RELIABILITY OF THE LINEAR CORRELATION OF ROCK MASS RATING (RMR) AND TUNNELLING QUALITY INDEX (Q)

J. Ranasooriya
Senior Geotechnical Engineer, Department of Mines and Petroleum, Western Australia
H. Nikraz
Professor, Department of Civil Engineering, Curtin University, Western Australia

ABSTRACT

With the advent of the RMR and Q classification methods for underground excavation support design, a linear correlation between the two methods was suggested by linear regression analysis of the data obtained from several case studies. The data used in deriving the relationship was widely scattered and the range of values covered by the 90% confidence limits demonstrated that the relationship had very little practical value. In subsequent publications, the 90% confidence limits were omitted when referring to the relationship. Consequently, some practitioners in the field of rock engineering assumed that this relationship, expressed as a semi logarithmic equation, is universally applicable for transforming the ratings assigned by one system to the ratings of the other. This assumption is erroneous and deserves scrutiny. This paper reviews some of the relevant published information and illustrates that there is no sound scientific basis to assume a universally applicable linear relationship between the two.

1 INTRODUCTION

Of the several rock mass classification methods developed for underground excavation support design applications, only RMR and Q, introduced by Bieniawski (1973) and Barton *et al.* (1974), respectively, have stood out. Over the years, these methods have been revised and updated, and the current versions are RMR_{89} (Bieniawski, 1989) and Q_{94} (Barton and Grimstad, 1994). Their main applications are in the prediction of support requirements, stable unsupported spans and stand-up times of underground excavations, particularly during the planning stage of projects. Others include estimations of modulus of rock mass deformation and rock mass strength, which are input parameters for elegant design tools such as numerical modelling.

Both RMR and Q methods are based on six parameters considered to represent the behaviour of rock masses. The primary aim of these classification systems is to divide the rock mass into distinct classes of similar characteristics that are easily identified by visual observation or by simple tests. Since both methods aim at the same objective, a correlation may be expected between the two. If a true correlation exists, then it should be possible to obtain ratings for one system by transforming the ratings determined for the other. This would save time and effort if both systems are to be applied for the design of an excavation project.

A correlation based on linear regression analysis of *RMR* and *Q* values was first presented by Bieniawski (1976). Since then several other researchers have also presented somewhat different correlations based on regression analysis of *RMR* and *Q* values obtained from tunnelling and mining projects in different parts of the world. While these correlations may be valid for the rock mass conditions from which they were derived, they may not necessarily be applicable to other rock mass conditions. Despite the fact that different correlations can be obtained from different rock mass conditions, there is a tendency among some practitioners of rock engineering to overly rely on the first correlation published in 1976 and transform ratings between the two systems. In recent years this injudicious tendency has found its way into the underground mining sector in Western Australia where RMR and Q methods are often used for excavation support design.

This paper presents a brief overview of the evolution of the RMR and Q methods and their existing correlations, and a discussion on the differences of the two. In light of the existing correlations and the scattering of the data used in deriving them, the paper illustrates that there is no sound scientific basis to assume a universally applicable linear relationship between RMR and Q, as alluded to by some publications.

2 THE RMR SYSTEM

The RMR system evolved through several versions (Bieniawski, 1973, 1974, 1975, 1976, 1979 and 1989). It is an index of rock mass competency based on six parameters:

- Intact rock strength (*IRS*)
- Rock quality designation (*RQD*)
- Joint (discontinuity) spacing (*JS*)
- Joint surface condition (*JC*)
- Groundwater condition (*GW*)
- Rating adjustment (*RA*) for discontinuity orientation

Each of the six classification parameters is given five separate ranges of rating values. Guidelines on the selection of ratings based on the observed or measured conditions in a rock mass are provided in the system. The sum of the ratings assigned to the six parameters is defined as the *RMR* value, which linearly varies from 0 to 100.

From 1973 to 1989 the ratings scales and some of the parameters used in the RMR system have changed as listed in Table 1. In the 1973 version, eight parameters were used and from 1974 onwards these were reduced to six by combining joint separation, continuity and weathering parameters of the first version to create the joint condition parameter, *JC*. From 1974 to 1975 the maximum ratings given to *JC* and *IRS* were increased by 10 and 5 points, respectively.

