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Phenomenon of Slope Failure Occurrences along Gerik-Jeli Highway, Malaysia

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ABSTRACT

The structural development of the late Palaeozoic metamorphic rocks in the study area has become weak since Cretaceous deformations due to presence of discontinuity planes. Because of long exposure, the climatic factors and weathering process have caused the crop out of these rocks and have experienced failure and movements. The aim of this study is to determine direction of slope failures of the rocks based on structural interpretation. The geology of study area is dominated by low-grade metamorphic rocks, consisting of interbedded phyllite, schist and quartzite. The dip direction and dip amount of the beddings and joints were measured during fieldwork, the result were plotted and interpreted on the Schmidt net in order to recognize and characterise their structural pattern. The weathered rock slope is characterised by high angle joints (74-80°) with dip directions between 330° and 20°. The rocks folded with northwest trending fold axes with dip direction and dip amount of the beddings are 235°/25°, 246°/23° and 250°/24° and other bedding planes are 351°/25°, 352°/24°, 354°/24°. The joint orientations are approximately perpendicular to the direction of the beddings. Some reverse faults (55°/15°, 60°/22°, 75°/35°, 85°/45° and 87°/28°) also cut across the bedding planes. Based on the discontinuity and landslide analyses, the failure occurred along the easterly dipping of the discontinuities, intersecting with variably oriented releasing joints that give rise to planar, toppling and wedge failures.

Key words: Metamorphic rocks, weathered rock, slope failures, structural control

INTRODUCTION

Slope failure is a very common feature in tropical countries such as Malaysia, which is characterised by a humid, tropical region and thick weathering profile. The site of this study is located in the western part of Peninsular Malaysia, near the equator and within the wettest region of Peninsular Malaysia, where the Precipitation (P) minus Potential Evapotranspiration (PE) is greater than 1500 mm. The climate of this site reflects the general equatorial climate of Peninsular Malaysia and it is characterised by high average annual rainfall, temperature, evaporation and humidity. The annual rainfall in the study area ranges from 1,200-2,700 mm, with an average of 2,300 mm per year. The lowest monthly rainfall is 56 mm in February and the highest is 476 mm in October, for an average of 261 mm (Fig. 1). The lowest recorded temperature was 30°C in December 1996 and the highest was 36°C in April 1998, with an average monthly temperature of 33°C.

Structural data indicate the feasibility that both sliding and toppling has occurred along a deep-seated shear zone, accompanied by movement of a downslope extension of the moving mass. A rock-slope deformation was reported by

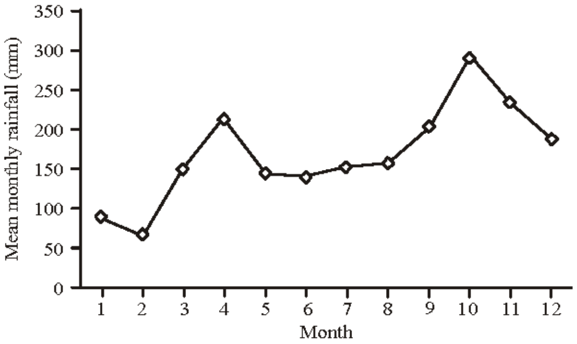

Fig. 1: Mean monthly rainfall derived from the RSP Ayer Banun Climatological Station (1990-2010)

Bovis (1990) from Affliction Creek, in the southern Coast Mountains of British Columbia; the rocks consist of monzonite basement and overlying Garibaldi-aged volcanic material that crop out on steep slopes, as the rock faces have strong planar jointing and are glacially undercut. Pritchard and Savigny (1991) described that variations in discontinuity orientations, hydraulic conductivity, RQD and shear fabric in rock masses may be the best predictable manifestations of toppling failure. The Gerik-Jeli Highway was constructed in the early 1980s to provide rapid access between the northwestern region and the eastern coast of the Malaysian Peninsula. The highway cuts across variably dipping sedimentary, metamorphic rocks and granitoids. Recently, numerous landslides have occurred in weathered cut-slopes; the failures occurred due to structurally controlled events. Rafek and Komoo (1989) and Jamaluddin (1991) conducted detailed discontinuity surveys and slope failure studies along the Gerik-Jeli Highway and they concluded that structurally controlled failures were dominant in this area. Rafek and Komoo (1989) added that the Gerik-Jeli Highway is one of the eight locations identified and declared by the Malaysian Public Works Department as a high-risk, landslide-prone area. Shuib *et al.* (2006) pointed out that the structural control process along the Gerik-Jeli Highway is the dominant factor that gave rise to planar, wedge and toppling failures. A complete slope failure classification has been proposed by Varnes (1978). Slope failures are classified into three main groups: Soil slope failures, rock slope failures and special types of failures (Komoo, 1985). Rock failures of the Crocker Formation in Sabah are due to the structural behaviour of the rock formation, which consists of folded, faulted and thrusted strata which has generated a series of landslides (Gasim and Brunotte, 1987). Nineteen years later, Roslee *et al.* (2006), continued studies on slope failures on rock formation of the Crocker Formation in surrounding Kota Kinabalu and they found that most of the failures were correlated with discontinuity problems. The objectives of this study are: (1) To determine geological characteristics in the study area: (2) To identify the structural behaviour of rocks and: (3) To interpret the direction of slope failure.

