Modification of Slope Mass Rating for Stable Slope Design

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Abstract

Slope Mass Rating (SMR) is a simple method to assess stable slope on cut-slope design. Application of SMR is used to provide safe slope on open-pit mine planning, road planning, or highway planning. SMR value presupposes Rock Mass Rating (RMR) according to geomechanics method from Bieniawski. Result of SMR gives different values based on some researchers (i.e. Laubscher, Hall, and Orr). In order to get the optimum value, SMR's modification of stable slope is required. SMR modification involved some sedimentary rocks of Halang Formation, tuff of the Young Volcanic Product, andesitic igneous rock, and limestone of Rajamandala Formation. Result of the SMR modification yielded an equation as follows: SMR = 8.2348 $RMR^{0.4932}$ with correlation coefficient R= 0.99. Safe slope determination in stable-slope design can be specified as: (1) Very Poor Quality Rock: Stable slope is designed only with slope < 36^o; (2) Poor Quality Rock: Stable slope is designed with slope 37^o – 51^o; (3) Fair Quality Rock: Stable slope is designed with slope 51^o – 62^o; (4) Good Quality Rock: Stable slope is designed with slope 63^o – 71^o; (5) Very Good Quality Rock: Stable slope is designed with slope 72^o – 80^o.

Keywords: SMR modification, RMR, stable-slope

1. Introduction

As one of studies in slope stability, Slope Mass Rating (SMR) is a method that can provide quick suggestion for determining stable slope angle in both mining engineering (open-pit mining) and civil engineering (planning). Some researchers proposed different formulas of SMR, therefore to get optimum value of SMR, an approach was carried out through modification. Research about SMR had been conducted in Majalengka, West Java (Fig. 1), at Halang Formation and Young Volcanic Product. In the region of Majalengka, development is still growing. Local Government will build Kertajati International Airport. Due to the construction of this airport, it is required offices, public facilities, parks, restaurants, hospitals, and others.

Other research was conducted on limestone hill of Rajamandala Formation in Pasir Pabeasan, Citatah, (Fig. 1), Padalarang, West Java (Zakaria, 2013). In the Pasir Pabeasan, Citatah, limestone is mined by the mining company. A part of the territory will be planned for an alternative road.

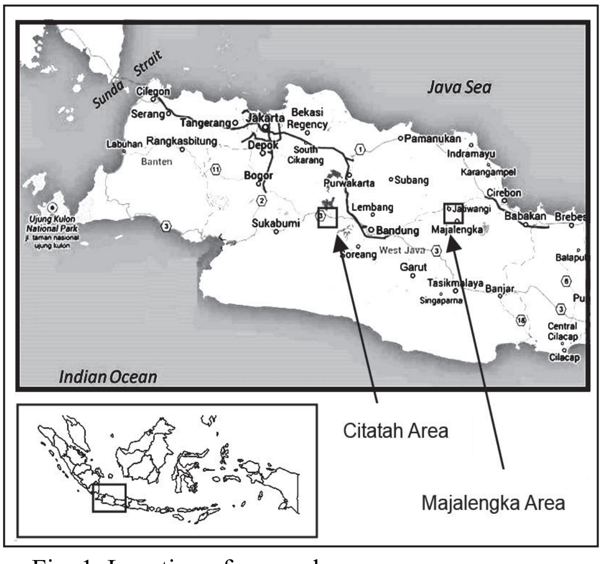

Fig. 1. Location of research

2 Methods

2.1. Rock Mass Rating

Rock Mass Rating (RMR) is an assessment of

Table 1. Rock Mass Rating System (Modified After Bieniawski,1989)

1A. CLASSIFICATION PARAMETERS AND THEIR RATING

	PARAMETER		Range of values						
1	Strength of intact rock material	*Point-load strength index*					*For this low range - uniaxial compressive test is preferred*		
		Point Load	> 10 M Pa	4 - 10 M Pa	2 - 4 M Pa	1 -2 M Pa	-		
		Uniaxial comp. strength	> 250 MPa	100-250 MPa	50-100 Mpa	25 - 50 MPa	10-25 (unit M Pa)	3-10	<3
		Rating	15	12	7	4	2	1	0
2	RQD Rock Quality Designation		90 - 100 %	75 - 90 %	50 - 75 %	25 - 50 %	< 25 %		
		Rating	20	17	13	8	3		
3	Spacing of discontinuities		> 200 cM	60 - 200 cM	20-60 cM	6-20 cM	<6 cM or <60 mm		
		Rating	20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock *(hard wall)*	Slightly rough surfaces Separation < 1 mm. Slightly weathered walls *(hard wall)*	Slightly rough surfaces Separation < 1 mm Highly weathered walls *(soft wall)*	Slickenside surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
		Rating	30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length (l/m)	Non	<10	10 – 25	25 – 125	> 125		
		(Joint water press)/ (Major principal V).	0	0 - 0,1	0,1 - 0,2	0,2 - 0,5	> 0,5		
		General conditions	Completely	Dry	Wet	Dripping	Flowing		
		Rating	15	10	7	4	0		

