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Engineering Geology of the Kota Kinabalu Area, Sabah, Malaysia

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Abstract: The geology of the Kota Kinabalu area provides a favourable setting for engineering geological instability. Kota Kinabalu is underlain by the Late Eocene – Early Miocene Crocker Formation and Quaternary Alluvium. The Crocker Formation is composed of thick sandstone unit, interbedded sandstone – shale unit and shale unit. These rock units are dissected by numerous lineaments with complex structural styles developed during series of regional Tertiary tectonic activities. The tectonic complexities reduced the physical and engineering properties of the rock masses and produced intensive displacements and discontinuities among the strata, resulting in high degree of weathering process and instability. The weathered materials are unstable and may cause subsidence, sliding and falling induced by high pore pressure subjected by both shallow and deep hydrodynamic processes. This paper describes the engineering geological investigation, appreciation of the complex geology, examination of material properties under specific geological laboratory tests, field testing and mapping, verification of the mechanism of failure and the deduced possible causes of slope failures, settlement, land subsidence and foundation instability. Much of the findings could not have been ascertained without sound understanding of the site geological evolution, inherited unfavourable geological relics and the peculiar but hazardous engineering properties in the Kota Kinabalu area. Geological evaluation should be prioritized and take into consideration in the initial step in all infrastructure program. This engineering geological study may play a vital role in engineering geological problems assessment to ensure the public safety..

INTRODUCTION

The rapid development since the eighties (80's) had a spill over effect in the Kota Kinabalu area where lands was cleared for the construction of highways, high-rise buildings, industrial, housing area and several other heavy infrastructures. These activities had, besides spurring economic growth, also caused environmental management problems, such as streams were polluted with pesticides, fertilizers and siltation. There was also widespread erosion in the cleared areas and mass movement had frequently occurred. Mass movement have presently impact the community and its socio-economic development, in addition to adding a strain to the government in the heightened costs of repair and maintenance.

In view of the increasing land use activities, demanding terrain, looming geohazard risks and challenging geology, the Kota Kinabalu area as capital city of Sabah state was thus chosen as the pioneer engineering geological research. This paper will discuss some of the engineering geological aspects of Kota Kinabalu area. Its main focus will be on aspects of weathering profiles, groundwater condition, physical and engineering properties of rock and soil and discussions of some cases of geohazards occurrences. It is hoped that by understanding of the engineering geological aspects, one can optimize expenditure and increases the safety level of the in progress or future engineering construction works.

METHODOLOGY

The laboratory works for soil samples such as grain size, atterberg limit, shrinkage limit, specific gravity, water content, permeability 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

