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Application of Modified Slope Mass Rating (M-SMR) System in Ultrabasic Rock: A Case Study in Telupid, Sabah, Malaysia

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Abstract - Modified Slope Mass Rating (M-SMR) was proposed as a geomechanically classification scheme for sedimentary Crocker Formation rock slope in the Kota Kinabalu area, but has never been applied in ultrabasic rock. Then, this study was conducted on ultrabasic rock cut slopes in Telupid, Sabah, Malaysia. This system was used to characterize and to propose preliminary rock cut slope design, slope stabilization, protection measures, and recommendation levels for slope re-investigation. The UCS test, Deere RQD method, a weighted average of discontinuity set spacing, weighted average and statistical mode, weighted average, and new approach of adjustment factor (NAAF) methods were used to evaluate the uniaxial compressive strength (UCS), RQD, discontinuity spacing, discontinuity condition, water flow and discontinuity orientation parameters, respectively. The result of this study shows that the M-SMR classes for the slopes are class III (moderate), IV (poor,) and class V (very poor). Recommended and highly recommended for slope re-investigation by well-trained, experienced, or expert engineering geologist/ geotechnical engineer are for classes III, IV, and V, respectively. The recommendation for slope stabilization and protection measures are local trimming, surface drainage, horizontal drain, weep hole, systematic bolting, dowels, concrete detention or buttress, shotcrete, wire mesh or rope nets, and rock trap ditch.

Keywords: Modified Slope Mass Rating (M-SMR), ultrabasic rock, Telupid, slope re-investigation

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Introduction

The rock mass classification system can be used as a tool for rock slope design. This classification provides quantitative data and guidelines for engineering purposes that can originally improve the descriptions of rock mass characteristics by a simple arithmetic algorithm (Romana, 1993; Pantelidis, 2009).

The Modified Slope Mass Rating (M-SMR) system was proposed by Rahim (2011) as the most suitable rock mass classification for the rock cut slope design for the interbedded, soft in general, and structurally complex due to tectonic processes took place on sedimentary rock.

The ultrabasic rock is well exposed in the Telupid, Sabah area (Kirks, 1968; Tahir and Musta, 2007). The ultrabasic rocks in Telupid are mostly strongly serpentinized peridotite due to the metamorphism processes. Also closely associated with these ultrabasic rocks (serpentinites and peridotites) are intrusive rocks (dolerites) and metamorphic rocks (hornblende schist and gneiss). This association of rock types, which resembles an Ophiolite sequence, is interpreted to represent an oceanic crust of the Mesozoic age and forms the basement rock (Kirks, 1968). The studied area only represented part of this Ophiolite Complex, *i.e.* peridotite rock and Quaternary alluvium along the rivers (Figure 1).

The Telupid area is also dominated by NE - SW and NW - SE ridges. The NW - SE ridges represent bedding strikes of the Crocker Formation and Kulapis Formation in the western and eastern parts of the area, respectively. These ridges are cut through by NE - SW ridges, representing elongated bodies of ophiolitic rocks. The boundary of these two trends is characterized by a disrupted zone. Several horizontal and thrust faults, mostly trending NW - SE dissect Ophiolitic rocks, exposing slivers of sedimentary rock mostly from the Crocker Formation, thrusting to the northeast and affecting the Kulapis Formation, Crocker Formation, and Ophiolitic rocks (Tongkul, 1997).

Sabah, Malaysia, is a country that is underlain by complex rock units, and its tectonic history is experiencing a rapid development. The construction of public transport, especially the major east-west road or highway for communication, will be involving ultrabasic rocks.