1B. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 - 81	80 - 61	60 - 41	40 - 21	< 21
Class Number	I	II	III	IV	V
Descriptions	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

rock mass. Assessment of rating system can be seen in Table of Geomechanics Classification (Table 1A and 1B). Result of the assessment is sum of all parameters rating in Table A. The parameters are: 1) Strength of intact rock material, 2) RQD (Rock Quality Designation), 3) Discontinuity spacing, 4) Discontinuity condition, 5) Groundwater condition. Table 1B shows the total amount put into groups according to their rating, in order to get class number and description of each RMR value. The purposes of Geomechanics classification are to be a communication tool within engineering problems by geomechanics experts, to be a tool to estimate the properties of rock mass, and also to assess the stability of tunnel, foundation, and slope. Bieniawski's Geomechanics Classification System creates classification of rock quality based on Rock Mass Rating (RMR) to test quality with 0-100 scale (Table 1B). RQD (Rock Quality Designation) can be determined by using scan-line measurement (Harisson & Hudson, 2000) and can be calculated from outcrop in the field by equation: RQD = 100 $(0.1\,\lambda + 1)\, e^{-0.1\,\lambda}$, where λ = scan-line (joint/meter).

2.2 Slope Mass Rating

Slope Mass Rating (SMR) is an application of RMR to estimate angle of slope safety on cut-slope. In mining, this method is often encountered in designing open pit slope. In civil engineering, this method can be used to design stable slope for road design, especially at hilly terrain. Some researchers proposed SMR values based on Rock Mass Rating. Laubscher (1975, in Djakamihardja & Soebowo, 1996) discussed the relationship of RMR and SMR as in Table 2; Hall (1985), gave SMR value as follows:

$$SMR = 0.65\ RMR + 25 \qquad (1)$$

and Orr (1992) discussed the relationship as follows:

$$SMR = 35 \ln RMR - 71 \qquad (2)$$

Table 2. Laubscher's SMR methods

Value of RMR	Description RMR value for the quality of rock	Recommended slope angle
81 - 100	Very good rock	75^o
61 - 80	Good Rock	65^o
41 - 60	Fairly rock	55^o
21 - 40	Poorly rock	45^o
0 - 20	Very poorly rock	35^o

Table 3. Results of the calculation of the SMR, Majalengka

Material and location	RMR	Class	Slope Mass Rating (^{o})		
			Laubcher	Hall	Orr
Tuff rock. Location at Babakan Jawa	50	III	**55**	58	66
Sandstone. Location at Majalengka	53	III	**55**	59	68
Polymictic breccia. Location at Majalengka	64	II	**65**	67	75
Andesitic igneous rock. Intrusion of igneous rock. Location: Cibodas-1,	65	II	**65**	67	75
Sedimentary rock. Sandstone, intercalated sandstone & clay. Location: Cibodas-2,	60	III	65	**64**	73

Source: BPREC-FTG (2009), Zakaria & Muslim (2014)

Note:

Based on SMR, the value of slope angle suggested is the smallest slope angle on each methods

3 Result and Discussion

3.1 Halang Formation, Lava, and Andesite

RMR in Majalengka observations (Table 3) were obtained from several locations as follows:

- Location at Babakan Jawa. Including the results of the Young Volcanic Product. Tuff rock in the form of a yellowish brown, very fine grain size. Rock strength UCS = 1.33 MPa (rating = 0); scan-line, λ = 3.5, the value of RQD = 95.13 (rating = 20), spacing of discontuinity is <60 mm (rating = 5), the condition of the field discontinuity has a very rough surface, weathered, there is a gouge <5 mm, strain gouge constantly -5 mm (rating = 10). Dry soil water conditions (rating = 15). RMR = 50.
- Location in Majalengka, around the base of the bridge. Sedimentary rock in the form of sandstone, medium hardness, easily destroyed if hit by hammer, the estimated strength of the rocks (based on Deere, 1969, and Party, 1975, in Hunt, 2007) around 9.81 MPa (rating = 1); scan-line, λ = 7, the value of RQD = 84.42 (rating = 17), spacing of discontuinity is 20-60 cM (rating = 10), rough surface, the majority a little weathered, there is a gouge <1mm (rating = 10). Rock Mass Rating = 53.

