COMPARING THE RMR, Q, AND RMi CLASSIFICATION SYSTEMS

PART 2: CORRELATIONS OF THE THREE SYSTEMS

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In Part 1, it was shown how the input parameters to the three classification systems can be combined into one set of parameters, common to all of them. In Part 2, two examples are shown how the values of the combined input parameters are found and used. In addition, correlations between the three systems are shown, which gives a better understanding of the relations between these classification systems and hopefully better use of these classification systems.

1. INTRODUCTION

A spreadsheet has been worked out to easily find the RMR, Q and RMi values from the set of combined parameters shown in Part 1. This has been used to work out comparisons between the three systems, which are described here in Part 2.

2. TWO WORKED EXAMPLES

The practical use of the combined input 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.

2.1 Example 1: A tunnel in ***moderately jointed rock***

In a 10m wide road 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 relative to the tunnel. In addition, some random joints occur. Average degree of jointing is: RQD = 85, block volume Vb = 0.1 m^3, joint spacing S = 0.2 – 0.4m. The fresh, continuous joints of the main set (which are used as input) are rough & planar, tight and mostly longer than 3m. It is "damp" water condition, and 100m rock overburden, i.e. medium stress level. Based on this the Q, RMR and RMi input values together with the estimated rock support are shown in Table 3.

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

Table 1. Example 1 with ratings of the various input parameters found with estimated rock support

Example 1: Moderately jointed rockmass			Input symbol	Values or ratings used 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
Calculated 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							
Rock bolt spacing				2.5m		2.5m	2.5 – 3m
Shotcrete thickness				50mm *)		-	40 - 50mm
*) where required							

2.2 Example 2: A tunnel in *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 foliation joints with coating of mica and/or chlorite are often longer than 3m. In addition to these, 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 rock block volumes of Vb = 0.0005 – 0.005m³ (average Vb = 0.001m³ is used here). The RQD = 10 and the 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 long 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 long blast rounds and support by thick shotcrete (fibre reinforced) and dense rock bolting were partly used.

As seen from Table 2, none of the systems indicate concrete lining. The Q system prescribes less rock support than what was found necessary during excavation, while the RMR system estimates steel ribs where required, which in the tunnel were replaced by concrete lining.