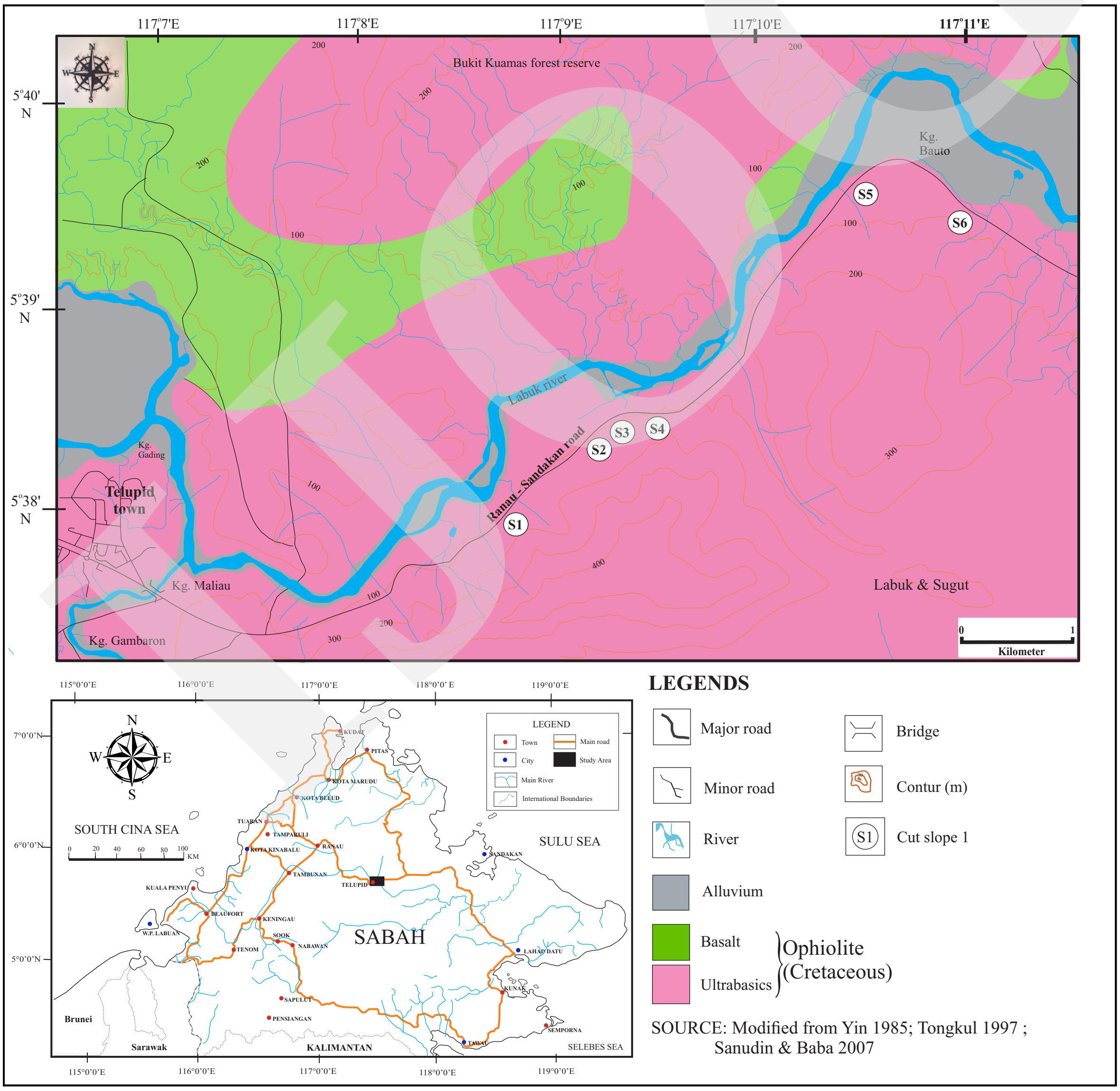

Figure 1. Location of the studied area, geological map, and selected slopes.

Until now, the application of the M-SMR system is used as a tool for rock slope design and engineering purposes in ultrabasic rock cut slopes in Sabah, Malaysia, but has never been documented. This study has been conducted to determine rock mass quality, the level of slope re-investigation (DMR and slope remapping) and slope stabilization and protection measures for existing ultrabasic rock cut slopes (Figure 1).