In the 1973 and 1974 versions, the *RA* was given a positive rating ranging from 0 for the most unfavourable orientation to 15 for the most favourable orientation. From 1975 onwards this parameter was given a negative rating from 0 for the most favourable orientation to -12 for the most unfavourable orientation. From 1975 to 1976 the rating scales were not changed, but the rock mass class boundaries for support selection were. In the 1979 version, the maximum rating for the *JS* term was reduced by 10 points and the influence of both *JC* and *GW* was increased by 5 rating points each. In the 1989 version (RMR_{89}), the rating ranges did not change, but the assessment of sub-horizontal discontinuities (joints) was changed from unfavourable to fair for the stability of tunnels. This results in a difference of 5 rating points in the RMR value.

The *RMR* value of a given rock mass is related to five rock mass classes and each class in turn is related to permanent support measures and construction procedures presented in a tabulated form for 10 m wide horseshoe shaped tunnels with a vertical stress of less than 25 MPa excavated by drill and blast methods. The method also provides an unsupported span versus stand-up time chart, which may be used to estimate the stand-up time and the maximum stable unsupported span for a given *RMR* value.

Table 1: Rating allocations in different versions of the RMR system.

Parameter	1973	1974	1975	1976	1979	1989
Intact rock strength (*IRS*)	0 - 10	0 - 10	0 - 15	0 - 15	0 - 15	0 - 15
RQD	3 - 16	3 - 20	3 - 20	3 - 20	3 - 20	3 - 20
Joint spacing (*JS*)	5 - 30	5 - 30	5 - 30	5 - 30	5 - 20	5 - 20
Separation of joints	1 - 5					
Continuity of joints	0 - 5					
Weathering	1 - 9					
Condition of joints (*JC*)	-	0 - 15	0 - 25	0 - 25	0 - 30	0 - 30
Groundwater (*GW*)	2 - 10	2 - 10	0 - 10	0 - 10	0 -15	0 - 15
Rating adjustment (*RA*)	3 - 15	3 - 15	0 - (-12)	0 - (-12)	0 - (-12)	0 - (-12)

3 THE Q SYSTEM

The Q system, developed by Barton and co-workers (Barton *et al.*, 1974, 1975, 1977, 1980 and Barton, 1976), also uses six parameters considered to represent the behaviour of rock masses:

- Rock quality designation (*RQD*)
- Joint (discontinuity) set number (*Jn*)
- Joint roughness number (*Jr*)
- Joint alteration number (*Ja*)
- Water reduction factor (*Jw*)
- Stress reduction factor (*SRF*)

In the Q system the *RQD* is used as determined by core logging or scanline mapping, without allocating a system specific rating. *RQD* intervals of 5 are considered to be accurate enough and, if *RQD* is ≤ 10, a nominal value of 10 is used. The recommended rating values for the other five parameters and guidelines for their selection are provided in the system. Once the numerical ratings are assigned to the six parameters, the *Q* value is calculated using the equation:

$$Q = (RQD/Jn)(Jr/Ja)(Jw/SRF) \qquad \textbf{(1)}$$

The *Q* value is related to support requirements through an "equivalent dimension", *De*, which is defined as:

$$De = (Span,\ diameter\ or\ height)/ESR \qquad \textbf{(2)}$$

where *ESR*, excavation support ratio, is a dimensionless function of the purpose of the opening. A list of recommended *ESR* values is provided in the system. The Q system provides a support chart with a *Q* value as its abscissa and *De* as its ordinate. By plotting the *Q-De* pair on the chart, the support requirements for excavations can be determined.

For nearly 20 years the system remained unchanged from its original version proposed in 1974 which consisted of 38 support categories plus a no support "zone". In 1993, the system was revised and updated (Grimstad and Barton, 1993; Barton and Grimstad, 1994) to incorporate the experience and technological advances subsequent to its initial introduction. In the updated version, the original classification parameters have not changed and their rating ranges also remain largely unchanged, except for changes in the *SRF* term to accommodate rock slabbing and bursting. The 1993 version also provided a revised support chart and reduced the number of support categories to nine. The revised chart has simplified the support selection process and is more user-friendly compared to the earlier version.

