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ROCK SLOPES KINEMATIC ANALYSIS ALONG THE BUNDU TUHAN TO KUNDASANG HIGHWAY, SABAH, MALAYSIA

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ABSTRACT

This study focused on the discontinuity survey and mode of rock slope failure along the Bundu Tuhan to Kundasang road, approximately 84th km to 96th km from Kota Kinabalu city, Sabah. The area is underlain by the Trusmadi Formation (Palaeocene to Eocene age), the Crocker Formation (Late Eocene to Early Miocene age) and the Pinousuk Gravels (Upper Pleistocene to Holocene age). These rock units show numerous lineaments with complex structural styles developed during several 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 sliding and falling induced by high pore pressure subjected by both shallow and deep hydrodynamic processes. In this study, a total of ten (10) selected critical rock slopes failure was studied. Kinematics slope stability analyses indicates that the variable potential of circular, planar, wedge and toppling failures modes as well as the combination of more than one mode of aforementioned failure. The rock properties of ten (10) rock samples indicated that the point load strength index ranges from 0.33 MPa to 0.52 MPa (moderately week) and the uniaxial compressive strength range from 7.81 MPa to 12.57 MPa (moderately week). Development planning has to consider the hazard and environmental management program. This engineering geological study may play a vital role in rock slope stability assessment to ensure the public safety.

1. INTRODUCTION

This paper deals with the rock slope failures study for ten (10) selected critical slopes in the study area with the aim of identifying the mode of rock slope failure, the main factors contributing to failures and to recommend the mitigation measures. The Bundu Tuhan – Kundasang highway connecting the Kota Kinabalu city to the town of Ranau is the only road in Sabah connecting the west coast and the east coast. It is bounded by longitude E 116o 30.946’ to E 116o 39.268’ and latitude N 06o 00.598’ to N 05o 56.635’ (Figure 1). The 12 km study area, 84th km to 96th km, crosses over 90 % rugged mountainous terrain with a different of elevation exceeding 1000 m. Since it’s opening in 1980, the problem of slope stability has adversely affected the use of the highway. The Public Work Department of Malaysia (JKR) authority has started a program of repairing and rehabilitation of slope failures since 1990 to improve the highway. This work is still going on today.

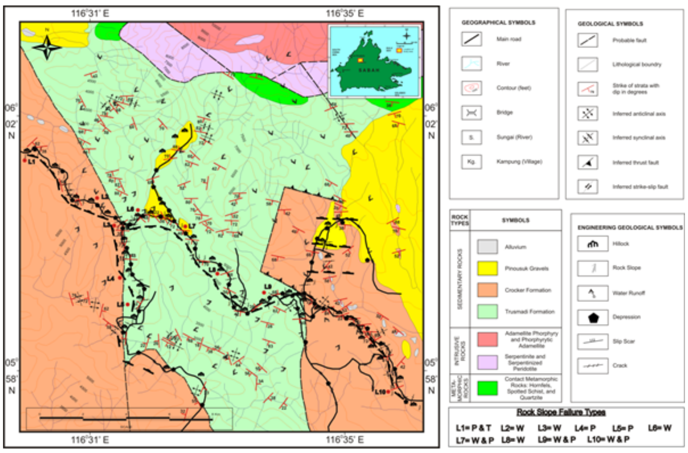

Figure 1: Engineering geology map with their location of rock slope failures

2. METHODOLOGY

Several classifications can be used to describe rock slope failures. For this study in the topics, the types of rock slope failures were classified according to the basic proposals by a researcher [1]. In this system, rock slope failures were divided into circular failure, planar failure, wedge failure and toppling failure. In this study, only failures with volume exceeding 10 m3 were considered, since failures involving smaller volume did not generally affect the road users. On the basis, the rock slope failure was divided into three groups: small (10 – 50 m3), Medium (50 – 500 m3) and Large (> 500 m3).

Discontinuity orientation data has been collected from ten (10) selected of rock slope failure by random method. For each rock slope failures that were studied (Figure 1), the geometry of the slope, dip direction and dip value, persistence, roughness, unevenness, aperture, infilling material, water condition, weathering, geological background characteristics, engineering properties of the sliding materials and an interpretation of the factors causing the failure were recorded. The laboratory works such as point load test and uniaxial compressive strength were carried out in compliance and accordance to ISRM [2,3].