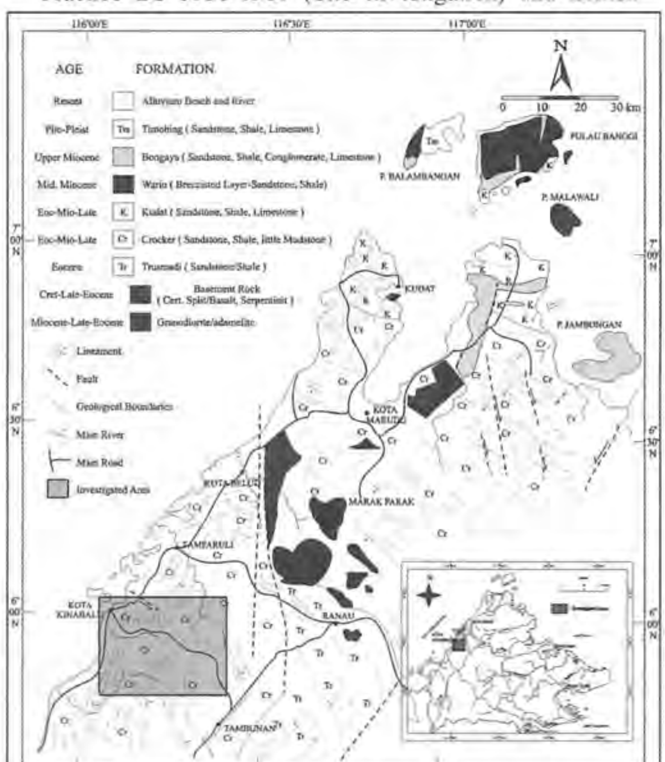

Figure 1: Location Map

Standard Code of Practice BS 1377-1990 (Method of Test for Soils for Civil Engineering Purposes). In other matters, the experimental methods for rock samples such as water content, point load test and uniaxial compressive strength are based on ISRM (1979; 1979b & 1985).

LOCATION AND ACCESSIBILITY

The study area lies centrally on the western coast of Sabah roughly about longitude E 116 degrees 02' to E 116 degrees 09' and latitude N 05 degrees 55' to N 06 degrees 01'. The total area covered by the study is approximately 120 km2 (Fig. 1). The mainland part of the Kota Kinabalu area is the accessible part of Western Sabah.

Good networks of sealed and unsealed roads connect most of the prime towns around it. However, most of the roads are found along the coasts and valleys. Roads cutting through the mountainous areas are limited. The rest of the hills and mountains are still inaccessible and geologically unexposed, apart from the common footpaths in the jungle.

TOPOGRAPHY AND DRAINAGE

The Kota Kinabalu area lies

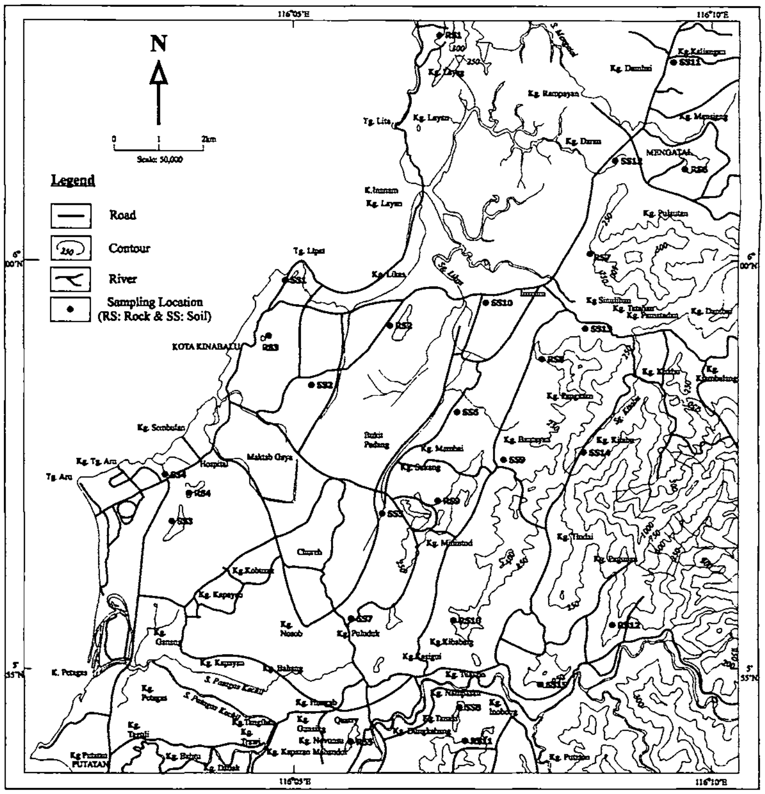

Figure 2. Topography and Drainage map

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.
Late Eocene to Early Miocene	Crocker Formation	Shale	This unit is composed of 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.
		Interbedded Shale-Sandstone	It is a sequence of interlayering of permeable sandstone with impermeable shale. The permeability of this unit is quite variable.	Groundwater in this unit tends to be under semi-confined to confined system. Little importance to groundwater provides some water but not enough for groundwater development.	Dangerous site for heavy structures and high potential for mass movement.
		Sandstone	Light grey to cream colour, medium to course -grained and some time pebbly. It is highly folded, faulted, jointed, fractured occasionally cavernous, surfically oxidized and exhibits 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.