Methodology

This study consists of the early study, field study, sampling, laboratory study, and data analysis. The early study includes a literature review and field data sheet preparation. Geological mapping, slope and slope failure survey, discontinuity survey (scanline), and hand and block rock sample collection were conducted in the field study and sampling. Laboratory analysis includes petrographic study and uniaxial compressive strength (UCS) test. Petrographic studies were used to classify the rock unit (Le Bas and Streckeisen, 1991) after a thin section sample was prepared. The UCS test was conducted to determine the UCS values.

Data analysis is only concentrated to calculate the M-SMR rating value by following the procedure of Rahim (2015). The Modified Slope Mass Rating (M-SMR) (Rahim *et al.*, 2009) is a modification of RMR (Bieniawski, 1989) and SMR (Romana, 1985; Anbalagan *et al*., 1992; Tomas *et al.,* 2012) classification systems in terms of parameter calculation and determination methods (Romana *et al.,* 2015). This method was discussed in Rahim (2011), Rahim *et al.* (2009), Rahim *et al.* (2012), and Rahim (2015).

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

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

where:

$RMR_b = R1 + R2 + R3 + R4 + R5$

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

R1 = Uniaxial 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

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) (Rahim, 2015). Discontinuities characterization and sample from six slopes were utilized for this study (Figure 2).

There are two assumptions that have been made in this study as shown below:

1. The distribution of discontinuities in the small or limited area that had been causing their characteristics could be considered similar. The sets and pattern of discontinuities are uniform throughout the area.
2. The uniaxial compressive strength for all slope forming materials is similar due to homogeneity in ultrabasic rock masses and difficulty in collecting rock blocks for core samples.

The calculation of M-SMR parameters is based on Bieniawski's (1989) scheme, but not on the determination and calculation methods for uniaxial compressive strength (UCS), discontinuity spacing and infill material, degree of weathering, roughness, and discontinuity orientation. In M-SMR, the UCS (R1) parameter is represented by intact rock strength for slope-forming rock material and was determined by the UCS test (ISRM, 2015).

Deere *et al*. (1967) method was applied on slope faces or outcrops to calculate the Rock

Figure 2. Photographs of selected slopes studies. a- slope S1; b- slope S2; c- slope S3; d- slope S4; e- slope S5 and f-slope S6.

Quality Designation (RQD) rating values (R2). The value of discontinuity spacing was determined by a weighted average of the discontinuity set spacing method (Rahim, 2015). The spacing of all discontinuities in which cross scanline was measured and analyzed to determine discontinuity sets. Then the average spacing of discontinuity sets was used as discontinuity spacing (R3).

The value of persistence and aperture of discontinuity was measured by using the weighted average method, whereas the type of infill materials, degree of weathering, roughness, and water flow were determined using the statistical mode method (Rahim, 2015). The water flow (R5) was determined by using general conditions and sunny days to avoid the worst conditions.

The favourability or discontinuity orientation (R6) was determined by using the new approach of adjustment factor (NAAF) method as proposed by Rahim *et al*. (2012). The difference between NAAF and original SMR R6 charts is in subparameter F1 (parallelism between discontinuity with slope) for toppling failure. In Romana (1985) and Anbalagan *et al*. (1992), the value of parallelism is overestimated if the plunge orientation or discontinuity dip direction is higher than the slope dip direction. But in NAAF, the value remains acceptable. The symbols of 'absolute' in Romana (1985) and Anbalagan *et al.* (1992) are also ignored by subtracting the bigger with smaller numbers in NAAF. The R6 rating value represented the favourability of discontinuity and assigned by following Rahim's (2011) scheme.

The level for slope re-investigation by Design Model Review (DMR) and slope stabilization and protection measures followed Rahim (2015) as given in Tables 1 and 2.

Results

The lithological and petrographic study shows that the peridotite is classified as lherzolite (Mohamad, 2018) (Figure 3). The UCS test found that the UCS for ultrabasic rocks is strong (92.88 MPa) (Table 3). Then, the rating for R1 is 7. The textures are slightly fractured, interlocking, with low permeability (low pore spaces), consisting of olivine, orthopyroxene, and serpentine mineral assemblage which characterize moderately hard minerals (in Mohs scale).

