COMPARING THE RMR, Q, AND RMi CLASSIFICATION SYSTEMS

PART 1: COMBINING THE INPUT PARAMETERS USED IN THE THREE SYSTEMS

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The main rockmass classification systems make use of similar rockmass parameters. It is therefore possible to combine the input parameters to three of the systems in a set of common parameter tables. This enables the ground quality to be found directly in these systems from only one set of input parameters. Thus, the estimated rock support found in one system can be easily be compared and checked in the other systems. This leads to more reliable rock support estimates, provided the actual ground is within the limitations of the systems and that the ground characterization is properly made.

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 (Rock Mass Rating) systems, use some of 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 properties 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.

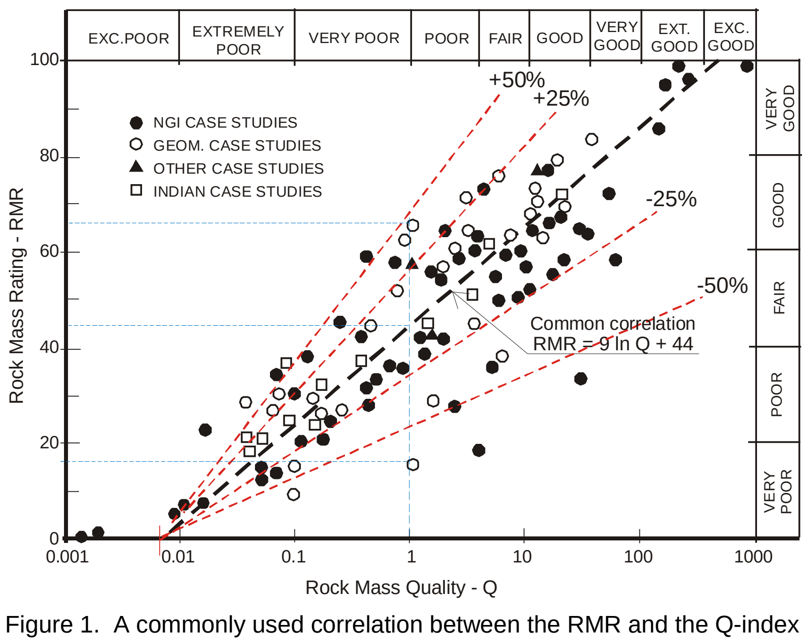

Figure 1. A commonly used correlation between the RMR and the Q-index where deviations from the common correlation are shown. As seen, for Q = 1, RMR varies from less than 20 to 66. Note that the Q system applies logarithmic scale while RMR has a linear scale (revised after Bieniawski, 1976).

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 (or 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, the equation used here 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, which may lead to wrong decisions. Another error may be imposed from the fact that the two systems have different limitations. The paper "Classification as a tool in rock engineering" (Stille and Palmström, 2003) outlines some other limitations in classification systems.

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

The RMR system was first published by Bieniawski in 1973, while the Q system was first described by Barton et al. in 1974. 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.

2.1 The RMR system

Significant revisions to the RMR system have been made in 1974, 1975, 1976, and 1989; of these the 1976 and the 1989 versions of the classification system are mostly used. The RMR value is found from

$$RMR = A1 + A2 + A3 + A4 + A5 + B$$

where
A1 = rating for the uniaxial compressive strength of the rock material; A2 = rating for the RQD; A3 = rating for the spacings of joints; A4 = rating for the condition of joints; A5 = rating for the ground water conditions; and B = rating for the orientation of joints.

From the value of RMR in the actual excavation, the rock support can be estimated from an excavation and support table (for tunnels of 10m span). Bieniawski (1989) strongly emphasises that a great deal of judgement is used in the application of rock mass classification in support design.

<u>Limits</u>
It is no input parameter for rocks stresses in the RMR system, but stresses up to 25MPa are included. Thus, overstressing (rock bursting, squeezing) is not covered. Whether or how faults and weakness zones are included, is unclear. No parameters for such features are 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.

2.2 The Q system

The Q system for estimating rock support in tunnels is based on a large database of tunnel projects. The value of Q is defined by six parameters combined in the following equation:

$$Q = RQD/Jn \times Jr/Ja \times Jw/SRF$$

where
RQD = the actual values of RQD; Jn = rating for the number of joint sets; Jr = rating for the joint roughness; Ja = rating for the joint alteration, Jw = rating for the joint or ground water, and SRF = rating for the rockmass stress situation.

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.