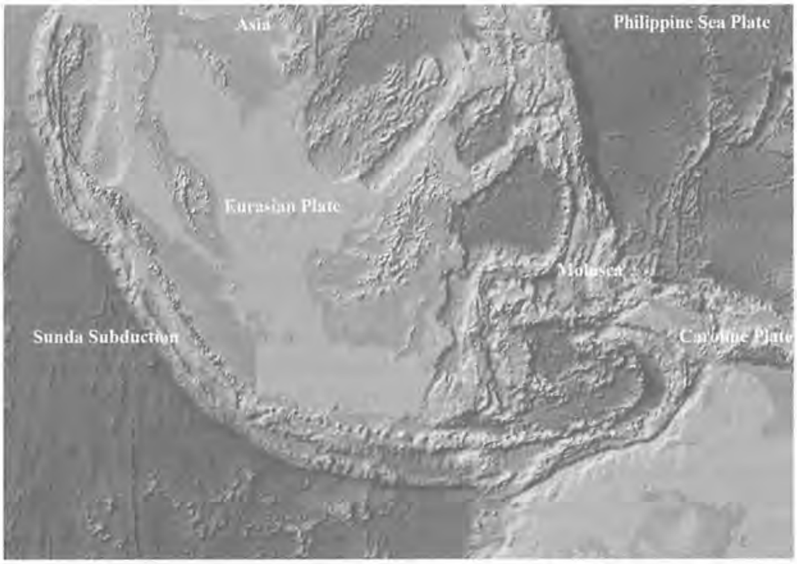

Figure 3. Present tectonic setting of the South China Sea – Palawan – North Borneo – Celebes Sea – Sulawesi region (After Nanang, 2004)

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 (Fig. 2). 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 about180 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 (Fig. 2). The coastline is fairly straight, but is broken by several points and headlands; Tg. Dumpil, Tg. Aru, Tg. Lipat and Likas Bay. Grouped around the coast are the five islands, of which the largest is P. Gaya, occupying about 6 km2. 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 sedimenttary rocks are intensely dissected and form a trellis and parallel drainage pattern.

TECTONIC SETTING AND GEOLOGY

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 (Hamilton, 1979) (Fig. 3).

The exposed rocks in the study area and its surrounding vary in types and ages, from Late Eocene-Early Miocene sandstone and shale of Crocker Formation to Young Alluvial sediments which are still being deposited (Table1).

The sandstone-siltstone-shale unit is defined by aninterbedded sandstone and shale with occasional

Figure 4. Slope failure at Bundusan road, Luyang

Figure 5. Grade III to IV sandstone and shale of the weathering profiles (Location: Survey Hypermarket, Likas)

siltstone. The thickness of the individual beds range from 2 to 130cm. The sandstone is normally fine to very fine-grained and highly fractured while the shale layers are sheared. The shale unit is generally composed of red and grey types of shale. The grey variety is occasionally calcareous. This alternating sequence is commonly interbedded with siltstone or very fine grained sandstone. The shale comprises about 12% of the total volume of Crocker Formation.

The sandstone composition is dominated by quartz with subordinate amounts of feldspars and chloritized, illitized or silicified lithic fragments. Calcareous fractions are rare. These are poorly sorted and well compacted with the pores filled by fine-grained detritus or squeezed lithoclasts resulting in very low to nil primary porosity. The sandstone unit is characterized by very low to nil porosity but moderate to high secondary permeability. It is defined by its great thickness, medium to very coarse-grained and sometime pebbly. Thin shale or siltstone bed between 3 to 40 cm thicknesses occurred between the thick sandstone beds. The argillaceous beds are frequently site of shearing while the sandstone beds site of fracturing or jointing.