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

<table>
<tr><td colspan="4">Example 2: Highly jointed rockmass</td><td rowspan="2">Rating symbol</td><td colspan="4">Values or ratings used in:</td></tr>
<tr><td colspan="4">INPUT PARAMETERS</td><td colspan="2">RMR</td><td>Q</td><td>RMi</td></tr>
<tr><td>A. ROCK</td><td colspan="3">A1. Uniaxial compressive strength</td><td>e //value</td><td colspan="2">A1 = 7</td><td>-</td><td>σ_c = 100MPa</td></tr>
<tr><td rowspan="3">B. DEGREE OF JOINTING</td><td colspan="3">B1. RQD</td><td>e //value</td><td colspan="2">A2 = 5</td><td>RQD = 10</td><td>-</td></tr>
<tr><td colspan="3">B2. Block size</td><td>value</td><td colspan="2">-</td><td>-</td><td>$Vb = 0.001m^3$</td></tr>
<tr><td colspan="3">B3. Average joint spacing</td><td>d</td><td colspan="2">A3 = 8</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">C. JOINTING PATTERN</td><td colspan="3">C1. Number of joint sets</td><td>e</td><td colspan="2">-</td><td>Jn = 6</td><td>Nj = 1.2</td></tr>
<tr><td colspan="3">C2. Orientation of main joint set (in roof)</td><td>c</td><td colspan="2">B = -5</td><td>-</td><td>Co = 1.5</td></tr>
<tr><td rowspan="6">D. JOINT CHARAC-TERISTICS</td><td>D1. Smoothness</td><td colspan="2" rowspan="2">joint roughness</td><td>d</td><td>A4c = 1</td><td rowspan="6">A4 = 13</td><td rowspan="2">Jr = js × jw = 1</td><td>js = 1</td></tr>
<tr><td>D2. Undulation</td><td>e</td><td>-</td><td>jw = 1</td></tr>
<tr><td rowspan="2">D3. Joint alteration</td><td colspan="2">weathering</td><td rowspan="2">f</td><td>A4e = 0</td><td rowspan="2">Ja = 3</td><td rowspan="2">jA = 3</td></tr>
<tr><td colspan="2">filling</td><td>A4d = 6</td></tr>
<tr><td colspan="3">D4. Joint size or persistence</td><td>e</td><td>A4a = 2</td><td>-</td><td>jL = 1</td></tr>
<tr><td colspan="3">D5. Joint separation (aperture)</td><td>c</td><td>A4b = 4</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">E. INTERLOCKING OF ROCKMASS</td><td>b</td><td colspan="2">-</td><td>-</td><td>IL = 1</td></tr>
<tr><td colspan="4">F. GROUND WATER</td><td>c</td><td colspan="2">A5 = 7</td><td>Jw = 0.66</td><td>GW = 1</td></tr>
<tr><td colspan="4">G. STRESSES AROUND TUNNEL</td><td>c</td><td colspan="2">-</td><td>SRF = 1</td><td>SL = 1</td></tr>
<tr><td colspan="5" rowspan="2">Calculated parameters for support evaluation →</td><td colspan="2">RMR = 35</td><td>Span/ESR = 10
Q = 0.28</td><td>Sr = 75
Gc = 0.34</td></tr>
<tr><td colspan="2">poor</td><td>very poor</td><td>very poor</td></tr>
<tr><td colspan="5">Rock support, in roof</td><td colspan="2">RMR</td><td>Q</td><td>RMi</td></tr>
<tr><td colspan="5">Rock bolt spacing</td><td colspan="2">1 - 1.5</td><td>1.4 m</td><td>1.2 – 1.5m</td></tr>
<tr><td colspan="5">Shotcrete thickness</td><td colspan="2">100 – 150mm</td><td>100 – 150mm</td><td>200mm</td></tr>
<tr><td colspan="5">Additional support</td><td colspan="2">Light steel ribs spaced 1.5m where required</td><td></td><td></td></tr>
</table>

3. COMPARISON BETWEEN THE THREE CLASSIFICATION SYSTEMS

The computer spreadsheet used to estimate the values in all the tree systems has been based on the combined input parameters in Part 1[1]. By using this spreadsheet, it is easy to calculate the corresponding ground qualities in the three classification systems from the set of 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. As overstressing (rock burst and squeezing) is not well covered in the RMR system, this feature is not used in the comparisons.

Figure 2 shows the results from comparisons found. It shows the same trend as Figure 1 of Part 1 shows, that there may be large inaccuracies from the average correlation equation between the values found for RMR and Q, often ± 30 - 50%.

The figure further shows that it is generally a 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. It further shows that weakness zones are poorly covered by the commonly used correlation equation (see Figure 1 in Part 1) between Q and RMR.

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

[1] The Excel spreadsheet used can be downloaded from www.rockmass.net.

