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REVIEW OF ROCK MASS RATING CLASSIFICATION: HISTORICAL DEVELOPMENTS, APPLICATIONS, AND RESTRICTIONS

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Historical development of the rock mass rating (RMR) system, first developed and later reviewed by Bieniawski, and contributed by other researchers, is presented. The advanced version of RMR classification and the scope of its application are specified.

Rock mass, Bieniawski's classification, score estimation

INTRODUCTION

Rock mass classification systems used to be of prime importance to estimate rock mass behavior and to develop counter measures to provide safe and economical mining operations. The system, being the object of discussion in the present paper, ranks as the most popular one, alternatively to a variety of available rock mass classification systems [1 – 5] (Table 1), providing efficient and safe development of mineral deposits at present. The system, though developed independently, has a number parameters in common with other systems, but their functional value and interpretation are different. RMR classification [1] is widely known and referred to in investigations, performed by employing this system. Since every study area has its own specific features, the use of RMR classification system requires special experience and involves multidisciplinary studies.

1. ROCK MASS RATING SYSTEM

In 1973 Bieniawski was the first who developed the rock mass rating (RMR) system (CSIR known as the South African Council of Scientific and Industrial Resarch), and sustained its development until 1989. By the available data its versions found more than 350 applications in underground opening, tunnels, underground mines, and open-pit slope designs. The most common mistake made in our days is that still old versions are in use, though the system was regularly revised during last 16-year period [6].

RMR system has been developed as a predesign tool for determination of a tunnel support type, like other rock mass clasisfication systems. The first RMR version allowed evaluating a stable period for an unsupported span of an underground opening (distance between tunnel face and a supported section in a tunnel) in shale and clay-bearing rocks, exposed to water and wetting-drying processes [7 – 9]. In 1974 Bieniawski revised RMR system and introduced first modifications: deterioration, discontinuity span and continuation parameters were united in term "discontinuity condition" with changes of relative points [10], thus, number of parameters, constituting RMR system, was reduced from eight to six ones.

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TABLE 1. RMR Classification Systems [5]

Classification system	Form and type*	Main applications	Reference
Terzaghi rock load classification system	Descriptive and behaviouristic form Functional type.	Design of steel support in tunnels	Terzaghi, 1946
Lauffer's stand-up time classification	Descriptive form General type	Tunnelling design	Laufer H., 1958
New Australian tunneling method (NATM)	Descriptive and behaviouristic form Tunneling concept	Excavation and design in incompetent (overstressed) ground	Rabcewicz, Müller and Pacher, 1958 – 1964
Rock classification for rock mechanical purposes	Descriptive form General type	Input in rock mechanics	Patching and Coates, 1968
Unified classification of soils and rocks	Descriptive form General type	Based on particles and blocks for communication	Deer et al., 1969
Rock quality designation (RQD)	Numerical form General type	Based on core logging; used in other classification systems	Deer et al., 1967
Size-strength classification	Numerical form Functional type	Based on rock strength and block diameter, used mainly in mining	Franklin, 1975
Rock structure rating classification (RSR)	Numerical form Functional type	Design of (steel) support in tunnels	Wickham et al., 1972
Rock mass rating classification (RMR)	Numerical form Functional type	Design of tunnels, mines, and foundations	Bieniawski, 1973
Q-classification system	Numerical form Functional type	Design of support in underground excavation	Barton et al., 1974
Typological classification	Descriptive form General type	Use in communication	Maluta and Holzer, 1978
Unified rock classification system	Descriptive form General type	Use in communication	Williamson, 1980
Basic geotechnical classification (BGD)	Descriptive form General type	General applications	ISRM, 1981
Geological strength index (GSI)	Numerical form Functional type	Design of support in underground excavation	Hoek, 1994
Rock mass index system (RMi)	Numerical form Functional type	General characterization, design of support, TMB progress	Palmström, 1995

*Glossary:

— Descriptive form: input to the system is mainly based on descriptions;

— Numerical form: input parameters are given numerical ratings according to their character;

— Behaviouristic form: input is based on rock mass behaviour in a tunnel;

— General type: system is worked out to serve as a general characterization;

— Functional type: system is structured for a special application (for example, for rock support).