The alluvium is restricted to the low land. It mainly represent unconsolidated alluvial sediment on river terraces and flood plains composed of unsorted to well-sorted, sand, silt and clay of varying proportions which were derived from upstream bed rocks. They occur in irregular lenses varying in the form and thickness. Towards the coastal area, the alluvium becomes finer-grained and interbedded with argillaceous deltaic and marine strata. The alluvium may also consist of very thin layer of organic matter. The alluvium sediment is soft, compressible and may be prone to settlement.

WEATHERING PROFILES

In humid tropical regions like the study area, thick weathering profiles are found over all types of bedrock, as the result of favourable tectonic and climatological conditions. The result of a prolonged and pervasive chemical and physical weathering produced profiles, which are characterized by morphological zones or grades; each consists of weathered materials, which preserve varying degrees of the texture, minerals and structures of the original bedrock.

Materials in outcrops in study area involved from grade III to VI, usually containing mixtures of soil, gravel and small boulders. Grade IV to VI can be clearly seen on the scarp of the slide (Fig. 4). The occurrences of discontinuities failures in the study area involve grade III to IV of the weathering profile. Rock mass in these zones were highly fractured, jointed and faulted (Fig. 5). Due to the removal of the upper profiles by excavation, the discontinuities of the rock mass became exposed. Sliding would occur when the plane of the intersecting