MATERIALS AND METHODS

After completion of the Gerik-Jeli Highway construction in the early 1990s, a serious slope movement occurred at 36.2 km in 1999. After slope reconstruction was completed in 2000, a serious rate of erosion along the discontinuity planes took place, followed by other slope disturbances that have broken the drains. The study area presented herein is located at Banding Island, approximately halfway between Gerik and Jeli (Fig. 2). The island is connected to the mainland by two bridges. Slope failures have been identified and they have occurred extensively in certain areas along the highway on the island; different structural characteristics on different rock components are likely to be the key contributors to the occurrence of slope failures.

A rock slope investigation was conducted on a terraced slope with an altitude of 385 m above sea level, or approximately 100 m from the ground. The slope contained 13 berms, each about 105 m long and 7-8 m high. Soil was the primary component of the corresponding hilltop, which contained vegetation that was 15-20 m thick, containing primarily bushes and bamboos, followed by a sequence of dense, weathered meta-sandstone about 20-30 m thick. Surface erosion was prevalent through the accumulation of sand and clay materials along the drain in the slope toes.

Methods: Detailed geological mapping during field observations were carried out to identify and determine trend of structural geology, weathering classification, geometry of the slope and types of failure.

The possible factors causing the slope failure were also investigated. In this study, geological characteristics of the slope, such as bearing and direction of the slope failures, the orientations of the structural discontinuity planes were identified. At least 100 readings of dip and direction of joints of the beddings were measured during the fieldworks in order to recognise and interpret their influence as part of structural control. In this slope measurement study, an approach on kinematic mechanism regarding slope failures, such as slope orientation and degree of slope face, discontinuity survey, plunge of intersection and friction angle, based on (Hoek and Bray, 1974) concept, were determined and analysed in order to interpret their structural discontinuity orientation relative to the mechanisms of slope failure. Observations on rock weathering during geological mapping were based on grading classification from Grade I for fresh rock to Grade V for soil/weathered rock (Matula, 1981).

RESULTS AND DISCUSSION

Geology of the study area: The profile of the slope in the present study area is characterized by low-to-medium grade metamorphic rocks, consisting of fine-to-medium grained quartzite, mica schist, hornblende schist, phyllite and thick meta-sandstone. Schist and phyllite are well established as problematic rock types, due to their strongly foliated surfaces and low durability (Best, 1982). Both rock types have weak segregation, with layering of felsic and mafic materials that generally augment the already strong schistosity expressed by lepidoblastic phyllosilicate mineral grains (Rafek and Komoo, 1989). Quartzite is composed primarily of quartz and sericite, biotite and traces of graphite. Mica schist contains predominantly quartz, orthoclase andesine and biotite, while hornblende schist consists of quartz, orthoclase andesine and hornblende. Phyllite consists of sericite, chlorite and clay minerals. These metamorphic rocks are deformed and folded around the northwest trending fold axes, consist of sequences of argillaceous and arenaceous rocks and belong to the Baling Group of the Lower Palaeozoic age (Jones, 1970;