The Rock Quality Designation (RQD) (R2) varies from 83 - 96% and is classified as 'excellent' quality (Deere *et al.*, 1967), then the R2 is entitled with 17 and 20 rating values. The discontinuity spacing (R3) ranges from 0.17 m to 1.1 m with an 8 - 15 rating value, and is categorized as moderately wide to wide. Most of the discontinuity conditions for all slopes are slightly rough surfaces, separation <1 mm, and slightly weathered wall unless slightly rough surfaces, separation <1 mm, and highly weathered wall for slope 2, then rating values for R4 are given as 25 and 20, respectively. The rating values of 15 and 10 were given, because dry and damp water flow parameters were observed dominantly on the discontinuity planes, respectively (Table 3).

Table 1. Level of Slope Re-investigation or DMR and Slope Remapping (adapted from Rahim, 2015)

M-SMR Classes	M-SMR Value	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 a well-trained engineering geologist/ geotechnical engineer.
III	41-60	Recommended for detailed DMR and slope remapping by a well-trained engineering geologist/geotechnical engineer.
IV	21-40	Highly recommended for detailed DMR and slope remapping by an experienced engineering geologist/geotechnical engineer.
V	1-20	Highly recommended for detailed DMR and slope remapping by an expert engineering geologist/geotechnical engineer.
VI	<1	

Table 2. Slope Stabilization and Protection Measures (adapted from Rahim, 2015)

M-SMR Class	M-SMR Value	Slope Stabilization and Protection Measures
I	81-100	None, local trimming or scaling if required.
II	61-80	Local trimming, weep holes, concrete dentition, and spot to systematic bolting or dowels.
III	41-60	Local trimming, surface drainage and horizontal drain, systematic bolting or dowels, wire mesh or rope nets, and rock trap ditch.
IV	21-40	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	Local trimming, horizontal drain or weep holes, systematic bolting or dowels, and shotcrete or wire mesh or rope nets.
VI	<1	Slope reprofiling or horizontal drain, reinforce shotcrete or wire mesh or rope nets with systematic rock bolts.

The calculation and results of the favourability or discontinuity orientation factor (R6) for all slopes are shown in Table 4. The favourability rating values varied from 'favourable' to 'very unfavourable' with -20 to -60 rating values (Table 4).

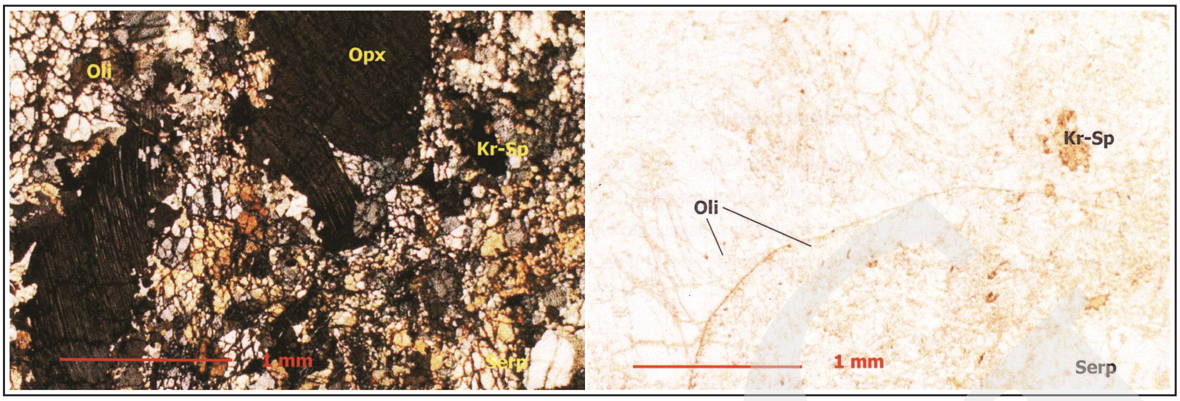

Figure 3. Photomicrographs showing mineralogy and texture of ultrabasic rock under cross-polarized light, XPL (left) and parallel polarized light, PPL (right) in 10x objectives. Note: Oli-olivine; Opx-orthopyroxene; Cpx-clinopyroxene.