RMR system was again revised by Bieniawski in 1976 [11]. The most important component of this revision is that of the support selection guide in tunnels of a horseshoe shape and 10 m in width. The length of rock bolts was shortened and shotcrete thickness was reduced. The score range for the first-class rock mass was changed from 90 – 100 to 81 – 100. The roughness concept was added to the system with regard to discontinuities, number of evaluation points was increased. As rocks of 1 MPa strength are hard to handle the point load strength index was involved into the system. In 1979 Bieniawski made changes pertinent to the discontinuity condition and ground water [12]. The generalized definition was introduced for cases when ground water is not measured and the number of groups was increased to five, the correction factor with regard to the discontinuity orientation was derived for tunnels, foundations and slopes.

The latest modifications of RMR system done by Bieniawski are listed below [13, 14]:

— "Parameter – score" graphs were introduced for more precise scoring;

— Parameters of discontinuity continuation, discontinuity spacing, roughness, backfill and degree of deterioration were specified and scored according to ISRM [15];

— Correction factors for determination of rock masses, weakened by mining activity impact, were recommended;

— The unsupported-span graph was re-arranged.

No chart-graph or table was given for RMR, because the older RMR versions are in use up to now. Only separate details of the new RMR version are reported below in order to eliminate the description complexity.

Prior to the latest RMR version a rock mass could be unfairly referred to a wrong group by the charted score for strength, being one of classification parameters. Graphs "parameter – score" (Fig. 1) are recommended to exclude this imperfection [14, 15].

1.1. CONTRIBUTIONS TO ROCK MASS RATING SYSTEM

The rock-mass strength is always among important parameters in design planning. It is really difficult to arrange a sample for a uniaxial compression test under optimal conditions. In this connection, the use of point load index was initiated to determine the rock mass strength. However, it is considerably hard to conduct point load tests in rocks having frequently-spaced weakness planes. For this purpose, the Block Punch Index (PBI) test was executed [16]. Later, standards for the block punch index estimate were developed and the equation with the strong BPI-UCS correlation was derived [17 – 19]:

$$\sigma_c = 5.5\text{BPI}. \tag{1}$$

The graph in Fig. 2 was proposed to evaluate a scoring [20, 21].

This suggestion was fulfilled in [24, 25]. Moreover, Bieniawski proposed a table, regarding the scoring of discontinuity surfaces (Table 2) [14]. Besides, the corrections for blasting in tunneling and mining activities were introduced [22, 23]. Scheme of RMR evaluation is given in Fig. 3.

