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**Research Article**

# Rock Mass Assessment using Geological Strength Index (GSI) along the Ranau-Tambunan Road, Sabah, Malaysia

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**Abstract:** This study discusses the characterization of rock slopes along the 54 km road from Ranau to Tambunan (RTM), Sabah, Malaysia. Along this stretch, seven slopes were assessed, with two (B20 and B35) located in the Crocker Formation and the others (B4, B5, B7, B13 and B16) in the Trusmadi Formation. The Geological Strength Index (GSI) technique was used to characterize the weathering condition and rock structures of the slopes. These two parameters are used to assign a GSI value that will indicate the quality of the rock masses. From the finding, it was found that slopes located in the Trusmadi Formation have lower GSI values and poorer surface conditions compared to those in the Crocker Formation. Based on field observations, the slopes in the Trusmadi Formation are sheared, highly weathered and folded. The weathering grade for these slopes range from moderate to high and the GSI values range from 20-35. In comparison, the two slopes (B20 and B35) in the Crocker Formation exhibit lower weathering grades, fewer intersecting joints and GSI values from 60-80. Apart from the GSI assessment, rock specimens were tested using-the Point Load Index (PLI) test for strength measurement. The value from this test was later converted to UCS for strength classification. The lithologies tested are quartzite, meta-sandstone, sandstone and phyllite. Quartzite and meta-sandstone exhibit higher strength values than the other rock types. The rocks strength as observed in this study was influenced by the type of lithology, failure mode and by the weathering condition.

**Keywords:** Discontinuity, GSI, rock mass condition, rock slope, rock strength, weathering

## INTRODUCTION

Discontinuity and weathering are prominent in deteriorating the condition of rock masses, hence, reducing their quality. Both parameters or either one of them are commonly used in many rock mass investigations globally (Hack and Price, 1997; Ehlen, 2002; Osada *et al*., 2005; Santi, 2006; Borelli *et al*., 2007; Fahimdanesh and Moghadas, 2014) and have been incorporated in various rock assessment schemes (Selby, 1980; Bieniawski, 1973, 1989; Romana, 1993; Liu and Chen, 2007). Deterioration due to weathering may weaken the overall rock mass strength (Ali *et al*., 2013). Weathering degrades the surface condition of slopes, thus may cause local landslides, in particular where slopes with weak rock were excavated (Miščević and Vlastelica, 2014). Weathering and discontinuities interact with each other with water entering the slopes through the discontinuities. The presence of discontinuities such as joints will allow flowing waters to enter the rock mass that subsequently increase the rate of degradation along the joints and also inside the rock mass (Dochez *et al*., 2013).

This study focuses on characterizing rock slope properties along the Ranau- Tambunan road using the Geological Strength Index (GSI) published by Marinos and Hoek (2000). Both the discontinuity and weathering that affects the surface condition of rock masses will be assessed and quantified using the GSI

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chart. Besides the rock mass assessment in the field, the strength of the slope materials for each of the assessed slopes will also be tested in the laboratory.

## STUDY AREA

The study area is located along the 54 km stretch of the Ranau-Tambunan road in Sabah, Malaysia. Along this stretch, slope failures are common and occur in both soil and rock slopes. This road crossing through the Crocker and Trusmadi Formations is well known for its instability (Fig. 1).

Both the Crocker and Trusmadi Formations were deposited around the Paleocene to Eocene with the latter deposited during the Late Eocene (Jacobson, 1970). Although the study area is dominated by these two formations, Quaternary alluvium deposits can also be seen in some parts of the study area (Jacobson, 1970). The igneous rocks that consist of mainly granite and ultrabasic rocks are found dominantly in the vicinity of the Ranau district. The Trusmadi Formation rock sequence can be divided into four main lithological units; interbedded sequences (turbidites), argillaceous rocks, cataclasites and massive sandstones (Jacobson, 1970). The presence of well- stratified dark argillaceous sequence of siltstone and thin bedded turbidite in the Trusmadi Formation makes it distinct from the Crocker Formation. Low grade metamorphosed rocks such as slate, phyllite and quartzite were also presents in the Trusmadi Formations. In terms of structural orientation, NW-SE and NE-SW were the major orientations (Tongkul, 2007).

Jacobson (1970) categorized the Crocker Formation into four main lithological units; these units are thick bedded sandstone, thinly bedded sandstone and siltstone/shale, red and dark shale and slumped deposits. According to Roslee *et al*. (2006), the sandstone unit of the Crocker Formation is made of fine to very fine- grain texture but is highly fractured. They continued that the shale unit is normally of red and grey colours where the latter is occasionally calcareous and the shale layers are often sheared. In the thinly bedded sandstone and siltstone/shale, the thickness of the siltstone/shale layers are between 3 to 40 cm while the sandstone layer can be few centimeters to several meters thick. Sandstone beds usually show massive fracturing and jointing while the argillaceous beds frequently show signs of shearing (Roslee *et al*., 2011).

