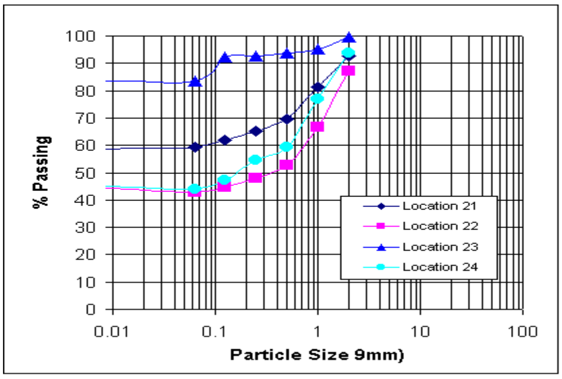


Table 2: Result of laboratory analysis for physical and mechanical properties with their engineering characteristic

Location			**KM 91.0 (K)**	**KM 91.5 (K)**	**KM 92.5 (K)**	**KM 93.1 (K)**	**KM 93.3 (K)**	**KM 94.1 (K)**	**KM 94.5 (K)**	**KM 96.1 (K)**
Depth (m)			**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**	**2.00-2.50**
Sample No.			**L17/BH1/UD2**	**L18/BH1/UD2**	**L19/BH1/UD2**	**L20/BH1/UD2**	**L21/BH1/UD2**	**L23/BH1/UD2**	**L26/BH1/UD2**	**L27/BH1/UD2**
Classification	BS 5930		CLG	MHG	SCI	SCI	CIG	SCI	CI	CLG
Clay 0.002 mm	%		36.367	18.06	18.432	28.76	52.19	41.18	75.58	41.31
Silt 0.002 - 0.0063 mm	%		25.496	39.37	20.13	6.15	6.97	1.85	8.1	2.72
Sand 0.0063 - 2 mm	%		38.137	42.57	61.438	65.09	40.84	56.97	16.32	55.97
Gravel	%		0	0	0	0	0	0	0	0
	Sample No.									
Particle Size	20	mm								
Distribution	14	mm								
(% Passing)	10	mm								
	6.3	mm								
	5	mm								
	3.35	mm	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	2	mm	97.494	93.228	99.796	85.53	92.54	87.33	99.59	93.63
	1	mm	94.695	85.818	99.476	65.24	81.48	66.6	95.36	77.08
	0.5	mm	90.517	79.288	95.018	53.94	69.51	52.66	93.69	59.2
	0.25	mm	83.635	72.725	77.124	43	65.26	48.13	92.69	54.48
	0.125	mm	74.919	66.07	57.455	38.71	61.93	44.51	92.34	47.24
	0.063	mm	61.863	57.428	38.562	34.91	59.16	43.03	83.68	44.03
	0.001	mm	36.367	18.062	18.432	28.76	52.19	41.18	75.58	41.31
	0.0001	mm	0	0	0	0	0	0	0	0
Liquid Limit (L.L)	%		32	57	42	30	31	30	30	29
Plastic Limit (P.L)	%		16	37	21	13	14	14	15	19
Plastic Index (Ip)	%		16	20	21	17	17	16	15	10
Natural Moisture Content	%		17.00	27.00	20.00	15.00	18.76	14.53	15.51	23.35
Specific Gravity			2.59	2.670	2.610	2.620	2.63	2.620	2.65	2.63
Permeability	K cm/s		0.00673	0.00583	0.33	0.00847	0.014	0.0056	0.00689	0.00649
One Dimensional	M_v (m²/MN)		0.0-0.014	0.003-0.22	0.002-0.206	0.014-0.56	0.049-0.31	0.037-0.168	0.013-0.096	0.013-0.098
Consolidation Test	C_v (m²/year)		88.32-96.48	74.89-91.98	81.11-97.72	79.11-98.103	83.60-94.23	84.47-92.09	89.98-97.32	88.01-97.28
Trixial Compression Test										
Saturated Unconsolidated	S_u kN/m²		48.06-53.72	76.97-86.13	78.18-86.55	81.86-93.85	115.02-127.44	85.75-99.97	5.42	27.51-47.88
Undrained	⍰									
Consolidated Isotropic	c' kN/m²		5.07	9.73	9.91	17.35	10.42	13.9	5.41	7.19
Undrained	⍰'		32.81	30.88	29.52	33.74	34.5	32.65	26.92	28.74
Unconfined Compression	c kN/m²		19.54	232.17-283.14	127.37-180.98	171.40-183.74	154.24-230.32	167.29-184.51	57.91	45.71