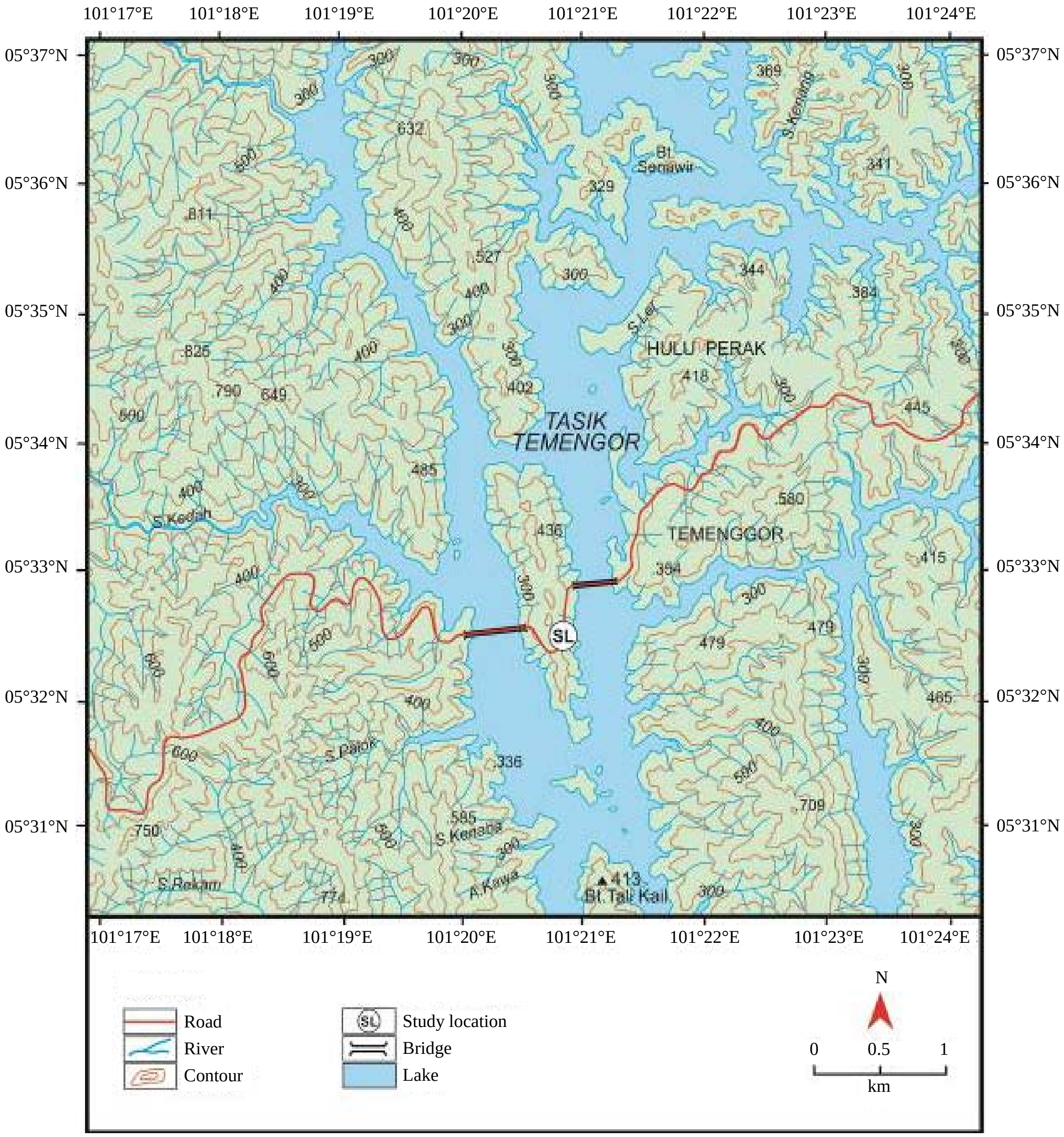

Fig. 2: Location of the study site at the banding island

Burton, 1970). Regional metamorphism has deformed the rock's sequence in the study area and it has become a constituent part of the Stong Complex (Hutchison, 1969; Singh *et al*., 1984).