The alluvium unit is limited to the lowland areas and found close to Ranau and Tambunan townships. It mainly comprises of unconsolidated alluvial sediments on river terraces with unsorted to well-sorted sand, silt and clay of different thickness and proportions. The alluvium may also consist of a very thin layer of

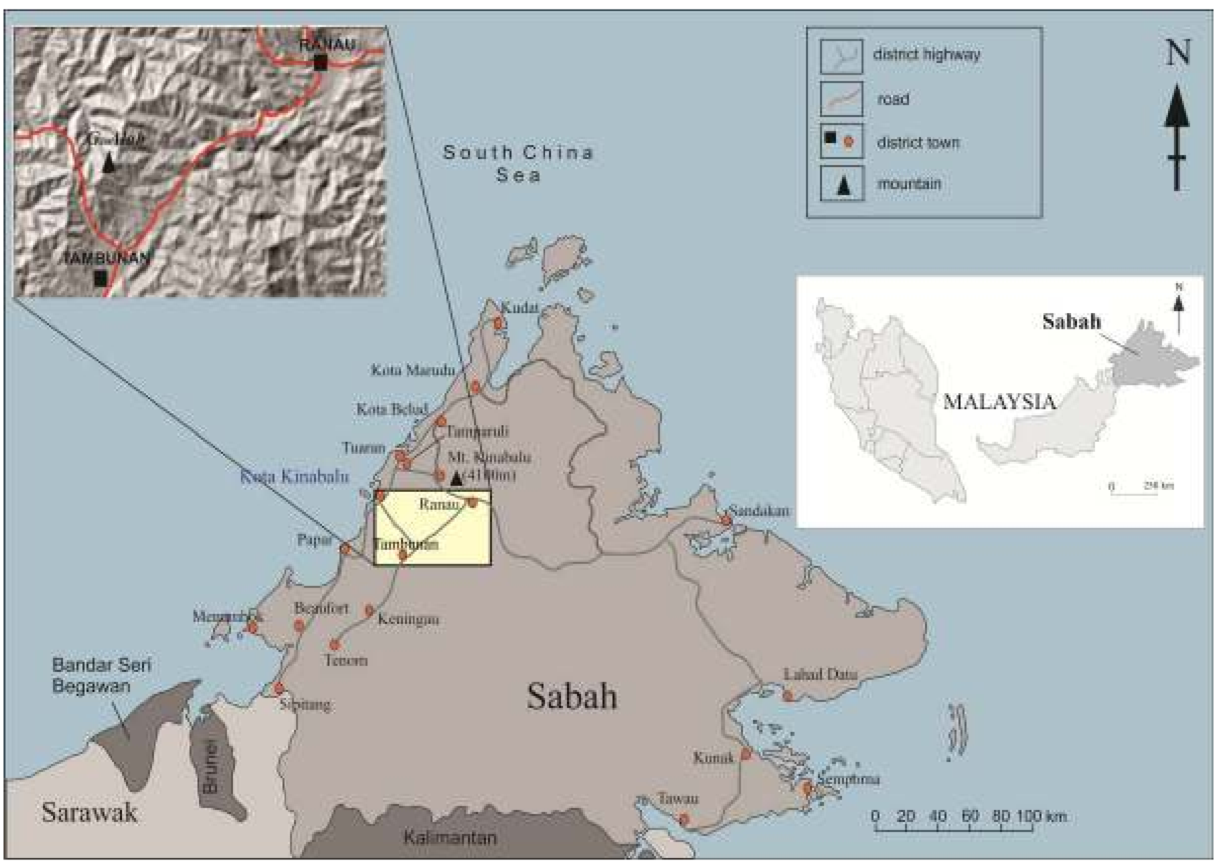


Fig. 1: The location of the study area (inset box)