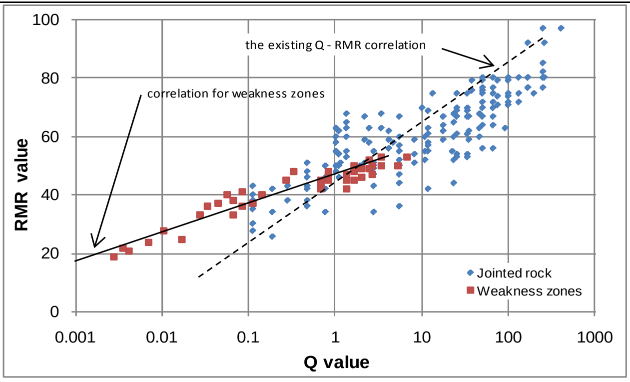

Figure 1. Comparison between the RMR and Q systems

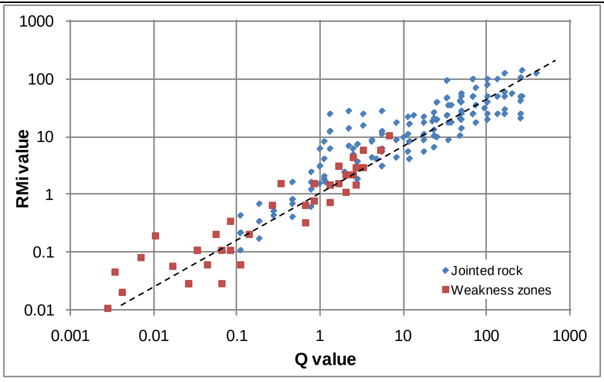

Figure 2. Comparison between the Q and RMi systems

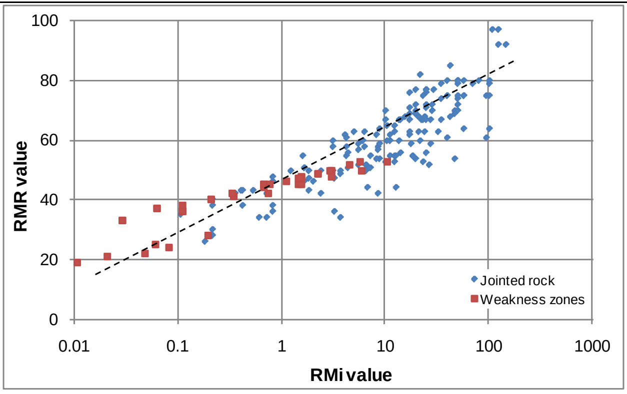

Figure 3. Comparison between the RMR and RMi systems

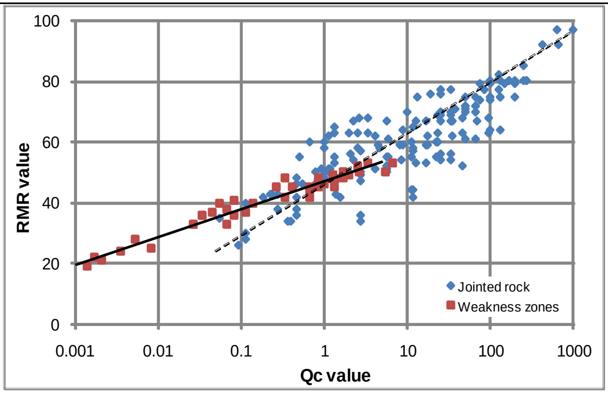

Figure 4. Comparison between the Qc and RMR systems

4. CONCLUSIONS

The use of two or more classification systems in design and rock engineering, gives a check of the estimates made. Though there are many similarities between the RMR, Q and RMi classification systems, the differences in their structure cause that the commonly used correlation equations between them (Figure 1 in Part 1) can lead to severe errors. Significantly more reliable values of the RMR, Q and RMi are found using the combined input values shown in Part 1 to find the RMR, Q and RMi values independently. With a spreadsheet the calculations can be easily done.

All three systems work best in blocky ground in which the degree of jointing (i.e. RQD, block size or joint spacing) is often the input parameter with the strongest influence on stability. 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 other input parameters and automatically used when no information of these 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 known and are used.

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) caused by the inaccuracy in the RQD measurement and its limits to characterize massive rock and highly jointed rock;

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

Barton and Bieniawski 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. Being easy to use they may also be easily misused by inexperienced people.

All three classification systems estimate rock support for tunnel excavation by drilling and blasting. The (total) rock support found in the two examples shows that the RMi system predict somewhat more support than RMR and Q. This is also the experience from practical applications of the Q and RMi systems. A reason for this is that the RMi system was developed later than the two others and has included the increasing requirements towards safer working conditions, i.e. stronger rock support.

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