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Geomechanical classification scheme for heterogeneous Crocker Formation in Kota Kinabalu, Sabah, Malaysia: An update

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Abstract: Geomechanical classification scheme for heterogeneous Crocker Formation in Kota Kinabalu, Sabah has been proposed in 2009 and known as Modified Slope Mass Rating (M-SMR). M-SMR was used to characterize and to propose preliminary rock cut slope design such as slope stabilization and protection measures and recommendation levels for design model review and slope remapping by suitable engineering geologist or geotechnical engineers. The 'lithological unit thickness' approach, RQD method, weighted average of discontinuity set spacing, weighted average, statistical mode and new approach of adjustment factor (NAAF) methods were used to evaluate the parameters in M-SMR. The classes in M-SMR scheme consists of class I (very good) to class VI (extremely poor). Local trimming, slope re-profiling, weep hole, horizontal drainage, concrete dentition or buttress, sport bolting or dowel, wire mesh or rope nets, reinforce shotcrete and benching are proposed slope stabilization and protection measures. Normal to detailed Design Model Review (DMR) and slope remapping are recommended to highly recommended by engineering geologist or geotechnical engineers to expert engineering geologist or geotechnical engineers for class I to class VI, respectively. In this paper, M-SMR classes, names and slope designs have been updated.

Key words: Geomechanical classification, Modified Slope Mass Rating (M-SMR), Crocker Formation, Kota Kinabalu

INTRODUCTION

Rock mass classification systems are a worldwide communication system for investigators, designers and constructors that facilitate characterization, classification and knowledge of rock mass properties. They provide quantitative data and guidelines for engineering purposes that can improve originally abstract descriptions of rock mass from inherent and structural parameters (Pantelidis, 2009) by a simple arithmetic algorithm (Romana, 1993). Rock mass classification scheme is also a simple and effective way to represent rock mass quality and to encapsulate precedent practice (Harrison & Hudson, 2000).

The rock mass classification system has recently been quite popular and when used correctly, can be a powerful tool in rock slope design. In fact, in many projects the classification approach serves as the only basis for the design of complex underground structures (Singh & Geol, 1999).

The rock cut slope design for heterogenoes Crocker Formation cannot be easily made using present rock mass classification systems. The rock unit is interbeded, soft in general and structurally complex due to their tectonic history. The Modified Slope Mass Rating (M-SMR) system was proposed as the most suitable rock mass classification and rock cut slope design for the Crocker Formation in Kota Kinabalu, Sabah (Ismail Abd Rahim *et al.,* 2009a) (Figure 1).

M-SMR was used to characterize and propose preliminary rock cut slope design such as slope stabilazation and protection measures and recommendation level for design model review (DMR) and slope remapping by qualified engineering geologists or geotechnical engineers. The characteristic of rock material has been used to classify the rock cut slopes. This paper is a continuation of previous M-SMR by Ismail Abd Rahim *et al.* (2009a) and Ismail Abd Rahim (2011) and was written as an update in M-SMR classes, names and slope designs.

GEOLOGICAL SETTING

The study area is underlain by Crocker Formation of Late Eocene – late Early Miocene ages. Crocker Formation is a turbidite deposit and consists of interbedded sandstone, siltstone and shale. The thicknesses of sandstone and shale units are estimated as 500 and 100 meter, respectively (Tongkul, 1991). Based on the east-west Sabah cross section, the thickness is about 2000m (Sanudin & Baba, 2007). The quartzose nature of sandstones suggests that they have recycled from orogenic source (Van Hattum, 2003).

Bouma sequences can be identified in some beds and sole marks are often found on their base. Sandstone to shale ratios varies from one outcrop to another.

The sandstone is grey to brown and moderately sorted. It is very thin to thick-bedded. The sandstone units can be divided according to grain size to medium sandstone, fine sandstone and very fine sandstone and can be classified as medium lithic wacke, fine lithic wacke and medium lithic wacke, respectively. The beds of fine sandstone and very fine sandstone are rich in sole marks, load cast, flute cast, graded bedding, parallel, cross and convolute laminations and trace fossils.

The siltstone is thinly bedded (less than 5 cm), grey to greenish grey, predominantly of silt material, hard when fresh but soft and buff when weathered. The weathered zone of the siltstone beds resulting in joint face commonly covered with dust and difficult to recognize the joint spacing.

Shale unit can be divided into grey and red shale. The grey shale unit has 0.5-9m thick and represented by rhythmic interbedded of thick grey shale and thin very fine sandstone, parallel to wavy laminated, less well developed sole marks, occasional trace fossil (*Nereites* association) and common slumps deposition. The red shale is 0.3-1m thick, argillaceous with occasional interbeds of very thin siltstone, parallel to wavy laminated, slumps deposit and patched of grey or green shales.