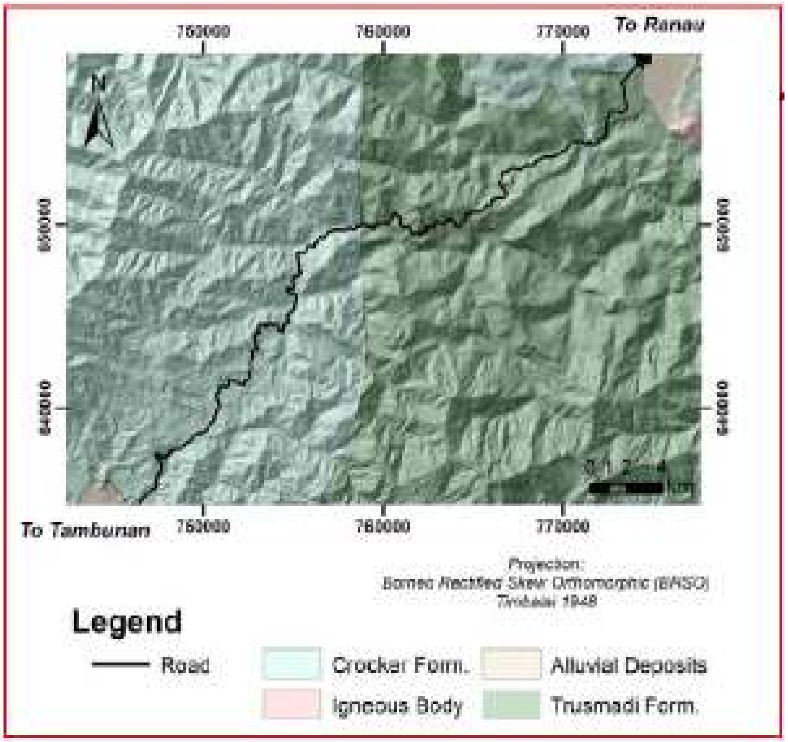


Fig. 2: Lithology map of the study area with the Ranau-Tambunan road crossing both the Crocker and Trusmadi Formations (modified from Yin, 1985)

organic matter. The alluvium sediment is soft, compressible and may be prone to settlement (Roslee *et al*., 2006, 2011). The lithology map of the study area is shown in Fig. 2.

## METHODOLOGY

The methodology employed in this study consists of two methods; measuring the rock strength using the point load index test and assessing the surface conditions of the rock masses in the field using the Geological Strength Index (GSI) scheme. Brief explanations on how each technique was applied in this study are given as follows:

**Point Load Index test (PLI):** A total of 19 rock samples were tested across various rock types. All samples were of irregular shapes and tested based on the testing procedure recommended by ISRM (2007). The rock strength obtained from testing was later classified into different categories according to the standards published by ISRM (1981) (Table 1). The equivalent UCS value from the PLI test was calculated based on the following equation:

$$UCS = 24 \times I_{s\,(50)}\ (MPa)$$ (Bieniawski, 1975)

**Geological Strength Index (GSI):** The Geological Strength Index (GSI) that was developed by Marinos and Hoek (2000) was used in this study as it gives easy, albeit subjective, measures of the rock mass surface conditions. The surface conditions, which measures in ‘GSI value’ can be estimated based on visual interpretation made in the field. The surface condition is classified based on their blockiness and types of rocks. Based on the GSI technique, the surface condition can be classified into five different categories: Very good, good, fair, poor and very poor (Marinos *et al*., 2005). To apply this technique in the field, firstly, the structure conditions (discontinuity) observed on the rock surface must be determined and subsequently followed by identifying the weathering condition experienced by the rock slope. By determining these two parameters in the field, the GSI values which give the qualitative measurement of the rock mass surface conditions can be acquired. In this study, the weathering grade (1, 2, 3, 4, 5) respond to the Very Good, Good, Fair, Poor and Very Poor

Table 1: Description of rock strength based on the point load index test and its equivalent UCS value

| Grade | Description | Equivalent UCS (MPa) |
|---|---|---|
| R0 | Extremely weak rock | 0.25-1 |
| R1 | Very weak rock | 1.0-5.0 |
| R2 | Weak rock | 5.0-25 |
| R3 | Medium strong rock | 25-50 |
| R4 | Strong rock | 50-100 |
| R5 | Very strong rock | 100-250 |
| R6 | Extremely strong rock | >250 |

Adapted from ISRM (1981)

respectively. The weathering grade of 6 is not included in the GSI chart because grade 6 is referred as soil (ISRM, 1981).

## RESULTS AND DISCUSSION

A total of eight rock slopes were assessed to obtain their physical and slope properties. Out of these eight slopes, four are failed slopes and the other four are stable slopes. In order to assess the rock mass properties, the GSI technique was employed. In addition to the field assessment, rock samples were tested in the laboratory for their strength. The distribution of the rock slopes assessed along the RTM are shown in Fig. 3.

**Description of the rock slopes:** The rock slopes consist of sedimentary and meta-sedimentary rocks; both massive and interbedded slopes are present. The common lithologies are siltstone, sandstone, shale, phyllite and quartzite. The descriptions of the rock slopes as observed in the field are shown in Table 2.

