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Most Used Rock Mass Classifications for Underground Opening

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Abstract: Problem statement: Rock mass characterization is an integral part of rock engineering practice. The empirical design methods based on rock mass classifications systems provide quick assessments of the support requirements for underground excavations at any stage of a project, even if the available geotechnical data are limited. The underground excavation industry tends to lean on empirical approaches such as rock mass classification methods, which provide a rapid means of assessing rock mass quality and support requirements. **Approach:** There were several classifications systems used in underground construction design. This study reviewed and summarized the must used classification methods in the mining and tunneling systems. **Results:** The method of this research was collected of the underground excavations classifications method with its parameters calculations procedures for each one, trying to find the simplest, less costs and more efficient method. **Conclusion:** The study concluded with reference to errors that may arise in particular conditions and the choice of rock mass classification depend on the sensitivity of the projects, costs and the efficient.

Key words: Rock mass, classification, underground, tunneling

INTRODUCTION

In underground excavation engineering, rock mass classification methods have always played an important role, particularly in predicting support requirements for excavations in rock. Based on experience in broadly similar ground conditions elsewhere in previous projects, these methods relate rock mass conditions to support requirements and construction procedures in new projects. In contrast the rational or theoretical approach to underground excavation design uses explicit models representing the behavior of rock masses developed based on the principles of the mechanics of materials. The application of this approach requires access to accurate information on the rock mass properties, groundwater conditions and in situ stress condition and is often time consuming and costly. While both approaches serve the same purpose, the classification methods are used when there is insufficient information to establish an explicit model or when time and cost limitations prevent the use of other models. This means in underground excavation engineering these are primarily found in two applications:

- Before the commencement of construction when geological, geotechnical and construction data are limited, but time is not strictly limited. At this stage the main applications are for detailed planning and the design of initial support, determination of construction procedure and preliminary design of final support
- During construction when detailed information on the rock mass can be readily obtained by observations or simple tests, but time is limited due to contractual obligations and project completion deadlines. The main applications at this stage are for the determination and adaptation of initial support details, determination or confirmation of construction procedure and detailed design of the final support

In order to be efficient and reliable at both stages of these applications, as noted by Einstein *et al*. (1979), a rock mass classification method should:

- Be easily applicable and robust
- Use easily determinable input parameters
- Accurately represent rock mass behavior
- Avoid subjectivity
- Ensure safety and economy

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MATERIALS AND METHODS

Methods that have been used in designing support for underground opening in rock:

Rock Quality Designation (RQD): The RQD is a core recovery percentage that is indirectly based on the number of fractures and the amount of softening in the rock mass that is observed from the drill cores. Only the intact pieces with a length longer than 100 mm (4 in.) are summed and divided by the total length of the core run:

$$\text{RQD} = \frac{\sum \text{langth of core piesces} > 10 \text{ cm}}{\text{Total core length}} \times 100(\%)$$

It is used as a standard parameter in drill core logging and its greatest value is perhaps its simplicity and quick determination and also that it is inexpensive. RQD is to be seen as an index of rock quality where problematic rock that is highly weathered, soft, fractured, sheared and jointed is counted in complement to the rock mass (Deere and Deere, 1988).

Direct method (core logs available): The procedure for measuring RQD directly is illustrated in Fig. 1. The recommended procedure of measuring the core length is to measure it along the centerline. Core breaks caused by the drilling process should be fitted together and counted as one piece. All the artificial fractures should be ignored while counting the core length for RQD, even if they pass the requisite 100 mm length.

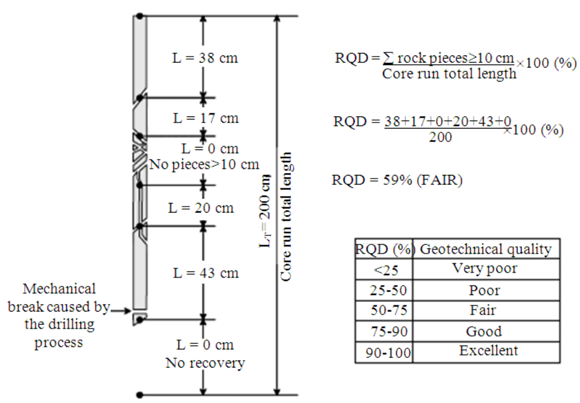

Fig. 1: Procedure for measurement and calculation of Rock Quality Designation (RQD) (Deere and Deere, 1988)