Georient computer program of lower hemisphere spherical projection has been used to perform pole plot of the discontinuities [4]. This has result in cluster of discontinuity and identified as discontinuities sets. Determination of critical discontinuities plane and potential mode of the rock slope failure has been performed by Markland test. RockPack III program for Markland test has been used in this analysis [5]. Markland test is an analysis that required slope orientation, discontinuities sets and friction angle.

2.1 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 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 [6].

The geology of the study area is made up of three sedimentary rock formations: the Trusmadi Formation (Palaeocene to Eocene age) and the Crocker Formation (Late Eocene age) (Figure 1). Table 1 shows the composite stratigraphic column of rock units their water bearing and engineering properties. The effect of faulting activity can be observed on the lithologies of the study area. 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 subphyllite and 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 rock slope failure in study area [7].

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 fractured consolidated deposit.	Poorly consolidated. Not suitable for heavy structure. Born to be heavy sliding.
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 coarse -grained and sometime 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.
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.	Fractured sandstone has significant to groundwater.	Dangerous site for heavy structure. Improvement should be conducted before any project.

2.2 MODE OF ROCK SLOPE FAILURE

In this study, a total of ten (10) selected critical rock slope failures were studied. The types of failures and the results of a detailed analysis according to volume are shown in Table 2. Result of the analysis on every rock slope failures locations will be discussing in detail for their potential or possibility mode of failure and identification of involved joints with their roles in creating sliding plane on the slope as described bellows;

2.2.1 East KM 82.00

There are seven (7) sets of joints (J1-J7) (Figure 2) which intersecting randomly in all direction and intersection point fall outside from the critical zone or plunge of the intersect planes less then 30o (friction angle), then formation of wedge failure on this slope is not possible. Joints J4 and J6 is the most critical plane in this location because their orientation almost parallel to the slope face and their dip vector and pole point falls into the critical zone which creating the circular failure, planar failure or toppling failure, respectively.

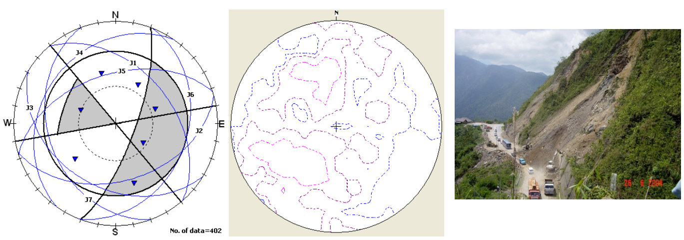

Figure 2: Streoplots and view of rock slope failure for the location of East KM 82.00

2.2.2 East KM 84.00

This location has five (5) major sets of joints (Figure 3). Three intersection points (J3 X J4, J2 X J3 and J2 X J4) of the joints has been recognized and falls in critical zone to create three potential wedge failures. Joints J2 and J3 are become critical planes while other joints (J1, J4 and J5) as release planes of wedge failure in this location.

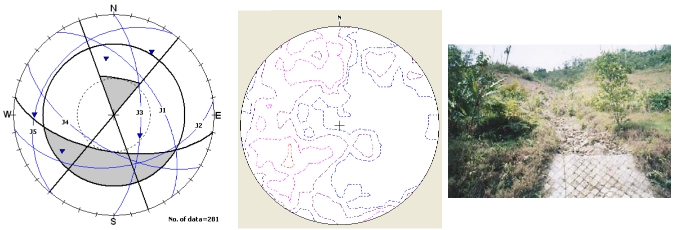

Figure 3: Streoplots and view of rock slope failure for the location of East KM 84.00

2.2.3 East KM 84.40

Seven (7) sets of joints have been identified in this location (Figure 4). One potential circular failure and two potential wedge failures can be created by intersections point of joint J2 X J6 and J2 X J4 X J7 which fall within critical zone with joint J4 and J6 become critical planes. Parallel orientation but opposite dip direction of joint J5 and slope face has been interpreted for possibility occurrence of toppling failure in this location because pole point of joint J5 is falls just behind the critical zone.