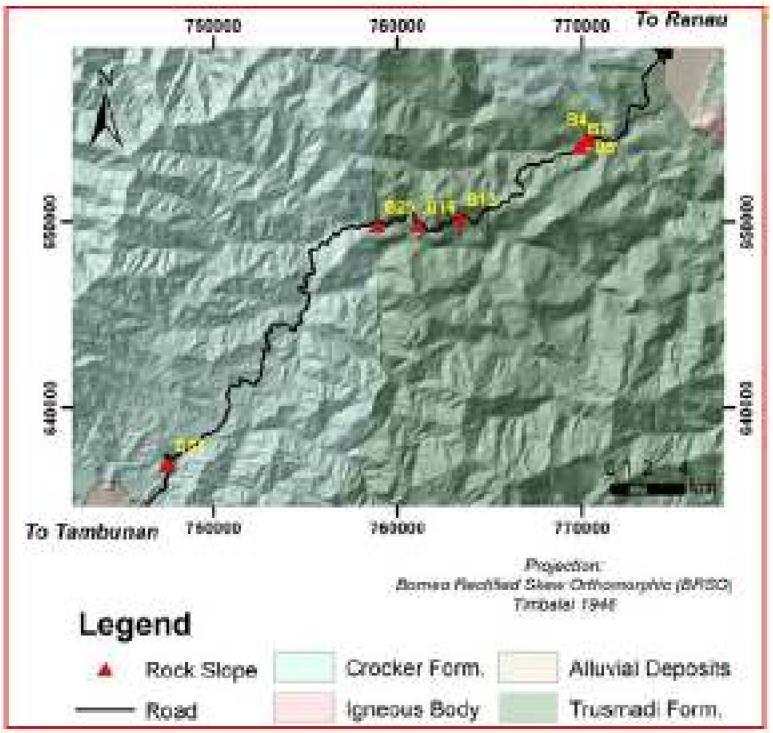


Fig. 3: Location of stations along the RTM. Two of the rock slopes were in the Crocker formation and the other five were in the Trusmadi formation (geology map modified from Yin, 1985)

Table 2: Rock slopes description as observed in the field for each station

| Station | Geological description |
|---|---|
| B4 | Interbedded of quartzite and phyllite. Bedding thickness varies from 5cm to 10cm. Weathering grade of the slope is around 3-5. No seepage was observed and small scale wedge failure was found in the middle of the slope. Debris at foot slope mostly originated from weathered phyllite. |
| B5 | The type of lithology is the same with B4 but bedding between phyllite and quartzite is not clear in this station. However, in certain parts of the slope, both lithologies were found. Wedge failure was observed on top of the slope. In terms of weathering, the grade is moderately to highly weathered (grade 4-5). No seepage was observed. |
| B7 | Only meta-sandstone with weathering grade of 4-5 was observed. However, bedding was still visible at the top of the slope. Intersecting of joint sets was the cause of wedge failure in this station. No seepage was observed. |
| B13 | Layers of meta-sandstone with thickness of 6cm to 15cm were observed. No phyllite material was found in this station. Weathering grade is 4-5 with rocks disintegrated into individual blocks. No seepage was observed. |
| B16 | The material at this station is chaotic without clear bedding structure. Only few parts of the slope shows visible bedding plane. Folding of quartzite in this station is clearly seen. Boulders and blocks of weathered quartzite were observed around the slope. The weathering grade of the slope is 3-4. No seepage was observed. |
| B20 | This slope consists of meta-sandstone with "daylighting" strata. Rockfall was observed during slope inspection with soil slide occurring at the top of the slope. The rock material is fresh with weathering grade of 1-2. Unlike other stations in the same rock formation, this rock slope shows closed joints that probably occurred during tectonic activity in the past. These joints are now filled with vegetation that can widen the opening of the joints and increase the chances of rock slide and rock fall in the future. |
| B35 | Bedding of sandstone with lamination is visible. The thickness of each layer varies from around 15cm to 25cm. The weathering grade as observed is 2-3. |

