RMR and Q - Setting records

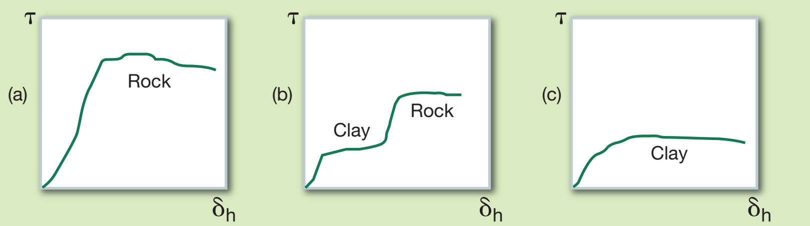
After 35 years of use throughout the tunnelling world, the RMR and Q classifications have proved themselves on numerous projects. They still face misconceptions however, as reflected in recent articles in T&T International. Here, Nick Barton, of Nick Barton & Associates, Norway, and ZT Bieniawski, of Bieniawski Design Enterprises, USA, clear common misunderstandings and provide the "ten commandments" for proper use of these rock mass classification systems

The RMR and Q rock mass classifications were independent developments in 1973 and 1974, whose common purpose was to quantify rock mass characteristics previously based on qualitative geological descriptions. They were originally developed for assisting with the rock engineering design of tunnels.

The value of thorough geological exploration was never disputed, indeed it was always emphasised. In addition, it was repeatedly stated that these classification systems were not "cookbooks" but had to be used for the purpose for which they were developed, as part of the engineering design process. This is clearly an iterative procedure in the case of underground works, where detailed knowledge of the ground develops from day to day.

At the time of the development of RMR and Q, geologists often worked in separate teams from those of engineers, leading to potential misunderstanding of what was required by whom, for engineering purposes. In fact, the advent of our rock mass classifications seems to have stimulated an opportunity to combine the efforts of engineers and geologists to act as one team, with clear statements of basic tunnel engineering needs and some carefully selected and quantitative geological data requirements. Needless to say, neither the engineering nor the geological parameters involved when using the two systems are exhaustive specifications in either the RMR or Q systems.

In essence, geologists should not be 'afraid' of quantified RMR and Q parameter ratings. The need for such quantification is perhaps appreciated more by certified engineering geologists who, although in short supply, do set an example to the traditional geologists, who are more the 'free spirits' of these basic earth science disciplines. Alas, the geological profession, even today, is not always in agreement on the scope of competence needed by engineering geologists.



	Jr							
(a) Rock wall contact		(thin coatings)						
	Ja =	0.75	1.0	2	3	4		
	Jr	tan⁻¹ (Jr/Ja)°						
A. Discontinuous joints	4	79°	76°	63°	53°	45°		
B. Rough, undulating	3	76°	72°	56°	45°	37°		
C. Smooth, undulating	2	69°	63°	45°	34°	27°		
D. Slickensided, undulating	1.5	63°	56°	37°	27°	21°		
E. Rough, planar	1.5	63°	56°	37°	27°	21°		
F. Smooth, planar	1.0	53°	45°	27°	18°	14°		
G. Slickensided, planar	0.5	34°	27°	14°	9.5°	7.1°		
(b) Rock wall contact when sheared		(thin fillings)						
	Ja =	4	6	8	12			
	Jr	tan⁻¹ (Jr/Ja)°						
A. Discontinuous joints	4	45°	34°	27°	18°			
B. Rough, undulating	3	37°	27°	21°	14°			
C. Smooth, undulating	2	27°	18°	14°	9.5°			
D. Slickensided, undulating	1.5	21°	14°	11°	7.1°			
E. Rough, planar	1.5	21°	14°	11°	7.1°			
F. Smooth, planar	1.0	14°	9.5°	7.1°	4.7°			
G. Slickensided, planar	0.5	7°	4.7°	3.6°	2.4°			
(c) No rock wall contact when sheared		(thick fillings)						
	Ja =	5	6	8	12	13	16	20
	Jr	tan⁻¹ (Jr/Ja)°						
Nominal roughness of discontinuity rock walls	1.0	11.3°	9.5°	7.1°	4.8ª	4.4°	3.6°	2.9ª

Above: Fig 1 - The parameters Jr and Ja are clearly related with 'rock behaviour', despite Goodman's reference to Riedmüller's doubts on this score. Other parameters used in RMR and Q are also clearly related to rock behaviour

The scope of RMR and Q systems

The RMR and Q systems are particularly well suited in the planning stage of a tunnelling project when a preliminary assessment of the most likely tunnel support requirements is required, based on core logging, field mapping, and refraction seismics. In the case of plans for cavern construction, even details of location may be influenced by the results. During construction, application becomes even more essential, as the appropriate support classes are selected on a day-by-day basis.