- Location in Majalengka, Polymictic breccia form of weathered rock breccia with chunks of andesitic. The strength of rocks (based on Deere, 1969, and Party, 1975, in Hunt, 2007) is 25 MPa (rating = 4). Scan-line, λ = 3.44, the value of RQD = 96.31 (rating = 20), spacing of discontuinity is between 40 to 70 cM (rating = 15), a rough surface on muscular surfaces, weathering being, there is a gouge on average 3 mm (rating = 10). Dry soil conditions (rating = 15). RMR = 64.
- Location Cibodas-1. Intrusion of Igneous Rock. Andesitic, in the form of light gray, porphyritic, containing minerals pyroxene and feldspar. Rock strength UCS = 1.76 MPa (rating = 0), the scan-line, λ = 1.3, the value of RQD = 95.13 (rating = 99.23), spacing of discontuinity is <6 mm, discontinuity field conditions showed a very rough surface , slightly weathered, stretch <5 mm, no gouge. (rating = 25), groundwater conditions no flow (rating = 150). RMR = 65.
- Location Cibodas-2, Lower member Halang Formations. Intercalated sandstone and claystone. Sedimentary rock. Rock strength = 1.26 MPa (rating = 0), the scan-line, λ = 3.95, RQD = 93.89 (rating = 20), spacing of discontuinity is <60 mm (rating = 5), very rough surface discontinuities field , slightly weathered, strain <1 mm, no gouge, Soft-wall (rating 20), groundwater conditions there is no flow of water / dry (rating = 15). RMR = 60.

Based on Geomechanics Classification System (Bieniawski, 1989), the results are divided into two classes as follows:

1) Tuff rock, at Babakan Jawa, RMR = 50, RMR = class III. Fair quality rock
2) Sandstone, at Majalengka, RMR = 53, RMR = class III. Fair quality rock.
3) Polymictic breccia, at Majalengka, RMR = 64, RMR = class II. Good quality rock.
4) Andesitic igneous rock, at Cibodas-1, RMR = 65, RMR = class II. Good quality rock.
5) Sandstone, at Cibodas-2, RMR = 60, RMR = class III. Fair quality rock.

3.2 Rajamandala Formation at Padalarang

Calculations had been made for the value of RMR (Zakaria et al., 2012) with some additional field data. There are 3 groups of limestone with different wall conditions.

- Eastern Wall: Limestone, hard to very hard, need a lot of hammer blows to take sample. Estimated value according to rock strength 196.13 MPa, scan-line = 4 joint/M, RQD = 93.84 % (based on Harisson & Hudson, 2000). Spacing of discontinuity is < 60 mM. Condition of discontinuities: rough fracture surface, slickenside wall, gouge 1-5 mm thick. Groundwater condition is dry.
- Middle Wall: Limestone, medium hardness, easy broken. Estimated value according to rock strength. Estimated value according to rock strength 9.81 MPa, scan-line = 23 to 24 joint/M, RQD = 33.09 to 30.84 % (based on Harisson & Hudson, 2000), Spacing of discontinuities 60-200 cM. Condition of discontinuities: Slightly rough fracture surface, slightly weathered, gouge > 5 mm thick. Groundwater condition is moist.
- Western Wall: Limestone, hard to very hard, need a lot of hammer blows to take sample. Estimated value according to rock strength 217.75 MPa to > 250 MPa, scan-line = 1.125 to 1. 4 joint/M, RQD = 99.11 – 99.41 % (based on Harisson & Hudson, 2000). Spacing of discontinuities, 60-200 cM. Condition of discontinuities: Very rough fracture surface, slightly weathered, no gouge, hard walls. Groundwater condition is dry

Based on Geomechanics Classification System (Bieniawski, 1989), the limestone are divided into three classes (in Table 4) as follows:

1) Eastern Wall, RMR = 72, class of RMR = II, fair rock
2) Middle Wall, RMR = 24, class of RMR = IV, poor rock
3) Western Wall, RMR = 82 to 85, clas of RMR = I, very good rock

Table 4. SMR Calculation results of limestone Rajamandala Formation

Location	RMR	Class	**Slope Mass Rating (^{o})**		
			(Laubscher)	(Hall)	(Orr)
Eastern Wall	**72**	II	**65**	72	79
Middle Wall	**24**	IV	45	41	**40**
Middle Wall	**24**	IV	45	41	**40**
Western Wall	**82**	I	**75**	78	83
Western Wall	**85**	I	**75**	80	84

To obtain the optimum slope, modification of SMR was made involving RMR. For the modification, this paper involves Rajamandala Formation at Citatah. Rock formation studied in Rajamandala Formation is limestone. In Majalengka, the rock formation is Halang Formation, Old Volcanic Deposit, and Young Volcanic Deposit. SMR method does not determine type of rock; it only assesses the RMR value.