Table 3: Summary of the point load index test result with the equivalent UCS value for rock samples collected from the assessed rock slopes along the RTM

| Station | Sample no | Weathering (rock) | Rock tested | Rock Strength (MPa) PI | UCS* | Rock Classification** | Failure mode |
|---|---|---|---|---|---|---|---|
| B4 | 1 | 3-5 | Quartzite | 4.9 | 117.6 | Very strong | Material |
| | 2 | | | 4.18 | 100.32 | Very strong | Material |
| B5 | 1 | 4-5 | Quartzite | 2.11 | 50.64 | Strong | Material |
| | 2 | | Phyllite | 0.71 | 17.04 | Weak | Material |
| | 3 | | Phyllite | 1.07 | 25.68 | Medium strong | Material |
| B7 | 1 | 4-5 | Meta-sandstone | 0.96 | 23.04 | Weak | Discontinuity |
| | 2 | | | 0.37 | 8.88 | Weak | Discontinuity |
| | 3 | | | 1.92 | 46.08 | Medium strong | Material |
| B13 | 1 | 4-5 | Meta-sandstone | 0.67 | 16.08 | Weak | Discontinuity |
| | 2 | | | 0.86 | 20.64 | Weak | Discontinuity |
| | 3 | | | 0.28 | 6.72 | Weak | Discontinuity |
| B16 | 1 | 3-4 | | 5.62 | 134.88 | Very strong | Material |
| | 2 | | Meta-sandstone | 5.51 | 132.24 | Very strong | Material |
| | 3 | | | 3.73 | 89.52 | Strong | Material |
| B20 | 1 | 1-2 | Sandstone | 3.84 | 92.16 | Strong | Material |
| | 2 | | | 1.13 | 27.12 | Medium strong | Discontinuity |
| B35 | 1 | | Sandstone | 0.28 | 6.72 | Weak | Material |
| | 2 | 2-3 | | 0.41 | 9.84 | Weak | Material |
| | 3 | | | 0.68 | 16.32 | Weak | Material |

*: UCS value obtained by conversion from the PLI test; **: Rock strength classified based on ISRM (1981)

**Rock strength properties:** The PLI test was used to measure the rock strength of material collected from each of the rock slopes and later was converted to the equivalent UCS value for rock strength classification purpose based on the ISRM (1981). Quartzite shows consistent strong to very strong rock strength, phyllite and meta-sandstone show varying strength from weak to very strong across the assessment stations. The sandstone samples tested from the B35 station that is located in the Crocker Formations are categorized as weak rock. The rock strength varies depending on the way they failed when tested. Rocks failed because of micro-discontinuity have lower strength than rocks that are failed because of their material. The test results are summarized in Table 3 with the equivalent UCS value derived from the point load index test.

The point load index test was not conducted on the shale and siltstone samples due to their highly weathered condition. The samples crumbled when tested. Due to this reason, the rock strength for both siltstone and shale will not be discussed in this section. Weathering slightly influences the rock strength; Station B4 and B5 for example consist of quartzite but their strength differs although the modes of failure for both lithologies are the same. Quartzite in station B4 is stronger and has a weathering grade of 3-4, whereas the weathering grade for the same rock type in Station B5 is categorized as 4-5.

**Geological Strength Index (GSI) assessment:** Based on the slope inspection, there are two to three joint sets that are visible for all slopes. Based on field observations, bedding and fold structures are one of the main causes of rockslides due to their "daylighting" planes from the slope (Fig. 4). All of these rock slopes either have failed completely, failed on some parts of the slopes or show potential for failure. Station B20 for example shows a moderately fresh rock but due to the nature of its daylighting discontinuities, rockfall is observed at the foot slope of this station.

Fig. 4: Rockslide causes by out-dipping of joint planes at station B20

Difficulties to determine the pattern and number of joint sets were encountered in slopes where rock and soil co-exists. Stations B5 and B7 for examples are failed slopes that consist of both rock and soil. Although this complexity arises, the joint set is still recognizable especially at the top parts of the slopes, where failures occurred and are controlled by two intersecting joint sets. Rock slopes with their joint sets and patterns are given in Fig. 5 with their summary in Table 4. These joint patterns are one of the main inputs besides the weathering conditions of that are used to assign the GSI value for each station.

Based on the weathering conditions described in Table 2 and joint patterns and sets in Table 4, the GSI value for each station was determined (Fig. 6). From

Table 4: Joint sets and patterns as observed in the field for each of the rock slopes

| Station | Joint pattern and set |
|---|---|
| B4 | Two sets. Mainly bedding plane with fault crossing through the failed section of the slope. |
| B5 | Three sets with day lighting bedding plane |
| B7 | Two sets with day lighting bedding plane |
| B13 | Two sets. |
| B16 | Three sets. |
| B20 | Three joint sets with two closed joints and one day lighting plane |
| B35 | Three joint sets |