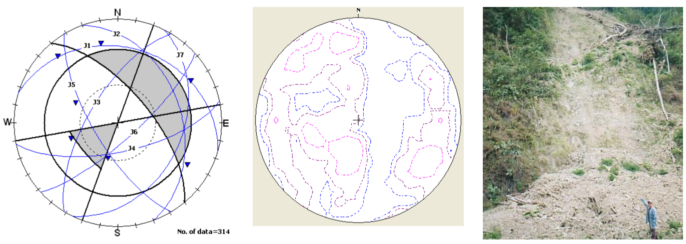

Figure 4: Streoplots and view of rock slope failure for the location of East KM 84.40

2.2.4 South KM 87.45

Kinematics analysis in this location has been produced three (3) joints sets (Figure 5). The potential failure is planar failure according to fallen dip vector of J3 inside the critical zone. Joint J3 is also identified as critical plane as well as release plane of joints J1 and J2.

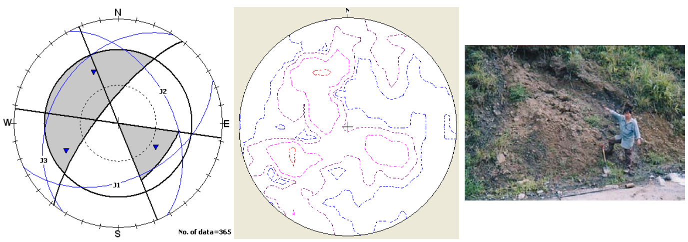

Figure 5: Streoplots and view of rock slope failure for the location of South KM 87.45

2.2.5 South KM 87.90

Nearly parallel orientation of joint J3 and slope face has been creating a planar failure in this location (Figure 6). This planar failure is also generated by the occurrences of release planes (joints J1 and J3) and critical plane of joint J3.

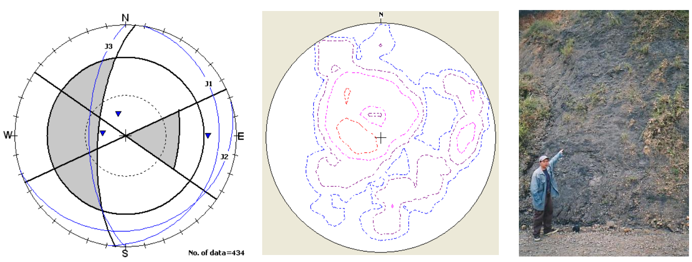

Figure 6: Streoplots and view of rock slope failure for the location of South KM 87.90

2.2.6 East KM 84.90

Seven (7) joints set have been recognized in this location (Figure 7). One circular and four wedge failures are also identified to be potential due to four joint intersection points (J3 X J7, J1X J3, J1 X J2 and J2 X J3) fall in critical zone. Joints J1, J2 and J3 become a critical planes and joints J1, J3, J4 and J5 contributed as release planes. Possible toppling failure has been identified by the occurrences of pole point and dip vector of joint J6 inside and outside the critical zone, respectively. The joint J6 is also as a critical plane for possibly toppling failure in this slope.

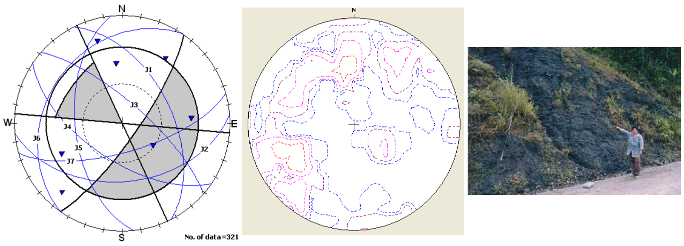

Figure 7: Streoplots and view of rock slope failure for the location of East KM 84.90

2.2.7 East KM 85.50

Stereonet analysis in this location indicates four (4) sets of joints and only a point of intersection falls in the critical zone (Figure 8). This means a wedge failure has been a potential wedge failure resulted from intersection of joint sets J2 X J4 which enhance by released planes of joint J1, J2 and J3 as well as critical plane of J4. Parallel orientation of slope face with joint J2 and the dip vector of joint J2 falling inside critical zone contributing to the formation of planar failure in this location. Opposite dip directions of slope face and joint J3 with nearly same direction on their orientation are also contributing to the possibility of toppling failure occurrence.