METHODOLOGY

The Modified Slope Mass Rating (M-SMR) is a modification of RMR Bieniawski (1989) and SMR (Romana, 1985; Anbalagan *et al*., 1992; Tomas *et al.,* 2012) classification systems in terms of parameters calculation and determination methods. The method was discussed in Ismail Abd Rahim *et al.* (2009a) and Ismail Abd Rahim (2011).

The calculation of M-SMR parameters is based on Bieniawski (1989) scheme except unaxial compressive

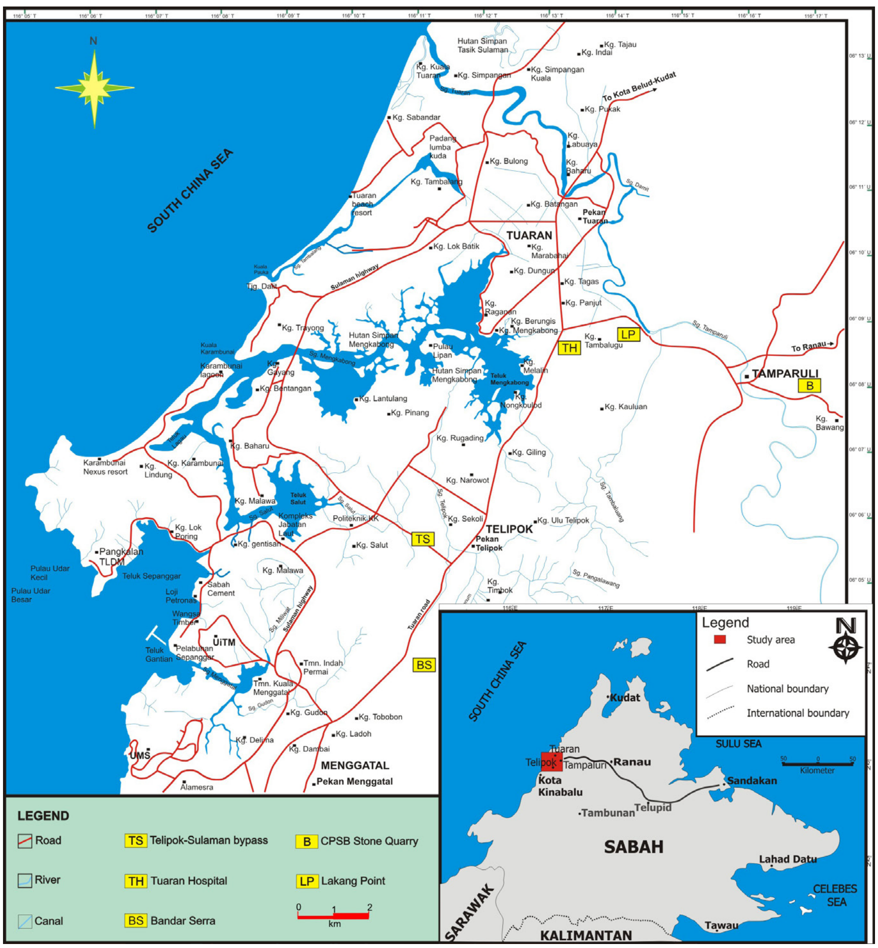

Figure 1: Location of the study area and selected slopes.

Table 1: The classes of M-SMR, parameters and rating values for selected slopes.

Slope	UCS (MPa)	RQD (%)	DC sp (m)	DC cond	Water	DOF	RMR_b	M-SMR	Class
	Rating								
BS	130	98	1.4	24	Dry	VF	86	81.5	I
	12	20	15		15	-4.5			Very Good
LP	37.05	97	3.20	16	Dry	F	76	67.10	II
	5.10	20	20		15	-9			Good
TS1 west	84.29	79	1.82	12	Dry	Fr	69.40	45.40	III
	10.40	17	15		15	-24			Moderate
TS2 west	88.40	80	1.27	19	Dry	UF	69.80	27.80	IV
	10.80	17	15		15	-42			Poor
B	108.19	87	0.56	12	Dry	VUF	66.20	7.20	V
	12.20	17	10		15	-59			Very Poor
TH	34.20	7	0.29	11	Dry	VUF	44.55	-15.45	VI
	5.55	3	10		15	-60			Extremely Poor

Note*: UCS-unaxial compressive strength; DC sp-discontinuity spacing; DC cond-discontinuity condition; DOF-discontinuity orientation factor;* RMR_b*-basic RMR; VF-Very favourable; F-favourable; Fr-fair; UF-unfavourable; VUF-very unfavourable.*

strength (UCS), discontinuity spacing, infill material, degree of weathering, roughness and discontinuity orientation. UCS parameter is represented by intact rock strength for slope forming rock material and was calculated by using the 'lithological unit thickness' approach (Ismail Abd Rahim *et al.,* 2009b). The value of discontinuity spacing was determined by weighted average of discontinuity set spacing method.

