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COMBINING THE RMR, Q, AND RMi CLASSIFICATION SYSTEMS

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Summary
The main rockmass classification systems make use of similar rockmass parameters. It is therefore shown how the input parameters of the RMR, Q and RMi systems can be combined into one set of tables. These enable the ground quality to be found directly and independently in the three systems from only one set of observations. Thus, the estimated rock support found in one system can be easily checked in other systems. This method results in better rock support estimates; provided the actual ground is within the limitations of the systems and that the ground characterization is properly made. The combined input and calculations can easily be made in a computer spreadsheet.
The paper also shows that there are crude correlations between the three systems, i.e. that the estimated quality of the same ground is calculated differently in the three systems. This supports the postulate of Bieniawski that at least two classification systems should be applied in rock engineering assessments.

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1 INTRODUCTION

As pointed out Barton and Bieniawski in T&T February, 2008, rock engineering classification systems play a steadily more important role in rock engineering and design. The main classification systems for rock support estimates, the Q and the RMR, use the most important ground features or parameters as input. Each of these parameters is classified and each class given values or ratings to express the quality of the ground with respect to tunnel stability. Also, the NATM (New Austrian Tunnelling Method) and the RMi (Rock Mass index) support method use similar parameters.

For arriving at appropriate results in rock engineering and design, Bieniawski (1984, 1989) advises application of at least two classification systems when applying such empirical tools. However, many users are practising this recommendation by finding the value (quality) in one classification system from a value in another, using some sort of transition equation(s). The most known of these transitions, between Q and RMR is presented in Figure 1. As seen, this equation is a very crude approximation, involving an inaccuracy of ± 50% or more. Thus, severe errors may be imposed, resulting in reduced quality of the rock engineering works, or even errors that may lead to wrong decisions. Another error may be imposed from the fact that the two systems have different limitations.

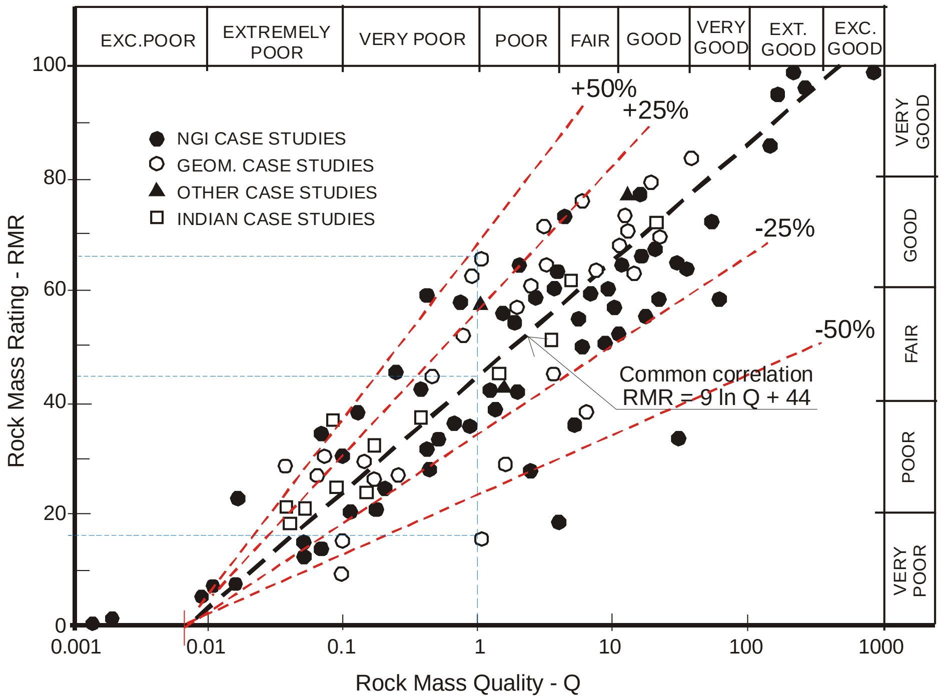

Figure 1: Correlation between the RMR and the Q-index with deviation from the common correlation. As seen, for Q = 1, RMR varies from less than 20 to 66. Note that the Q system applies logarithmic scale (After Bieniawski, 1976, and Jethwa et al., 1982).

This article outlines a method to combine the input parameters used in three of the systems into one set. By this, the ground quality values in the three systems can be found independently. Computer spreadsheet is very useful in the process of calculating the values. However, the rating values of each of the input parameters must be closely evaluated from the site geological conditions.

2 SHORT ON THE RMR, Q AND RMI CLASSIFICATION SYSTEMS FOR ROCK SUPPORT

The most common classifications systems used worldwide today are the RMR system published by Bieniawski in 1973 and the Q system, first described in 1974 by Barton et al. More recently, Palmström presented the RMi system in 1995. All these systems have quantitative estimation of the rock mass quality linked with empirical design rules to estimate adequate rock support measures.

The new Austrian tunnelling method (NATM) has been frequently used since it was presented in 1965. This method involves the whole sequence of rock tunnelling items from preinvestigations, through engineering and contracting, to construction and monitoring. As the ground is described behaviourally and allocating a ground class based on descriptions (and not on values or ratings), the NATM is not included here. Also the GSI system applies a descriptive input.

2.1 The RMR classification system

Bieniawski (1973 and 1974) published the details of a rock mass classification called the Geomechanics Classification or the Rock Mass Rating (RMR) system. Some changes have been made over the years with revisions in 1974, 1975, 1976, and 1989; the 1976 and the 1989 versions of the classification system are mostly used.

$$RMR = A1 + A2 + A3 + A4 + A5 + B \qquad \text{eq. (1)}$$

where

A1 = ratings for the uniaxial compressive strength of the rock material; A2 = ratings for the RQD; A3 = ratings for the spacing of joints; A4 = ratings for the condition of joints; A5 = ratings for the ground water conditions; and B = ratings for the orientation of joints. See Appendix 1.

From the value of RMR in the actual excavation, the rock support can be estimated from a special excavation and support table (for tunnels of 10m span), see Appendix 4. RMR can also be used to crudely estimate the deformation modulus of rock masses. Bieniawski (1989) strongly emphasises that a great deal of judgement is used in the application of a rock mass classification system in support design.

Limits

It is no input parameter for rocks stresses in the RMR system, but stresses up to 25MPa are included in the estimated RMR value. Thus, overstressing (rock bursting and squeezing) is not included. Whether or how faults and weakness zones are included, is unclear. No special parameter for such features is applied, but some of the parameters included in the system may represent conditions in faults, though the often complicated structure and composition in these features are generally difficult to characterize and classify. Therefore, it is probable that RMR does not work well for many faults and weakness zones. Swelling rock is not included in the RMR system.

2.2 The Q rock mass classification system

Based on a large database of tunnel projects, Barton et al. (1974) of the Norwegian Geotechnical Institute (NGI) worked out the Q system for estimating rock support in tunnels. The value of Q is defined by six parameters combined in the following equation:

$$Q = RQD/Jn \times Jr/Ja \times Jw/SRF \qquad \text{eq. (2)}$$

where

RQD = given as the value for this parameter; Jn = ratings for the number of joint sets; Jr = ratings for the joint roughness; Ja = ratings for the joint alteration, Jw = ratings for the joint or ground water, and SRF = ratings for the rockmass stress situation. See Appendix 1.

The Q-system is developed as an empirical design method for estimating rock support. Together with the ratio between the span or wall height of the opening and the stability requirements to the use of the tunnel or cavern (excavation support ratio called ESR the Q value defines the rock support in a support chart, see Appendix 2.

Limits

As pointed out by Palmstrom and Broch (2006) the Q system has several limitations, working best between Q = 0.1 and Q = 40 for tunnels with spans between 2.5m and 30m. Though there are input parameters for overstressing, Q should be used with care in rock bursting and especially in squeezing ground. The same is the case for weakness zones; especially where swelling ground occurs.

2.3 The RMi rockmass classification system and RMi used for rock support

2.3.1 The RMi rockmass classification

The rock mass index, RMi, was first presented by Palmström in 1995 and has been further developed and presented in several papers. It is a volumetric parameter indicating the approximate uniaxial compressive strength of a rock mass, and it can thus be compared with the GSI value. The RMi value is applied as input for estimating rock support and input also to other rock engineering methods.

The RMi system has some input parameters similar to those of the Q-system. Thus, the joint and jointing features are almost the same. The input parameters used can be determined by commonly used field observations and measurements. It requires more calculations than the RMR and the Q system, but spreadsheets have been developed (see www.rockmass.net) from which the RMi value and the type(s) and amount of rock support can be found directly.

In *jointed rock* the RMi makes use of the uniaxial compressive strength of intact rock (σ_c) and the reducing effect of the joints (JP) penetrating the rock mass, given as

$$RMi = \sigma_c \times JP \qquad \text{eq. (3)}$$

where

σ_c = uniaxial compressive strength of the intact rock, JP = the jointing parameter combines by empirical relations jC (joint conditions) and Vb (block volume) in the following exponential equation derived from strength tests on large jointed rock samples:

$$JP = 0.2\sqrt{jC} \times Vb^D \qquad (D = 0.37\, jC^{-0.2}) \qquad \text{eq. (4)}$$

where

jC = jR × jL/jA (jR = the joint roughness, jA = the joint alteration, and jL = the joint length), see Appendix 3. JP can easily be found from the chart presented in Appendix 7.

