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Some Important Issues in Engineering Rock Mass Classifications

R. K. Goel

CSIR-Central Institute of Mining & Fuel Research
Regional Centre, Roorkee, India

Email: rkgoel15@gmail.com

ABSTRACT

Engineering rock mass classifications, RMR (SMR for slopes) and Q are being used widely in our projects for rock mass characterization. GSI is different from these two as it is mainly used to provide input for the Hoek-Brown failure criterion. Over the years, it has been often observed that the person collecting the data in the field is unaware about the philosophy and importance of rating system of classifications. Hence, it is important to understand each parameter in details and its importance in the (post-construction) rock mass characterization for engineering purposes. Similarly, the weathering of soft and weak rock masses is found to be influential in modifying the rating of various parameters of these classifications. In the paper an attempt has been made to highlight some of the important issues of these classifications for the users. In designs, the actual post-construction ratings should be used.

Keywords: Engineering rock mass classification; Rock mass rating; Q system; Slope mass rating; Geological strength index; Important issues

1. INTRODUCTION

The engineering rock mass classifications form the back bone of the empirical design approach and are widely used in designs. It has been experienced that when used correctly, a rock mass classification can be a powerful tool in designs. Engineers prefer numbers in place of descriptions; hence, an engineering classification, besides providing a better communication between planners, geologists, designers, contractors and engineers, has considerable application in an overall assessment of the rock quality and characterization.

The empirical approach, based on the (post-construction) rock mass classifications, is popular probably because of its simplicity and ability of managing uncertainties. Moreover, the designers can take on-the-spot decisions on supporting measures etc., if there is sudden change in the geology.

Though with time the engineering rock mass classifications have gained popularity, but there are some important issues which shall be understood by the users. For example, while using the rock mass rating (RMR) of Bieniawski, quite often, the RMR_{basic} is used as RMR. Hence, it is important to know the difference between RMR_{basic} and RMR and where these shall be used. In case of slopes, the soft and weak rock masses are likely to be greatly influenced by

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the weathering. Hence it is important to characterize the rock mass considering the weathering effects in the designed life of the structure.

Obtaining the rating of SRF in Q is found to be difficult because it requires understanding of the rock mass behaviour and degree of squeezing. The rock mass number N developed by Goel (1994) and discussed here has been found to be complimentary to Q-system in terms of understanding the rock mass behaviour/ground condition and then to select the rating of SRF.

Geological strength index (GSI), which has been developed by Hoek (1994) to get the input parameter values for Hoek & Brown failure criterion, can also be obtained from RMR. For getting the value of GSI from RMR one must know about the parameters which have been discounted from RMR and for what range of RMR the equation shall be used. It is also equally important for the designers to remember that while computing GSI, the ground water has not been considered.

The above issues have been discussed in the following paper in brief. While writing this paper, it is understood that the readers have basic understanding of these classifications and how these are used in the field.

2. ROCK MASS RATING (RMR)

The geo-mechanics classification or the rock mass rating (RMR) system was initially developed at the South African Council of Scientific and Industrial Research (CSIR) by Bieniawski (1973). Since then the classification has undergone several significant evolutions. But, the following six parameters remained the same to get RMR.

(i) Uniaxial compressive strength (UCS) of intact rock material,
(ii) Rock quality designation RQD,
(iii) Joint or discontinuity spacing,
(iv) Joint or discontinuity condition,
(v) Ground water condition, and
(vi) Joint orientation.

As per the (post-construction) site conditions, the rating for each parameter is collected for each structural region. The sum of rating of above six parameters is RMR which is then used to classify and characterize the rock mass. It is important to highlight here that the person collecting the details at the site should have good understanding of each parameter and how the variation in rating is going to affect the rock mass characterization. The rating for discontinuity spacing and condition shall be obtained for the most critical (Tables 1 and 2) discontinuity set.