It is obviously incorrect to state they play no role during construction or final design, as those involved more frequently in tunnelling consultancy will surely acknowledge. The reasons for this are as follows:

1) RMR and Q originated, and have been specifically updated, for estimating tunnel support. Later[1,2,3,4] they were extended for assessing rock mass properties, such as the modulus of deformation, interpreting seismic velocities, and for assisting with the interpretation of monitoring during

straight

construction, via convergence-quality-tunnel-dimension links.

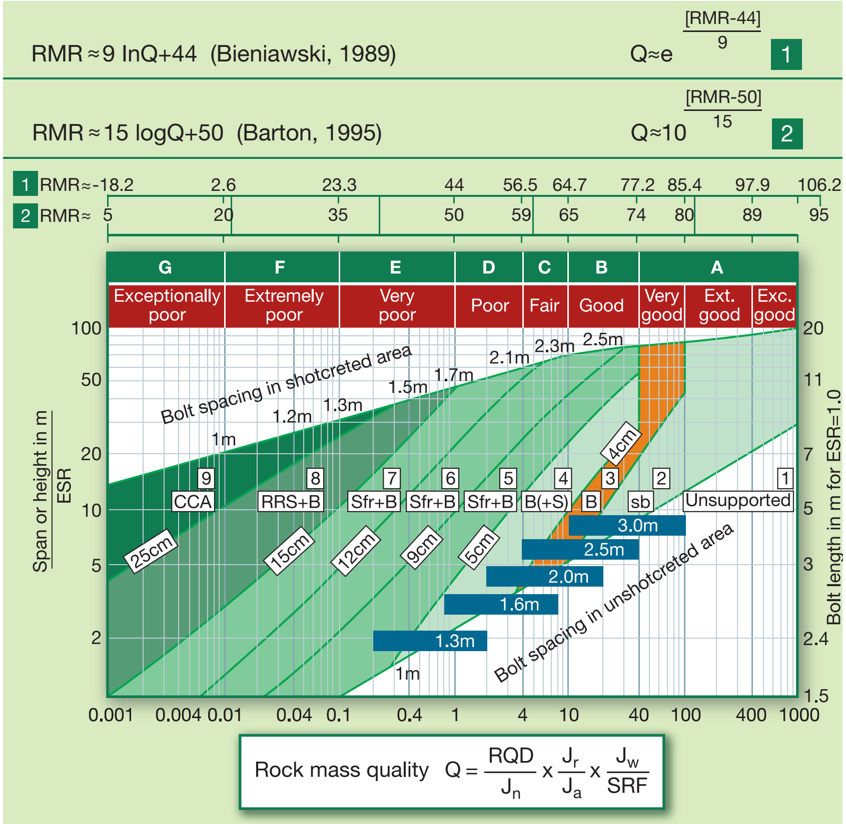
2) Estimating rock mass properties for numerical modelling has turned out to provide competitive alternatives to expensive and complex in situ tests, which rely on a number of assumptions for interpretation of the data. Significantly, plate bearing tests, large flat jack tests and pressure tunnel tests are nowdays rarely used because of their expense, and because of difficulties with disturbed zone phenomena. RMR and Q systems provide realistic estimates for modelling purposes, and through seismic measurement and interpretation[5], can assist in the interpretation of the disturbed zone characteristics.

3) Appropriate monitoring and recording of one or both rock mass classifications during construction is essential to quantify the encountered rock mass conditions, select the appropriate support class, and is useful in case of contractual disputes, arbitrations and design changes. Pells and Bertuzzi[6] will be aware of this, despite their preferred choice of applied mechanics beam theory for their tunnel and cavern design, apparently for seven of the nine Sydney cases they referred to from Australia. The support resulting from application of beam theory was reportedly heavier than stipulated by application of the Q-system, assuming that this was correctly applied. A further case record was used to criticise Q, where grouting of the rock bolts had been omitted, causing collapse in bedded sandstones: hardly a scientific approach for valid critique. Their reference[7], as supposedly supportive of their critique of Q, should be viewed with great care, since somewhat different agendas lie behind these two publications.

4) Technology has changed much in 35 years, hence support materials and methods must be modified. It is therefore that major updates have been made from time-to-time, such as the shift from mesh-reinforced to fibre-reinforced shotcrete[8,9] (see figure 2).

5) RMR and Q were found to be equally effective in very poor rock masses and in very good rock masses and it is incorrect to state that alternative descriptive methods might be preferable in poor rock mass conditions. As engineering geological techniques improve with advancing technology, our quantitative rating systems will always be preferable to qualitative descriptive assessments.