In *massive rock,* the few joints present have limited influence on the strength, therefore

$$RMi = \sigma_c \times f_\sigma \text{ (applied for cases where } f_\sigma > JP) \qquad \text{eq. (5)}$$

where

f_σ is called the massivity parameter, given as $f_\sigma = \sigma_c\, (0.05/Db)^{0.2}$ eq. (6)

(Db = block diameter). In most cases $f_\sigma \approx 0.5$

As the RMi value characterizes properties (strength) the dry rockmass material, it does not include the influence from rock stresses (and ground water).[1]

2.3.2 The RMi used for rock support estimates

The RMi method for rock support applies different equations whether the rock mass is jointed (discontinuous) or overstressed. In addition, an equation for weakness zones is included as shown below:

In jointed rock or blocky ground the RMi value is adjusted for the influence of stresses (SL), ground water (GW) to characterize the ground quality given as the

Ground condition factor, $Gc = RMi \times SL \times GW$ eq. (7)

Gc is combined in the support chart together with the

Geometrical or size ratio, $Sr = Dt/Db \times Co/Nj$ eq. (8)

where

Dt = tunnel diameter (span or wall height); Db = block diameter; Co = orientation of (main) joint set; Nj = rating for the number of joint sets. See Appendix 6.

For *weakness zones*, the thickness (Tz) of the zone is used in the geometrical ratio (Sr) instead of tunnel diameter (Dt) where Tz < Dt.

The support chart used for jointed rocks and weakness zones is shown in Appendix 2.

Where overstressing takes place in massive or particulate (highly jointed) ground, the required support is found in a special support chart using the competency of the ground, expressed as

$$Cg = RMi/\sigma_\theta \text{ (= rockmass strength/tangential stress)} \qquad \text{eq. (9)}$$

The RMi value can be found graphically, as shown in Appendix 7

[1] The effect of interlocking (IL) of the rockmass structure similar to what is used in the GSI system, can be included in the RMi by $RMi = RMi_{old} \times IL$, which is used in the following equations where RMi is involved. As seen in Table 4.E, the value of IL = 1 for normal tight (jointed) rockmass structures.

Limits of the RMi and the support estimate

The RMi system applies best to massive, jointed and crushed rock masses where the joints in the various sets have similar properties. It may also be used in overstressed, brittle ground, and as a first check for support in faults and weakness zones, but its limitations here are pointed out by Palmström (1995). As for the other classification systems, great care should be used in the characterization and estimate of support in complex weakness zones. Though separate calculations are given for overstressed ground, RMi should be applied with care in squeezing ground. Swelling is not dealt with in the RMi system.

2.4 Differences in the RMR, Q and RMi systems

Though the three systems have several common parameters, there are some differences. The main ones are:

1. The way the input values are combined in the systems to calculate the ground quality:
   - RMR uses addition of the ratings, while
   - Q applies multiplication and division;
   - RMi uses a combination of multiplication and exponential calculation.
2. The support is found in different ways from the ground quality calculated:
   - In RMR from a table (for tunnels with 10m span);
   - In Q from a chart where the Q value (ground quality) and the tunnel dimensions (span or wall height is used;
   - The RMi divides estimates of support between:
     a) Jointed rocks, where a chart for the ground conditions (quality) and the geometrical ratio (tunnel size and block size) is combined.
     b) Overstressed ground (in massive rocks and particulate rocks), where the system makes use of estimated tangential stress, which is compared with the RMi value.
3. The Q-system does not apply input for the rock properties directly, but this parameter is indirectly used in some other parameters. In 2002 the Qc was introduced (Barton, 2002), where the compressive strength of rock is included directly. So far, this parameter seems to be seldom applied in support estimates.
4. In the RMR system, stresses up to 25MPa are included. This means that RMR does not include stress problems in tunnelling (i.e. rock bursting, squeezing)
5. Weakness zones are characterized differently in the three systems. In the RMR, no special parameter is used; the Q applies a classification based on composition and depth of the zone; in the RMi the size of the zone is used.

3 COMBINING THE INPUT PARAMETERS TO RMR, Q AND RMI SYSTEMS

3.1 The input parameters used in the three systems

Table 1 shows the main ground parameters used as input to the RMR, Q, and RMi systems. Some special rockmass or ground conditions, like swelling, squeezing, and ravelling ground are not covered well in any of the three classification systems. For such conditions, the rock support should be evaluated separately using other rock engineering tools. For all three systems, the rock support is generally related to excavation by drilling and blasting.

During the field characterization and description, it is important to be aware of the relevant size of the observation area. Generally, it should be related to the size of the area to be supported, in most cases the span of the actual tunnel, and some 3 – 5m length along the tunnel; that is 15 – 25m² for a 5m wide tunnel. This condition is important when the input for the number of joint sets is selected.

Table 1: Overview of the input parameters used in the three systems

INPUT PARAMETERS			UNIT	Symbol used in:		
Parameter	**Classification**			**RMR**	**Q**	**RMi**
A. ROCK(S)	Uniaxial compressive strength of intact rock		MPa	A1	1)	σ_c
B. DEGREE OF JOINTING	RQD (Rock Quality Designation)		%	A2	RQD	-
	Block volume		m³	-	-	Vb
	Average joint spacing		m	A3	-	-
C. JOINTING PATTERN	Number of joint sets (at the actual location)		rating	-	Jn	Nj
	Orientation of main joint set		rating	B	-	Co
D. JOINT CHARACTERISTICS	Joint smoothness	Joint roughness (in Q and RMi systems)	rating	A4c	Jr 2)	jR 2) js
	Joint waviness		rating	-		jw
	Joint alteration (weathering and filling)		rating	A4e	Ja	jA
	Joint size (length)		rating	A4a	-	jL
	Joint persistence (continuity)		rating	-	-	cj
	Joint separation (aperture)		rating	A4b	-	-
E. INTERLOCKING	Compactness of rockmass structure		rating	-	-	IL
F. GROUND WATER	Water inflow or water pressure		rating	A5	Jw	GW
G. ROCK STRESSES (around tunnel)	Stress level		rating	-	SRF	SL
	Overstressing (rock burst or squeezing ground)		rating	-		CF 3)
H. WEAKNESS ZONE	Type of weakness zone		rating	-		-
	Size (thickness) of the zone		m	-	-	Tz
	Orientation of the zone		rating	-	-	Coz

1) Compressive strength of rock is included in the revised Qc = Q×σ_c/100 (Barton, 2002); 2) Jr = jR = js × jw; 3) CF = rockmass competency.
Interlocking of the rockmass structure is included in the RMi in this paper. In this way the effect of disturbed rockmasses is included.

3.2 Parameters for the degree of jointing

RQD, block volume, the volumetric joint count, and joint spacing are most frequently used to describe the degree of jointing. The three classification systems apply these measurements differently.

It has been a goal, when combining the three systems, to also combine the jointing measurements. Therefore, correlations between them are presented, as shown in the following.

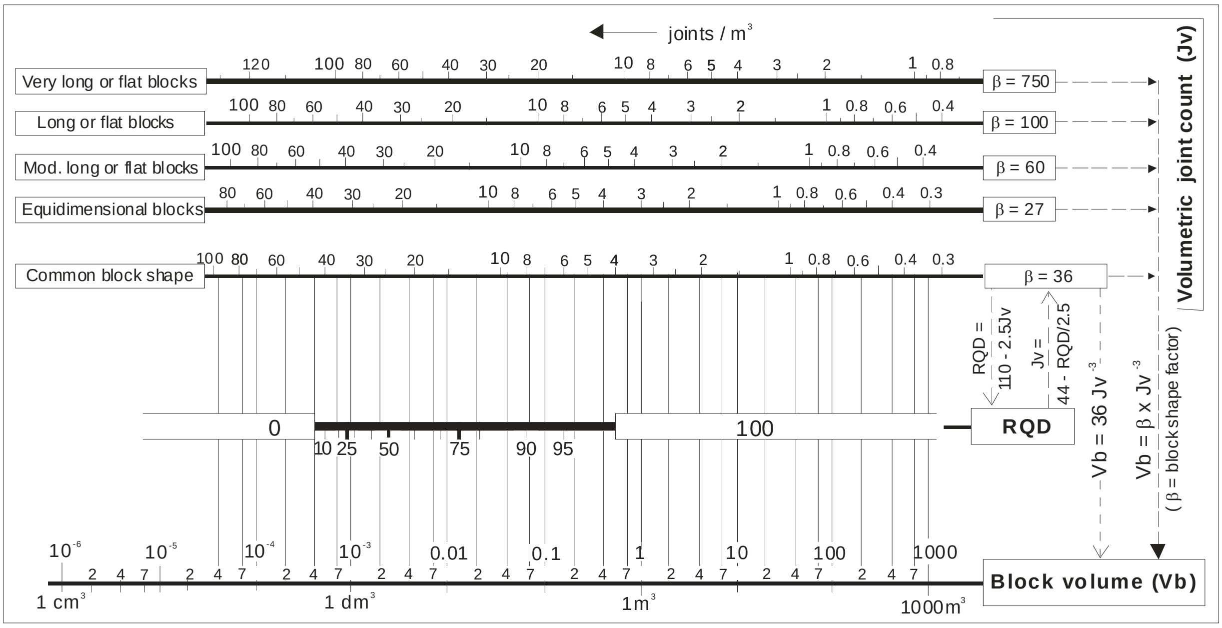

Figure 2: Correlation chart for various measurements of the degree of jointing: RQD, Jv and Vb (from Palmstrom, 2005). The block shape influences on the relations, for example, Jv = 6 for common block shape corresponds to Vb = 0.15 m³; while for Jv = 6 and very long blocks, Vb = 3 m³

As presented by Palmstrom (2005) it is no good correlation between RQD and Jv (volumetric joint count) or block volume (Vb). As an average, crude correlation, Palmstrom has suggested the following equation between RQD and Jv:

RQD = 110 – 2.5Jv Eq. (10)

The "old" equation RQD = 115 – 3.3Jv Eq. (11)
may, however, still be used.