Table 1: Assessment of joint orientation effect on tunnels (Bieniawski, 1989)

Strike Perpendicular to Tunnel Axis				Strike Parallel to Tunnel Axis		Irrespective of Strike
Drive with dip		Drive against dip				
Dip 45° - 90°	Dip 20°-45°	Dip 45°-90°	Dip 20°-45°	Dip 20°-45°	Dip 45° - 90°	Dip 0° - 20°
Very favourable	Favourable	Fair	Unfavourable	Fair	Very unfavourable	Fair

Table 2: Rating for adjustment for joint orientation (Bieniawski, 1989)

Joint Orientation Assessment for	Very Favourable	Favour -able	Fair	Unfavour-able	Very Un-favourable
Tunnels	0	-2	-5	-10	-12
Raft foundation	0	-2	-7	-15	-25
Slopes	0	-5	-25	-50	-60

The rating for discontinuity condition is given in Tables 3a and 3b. Table 3a was proposed originally combining all parameters of discontinuity conditions. Subsequently, Table 3b was proposed classifying all the parameters of discontinuity condition separately. Table 3b, thus, is more elaborated and shall be used. It is highlighted here that some conditions are mutually exclusive. For example, if infilling is present, it is irrelevant what the roughness may be, since its effect will be overshadowed by the influence of the gouge. In such cases use Table 3a directly (Bieniawski, 1989).

Table 3a: Rating for condition of discontinuities in RMR (Bieniawski, 1979)

Description	Rating
Very rough surfaces, not continuous, no separation, unweathered wall rock	30
Slightly rough surface, separation<1mm, slightly weathered walls	25
Slightly rough surface, separation<1mm, highly weathered walls	20
Slickensided surfaces or Gouge <5mm thick or Separation 1-5mm continuous	10
Soft gouge > 5mm or Separation >5mm, continuous discontinuity	0

Table 3b: Classification of condition of discontinuities for RMR (Bieniawski, 1989)

Parameter*	Ratings				
Discontinuity Length (Persistence/Continuity)	<1m	1-3m	3-10m	10-20m	>20m
	6	4	2	1	0
Separation (aperture)	None	<0.1mm	0.1-1.0mm	1-5mm	>5mm
	6	5	4	1	0
Roughness of Discontinuity Surface	Very rough	Rough	Slightly rough	Smooth	Slickensided
	6	5	3	1	0
Infillings (gouge)		Hard filling		Soft filling	
	None	<5mm	>5mm	<5mm	>5mm
	6	4	2	2	0
Weathering Discontinuity Surface	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
	6	5	3	1	0

2.1 RMR vs RMR_{basic}

RMR is the sum of rating of all the six parameters given above. RMR_{basic}, on the other hand, is the sum of rating of first five parameters (excluding the rating for joint orientation adjustment, Tables 1 and 2).

It can be seen that for different joint orientation effects with respect to tunnel axis (Table 1), the joint orientation adjustment rating varies from 0 to -12 for tunnels (Table 2). This shows that even if the RMR_{basic} of a rock mass is same, the RMR can vary as per Table 2 rating. Moreover, since the joint orientation adjustment rating is different for tunnels, slopes and foundations (Table 2), even if RMR_{basic} is same, the RMR for tunnels, slope and foundations would be different. This highlights that RMR_{basic} and RMR are two different values and shall be clearly understood and used as per the requirement. Moreover, RMR obtained from slope shall not be used for tunnels.

The parameter 'discontinuity orientation' reflects on the significance of various discontinuity sets present in a rock mass. The main or the dominant set is the set which control the stability of an excavation. For example, in tunnelling the dominant set will be the one whose strike is parallel to the tunnel axis.

Bieniawski (1989) indicated that in situations where no one discontinuity set is dominant and of crucial importance, or when estimating the rock mass strength and deformation modulus, the ratings from each discontinuity set are averaged for the appropriate individual classification parameter. Bieniawski (1989) has also shown that for estimating the deformability of rock mass in tunnels RMR_{basic} is used.