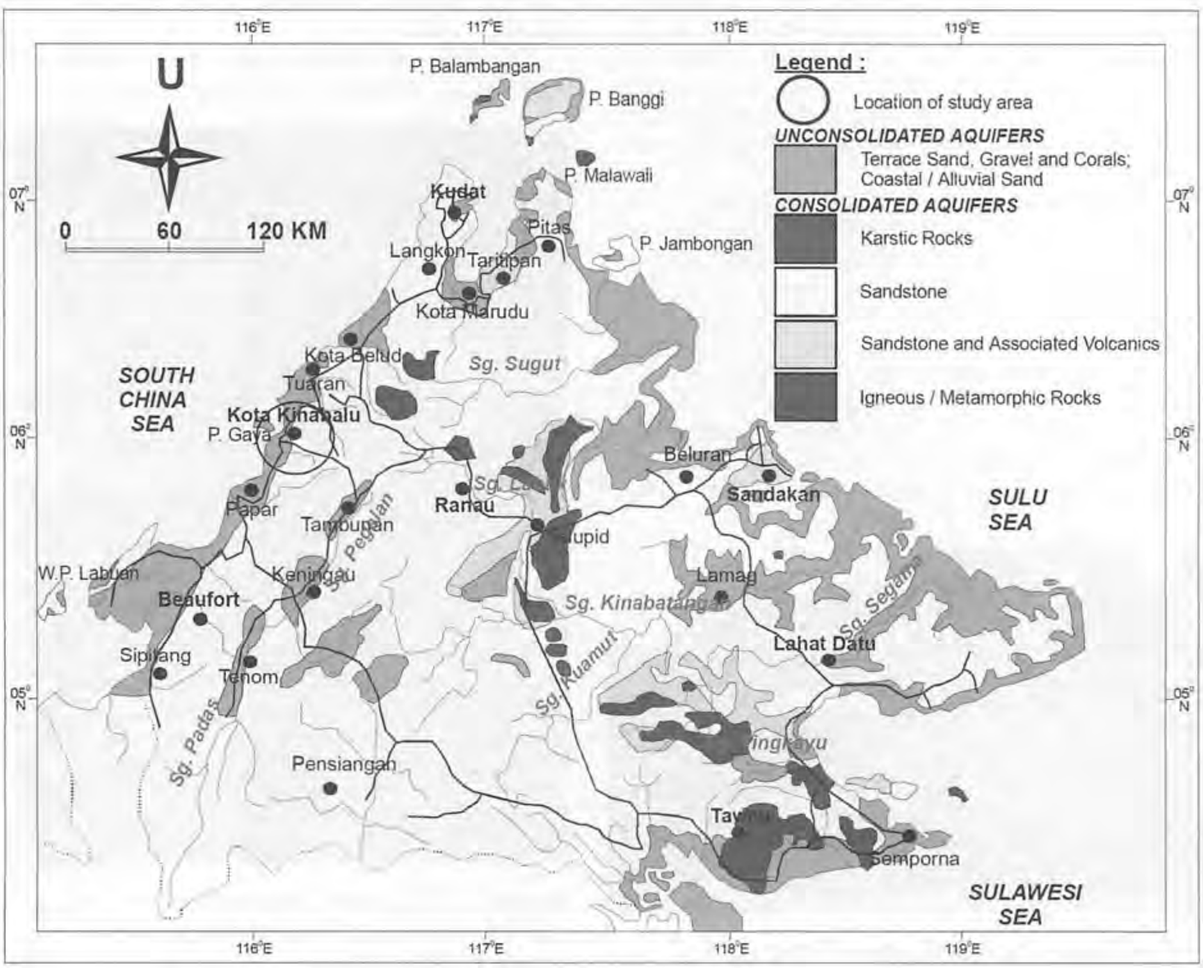

Table 2. Analysis results of soil samples

Outcrop Locations	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8
Weathering grade	IV to VI	IV to VI	IV to VI	IV to VI	IV to VI	IV to VI	IV to VI	IV to VI
Sand (%) (Ave.)	54.74	75.85	60.97	45.14	67.95	54.36	67.70	46.14
Silt (%) (Ave.)	23.16	12.66	11.12	32.05	12.56	10.08	8.01	14.05
Clay (%) (Ave.)	22.10	24.15	27.91	22.81	19.49	35.56	24.29	39.81
Liquid limit (%) (Ave.)	31	39	27	31	28	43	27	31
Plastic limit (%) (Ave.)	13	21	15	14	16	21	14	16
Plasticity index (%) (Ave.)	18	18	12	17	12	22	13	15
Liquidity index (%) (Ave.)	- 0.02	- 0.03	- 0.37	0.05	- 0.54	- 0.57	0.04	- 0.09
Clay activity (Ave.)	0.87	1.00	0.40	0.78	0.48	0.66	0.34	0.41
Shrinkage limit (%) (Ave.)	8.53	8.45	5.79	7.98	5.63	10.57	6.10	7.28
Moisture content (%) (Ave.)	12.94	20.53	10.85	14.30	9.49	7.76	11.37	13.92
Specific gravity (Ave.)	2.61	2.65	2.63	2.66	2.72	2.60	2.76	2.60
Permeability (cm/s) (Ave.)	5.41 X 10^{-3}	8.54 X 10^{-3}	8.68 X 10^{-3}	9.08 X 10^{-3}	9.68 X 10^{-3}	9.53 X 10^{-3}	9.15 X 10^{-3}	5.25 X 10^{-3}
Cohesion, C (Kn/m^2) (Ave.)	7.20	7.31	6.78	19.50	6.27	25.13	12.29	12.54
Friction angle (°) (Ave.)	26.30	29.20	28.90	35.50	32.90	7.70	17.30	9.30
Undrained shear strength (S) (Kn/m^2)	86.90	111.64	109.68	243.31	153.51	36.89	46.157	22.43