In another method by Romana et al. (2003), SMR is calculated by considering the type of excavation, whether with heavy equipment, with blasting, without blasting, and so on. This method is usually used in open-pit mining that use dynamite to blow up the rock.

In this study, modification of SMR should involve RMR value with complete class of RMR (class I to V). However, RMR class is not always complete; therefore it is combined with rock groups in other places. Then, in each location, the smallest values are collected to analyze the relationship between RMR and smallest value of SMR, so we get a new equation comprising the smallest values. Fig. 2 shows the results of relationship between RMR and SMR with the equation written as follows:

$$SMR = 8.2348\ RMR^{0.4932}\ (R = 0.99) \qquad (3)$$

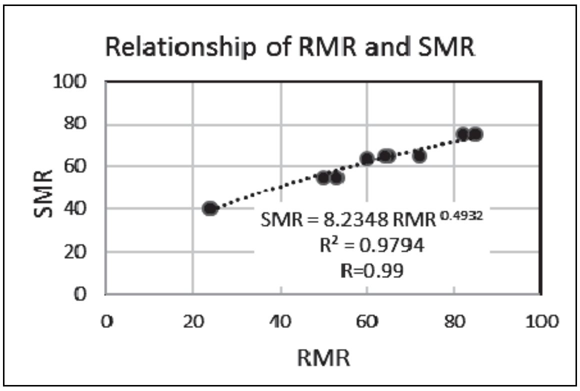

Fig. 2. Relationship of Slope Mass Rating and Rock Mass Rating

With this equati0n, the nodification of Slope Mass Raing value can be seen in Fig. 3. Based on Fig. 3, for RMR class and the description of rock quality, suggestion of the safe slope is:

Class I	= very good 81-100, SMR is 72° to 80°
Class II	= good 61-80 64.1, SMR is 63° to 71°
Class III	= moderate 41-60, SMR is 51° to 62°
Class IV	= poor 21-40, SMR is 37° to 51°
Class V	= very poor < 20, SMR is < 36°

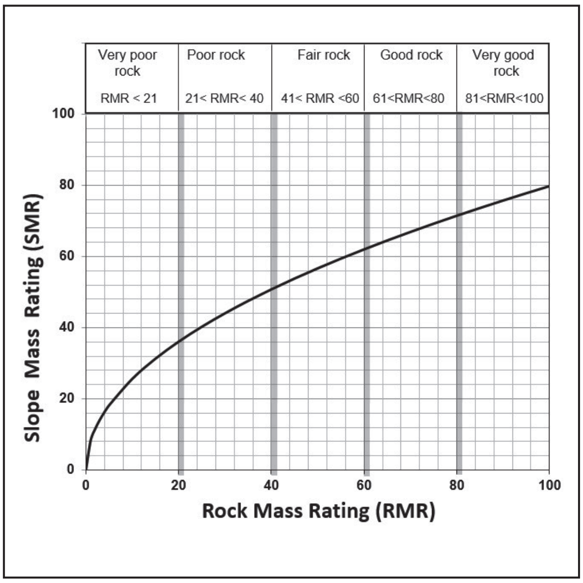

Fig. 3. Relationship between RMR with the recommended slope angle on modification SMR

4 Conclusion

This modification of SMR is an approach to provide optimum slope by considering three methods from Laubscher, Orr, and Hall. From two research location, the result of SMR modification is shown by Equation of Power Regression as SMR = 8.2348 $RMR^{0.4932}$, with correlation coefficient R = 0.99, according to the result of all method from researchers above. Safe slope determination in stable-slope design can be specified as:

(1) Very Poor Quality Rock: Stable slope is designed only with slope < 36°;

(2) Poor Quality Rock: Stable slope is designed with slope 37° – 51° ;

(3) Fair Quality Rock: Stable slope is designed with slope 51° – 62°;

(4) Good Quality Rock: Stable slope is designed with slope 63° – 71°;

(5) Very Good Quality Rock: Stable slope is designed with slope 72° – 80°.

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