6) Finally, both Q and RMR now form the basis of new TBM performance prognoses, in the shape of Q_{TBM}[10] and RME[11], which are developing both supporters and critics, as is only to be expected, in our challenging work-place.



Above: Fig 2 - The support selection chart, from Grimstad and Barton[8] with the addition of alternate correlations between RMR and Q, from Barton[10]

Latest concerns

In spite of the above well-known facts, misconceptions and misuse of the RMR and Q systems surfaced in two recent articles in *T&TI*[6,12].

Goodman[12] paid respects to the late professor Riedmüller of Austria attributing to him the misgivings that: "...Engineers seem to be relying on generalised correlations of rock behaviour with rock mass ratings by Bieniawski's RMR and Barton's Q; yet the assignment of parameters is too schematic, the collection of data from exposures might not be adequately representative, and the assigned parameters are neither independent nor directly connected with rock behaviour."

We are not sure which tunnelling projects were the source of Riedmüller's related concerns that... "quite a number of international case studies show that the importance of geological surface investigations is underestimated… or reduced to collecting the input data for a rock mass classification to be used for estimating support requirements" ...The authors of the RMR and Q methods have so much interaction with geologist and structural geologist colleagues that we have no hesitation in sharing some of Riedmüller's concerns. Geological surface investigations should be, and we thought always were, the essential forerunner of 'data collection from exposures', and of course dictate the location of subsequent boreholes and the interpretation of characteristics observed and quantified when core logging.

When using RMR and Q during construction, as of course is required, Riedmüller's concern that 'exposures might not be adequately representative' is only a

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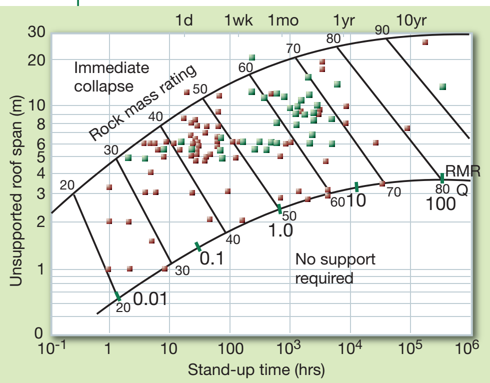
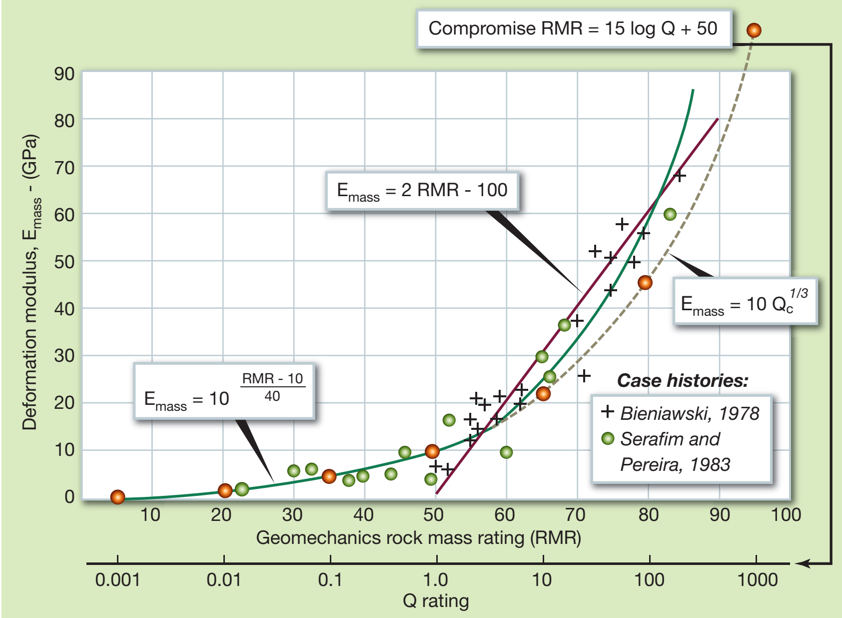
LORD KELVIN (1824-1907)



Aboce: Fig 3 - Stand up time data versus RMR from case histories after Bieniawski[2]. Conversion of RMR to Q after Barton[10]. Red represents tunnel, and green represents mine results



Above: Fig 4 - Static modulus of deformation Em versus RMR and Q. Case histories and RMR data compiled by Bieniawski[1], Q relationship by Barton[3]

temporary limitation (of any data collection activity, including structural geology).