4 THE EXISTING CORRELATIONS BETWEEN RMR AND Q

The first correlation between the two methods (Equation 3) proposed by Bieniawski (1976) was based on a linear regression analysis of 111 sets of *RMR* and *Q* values from Scandinavian, South African, North American, European and Australian case histories.

$$RMR = 9\ ln\ Q + 44 \qquad \textbf{(3)}$$

By adding Indian case histories compiled by Jethwa *et al.* (1982), Bieniawski (1989) supplemented the database used for Equation 3. When the *RMR-Q* relationship given by this equation was first published, Bieniawski (1976) provided the 90% confidence limits (Equation 3a) which would contain 90% of the data used.

$$RMR = 9\ ln\ Q + 44 \pm 18 \qquad \textbf{(3a)}$$

The range of values represented by the 90% confidence limits given by Equation 3a covers almost two RMR ground classes, and as a result Equation 3 was of little practical value. In subsequent publications (Bieniawski, 1979, 1989, 1993; Barton, 1995; Barton and Bieniawski, 2008) the 90% confidence limits were omitted when referring to Equation 3. Consequently, some practitioners of rock engineering assumed that this equation is universally applicable for transforming the ratings of one system to that of the other. This assumption appears to be flawed for two reasons. Firstly, the data used in deriving the equation are widely scattered. Secondly, subsequent to its establishment, several different correlations between *RMR* and *Q* were derived by others as given in Table 2 and the data used by them are also scattered.

4.1 DATA SCATTERING AND RELIABILITY

Obviously, wide scattering of the data used for the first correlation (Equation 3) can be seen from Figure 1, reproduced after Bieniawski (1989), which plots the data used in 1976 and the data from Jethwa *et al.* (1982). According to the data in Figure 1, when the *Q* value is 1.1 (poor rock), the corresponding *RMR* value can range from < 20 (very poor rock) to > 61 (good rock), while Equation 3 transforms it to a *RMR* value of 45 (fair rock). Further, when $Q < 0.008$ and $Q > 500$ Equation 3 returns RMR values which are outside the range defined in the system. In other words, if $Q < 0.008$, $RMR < 0$ and if $Q > 500$, $RMR > 100$. Palmstrom (2009) noted that this correlation is a very crude approximation, involving an inaccuracy of ±50% or more.

A review of the information available from the relevant publications shows scattering of the data used in deriving the other equations listed in Table 2

Rutledge and Preston (1978) derived Equation 4 in Table 2 using the data obtained from nine tunnel headings in New Zealand, noting that *"There is considerable scatter in the results"*. On the two relationships (Equations 5 and 6) obtained using bore core data and *in situ* observations in South African tunnels, Cameron-Clarke and Budavari (1981) stated the following: *"The scatter of points about the regression lines is greater for the* in situ *values than for the bore* *core values. In both cases, however, it is probably too great to indicate any meaningful correlation between the two classification systems.*" The linear relationship (Equation 7) presented by Moreno Tallon (1982) used rock mass data from four tunnel headings in Spain. Although not specifically mentioned, scattering of the data is evident from the fact that four separate equations were obtained by separately analysing the data collected from the four headings. The four equations are similar but not identical to each other or to the equation derived by combining all the data from the four headings.

Table 2: Correlations between *RMR* and *Q*.