Table 3. Summary of the M-SMR Classes

Slove	UCS (MPa)	RQD (%)	Spacing (m)	Discontinuity Condition	Water Flow	Discontinuity Orientation	RMR	M-SMR	
	Rating							Rating	Class
S1	92.88 7	88 17	1.1 15	25	Damp 10	VUF -60	74	14	V Very poor
S2	92.88 7	92 20	0.45 10	20	Damp 10	VUF -60	67	7	V Very poor
S3	92.88 7	96 20	0.56 10	25	Dry 15	UF -42	77	35	IV Poor
S4	92.88 7	94 20	0.17 8	25	Dry 15	Fr -24	75	51	III Moderate
S5	92.88 7	92 20	0.49 10	25	Damp 10	F -20	72	52	III
S6	92.88 7	83 17	0.84 15	25	Dry 15	Fr -35	79	44	III

Table 4. Summary of the R6 Calculation and Results

Slope (DD/D)		Mode of Failure	DC (ILO/ILA) or (DD/D)		F1		F2		F3		F4	F	Favourability
S1	299/68	W	J2J4	295/57	4	1	68	1	-11	-60	0	-60	VUF
S2	301/65	W	J2J4	297/46	4	1	65	1	-19	-60	0	-60	VUF
S3	300/58	W	J1J3	284/38	16	0.7	58	1	-20	-60	0	-42	UF
S4	306/78	W	J2J3	239/39	26	0.4	78	1	-21	-60	0	-24	Fr
S5	307/60	W	J4J3	279/55	28	0.4	60	1	-5	-50	0	-20	F
S6	71/64	T	J1	255/72	16	0.7	64	1	-6	-50	0	-35	Fr

Note: DD/D- discontinuity dip/dip; ILO/ILA- intersection line orientation/intersection line angle; VUF- very unfavourable; UF- unfavourable, F- favourable; Fr- fair.

Based on Tables 3 and 4, The M-SMR classes for ultrabasic rock are class III (moderate), class IV (poor), and class V (very poor). The proposed slope re-investigation and slope remapping, and the proposed slope stabilization and protection measures for M-SMR classes are summarized in Table 5.

DISCUSSIONS

The M-SMR classes for ultrabasic rock are class III (moderate), class IV (poor), and class V (very poor). The main factor that degrades the quality of rock mass is the discontinuity orientation parameter, R6. Most of the slopes are in the 'good' class for basic RMR (RMR_b). Nevertheles, due to 'favourable' to 'very unfavourable' discontinuity orientations, R6 the rock mass quality degrades into 'moderate' to 'very poor' classes (Table 3).

The RMR_b is a 'good' rock mass quality because the UCS is strong, 'excellent' RQD, moderately wide to wide spacing, highly friction properties for discontinuity conditions, and little to no influence of water flow on the surface of the discontinuity. The lherzolite is slightly fractured, has interlock texture, has low permeability (low pore spaces), and consists of olivine, orthopyroxene, and serpentine as the rock-forming minerals which characterize moderately hard minerals (in Mohs scale). These, in turn, have formed a 'strong' rock. The strength of this rock is 92.88 MPa on the average, and in the ranges of Turkey's peridotite (*i.e.* from 70 MPa to 116 MPa) as reported by Kamaci and Ozer (2018).

