SLOPE STABILITY ASSESSMENT OF THE TEMBURUNG FORMATION ALONG BEAUFORT-TENOM RAILWAY, SABAH

Ismail Abd Rahim

Natural Disasters Research Unit,
School of Sciences & Technology,
Universiti Malaysia Sabah, Jalan UMS
88400 Kota Kinabalu, Sabah, Malaysia
Phone: 088 320000 (5734/5999), Fax: 088 435324
Email: arismail@ums.edu.my

ABSTRACT. *This paper discusses the stability and to propose preliminary rock cut slope protection and stabilization measures for the Oligocene to Late Miocene Temburung Formation along the Beaufort-Tenom railway, Sabah. Nine (9) slopes were selected for this study. Geological mapping, discontinuity survey, kinematic analysis and prescriptive measures were used in this study. Result of this study conclude that the mode of failures are wedge, planar, circular and complex types. Gunite, soil nails, wire mesh, weep holes, subsurface drainage, slope reprofiling, terracing and surface drainage are proposed stabilization and protection measures for the slope in study area.*

KEYWORDS. Temburung Formation, Beaufort-Tenom, Railway, slope stability, mode of failure.

INTRODUCTION

The development of instability in rock cut slope is a serious problem with a significant economic and social impact. Catastrophic failures of rock cuts can result in property damage, injury and even death. Along Beaufort-Tenom railway this situation appears related to rock mass characteristic and its abundant rainfall.

The development of instability depends on the combination of the rock mass characteristics (strength, lithology, structure and degree of weathering), the preservation of the slope and how water enters into the system, depending on the relationship between the rainfall-runoff and the groundwater. Combinations of these factors contribute to the large number of accidents during and after construction work, as well as loss of both material resources and lives (Uribe-Etxebarria *et al.*, 2005).

The occurrence of slope failures at km 130.1 and 112 on 9 April 2013 (Photograph 1A and 1B) and km 123.8 of Beaufort-Tenom railway on 7 April 2008 (Photograph 1C) with 2 mortality has become issues for this study. These three (3) slope failures was happened in Temburung formation. Then, this study was conducted only in Temburung formation. Temburung formation is characterized by intense jointing and sheaing, small poligonal block shape ($1cm^3$ – $1m^3$) and irregular blocks type. To evaluate the rock slope stability, 9 cut rock slopes have been selected and identified as Slope 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively. The locations of cut rock slopes in the study area are shown in Figure 1.

Photograph 1. Slope failure. A - km 130.1 (2013); B – km 112 (2013); C – km 123.8 (2008).

METHODOLOGY

Geological mapping, discontinuity survey and kinematic analysis have been used to evaluate slope stability in this study area. Geological mapping includes lithological and structural observation and interpretation. For discontinuity survey, the scan line method was conducted by following ISRM (1981). DIPS 5.0 software package (Rocscience, 2009) has been used to identify the discontinuity sets and average orientations of discontinuity sets.

Evaluation of rock slope stability was performed by kinematic analyses (Markland, 1972). Kinematic refers to the motion of rock mass bodies without reference to the forces that cause them to move (Goodman, 1989). Kinematic analysis is very useful to investigate possible modes of failure of rock masses which contain discontinuities (Jeongi-gi Um & Kulatilake, 2001).

In the kinematic analysis, it is assumed that the friction angle (Ø) for the discontinuity planes is about 30° (Kliche, 1999; Hoek & Bray, 1981). This value is assumed to represents average friction angle for the slope material. However, it is noted that this value may be decreased down to as low as 27° in the presence of seepage along the discontinuity planes, or increased up to 35° in dry, very hard and rough discontinuity surfaces.

The slope stabilization and mitigation measures were determined by prescriptive measures (Yu *et al*., 2005) and using conventional engineering practices.

GEOLOGY

The study area is underlain by the Crocker and Temburong Formations, which is inter-fingering as well as alluvium deposits with the age of Pleistocene and Holocene (Figure 1). These two formations are part of turbidite deposits.