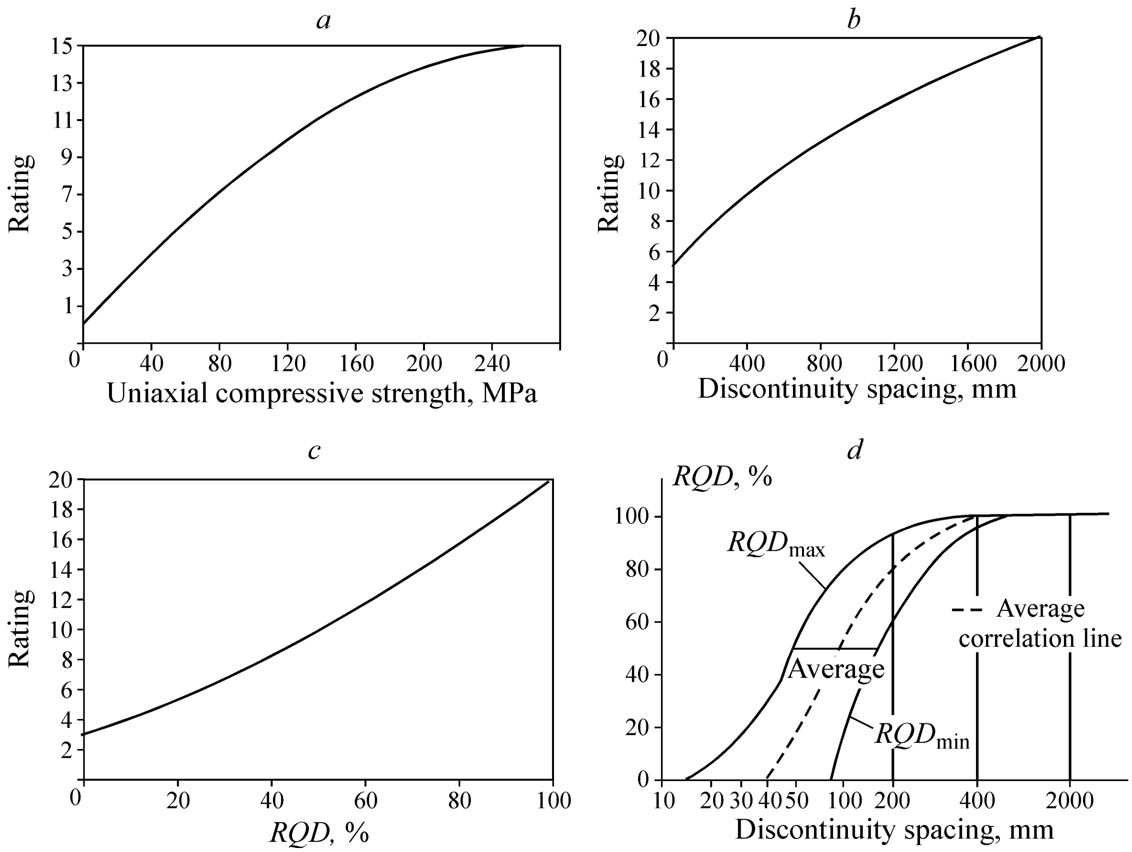

Fig. 1. Graphs "parameter-score" for RMR [14]

1.2. APPLICATIONS AND RESTRICTIONS FOR ROCK MASS RATING

The main RMR applications are tunneling, drift driving and underground rock engineering. RMR system is employed to determine the rock mass quality, to predesign excavation and processes to be proceeded within this framework. RMR is also useful to estimate the unsupported span time for a rock mass (Fig. 4), cohesion, an internal friction angle, support load, support selection, elasticity modulus, and strength values [26] or to assess an unsupported span period for TBM (Fig. 5) [27].

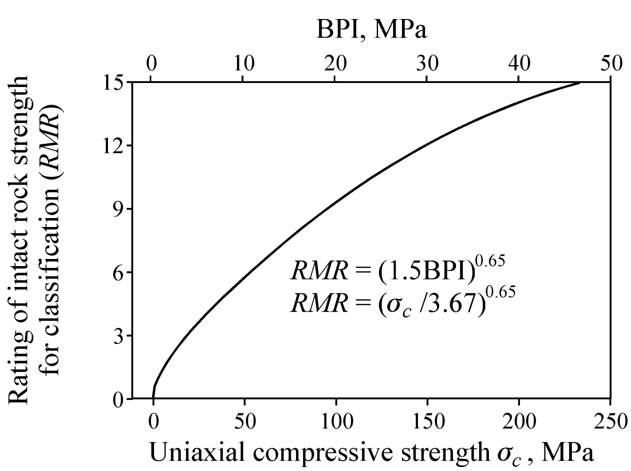

Fig. 2. Relation between BPI-σ_c and scoring graph [20, 21]