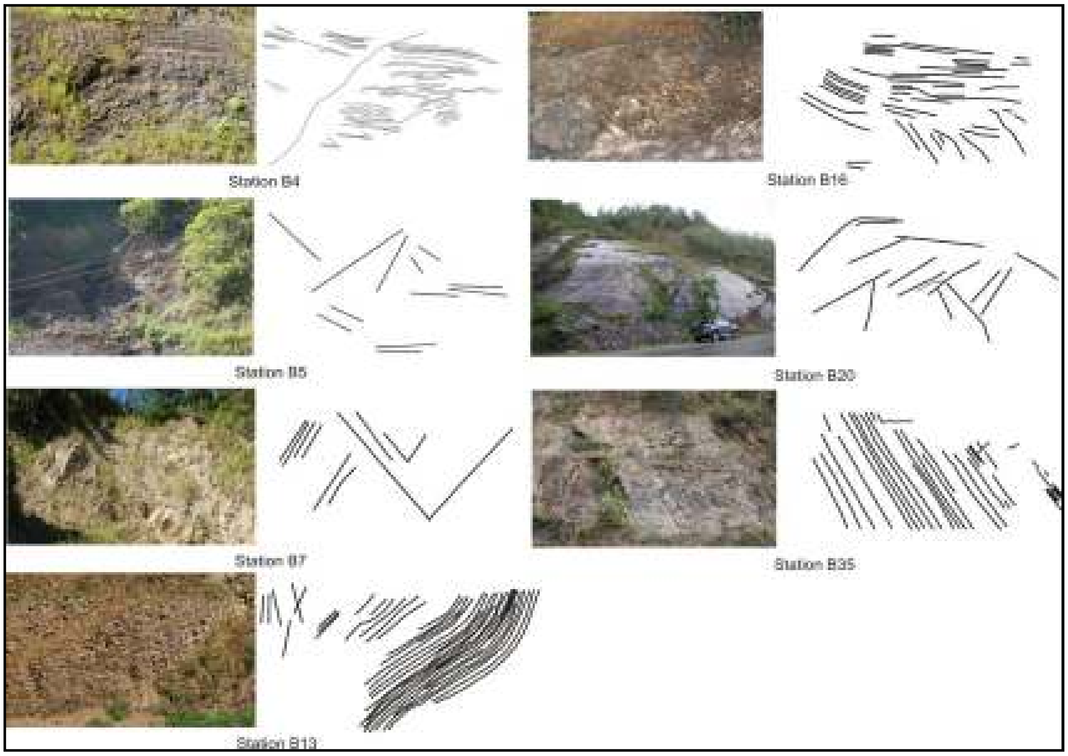


Fig. 5: Rock outcrops and their joint patterns

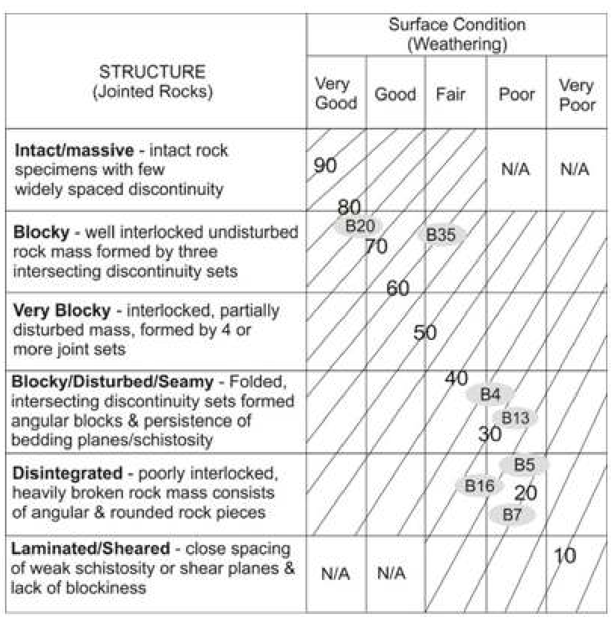


Fig. 6: The assignment of each station on the GSI chart for jointed rock (charts modified from Marinos *et al*., 2005)

