Correlation between RMR and SMR Based on Field Data: A Case Study in Limestone Mining Area in Citatah, West Java, Indonesia

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***Abstract*—** This paper presents a correlation between **RMR** and **SMR** based on the field data. **SMR** classification is a development of the Bieniawski 'Rock Mass Rating' **(RMR)** system which has become known worldwide, and applied by many technicians as a systematic tool to describe rock mass conditions. The **RMR** concept has been proven to be particularly useful in assessing the need for support in tunnel studies. Application of the **RMR** system to slopes has not been possible to date. The **SMR** system provides adjustment factors, field guidelines and recommendations on support methods which allow a systematic use of geomechanical classification for slopes.

***Keywords*—**adjustment factors, correlation, field data, RMR, SMR

I. INTRODUCTION

A. Concept of Rock Mass Classification (RMR):

BIENIAWSKI (1976) published the details of a rock mass classification called the Geomechanics Classification or the Rock Mass Rating (*RMR*) system. Over the years, this system has been successively refined as more case records have been examined and the reader should be aware that Bieniawski has made significant changes in the ratings assigned to different parameters. The discussion which follows is based upon the 1989 version of the classification (Bieniawski, 1989). Both this version and the 1976 version deal with estimating the strength of rock masses. The following six parameters are used to classify a rock mass using the *RMR* system:

1. Uniaxial compressive strength of rock material.
2. Rock Quality Designation (*RQD*).
3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.
6. Orientation of discontinuities.

Each of the six parameters is assigned a value corresponding to the characteristics of the rock. These values are derived from field-surveys. The sum of the six parameters is the "RMR value", which lies between 0 and 100.

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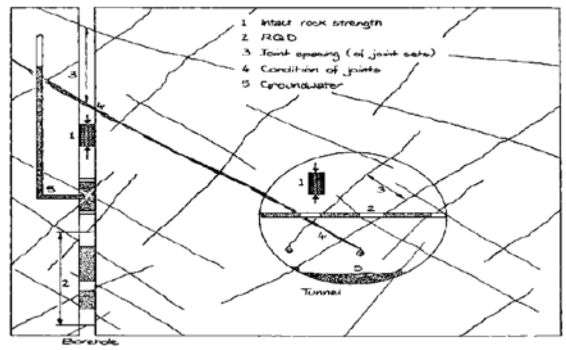


Fig. 1 Showing Parameters of RMR System

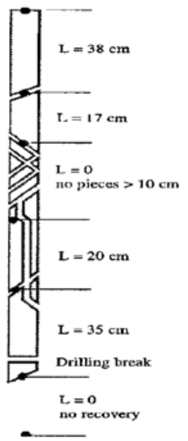
TABLE I
CLASSIFICATION TABLE FOR THE RMR SYSTEM

Rating	**Class**	**Description**
81-100	**I**	**Very Good Rock**
61-80	**II**	**Good Rock**
41-60	**III**	**Fair Rock**
12-40	**IV**	**Poor Rock**
Less than 20	**V**	**Very Poor Rock**

Rock Quality Designation' (RQD):

Rock Quality Designation (RQD) was defined by Deere as the total length of all the pieces of sound core over 10 cm long, expressed as a percentage of the length drilled. If the core is broken by handling or by the drilling process (giving a fresh fracture) the broken pieces must be fitted together and counted as one piece. The length of individual core pieces must be measured along the axis of the core, trying to avoid a joint parallel to the drill hole that penalizes the RQD values too much. RQD must be estimated for variable length, logging separately structural domains, weakness zones, individual beds and any other significant features in the rock mass. RQD was first established for igneous rocks, where it is much easier to apply than in metamorphic foliated rocks. It has become a widespread method of assessing rock mass quality.