The Crocker Formation is of Late Eocene to Early Miocene age and composed of a few types of lithologies such as thick sandstone unit, interbedded sandstone and shale unit and thick shale unit. The dominant north-south strike of the Crocker Formation gives rise to a series of elongated parallel ridges (Wilson & Wong, 1964). The major structural pattern in this area is dominated by thrust faults trending northeast-southwest with minor folds system plunging to northeast.

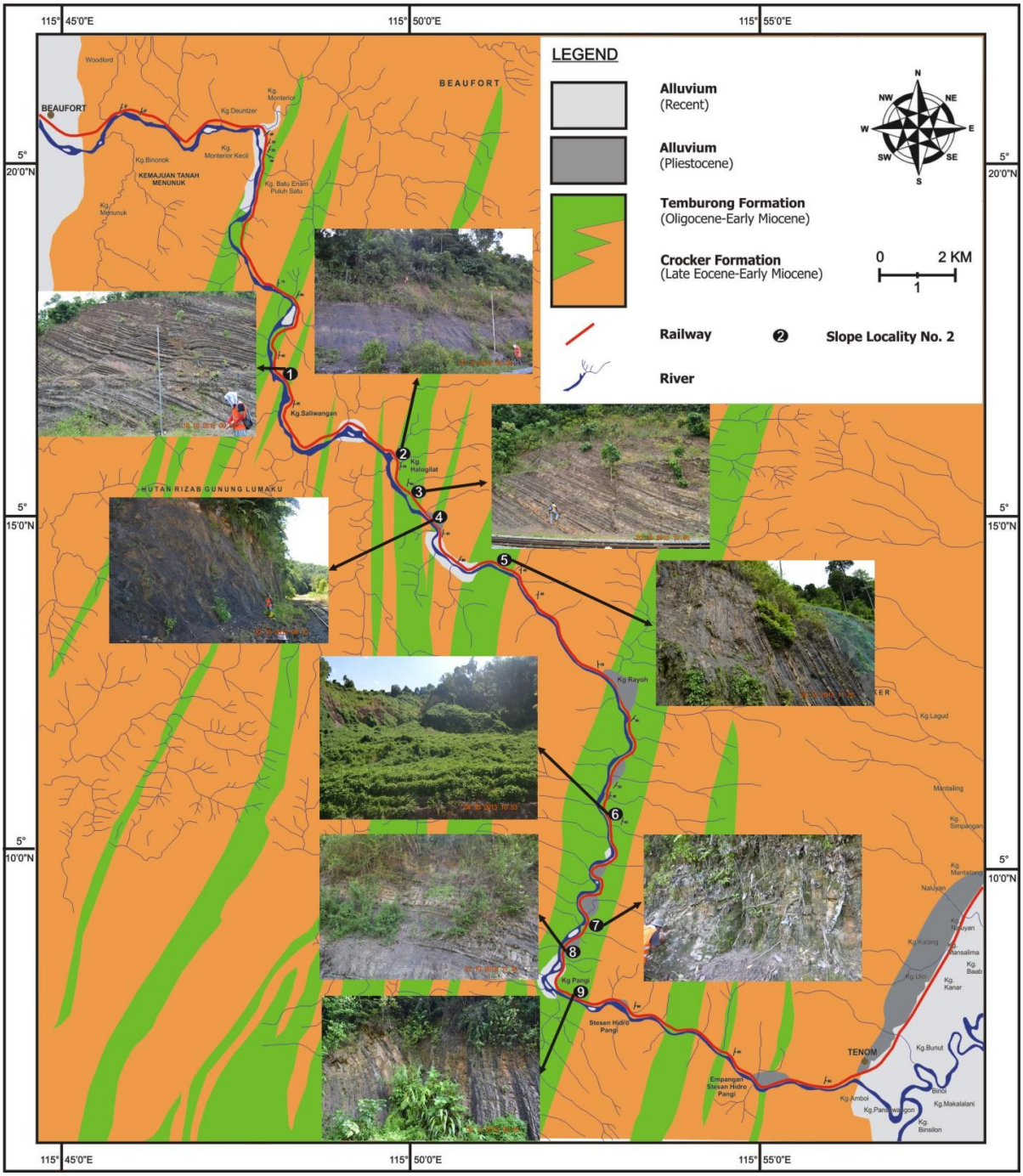

Figure 1 General geological map and slope locations of the Beaufort-Tenom railway area (modified from Wilson & Wong, 1954; Yin, 1985).