<u>Limits</u>
As pointed out by Palmstrom and Broch (2006) the Q system has some limits. It is 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 conditions. The same is the case for weakness zones; especially where swelling ground occurs.

2.3 The RMi and the RMi rock support method

2.3.1 The RMi rockmass classification

After the rock mass index (RMi) was first presented in 1995, it 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 can thus be compared with the GSI value. The RMi value is applied as the input to estimate rock support and also as input to other rock engineering methods.

The RMi system has some input parameters similar to those of the Q-system. Thus, the joint and the jointing features are almost the same. RMi 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 *discontinuous* ground (jointed rock) the RMi makes use of the uniaxial compressive strength of intact rock (σ_c) and the reducing effect of the joints penetrating the rock (JP) given as

$$RMi = \sigma_c \times JP \times IL$$

where
σ_c = uniaxial compressive strength of the intact rock, and IL = interlocking factor of the rockmass[1]. 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:

$$JP = 0.2\sqrt{jC} \times Vb^D \qquad (D = 0.37\ jC^{-0.2})$$

where
$jC = jR \times jL/jA$ (jR = the joint roughness, jA = the joint alteration, and jL = the joint length)

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

$RMi = \sigma_c \times f_\sigma \times IL$ (applied for cases where $f_\sigma < JP$), i.e. for Vb > approx. 5.5m³)

Here, f_σ is called the massivity parameter, given as $f_\sigma = (0.05/Db)^{0.2}$ (Db = block diameter). In most cases $f_\sigma \approx 0.5$

The basic RMi value does not include the influence from rock stresses and ground water. This parameter is included in the Gc = the ground condition factor, as shown below.

2.3.2 The RMi rock support

The RMi method for rock support applies different equations whether the rock mass is *jointed* (discontinuous) or it is *continuous*. The latter is where excavation problems from overstressing may take place. In addition to these two, an equation for weakness zones is included as shown in the following.

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 $Gc = RMi \times SL \times GW$

The ground condition factor is combined in the support chart together with the

Geometrical or size ratio $Sr = Dt/Db \times Co/Nj$

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.

For weakness zones, the thickness (Tz) of the zone is used in the geometrical ratio Sr = Tz/Dt Coz/Nj in cases where Tz < Dt (instead of the tunnel diameter (Dt)). For larger zones $Sr = Dt/Db \times Co/Nj$ as for jointed rock.

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[1] The effect of interlocking or compactness of the rockmass structure, similar to the interlocking in GSI system, has now been included in the RMi system

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

$$Cg = \text{rockmass strength/tangential stress} = RMi/\sigma_\theta$$

Limits

The RMi system is best applied in 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 RMi applies separate calculations for overstressed, continuous ground, RMi should be applied with care in squeezing ground.

2.4 Differences between the three classification 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 is found from addition of the input parameter ratings;
   - Q is calculated through multiplication and division of the input parameters values;
   - RMi is found from a combination of multiplication and exponential calculation of the input parameter values.
2. The support is found in different ways from the calculated ground quality:
   - In the RMR system from a table for 10m wide tunnels;
   - In the Q system from a chart where the Q value (ground quality) and the tunnel dimensions (span or wall height) is used;
   - In the RMi system the support estimates divide between:
     a) Jointed rocks and weakness zones, where a chart for the ground conditions (quality) and the geometrical ratio (tunnel size and block size) is combined.
     b) Massive rocks and particulate rocks, where the system makes use of the estimated tangential stress 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, Qc seems to be applied rather seldom 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, buckling, squeezing)
5. Weakness zones are characterized differently in the three systems. In the RMR, no special input parameter is used; the Q applies a classification based on composition and depth of the zone; in the RMi the size (thickness) of the zone is used.

3. COMBINATION OF THE INPUT PARAMETERS APPLIED IN THE THREE CLASSIFICATION SYSTEMS

3.1 The input parameters used in the 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 related to excavation by drilling and blasting.

All three systems estimate the rock support based on the instability of the actual area to be supported in the tunnel. That is mostly the roof and/or walls over a length of one blast round or two, i.e. some 3 – 6m length along the tunnel. For a 5m wide tunnel this area is 15 – 30m². During characterization and description of the ground, it is important to be aware of this, especially when the parameter for the number of joint sets is selected.

Often, the input of this parameter is given a higher rating than what is relevant, because also joint sets outside the actual area are counted for.