3. SLOPE MASS RATING (SMR)

For evaluating the stability of rock slopes, Romana (1985) proposed a classification system called slope mass rating (SMR) system. Slope mass rating (SMR) is obtained from Eq. 1.

$$SMR = RMR_{basic} + (F_1 . F_2 . F_3) + F_4 \tag{1}$$

In Eq. 1, RMR_{basic} is Bieniawski's basic rock mass rating, F_1, F_2 and F_3 are adjustment factors related to joint orientation with respect to slope orientation and F_4 is the factor related to the method of excavation.

Adjustment factors F_1, F_2 and F_3 are like the sixth parameter, joint orientation in RMR. On comparison of RMR and SMR, one can see that the rating of joint orientation adjustment for slopes given in Table 2 is almost matching with the F3 rating proposed by Romana (1985). For very unfavourable condition F3 rating in slope is -60 (Table 2), which is quite high in comparison to tunnels because of confinement of rock mass in tunnels. The rating for F_1 and F_2 varies from 0.15 for very favourable condition to 1.0 for very unfavourable condition. Therefore, in case of very unfavourable condition the combined rating of F_1, F_2 and F_3 would be equal to the rating given in Table 2.

The slopes are directly exposed to weathering compared to tunnels. Therefore, while collecting the parameters rating for RMR_{basic}, especially for SMR, it is important to consider the effect of weathering on the rock mass condition and on the rating of various parameters as discussed in the following section 4.

4. WEATHERING INFLUENCE ON PARAMETER RATINGS

With passage of time a fresh rock weathers after construction activity to residual soil. The weathering rate varies from rock to rock and from region to region. Generally, the soft sedimentary rock like siltstones, claystones, shales, mudstones, poorly cemented sandstone and other rocks having presence of fast weathering minerals and uniaxial compressive strength (UCS) less than 40MPa (Bell, 1983) are likely to be affected most by weathering during the engineering life span of a structure. Hence, engineering structures and slopes on such rocks are vulnerable to weathering and instability. The effect of weathering can reach up to great depth in water charged rock masses and in the rocks having vertical to sub-vertical joints. The (post-construction) weathering effect shall be considered for the evaluation of Q-value for the design of tunnel supports in water-charged rock masses and in shallow tunnels.

Hack and Price (1997) from the study of sandstone, limestone, dolomites, slates, shales, and granodiorite highlighted the influence of weathering on intact rock strength, spacing of discontinuities and condition of discontinuities (Table 4), the parameters of RMR_{basic}. Table 4 shows that the condition of discontinuities in a rock mass is less influenced by weathering than the intact rock strength and the spacing of discontinuities.

Goel and Mitra (2015), on the other hand, observed that the condition of discontinuities is also considerably influenced by weathering in soft and weak rock masses such as claystone, siltstone, mudstone and loosely cemented sandstone having UCS <50MPa. The revised fraction values for soft rocks suggested by the Goel and Mitra (2015) for condition of discontinuities are shown in the brackets in Table 4.

Table 4: Variation in rock properties with degree of weathering
(After Hack and Price, 1997)

Degree of weathering (BS 5930:1981)	Intact rock strength	Spacing of discontinuities	Condition of discontinuities	Number of Observations
Fresh, I	1.00	1.00	1.00	12
Slightly, II	0.88	0.93	0.99 (0.95)	168
Moderately, III	0.70	0.89	0.98 (0.8)	27
Highly, IV	0.35	0.63	0.89 (0.6)	6
Completely, V	0.02	0.55	0.77 (0.4)	2

Values in ( ) are proposed by Goel & Mitra (2015) for soft and weak rock masses

Gurocak and Kilic (2005) have studied the variation in RQD value for different degrees of weathering in basalts. As per their study the RQD value decreases with the increase in degree of weathering. The work of Gurocak and Kilic (2005) and Table 4 have been used by Goel and Mitra (2015) to derive the RQD factor in Table 5 for hard rocks.