The Temburung formation was deposited by the age range from Oligocene to Early Miocene (Sanudin & Baba, 2007). The Temburong Formation is slightly different compare to Crocker Formation. It is composed of thick shale unit (Photograph 2A) and interbedded shale and sandstone unit with 3:1 (Photograph 2B), 1:1(Photograph 2C) and 1:3 (Photograph 2D) ratios.

Photo 2. Lithological unit of the Temburung formation. A- thick shale unit at S4; B- interbedded 3:1 shale and sandstone unit at S5; C- interbedded 1:1 shale and sandstone unit at S9; D- interbedded 1:3 shale and sandstone unit at S9.

The Pleistocene alluvium is a terrace deposit which composed of coarse gravel in most outcrops. The Holocene alluvium was deposited along the riverside and flood-plain areas.

RESULTS

The nine (9) slopes, rock mass characteristics and slope instability in the study area are shown in Figure 1 and Table 1. The rock masses are generally highly jointed, sheared and faulted. Seepage occurs in moderate to thick shale bed slopes. The persistence of discontinuity is very low except fot the bedding planes. The block size is small for sandstone beds but very small for thin sandstone and shale beds. The block shape is tabular to irregular. The highly weathered thick shale unit shows the rock mass as soil like and weak.

Observed instability features on the slope face are planes circular failure (Photograph 4A), wedge failure (Photograph 4B) and complex failures (Photograph 4C), debris deposits and rock blocks. Results of the Markland test are shown in Figure 2 and Table 2. The potential modes of failures are wedge, circular, planar and complex failures.

Table 1. Rock mass characteristics and instability observation.

Slope	Characteristics	Instability Observation
S1	Interbedded 1:3 shale and sandstone unit. Highly jointed and faulted. No seepage. Low discontinuity persistence. Small block size and irregular block shape.	Rock block, wedge failure
S2	Interbedded 3:1 shale and sandstone unit. Highly jointed and sheared. No seepage. Low discontinuity persistence. Small block size and irregular block shape.	Rock block, wedge failure, debris deposit
S3	Interbedded 1:3 shale and sandstone unit. Highly jointed and faulted. Seasonal seepage. Low discontinuity persistence. Small block size and irregular block shape.	Rock block, wedge failure, debris deposit
S4	Interbedded 3:1 shale and sandstone unit. Highly jointed, sheared and faulted. Water seepage occurs. Low discontinuity persistence. Very small block size and irregular block shape. Soil like.	Circular failure, debris deposit
S5	Shale thicker than sandstone unit. Highly jointed and faulted. Seasonal seepage. Low discontinuity persistence. Very small block size and irregular block shape.	Wedge failure, debris deposit
S6	Interbedded 3:1, 1:1 and 1:3 shale and sandstone units. Highly jointed, sheared and faulted. Seepage occurs. Low discontinuity persistence. Small block size and irregular block shape.	Circular failure, debris deposit (colluvium deposit)
S7	Interbedded 3:1 shale and sandstone unit. Highly jointed and faulted. Seepage occurs. Low discontinuity persistence. Small block size and irregular block shape.	Wedge failure, debris deposit
S8	Interbedded 1:3 shale and sandstone unit. Highly jointed and faulted. Seepage occurs. Low discontinuity persistence. Small block size and irregular block shape.	Wedge failure, debris deposit
S9	Interbedded 1:1 and 1:3 shale and sandstone units. Highly jointed and faulted. Seepage occurs. Low discontinuity persistence. Small block size and irregular block shape.	Wedge failure, debris deposit

Photograph 3. Slope failures. A – circular failure; B – wedge failure; C – complex failure.