Rock Strength Tests									
Unconfined Compressive	kN/m²	-	-	11.28	-	-	10.56	-	6.96
Point Load Strength Index	kN/m²	-	-	0.47	-	-	0.44	-	0.29
Chemical Test									
pH									
Sulphate content	%								
Chloride content	%								
Organic content	%								





8. Mechanism of Failure

Mass movement take place when slope materials are no longer able to resist the force of gravity. These decrease the shear resistance resulting mass movement, which is due to internal and external factors. Internal factors involve some change in either physical or chemical properties of the rock and soil or its water content. External factors involve increase of shear stress on slope, which usually involves a form of disturbance that is induced by man. The triggering mechanism in the study area most likely involves heavy rainfall causing water saturation of the slope material and loss of cohesion along rapture planes. Heavy rainfall provided water that rendered rock and earth masses heavier and weakened cohesion along water lubricated bedding slide planes. The sheared shale, bedding and fault planes, and opening fractures are all structural weaknesses, which acting as pathways for water seepage, hastening the weakening and eventual mass movement in the study area.

9. Discussion

The study area lies in a fault zone. It is dissected by numerous heavy structural lineaments produced by a complex tectonic history. Several secondary fault and fracture systems can be observed traversing the fault zones. An evaluation of the structural lineaments distribution shows that the density of structural lineaments in the study area and it's surrounding is high. The geologic formation in study area and it's surrounding has undergone several tectonic events during the Late Oligocene to Late Miocene regionally structural evolution of South China basin. These events are shown in the tight folding of interlayered units, and in the serious of thrust and normal fault of various trends and dimension, resulting in highly fractured, deformed, displaced and brittle characteristic of the rocks. The rock material in study area exhibits a high degree of weathering. It may be covered by residual soil, which extends to a depth more than 20 meters. Thus, its mechanical and physical properties approach that of soil. These material are weak and generally cause sinking, sliding and subsidence.

The effect of faulting activity can be observed in the lithologies of the study area, which confirmed by the existence of transformed faulted material consisting of angular to sub angular sandstone fragments with fine recrystallined quartz along the joint planes with poorly sorted sheared. Transformed faulted material have formed a layer at the slope and base of the faulted scarps in the study area up to depths of 10 m to 15 m below the ground surface. The intersection of the faulting activity is also marked by the occurrence of fault gouge with fragments of subphyllite with slickensided surfaces. The geometry of these faulting activity is not well known but is expected to be complex due to the fact that there are intersection zone of different type. Highly fracture jointed sheared sandstone indicates resulted from faults activities, most of faulting shear existing within interbedded sandstone-shale. Breaks and fractures are developed by shearing stresses and caused the rapid disintegration and weathering of the rocks into relatively thick soil deposit, and in the alignment and orientation of the soil particles, which cause reduction of shear strength.

The layered nature of the sandstone, siltstone and shale of geologic formations in study area may constitute possible sliding surfaces. The sandstone-shale contact is easily accessible by water and such contact seepage may weaken the shale surface and cause slides within the rock formations. Interbedded sandstone, siltstone and shale may also present problems of settlement and rebound. The magnitude, however, depends on the character and extent of shearing in the shale. The shale units have an adequate strength under dry conditions but loose this strength when it is wet. During the rainy season, the soil becomes highly saturated with water, which increases the water pressure and reduces the shear resistance to sliding specifically within the sandstone – shale contact. This consequently allows the movement of the material from the west side of the road.