Table 5: Variation in RQD with degree of weathering for hard and soft rock masses

Degree of weathering (BS 5930:1981)	RQD Factor	
	Hard Rocks	Soft Rocks
Fresh	1.00	1.00
Slightly	0.80-0.90	0.70-0.80
Moderately	0.70	0.25 -0.50
Highly	0.30-0.50	0.0
Completely	0.05	0.0

In case of soft and weak rocks (UCS< 50MPa), there are more chances of core breaks because of drilling process and sometimes it may be difficult to fit the broken pieces. It is suggested by Deere and Deere (1989) that when in doubt about a break, it should be considered as natural. Thus, the RQD obtained from drill-core in fresh un-jointed soft and weak rock may not exceed 75%. Further, it has been observed that the reduction in RQD value with degree of weathering in soft rocks is at a faster rate compared to hard and strong rocks. As such, RQD factor for soft rocks with degree of weathering, as observed by Goel and Mitra (2015), is also given in Table 5.

Table 5 implies that a fresh hard rock having RQD of 80% shall have RQD of approximately 4% when it is completely weathered, after construction activity.

Tables 4 and 5 show the variation in the parameters of RMR_{basic} with degree of weathering. The cumulative effect of weathering in RMR_{basic} using Tables 4 and 5 is obtained as shown below in Table 6 with the help of an example.

Example: Fresh rock has UCS=150MPa (Rating 10), RQD = 80% (Rating 14.5); Spacing of discontinutites = 25cm (Rating 9); Condition of discontinuities = Slightly rough and moderately to highly weathered, wall rock surface separation <1mm (Rating 20); Ground water = Damp (Rating 10). The ground water condition and its rating have been assumed to be same for all degrees of weathering.

Table 6: Variation in RMR_{basic} with weathering grade

Degree of weathering (BS 5930:1981)	Intact rock strength		Spacing of discontinuities		Condition of discontinuities		RQD		Water	RMR_{basic}
		Rating		Rating		Rating		Rating	Rating	
Fresh	1.00	10	1.00	9	1.00	20	1.00	14.5	10	63.5
Slightly	0.88	9	0.93	8.5	0.99 (0.90)	18	0.85	10.5	10	56 (12%)
Moderately	0.70	7	0.89	8	0.98 (0.7)	14	0.70	9	10	48(24%)
Highly	0.35	5	0.63	7.5	0.89 (0.55)	11	0.50	6	10	39.5(38%)
Completely	0.02	1	0.55	7	0.77 (0.4)	8	0.05	3	10	29(54%)

Rating for different weathering grades in Table 6 has been obtained after multiplying the value of fresh rock with the fraction (using Tables 4 and 5) and selecting the rating for this value (as per Bieniawski, 1989). *For example*, UCS is 150 MPa for fresh rock, for slightly weathered rock the UCS would be reduced to 150*0.88 = 132MPa. Hence rating for 132MPa is obtained for slightly weathered rock from Bieniawski (1989).

It can be seen in Table 6 that a 'fresh' rock having RMR_{basic} = 63.5 will have RMR_{basic}=29 after it is 'completely' weathered with passage of time after the construction is over.

The above example shows that the basic rock mass rating (RMR_{basic}) of a freshly excavated rock mass, will change with time if left unprotected from weathering. The reduction in RMR_{basic} of a stronger rock (UCS = 50MPa) is upto 54 percent in Table 6. The reduction in RMR_{basic} values with degree of weathering in soft and weak rock masses will be even more and quicker. The soft rock masses having higher rate of weathering (clay rich rocks) will be badly affected with time after construction. The granite and such other rocks, on the other hand, are weathering resistant and therefore the change in RMR_{basic} may not be fast to observe in the designed life.

Hence, it is suggested that SMR for the slope rock mass characterization or any other such approach being used for landslide and slope stability analysis should also take care of the weathering effect for studying and projecting the behaviour of slope with time.