We certainly dispute that 'the assigned parameters are neither independent nor directly connected with rock behaviour'. We are quite sure that Riedmüller, his frequent co-author Schubert, and of course our respected colleague Goodman, were and still are, extremely aware of the importance of such features as joint and discontinuity characteristics, in determining both shear strength and swelling potential. Since stress in relation to strength, and joint spacing and number of joint sets are additional parameters in the two classification systems, it is hard to see that Riedmüller can really have believed that ...'the assigned parameters are neither independent nor directly connected with rock behaviour'. If true, then he must have partly misunderstood their structure and purpose.

For instance in the Q system, the parameter pair Jr/Ja gives a very close approximation to the coefficient of friction, as measured in numerous in situ shear tests of filled discontinuities (figure 1). These two parameters, though independently acquired, in combination reflect realistic magnitudes of shear resistance to overbreak and general instability. This part of the Q-value is also sensitive to the details of shear resistance, with φ+i, φ, or φ-i, in the three contact categories, representing dilatant, non-dilatant, or contractile shear behaviour. Of course such details are 'directly connected with rock behaviour' around tunnels. So we respectfully disagree, and wonder why this lack of understanding has developed. Why would so many, presumably intelligent people, develop and apply such systems in very many countries, if these concerns were founded in reality?

A month after Goodman's contribution, another concern was expressed by Pells and Bertuzzi[6] that: "Classification systems are good for communication... but... should not be used as the primary tool for the design of primary support. Q and RMR values are not factual data in respect to the engineering geology of the rock mass; they include a significant degree of interpretation. Therefore, they should not appear on engineering geological logs of boreholes or on records of line mapping of excavations."

It is hard to counter critique of the classification systems from those who either have other agendas, or who prefer the mechanics of beam theory for designing tunnels and caverns in a medium as variable and complex as rock. Our first reaction is to wonder how many engineers share the above conviction that this is the way to go.

Indeed, Q and RMR 'include a significant degree of interpretation', but it must be hoped that this would also apply to the application of beam theory. It is remarkable that Pells and Bertuzzi[6] should be so against 'main stream' engineering geology and tunnelling practice, to advise that Q and RMR values 'should not appear on engineering geological logs of boreholes and on records of line mapping of excavations'. When so obviously conflicting with convention, their publication is a surprise.

'Ten commandments' for using RMR and Q

To avoid confusion, we would like to offer "ten commandments" of broad principles for proper use of our rock mass classifications:

I) Ensure that the classification parameters are quantified (measured, not just described), from standardised tests, for each geologically designated structural region, employing boreholes, exploration adits and surface mapping, plus seismic refraction for interpolation between the inevitably limited numbers of boreholes.

II) Follow the established procedures for classifying the rock mass by RMR and Q and determining their typical ranges and the average values.

III) Use both systems and then check with at least two of the published correlations of Bieniawski[2] and Barton[4].

IV) Estimate support and rock reinforcement requirements (figure 2). The Q-system supplies permanent support, but only if the components B adn S(fr) are of good quality.

V) Estimate stand-up time (figure 3) and rock mass modulus for preliminary modelling purposes (figure 4). A stress-dependent modulus may be needed if depth is significant[4,5].

VI) Perform numerical modelling in appropriate cases (large spans, special conditions) and check if sufficient information is available.

VII) If sufficient information is not available, recognising the iterative design process, request further geological exploration and parameter testing, e.g. stress measurements, if necessary.

VIII) Consider the construction process, and in the case of TBM feasibility studies, estimate the rates of advance, using the Q_{TBM} and RME methods.

IX) Ensure that all the rock mass characterisation information is included in the Geotechnical Baseline Report, which discusses design procedures, assumptions and specifications.

X) Perform RMR and Q mapping as the construction proceeds so that comparisons can be made of expected and encountered conditions, leading to design verification or appropriate changes.

Of course, it goes without saying that laboratory tests must be included and performed diligently according to standardised procedure and with a sufficient budget. The engineers and geologists should act as a team and communicate regularly among themselves and the client.

"IT IS NOT THE THINGS YOU DON'T KNOW THAT GET YOU INTO TROUBLE. IT IS THE THINGS YOU THINK YOU KNOW FOR SURE." SIR WINSTON CHURCHILL

Conclusion

After 35 years of use throughout the world in tunnelling and mining, the record of the RMR and Q systems in geological and engineering practice speaks for itself. These two systems have become entrenched as the most effective empirical design tools for determination of rock mass quality and estimating rock mass properties and tunnel support measures.

However, it is prudent to apply these classifications in the letter and spirit for which they were developed, and to learn from corroborative case histories.

Let us conclude with this applicable wisdom: "It is not the things you don't know that get you into trouble. It is the things you think you know for sure." (Attributed to Sir Winston Churchill) T&T

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