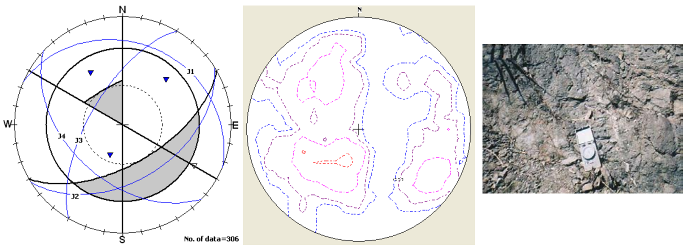

Figure 8: Streoplots and view of rock slope failure for the location of East KM 85.50

2.2.8 East KM 86.80

Potential wedge failure and possible planar failure has been identified in this location (Figure 9), respectively. Intersection point of joint J2 X J4 in critical zone creating a sliding plane of wedge failure and nearly parallel orientation of joint J3 with the slope face for planar failure. Joints of J2 plane and J3 have become critical planes in this location.

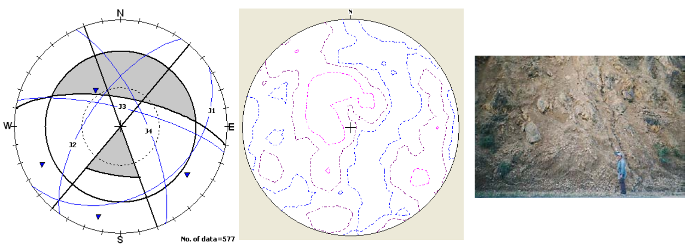

Figure 9: Streoplots and view of rock slope failure for the location of East KM 86.80

2.2.9 East KM 92.50

One potential circular failure with two potential wedge failures and a planar failure have been recognized in this location (Figure 10). Falling of joint intersection point (J2 X J3 and J2 X J6) and dip vector of joint J4 in the critical zone has resulted in wedge failure and planar failure. Joint J3, J2 and J4 have become the critical planes these circular, wedge or planar failures.

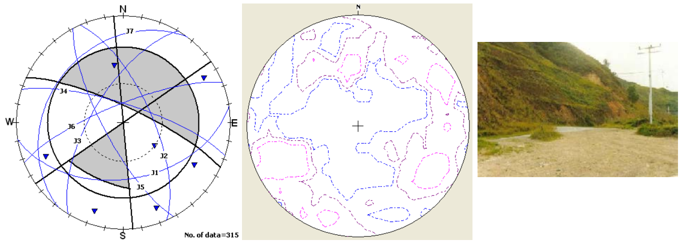

Figure 10: Streoplots and view of rock slope failure for the location of East KM 92.50

2.2.10 East KM 95.70

Two intersection point and a dip vector have been identified fall within critical zone in this station which can be interpreted as two potential a wedge failure and a planar failure, respectively. The wedge failure will be generated by intersection of joint J1 X J3 and J1 X J2 as well as contribution of critical planes of joints J2 and J3 for this failure. Joint J1 is also a critical plane for the formation of planar failure which created by parallel orientation with the slope face.

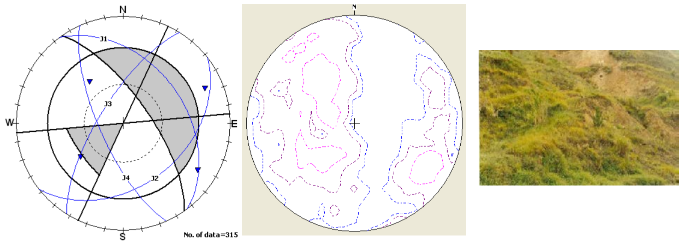

Figure 11: Streoplots and view of rock slope failure for the location of East KM 95.70

3. DISCUSSIONS

The main factor contributing to rock slope failures was the orientation and intensity of discontinuity planes. That is why rock slope failures occurred most frequently along the highway on sedimentary rocks, which were highly breccias and fractured. About 50 % of the rock slope failures occur in sedimentary rocks of the Crocker Formation while the remaining 50 % occur in the meta sedimentary rocks of the Trusmadi Formation. Generally the failed material underwent only moderately to completely weathering (grade III to V). Other factors contributing to failure were the presence of groundwater, climatological setting, joints filling material, high degree of rock fracturing due to shearing in shear, steep of slope angle, high intensive of faulting and folding activities, artificial changing and locating at the fault zones area [8]. The rock properties of ten (10) rock samples indicated that the point load strength index ranges from 0.33 MPa to 0.52 MPa (moderately week) and the uniaxial compressive strength range from 7.81 MPa to 12.57 MPa (moderately week).