5. GEOLOGICAL STRENGTH INDEX (GSI)

Strength of a jointed rock mass depends on the properties of the intact rock pieces and also upon the freedom of these pieces to slide and rotate under different stress conditions. This freedom is controlled by the geometrical shape of the intact rock pieces as well as the condition of the surfaces separating the pieces. Angular rock pieces with clean, rough discontinuity surfaces will result in a much stronger rock mass than one which contains rounded particles surrounded by weathered and altered material (Hoek and Brown, 1997). Thus, considering the two parameters, 'rock structure' and the 'condition of discontinuities', a chart for estimating the geological strength index (GSI) qualitatively was proposed by Hoek and Brown (1997). Subsequently, attempts have been made by various researchers to quantify the approach for obtaining GSI. One such attempt was by Sonmez and Ulusay (2002) who have related 'rock structure' with volumetric joint count (measure of rock mass blocks or pieces) and 'discontinuity condition' with the discontinuity condition rating as shown in Table 3b (excluding the ratings for discontinuity persistence and aperture).

It is generally recommended to collect the GSI parameters directly from the field observations. However, for estimating GSI from RMR, an inter-relation (Eq. 2) is proposed by Hoek (1994) between RMR and GSI for $RMR_{89} > 23$.

$$GSI = RMR_{89} - 5 \qquad [\text{for } RMR_{89} > 23] \qquad (2)$$

In Eq. 2, RMR_{89} is RMR_{basic} as per Bieniawski (1989) and setting the groundwater rating as 15 (for dry condition).

Hoek (1994) has found that Bieniawski's RMR cannot be used to get GSI for $RMR_{89} < 23$ and instead suggested to use Barton's Q parameter as per Eq. 3.

$$GSI = 9 \ln[(RQD/J_n)(J_r/J_a)] + 44 \qquad [\text{for } RMR_{89} < 23] \qquad (3)$$

RQD, J_n, J_r and J_a are as defined in Eq. 4.

Though Hoek (1994) has suggested to not use Eq. 2 for $RMR_{89} < 23$. But, Bieniawski (2014) advocated that RMR can be used for poor rock masses as well.

In Eqs. 2 & 3 RMR and Q have been modified to get GSI. This has been done to make the systems equivalent to GSI and to avoid the double accounting of water condition and stresses. But, uniaxial compressive strength of intact rock material (σ_c) has not been removed from RMR_{89} and accounted twice, once in GSI estimation from RMR_{89} (Eq. 2) and secondly as an input parameter in Hoek and Brown failure criterion.

GSI value obtained from a fresh rock exposure will also be considerably affected by weathering in soft and weak rock masses. Tables 4 and 5 can be used to get the GSI value for weathered rock masses from RMR and Q.

GSI developers pointed out that it is an index of rock mass characterization, not meant for replacing a classification system of the type of RMR or Q - but this was overlooked in practice (Bieniawski, 2014). It shall be noted that the main function claimed for GSI, as mentioned above, was an estimation of the rock mass strength using the Hoek-Brown failure criterion (Bieniawski, 2014).

In the GSI the ground water condition has not been considered. The most basic impact of groundwater is upon the mechanical properties of the intact rock components of the rock mass. This is particularly important when dealing with soft and weak rocks such as shales, siltstones, claystone and similar rocks that are susceptible to changes with moisture content. Many of these materials will disintegrate quickly if they are allowed to dry out after removal from the core barrel. For this reason, to determine the uniaxial compressive strength and the constant m_i, testing of the intact rock material must be carried out under conditions that are as close to the in situ moisture conditions as possible (Hoek and Brown, 1997). Softwares are expected to account for ground water and orientation of rock joints. Thus, double-accounting of rating is eliminated.

6. ROCK MASS QUALITY Q-SYSTEM

Barton, Lien and Lunde (1974) at the Norwegian Geotechnical Institute (NGI) originally proposed the rock mass quality Q-system of rock mass classification on the basis of about 200 case histories of tunnels and caverns. This has subsequently been revised considering more than 1000 case histories. They have defined the rock mass quality Q by the following equation.

$$Q = \left[RQD/J_n\right]\left[J_r/J_a\right]\left[J_w/SRF\right] \tag{4}$$

where

RQD = Deere's Rock Quality Designation ≥ 10,
= $115 - 3.3\,J_v \leq 100$ (5)
J_v = Volumetric joint count per m^3,
J_n = Joint set number,
J_r = Joint roughness number for critically oriented joint set,
J_a = Joint alteration number for critically oriented joint set,
J_w = Joint water reduction factor, and
SRF = Stress reduction factor.