Table 5: The overall results for the seven rock slopes assessed in this study

| Station | Sample no | Rock tested | Rock strength classification* | Weathering** | Rock structure** | GSI value | Failure mode |
|---|---|---|---|---|---|---|---|
| B4 | 1 | Quartzite | Very strong | Fair-poor | Disturbed/seamy/folded | 30-35 | Material |
| | 2 | | Very strong | | | | Material |
| B5 | 1 | Quartzite | Strong | Poor-very poor | Disintegrated | 20-25 | Material |
| | 2 | Phyllite | Weak | | | | Material |
| | 3 | Phyllite | Medium strong | | | | Material |
| B7 | 1 | Meta-sandstone | Weak | Poor | Disintegrated | 20-25 | Discontinuity |
| | 2 | | Weak | | | | Discontinuity |
| | 3 | | Medium strong | | | | Material |
| B13 | 1 | Meta-sandstone | Weak | | Disturbed/seamy/folded | 25-30 | Discontinuity |
| | 2 | | Weak | Poor | | | Discontinuity |
| | 3 | | Weak | | | | Discontinuity |
| B16 | 1 | Meta-sandstone | Very strong | Fair-poor | Disintegrated | 25-30 | Material |
| | 2 | | Very strong | | | | Material |
| | 3 | | Strong | | | | Material |
| B20 | 1 | Sandstone | Strong | Very good-good | Blocky | 75-80 | Material |
| | 2 | | Medium strong | | | | Discontinuity |
| B35 | 1 | Sandstone | Weak | Good-fair | Blocky | 60-65 | Material |
| | 2 | | Weak | | | | Material |
| | 3 | | Weak | | | | Material |

* Based on UCS value obtained by conversion from the PLI test; ** Based on GSI chart

the figure, two of the stations (B20 and B35) were categorized in the very good to fair weathering condition and blocky with the GSI values of 60-65 and 70-75 respectively for both stations. These observations indicate that both of these stations have better conditions than the other five stations (B4, B5, B7, B13 and B16) that are clustered around in the fair to poor weathering conditions with disintegrated to blocky/disturbed joint structures. The GSI values for the five stations are lower ranging from 20 to 35.

The similarity between the stations B20 and B35 are that they both are in the Crocker Formation which comprises of sedimentary rocks such as sandstone, siltstone and shale. On the contrary, the other five stations are located in the Trusmadi Formation, which are dominated by sheared met-sedimentary rocks such as phyllite, quartzite and slate. The poor condition of these slopes in the Trusmadi Formation is due to high weathering and shearing processes that have occurred in the past. Due to the tectonic activity in the past, rocks in this formation have been sheared, folded and broken into pieces, as the name implies in the local language as the 'broken formation' (Müller, 1991). The shearing experienced by this formation has resulted in many landslide occurrences in the Trusmadi Formation as discussed in Roslee *et al*. (2010). Therefore, the highly weathered and sheared materials contribute to the low GSI values of the five stations (B4, B5, B7, B13 and B16). Table 5 summarizes the overall results obtained from this study.

## CONCLUSION

GSI assessment on seven rock slopes has been conducted along the Ranau- Tambunan Highway. From the assessment, five slopes (B4, B5, B7, B13 and B16) which are located in the Trusmadi Formation were classified into the disintegrated to disturbed/ seamy/ folded rock structure with weathering condition from fair to very poor. Out of these five slopes, two have failed. The other two rock slopes (B20 and B35) which are located in the Crocker Formation show better GSI value and blocky rock structure with fair to very good weathering condition.

This study considers that the low GSI value and unfavorable surface condition of the five slopes in the Trusmadi Formation were due to the shearing processes which occurred as a result of tectonic activities in the past apart from their lithologies which are easily weaken when weathered. Although the B20 and B35 slopes have better condition than the other five slopes, they are still susceptible to failure especially on slope B20 where the dipping plane is daylighting (i.e., facing on the road).

In terms of the rock strength, it varies for the different lithologies. Their strengths were influenced by weathering conditions and also by the presence of micro-fractures in the rock specimens. Rocks that failed along the micro-fracture line exhibit lower strength values than rocks that failed because of their material. Rocks with higher weathering condition also exhibit lower rock strength than rocks that were relatively fresh. This is evident when same rocks from different slopes failed under the same failure mode but displayed different strength.

The GSI technique offers a simple guided procedure for rock mass assessment in the field. The variables provided by this technique guide researchers to assess the behavior of rock masses in the field. Hence, the interaction between variables can be explained clearly (Marinos *et al*., 2005). The results obtained in this study enable researchers to understand the influence of lithologies, discontinuity and the effect of tectonic activity on the conditions of rock slopes. The GSI technique was successfully applied in this study to reveal the condition of the rock slopes that were affected by these elements.

## ACKNOWLEDGMENT

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## REFERENCES

Ali, S., G. Ivan and D.H. Kim, 2013. Rock slope stability problems in Gold Coast area, Australia. Int. J. Geomate, 4(1): 501-504.

Bieniawski, Z.T., 1989. Engineering Rock Mass Classifications. John Wiley and Sons, New York, pp: 251.

Bieniawski, Z.T., 1973. Engineering classification of jointed rock masses. Trans. Inst. Civil Eng. South Afr., 15(12): 335-344.