TABLE 2. Rock Mass Rating System

A. Classification Parameters and Their Rating									
Parameter			Range of values						
1.	Strength of intact material, MPa	Point-load strength index	> 10	4 – 10	2 – 4	1 – 2	< 1 (prefered for this low-range uniaxial compressive test)		
		Uniaxial compr. strength	> 250	100 – 250	50 – 100	25 – 50	5 – 25	1 – 5	< 1
	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.	Discontinuity spacing, mm		> 200	60 – 200	200 – 600	60 – 200	< 60		
	Rating		20	15	10	8	5		
4.	Condition of discontinuities (See E)		Very rough surface; 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; gouge < 5 mm thick; or separation 1-5 mm continuous	Soft gouge > 5 mm thick; separation > 5 mm; continuous		
	Rating		30	25	20	10	0		
5.	Ground water	Inflow per 10 m tunnel length, l/m	None	< 10	10 – 25	25 – 125	> 125		
		Summary water pressure	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		

TABLE 2 (continued)

B. Rating Adjustment for Discontinuity Orientation (See F)

Strike and dip orientations		Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
Rating	Tunnels and mines	0	−2	−5	−10	−12
	Foundations	0	−2	−7	−15	−25
	Slopes	0	−5	−25	−50	

C. Rock Mass Classes by Summary Ratings

Rating	100 – 81	80 – 61	60 – 41	40 – 21	< 21
Class number	I	II	III	IV	V
Rock description	Very good	Good	Fair	Poor	Very poor

D. Rock Classes by Stand-up Span Time

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 h 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

TABLE 2 (concluded)

E. Guidelines for Classification of Discontinuity conditions

Discontinuity length (persistence), m	< 1	1 – 3	3 – 10	10 – 20	> 20
Rating	6	4	2	1	0
Separation (aperture), mm	None	< 0.1	0.1 – 1.0	1 – 5	> 5
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge), mm	None	Hard filling < 5	Hard filling > 5	Soft filling < 5	Soft filling > 5
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Rating	6	5	3	1	0

F. Effect of Discontinuity Strike and Dip Orientation in Tunneling*

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 – 90°	Drive with dip - dip 20 – 45°	Dip 45 – 90°	Dip 20 – 45°
Very favourable	Favorable	Very unfavorable	Fair
Drive against dip - Dip 45 – 90°	Drive against dip - Dip 20 – 45°	Dip 0 – 20° irrespective of strike	
Fair	Unfavorable	Fair	

* Modified after Wickham et al (1972).