Table 1: Correlation between RQD and rock mass quality

RQD (%)	Rock quality
<25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

For RQD determination, the International Society for Rock Mechanics (ISRM) recommends a core size of at least 54.7 mm. According to Deere and Deere (1988), the recommended run length for calculating RQD is based on the actual drilling-run length used in the field, preferably no greater than 1.5 m. The ISRM Commission on Standardization of Laboratory and Field Tests recommends RQD-calculations using variable “run lengths” to separate individual beds, structural domains and weakness zones, so as to indicate any inherent variability and provide a more accurate picture of the location and width of zones with low RQD values. The relationship between the numerical value of RQD and the engineering quality of the rock mass is given in Table 1.

Indirect method (no core logs are available): *In situ* estimations of RQD was in 1973 suggested to be carried out using the following equation (Afrouz, 1992):

$$\text{RQD}(\%) = A^x - B^y \cdot D_v$$

where, D_v is the total number of discontinuities per cubic meter of rock mass. The plane of discontinuities is not perpendicular to the direction of maximum principal stress. The constants A, B, x, y are related to the above noted factors in such a way that A_x is 105-120 and By is 2-12.

Priest and Hudson found that an estimate of RQD could be obtained from joint spacing (λ joints/m) measurements made on an exposure by using (Brady and Brown, 2004):

$$\text{RQD} = 100e^{-0.1\lambda}(0.1\lambda + 1)$$

Though RQD is dependent on the borehole orientation. In principle, it is based on the measurement of the angle between each joint and the surface or the drill hole. The weighted Joint density (wJd) is for measurements on rock surfaces:

$$\text{wJd} = \frac{1}{\sqrt{A}} \sum \frac{1}{\sin \delta_1}$$

and for measurements along a drill core or scan line:

$$\text{wJd} = \frac{1}{\sqrt{L}} \sum \frac{1}{\sin \delta_1'}$$

Where:

δ_1 = The intersection angle, i.e., the angle between the observed plane or drill hole and the individual joint

A = The size of the observed area in m^2
L = The length of the measured section along the core or scan line, Fig. 2

Rock Structure Rating (RSR): The Rock Structure Rating (RSR) introduced numerical ratings of the rock mass properties and was a precursor to the two most used classification systems today (the RMR and the Q-system). The RSR value is a numerical value in the interval of 0-100 and is the sum of weighted numerical values determined by three parameters. The three parameters are called A, B and C. Parameter A is said to combine the generic rock type with an index value for rock strength along with the general type of structure in the studied rock mass. Parameter B relates the joint pattern with respect to the direction of drive. Parameter C considers the overall rock quality with respect to parameters A and B and also the degree of joint weathering and alteration and the amount of water inflow. The US Bureau of Mines (Skinner, 1988) developed the RSR system further and selected six possible factors as being the most essential for prediction of the support requirements. By using only six factors they tried to make a method that is simple and easy to use. The six factors are:

1. Rock type with a strength index 2. Rock type with a strength index	} A (maximum = 30)
3. Rock joint spacing 4. Orientation with respect to tunnel drive	} B (maximum = 45)
5. Joint condition 6. Groundwater inflow	} C (maximum = 25) $\sum = 100$

Higher RSR value requires less support under normal tunneling conditions.

Rock Mass Rating (RMR): The reasons for using RMR are, according to Bieniawski (1989), the ease of use and the versatility in engineering practice. It should be observed that the RMR-system is calibrated using experiences from coalmines, civil engineering excavations and tunnels at shallow depths. The RMR system uses the following six parameters, whose ratings are added to obtain a total RMR-value:

- Uniaxial compressive strength of intact rock material
- Rock Quality Designation (RQD)
- Joint or discontinuity spacing
- Joint condition
- Ground water condition
- Joint orientation

Each of these parameters is given a rating that symbolizes the rock quality description All the ratings are algebraically summarized for the five first given parameters and can be adjusted depending on the joint and tunnel orientation by the sixth parameter as shown in the following equations:

$$RMR = RMR_{basic} + \text{adjustment for joint orientation}$$
$$RMR_{basic} = \sum \text{parameters } (i + ii + iii + iv + v)$$

The final RMR values are grouped into five rock mass classes, where the rock mass classes are in groups of twenty ratings each Table 2.