Laboratory analysis indicated that most of the weathered products in study area have high clay content, which subsequently cause instability. The clay material structures can accommodate thick interlayered sheet of absorbed water, which leads to their expansiveness. These have leads the soil to be of low permeability and high porosity. During the rainy period, water accumulates within the soil grains, and this serves to increase the hydrostatic pressure. According to the Mohr-Coulumb theory of failure, an increase in the pore water pressure leads to the decrease in effective stress, which contributed to a reduction in the shear strength of the materials causing the failure. Their relationship is expresses as:

$$S = C + (\sigma - u) \tan \phi \quad (1)$$

Where: S = Shear Strength
C = Cohesion
σ = Normal Stress
u = Pore Water Pressure
$(\sigma - u)$ = Effective Stress
ϕ = Friction Angle

The clayey materials deposit has low plasticity content and is friable. Therefore, with the increase in water content during the rainy period the soil cohesion will decrease causing the soil to slide like a viscous liquid. As a corollary to this, in rock bodies, the surface roughness of joints are generally smooth to rough planar. A relatively smooth surface decreases the frictional resistance to sliding at the joints, therefore allowing the possibility of slipping movement to take place. The rainwater infiltrates the soil from the slope areas of the road causing the soil to be saturated, contributing to the decrease in shear resistance of the soil. The consequently allows the movements of the material from the side of the road, further down towards the valley sides.

The upper part of the movement of this slump is downward with common horizontal component. The load of the vehicles and to some extent, the weight of the back filling material contributes to the driving force. Cracks along the road, and an eastern offset of a part of the road are evidence of quite perceptible downward movement of this portion. Furthermore, along the shear plan (slip surface) the orientation and alignment of the soil particles could take place reducing resistance to sliding, and thus leads to continuity of the movement. Artificial change in the slope gradient, usually due to man made structures such as embankment of the road, lead to the increase in steepness of the toe, therefore, rendering the slope unsupported.

Natural change is exemplified by erosive action of the creeks. The moment the toe has been unsupported, the load of the overburden materials, result in an increase of the shear stress thus contributing to a decrease in the shear strength and factor of safety, therefore the failure could occur. Factor of safety is defined as:

$$\text{Factor of Safety} = \frac{\text{Shear Strength}}{\text{Shear Stress}} \qquad (2)$$

The tremor shocks, which affected the study area between times to time, might be considered as an external causes of the mass movement. These is due to the increasing of the shear stress along the slip surface where the shear strength remains unchanged, hence the shocks reduce the factor of safety.

10. Conclusion

In light of available information, the following conclusion may be drawn from the present study:

1. The geologic setting of the study area has major effects on the slope stability of the area. These geologic setting reduce the mechanical and physical properties, and engineering characteristic of the rock and soil and produces intensive displacement in substrata resulting in intensive weathering processes and subsequently intensive mass movement along sensitive slopes.
2. The clayey and shaley material within the sedimentary rocks is the specific site of instability in study area.
3. The general movement of groundwater flow in study area is from highland to lowland and this is might be the main causes of mass movement in study area.
4. Landslides take place when slope materials are no longer able to resist the force of gravity. This decrease in shear resistance resulting in mass movements is due either to internal or external causes. Internal causes involve some change in either the physical or the chemical properties of the rock or soil or its water content. External causes that lead to an increase in shear stress on the slope usually involve a form of disturbance that may be either natural or induced by man.

11. 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) A good vegetation cover;
   c) A good drainage pipe system and gutter system; and
   d) Shotcrete or other means of reducing erosive action of rainwater runoff.
3. Subsurface drainage, i.e. horizontal drainage method.

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