Table 2. *(Cont'd)* Analysis results of soil samples

Outcrop Locations	SS9	SS10	SS11	SS12	SS13	SS14	SS15
Weathering grade	IV to VI	IV to VI	IV to VI	IV to VI	IV to VI	IV to VI	IV to VI
Sand (%) (Ave.)	61.44	22.73	45.25	67.95	69.35	56.82	23.75
Silt (%) (Ave.)	6.73	55.01	18.12	12.56	15.61	15.44	55.20
Clay (%) (Ave.)	31.83	22.26	36.63	19.49	15.04	27.74	21.05
Liquid limit (%) (Ave.)	26	32	39	28	32	31	31
Plastic limit (%) (Ave.)	14	13	19	16	17	13	12
Plasticity index (%) (Ave.)	12	19	20	12	15	18	19
Liquidity index (%) (Ave.)	- 0.80	- 0.25	0.14	- 0.54	- 1.53	0.16	- 0.30
Clay activity (Ave.)	0.38	1.00	0.53	0.48	0.66	0.64	0.98
Shrinkage limit (%) (Ave.)	5.63	9.16	8.84	5.63	7.04	8.22	8.68
Moisture content (%) (Ave.)	4.46	7.79	22.85	9.49	7.77	16.94	6.52
Specific gravity (Ave.)	2.66	2.61	2.60	2.72	2.73	2.66	2.60
Permeability (cm/s) (Ave.)	8.78 X 10^{-3}	5.60 X 10^{-3}	5.66 X 10^{-3}	9.66 X 10^{-3}	8.28 X 10^{-3}	3.22 X 10^{-3}	7.25 X 10^{-3}
Cohesion, C (Kn/m^2) (Ave.)	11.43	17.27	7.76	9.62	10.40	9.82	12.80
Friction angle (°) (Ave.)	11.29	23.70	27.70	21.20	34.50	29.50	31.50
Undrained shear strength (S) (Kn/m^2)	93.52	86.77	102.86	62.15	203.78	132.54	148.86

Table 3. Analysis results of rock samples

Outcrop Locations		RS1	RS2	RS3	RS4	RS5	RS6
Weathering grade		IV to V	IV to V	III to IV	III to IV	III to IV	IV to V
Discontinuity plane orientation and intensity	Orientation (Strike / dip) (°)	345/76	010/62	350/58	352/40	330/60	335/45
	Discontinuity Intensity (1)	Very high	Very high	High	High	High	High
Moisture content (%) (Ave.)		0.26	0.15	0.12	0.22	0.20	0.16
Point load strength index, $I_{s(50)}$		0.47	0.42	0.46	0.40	0.38	0.45
Uniaxial compressive strength correlation, UCS = 24 $I_{S\ (50)}$ (mPa)		11.28	10.08	11.04	9.60	9.12	10.80

Table 3. *(Cont'd)* Analysis results of rock samples

Outcrop Locations		RS7	RS8	RS9	RS10	RS11	RS12
Weathering grade		IV to V	IV to V	III to IV	IV to V	III to IV	III to IV
Discontinuity plane orientation and intensity	Orientation (Strike / dip) (°)	320/45	030/35	340/60	020/40	330/20	025/35
	Discontinuity Intensity (1)	Very high	Very high	High	Very High	High	Very High
Moisture content (%) (Ave.)		0.28	0.18	0.20	0.16	0.25	0.21
Point load strength index, $I_{s(50)}$		0.36	0.49	0.48	0.44	0.38	0.50
Uniaxial compressive strength correlation, UCS = 24 $I_{S\ (50)}$ (mPa)		8.64	11.79	11.54	10.56	9.12	12.00

(A)

(B)

Figure 7. Land subsidence occurrences in the Crocker Formation (Locations: a) Taman Landmark, Penampang and b) TNGC Recreation Centre, Bundusan)

discontinuities is unfavourable to the slope orientation. Because of the interbedding between sandstone and shale in certain part of location, the size of the wedges of rock involved in the failures is limited to the corresponding thickness of the sandstone beds. Instead of a single large wedge, the interbedded lithology and geological discontinuities creates plane failures. These plane failures, explains the scattering of angular rock fragments at the toe of the slope. In the field, it has been observed that exposed materials from grade IV on slope cuts, weathered into materials of grade V and higher. This highlights the importance of exposed slope cuts to be revegetated as soon as possible, preventing further erosion or slope failures.