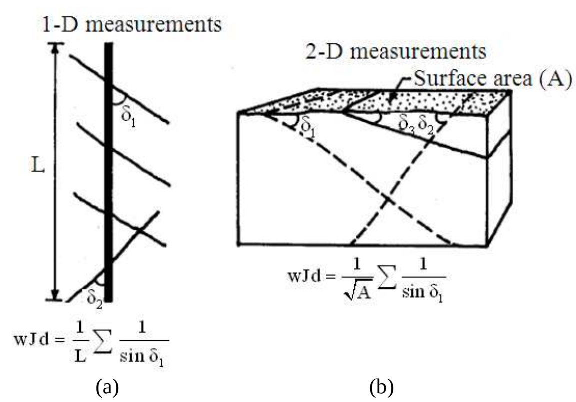

Fig. 2: (a) The intersection between joints and bore core (b) The intersection between joints and a surface

Table 2: Meaning of rock mass classes and rock mass classes determined from total ratings (Bieniawski, 1978)

Parameter/properties of rock mass	Rock mass rating (rock class)				
Rating	100-81	80-61	60-41	40-21	<20
Classification of rock mass	Very good	Good	Fair	Poor	Very poor
Average stand-up time	10 years for 15 m span	6 month for 8 m span	1 week for 5 m span	10 h for 2.5 m span	30 min for 1 m span
Cohesion of the rock mass	>400 kpa	300-400 kpa	200-300 kpa	100-200 kpa	<100 kpa
Friction angle of the rock mass	>45°	35-45°	25-35°	15-25°	<15°

The rock mass Quality (Q)-system: Barton (1988) first introduced the rock tunneling Quality Index, the Q-system in 1974. The original Q-system (Barton *et al*., 1974) uses the following six parameters: RQD, Number of joint sets, Joint roughness, Joint alteration, Joint water conditions and Stress factor. The fundamental geotechnical parameters are, according to Barton (1988), block size, minimum inter-block shear strength and active stress. These fundamental geotechnical parameters are represented by the following ratios (Barton, 2002):

- Relative block size = RQD/J_n
- Relative frictional strength = J_r/J_a
- Active stress = J_w/SRF

The rock mass quality is defined as (Barton *et al*., 1974):

$$Q = \left[\frac{RQD}{l_n}\right]\cdot\left[\frac{J_r}{l_n}\right]\cdot\left[\frac{J_w}{SRF}\right]$$

Where:

RQD = Deere's Rock Quality Designation ≥10
J_n = Joint set number
J_r = Joint roughness number (of least favorable discontinuity or joint set)
J_a = Joint alteration number (of least favorable discontinuity or joint set)
J_w = Joint water and pressure reduction factor
SRF = Stress reduction factor-rating for faulting, strength/stress ratios in hard massive rocks and squeezing and swelling rock

Use of the Q-system is specifically recommended for tunnels and caverns with an arched roof. The rock mass has been classified into nine categories based on the Q value, as can be seen in Table 3. The range of Q values varies between 0.001 and 1000.

To relate the tunneling Quality index (Q) to the behavior and support requirements of an underground excavation a term called the equivalent Dimension (D_c) was defined:

$$D_c = \frac{\text{Exca var ion span, diameter or heighr (m)}}{\text{Excavation support ratio}}$$

The Excavation Support Ratio (ESR) was determined from investigations of the relation between existing maximum unsupported excavation span (SPAN) and Q around an excavation standing up for more than 10 years. The following relationship was defined:

$$SPAN = 2Q^{0.66} = 2(ESR)Q^{0.4}$$

Barton *et al*. (1976) gives suggested values for ESR according to Table 4.

The Q-system has been modified due to changes in the stress reduction factor (Grimstad and Barton, 1993) and they presented an updated Q-support chart for the new supporting methods, Fig. 3.