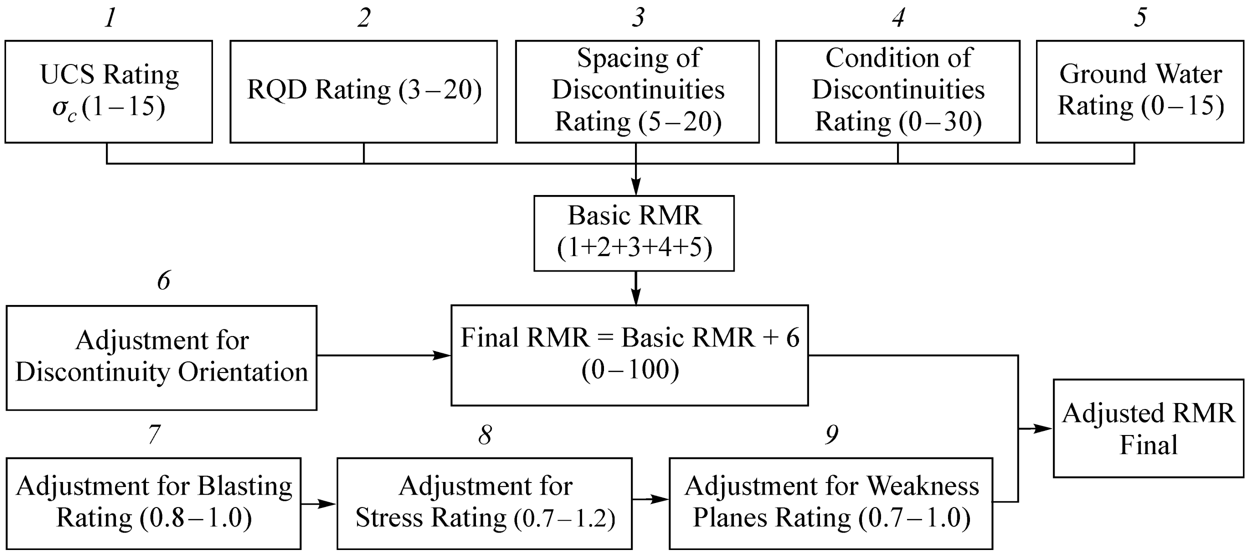

Fig. 3. RMR calculation algorithm

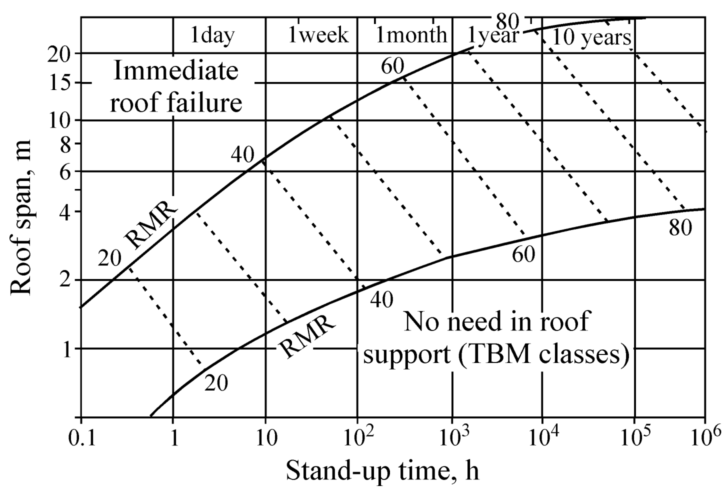

Fig. 4. Relationship between stand-up time, span and RMR classification [14]

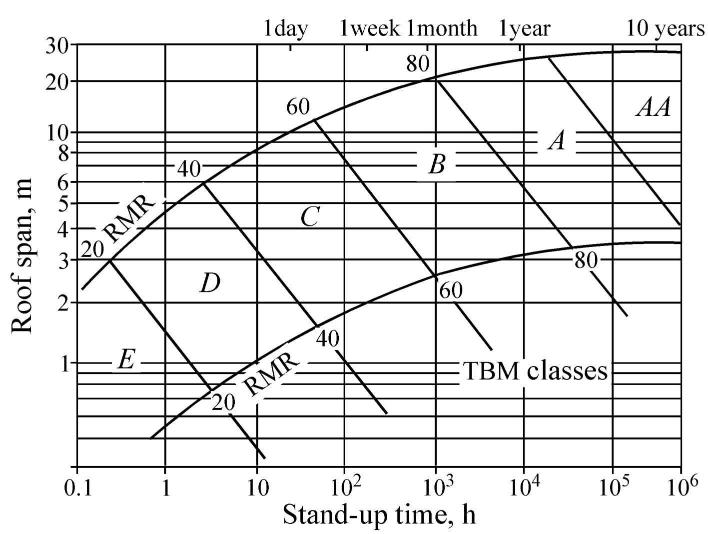

Fig. 5. Modified relationship between stand-up time, roof span for TBM [27]

Estimates of cohesion and an internal friction angle, determined with help of RMR system, will be valid for slopes, driven in water-saturated and transformed rock masses [26].

By using RMR system the load on a support system can be calculated from:

$$P = \left(\frac{100 - RMR}{100} \right) \gamma BS\,, \tag{2}$$

where P is support pressure, KN/m^2; γ is rock volume weight unit, KN/m^3; B is tunnel width, m; S is tension factor for a rock mass.

As the available publications state the equaton is extremely safe for large tunnels and and insecure for small tunnels with anchored roof, and the following ratio is proposed [28]

$$P = \frac{0.75 B^{0,1} H^{0,5} - RMR}{2RMR}\,, \tag{3}$$

where P is short-term support pressure on a tunnel roof, MPa; B is width of an opening, m; H is overburden stratum thickness, m.

