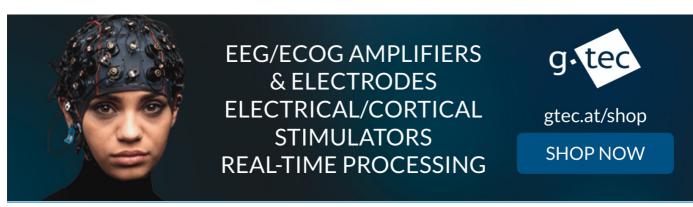PAPER • OPEN ACCESS

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Slope stability analysis of rock mass using Rock Mass Rating and Slope Mass Rating

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Abstract. The rapid development in the construction of infrastructure on the hilly terrain has led to excavation of large bodies of rock mass to form cut slopes, resulting in the deformation and reduction in the stability of the rock material. As the slopes were cut more than 10 years ago, it is worried that there should be strength deterioration of the rock slope that could affect the stability of the slope. A study should be carried out to evaluate the recent condition of the slope in terms of its stability and safety after a long period of the exposure. A field study was conducted to collect the discontinuity data and laboratory test for the purpose of stability analysis using the existing stability analysis scheme of Rock Mass Rating (RMR) and Slope Mass Rating (SMR). The study was taken place at an exposed cut slope of a highway in Sri Jaya, Pahang. The objective of this study is to determine and evaluate the stability of the rock cut slope. A classification of the discontinuity parameters such as the strength, Rock Quality Designation (RQD), spacing, aperture, infilling, persistence, weathering, and groundwater have been used to determine the rock mass condition. The classification also need laboratory test for the point load strength (PLT) parameter. The RMR classification showed the rock to be very good condition, while the SMR showed the slope to be completely stable to stable. This study provide a good database in assessing the rock slope condition from time to time for the slope authority management.

Keywords: Rock slope stability, Rock mass rating, Slope mass rating

1. Introduction

Presently Malaysia is experiencing massive growth in its developments and constructions. This includes the development of rock slopes for the construction of infrastructures especially roads and highways. Rock slopes are susceptible to instability and failure problems cause by the difference in the rock mass conditions and external factors that are affected by the environments such as seismic activities and the presence of subsurface water. In order to mitigate the risk of rock slope failure from occurring the foreseeable future, the rock slope stability assessment is an important aspect to be looked by the authority of the infrastructures [1]. Insufficient investigation of rock slope stability can lead to damage of properties, increasing maintenance cost and causing injuries and fatalities.

Rock slope stability can be considered as one of the most important component in the development of rock and soil mechanics. Proper investigations by engineering geologists or geotechnical engineers are

needed to reduce the potential of slope failure from occurring and to ensure safe construction and development. Rock mass characterization is an important part in the investigation of rock slope stability. The study of slope stability for rock mass characterization includes the strength of rock, condition of discontinuities and groundwater. To achieve the objective, rock mass classification can be used as a guide for planners and developers to forecast possible failures and come out with the best ways possible to overcome the problems for the construction and the development of structures [2]. The rock mass classification, which represent one of the empirical method for slope stability assessment, is applicable to many rock engineering related projects such as tunnels, road and slope stability analysis [3]. With the availability of more data and in-depth studies of a site, a deeper understanding on the slope's stability and potential for slope failures can be determined.

One of the most well-known and widely used rock mass classification is the Rock Mass Rating (RMR), developed by [4]. The original RMR system by [5] contains five parameters that represent the different condition of rock and discontinuities: strength of intact rock material (uniaxial compressive test (UCS) or point load strength) (R_δ), rock quality designation (RQD) (R_{RQD}), spacing between discontinuities (R_{SD}), condition of discontinuities (R_{CD}), and groundwater condition (R_{CG}). The parameter by [6] with a more detailed RCD parameter is preferred for a more accurate description of the discontinuity condition of the rock mass. RMR is calculated by the formula:

$$RMR = R_\delta + R_{RQD} + R_{SD} + R_{CD} + R_{CG} \tag{1}$$

The drill core RQD was developed by [7] that preceded the RMR classification. It is defined as the percentage of intact piece in core sample that are longer than 100 mm. In the field, where core sample is not presented, the parameter was calculated using the formula by [8]:

$$RQD = 100e^{-\lambda t}(\lambda t + 1) \tag{2}$$

$$\text{where } \lambda = \text{no of discontinuities along scanline (n) / length of scanline (L)} \tag{3}$$