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

INPUT PARAMETERS		UNIT	The symbols used in:		
PARAMETER	CLASSIFICATION		RMR[1989]	Q	RMi
ROCK(S)	A. Uniaxial compressive strength of intact rock	rating//value(MPa)	A1	1)	σ_c
DEGREE OF JOINTING	B1. (RQD or block volume)	rating//value (%)	A2	RQD	-
	B2. Block volume	value (m³)	-	-	Vb
	B3. Average joint spacing	rating	A3	-	-
JOINTING PATTERN	C1. Number of joint sets (at the actual location)	rating	-	Jn	Nj
	C2. Orientation of main joint set	rating	B		Co
JOINT CHARAC-TERISTICS	D1. Joint smoothness (Joint roughness in Q and RMi systems)	rating	A4c	Jr 2)	jR 2): js
	D2. Joint waviness (Joint roughness in Q and RMi systems)	rating	-		jw
	D3. Joint alteration (weathering and filling)	rating	A4e	Ja	jA
	D4. Joint size (length)	rating	A4a	-	jL
	D5. Joint persistence (continuity)	rating		-	cj
	D6. Joint separation (aperture)	rating	A4b	-	
INTERLOCKING 4)	E. Compactness of rockmass structure	rating	-	-	IL
GROUND WATER	F. Water inflow or water pressure	rating	A5	Jw	GW
ROCK STRESSES (around tunnel)	G1. Stress level	rating	-	SRF	SL
	G2. Overstressing (rock burst or squeezing ground)	rating	-		CF 3)
WEAKNESS ZONE	H1. Type of weakness zone	rating	-		-
	H2. Size (thickness) of the zone	value (m)	-	-	Tz
	H3. 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.
4) The effect of interlocking of the rockmass structure, is here included in the RMi.

3.2 Some comments to the input parameters

3.2.1 Ground water features

All three systems apply input for water, but the characterization and application are somewhat different. The reason is that the recommended rock support in the RMR and Q may not be relevant where large water inflows occur, as the use of shotcrete (sprayed concrete) is difficult or not suitable in flowing water. In such cases, the working conditions often require other works, such as grouting, before the rock support can be installed. These works will reduce the inflow and hence result in revised lower input parameter for water, see table F in Table 2. Therefore, the RMi system preferably uses the influence of water on stability limited to gushing inflow. Water pressure has often special influence on the tunnelling conditions and should in such cases be handled separately and outside the ordinary classification systems.

3.2.2 Rock stress parameters

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

Stresses are applied differently in the three classification systems, as can be seen in Table 2. RMR has, as mentioned earlier, no input for stress related problems. In the Q system, the stress input is given in the SRF factor. SRF is divided in three groups: 1) no stress problems; 2) overstressing in massive, brittle rock; 3) overstressing where squeezing may take place. In addition, SRF covers the occurrence of weakness zones (see next section). In the RMi system, the stress level is used in blocky ground; in continuous ground the calculated stresses are compared with the strength of the ground in the *competency of the ground* (Cg).

3.2.3 Weakness zone parameters

According to definition, *weakness zone* is a structure, layer or zone in the ground in which the mechanical properties are significantly lower than those of the surrounding rock mass. Weakness zones can be faults, shears

/ shear zones, thrust zones, weak mineral layers, etc., and may have sizes from less than a metre to some tens of metres. (Being larger than that, it should not be regarded a zone, but a layer or formation.)

Weakness zones (faults, etc.) are applied differently in the three systems. The Q system applies the SRF (stress reduction factor) values for some specified types of weakness zones, but it does not have an input for the size of the zone. RMi applies the thickness (size) of the zone, while RMR has no special parameter for weakness zones.

In the opinion of the author, it is difficult to include the many variable conditions 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.

4. COMBINING THE INPUT PARAMETERS OF THE THREE CLASSIFICATION SYSTEMS

Table 2 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 used. 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 or rating for most of them. Note that swelling is not included in Table 2 (except in the joint alteration number, Ja, in the Q system).

In Part 2, two examples will show how the RMR, Q and RMi values are found from the input parameters given in Table 2, together with comparisons of the estimated rock support. In addition, correlation figures of the three classification systems will be presented.