Procedure of Calculating RQD:



Total length of core run = 200 cms

$$RQD = \frac{\sum \text{Length of core pieces} > 10\,\text{cm length}}{\text{Total length of core run}} \times 100\%$$

$$RQD = \frac{38+17+20+35}{200} \times 100\% = 55\%$$

	Quality	RQD (%)
A.	Very poor	0 – 25
B.	Poor	25 – 50
C.	Fair	50 – 75
D.	Good	75 – 90
E.	Excellent	90- 100

Fig. 2 Procedure of calculating RQD

TABLE I I
ROCK MASS RATING SYSTEM (AFTER BIENIAWSKI 1989)

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS							
	Parameter		Range of values				
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa / 1 - 5 MPa / < 1 MPa
	Rating		15	12	7	4	2 / 1 / 0
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%
	Rating		20	17	13	8	3
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm
	Rating		20	15	10	8	5
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided 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	Groundwater	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125
		(Joint water press)/ (Major principal V)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing
	Rating		15	10	7	4	0
B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)							
Strike and dip orientations			Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings		Tunnels & mines	0	-2	-5	-10	-12
		Foundations	0	-2	-7	-15	-25
		Slopes	0	-5	-25	-50	
C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS							
Rating			100 m 81	80 m 61	60 m 41	40 m 21	< 21
Class number			I	II	III	IV	V
Description			Very good rock	Good rock	Fair rock	Poor rock	Very poor rock
D. MEANING OF ROCK CLASSES							
Class number			I	II	III	IV	V
Average stand-up time			20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)			> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)			> 45	35 - 45	25 - 35	15 - 25	< 15
E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions							
Discontinuity length (persistence)			< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m
Rating			6	4	2	1	0
Separation (aperture)			None	< 0.1 mm	0.1 - 1.0 mm	1 - 5 mm	> 5 mm
Rating			6	5	4	1	0
Roughness			Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating			6	5	3	1	0
Infilling (gouge)			None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm
Rating			6	4	2	2	0
Weathering			Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Ratings			6	5	3	1	0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**			
Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90q	Drive with dip - Dip 20 - 45q	Dip 45 - 90q	Dip 20 - 45q
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90q	Drive against dip - Dip 20-45q	Dip 0-20 - Irrespective of strikeq	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et al (1972).

In applying this classification system, the rock mass is divided into a number of structural regions and each region is classified separately. The boundaries of the structural regions usually coincide with a major structural feature such as a fault or with a change in rock type. In some cases, significant changes in discontinuity spacing or characteristics, within the same rock type, may necessitate the division of the rock mass into a number of small structural regions. The Rock Mass Rating system is presented in **Table-II**, giving the ratings for each of the six parameters listed above. These ratings are summed to give a value of ***RMR***.

The following example illustrates the use of these tables to arrive at an *RMR* value. A tunnel is to be driven through slightly weathered granite with a dominant joint set dipping at 60^o against the direction of the drive. Index testing and logging of diamond drilled core give typical Point-load strength index values of 8 MPa and average *RQD* values of 70%. The slightly rough and slightly weathered joints with a separation of < 1 mm, are spaced at 300 mm. Tunnelling conditions are anticipated to be wet.

The *RMR* value for the example under consideration is determined as follows:

Table	*Item*	*Value*	*Rating*
II: A.1	Point load index	8 MPa	12
II: A.2	*RQD*	70%	13
II: A.3	Spacing of discontinuities	300 mm	10
II: E.4	Condition of discontinuities	Note 1	22
II: A.5	Groundwater	Wet	7
II: B	Adjustment for joint orientation	Note 2	-5
		Total	59

Note 1. For slightly rough and altered discontinuity surfaces with a separation of < 1 mm, **Table II.A.4** gives a rating of 25. When more detailed information is available, Table 4.E can be used to obtain a more refined rating. Hence, in this case, the rating is the sum of: 4 (1-3 m discontinuity length), 4 (separation 0.1-1.0 mm), 3 (slightly rough), 6(no infilling) and 5 (slightly weathered) = 22.

Note 2. **Table II.F** gives a description of 'Fair' for the conditions assumed where the tunnel is to be driven against the dip of a set of joints dipping at 60^o. Using this description for 'Tunnels and Mines' in **Table II.B** gives an adjustment rating of -5.