The conditions under which circular failure are occurred arise when the individual particles in a rock mass are very small as compared with the size of the slope and when these particles are not interlocked as result of their shape. Hence, crushed rock or/and relics discontinuities in a large waste dump will tend to behave as a soil (Figure 2, 4, 7 & 10) and large failures are occurred in a circular mode. Alternatively, the finely ground waste material, which has to be disposed of after completion of a milling recover process are exhibit circular failure surfaces, even in rock slopes of only a few meter in height. Highly to completely altered and weathered rocks (grade III to V) will also tend to fail in this manner. There are three mechanism failures for the occurrences of circular failure in the study area. The primary mechanism is the present of an abrupt change of rock type or a bedded rock sequence, which provide a weak stratum dipping gently towards a free topographic slope. Strong discontinuities parallel to and into the face, which clearly define a potential movement area, are also helpful. The second mechanism condition concerning block failure is that the slope may be unloaded by erosion or excavation to a point where the potential failure surface crops out above or close to the base level. The third major mechanism is high pore pressure, which cause of renewed movement once a block movement has failed and the strength conditions are at residual.

Planar failure is not necessarily preceded by slope undercutting. Slopes cut parallel or sub parallel to the strike and steeper than the dip of the day lighting planes, can lead to planar failure [9]. The mechanism of the failure is virtually similar to those of planar failure in rock slope. In the study area, planar sliding requires some orthogonal sets of joints as release planes for the rock slab to slide. This is mainly because the release plane for planar sliding to occur may develop within the slope materials itself. The detachment or release planes can be readily developed when the down pull weight of the earth slabs exceeds the tensile strength of the slope materials. This condition is favourably accomplished during or after heavy and prolonged rainfalls, when the rock bodies were saturated. This is aggravated by increased of pore water pressure subjected by both shallow and deep hydrodynamic processes. In such condition, the shear strength is drastically reduced and rapid down slope movement result in the originally tabular-shaped failed mass collapsing and spreading over the foot slope. The nature of the relict structures, along which the sliding plane developed, can be clearly seen in the failure scar (Figure 5 and 6).