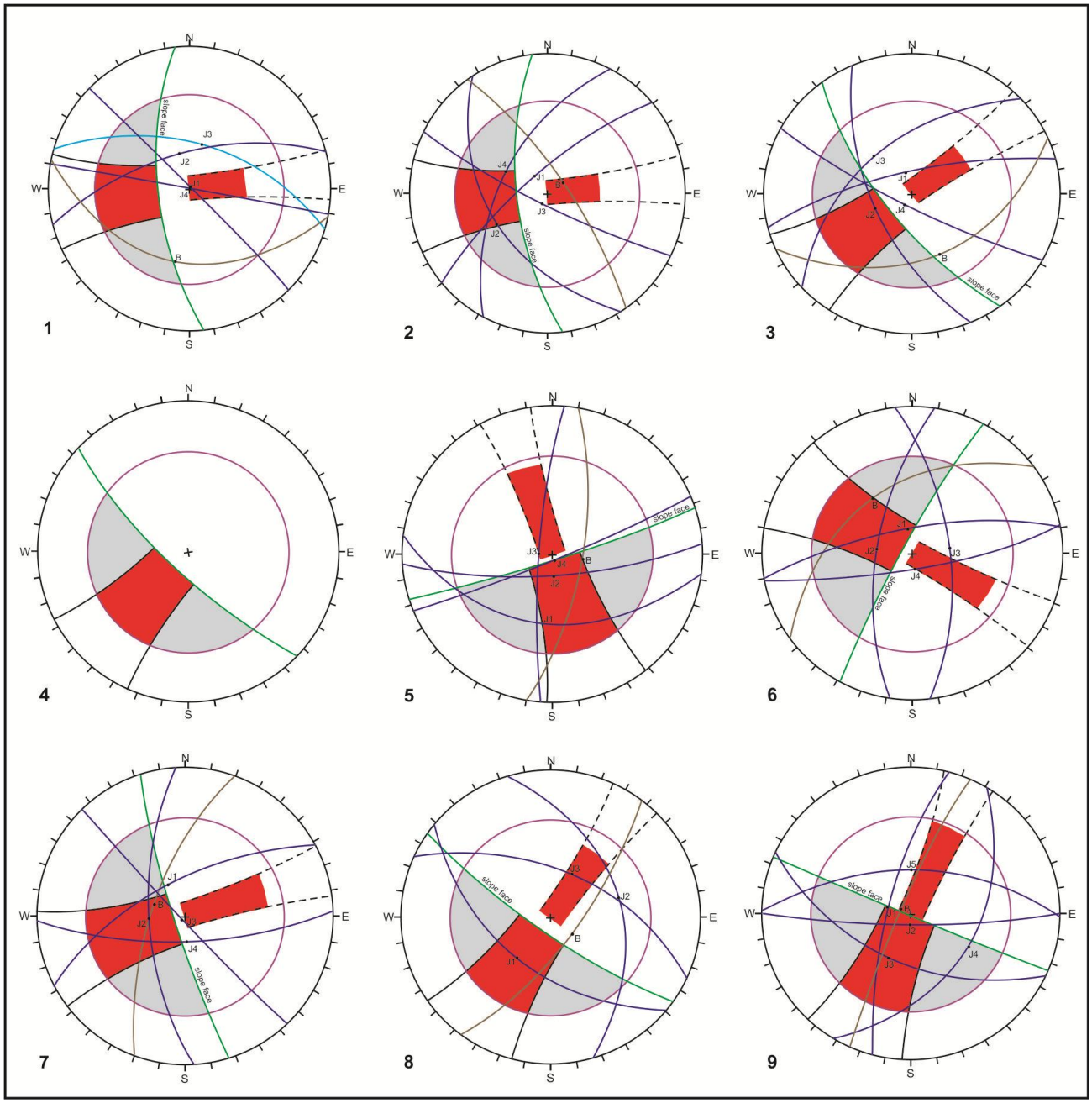

Figure 2. Markland test for slope 1 (S1) to slope 9 (S9). B- bedding; J1- joint 1; J2- joint 2; J3- joint 3; J4- joint 4; J5- joint 5; BJ3 – intersection of bedding and joint 3; BJ2 – intersection of bedding and joint 2; J1J2 – intersection of joint 1 and joint 2; J1J3 – intersection of joint 1 and joint 3; BJ1 – intersection of bedding and joint 1; J3 – discontinuity plane of joint 3.