Bieniawski (1989) published a set of guidelines for the selection of support in tunnels in rock for which the value of *RMR* has been determined. These guidelines are reproduced in **Table II**. Note that these guidelines have been published for a 10 m span horseshoe shaped tunnel, constructed using drill and blast methods, in a rock mass subjected to a vertical stress < 25 MPa (equivalent to a depth below surface of <900 m).

For the case considered earlier, with *RMR* = 59, **Table II** suggests that a tunnel could be excavated by top heading and bench, with a 1.5 to 3 m advance in the top heading. Support should be installed after each blast and the support should be placed at a maximum distance of 10 m from the face. Systematic rock bolting, using 4 m long 20 mm diameter fully grouted bolts spaced at 1.5 to 2 m in the crown and walls, is recommended. Wire mesh, with 50 to 100 mm of shotcrete for the crown and 30 mm of shotcrete for the walls, is recommended.

The value of *RMR* of 59 indicates that the rock mass is on the boundary between the 'Fair rock' and 'Good rock' categories. In the initial stages of design and construction, it is advisable to utilise the support suggested for fair rock. If the construction is progressing well with no stability problems, and the support is performing very well, then it should be possible to gradually reduce the support requirements to those indicated for a good rock mass. In addition, if the excavation is required to be stable for a short amount of time, then it is advisable to try the less expensive and extensive support suggested for good rock. However, if the rock mass surrounding the excavation is expected to undergo large mining induced stress changes, then more substantial support appropriate for fair rock should be installed.

B. Concept of Slope Mass Rating (SMR):

Slope Mass Rating (SMR) is the application of the RMR to estimate the angle of slope stripping. Weighting of rock slope (SMR) is done by using mathematical calculations. This calculation is recommended by some experts. Among the SMR calculation is:

Laubscher (1975, in Djakamihardja & Soebowo, 1996) discusses the relationship RMR and SMR as follows:

TABLE III

SLOPE ANGLE OF THE MINIMUM WAGE TO LAUBSCHER (1975)

The recommended slope angle (Weighting slope mass, SMR)	For the total value of RMR (Weighting rock mass)
75°	81 – 100
65°	61 – 80
55°	41 – 60
45°	21 – 40
35°	0 – 20

Hall (1985, in Djakamihardja & Soebowo, 1996) providing SMR values as follows:

SMR= 0.65 RMR +25

Orr (1992, in Djakamihardja & Soebowo, 1996) discusses the relationship as follows:

SMR=35 ln RMR -71

II. METHODOLOGY

The correlation between **RMR** and **SMR** has been done based on the field data. The study was conducted in Limestone mining area in Citatah, on one hill (Hill-II) located in the south at the Limestone mine area, the location of KM 23-25, Jl. Bandung Raya-Cianjur.

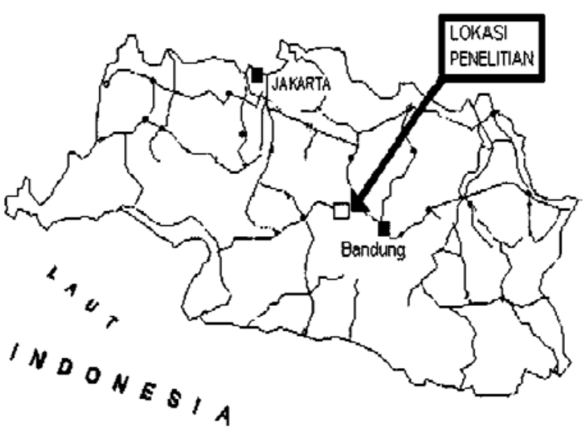


Fig. 3 Location of the study area

Conditions in the western hills, limestone hard to very hard, need a lot of hammer blows to take samples. Estimated value according to the rock strength 2200 kg/cm^2 or 217.75 Mpa. Fracture surface is very rough, strain <1 mm to not stretch, slightly weathered, there are no gouge, hard walls, no water flow, fracture spacing 60-200 cm.