Table 2: Analysis results of rock slope failures

Location (km)	Slope	Geological formations	Lithology	Weathering grade	Slope face orientation (°)	Volume (1)	Major Discontinui-ties (°)	Intersect involved	Critical	Release	Potential	Possible	Point load strength index, $I_{s(50)}$ (MPa)	Uniaxial compressive strength correlation, $UCS = 24 I_{s(50)}$ (MPa)	Main factors causing failures (2)	Mitigation measure
East KM 82.00	L1	Crocker Formation	Sediment	III to V	110/74	Large	J1=049/44, J2=164/42, J3=250/34, J4=305/27, J5=343/51, J6=111/30 & J7=210/36	J6	J6	J1, J2, J5 & J7	Plane	Circular	0.33	7.81	D, SA, W, GWL, MC, WR, CR, BF, D, GC & AC	RB, RD, S & RHD
								J4	J4	-	Toppling	-				
East KM 84.00	L2	Crocker Formation	Sediment	III to IV	190/60	Large	J1=055/53, J2=172/47, J3=090/68, J4=211/62 & J5=309/27	J3 X J4 J2 X J3	J3	J1, J2, J4 & J5	Wedge	-	0.42	10.11		
								J2 X J4	J2	J3 & J4						
East KM 84.40	L3	Crocker Formation	Sediment	III to IV	050/65	Medium	J1=016/29, J2=071/39, J3=301/67, J4=168/67, J5=240/70, J6=138/75 & J7=115/37	J2 X J6 J2 X J4 X J7	J6 J4	J3 & J5 J2 & J6	Wedge	Circular	0.42	9.88		
								J5	J5	J1, J3, J4, J6 & J7	-	Toppling				
South KM 87.45	L4	Crocker Formation	Sediment	III to IV	308/75	Medium	J1=154/45, J2=062/47 & J3=303/35	J3	J3	J1 & J2	Plane	-	0.41	9.74		
South KM 87.90	L5	Trusmadi Formation	Meta Sediment	III to IV	275/70	Large	J1=096/17, J2=161/17 & J3=270/63	J3	J3	J1 & J2	Plane	-	0.47	11.37		
East KM 84.90	L6	Trusmadi Formation	Meta Sediment	III to IV	125/78	Medium	J1=063/53, J2=174/46, J3=041/74, J4=214/61, J5=306/29, J6=266/54 & J7=163/68	J3 X J7 J1 X J3 J1 X J2 J2 X J3	J3 J1 J2 J2	J4 & J5 J1, J3 & J5 J1, J4 & J7 J1, J3 & J7	Wedge	Circular	0.48	11.64		
								J6	J6	J1, J2, J3 & J7	-	Toppling				
East KM 85.50	L7	Trusmadi Formation	Meta Sediment	III to IV	150/60	Large	J1=023/25, J2=148/47, J3=300/65 & J4=224/48	J2 X J4	J4	J1, J2 & J3	Wedge	-	0.47	11.27		
								J2	J2	J1, J3 & J4	Plane	-				
								J3	J3	J1 & J4	-	Toppling				
East KM 86.80	L8	Trusmadi Formation	Meta Sediment	III to IV	010/68	Large	J1=145/34, J2=306/66, J3=014/76 & J4=064/71	J2 X J4	J2	J3 & J4	Wedge	-	0.52	12.57		
								J3	J3	J1, J2 & J4	-	Plane				
East KM 92.50	L9	Trusmadi Formation	Meta Sediment	III to V	025/78	Large	J1=171/45, J2=066/68, J3=301/66, J4=018/76, J5=241/75, J6=339/75 & J7=307/30	J2 X J3 J2 X J6	J3 J2	J2 & J6 J4 & J6	Wedge	Circular	0.47	11.34		
								J4	J4	J1, J2 & J5 J3, J4 & J6	Plane	-				
East KM 95.70	L10	Crocker Formation	Sediment	III to IV	055/70	Medium	J1=052/42, J2=141/41, J3=302/71 & J4=247/73	J1 X J3 J1 X J2	J3 J2	J1, J2 & J4 J1, J3 & J4	Wedge	-	0.44	9.95		
								J1	J1	J2, J3 & J4	Plane	-				

- **Note**
  (1) Volume: small (10 – 50 m^3), Medium (50 – 500 m^3) and Large (> 500 m^3)
  (2) Discontinuity (D), Slope angle (SA), Weathering (W), Groundwater level (GWL), Material characteristics (MC), Weak rock (WR), Crushed rock (CR), Blocks and fragments (BF), Debris (D), Geological characteristics (GC) and artificial changing (AC)
  (3) Rock bolt (RB), Rock dowel (RD), Shotcrete (S) & Rock horizontal drainage (RHD)

Wedge failure develops when the intersection of two major sets of joints discontinuities outcrops in the slope face. Wedge failure in the study area is usually induced by revelling and erosions of the lower slope sections. The size and geometry of the wedge is controlled by the orientation of the intersecting joints discontinuities with respect to the slope geometry. Slope undercutting either by revelling and/or erosions can cause wedge failure to occur in more competent soil layers even when the lines of intersection do not initially outcrop on the slope face (Figures 3, 4, 7, 9, 10 & 11). When the line of intersection is steeper than the slope face, the earth wedge has a greater tendency to move downward than outward. When the line of intersection is nearly vertical, as will be the case for a wedge formed by nearly vertical relict discontinuities, the wedge can fail only by downward movement. Such movement can occur only if the underlying rock is removed through the process of revelling or erosions [10]. The term “wedge falls” can be appropriately used to describe such combinations of wedge failures and earth falls.