Site description: After the 1999 major landslide, slope rehabilitation was carried out in the study area by terracing the slope. The present study emphasises the rock characteristics of each terrace (berm) that have an impact on soil erosion and minor slope failure and which cause the slope to potentially lose its strength. The variation of each berm, from the bottom (B.1) to the top (B.13), is characterised by varying lithologies, rock hardness, structural patterns and weathering grades (Fig. 3). Most of the beds have been deeply weathered to clayey soil and the rock weathered to orangey-brown silty clay or Grade III. These varying degrees of weathering are controlled by percentage concentration of structural discontinuity planes from one berm to another. The whole area on the top surface of the slope (berm 13) consists of soil (Grade V). The grade of weathering decreases from berm 12 (weathered rock) through berm 10 (intact weathered rock or Grade III) but in the middle of the slope, from berm 8 to berm 4, the exposure consists of complex structures of metamorphic rock, which may have caused the development of weak zones. Failure also commonly occurred via sliding along the wedges that plunge easterly, due to the intersection

Fig. 3: Slope profile of the study area consists of 13 berms

Fig. 4: Parallelism between the cleavage planes (top) and bedding planes

between the two differently oriented joint surfaces, where fault planes are followed by rapid tumbling of the failed mass down the slope. Finally, the major component of the foothill consisted of intact, but slightly weathered, metamorphic rocks, such as schist and phyllite, about 50-60 m thick.

Compression history: The geology of the study area was initiated by the development of folding at the NNW axis due to NNE compression during the Late Palaeozoic to Early Mesozoic deformation. The direction of the compression, based on the rosette diagram, is N44E and it is more promising, as the relationship between fold and joint/fault planes is positively related. Another deformation occurred during the Cretaceous period (Tjia, 1998) in an E-W compression direction. The later orogeny cut across the rocks and the previous fold axis by a NNE-trending lateral fault. The structural interpretation of the metamorphic rocks in the study area has been subjected to polyphase deformations, meaning that at least two phases of folding, with one fold axis trending NW-SE and another fold trending N-S, have been identified. The bed strikes NNW and SSE, with a dip steeply toward the SSW and ENE. It is also reported that a reverse fault system developed after brittle deformation occurred. The N-S fault zone is the youngest known fault zone in the study area, cutting across the young granitic rock and subsequently cut by a lateral fault system (Tjia, 1998). The direction N44°E was considered the main regional compression direction for the peninsula, because it was also recorded at Pulau Kapas (Gasim, 1988) and Terengganu (Gasim *et al*., 2010).

Structural analysis and interpretation: Most of the original sedimentary rocks in the study area have become metamorphosed to low-grade metamorphic rocks, such as schist, quartzite, phyllite and meta-sandstone, under two different compression directions during deformation. The first deformation was in a P1 (44-224°) direction, or NE-SW direction and it was responsible for the bedding formation and development of the northwest trending fold axes. The right-lateral fault (10°/88°) was formed during the late episode of the first deformation, with a position of 30° to P1. The second deformation was P2 with an E-W (90-270°) direction; this direction correlated with the development of a series of reverse faults in this area, in which the tensional joint had an orientation to the west, with higher dips (75-85°). The cleavage planes and foliation are sub-parallel to the bedding planes due to the same compression history and contortions give rise to warping of the strata (Fig. 4).

Although, the strata are irregular, they generally have a dip direction to the SW and NE. Reverse faults (55°/26°, 85°/45° and 87°/28°) (Fig. 5a) are thought to have occurred during the second deformation; they cut across the beddings (352°/24° and 235°/25°) and right-lateral fault plane (10°/88°). Development of the normal fault (155°/70°) at the end of the deformation (during brittle deformation) was characterised by a decrease in the stability of the rock components (Hobbs *et al*., 1976); it cut perpendicularly across the beddings, reverse faults and foliation planes and is considered to be the beginning of the development of the failure planes for the slope instability in the study area (Fig. 5b).

Analysis of discontinuities: The structural discontinuity data was plotted and interpreted on the Schmidt Net to obtain the relationships between the structural discontinuity planes and the directions of the failure. To estimate the slope stability, the relationship among slope face, plunge of intersection and friction angle are evaluated (Hoek and Bray, 1974) as follows:

$$\psi_f > \psi_i > \varphi$$

where, ψ_f is slope face, ψ_i is plunge of intersectionm, φ is friction angle.