Since laboratory tests, conducted on rock material, are not representative for natural rock masses, the deformability modulus for a rock mass can be evaluated from ratio:

$$E_m(GPa) = 2RMR - 100 \quad \text{(RMR > 50)}, \tag{4}$$

for hard rocks [29] and from ratio:

$$E_m(GPa) = 10^{(RMR-10)/40} \quad \text{(RMR < 50)} \tag{5}$$

for soft rocks [30].

To take into consideration the scale effect and primal stresses in natural rock masses in these equations the reduction factor is considered reasonable [31]

$$E_m = E_{MC}(RF)\,, \tag{6}$$

where E_{MC} is elasticity modulus, obtained under laboratory conditions for rocks ($E_{MC} = \sigma_c / \varepsilon_{lc}$); RF is a reduction factor.

The relation between RMR and reduction factor is presented in Fig. 6. Moreover, the relation between the deformability modulus for the rock mass and RMR is illustrated in Fig. 7. Taking RMR value, calculated for a jointed marl rock mass at an open pit mine, as a basic one, it was established that the deformability modulus is higher than that, obtained under laboratory conditions [32]. It is essential to emphasize that the better deformability modulus evaluation is obtained by using the reduction factor in numerical modeling [33].

Furthermore, the inner tunnel convergance and ground settlements match with in-situ measurements at a 20 m deep tunnel when the reduction factor is involved into evaluation of E_m in numerical modelling studies [34, 35]. In [36] it is indicated that in tunnels of more than 50 m in depth E_m depends on the lateral pressure and can be evaluated from:

$$E_m = 0.3 H^{\alpha} 10^{\frac{(RMR-20)}{38}}\,, \tag{7}$$

where $\alpha = 0.16 - 0.30$ (higher for weak rocks); H is tunnel depth, m.

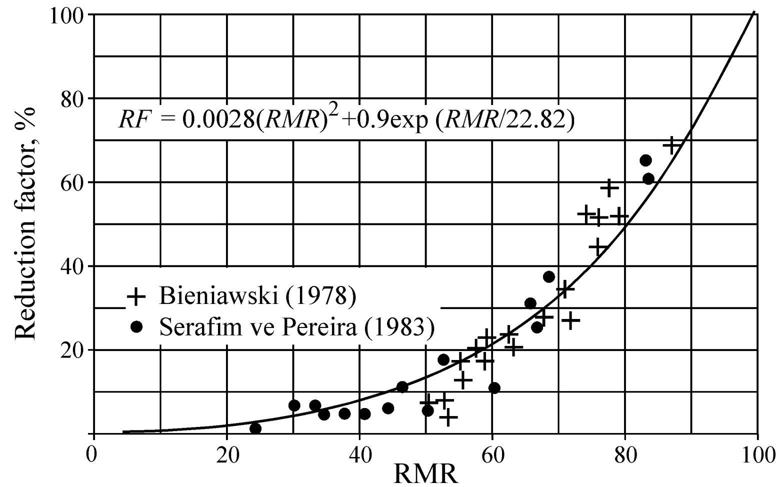

Fig. 6. Relation between reduction factor and RMR [31]

It is imperative that evaluation of E_m should involve consideration for medium conditions and restrictions, furthermore, in-situ tests should be performed properly [6].

In the previous practice the relative failure criteria [37] were used to assess strength parameters for RMR. Later, introduction of the geological strength index (GSI) entailed the exclusion of RMR from the assessment system.

As for restrictions, RMR system mainly depends on observations, experts' experience and it may result in extremely safe or unsafe conditions. In this connection, it is preferable to apply field observations together with field surveys. Another RMR system restriction deals with the discontinuity-orientation parameter. This parameter is discarded for extremely joint and completely crushed rock masses. In [38, 39] M-RMR, a modified RMR version, is proposed, and the stiff core efficiency is suggested relative to this parameter (Table 3).