The value of persistence and aperture has been determined by using weighted average method but infill material, degree of weathering, roughness and water flow by statistical mode method. The new approach of adjustment factor (NAAF) method (Ismail Abd Rahim *et al.,* 2012) has been used in determining discontinuity orientation parameter.

Slope stabilization and protection measures have been formulated from field observation, Romana (1985) and prescriptive measures (Yu *et al.*, 2005). DMR and slope remapping was formulated based on the level of recommendation for detailed DMR and slope remapping (normal to highly recommended) and the experience level of the engineering geologist/geotechnical engineer (either junior, well-trained, experienced to experts).

MODIFIED SLOPE MASS RATING (M-SMR) CLASSIFICATION

The total value of M-SMR is 100 and produced from the sum of basic RMR (RMR_b) (Bieniawski, 1989) and discontinuity orientation factor (R6) (Equation 1).

$$M\text{-}SMR = RMR_b + R6 \quad (1)$$

Where;

$$RMR_b = R1 + R2 + R3 + R4 + R5 \quad (2)$$

$$R6 = (F_1 \times F_2 \times F_3) + F_4 \quad (3)$$

R1 = Unaxial compressive strength (UCS)
R2 = Rock Quality Designation (RQD)
R3 = Discontinuity spacing
R4 = Discontinuity condition
R5 = Water flow
R6 = Discontinuity orientation
F_1 = parallelism between discontinuity and slope direction
F_2 = discontinuity dip angle
F_3 = relationship between discontinuity and slope dips
F_4 = method of excavation

There are only five (5) classes in previous M-SMR classification scheme for heterogenous Crocker Formation i.e. class II, class III, class IV, class V and class VI. But after the discovery of 'very favourable' discontinuity orientation and higher discontinuity condition rating value in slope BS (Figure 1), class I for M-SMR was proposed.

Based on recent study, the class for M-SMR consists of class I (very good), class II (good), class III (moderate), class IV (poor), class V (very poor) and class VI (extremely poor). Selected rock cut slope that represent complete M-SMR classes (Figure 2) with their parameter values in the study area are shown in Table 1. M-SMR class name has been changed because the term of 'risk' is not suitable for rock mass classification or quality. The updated M-SMR class names are shown in Table 2.

ROCK SLOPE DESIGN

The form of slope design in M-SMR system are slope stabilization and protection measures and design model review and slope remapping. The discussion of slope design for M-SMR system has been reported by Ismail Abd Rahim (2011). Updated rock cut slope stabilization and protection measures for rock cut slope in the Crocker Formation are shown in Table 3 and Figure 3.

SLOPE STABILIZATION AND PROTECTION MEASURES

There is no sign or evidence of failure in class I slope, then no support is needed unless local trimming or scaling if necessary. Local trimming, weep holes, concrete dentition and spot to systematic bolting or dowels are needed for class II (good) slope due to the occurrences of some hanging blocks, shale beds and minor wedge failures.

Local trimming, surface drainage and horizontal drain, systematic bolting or dowels, wire mesh or rope nets and rock trap ditch are recommended because of the occurrences of hanging blocks, shale beds, wedge and planar failures in class III (moderate) slope. Class IV (poor) slope is recommended for local trimming, horizontal drain or weep holes, systematic bolting or dowels, concrete dentition or buttress, shotcrete or wire mesh or rope nets and rock trap ditch.

Table 2: The names of M-SMR classes for 2009a, 2011 and newly revised in 2014.

M-SMR CLASS	2009a & 2011	2014 (revised)
I	Very Low Risk	Very Good
II	Low Risk	Good
III	Moderate Risk	Moderate
IV	High Risk	Poor
V	Very High Risk	Very Poor
VI	Extremely High Risk	Extremely Poor

Table 3: Slope stabilization and protection measure (Adapted from Ismail Abd Rahim*,* 2011).

M-SMR Class	M-SMR Value	Slope	Slope stabilization and protection measure
I	81-100	BS	None, local trimming or scaling if required.
II	61-80	LP	Local trimming, weep holes, concrete dentition and spot to systematic bolting or dowels.
III	41-60	TS2	Local trimming, surface drainage and horizontal drain, systematic bolting or dowels, wire mesh or rope nets and rock trap ditch.
IV	21-40	TS1	Local trimming, horizontal drain or weep holes, systematic bolting or dowels, concrete dentition or buttress, shotcrete or wire mesh or rope nets and rock trap ditch.
V	1-20	B	Local trimming, horizontal drain or weep holes, systematic bolting or dowels and shotcrete or wire mesh or rope nets.
VI	<1	TH	Slope re-profiling or horizontal drain, reinforce shotcrete or wire mesh or rope nets with systematic rock bolts.