The RQD (R2) is classified as 'excellent' quality by following Deree *et al.* (1967), because the distance between discontinuities is more than 10 cm over a total length of scan line ranging from 83−96%. There are three to five sets of discontinuities found on rock cut slopes, and the average spacing of discontinuity sets ranges from 0.17 m to 1.1 m. By following Bieniawski (1989), the spacing (R3) is classified as moderately wide to wide. This in turn shows a 'big' block volume (Palmstorm, 1995). The discontinuity condition (R4) of most of the slopes are slightly rough surfaces, separation < 1 mm, and slightly weathered walls but slightly rough surfaces, separation < 1 mm, and highly weathered walls for slope 2. These conditions give 25 rating values for all slopes and 20 for slope 2. Dry and damp water flows (R5) were observed dominantly on the discontinuity planes. These show that the rock masses are less or without fracture and shear zones. The water may be flowing along the bedding planes, and then damping around certain beddings on the surface.

The favourability or discontinuity orientation factor for all slopes varied from 'favourable' to 'very unfavourable'. This orientation will give or reduce -20 to -60 rating values. In this study, the RMR_b ranged from 67 to 79 rating value, and

Table 5. Summary of Slope Re-investigation and Remapping, and Slope Stabilization and Protection Measures for the Studied Area

Clas II	- The level of slope re-investigation and remapping - slope stabilization and protection measures	- Detailed design model review (DMR) and slope remapping are recommended by well-trained engineering geologist or geotechnical engineer. - Local trimming, surface drainage and horizontal drain, systematic bolting or dowels, wire mesh or rope nets and trap ditch.
Class IV		- Detailed design model review (DMR) and slope remapping are highly recommended by experienced engineering geologist or geotechnical engineers. - 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.
Class V		- Detailed design model review (DMR) and slope remapping are highly recommended by expert engineering geologist or geotechnical engineers. - Local trimming, horizontal drain or weep holes, systematic bolting, dowels and shotcrete or wire mesh or rope nets.

was classified as class II 'good' quality. But due to 'favourable' until 'very unfavourable' discontinuity orientation, the quality of the slope mass decreases into III 'moderate' (for slopes S4, S5, and S6), IV 'poor' (slope 3 and slope 1) to V 'very poor' (slope 2). This shows that the quality of rock slope mass (M-SMR) is highly affected by discontinuity orientation factors (R6).

The level of slope re-investigation and re-mapping either normal or detailed by a suitable level of junior to expert engineering geologist or geotechnical engineer, and slope stabilization and protection measures were proposed for the rock cut slope in the studied area as shown in Table 5. The good quality of M-SMR is normally recommended for normal slope re-investigation and remapping by junior engineering geologist/geotechnical engineer but highly recommended for detailed re-investigation and remapping by expert engineering geologist/geotechnical engineer for poor quality.

Detailed design model review (DMR) and slope remapping are recommended by well-trained engineering geologists or geotechnical engineers for slope class III, but highly recommended by experienced and expert engineering geologists or geotechnical engineers for class IV and V, respectively. Proposed slope stabilization and protection measures for class III are local trimming, surface drainage and horizontal drain, systematic bolting or dowels, wire mesh or rope nets and rock trap ditch. For class IV are local trimming, horizontal drain or weep holes, systematic bolting or dowels, concrete dentition or buttress, shotcrete or wire mesh or rope nets. While for class V are rock trap ditch and local trimming, horizontal drain or weep holes, systematic bolting or dowels, and shotcrete or wire mesh or rope nets.

CONCLUSIONS

This is a preliminary study to access the quality of the ultrabasic rock by the M-SMR system for preliminary rock engineering work. Based on this study, the M-SMR system has successfully been utilized in proposing the level of slope re-investigation and slope stabilization and protection measures in this rock formation.

The M-SMR classes for ultrabasic rock in the studied area are class III (moderate), class IV (poor), and class V (very poor). These classes or qualities are highly affected by the favourability of discontinuity or discontinuity orientation factor (R6). The level of recommendation (from normal to high) for slope re-investigation (detailed DMR and slope re-mapping) by a suitable level of engineering geologist/geotechnical engineer for M-SMR classes was proposed. The proposed slope stabilization and protection measures for rock cut slopes of M-SMR classes are local trimming, surface drainage and horizontal drain, systematic bolting or dowels, concrete dentition or buttress, shotcrete or wire mesh or rope nets, and rock trap ditch.

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