As seen in Figure 2, the RQD covers only a limited part of the jointing range, but often the main part of it responsible for block falls in tunnels. In addition, the RQD has limited possibilities to accurately characterize the degree of jointing as has been discussed in the GeoEng2000 workshop and by Palmstrom (2005), see www.rockmass.net. For further information on joint measurements, see Hadjigeorgiou et al. (1998).

Spacing (S) is used as input to RMR, where the spacing of the set with smallest spacing is applied. From Vb the spacing may be found as $S \approx Vb^{1/3}$. From RQD no correlation to spacing has been found in the literature. When spacing is calculated from the other types of jointing measurements, only average spacing values are found, which may not be the smallest one.

3.3 Parameters for the joint characteristics

The main joint characteristics include:

– Joint roughness (smoothness, waviness or undulation),
– Filling or coating, and weathering of joints,
– Width or aperture of joint, as well as
– Joint size.

The Q and the RMi systems apply similar measurements and characterisation for roughness and filling (alteration), while RMR has another layout, as shown in Table 2.

Table 2: The parameters for joint roughness, alteration, weathering and infill applied the three classification systems

Q		RMi		RMR
Joint roughness (Jr) consisting of small scale smoothness and large scale waviness		Joint roughness (jR) jR = Jr = js × jw	joint smoothness (js)	Roughness (A4c) given as small scale smoothness
			joint waviness (jw)	-
Joint alteration (Ja)	unfilled	Joint alteration (jA)	unfilled	Weathering (A4e)
	filled		filled	Infilling (A4d)

The Q system applies Jr = 1 for filled, as roughness in such cases will have little effect on the shear strength. In RMR, however, it is possible to use rating for rough joint planes in filled joints, though it will seldom occur in practice. When combining the systems, the principle applied here in the Q system has been chosen.

Only RMR applies input for joint aperture or separation. Interlocking of the rockmass as is used in the GSI system, is considered to partly cover joint aperture and separation. As described earlier, this parameter has been included in the RMi system.

RMR and RMi systems apply input for joint size (length, persistence), but not the Q system. RMi uses the parameter 'discontinuous joints' joints ending in massive rock in combination with joint size. In the combined rockmass classification system this feature is included in the parameter for joint waviness (See Table 4.D2)

In connection with the Tables 4, the following expressions may need explanation:

– *Seam* is a minor, often clay-filled zone with a thickness of a few centimetres. When occurring as weak clay zone in a sedimentary sequence, a seam can be considerably thicker. Otherwise, seams may represent very minor faults or altered zones along joints, dikes, beds or foliation (Brekke and Howard, 1972).
– *Shear* is a seam of sheared and crushed rock of several millimetres to as much as a metre thickness of soft or friable rock or soil. [2]

[2] ISRM (1975) advises against the use of the terms ***tension joint*** and ***shear joint***, since there are many possible ways that they can be developed. For example, tension joints can be developed from cooling of igneous rock, from shrinkage of sediments, from folding, or from ice retreat.

– *Singularity* is used as a general term for seams, filled joints, shears or other persistent discontinuities, which are not considered to belong to the normal, overall or detailed jointing.

3.4 Ground water features

Ground water influences the condition in an underground excavation in three ways:

1. As joint or cleft pressure by adding stresses to the ground surrounding the excavation, and thereby reducing the stability. This is mainly the case for large water inflows. (For small inflows the draining effect of the tunnel will often prevent large water pressures from being built up near the tunnel surface.)
2. By softening clay, talc or other joint fillings or by washing out such fillings after these have been encountered during excavation. This is especially the case with pressurized inflow (water gushes or flows rapidly) into the tunnel. When the excavation is located below groundwater table, the filling material is already wet, but reduced stresses across the joint may cause increased saturation of the filling material and thus some reduced friction and shear strength.
3. As inflow of water by affecting the working conditions for the tunnel crew.

Table 3: The divisions of ground water occurrences applied in the three classification systems

RMR			Q		RMi
Description used	Water inflow per 10m tunnel (litres/min)	Joint water pressure / major principal stress $p_w / \sigma 1$	Description used	Water pressure (kg/cm^2)	Description (influence on stability)
Completely dry	none	0	Dry excavations or minor inflow, i.e. < 5 litres/min locally	< 1	Dry or wet: No or minor stability influence
Damp	< 10	0 - 0.1	Medium inflow or pressure, occasional outwash of joint fillings	1 - 2.5	
Wet	10 - 25	0.1 - 0.2	Large inflow or high pressure in competent rock with unfilled joints	2.5 - 10	Seeping/dripping: Unfavourable joints with seeping may seldom influence
Dripping	25 - 125	0.2 - 0.5	Large inflow or high pressure, considerable outwash of joint fillings	2.5 - 10	Gushing: May clearly influence on stability
Flowing	> 125	> 0.5	Exceptionally high inflow or water pressure at blasting, decaying with time	> 10	
			Exceptionally high inflow or water pressure continuing without noticeable decay	> 10	
			Note: *(i) The last four factors are crude estimates*		

All three systems apply input for water, but the characterization and application are somewhat different, see Table 3. The RMR system, and especially the Q system, applies input of flowing water situations. In such cases the support recommendation may not be relevant, as the use of shotcrete (sprayed concrete) is difficult or not suitable. Such working conditions often require other works, such as sealing of the water by grouting, to be implemented before estimated the support by can be installed.[3] Such sealing works are not prescribed in the two systems.

The RMi support system preferably uses the influence water may have on stability (where that in practice is possible to estimate) as ground water input, but limited to gushing inflows.

A classification of the inflow of water into underground excavations, measured along 10m of the tunnel is suggested as:

seepage	for inflow volumes < dm^3/day;
dripping	for inflow volumes of dm^3/day to m^3/hour;
flowing / gushing	for inflow volumes of m^3/hour to several m^3/min;
water in-burst	for inflow volumes of several m^3/s.

[3] Grouting will reduce the inflow and hence result in reduction of the input parameter for ground water

3.5 Rock stress parameters

It is important to divide between stresses below and stresses exceeding the strength of the rock masses surrounding the excavation. It is generally difficult to measure or calculate the magnitude of the tangential stresses acting around the surface of an excavation.

In massive ground, overstressing is of particular importance as the ground behaviour will change from stable at moderate stress levels to bursting (in brittle rocks) or squeezing (in deformable rocks). Squeezing may also occur in highly jointed (particulate) rock with clay or other materials with deformable properties.

Stresses are applied differently in the three classification systems. RMR has as earlier mentioned, no input of stresses, but stresses below 25MPa are included in the support estimates. For Q, the input is characterized in the SRF factor (which also represents weakness zones). SRF for stresses is divided into three groups:
1) stresses below rock mass strength, 2) overstressing in massive, brittle rock, and 3) overstressing where squeezing may take place. In the RMi rock support as special chart is applied for overstressing.

The two different ways for input of stresses in Q and RMi have been combined, using the division in the Q system. Here, it might be mentioned that the estimated rock support can be found directly (without input of all input parameters) from the RMi support diagram for overstressed ground if the $\sigma_\theta / \sigma_{cm}$ or σ_θ/ RMi is known.

3.6 Weakness zone parameters

According to definition, *weakness zone* is a part, layer or zone in the ground in which the mechanical properties are significantly lower than those of the surrounding rock masses. Weakness zones can be faults, shears / shear zones, thrust zones, weak mineral layers, etc. In the opinion of the author, a weakness zone may range from about a metre to some tens of metres.

Weakness zones are applied differently in the three systems. The Q system applies a part of the SRF (stress reduction factor) values for some specified types of zones, In the RMi and RMR systems the composition of the zone is given through input of the composition characteristics of the zone. RMi applies in addition, the thickness (size) of the zone as the zone input, while RMR has no special parameter for weakness zones.

The type and the size of zone intersecting the excavation are used as inputs for weakness zones.

In the opinion of the author, it is difficult to include the many variable conditions and features involved in faults and weakness zones in a general classification system. Therefore, there are several limitations in the application of weakness zones in all the three classification systems.

3.7 The combined input tables to the classification systems

Table 4 shows the combined, common input parameters with the values or ratings used in each of the three systems. The experienced reader will find that many of the parameters presented are more or less similar to what is used in the RMR and the Q systems, though some new combinations are introduced. It is important to keep in mind that the parameters give averaged values, and that it might be significant variation between the lowest and highest value and rating for most of them. Note that swelling is not included in Table 4 (except in the joint alteration number, Ja, in the Q system)

Table 4: The combined input parameters of ground conditions

A. ROCKS			**RMR**	**Q**	**RMi**
A1. Compressive strength (σ_c) of intact rock			A1 =	-	σ_c =
Soil		σ_c < 1 MPa	*0*	Not included, except in Qc = Q x σ_c /100	Use actual value of σ_c
Rock	a. Very low strength	1 – 5MPa	1		
	b. Low strength	5 – 25MPa	2		
	c. Moderate strength	25 – 50MPa	4		
	d. Medium strength	50 – 100MPa	7		
	e. High strength	100 – 250MPa	12		
	f. Very high strength	> 250MPa	15		

B. DEGREE OF JOINTING		**RMR**	**Q**	**RMi**
B1. Rock quality designation (RQD)		A2 =	RQD =	-
a. Very good	RQD = 90 - 100	20	Use actual RQD value (min RQD = 10)	Not included
b. Good	75 - 90	17		
c. Fair	50 - 75	13		
d. Poor	25 - 50	8		
e. Very poor	< 25	5		
An approximate correlation between RQD and Jv is: RQD = 110 – 2.5Jv (Jv = jointing parameter)				
B2. Block size		-	-	Vb =
Block volume (Vb)		Not included	Not included	Use actual value of Vb in m^3
The block volume can be calculated from the Jv: $Vb = \beta \times Jv^{-3}$ *For cubical block shapes β= 27-32, for slightly long or flat shapes β = 32 - 40, for long or flat shapes β = 40 - 75*				
B3. Joint spacing		A3 = [1)]	-	-
a. Very large spacing	Spacing >2m	20	Not included	Not included
b. Large spacing	0.6 - 2m	15		
c. Moderate spacing	200 - 600mm	10		
d. Small spacing	60 - 200mm	8		
e. Very small spacing	< 60mm	5		
[1)] Where more than one joint set occurs, the rating for the smallest spacing should be applied				