Mining Rock Mass Rating (MRMR): The MRMR-system takes into account the same parameters as the basic RMR-value. The MRMR is determined by the rating of intact rock strength, RQD, joint spacing and joint condition. The range of MRMR lies, as the RMR-system, between zero and 100, values that are stated to cover all variations in jointed rock masses from very poor to very good. The rating system is divided into five classes and ten sub-classes. The five classes rates between 0-20 points and the subclasses with a 10-point rating. Laubscher (1984) presented a relation between MRMR and the in *situ* rock mass strength as:

$$\sigma_{cm} = \sigma_c \cdot \frac{(MRMR - \text{rating for } \sigma_c)}{100}$$

σ_{cm} = Uniaxial compressive strength of the rock mass
σ_c = Uniaxial compressive strength of intact rock

The Unified Rock Classification System (URCS): The Unified Rock Classification System (URCS) dates from 1975 and is used by the US Forest Service for design of forest access roads (Williamson, 1984). The URCS consists of four fundamental physical properties:

- Degree of weathering
- Estimated strength
- Discontinuities or directional weaknesses
- Unit weight or density

Table 3: Classification of rock mass based on Q-values (Barton *et al*., 1974)

Q	Group	Classification
Oct-40	1	Good
40-100		Very good
100-400		Extremely good
400-1000		Exceptionally good
0.1-1.0	2	Very poor
1.0-4.0		Poor
4.0-10.0		Fair
0.001-0.01	3	Exceptionally poor
0.01-0.1		Extremely poor

Table 4: ESR values for different excavation categories

Excavation category	ESR
A: Temporary mine openings	3-5
B: Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks) pilot tunnels, drifts and headings for large excavation	1.6
C: Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels	1.3
D: Power stations, major road and railway tunnels, civil defense chambers, portals, intersections	1.0
E: Underground nuclear power stations, railway stations, sports and public facilities, factories	0.8

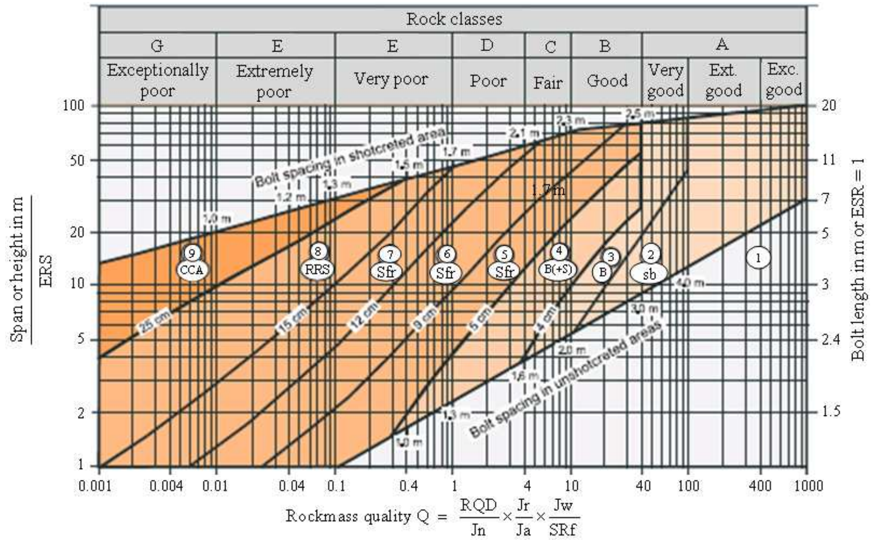

Fig. 3: Chart for design of steel fiber reinforced concrete and systematic bolting support (Grimstad and Barton, 1993)

Table 5: Layer thickness (International Society for Rock Mechanics, 1981)

Intervals (cm)	Symbols	Descriptive terms
> 200	L_1	Very large
	$L_{1,2}$	Large
60-200	L_2	Large
20-60	L_3	Moderate
6-20	L_4	Small
	$L_{4,5}$	Small
<6	L_5	Very small

Table 6: Fracturing intercept (International Society for Rock Mechanics, 1981)

Intervals (cm)	Symbols	Descriptive terms
>200	F_1	Very wide
	$F_{1,2}$	Wide
60-200	F_2	Wide
20-60	F_3	Moderate
6-20	F_4	Close
	$F_{4,5}$	Close
<6	F_5	Very close