Figure 8. The cutting of hill slope, removing trees and vegetation from the hill slope reduces the stability of the slope. (Location: Kibabaig road, Penampang)

GROUNDWATER CONDITIONS

The study area consisted 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 hydrogeological map of Sabah (Fig. 6), 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 and occasional brecciaated units that have limited primary porosity and moderately well developed secondary porosity. The areas where there are no significant occurrences of ground water resources are made up principally of shale unit sequences.

Occurrence of groundwater in areas with alluvial deposits will depend on the alluvial sediments deposited from the catchments area. Catchments area with coarse sandstones will produce coarse alluvial deposits to provide thick productive aquifers in the alluvial deposits, while catchments with shale will produce clay dominated alluvial deposits with few aquifers.

There are areas within the study area with beach deposit, which has good potential to have groundwater resources. These study area are low level (almost seawater level) and are bounded by sea and tidal creeks and estuaries. These features consequently limit the groundwater storage to relatively small.

PHYSICAL AND ENGINEERING PROPERTIES OF SOIL AND ROCK

In this study, a total of twenty seven (27) selected samples from different locations were studied. The samples were divided into two main groups: soil samples (SS) (fifteen; 15) and rock samples (RS) (twelve; 12) (Fig. 2).

Results of a detailed analysis of soil samples are presented in Table 2. Physical and engineering properties of fifteen (15) soil samples indicated that the soil materials mainly consist of poorly graded to well graded materials of clayey loamy soils, which are characterized by low to intermediate plasticity, containing of inactive to normal clay (0.34 to 1.00), very high to medium degree of swelling (5.63 to 10.57), variable low to high water content (4.46 % to 22.85 %), specific gravity ranges from 2.60 to 2.76, low permeability (9.68 X 10-3 to 3.22 X 10-3 cm/s), cohesion (C) ranges from 6.27 kPa to 25.13 kPa and friction angle (ϕ) ranges from 7.70° to 35.50° with soft to very stiff of undrained shear strength (22.43 KN/m2 to 243.31 KN/m2).

Table 3 shows the results of a detailed analysis of rock samples. The rock properties characterization for twelve (12) rock samples indicated that the rock materials mainly consist of variable low to high water content (12 % to 28.0 %), point load strength index ranges from 0.36 MPa to 0.50 MPa (moderately weak) and uniaxial compressive strength range from 8.64 MPa to 12.00 MPa (moderately weak)

DISCUSSION

Engineering works may involves levelling, excavating, removing of the existing overburden soil and weathered rocks, filling of lowland and cutting of hill slope. These processes exposed the rock and soil in the study area to weathering and erosion. The material becoming weak and loss its engineering properties and may cause sinking, sliding, falling and subsidence (Figs. 4 & 7). Moreover the weathered products have high content of clay which may lower the rock strength and its engineering properties, approaching that of soil.

The cutting of hill slope, dumping of the stream within or along the slope and removing trees and vegetation from the hill slope reduces the stability of the slope. As a result the hill slope becomes critical/unstable (Fig. 8).

Sinking, subsidence and slope failures are amongst the major problems found in the study area especially in the deformed weathered hilly slope. Talus deposits which cover the lower slope in hilly areas are highly permeable, unstable and susceptible to slope failures. This site should be avoided as possible from locating any prospective foundation site (Fig. 9).

Settlement and low shear strength problems arise from development of engineering works within alluvial deposits due to the presence of fine-grained cohesive clayey loamy materials. On the other hand, water leakage from seeping is usually the problem for coarse-grained gravel and sand of alluvium deposit.

The layered nature of the sandstone, siltstone and shale of the Crocker Formation may constitute possible sliding surfaces (Fig. 5). The sandstone-shale contact is easily accessible by water and such contact seepage may weaken the shale surface and cause slides and falls within the formations which dip away from the foundation (Fig. 9). Severe uplift pressures may also develop beneath shale beds in foundation sites and appreciably reduce its resistance to sliding. Interbedded sandstone, siltstone and shale may also present problems of settlement and rebound (Fig. 7). The magnitude, however, depends on the character and extent of shearing in the shale.