C. JOINTING PATTERN	**RMR**	**Q**	**RMi**
C1. Joint set number	-	Jn =	Nj =
No or few joints	Not included	0.75	6
a. 1 joint set		2	3
b. 1 joint set + random joints		3	2
c. 2 joint sets		4	1.5
d. 2 joint sets + random joints		6	1.2
e. 3 joint sets		9	1
f. 3 joint sets + random joints		12	0.85
g. 4 joint sets or more; heavily jointed		15	0.6
h. Crushed, earth-like		20	0.5
C2. Orientation of main joint set	B =	-	Co =
a. Very favourable	0	Not included	1
b. Favourable	-2		1
c. Fair	-5		1.5
d. Unfavourable	-10		2
e. Very unfavourable	-12		3

D. JOINT CHARACTERISTICS	RMR	Q[1)]	RMi
D1. Joint smoothness (small scale roughness) (called 'roughness' in the RMR)	A4c =	(js =)	js =
a. Very rough	6	2	2
b. Rough or irregular	5	1.5	1.5
c. Slightly rough	3	1.25	1.25
d. Smooth	1	1	1
e. Polished	0	0.75	0.75
f. Slickensided	0	0.5	0.5
D2. Joint undulation or waviness (large scale roughness)	-	(jw =)	jw =
a. Discontinuous joints	Not included	4	4
b. Strongly undulating		2.5	2.5
c. Moderately undulating		2	2
d. Slightly undulating		1.4	1.4
e. Planar		1	1

[1)] Joint roughness number Jr = js x jw
Note: Jr = js x jw = 1 for filled joints

D3. Joint alteration or weathering	A4e =	Ja =	jA =
a. Healed or welded joints	6	0.75	0.75
b. Unweathered, fresh joint walls	6	1	1
c. Slightly weathered joint walls (coloured, d. stained)	3	2	2
e. Altered joint wall (no loose material)	0	4	4
f. Coating of friction materials (silt, sand, etc.)	1	3	3
g. Coating of cohesive materials (clay, chlorite, etc.)	0	4	4
Filled joints	0	See below	See below

Filled joints *(t = joint thickness)*	A4d =		Ja =		jA =	
	t < 5mm	t > 5mm	wall contact [1)]	no wall contact [2)]	t < 5mm	t > 5mm
No filling	6	-	-	-	-	-
h. Friction materials (silt, sand, etc.)	5	2	4	8	4	8
j. Hard, cohesive materials (clay, talc, chlorite)	4	2	6	8	6	8
l. Soft, cohesive materials (soft clay)	2	0	8	12	8	12
n. Swelling clay materials	0	0	10	18	10	18

1) Wall contact before 10cm shear; 2) No contact when sheared;
Note: Q and RMi apply a combination of joint weathering and infilling, while RMR has input of both weathering and infilling

D4. Joint length		A4a =	-	jL =
a. Crack [1)] (irregular break)	Length < ~0.3m	8	Not included	5
b. Parting (very short, thin joint)	< 1m	6		3
c. Very short joint	0.3 – 1m			2
d. Short joint	1 – 3m	4		1.5
e. Medium joint	3 – 10m	2		1
f. Long joint	10 – 30m [2)]	1		0.75
g. Filled joint, or seam [3)]	> 10m	0		0.5

[1)] "Crack" has been introduced in this table; [2)] Length 10 – 20 m is applied in the RMR; [3)] Used in cases where most joints in the location are filled
Persistence (continuity) of joints in the RMi system has been replaced by 'Discontinuous joints' in Table D2

D5. Joint separation or aperture (A)		A4b =	-	-
a. Very tight	None	6	Not included	Partly included in the input for 'Interlocking of structure'
	A < 0.1mm	5		
b. Tight	0.1 – 0.5mm	4		
c. Moderately open	0.5 - 1mm			
	1 – 2.5mm	1		
d. Open	2.5 - 5mm			
	5 - 10mm	0		
e. Very open	10 - 25mm			

E. INTERLOCKING OF ROCKMASS		RMR	Q	RMi
Compactness of structure		-	-	IL =
a. Very tight structure	Undisturbed rock mass	Not included	Not included	1.3
b. Tight structure	Undisturbed rock mass with some joint sets			1
c. Disturbed / open structure	Folded / faulted with angular blocks			0.8
d. Poorly interlocked	Broken rockmasses with angular and rounded blocks			0.5
Note: Interlocking has been introduced in this table, based on its effects used in the GSI system				

F. GROUND WATER CONDITIONS			RMR	Q	RMi
Water inflow to tunnel (q in litres/min) **or water pressure** (p_w)			A5 =	Jw =	GW =
a. Dry or damp	q = 0	p_w < 1 kg/cm²	15	1	1
b. Wet or small seeps	q < 10	p_w = 1-2.5 kg/cm²	10	0.66	
c. Dripping	q = 10-25	p_w = 2.5-10 kg/cm²	7	0.5	2.5
d. Gushing/material outwashing	q = 25-125		4	0.3	5
e. Flowing, decaying with time	q > 125	p_w > 10 kg/cm²	0	0.15	-
f. Large, continuous inflow			-	0.08	-
NOTE! GW – is related to groundwater's influence on rockmass stability					

G. ROCK STRESSES (around tunnel)		RMR	Q	RMi
G1. Stresses below rockmass strength ($\sigma_\theta < \sigma_{cm}$)		-	SRF =	SL =
a. Very low stress level (as in portals)		Not included	2.5	0.1
b. Low stress level				0.5
c. Medium stress level			1	1
d. High stress level			0.67	1.5
G2. Overstressing; stresses > rockmass strength ($\sigma_\theta > \sigma_{cm}$)		-	SRF =	CF= RMi /σ_θ
in massive, brittle rocks	e. Moderate slabbing after >1 hr	Not included	25	0.75
	f. Slabbing and rock burst after few minutes		100	0.5
	g. Heavy rock burst		300	0.2
in deformable rocks	h. Mild squeezing		10	0.75
	i. Heavy squeezing		20	0.5
σ_θ = tangential stresses around the opening; σ_{cm} ~ RMi = compressive strength of rock mass				

H. WEAKNESS ZONES *)		RMR	Q	RMi
H1. Type of weakness zone		-	SRF =	-
a. Multiple weakness zones	any depth	Weakness zones and shears are not explicitly included in RMR	10	(Zone or shear characteristics are included in the other input parameters)
b. Single weakness zone	depth < 50m		5	
c. Single weakness zone	depth > 50m		2.5	
d. Multiple shear zones	any depth		7.5	
e. Single shear zone	depth < 50m		5	
f. Single shear zone	depth > 50m		2.5	
g. Loose, open joints	any depth		5	
h. Heavily jointed ("sugar cube")	any depth		5	
H2. Size of the zone		-	-	Tz =
Thickness or width of the zone (Tz)		Not included	Not included	Use width of zone in m
H3. Orientation of zone related to excavation		-	-	Coz =
a. Very favourable		Not included	Not included	1
b. Favourable				1
c. Fair				1.5
d. Unfavourable				2
e. Very unfavourable				3
*) *Most weakness zones should be especially evaluated, together with the use of engineering judgement*				

4 TWO WORKED EXAMPLES

The practical use of the correlations is shown below in the following two examples. The ground conditions in the tunnel roof have been used. A value of the excavation support ratio, ESR = 1 is used for the estimated support in the Q system.

4.1 Example 1: Moderately jointed rock

In a 10m wide tunnel, the ground conditions have been characterized as follows: A granite with uniaxial compressive strength, σ_c = 125MPa is penetrated by 2 joint sets, both with favourable orientation of the main joint set. In addition, some random joints occur. Average degree of jointing is: RQD = 85; block volume, Vb = 0.1 m³; joint spacing, S = 0.2 – 0.4m. The fresh, continuous joints of the main set are rough & planar, tight and mostly longer than 3m. It is "damp" water condition, and approximately 100m rock overburden, i.e. medium stress level. Based on this, the Q, RMR and RMi input values and the estimated rock support are shown in Table 3.

Table 5: Example 1 with ratings of the various input parameters with estimated rock support based on Table 4

Example 1: Moderately jointed rockmass			input symbol	Values or ratings in:			
INPUT PARAMETERS				**RMR**		**Q**	**RMi**
A. ROCK	A1. Uniaxial compressive strength		f / value	A1 = 12		-	σ_c = 125MPa
B. DEGREE OF JOINTING	B1. RQD		b / value	A2 = 17		RQD = 85	-
	B2. Block size		value	-		-	Vb = 0.1m³
	B3. Average joint spacing		c	A3 = 10		-	-
C. JOINTING PATTERN	C1. Number of joint sets		e	-		Jn = 6	Nj = 1.2
	C2. Orientation of main joint set in roof		b	B = -2		-	Co = 1
D. JOINT CHARAC-TERISTICS	D1. Smoothness	joint roughness	b	A4c = 5	A4 = 23	Jr = js × jw = 1.5	js = 1.5
	D2. Undulation		e	-			jw = 1
	D3. Joint alteration	weathering	b	A4e = 6		Ja = 1	Ja = 1
		filling		A4d = 6			
	D4. Joint size or persistence		e	A4a = 2		-	Jl = 1
	D5. Joint separation (aperture)		c	A4b = 4		-	-
E. INTERLOCKING OF ROCKMASS			b	-		-	IL = 1
F. GROUND WATER			b	A5 = 10		Jw = 1	GW = 1
G. STRESSES AROUND TUNNEL			c	-		SRF = 1	SL = 1
Ground parameters for support evaluation				**RMR = 70**		**span/ESR = 10** **Q = 21.3**	**Sr = 13.5** **Gc = 14.0**
				good		*good*	*good*
Estimated rock support, in roof				**RMR**		**Q**	**RMi**
Rock bolt spacing				2.5m		spot bolting	2 - 3m
Shotcrete thickness				50mm *)		-	40 - 50mm
*) where required							

Comment

The RMi generally estimates heavier rock support than the two other classification systems. A main reason is that it is based on newer tunnel support examples where a higher degree of safety is required, which often includes more use of shotcrete.