Each of these four properties consists of five categories ranging from A through E, which represents the design limiting conditions of each of the basic elements of the system. Rock material designated AAAA will require the least design evaluation while EEEE will require the most. The URCS is used for making rapid initial assessments of rock conditions, using simple field equipment and relate those to design. According to Williamson (1984): "The equipment used for the field tests and observations is simple and available: One's fingers, a 10 power hand lens, a 1-pound (0.5 kg) ball peen hammer, a spring-loaded "fish" scale of the 10-pound (5 kg) range and a bucket of water. Fingers are used in determining the degree of weathering and the lower range of strength. The hand lens is used in defining the degree of weathering. The ball peen hammer is used to estimate the range of unconfined compressive strength from impact reaction. The spring-loaded scale and bucket of water are used to measure the weight of samples for determining apparent specific gravity. "According to Williamson (1984), the density or unit weight is one of the most useful and reliable parameter for determining rock quality.

Basic Geotechnical Description (BGD): A Basic Geotechnical Description of Rock Masses (BGD) was established in 1981 by ISRM. The intent was to characterize the various zones that constitute a rock mass, in a simplified form. The rock mass should be divided into geotechnical units and zones before applying the BGD. The representative BGD-value for each zone is determined by:

- The rock name, with a simplified geological description such as geologic structure, color, texture and degree of weathering
- Two structural characteristics of the rock mass: The layer thickness and fracture intercept, Table 5 and 6
- Two mechanical characteristics; the uniaxial compressive strength of the rock material and the angle of joint friction, Table 7 and 8

This classification of BGD results in that each zone is characterized by its rock name followed by the interval symbols

Table 7: Uniaxial compressive strength (International Society for Rock Mechanics, 1981)

Intervals (MPa)	Symbols	Descriptive terms
>200	S_1	Very high
	$S_{1,2}$	High
60-200	S_2	High
20-60	S_3	Moderate
6-20	S_4	Low
	$S_{4,5}$	Low
<6	S_5	Very low

Table 8: Angle of joint friction (International Society for Rock Mechanics, 1981)

Intervals (^{O})	Symbols	Descriptive terms
>45	A_1	Very high
	$A_{1,2}$	High
35-45	A_2	High
25-35	A_3	Moderate
15-25	A_4	Low
	$A_{4,5}$	Low
<15	A_5	Very low

Table 9: The ratings reduction of different joint sets in RMS (Stille *et al*., 1982)

		1 or 2 joint sets		
Type of joint	One prominent joint	Strength in joint direction	Remaining conditions	More than 2 joint sets
Continuous	-15	-15	0	-15
Not continuous	-5	-5	0	-10

Table 10: The rock mass strength as a function of the RMS-value (Stille *et al*., 1982)

RMS-value	100-81	80-61	60-41	41-20	<20
σ_m, MPa	30.0	12.0	5.0	25.0	0.5
Parameter in ∅	55.0°	45.0°	35.0°	25.0°	15.0°
the mohr-coulomb failure criterion c, MPa	4.7	2.5	1.3	0.8	0.2

Rock Mass Strength (RMS): The Rock Mass Strength (RMS) classification by Stille *et al*. (1982), is a modification of the RMR-system, as it includes the first five parameters of RMRbasic. The loading conditions and initial stress field are not considered which means that the RMS is a strength classification. In addition to the RMRbasic value, every combination of three different types of joint sets and two different types of joints is rated as can be seen in Table 9.

The sum of the RMRbasic and the rating reduction, due to the number of joint sets, is the RMS-value for the rock mass. Using the RMS-value, the rock mass strength can be estimated according to Table 10.

Modified Basic RMR system (MBR): The Modified Basic RMR system (MBR) is a modified RMR for mining applications and therefore uses many of the same input parameters. The data base values of MBR range from 20 to almost 70. The studied depths varied from about 213 m to over 610 m (Kendorski *et al*., 1983). The final mining, FMBR, which is used to obtain permanent drift support recommendations, can be expressed as:

$$FMBR = AMBR \cdot DC \cdot PS \cdot S$$

Where:

- DC = The adjustment rating for the distance to cave line
- PS = The block/panel size adjustment
- S = The adjustment for orientation of major structures, dependent on their width, dip and distance and the Adjusted MBR (AMBR) is expressed by:

$$AMBR = MBR.A_B \cdot A_S \cdot A_o$$

where, the Modified Basic RMR (MBR) is dependent on the strength of intact rock, discontinuity density (RQD, spacing), discontinuity condition and groundwater condition, A_B is the adjustment due to used blasting method and its blasting damage, A_S is the induced stress adjustment and A_O is the adjustment for fracture orientation.