Commenting on the joint orientation, as in RMR, Barton et al. (1974) stated that it was not found to be an important parameter as expected. Part of the reason for this may be that the orientation of many types of excavation can be, and normally are, adjusted to avoid the maximum effect of unfavourably oriented major joints. Barton et al. (1974) also stated that the parameters J_n, J_r and J_a appear to play a more important role than the joint orientation, because the number of joint sets determines the degree of freedom for block movement (if any); and the frictional and dilatational characteristics (J_r) can counter-balance the down-dip gravitational component of weight of wedge formed by the unfavourably oriented joints. If joint orientation had been included, the classification system would be less general. *Looking into this explanation, is it possible to modify the RMR for tunnels by removing 'joint orientation rating' and incorporating new parameter or increasing the weightage of parameters of* RMR_{basic}?

However, it is suggested to collect the rating for J_r/J_a for the most critical joint set. The critical joint set or 'very unfavourable joint set' with respect to tunnel axis may be obtained from Table 1.

In the case of hydroelectric projects, J_w should be selected according to future ground water conditions. It is generally assumed that the future ground water pressure will be equal to the internal water pressure in the pressure tunnels. Further, erodible joint fillings down-grade the rock mass quality drastically.

6.1 Inter-relation between Q and RMR

Inter-relations between the two most widely used classification indices, the rock mass rating RMR of Bieniawski (1976) and the rock mass quality Q of Barton et al. (1974), have been proposed by many researchers. Bieniawski (1976) and Barton (2002) proposed Eqs. 6 and 7 respectively.

$$\mathrm{RMR} = 9 \ln Q + 44 \tag{6}$$

$$\mathrm{RMR} = 15 \log Q + 50 \tag{7}$$

Attempts to correlate Q and RMR in Eqs. 6 and 7 ignore the fact that the two systems are not truly equivalent. Stress reduction factor (SRF) in the Q system and uniaxial compressive strength and joint orientation in the RMR system are not common parameters. Since, the RMR and Q are not having all common parameters, the inter-relation between Q and RMR as given in Eqs. 6 and 7 shall also be used with proper understanding and caution.

Further, Goel et al. (1995) and Singh and Goel (2011) have modified Q and RMR to make them equivalent to N and RCR respectively and proposed an inter-relation as shown in Eq. 8.

$$\mathrm{RCR} = 8 \ln N + 30 \qquad \text{for } \sigma_c > 5\mathrm{MPa} \tag{8}$$

where

RCR = Rock condition rating,
= RMR without including the ratings of the UCS and the joint orientation,
N = Rock mass number,
= Q with SRF = 1, and
σ_c = Uniaxial compressive strength of intact rock material.

The following example explains the importance of parameter equivalence and how Eq. 8 could be used to obtain RMR from Q and vice-versa.

Example: The ratings/values of the parameters of RMR and Q collected from the field are given in Table 7.

Table 7: Rating of RMR and Q parameters collected from the field

RMR - SYSTEM		Q - SYSTEM	
Parameters for RMR	Rating	Parameters for Q	Rating
RQD (80 %)	17	RQD	80
Joint spacing	10	J_n	9
Joint condition	20	J_r	3
		J_a	1
Ground water condition	10	J_w	1
RCR =	**57**	**N =**	**26.66**
Uniaxial compressive rushing strength σ_c	+12	SRF	1
Joint orientation	(-)5	--	--
RMR =	**64**	**Q =**	**26.66**
RMR(from Eq.6)	73.5		
RMR(from Eq.7)	71.4		