Results of the measurements show that the slope face has dipped 60° and the dip direction is to the east, while the plunge of intersection is 45°, with an assumed friction angle of 30° located inside of dashed line (Fig. 6). The slope stability in the area is in the critical range, as ψ_i has a value between ψ_f and φ. In addition, the dip direction of ψ_i is parallel to the direction of

Fig. 5(a-b): Reverse fault was upthrusted the beddings to the (a) Left and (b) Normal displacement due to gravitational force

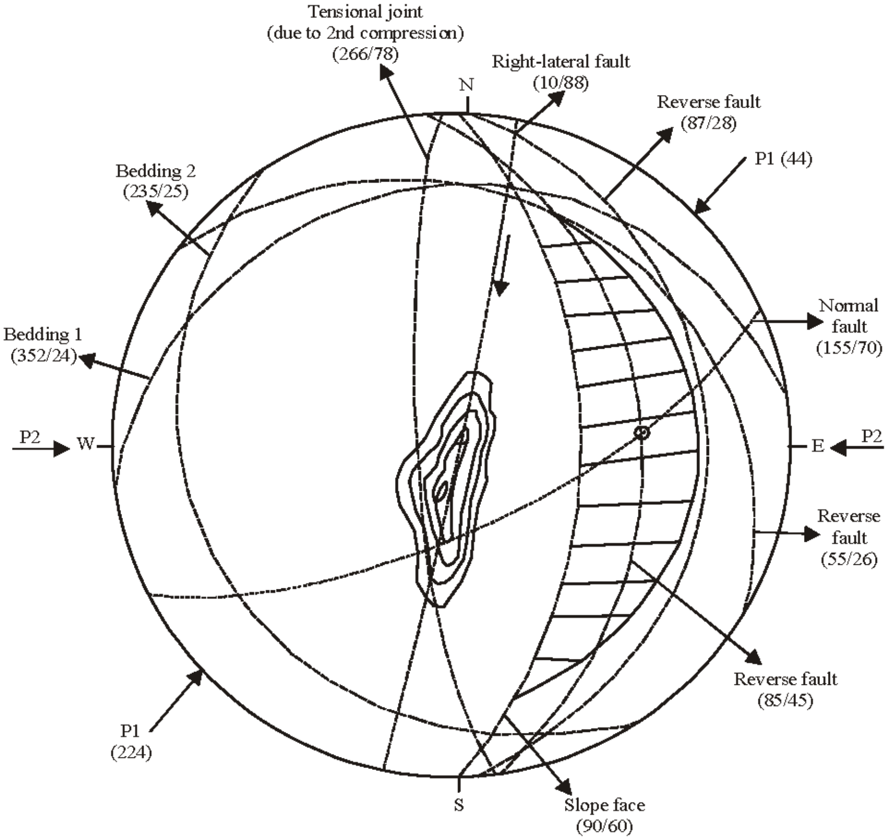

Fig. 6: A critical condition of slope, whereas, plunge of intersection located between slope face and friction angle

the slope and seepages flow out of the slope in several areas. Based on this concept, it was predicted that the slope would fail eastward, which is really occurred.

Landslide analysis: The slope of the study area is oriented in an eastward position or facing the road cutting, striking north-south and sloping 60° eastward. In certain instances, small landslides occurred in the form of wedge and toppling failures at berms 4 and 8. An additional concern is the slope face erosion, which can be seen as sand and clay accumulation along the slope drains. Dips of the slope face in the study area are in the easterly direction and the bedding plane has dips in the opposite (westward) direction (Fig. 7). Therefore, the problem associated with the "Day lighting" of a major

Fig. 7: Slope face dips to the east and the bedding plane dips to westward direction

discontinuity plane does not arise. However, due to the multiple deformations of the rocks, there exist a number of foliation and fracture planes with different orientations, resulting in the instability of the slope.

Bedding and foliation in the study area have a similar orientation (i.e., dipping to the west), but foliations are more steeply inclined, while all the fault orientations have a dip direction to the east, parallel with the slope face. Fragmented rocks, such as weathered phyllite and quartzite blocks, are exposed on the surface of the slope and subsequently detach from the rock mass, causing them to slide down the east slope at a rapid rate, accumulating rock debris at the slope toe. Observation of these landslides has indicated that failure occurs either along one plane of weakness or at the intersection of two planes. In the latter case, the unstable block is subject to planar, wedge and toppling failures.

CONCLUSION

Slope failures that occurred at 36.2 km, Gerik-Jeli Highway, were largely controlled by the unfavourable orientations of discontinuities with respect to the slope face, compounded by the weathered nature of the rocks in the area. This was determined based on the abundance of planar slides in the contained metamorphic rocks; most of their orientation was to the east and parallel to the slope face direction. Based on the discontinuity and landslide analyses, the failure occurred along the easterly dipping of the discontinuities, intersecting with variably oriented releasing joints that give rise to planar, toppling and wedge failures. The high intensity and frequency of rainfall helped to accelerate the weathering process and weakened the rock mass. Infiltration of water and a continuous flow of groundwater also contributed to weakening of the slope and the subsequent triggering of down-slope movement. The repeated occurrences of slope failures in the study area may be the result of inadequate attention to the structural features during landslide studies throughout the period of the previous site investigation and construction.