When applying RMR for slopes, some meaningless results used to appear, thus, a number of instability models are developed for scoring in order to adjust the discontinuity orientation and to eliminate this situation [40]. At previous studies, aimed at prevention of such results, the orientation adjustment, equal to (– 5), is assumed. The calculated values for shear strength parameters are consistent with strength parameters, determined by the relative failure value [6, 32, 33, 41, 42].

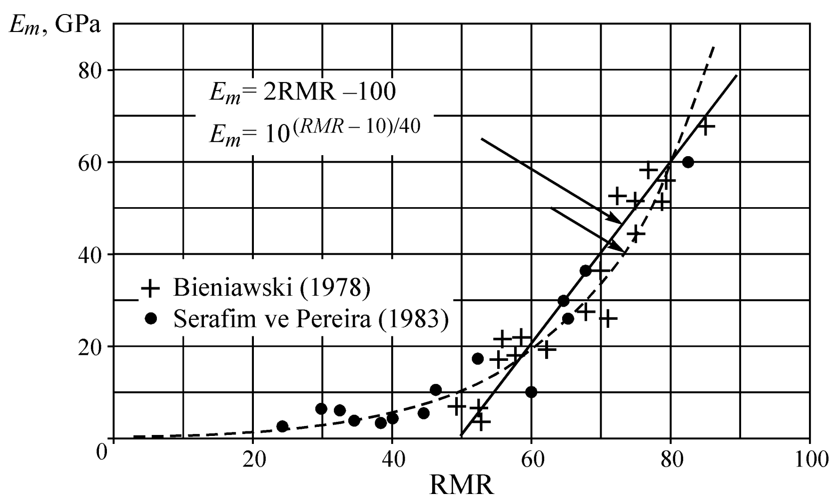

Fig. 7. Relation between deformability modulus for a rock mass E_m and RMR [32]

TABLE 3. Relation between Scoring and the Stiff Core Efficiency

Intact core recovery (ICR), %	Rating
ICR < 5	– 12
5 < ICR < 15	– 10
15 < ICR < 25	– 8
ICR > 25	– 5

In [43] it was stated that the provision should be made for the ground water concept in the classification system for weak rocks, in particular. The slake durability index was added as the multiplier coefficient to the system.

The rock material strength is one of major components and basic RMR parameters. The uniaxial compression strength and point load strength were suggested for evaluation of this parameter. Alternatively, rock masses exhibiting laminations and schistosity are difficult for assessment of the uniaxial compression strength and point load strength. BPI process is more preferable in this particular case [15,20].

Unfortunely, RMR process does not suffice for classification of the melange rock mass type, containing blocks within a weak matrix [6]. However, when studying areas which bear two materials of different strength, classification systems, other than RMR system also pose some constraints.

The next restriction for RMR system is detremination of class ranges. It would be reasonable to set a narrower interval for weak and clay-bearing rocks, in particular, for rock masses where RMR < 40, and significant deviations between RMR and M-RMR are apparent [32].

TYPICAL ERRORS OF RMR SYSTEM APPLICATION

Rock mass rating system is helpful exclusively for predesign. It is explicit that application of the system involves high-class experience of users. The data, obtained by applying RMR system, should be considered in combination with both analytical and numerical study data. In case of tunnelling with 20 – 25 m roof span, you should be very careful because this tunnel roof level is actually crucial from the carrying load stand point. In practice, there are cases when RMR system fails to distinguish heterogenous rock masses.

At present, typical errors of RMR system applications mainly deal with the use of old versions of RMR system.

CONCLUSIONS

RMR system is applicable for pre-designing of safe tunneling, underground openings, underground and open-pit mining with the use of empirical formulae and rock mass classification systems. It is essential to emphasize the expediency of applying the latest RMR system versions, followed by absolute checking with in-situ observations.

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