(a) RMR from Q using Eq. 8

$N = (RQD\ J_r\ J_w) / (J_n\ J_a) = 26.66$ as shown in Table 7
Corresponding to N = 26.66, RCR = 56.26 (Eq. 8)
RMR = RCR + (ratings for σ_c and joint orientation)
RMR = 56.26 + [12 + (-)5]
RMR = 63.26 (It is comparable to RMR= 64 obtained from direct estimation as shown in Table 3)

(b) Q from RMR using Eq.8

RCR = RMR - (ratings for q_c and joint orientation as per Eq. 8)
RCR = 64 - (12 - 5)
RCR = 57
Corresponding to RCR = 57, N = 29.22 (Eq.8)
Q = (N / SRF) = 29.22 / 1
Q = 29.22 (almost equal to the field estimated value of 26.66, Table 7)

The slight difference in directly estimated values of Q and RMR and those obtained by the proposed inter-relation are due to the inherent scatter in Eq. 8. Moreover, the scatter is practically insignificant.

Last two rows in Table 7 show the value of RMR obtained from Eqs. 6 and 7 which are not matching with the field estimates.

7. ROCK MASS NUMBER AS COMPLIMENTARY TO Q

Rock mass number is proposed because of the problems and uncertainties in obtaining the correct rating of Barton's SRF parameter (Kaiser et al., 1986). Moreover, it has been experienced that in case of squeezing ground condition, it is also difficult to get the rating of SRF as it depends on the degree of squeezing.

Rock Mass Number, denoted by N and as explained above, is stress-free rock mass quality Q. Stress - effect has been considered indirectly in form of overburden height H. Thus, N can be defined by the following Eq. 9.

$$N = [RQD/J_n]\ [J_r/J_a]\ [J_w] \tag{9}$$

Using the rock mass number N, tunnel depth H in meters and tunnel span B in meters, as shown in Fig. 1, an approach for estimating the ground condition for tunnelling was developed by Goel et al. (1995b) and Singh and Goel (2011). The equations of demarcation lines are give in Table 8. Once the ground condition for tunnelling is estimated, the SRF rating accordingly can be obtained from Barton's chart of SRF rating. Therefore, N is found to be complimentary to Q system.