Figure 2: Modified Slope Mass Rating (M-SMR) classes for selected slopes. A – Slope BS; B – Slope LP; C – Slope TS2; D – Slope TS1; E – Slope B; F – Slope TH.

Class V (very poor) slope is recommended for local trimming, horizontal drain or weep holes, systematic bolting or dowels and shotcrete or wire mesh or rope nets. Slope re-profiling or horizontal drain, reinforce shotcrete or wire mesh or rope nets with systematic rock bolts are recommended for class VI (extremely poor) slope due to the occurrences of thick shale beds and many wedge and circular failures.

DESIGN MODEL REVIEW (DMR) AND SLOPE REMAPPING

The design model review (DMR) and slope remapping for the M-SMR classes are recommended in order to ensure the stability and safety of the rock cut slope (Table 4). Detailed DMR and slope remapping by expert engineering geologists or geotechnical engineers is highly recommended for both class VI and V. Detailed DMR and slope remapping is recommended by experienced and well-trained engineering geologists or geotechnical engineers are highly recommended and recommended for class IV and III, respectively. DMR and slope remapping by well-trained engineering geologists or geotechnical engineers and junior engineering geologists or geotechnical engineers are recommended for slope class II and class I, respectively.

CONCLUSIONS

The conclusions of this study are;

1. The rock mass quality of M-SMR for interbedded Crocker Formation are class I (very good), class II (good), class III (moderate), class IV (poor), class V (very poor) and class VI (extremely poor).
2. Local trimming, slope reprofiling, weep hole, horizontal drainage, concrete dentition or butress, rock bolts or dowels, wire mesh or rope nets or shotcrete are proposed stabilization and protection measures for M-SMR.

Table 4: Design model review and slope remapping (Adapted from Ismail Abd Rahim, 2011).

M-SMR Classes	M-SMR Value	Design Model Review (DMR) and Slope Remapping
I	81-100	Recommended for DMR and slope remapping by engineering geologist/ geotechnical engineer.
II	61-80	Recommended for DMR and slope remapping by well-trained engineering geologist/geotechnical engineer.
III	41-60	Recommended for detailed DMR and slope remapping by well-trained engineering geologist/geotechnical engineer.
IV	21-40	Highly recommended for detailed DMR and slope remapping by experienced engineering geologist/ geotechnical engineer.
V	1-20	Highly recommended for detailed DMR and slope remapping by expert engineering geologist/geotechnical engineer.
VI	<1	

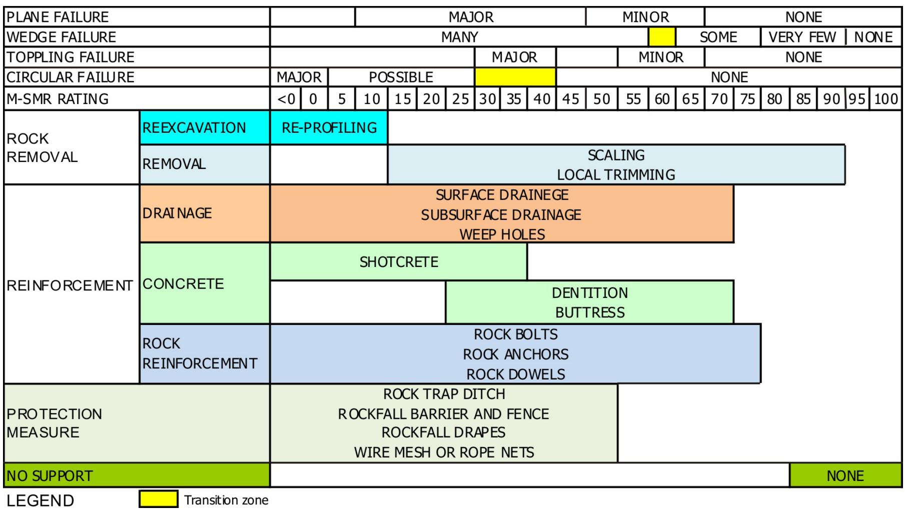

Figure 3: Slope stabilization and protection measures (Adapted from Ismail Abd Rahim, 2011).

3. Normal to detail design model review and slope remapping are recommended to highly recommended by engineering geologist or geotechnical engineers to expert engineering geologist or geotechnical engineers for class I slope to class VI slope, respectively.

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