Table 2. Slope geometry, mode of failure and instability.

Slope			Discontinuity plane or intersection	Mode of Failure	Slope stability
Slope	Orientation (^{o})	Angle (^{o})			
1	174	65	J4J2	W	Potential for W failure
2	170	64	J4J1 J4J2 J4J3 J1J2	W W W W	Possible for W failure and potential for Cx failure
3	143	69	J2 BJ3	P W	Potential for C and Cx failures
4	130	78	-	C	Potential for C failure
5	72	85	BJ1 BJ2 J3J2 J2	W W W P	Potential for W and Cx failures
6	209	82	J1J2	W	Potential for W and Cx failures
7	162	80	BJ2 BJ4 J1J4 J2J4 J2	W W W P	Potential for W and Cx failures
8	127	77	BJ1 J1	W P	Potential for P and Cx failures
9	113	88	BJ3 BJ2 J1J2 J1J3 BJ1 J3	W W W W W P	Potential for W, P and Cx failures

Note: W=Wedge; P=Planar; C=Circular; Cx=Complex; BJ3 – intersection of bedding and joint 3; BJ2 – intersection of bedding and joint 2; J1J2 – intersection of joint 1 and joint 2; J1J3 – intersection of joint 1 and joint 3; BJ1 – intersection of bedding and joint 1; J3 – discontinuity plane of joint 3

DISCUSSION

The Temburung Formation has varies engineering geological properties with two (2) to four (4) sets of joints including bedding planes. According to Markland's test, a plane failure is likely to occur when a discontinuity dips in the same direction (within 20°) with the slope face and at an angle gentler than the slope angle but greater than the friction angle along the failure plane.

A wedge failure may occur when the line of intersection of two discontinuities, forming the wedge-shaped block, plunges in the same direction with the slope face and the plunge angle is less than the slope angle but greater than the friction angle along the planes of failure. A toppling failure may result when a steeply dipping discontinuity is parallel to the slope face (within 10°) and dips into it (Hoek & Bray, 1981; Ismail Abd Rahim, 2011). Combination of more than two wedge failures or with other failures such as planar, toppling or circular will form a complex failure.

Intersection of J4 with J2, J1 with B, J1 with J2, J1 with J4 and J3 with B in slope 1, 5, 6, 7 and 9 contributes to the formation of wedge failures, respectively. The wedge failure is only possible in slope 2 because the differences between intersection lines and dip direction of slope faces for J4 with J1, J4 with J2 and J1 with J2 more than 20° but combination between these wedge failures will potential to form complex failure. Occurrences of

individual joint that parallel and daylight on slope face is also contribute to the formation of planar failures in slope 3, 5, 7, 8 and 9.

Combination of potential wedge failue with others potential and possible planar and wedge failures contribute to the formation of complex failures in slope 3, 5, 7, 8 and 9. Combination of planar and wedge failures in slope 5 was identified as the factor for huge complex failure on 7 April 2008.

Application of geological characteristics, properties of the rock mass and mode of failures to proposed remedial measures for rock cut slopes was used widely (Amin, 1999; Kentil & Topal, 2004; Ismail Abd Rahim *et al.*, 2010; Yu *et al*., 2005)). Summary of the slope protection and stabilization measures for the study area are shown in Table 4.

Table 4. Slope protection and stabilization measures.

Slope	Slope reprofiling	Gunite	Subsurface drainage	Weep hole	Terrace	Surface drainage	Wire mesh	Soil nail	Retaining structure
S1	/			/	/	/	/		
S2	/	/	/	/	/	/	/		
S3	/			/	/	/	/		
S4	/	/	/	/				/	/
S5	/	/	/	/			/	/	/
S6	/	/	/	/	/	/	/	/	/
S7	/	/		/	/	/	/		
S8	/			/	/	/	/		
S9	/			/	/	/	/		

Based on kinematic analysis, all slopes need to be reprofiling as well as instalation of weep holes due to the occurrences of shale layers. In the slopes where shale thicker then sandstone layers, subsurface drainage is required to reduce pore pressure behind slope face such as slope slope 2, 4, 5 and 6. Wire mesh is another option for most of the slopes as a retention structure and avoiding the rock block falling on the rail track except thick shale slope of slope 4. Dominan shale slopes of slope 2, 4, 5 and 6 can be protected from weathering, runoff and water infitration by guniting. High slopes of slope 1, 2, 3, 6, 7, 8 and 9 must be terraced and surface drainage to control runoff (erosion) and water infiltration. Soil nails and retaining structures need to be installed in thick shale and fails slopes such as slope 4, 5 and 6.