4.2 Example 2: Strongly jointed rocks

This example refers to ground conditions encountered in the North Cape sub-sea road tunnel in Norway, constructed in 1995 to 1999. Half of this 8 m span, 6km long tunnel is located in sub-horizontal layers of meta-sandstone (σ_c = approx. 100MPa). The tight, smooth and planar joints with coating of mica and/or chlorite along the foliation are often longer than 3m. In addition to these foliation joints, it is a set of vertical joints and some random joints. However, the rock splits easily into smaller pieces, because of tiny, irregular (often partly welded) cracks, which are easily activated from the blasting. The result is a block volume of Vb = 0.0005 – 0.005m³ (representative Vb = 0.001m³ is used), RQD = 10, joint spacing mostly 5 - 20cm. The main joint set has fair orientation with regard to the tunnel. The rock overburden along the tunnel is 40 - 100m (medium stress level) and it was no or minor water inflows.

The tunnel was excavated mostly by 4m blast rounds. However, the stability in the tunnel was generally very poor. Shortly after blasting, small blocks started to fall. Therefore, it was important to quickly apply shotcrete on the unstable face, roof and walls to obtain safe working conditions. Then, cast-in-place concrete lining was installed before next blast round. Alternatively, 2 – 3m blast rounds and support by thick shotcrete (fibre reinforced) and dense rock bolting were partly used.

Table 6: The Ratings and values of the various rockmass parameters in Example 2 with estimated rock support

Example 2: Highly jointed rockmass				Values or ratings in:			
INPUT PARAMETERS			**input**	**RMR**		**Q**	**RMi**
A. ROCK	A1. Uniaxial compressive strength		e / value	A1 = 7		-	σ_c = 100MPa
B. DEGREE OF JOINTING	B1. RQD		e / value	A2 = 5		RQD = 10	-
	B2. Block size		value	-		-	Vb = 0.001m³
	B3. Average joint spacing		d	A3 = 8		-	-
C. JOINTING PATTERN	C1. Number of joint sets		e	-		Jn = 6	Nj = 1.2
	C2. Orientation of main joint set (in roof)		c	B = -5		-	Co = 1.5
D. JOINT CHARAC-TERISTICS	D1. Smoothness	joint roughness	d	A4c = 1	A4 = 13	Jr = js × jw = 1	js = 1
	D2. Undulation		e	-			jw = 1
	D3. Joint alteration	weathering	f	A4e = 0		Ja = 3	jA = 3
		filling		A4d = 6			
	D4. Joint size		e	A4a = 2		-	jL = 1
	D5. Joint separation (aperture)		c	A4b = 4		-	-
E. INTERLOCKING OF ROCKMASS			b	-		-	IL = 1
F. GROUND WATER			c	A5 = 7		Jw = 0.66	GW = 1
G. STRESSES AROUND TUNNEL			c	-		SRF = 1	SL = 1
Parameters for support evaluation				**RMR = 35**		**Span/ESR = 10** **Q = 0.28**	**Sr = 75** **Gc = 0.34**
				poor		*very poor*	*very poor*
Rock support, in roof				**RMR**		**Q**	**RMi**
Rock bolt spacing				1 - 1.5		1.5 m	1 - 1.25m
Shotcrete thickness				100 – 150mm		100 – 150mm	150 – 250mm
Additional support				Light steel ribs spaced 1.5m where required			

As seen from Table 4, the RMR system, and especially the Q system, indicates less rock support than what was necessary during excavation. The RMi system indicates that special support evaluations should be made, which is more in line with the stability and rock support used.

5 COMPARISON BETWEEN THE THREE CLASSIFICATION SYSTEMS

A computer spreadsheet to estimate the values in all the tree systems has been worked out, based on the combined input parameter tables in Table 4. By this, it is easy to calculate the corresponding ground qualities in the three classification systems from the common input values or ratings. Thus comparisons between the systems can be made, provided that the inputs of ground conditions are within the limits of all the three systems. Therefore overstressing (rock burst and squeezing) is not used in the comparisons, because it is not covered in the RMR system. The Excel spreadsheet used can be downloaded from www.rockmass.net

Figure 5 shows the results from comparisons found by using the spreadsheet. Also these show that there may be large inaccuracies from the average, often ± 30 - 50%.

As shown, it is generally better correlation between Q and RMi and between RMR and RMi than between Q and RMR. A main reason for this is that Q does not use input of the compressive strength of intact rock. Weakness zones are poorly covered by the commonly used equation between Q and RMR (RMR = 9 lnQ + 44). However, when Qc (= $Q \times \sigma_c/100$) is used, much better correlations are found.

Some special features cannot be appropriately estimated in classification systems, namely swelling and slaking. Also the conditions in weakness zones can, as mentioned, be difficult to classify correctly.

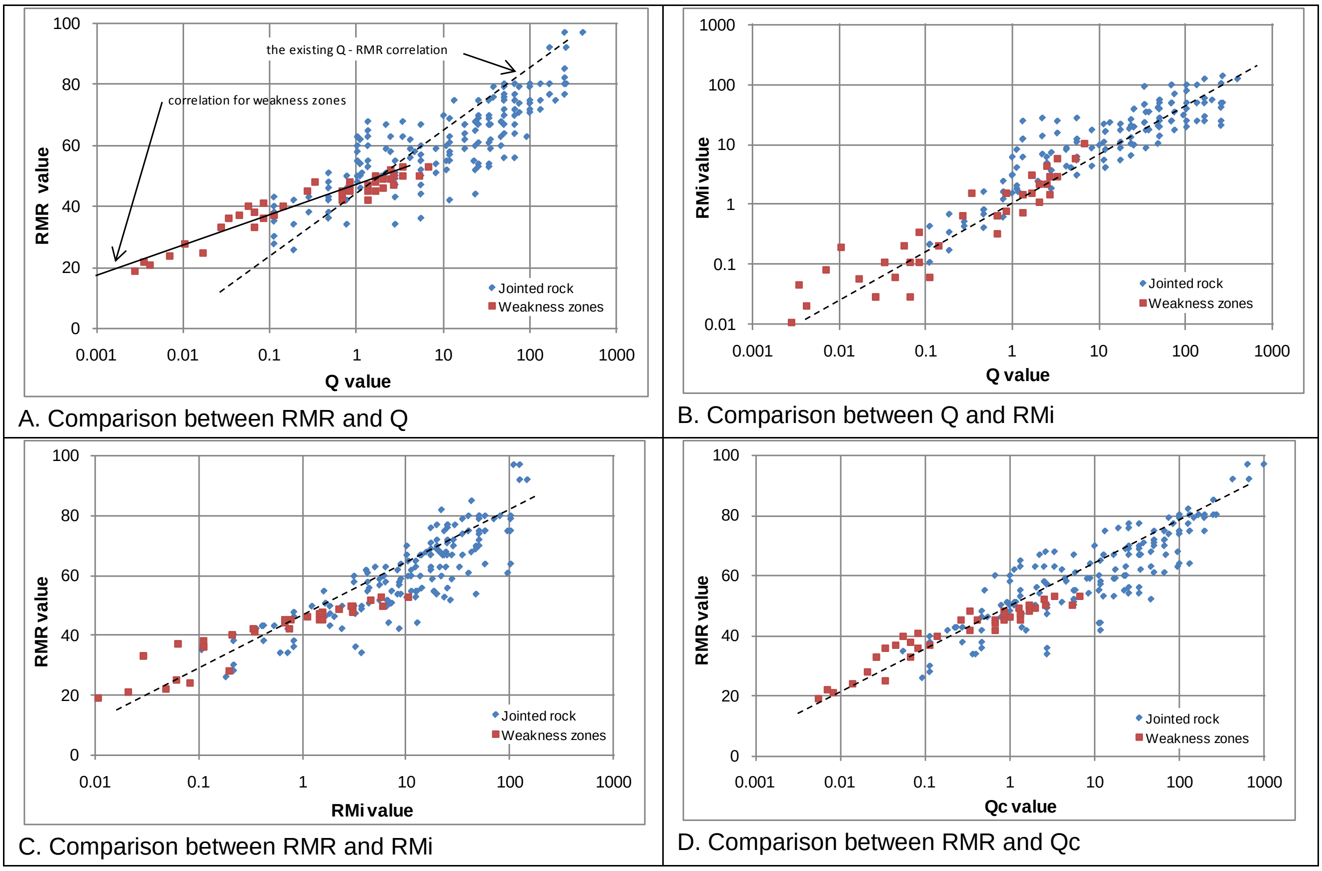

Figure 5: Comparisons between the RMR, Q and RMi classification systems, excluding stresses larger than 25MPa

6 CONCLUSIONS

The use of two or more classification systems in design and rock engineering, will generally lead to better and more accurate results.

Though there are many similarities between the RMR, Q and RMi classification systems, the differences between the parameters applied and their structure cause that the commonly used correlation equations between them can lead to severe errors. Better correlation results can be obtained if the combination of the input values shown in Table 4 is applied. With a spreadsheet the Q, RMR and RMi values can be easily and adequately found.