Table 2. The combined input values of the ground parameters. The input symbols can preferably be used in spreadsheets. For some parameters both symbol and the actual value (strength, size, etc.) of the parameter is applied

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

B. DEGREE OF JOINTING		**input symbol**	**RMR**	**Q**	**RMi**
B1. Rock quality designation (RQD)			A2 =	RQD =	-
Very good	RQD = 90 - 100	a //value	20	*Use actual RQD value (min RQD = 10)*	*Not included*
Good	75 - 90	b//value	17		
Fair	50 - 75	c//value	13		
Poor	25 - 50	d//value	8		
Very poor	< 25	e//value	5		
An approximate correlation between RQD and Jv is: RQD = 110 – 2.5Jv (or the older RQD = 115 – 3.3Jv)					
B2. Block size			-	-	Vb =
Block volume (Vb)		value	*Not included*	*Not included*	*Use actual value of Vb (in m³)*
The block volume can crudely be calculated from the Jv: $Vb = \beta \times Jv^{-3}$ For cubical block shapes β = 27-32; for slightly long or flat blocks β = 32 – 50; for long or flat blocks β = 50 – 100; for very long or flat blocks β = 100 - 500					
B3. Joint spacing			A3 = [1)]	-	-
Very large spacing	Spacing >2m	a	20	*Not included*	*Not included*
Large spacing	0.6 - 2m	b	15		
Moderate spacing	200 - 600mm	c	10		
Small spacing	60 - 200mm	d	8		
Very small spacing	< 60mm	e	5		
[1)] Where more than one joint set occurs, the rating for the smallest spacing should be applied					

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

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

2)Joint roughness number Jr = js x jw *Note: Jr = js x jw = 1 for filled joints*

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

Filled joints *(t = joint thickness)*		A4d =		Ja =		jA =	
		t < 5mm	t > 5mm	wall contact [3)]	no wall contact [4)]	t < 5mm	t > 5mm
No filling	g	6	-	-	-	-	-
Friction materials (silt, sand, etc.)	h // i	5	2	4	8	4	8
Hard, cohesive materials (clay, talc, chlorite)	j // k	4	2	6	8	6	8
Soft, cohesive materials (soft clay)	l // m	2	0	8	12	8	12
Swelling clay materials	n // o	0	0	10	18	10	18

3) Wall contact before 10cm shear; 4) 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 =
Crack [5)] (irregular break)	Length < ~0.3m	a	8	*Not included*	5
Parting (very short, thin joint)	< 1m	b	6		3
Very short joint	0.3 – 1m	c			2
Short joint	1 – 3m	d	4		1.5
Medium joint	3 – 10m	e	2		1
Long joint	10 – 30m [6)]	f	1		0.75
Filled joint, or seam [7)]	> 10m	g	0		0.5

5) "Crack" has been introduced in this table; 6) Length 10 – 20 m is applied in the RMR; 7) Used in cases where most joints in the location are filled

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

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

F. GROUND WATER CONDITIONS		**input symbol**	**RMR**	**Q**	**RMi**
Water inflow to tunnel or water pressure (p_w)			A5 =	Jw =	GW =
Dry excavation	$p_w < 1$ kg/cm²	a	15	1	1
Damp	$p_w = 1\text{-}2.5$ kg/cm²	b	10		
Wet		c	7	0.66	
Dripping	$p_w = 2.5\text{-}10$ kg/cm²	d	4	0.5	2.5
Gushing		e		0.3	5
Flowing, decaying with time	$p_w > 10$ kg/cm²	f	0	0.15	Outside limit of RMi
Large, continuous inflow		g		0.08	
NOTE! GW – is related to groundwater's influence on rockmass stability					

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

H. WEAKNESS ZONES (faults, etc.) [8]		**input symbol**	**RMR**	**Q**	**RMi**
H1. Type of weakness zone			-	SRF =	-
Multiple weakness zones	any depth	j	*Weakness zones and shears are not explicitly included in RMR*	10	*Weakness zones and shears are not explicitly included in RMi*
Single weakness zone	depth < 50m	k		5	
	depth > 50m	l		2.5	
Multiple shear zones	any depth	m		7.5	
Single shear zone	depth < 50m	n		5	
	depth > 50m	o		2.5	
Loose, open joints	any depth	p		5	
Heavily jointed ("sugar cube")	any depth	q		5	
H2. Size of the zone			-	-	Tz =
Thickness or width of the zone (Tz)		value	*Not included*	*Not included*	*Use the width of zone(in metres)*
H3. Orientation of zone related to excavation			-	-	Coz =
Very favourable		a	*Not included*	*Not included*	1
Favourable		b			1
Fair		c			1.5
Unfavourable		d			2
Very unfavourable		e			3

[8] *Most weakness zones should be especially evaluated, together with the use of engineering judgement*