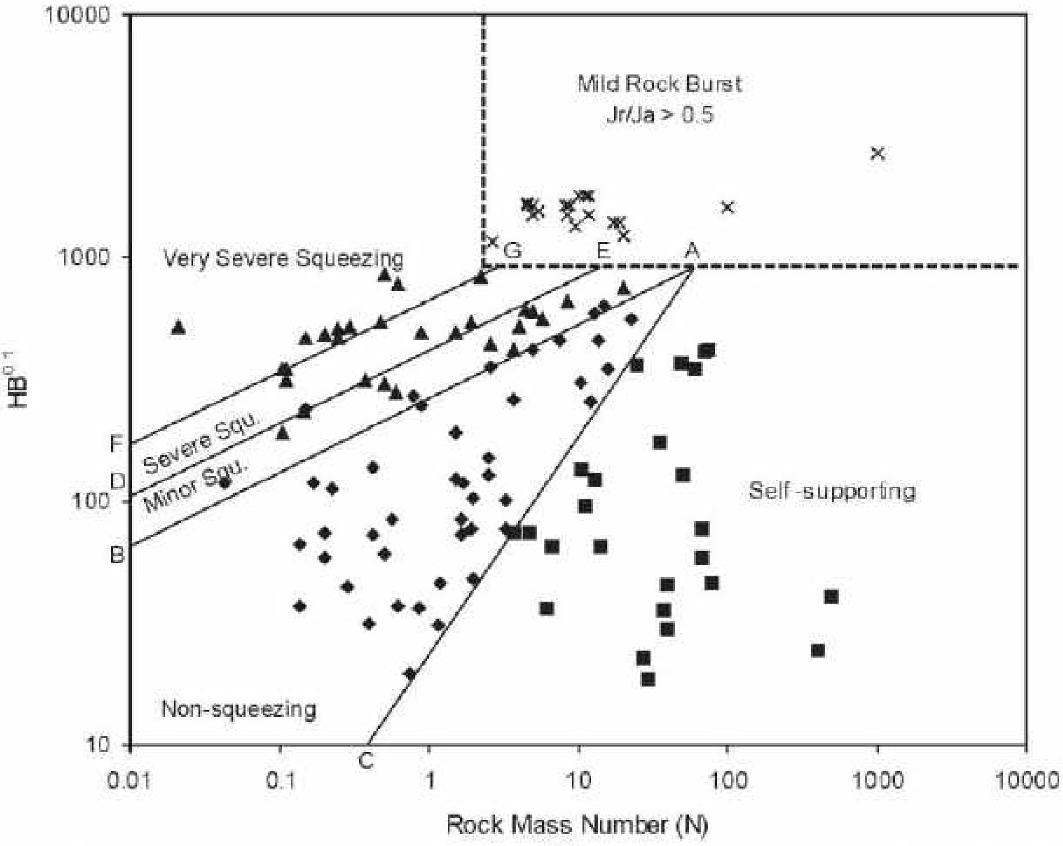

Fig. 1: Plot between rock mass number N and $HB^{0.1}$ for predicting ground conditions (Singh and Goel, 2011)

For rock burst conditions, Fig. 1 and Table 8 show that $J_r/J_a > 0.5$ and $N > 2$. It may be noted here that $J_r/J_a > 0.5$ will be obtained in the rock mass having condition 'a' (wall rock in contact) of J_r and J_a rating tables. It means the rock burst is expected in joints or discontinuities which are rough, tight and has no fillings. Squeezing ground condition in tunnelling, on the other hand, is expected in conditions 'b' and 'c' of J_r and J_a.

Table 8: Prediction of ground condition using N (Singh and Goel, 2011)

S. No.	Ground Conditions	Correlations for Predicting Ground Condition
1.	Self-supporting	$H < 23.4\ N^{0.88}.\ B^{-0.1}$ & $1000\ B^{-0.1}$ and $B < 2\ Q^{0.4}$ m
2.	Non-squeezing	$23.4\ N^{0.88}.B^{-0.1} < H < 275 N^{0.33}.\ B^{-0.1}$
3.	Minor or mild squeezing (u_a/a =1-3%)	$275\ N^{0.33}.\ B^{-0.1} < H < 450 N^{0.33}.\ B^{-0.1}$ and $J_r/J_a < 0.5$
4.	Severe or Moderate squeezing (u_a/a =3-5%)	$450\ N^{0.33}.\ B^{-0.1} < H < 630 N^{0.33}.\ B^{-0.1}$ and $J_r/J_a < 0.5$
5.	Very severe or High squeezing ($u_a/a > 5\%$)	$H > 630 N^{0.33}.\ B^{-0.1}$ and $J_r/J_a < 0.25$
6.	Mild Rock Burst	$H.B^{0.1} > 1000$m, $J_r/J_a > 0.5$, $N > 2.0$

Notations: H = tunnel depth in m, B = tunnel width in m, Q = as per Eq. 3; N = as per Eq. 8, u_a = radial tunnel deformation or closure and a = tunnel radius

8. CONCLUSIONS

- The difference between RMR and RMR_{basic} and their uses have been highlighted.
- Effect of the (post-construction) weathering on various parameters of rock mass classification in soft and weak rock masses have been presented. This shows that RMR and SMR are affected by weathering, which shall be kept in mind for designs of structures on or in soft and weak rock masses having UCS<50MPa.
- GSI shall not be used as an index for replacing a classification system of the type of RMR or Q. It is used in the application of Hoek-Brown failure criterion for estimation of the rock mass strength. In case of water-charged and saturated rock masses, the laboratory tests should be carried out at moisture contents which are as close as possible to those occur in the field. Double accounting for parameters should be avoided in classification and analysis by software.
- An approach for estimating the ground condition for tunnelling using rock mass number N (Q with SRF=1), tunnel depth and tunnel size is discussed. It is also shown as to how N is complimentary to Q-system and helps in selecting the rating for parameter SRF in Q.

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