As all three systems work best in blocky ground, the degree of jointing (i.e. RQD, block size or joint spacing) is often the most important input parameter. This has been utilized in the spreadsheet presented in www.rockmass.net, where common conditions (i.e. the most frequent values of the input parameters) are implemented for most of the input parameters other than degree of jointing. These values are used when no information (input) is given. Thus from a limited amount of input parameters, it is possible to find crude estimates of the RMR, Q and RMi values. Obviously, better or more accurate results will be found when input values of all parameters are given.

The presented input values to the systems can be estimated from standard or common measurements and descriptions of the rock masses, stresses and groundwater conditions. There may turn up occasional difficulties when the input for block size is estimated from RQD (refer to Palmstrom, 2005). Two main reasons for this are:

a) the inaccuracy in the measurement of RQD and its limits in characterizing massive rock and highly jointed rock; and
b) the difficulties in measuring block volumes and selecting the representative sizes in a location.

In many cases the volumetric joint count can be used as input. The block volume to be used in the RMi and the RQD used in RMR and Q can also be calculated from a crude correlation.

Barton and Bieniawski (2008) have pointed out ten important commandments for proper use of classification systems. Another commandment is that the user knows the limits of the classification systems, and in addition has practical, geological knowledge and experience. In fact, it has often been found that simple systems may lead to errors or inaccuracies, because they are easily misused by inexperienced people.

In addition, it is a provision that the actual ground conditions are correctly characterized from measurements and observations (that the input parameters used in the systems represent the site conditions), and that the user has knowledge on how the input parameters are used in the systems.

The comparisons made between the three classification systems show the same as in Figure 1, that there are inaccuracies between them in their ability to arrive at the same ground quality with respect to instability in an excavation. The (total) rock support found in the two examples shows that the RMi system predicts somewhat more support than the RMR and Q. This is also the experience from practical applications of the Q and RMi systems.

It is important to keep in mind that most empirical methods in rock engineering give averaged values, and that it might be significant variation between the lowest and highest value. As has been pointed out by Palmstrom and Stille (2005), also the support guidelines in the various systems or methods are given as average values.

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8 APPENDICES

Appendix 1. The input parameters used in the RMR_{1989} classification system

A. Classification parameters and their ratings in the RMR system

	PARAMETER		Range of values // **RATINGS**						
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 compr. strength is preferred		
		Uniaxial compressive 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**	**5**		
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 discon-tinuities	a. Length, persistence	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m		
		Rating	**6**	**4**	**2**	**1**	**0**		
		b. Separation	none	< 0.1 mm	0.1 - 1 mm	1 - 5 mm	> 5 mm		
		Rating	**6**	**5**	**4**	**1**	**0**		
		c. Roughness	very rough	rough	slightly rough	smooth	slickensided		
		Rating	**6**	**5**	**3**	**1**	**0**		
		d. Infilling (gouge)	none	Hard filling		Soft filling			
			-	< 5 mm	> 5 mm	< 5 mm	> 5 mm		
		Rating	**6**	**4**	**2**	**2**	**0**		
		e. Weathering	unweathered	slightly w.	moderately w.	highly w.	decomposed		
		Rating	**6**	**5**	**3**	**1**	**0**		
5	Ground water	Inflow per 10 m tunnel length	none	< 10 litres/min	10 - 25 litres/min	25 - 125 litres/min	> 125 litres /min		
		$p_w / \sigma 1$	0	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**		

p_w = joint water pressure; $\sigma 1$ = major principal stress

B. RMR rating adjustment for discontinuity orientations

		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
RATINGS	Tunnels	**0**	**-2**	**-5**	**-10**	**-12**
	Foundations	**0**	**-2**	**-7**	**-15**	**-25**
	Slopes	**0**	**-5**	**-25**	**-50**	**-60**

C. Rock mass classes determined from total RMR ratings

Rating	100 - 81	80 - 61	60 - 41	40 - 21	< 20
Class No.	I	II	III	IV	V
Description	VERY GOOD	GOOD	FAIR	POOR	VERY POOR

D. Meaning of ground classes

Class No.	I	II	III	IV	V
Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes 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°

Appendix 2. The input parameters used in the Q classification system

A. Rock quality designation (RQD)

Very poor	RQD = 0 - 25%
Poor	25 - 50
Fair	50 - 75
Good	75 - 90
Excellent	90 - 100

Notes:

(i) Where RQD is reported or measured as < 10 (including 0), a nominal value of 10 is used to evaluate Q

(ii) RQD intervals of 5, i.e. 100, 95, 90, etc. are sufficiently accurate

B. Classification with ratings for the Joint set number (Jn)

Massive, no or few joints	Jn = 0.5 - 1
One joint set	2
One joint set plus random	3
Two joint sets	4
Two joint sets plus random	6
Three joint sets	9
Three joint sets plus random	12
Four or more joint sets, heavily jointed, "sugar-cube", etc.	15
Crushed rock, earth-like	20

Notes: *(i) For tunnel intersections, use (3.0 x Jn); (ii) For portals, use (2.0 x Jn)*

C. Classification with ratings for the Joint roughness number (Jr)

a) Rock-wall contact, b) rock-wall contact before 10 cm shear	
Discontinuous joints	Jr = 4
Rough or irregular, undulating	3
Smooth, undulating	2
Slickensided, undulating	1.5
Rough or irregular, planar	1.5
Smooth, planar	1.0
Slickensided, planar	0.5

Note: *i) Descriptions refer to small scale features, and intermediate scale features, in that order*

c) No rock-wall contact when sheared	
Zone containing clay minerals thick enough to prevent rock-wall contact	Jr = 1.0
Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0

Notes:

i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3 m

ii) Jr = 0.5 can be used for planar, slickensided joints having lineations, provided the lineations are oreintated for minimum strength

D. Classification with ratings for the Joint alteration number (Ja)

	JOINT WALL CHARACTER		**Condition**	*Wall contact*
Contact between joint walls	CLEAN JOINTS:	Healed or welded joints:	filling of quartz, epidote, etc.	Ja = 0,75
		Fresh joint walls:	no coating or filling, except from staining (rust)	1
	JOINTS WITH COATING OF:	Slightly altered joint walls:	non-softening mineral coatings, clay-free particles, etc.	2
		Friction materials:	sand, silt calcite, etc. (non-softening)	3
		Cohesive materials:	clay, chlorite, talc, etc. (softening)	4

	FILLING OF:	**Type**	*Wall contact before 10 cm shear*	*No wall contact when sheared*
Partly or no wall contact	Friction materials	sand, silt calcite, etc. (non-softening)	Ja = 4	Ja = 8
	Hard cohesive materials	compacted filling of clay, chlorite, talc, etc.	6	5 - 10
	Soft cohesive materials	medium to low overconsolidated clay, chlorite, talc, etc.	8	12
	Swelling clay materials	filling material exhibits swelling properties	8 - 12	13 - 20

E. Classification with ratings for the Joint water reduction factor (Jw)

Dry excavations or minor inflow, i.e. < 5 l/min locally	p_w < 1 kg/cm^2	Jw = 1
Medium inflow or pressure, occasional outwash of joint fillings	1 - 2.5	0.66
Large inflow or high pressure in competent rock with unfilled joints	2.5 - 10	0.5
Large inflow or high pressure, considerable outwash of joint fillings	2.5 - 10	0.3
Exceptionally high inflow or water pressure at blasting, decaying with time	> 10	0.2 - 0.1
Exceptionally high inflow or water pressure continuing without noticeable decay	> 10	0.1 - 0.05

Note: *(i) The last four factors are crude estimates. Increase Jw if drainage measures are installed*

(ii) Special problems caused by ice formation are not considered

F. Classification with ratings for the Stress reduction factor (SRF)

				SRF
Weakness zones intersecting excavation	Multiple weakness zones with clay or chemically disintegrated rock, very loose surrounding rock (any depth)			SRF = 10
	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation < 50 m)			5
	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation > 50 m)			2.5
	Multiple shear zones in competent rock (clay-free), loose surrounding rock (any depth)			7.5
	Single shear zones in competent rock (clay-free), loose surrounding rock (depth of excavation < 50 m)			5
	Single shear zones in competent rock (clay-free), loose surrounding rock (depth of excavation > 50 m)			2.5
	Loose, open joints, heavily jointed or "sugar-cube", etc. (any depth)			5
Note: *(i)*	*Reduce these values of SRF by 25 - 50% if the relevant shear zones only influence, but do not intersect the excavation*	σ_c / σ_1	σ_θ / σ_c	SRF
Competent rock, rock stress problems	Low stress, near surface, open joints	> 200	< 0.01	2.5
	Medium stress, favourable stress condition	200 - 10	0.01 - 0.3	1
	High stress, very tight structure. Usually favourable to stability, maybe except for walls	10 - 5	0.3 - 0.4	0.5 - 2
	Moderate slabbing after > 1 hour in massive rock	5 - 3	0.5 - 0.65	5 - 50
	Slabbing and rock burst after a few minutes in massive rock	3 - 2	0.65 - 1	50 - 200
	Heavy rock burst (strain burst) and immediate dynamic deformation in massive rock	< 2	> 1	200 - 400

Notes: *(ii) For strongly anisotropic stress field (if measured): when 5 <* σ_1/σ_3 *<10, reduce* σ_c *to 0.75* σ_c*. When* $\sigma 1/\sigma 3$ *> 10, reduce* σ_c *to 0.5*σ_c
(iii) Few case records available where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for low stress cases

			σ_θ / σ_c	SRF
Squeezing rock	Plastic flow of incompetent rock under the influence of high pressure	Mild squeezing rock pressure	1 - 5	5 - 10
		Heavy squeezing rock pressure	> 5	10 - 20
Swelling rock	Chemical swelling activity depending on presence of water	Mild swelling rock pressure		5 - 10
		Heavy swelling rock pressure		10 - 15