For cut rock slope, the Slope Mass Rating (SMR) is used for the stability analysis. This classification was created by [9] by modifying the SMR to include parameters that are related to discontinuity orientation. For SMR, there is a need to identify the different types of potential mode of failure of a slope before calculating the final value of the system. In order to apply the parameters for the classification, kinematic analysis needs to be carried out to identify the potential mode of failure in the slope. SMR were calculated using formula

$$SMR = RMR + (F1 \text{ X } F2 \text{ X } F3) + F4 \tag{4}$$

where the adjustment parameters for discontinuities based on the potential mode of failure (F1-F3) and an adjustment parameter for the type of exaction for slope (F4) [10-11] were calculated.

The objective of this study is to characterize the rock mass condition of the slope and to determine the stability of the slope. This involves the application of RMR and SMR as the methods to analyse and study the stability of selected large exposed slope from Sri Jaya area, Pahang. From this study, the characteristics of the rock slope could be obtained, where it can then be determined whether the slope is safe and stable.

2. Methodology

2.1. Field data collection
Field work was carried out to characterize the rock slope and to obtain the discontinuity data required for rock mass rating and slope mass rating. The discontinuity data was obtained using the scanline survey method. The purpose of carrying out the scanline survey is to measure the discontinuities along the slope face. Measuring tape was placed along the rock face with exposed discontinuities of joints

and faults (Figure 1). Each discontinuity that intersects with the tape along the distance was recorded in the scanline survey logging form. For RMR, the parameters collected are the strength (point load test/PLT), RQD, spacing of discontinuities, condition of discontinuities (persistence, aperture, roughness, infilling, weathering), and groundwater condition [6].

Figure 1. Scanline measurement along slope face

The discontinuity orientation data was later analysed using software Dips [11] to predict the potential rock failure through kinematic analysis. The other data obtained using the scanline survey method was input into the Rock Mass Rating (RMR) and Slope Mass Rating (SMR) to characterize the rock mass and slope mass.

2.2. Strength test
The strength test of PLT was carried out to analyse and determine the strength parameter of rock mass. It may also be used to predict other strength parameters, i.e. Uniaxial Compression Strength (UCS) for the study of engineering properties of the rock mass. The purpose of the test being carried out is to measure the Point Load Strength Index ($Is_{(50)}$), which is one key component of the RMR parameter. Rock samples in the form of either core, cut blocks or irregular lumps are tested by application of concentrated load through a pair of spherically truncated, conical platens. The procedure follows the standard of [12].

3. Results and discussion
The result of the field and laboratory measurements were presented in the RMR and SMR scheme of rock slope stability classification.

3.1. Rock Mass Rating (RMR)
For the strength of intact rock material parameter, value from point load testing of selected samples were used, as shown in Table 1:

Table 1. Average point load strength of samples collected from the slope

Chainage (m)	*Average of $I_{s(50)}$ (MPa)*
10	4.68
40	5.83
60	5.67
225	8.73
280	0.3
	5.04

The calculated λ value for the joints are:

$$\lambda = 401 / 334.7 = 1.20\text{m}^{-1}$$

A value of 99.34% was obtained for the RQD value, representing excellent rock mass quality following the classification by [7].

The spacing of discontinuity parameter was calculated using formula:

$$\text{Spacing of discontinuity} = \text{length of chainage} / \text{total discontinuity} \tag{5}$$

The total length of measured scanline is 334.7 m, and the total discontinuity data obtained is 404. Thus, the calculated spacing of discontinuity is 0.83 m.