Simplified Rock Mass Rating (SRMR) system for mine tunnel support Brook and Dharmaratne (1985): Since Brook and Dharmaratne (1985) thought that the joint spacing ratios were mysteriously obtained in the MRMR system and since they preferred a simplified system that does not need the RQD-value, the SRMR was developed. The simplified rock mass rating has three major components the intact rock strength, joint spacing and joint type. The final rating is based on the three major components, together with groundwater consideration, (Table 11).

RESULTE AND DISCUSSION

Ramamurthy and Arora classification: Ramamurthy and Arora (1993) suggested a classification for intact rock and jointed rocks based on their compressive strengths and modulus values in unconfined state. This classification is based on the modulus ratio (M_{rj}) of a linear stress-strain condition, which is stated as:

$$M_{rj} = \frac{E_{tj}}{\sigma_{cj}} = \frac{1}{\varepsilon_f}$$

where, subscript j refers to jointed rock. E_t is the tangent modulus at 50% of the failure stress.

Table 11: Simplified rock mass rating (Brook and Dharmaratne, 1985)

Parameter	Maximum rating (%)	In *situ* values quantity	Rating				
Intact rock strength, σ_c	30	Compressive strength,(MPa)	30% (σ_c /200)				
Joint spacing	30	Spacing relative to excavation size	> 0.3	0.3-0.1	0.1-0.03	0.03-0.01	<0.01
		One joint set	30%	25-30%	20-25%	15-20%	10-15%
		Two joint sets	25-30%	20-25%	15-20%	10-15%	5-10%
		Three joint sets	20-25%	15-20%	10-15%	5-10%	0-5%
Joint type	30		Exact value interpolated if necessary.			30% · Adjustment factor	
			Adjustment			Adjustment factor	
		Expression and continuity	Discontinuous			1.0	
			Wavy			0.75-1.0	
			Straight			0.5-0.75	
		Surface if in contact	Rough			1.0	
			Slightly rough			0.75-1.0	
			Smooth to polished			0.5-0.75	
		Separation	1<				
			2-1 mm			0.8-0.9	
			5-2 mm			0.7-0.8	
			10-5 mm			0.6-0.7	
			>10 nm			0.5-0.6	
		Gouge properties	Hard packed			1.0	
			Sheared			0.75-1.0	
			Soft, clay			0.5-0.75	
Groundwater	10		Dry	Moist	Wet	Moderate pressure	High pressure
			10%	8%	5%	2%	0

Table 12: Strength classification of intact and jointed rocks (Ramamurthy and Arora, 1993)

Class	Description	$\sigma_{ci,\ i}$(MPa)
A	Very high strength	>250
B	High strength	100-250
C	Moderate strength	50-100
D	Medium strength	25-50
E	Low strength	5-25
F	Very low strength	<5

Table 13: Modulus ratio classification of intact and jointed rocks (Ramamurthy and Arora, 1993)

Class	Description	Modulus ratio of rock
A	Very high modulus ratio	>500
B	High modulus ratio	200-500
C	Medium modulus ratio	100-200
D	Low modulus ratio	50-100
E	Very low modulus ratio	<50

To estimate the rock strength and modulus ratio one has to determine the joint factor. The joint factor represents a factor of weakness in the rock mass due to the influence of the joint systems. This resulted in the following:

$$\frac{\sigma_{cj}}{\sigma_{cj}} = \exp(-0.008 \cdot J_f) \quad \frac{E_{tj}}{E_{tj}} = \exp(-0.0115 \cdot J_f)$$

σ_{cj} is the jointed rock strength, whose description is stated in Table 12. Since the σ_{cj} and E_{tj} are known, the modulus ratio can be estimated and classified according to Table 13.

The rock (mass) is described by two letters, for instance CD means that the rock has moderate compressive strength in the range of 50-100 MPa, with a low modulus ratio of 50-100.