Appendix 3. The input parameters used in the RMi system

				INPUT	
A. Uniaxial compressive strength of intact rock, σ_c					
Found from lab. tests, simple field hammer test or assumed from handbook tables				**value** of σ_c (in MPa)	
B. Block volume, Vb					
Found from measurement at site or from drill cores, etc. (Vb can also be calculated from RQD or Jv)				**value** of Vb (in m^3)	
C. Joint roughness factor, jR (similar to Jr in the Q-system) jR = Jr = js × jw					
Small scale smoothness of joint surface	Very rough or interlocking			js = 3	
	Rough or irregular			2	
	Slightly rough			1.25	
	Smooth			1	
	Polished or slickensided *)			0.5 – 0.75	
**) For slickensided surfaces the ratings apply to possible movement along the lineations*					
Large scale waviness of joint plane	Planar			jw = 1	
	Slightly undulating			1.4	
	Moderately undulating			2	
	Strongly undulating			2.5	
	Discontinuous joints*)			6	
**) Discontinuous joints end in massive rock (For filled joints jR = 1)*					
D. Joint alteration factor, jA (the ratings are based on Ja in the Q-system)					
Contact between joint walls	CLEAN JOINTS:	Healed or welded joints	filling of quartz, epidote, etc.	jA =0.75	
		Fresh joint walls	no coating or filling, except from staining (rust)	1	
		Altered joint walls	- one grade higher alteration than the rock	2	
			- two grades higher alteration than the rock	4	
	COATING OF:	Frictional materials	sand, silt calcite, etc. without content of clay	3	
		Cohesive materials	clay, chlorite, talc, etc.	4	
Partly or no wall contact	FILLING OF:			Thin filling (< ca. 5 mm)	Thick filling
		Frictional materials	sand, silt calcite, etc. (non-softening	jA = 4	jA = 8
		Hard, cohesive materials	clay, chlorite, talc, etc.	6	5 - 10
		Soft, cohesive materials	clay, chlorite, talc, etc.	8	12
		Swelling clay materials	smectite, montmorillonite etc.	8 - 12	13 - 20
E. Joint size factor, jL (length of the joint) *discontinuous joints (earlier included here) have been included in the joint roughness*					
Bedding or foliation partings		length < 0.5m		jL = 3	
Joints		with length 0.1 - 1m		2	
		with length 1 - 10m		1	
		with length 10 - 30m		0.75	
Long joint, filled joint, seam or shear *)		length > 30m		0.5	
**) Often a singularity and should if it has a significant impact on stability, be treated separately*					
F. Interlocking (compactness) of rockmass structure, IL					
Very tight structure		Undisturbed rock mass, tightly interlocked		IL = 1.3	
Tight structure		Undisturbed, jointed rock mass		1	
Disturbed / open		Folded / faulted with angular blocks		0.8	
Poorly interlocked		Broken with angular and rounded blocks		0.5	

Appendix 4. The support table used in the RMR classification system

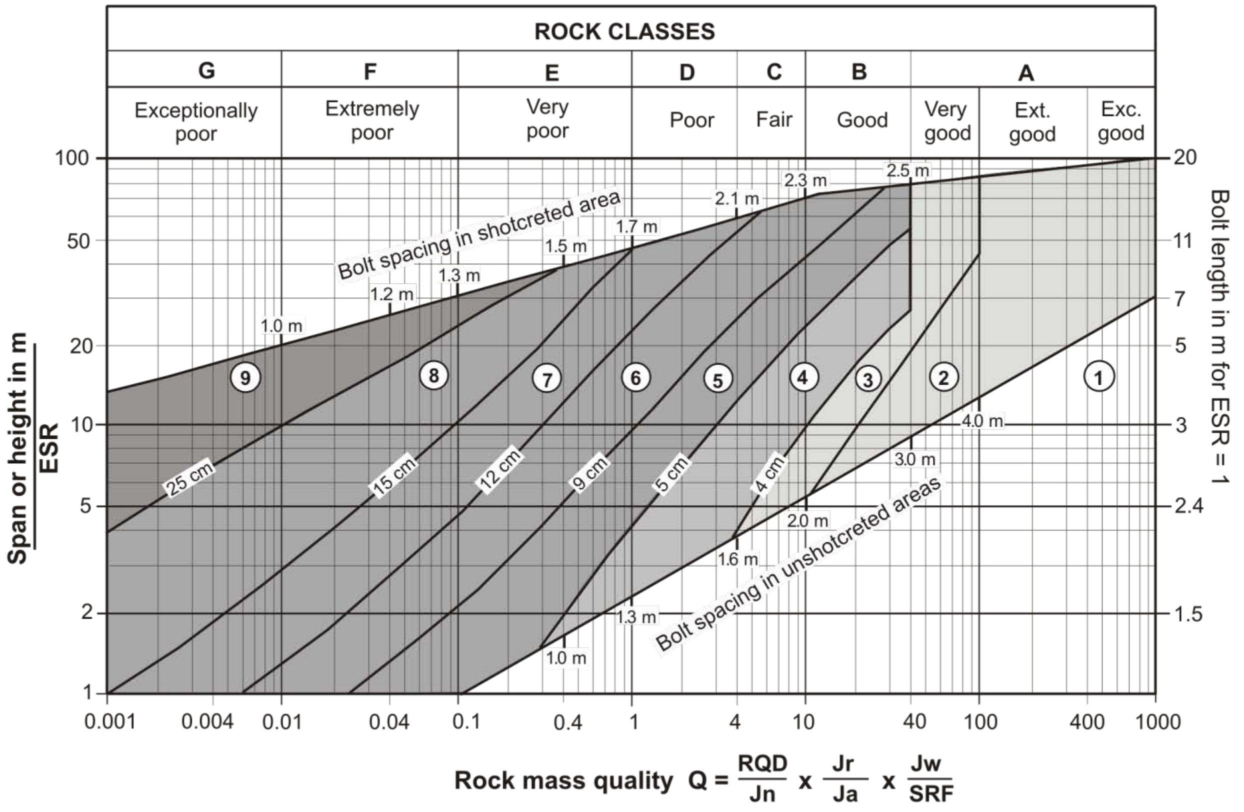
Ground mass class	Excavation	Support		
		Rock bolts (20 mm diam., fully bonded)	Shotcrete	Steel sets
1.Very good rock RMR: 81-100	Full face: 3 m advance	Generally no support required except for occasional spot bolting		
2.Good rock RMR: 61-80	Full face: 1.0-1.5 m advance; Complete support 20 m from face	Locally bolts in crown, 3 m long, spaced 2.5 m with occasional wire mesh	50 mm in crown where required	None
3.Fair rock RMR: 41-60	Top heading and bench: 1.5-3 m advance in top heading; Commence support after each blast; Commence support 10 m from face	Systematic bolts 4 m long, spaced 1.5-2 m in crown and walls with wire mesh in crown	50-100 mm in crown, and 30 mm in sides	None
4.Poor rock RMR: 21-40	Top heading and bench: 1.0-1.5 m advance in top heading; Install support concurrently with excavation - 10 m from face	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh	100-150 mm in crown and 100 mm in sides	Light ribs spaced 1.5 m where required
5.Very poor rock RMR < 21	Multiple drifts: 0.5-1.5 m advance in top heading; Install support concurrently with excavation; shotcrete as soon as possible after blasting	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert	150-200 mm in crown, 150 mm in sides, and 50 mm on face	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert

Note: Applies to tunnels with 10m span width

Appendix 5. The support chart used in the Q_{1993} system

The Excavation Support Ratio, ESR

Type of excavation	ESR
Temporary mine openings.	3 - 5
Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks), pilot tunnels, drifts and headings for large excavations.	1.6
Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels.	1.3
Power stations, major road and railway tunnels, civil defence chambers, portal intersections.	1.0
Underground nuclear power stations, railway stations, sports and public facilities, factories.	0.8

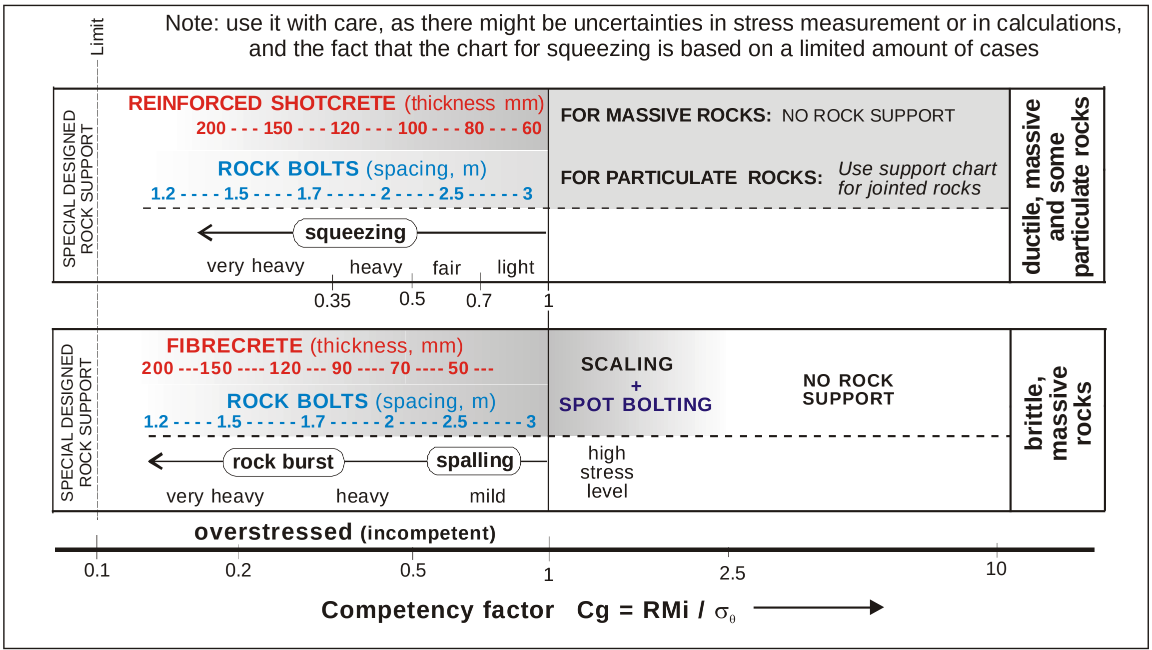


REINFORCEMENT CATEGORIES:

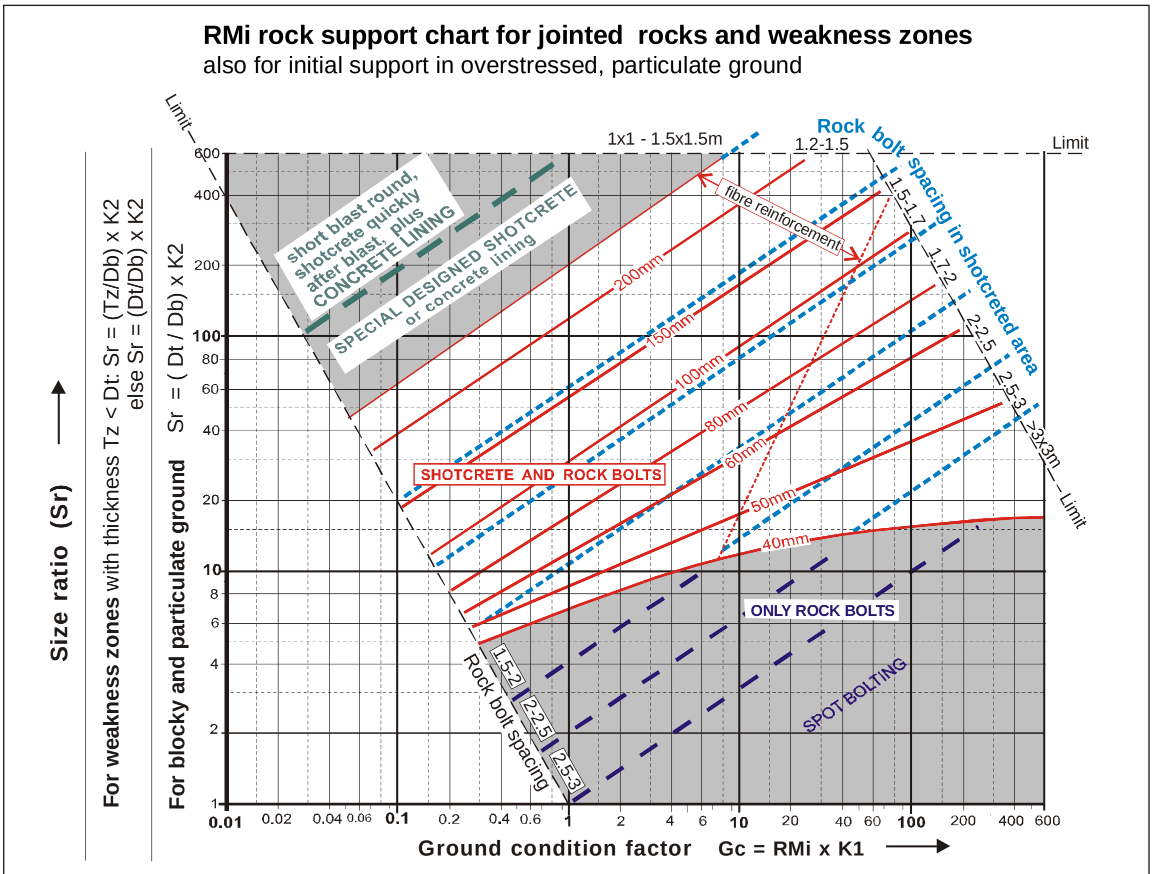
1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting, (and unreinforced shotcrete, 4 - 10 cm)
5) Fibre reinforced shotcrete and bolting, 5 - 9 cm
6) Fibre reinforced shotcrete and bolting, 9- 12 cm
7) Fibre reinforced shotcrete and bolting, 12 - 15 cm
8) Fibre reinforced shotcrete, > 15 cm, reinforced ribs of shotcrete and bolting
9) Cast concrete lining

The Q support chart for various sizes of underground excavations

6. The support charts used in the RMi support method



The RMi support chart for ground with stress problems



Dt = diameter of tunnel (span or wall height)
Db = diameter of representative rock block
Tz = thickness (width) of weakness zones
K1 and K2 are adjustment factors

K1 = SL x C x GW x IL
(SL = stress level; C = factor for roof vs. wall; GW = water inflow; IL = interlocking of rockmass structure))

K2 = (Co/ Nj) (Co = factor for orientation of joint set or weakness zone, Nj = factor for number of joint sets)

The RMi support chart for ground without stress problems

The input parameters with ratings used in the RMi calculation of rock support

GROUND WATER INFLOW, GW *)	
Dry excavation	GW = 1
Damp	
Wet	
Dripping *)	2.5
Gushing *)	5
Flowing, decaying with time	Outside limit of RMi
Heavily flowing, without noticeable decay	

*) *GW is related to groundwater's influence on rockmass stability*

INCLINATION OF TUNNEL SURFACE, C	
Horizontal (roof)	C = 1
30° inclination (roof in shaft)	1.5
45° inclination (roof in shaft)	2.2
60° inclination (roof in shaft)	3
Vertical (and steep walls)	5

STRESS LEVEL, SL		
Very low (in portals, etc.)	(overburden < 10 m)	SL = 0.1
Low	(overburden 10 - 35 m)	0.5
Moderate	(overburden 35 - 350 m)	1
High	(overburden > 350 m)	1.5 *)

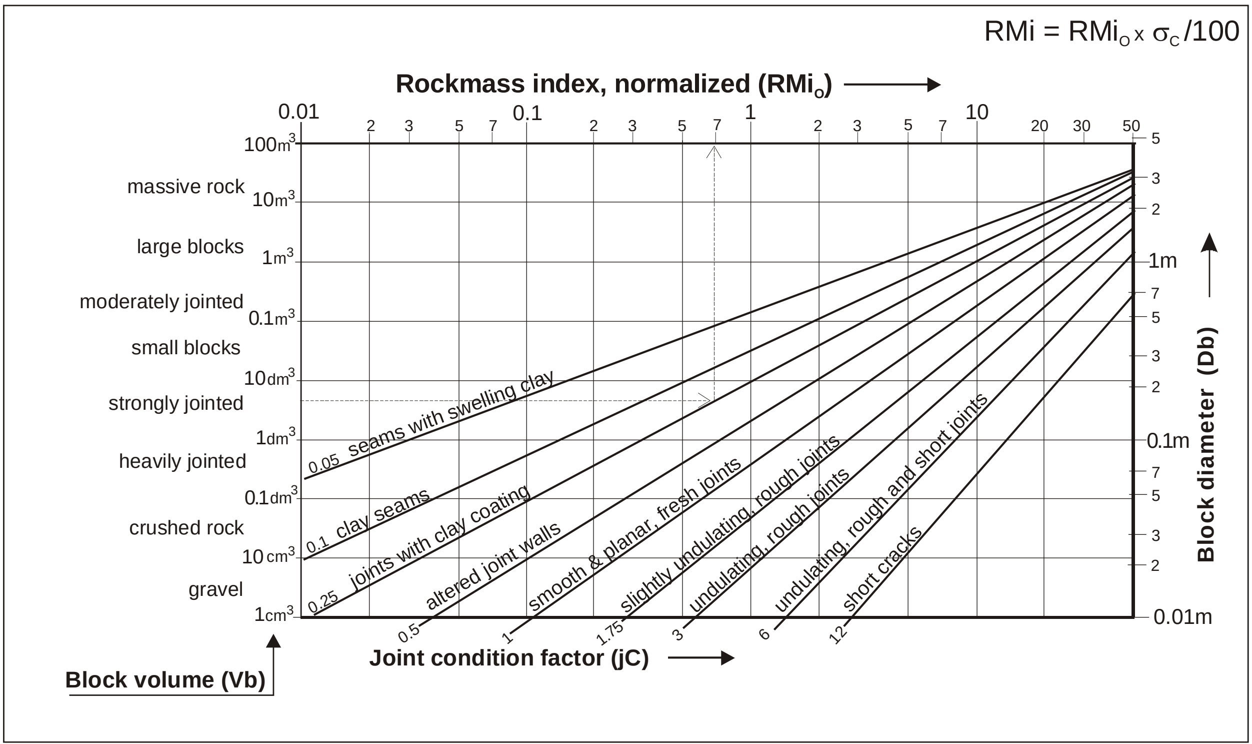
*) For stability in high *walls* a high stress level may be unfavourable. Possible rating, SL = 0.5 - 0.75

NUMBER OF JOINT SETS, Nj *)			
One set	Nj = 3	Three sets	Nj = 1
One set + random	2	Three sets + random	0.85
Two sets	1.5	Four sets	0.75
Two sets + random	1.2	Four sets + random	0.65

*) Means the number of joint sets, in the actual location only

ORIENTATION OF JOINTS AND ZONES, Co (related to the tunnel)			
Very favourable	Co = 1	Unfavourable	Co = 2
Favourable		Very unfavourable	3
Fair	1.5		

Appendix 7. Graphical method to easily estimate the RMi value



Example shown: Strongly jointed rock (Vb = 5 dm3) with coated joints (jC = 0.25) gives RMi_o = 0.7. With a uniaxial rock strength of σ_c = 150MPa, RMi = 1.05