Discontinuities dipping back into a rock mass may cause rock blocks to topple out of the rock mass. If the interlayer slip is controlled by friction angle, toppling will occur if the normal to the toppling layers are inclined less steeply than a line inclined degrees above the plane of the slope. In addition, toppling will occur only if the layers strike nearly parallel to the strike of the slope, typically within 30o. Toppling failure is rarely occurred in study area. The toppling failure can be along major joints, which have sub vertical to overhanging slopes often undercut at the base (Figures 2, 4, 7 & 8).

4. CONCLUSIONS

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

1 A total of ten (10) selected critical rock slope failures were studied. Kinematics slope stability analyses indicates that the variable potential of circular, plane, wedge and toppling failures modes as well as the combination of more than one mode of aforementioned failure.
2 The main factor contributing to rock slope failures was the orientation and intensity of discontinuity planes and intensive weathering process. Other factors contributing to failure were the presence of groundwater, climatological setting, joints filling material, high degree of rock fracturing due to shearing in shear, steep of slope angle, high intensive of faulting and folding activities, artificial changing and locating at the fault zones area.
3 Slopes that are deemed safe under drought conditions may easily fail during heavy rainfall. The triggering mechanism in the study area most likely involves heavy rainfall causing water saturation of the slope materials and loss of cohesion along discontinuity planes. The fractured porosity facilitates favourably the movement and circulation of groundwater within the bedrock, especially sandstone unit. The sheared shale, bedding and fault planes, and opening fractures are all structural weaknesses, those acting as pathways for water seepage, hastened the weakening zones and eventually caused rock slope failures in the study area.
4 The rock properties of ten (10) rock samples indicated that the point load strength index ranges from 0.33 MPa to 0.52 MPa (moderately week) and the uniaxial compressive strength range from 7.81 MPa to 12.57 MPa (moderately week).

RECOMMENDATION

To correct or prevent the rock slope failure in the study area, the following recommendations are proposed:

1 Sealing off of the cracks.
2 Surface drainage, which include:
  a) Shotcrete or other means of reducing erosive action of rainwater runoff.
  b) Retaining wall with bore piles.
  c) Subsurface drainage, i.e. horizontal drainage method.
3 Spot bolting (with tensioned rock bolts and rock dowels).
4 Scaling (removal of debris, rock fragments and small boulders).
5 Wire netting or curtains can be used for holding back loose blocks on slope face or for catching and guiding falling blocks, to restrict their movements, hence preventing damage to structures.

REFERENCES

[1] Hoek, E., and Bray, J. 1981. Rock Slope Engineering, Institution of Mining and Metallurgy, London.

[2] ISRM. 1979. Suggested methods for determining the uniaxial compressive strength and deformability of rock materials. ISRM Commission on Standardization of Laboratory and Field Tests. International Journal of Rock Mechanics and Mining Sciences, 16, 135-140.

[3] ISRM. 1985. Suggested methods for determining point load strength. ISRM Commission on Standardization of Laboratory and Field Tests. International Journal of Rock Mechanics and Mining Sciences, 22 (2), 51-60.

[4] Holcombe, R. 1998. GEOrient plots stereographic projections and rose diagrams [Program], available: http:// www.earthsciences.uq.edu.au/ rodh/software/ [6 November1998].

[5] Watts, C. F. 2003. Rockpack III for Windows. ROCK Slope Stability Analysis PACKage. User’s Manual. Radford Computerized University, Radford, Virginia.

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

[7] Roslee, R. 2004. Study of Mass Movement along Bundu Tuhan to Kundasang Highway, Sabah, Malaysia. MSc Thesis. Unpublished. Universiti Malaysia Sabah.

[8] Roslee, R. 2001. Engineering geological study along Bundu Tuhan to Kundasang Highway, Sabah, Malaysia. BSc Dissertation. Unpublished. Universiti Malaysia Sabah.

[9] Jamaluddin, T.T., and Deraman, M.F. 2000. Relict structures and cut slope failures in highly to completely weathered rocks along Jalan Tg. Siang, Kota Tinggi, Johor. Bulletin of the Geological Society of Malaysia, 46, 305-312.

[10] Jacobson. G. 1970. Gunong Kinabalu area, Sabah, Malaysia. Sabah: Geological Survey Malaysia Report 8.