Geological Strength Index (GSI): This GSI estimates the reduction in rock mass strength for different geological conditions. There are three ways of calculating the GSI:

- By using the rock mass rating for better quality rock masses (GSI>25)
- By using the Q-system
- By using their own GSI-classification

Rock mass Number (N) and Rock Condition Rating (RCR): The rock mass number, N and rock condition rating, RCR, are modified versions of the Q-system and RMR-system. The N-system is a stress-free Q-system, as can be seen by its definition:

$$N = [RQD / J_n / J_r / J_a][J_w]$$

The RCR-system is the RMR without ratings for the compressive strength of the intact rock material and adjustments of joint orientation as:

$$RCR = RMR - (\text{Rating for } \sigma_c + \text{adjustment of joint orientation})$$

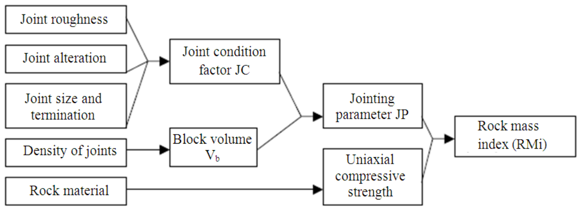

Fig. 4: Parameters applied in the RMi

The RCR and the N-system were proposed to find a relation between the Q-system and the RMR-system. The Q-system and the RMR system are equivalent if the joint orientation and intact rock strength are ignored in the RMR-system and the stress reduction factor is ignored in the Q-system.

Rock Mass index (RMi): The Rock Mass index, RMi, has been developed to characterize the strength of the rock mass for construction purposes. The main focus of the development of RMi was on the effects of the defects in a rock mass that reduce the strength of the intact rock. The RMi is linked to the material and represents only the inherent properties of a rock mass. The input parameters in a general strength characterization of a rock mass are selected as:

- The size of the blocks delineated by joints-measured as block volume
- The strength of the block material-as uniaxial compressive strength
- The shear strength of the block faces-measured as friction angle
- The size and termination of the joints-measured as length and continuity

The RMi is principally the reduced rock strength caused by jointing and is expressed as:

$$RMi = \sigma_c \cdot JP$$

where, JP is the jointing parameter, which is a reduction factor representing the block size and the condition of its faces as represented by their friction properties and the size of the joints. The value of JP varies from almost 0 for crushed rocks to 1 for intact rock. Its value is found by combining the block size and the joint conditions. An overview of the parameters applied in RMi can be seen in Fig. 4.

The joint condition factor jC represents the inter-block frictional properties and is expressed as:

$$jC = jL.\left[\frac{jR}{jA}\right] = jL \cdot \left[\frac{js.jw}{jA}\right]$$

where, jL is the size factor representing the influence of the size and termination of the joint. The joint size factor (jL) is chosen as larger joints have a markedly stronger impact on the behavior of a rock mass than smaller joints have. The roughness factor (jR) represents the unevenness of the joint surface which consists of:

- The smoothness (js) of the joint surface
- The waviness (jw) or planarity of the joint wall

The alteration factor (jA) expresses the characteristics of the joint:

- The strength of the rock wall
- The thickness and strength of a possible filling

The factors jR and jA are similar to Jr and Ja in the Q-system. JP is given by the following expression:

$$JP = 0.2\sqrt{jC}.V_b^D$$

Where:
V_b = The block volume is given in m^3
D = $0.37jC^{-0.2}$ is a constant

CONCLUSION

Rock mass classification is one of the only approaches for estimating large-scale rock mass properties. In the underground industry the classifications systems forms the basis of many empirical design methods, as well as the basis of failure criteria used in many numerical modeling programs. Practitioners should be aware that classification and design systems are evolving and that old versions of classification systems are not always compatible with new design approaches. Care must be taken when using classification systems with empirical design methods. The user must be sure that the classification system used matches the approach taken for the development of the empirical design method. Under these circumstances, for purposes of continuity, it is sometimes necessary to continue using an earlier version. Design methods which do not rely on case histories or past experience, do not have the same constraints. This approach to classification is warranted in complex mining situations. Serious errors can result if these simplified classification systems are applied to the empirical civil tunnel design approaches such as the Q support graph. Despite their limitations, the reviewed classification systems are still in use as they provide an invaluable reference to past experience.

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