CONCLUSION

Conclusions of this study are;

1. The potential modes are wedge, planar, circular and complex failures.
2. Most of the rock cut slopes are unstable.
3. Slope reprofiling, guniting, subsurface drainage, drainage, wire mesh, soil nailing, terrace and retaining structure are proposed mitigation and stabilization measures.

REFERENCES

Amin, A. A. 1999. Geologic hazard along part of Al-sayl-Alkabeir Al-Jammun road in Saudi Arabia. *Environmental Geology*, **39 (1)**: 20-24.

Goodman, R. E. 1989. *Introduction to Rock Mechanics*. 2nd ed. John Wiley & Son, New York.

Hoek, E. & Bray, J. W. 1981. *Rock Slope Engineering.* 3rd ed. Institution of Mining and Metallurgy, London, 359pp.

Ismail Abd Rahim, Sanudin Tahir, Baba Musta & Shariff A. K. Omang. 2010. Slope Stability Evaluation of Selected Rock Cut Slope of Crocker Formation in Kota Kinabalu, Sabah. *Proceeding of the 3rd Southeast Asian Natural Resources and Environmental Management (SANREM 2010),* 3-5 August 2010, Promenade Hotel, Kota Kinabalu, Sabah.

Ismail Abd Rahim. 2011. *Rock mass classification system of the Crocker Formation in Kota Kinabalu for rock slope engineering purposes, Sabah*. PhD Thesis. Universiti Malaysia Sabah, Kota Kinabalu.

ISRM, 1981. *Rock Characterization, Testing and Monitoring*. *International Society for Rock Mechanics (ISRM) Suggested Methods*. In: Brown, E.T. (Ed.). Pergamon, Oxford. 211 pp.

Jeongi-gi Um & Kulatilake, P. H. S. W. 2001. Kinematic and Block Theory Analysis for Shiplock Slope of the Three Gorges Dam Site in China. *Geotechnical and Geological Engineering,* **19**: 21-42.

Kentil, B. & Topal, T. 2004. Evaluation on rock excavatability and slope stability along a segment of motorway, Pozanti, Turkey. *Environmental Geology,* **46**: 83-95.

Kliche, C.A., 1999. *Rock slope stability*. Society for Mining, Metallurgy and Exploration, Inc.

Markland, J. T. 1972. A Useful Technique for Estimating the Stability of Rock Slopes when the Rigid Wedge Slide Type of Failure is Expected. *Imperial College Rock Mechanics Research reprint*, n. **19**.

Rocscience. 2009. Dips 5.0 Graphical & Statistical Analysis of Orientation Data©2009. Rocscience Inc. http://www.rocscience.com.

Sanudin Tahir & Baba Musta, 2007. *Pengenalan kepada stratigrafi*. University Malaysia Sabah, Kota Kinabalu, Sabah.

Uribe-Etxebarria, G., Morales, T, Uriarte, J. A. & Ibarra V., 2005. Rock Cut Stability Assessment in Mountainous Regions. *Environmental Geology,* **48 (8)**: 1002–1013.

Wilson, R.A.M. and Wong, N.P.Y., 1960. The geology and mineral resources of the Labuan and Padas Valley area, Sabah, Malaysia. *Geol. Surv. Malaysia Mem.* **17**.

Yin, E. H., 1985. *Geological map of Sabah, East Malaysia*. 3rd ed. 1:25 000 scale, geol. Sury. of Malaysia

Yu, Y. F., Siu, C. K. & Pun, W. K. 2005. Guidelines on the use of prescriptive measures for rock cut slope. *Geo Report No.* **161**. Geotechnical Engineering Office, Hong Kong.