For the condition of discontinuity parameter, it involved the determination of the discontinuity persistence, aperture, roughness, infilling and weathering. Table 2 shows the value and rating for each rating for conditions of discontinuity that was recorded from the site.

Table 2. Discontinuity condition value and rating

Discontinuity condition	Value/description	*Rating*
Persistence	3-10 m	2
Aperture	0.1-1 mm	4
Roughness	Slightly rough	3
Infilling	None	6
Weathering	Slightly weathered	5
Total rating for condition of discontinuity		20

The groundwater parameter was determined using the water flow that were observed and recorded in the scanline survey form. The discontinuities were found to be mostly in dry condition.

By comparing the field data with the classification of [6], a rating value for each parameter was achieved. The parameter of rock mass rating system and the rating obtained for each parameter is compiled in Table 3.

Table 3. Rock mass rating parameter and rating

Parameter	*Value/ condition*	*Rating*
Strength of intact rock mineral (Point load test)	5.04 MPa	12
RQD	99.34%	20
Spacing of discontinuity	0.83 m	15
Condition of discontinuity	Joints 3-10 m persistence, 0.1 – 1 mm wide, slightly	20

	rough surface, no infilling, slightly weathered	
Groundwater	Completely dry	15
RMR		82

The cumulative rating of the RMR parameter gives a value of 82. This result indicated that the classification class of rock sample is Class I (Very good rock) according to the RMR classification [13] This means that the rock has a long average stand-up time, with low chance of immediate failure.

3.2. Slope Mass Rating (SMR)

The software Dips [11] was used to analyse the discontinuity orientation by inserting the value of slope orientation and the discontinuity (joint) orientation, so that the potential mode of slope failure could be calculated. By this input, it is predicted that the highest probability of potential mode of failure to take place is toppling failure, as shown in Table 4.

Table 4. Potential mode failure for each type of failure

Planar failure (%)	Wedge failure (%)	Toppling failure (%)	
		Flexural	**Direct**
0.25	13.22	11.44	20.98

From kinematic analysis, the potential for wedge failure and toppling failure was identified. A reading for the wedge intersection and toppling surface is identified, as shown in Table 5. The value of the SMR corresponding to each mode of failures were calculated by calculating the joint adjustment F1-F3 for each potential failures, with the F4 adjustment factor for the whole slope identified as smooth blasting, following the parameter of [9]:

Table 5. SMR rating calculation

Mode of failure	F1	F2	F3	F4	SMR	Class	Stability	Probability of failure
Wedge: 143°/11°	0.15	1	0	8	90	I, Very good	Completely stable	0
Toppling:246°/83	0.15	1	-25	8	86.25	I, Very good	Completely stable	0

The value of SMR calculated range from 86.25 to 90. Therefore, the slope is classified as very good, which is completely stable. Following the classification by [13] and [9], the slope has a probability of failure of 0. For the slope, only scaling is suggested as the support method, following the recommendation of [9].

4. Conclusion

Based on the field work, laboratory test data and the analysis of rock mass rating and slope mass rating, it was found that the rock slope is classified as Class I for both RMR and SMR, which indicates it to be very good rock and completely stable slope respectively. The kinematic analysis and SMR is very applicable to rock slope that is cut by discontinuity sets, where initial rock condition and stability can be assessed based on the rock condition and discontinuity distribution. By combining both classification scheme of RMR and SMR, it was found that currently the whole slope does not appear to be in immediate danger of failing. Although kinematic analysis shows a high potential of wedge and toppling failure, no immediate failures could be observed in the slope surface. However, the analysis does not take into consideration of the engineering properties of several section of the slopes that have

exhibited different weathering grade – which could potentially weaken the properties of the slope. Further studies that focus on the weathering grade of the rock slope and its engineering properties would be needed to further study the characteristic of rock material that makes up the slope, and the effect on the present discontinuities sets.

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