The strength of the sandstone will also depend on the amount and type of cement-matrix material occupying the voids. The Crocker sandstones are compacted and in grain to grain contact with each other. Instead of chemical cement (vein) or matrix, the pores are filled by finer-grained sands to silt-sized materials or squeezed rock fragments. The absence of chemical cement reduces the strength of the sandstone especially when it is weathered or structurally disturbed.

The shale units of the Crocker Formation have an adequate strength under dry conditions but lose this strength when wet. During the rainy season, the shale becomes highly saturated with water which increases the water pressure and reduces resistances to sliding and falling especially within the sandstones-shale contact. This condition, in addition to varying amounts of bitumen and levels of degradation, makes shale unpredictable and unsuitable for construction sites. Its unstable nature can be remedied by proper management of soaking and draining of water from the rock or along the sandstone-shale contact.

The bearing capacity of the Crocker sandstone is reduced by the absence of chemical cement (vein) and the presence of discontinuities (Fig. 5). This rock type should be carefully evaluated in each development area so as not to be misled by the theoretical strong behaviour of the sandstone material.

Discontinuities in the study area pose the most serious problem in the stability of any development project. Aside from reducing the engineering properties of the rocks, movement along these structures caused extensive displacements in the substrata which make correlation and projections of rock types, permeable and impermeable layers difficult or impossible even in small areas. Structurally controlled water circulation and seepage are like wise difficult to project as a result of these displacements.

Results for physical and engineering properties analysis of the soil samples indicated that the soil materials mainly consist of poorly graded to well graded materials of clayey loamy soils, which is characterized by low to intermediate plasticity, containing of inactive to normal clay, very high to medium degree of swelling, variable low to high water content, specific gravity ranges from 2.60 to 2.76, low permeability, cohesion (C) ranges from 6.27 kPa to 25.13 kPa and friction angle (ϕ) ranges from 7.70° to 35.50° with soft to very stiff of undrained shear strength.

The rock properties characterization indicated that the rock materials mainly consist of variable low to high water content, point load strength index and uniaxial compressive strength shows it's moderately weak. These engineering properties are dependent to a large extent on the degree of weathering. Weak, weathered materials should be removed until the bedrock is exposed.

CONCLUSION

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

The geologic setting of Kota Kinabalu has had adverse effects on the construction stability of the area. This setting reduces the engineering properties of the rocks and produces intensive displacement in the substrata resulting in difficulty in geologic correlation studies even in small areas.

The clay materials within the Quaternary alluvium and the sheared shale units of the Crocker Formation are specific sites of geohazards occurrences such slope failure in Kota Kinabalu.

Physical and engineering properties of the soil materials from the Crocker Formation mainly consist of poorly graded to well graded materials of clayey loamy

Figure 9. Foundation problems associated with the Crocker Formation (Location: Bukit Padang)

soils, which characterized by low to intermediate plasticity, containing of inactive to normal clay (0.34 to 1.00), very high to medium degree of swelling (5.63 to 10.57), variable low to high water content (4.46 % to 22.85 %), specific gravity ranges from 2.60 to 2.76, low permeability (9.68 X 10^{-3} to 3.22 X 10^{-3} cm/s), cohesion (C) ranges from 6.27 kPa to 25.13 kPa and friction angle (ϕ) ranges from 7.70° to 35.50° with soft to very stiff of undrained shear strength (22.43 KN/m^2 to 243.31 KN/m^2).

The rock properties characterization indicated that the rock materials mainly consist of variable low to high water content (12 % to 28.0 %), point load strength index ranges from 0.36 MPa to 0.50 MPa (moderately weak) and uniaxial compressive strength range from 8.64 MPa to 12.00 MPa (moderately weak).

RECOMMENDATIONS

An environmental management program should be strictly implemented in Kota Kinabalu to prevent these properties losses. Geological studies play a vital role in ground stability assessment which is critical for public safety.

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