Bieniawski, Z.T., 1975. The point load test in geotechnical practice. Eng. Geol., 9(1): 1-11.

Borelli, L., R. Greco and G. Gullà, 2007. Weathering grade of rock masses as a predisposing factor to slope instabilities: Reconnaissance and control procedures. Geomorphology, 87: 158-175.

Dochez, S., F. Laouafa, C. Franck, S. Guedon, F. Martineau, M. Bost and J. D'Amato, 2013. Influence of water on rock discontinuities and stability of rock mass. Proc. Earth Planet. Sci., 7: 219-222.

Ehlen, J., 2002. Some effects of weathering on joints in granitic rocks. Catena, 49: 91-109.

Fahimdanesh, S. and N.H. Moghadas, 2014. Geomechanical characteristics of the rock mass of giladeh mine. Res. J. Environ. Earth Sci., 6(10): 475-481.

Hack, R. and D. Price, 1997. Quantification of weathering. In: Marinos, P.G., G.C. Koukis, G.C. Tsiambaos and G.C. Stournaras (Eds.), Engineering Geology and the Environment. Proceedings of an International Symposium of the IAEG. Athens, Greece, pp: 145-150.

ISRM, 1981. Rock Characterization Testing and Monitoring. ISRM Suggested Methods. International Society for Rock Mechanics. Pergamon Press, Oxford, pp: 32.

ISRM, 2007. The Complete ISRM Suggested Methods for Characterization, Testing and Monitoring: 1974-2006. ISRM Turkish National Group, Ankara, pp: 53-61.

Jacobson, G., 1970. Gunong Kinabalu area, Sabah, Malaysia. Geological Survey Malaysia, Report 8.

Liu, Y.C. and C.S. Chen, 2007. A new approach for application of rock mass classification on rock slope stability assessment. Eng. Geol., 89: 129-143.

Marinos, P. and E. Hoek, 2000. GSI: A geologically friendly tool for rock mass strength estimation. Proceeding of the International Conference on Geotechnical and Geological Engineering. Melbourne, Australia, pp: 1422-1442.

Marinos, V., P. Marinos and E. Hoek, 2005. The geological strength index: applications and limitations. B. Eng. Geol. Environ., 64: 55-65.

Miščević, P. and G. Vlastelica, 2014. Impact of weathering on slope stability in soft rock mass. J. Rock Mech. Geotech. Eng., 6(3): 240-250.

Müller, C., 1991. Biostratigraphy and geological evolution of the Sulu Sea and surrounding area. In: Silver, E.A., C. Rangin, M.T. Von Breymann *et al*. (Eds.), Proc. ODP, Sci. Results. Ocean Drilling Program, College Station, TX, 124: 121-132.

Osada, M., A. Funato, R. Yoshinaka, H. Ito, T. Kitagawa, K. Sasaki, K. Aoki, O. Aydan, S. Akutagawa, H. Kiya, K. Kuwahara, M. Seto, S. Tanaka, K. Tani, T. Mimuro and T. Mori, 2005. Geotechnical description and JGS engineering classification system for rock mass. Int. J. Jpn. Committee Rock Mech., 1(1): 7-17.

Romana, M.R., 1993. A Geomechanical Classification for Slopes: Slope Mass Rating. In: Hodson, J.A. (Ed.), Comprehensive Rock Engineering. Pergamon Press, Oxford, 3: 575-600.

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

Roslee, R., S. Tahir, B. Musta and A.K. Omang, 2010. Geological inputs for Landslide Hazard Identification (LHI) in the Trusmadi formation slopes, Sabah, Malaysia. Borneo Sci., 26: 37-51.

Roslee, R., S. Tahir, S.A.K.S. Omang and A. Laming, 2011. Survey of Slope Failures (SFS) along the Bundu Tuhan Kundasang Highway, Sabah, Malaysia. Borneo Sci., 29: 46-59.

Santi, P.M., 2006. Field methods for characterizing weak rock for engineering. Environ. Eng. Geosci., 12(1): 1-11.

Selby, M.J., 1980. A rock mass strength classification for geomorphic purposes: With tests from Antarctica and New Zealand. Z. Geomorphol., 24: 31-51.

Tongkul, F., 2007. Geological inputs in road design and construction in mountainous areas of West Sabah, Malaysia. Proceeding of the 2nd Malaysia-Japan Symposium on Geohazards and Geoenvironmental Engineering. City Bayview Hotel, Langkawi, pp: 39-43.

Yin, E.H., 1985. Geological Map of Sabah. 3rd Edn., Geological Survey of Malaysia, Malaysia.