Conditions in the middle hills, rock-limestone, medium hardness, easily broken if jackhammer. Estimated value according to the rock strength 100 kg/cm^2 or 9.81Mpa, moist, slightly rough fracture surfaces,slightly weathered, strain 1-5 mm, and over, there is a gouge, 5mm(Fig. 4).

Conditions in the Eastern hills,rock-limestone, hard to very hard, need a lot of hammer blows to take sample. Estimated value according to the rock strength 2000kg/cm^2 or 196.13 Mpa. Rough fracture surface, strain >5 mm, most of the time, a bit weathered, slicken side wall, there is a gouge 1-5 mm thick, there is no water flow, dried(fig. 5).

Assessment of rock mass under the above conditions(in table IV), it was found that the limestone hills to the East, the value of RMR= 72, the middle limestone hills, the value of RMR=24, to the West the limestone hills, the value of RMR= 82.So based on the formula Laubscher(1975, in Djakamihardja & Soebowo, 1996) which discusses the relationship between RMR and SMR, the slope angle is recommended for conditions similar to the limestone of the area of research is presented in table V.

III. RESULTS AND DISCUSSION

TABLE IV

ASSESSMENT OF ROCK MASS IN THE LIMESTONE HILL-II

(Modified after Zakaria, 2005)

		Eastern Part	Middle Part	Western Part
Strength of intact rock (Deere, 1969 and Party, 1975, in Hunt, 1984)		Limestone, hard to very hard, need a lot of hammer blows to take sample. Estimated value according to the rock strength 2000kg/cm^2 or 196.13 Mpa.	Limestone, medium hardness, easily broken if jackhammer. Estimated value according to the rock strength 100 kg/cm^2 or 9.81Mpa.	Limestone hard to very hard, need a lot of hammer blows to take samples. Estimated value according to the rock strength 2200 kg/cm^2 or 217.75 Mpa.
Rating		12	1	12
Frequency of joint block/meter		4	23	1.4
RQD (Hudson, 1979, in Djakamihardja & Soebowo, 1996)		93.84	33.09	99.11
Rating		20	8	20
Fracture spacing		60 to 200 cm	Less than 6cm	60 to 200 cm
Rating		15	5	15
Fracture conditions		Rough fracture surface, strain >5 mm, most of the time, a bit weathered, slicken side wall, there is a gouge 1-5 mm thick	Slightly rough fracture surfaces, slightly weathered, strain 1-5 mm, and over, there is a gouge< 5mm	Very rough fracture surface , strain <1 mm to not stretch, slightly weathered, there are no gouge, hard walls.
Rating		10	0	20
Ground water	Flow	No water flow	No water flow	No water flow
	General state	Dry	Moist	Dry
Rating		15	10	15
Total Rating		72	24	82

	Eastern Part	Middle Part	Western Part
Rating	72 (between 80-61)	24 (between 40-21)	82 (between100 – 81)
Class number	II	IV	I
Description	Good	Poor	Very good

Fig. 4 The Middle Part of Limestone Hills (Field study, 2012)

Fig. 5 The Eastern Part of Limestone Hills (Field study, 2011)

TABLE V
RELATIONSHIPS BETWEEN RMR AND SMR
(Modified after Zakaria, 2005)

RMR	Condition	Slope Mass Rating(SMR) Recommended slope angles less than:		
		Laubscher (1975)	Hall (1989)	Orr (1992)
82	Applications for other similar hills to the condition of the western part of the limestone hills	**75.00°**	78.3°	83.24°
72	Applications for other similar hills to the condition of the eastern part of the limestone hills	**65.00°**	71.8°	78.68°
24	Applications for other similar hills to the condition of the middle part of the limestone hills	45.00°	40.6°	**40.23°**

IV. CONCLUSION

The new method presented, called Slope Mass Rating (SMR), allows the use of the Bieniawski (CSIR) classification for slopes. It requires the same data and gives a forecast of stability problems and support techniques for slopes in each stability class. More research is needed, and will be welcome, to check the proposed classification system.

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