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REFERENCES

Best, M.G., 1982. Igneous Metamorphic Petrology. W.H. Freeman and Co., New York, Pages: 630.

Bovis, M.J., 1990. Rock-slope deformation at Affliction Creek, Southern Coast Mountains, British Columbia. Can. J. Earth Sci., 27: 243-254.

Burton, C.K., 1970. Geological Survey West Malaysia District Memoir 12: Geology and Mineral Resources of the Baling Area, Kedah and Perak. Geological Survey of Malaysia, Ipoh, Malaysia, Pages: 150.

Gasim, M.B. and D.A. Brunotte, 1987. Structural behavior of Crocker formation and its implication to landslides. Proceedings of the 9th Conference on Southeast Asian Geotechnical, December 7-11, 1987, Bangkok, Thailand, pp: 1-67.

Gasim, M.B., 1988. [Geological structure of Kapas Island, Terengganu]. Sains Malaysiana, 17: 3-15, (In Malay).

Gasim, M.B., I.B. Sahid, S.A. Rahim and E. Toriman, 2010. Characteristics of history, morphology and landform of the Dungun area, Terengganu, Malaysia with special reference to Bukit Bauk. Asian J. Earth Sci., 3: 213-221.

Hobbs, B.E, W.D. Mean and P.F. William, 1976. An Outline of Structural Geology. John Wiley and Sons Inc., New York, USA., ISBN-13: 9780471401568, Pages: 571.

Hoek, E. and J.W. Bray, 1974. Rock Slope Engineering. Institution of Mining and Metallurgy, London, UK., ISBN-13: 978-0900488214, Pages: 309.

Hutchison, C.S., 1969. Some notes on the Stong metamorphic complex, Kelantan. Geol. Soc. Malaysia Newslett., 21: 8-11.

Jamaluddin, T.A., 1991. [Discontinuity survey and rocks slope failure pattern at East-West Highway]. Bulletin of the Geological Society of Malaysia, Volume 29, pp: 207-245, (In Malay).

Jones, C.R., 1970. Geological Survey West Malaysia: District Memoir 11: The Geology and Mineral Resources of the Grik Area, Upper Perak. Geological Survey of Malaysia, Ipoh, Malaysia, Pages: 144.

Komoo, I., 1985. [Slope failure classification in Malaysia]. Jurnal Ilmu Alam, 14-15: 47-58, (In Malay).

Matula, M., 1981. Rock and soil description and classification for engineering geological mapping report by the IAEG commission on engineering geological mapping. Bull. Int. Assoc. Eng. Geol., 24: 235-274.

Pritchard, M.A. and K.W. Savigny, 1991. The Heather Hill landslide: an example of a large scale toppling failure in a natural slope. Can. Geotechn. J., 28: 410-422.

Rafek, A.G. and I. Komoo, 1989. [Slope failure at East-West Highway: Survey from Jeli to Sri Banding]. Warta Geol., 15: 167-179, (In Malay).

Roslee, R., S. Tahir and S.A.K.S. Omang, 2006. Engineering geology of the Kota Kinabalu Area, Sabah, Malaysia. Bull. Geol. Soc. Malaysia, 52: 17-25.

Shuib, M.K., S.H. Taib and M. Abdullah, 2006. Discontinuity controlled cut-slope failures on weathered low grade metamorphic rocks along the East-West Highway, Grik-to Jeli. Geol. Soc. Malaysia Bull., 52: 43-53.

Singh, D.S., C.L. Heng, T.L. Hock, P. Loganathan, E.J. Cobbing and D.I.J. Mallick, 1984. The stong complex: A reassessment. Bull. Geol. Soc. Malaysia, 17: 61-77.

Tjia, H.D., 1998. Meredian-parallel faults and tertiary basin of Sunda land. Bull. Geol. Soc. Malaysia, 42: 101-118.

Varnes, D.J., 1978. Slope Movement Types and Processes. In: Landslides: Analysis and Control, Schuster, R.L. and R.J. Krizek (Eds.). National Academy of Sciences, Washington, DC., USA., ISBN-13: 9780309028042, pp: 12-33.