Correlation	Source	Equation No.
$RMR = 9 \ln Q + 44$	Bieniawski (1976)	3
$RMR = 5.9 \ln Q + 43 = 13.5 \log Q + 43$	Rutledge and Preston (1978)	4
$RMR = 5 \ln Q + 60.8$ (from in situ data)	Cameron-Clarke & Budavari (1981)	5
$RMR = 4.6 \ln Q + 55.5$ (from bore core data)	Cameron-Clarke & Budavari (1981)	6
$RMR = 5.4 \ln Q + 55.2 = 12.5 \log Q + 55.2$	Moreno Tallon (1982)	7
$RMR = 10.5 \ln Q + 41.8$	Abad et al. (1983)	8
$RMR = 7.5 \ln Q + 42$	Baczynski (1983)	9
$RMR = 5.3 \ln Q + 50.81 = 12.11 \log Q + 50.81$	Udd and Wang (1985)	10
$RMR = 6.3 \ln Q + 41.6$	Kaiser et al. (1986)	11
$RMR = 8.7 \ln Q + 38 \pm 18$ (probability theory)[a]	Kaiser et al. (1986)	12
$RMR = 6.8 \ln Q + 42$[b]	Sheorey (1993)	13
$RMR = 43.89 - 9.19 \ln Q$	Celada Thamames (1983)	14
$RMR = 10 \ln Q + 39$	Choquet & Charette (1988)	15
$RMR = 10.3 \ln Q + 49.3$ (when $Q \leq 1$, $SRF = 1$)[c]	Rawlings et al. (1995)	16
$RMR = 6.2 \ln Q + 49.2$ (when $Q > 1$, $SRF = 1$)[c]	Rawlings et al. (1995)	17
$RMR = 6.6 \ln Q + 53$ (when $Q \leq 0.65$)[c]	Rawlings et al. (1995)	18
$RMR = 5.7 \ln Q + 54.1$ (when $Q > 0.65$)[c]	Rawlings et al. (1995)	19
$RMR = 7 \ln Q + 36$	Tugrul (1998)	20
$RMR = 4.2 \ln Q + 50.6$	Asgari (2001)	21
$RMR = 5.97 \ln Q + 49.5$	Sunwoo & Hwang (2001)	22
$RMR = 4.7 \ln Q + 56.8$	Kumar et al. (2004)	23
$RMR = 8.3 \ln Q + 42.5$ (with $SRF = 1$)	Kumar et al. (2004)	24
$RMR = 6.4 \ln Q + 49.6$ (with revised SRF values)	Kumar et al. (2004)	25
$RMR = 3.7 \ln Q + 53.1$	Sari & Pasamehmetoglu (2004)	26

[a] assuming *RMR* and *ln Q* are normal variates and satisfy the central limit theory of probability; [b] derived from the data presented by Sheorey (1993); [c] from bore core data

Rawlings *et al.* (1995) analysed *RMR* and *Q* values assigned to bore core data from a geological formation comprising volcanic rocks. Two sets of Q values were considered: the first assumed *SRF*=1 and the second used the *SRF* values recommended in the Q system. By correlating the two sets of *Q* values with the relevant *RMR* values, Rawlings *et al.* obtained four separate relationships (Equations 16 to 19, inclusive), and suggested that the bilinear relationship given by Equations 16 and 17 for the un-factored (meaning *SRF*=1) *Q* values fitted well for the data used. Although Rawlings *et al.* (1995) did not provide the data used in the analysis, the apparent need to derive two different formulae from each of the two data sets indicates scattering of the data used.

Equation 22 in Table 2 was derived by Sunwoo and Hwang (2001) using approximately 300 data sets from widely different geological environments representing sedimentary, igneous and metamorphic rocks in Korea. The data used in this case are statistically significant in both numbers and range of rock mass conditions. Yet again, there is a wide scattering of the data.

From observations in major tunnelling projects in the Himalayas, India, Kumar *et al.* (2004) found that the *SRF* values provided in the Q system are not applicable to overstressed moderately jointed rocks that are subject to rock slabbing and bursting, and proposed a revised set of *SRF* values for those rock stress problems. The proposed *SRF* values range from 1.5 to 3.0, which are significantly smaller than the range of values (5 to 400) given by Barton and Grimstad (1994) for slabbing and bursting in competent rocks. Kumar *et al.* (2004) then presented three *RMR-Q* relationships. The first (Equation 23) assumed *SRF*=1, the second (Equation 24) used the revised *SRF* values, and the third (Equation 25) used the *SRF* values recommended in the Q system; all three relationships are different from Equation 3 proposed by Bieniawski (1976, 1989).

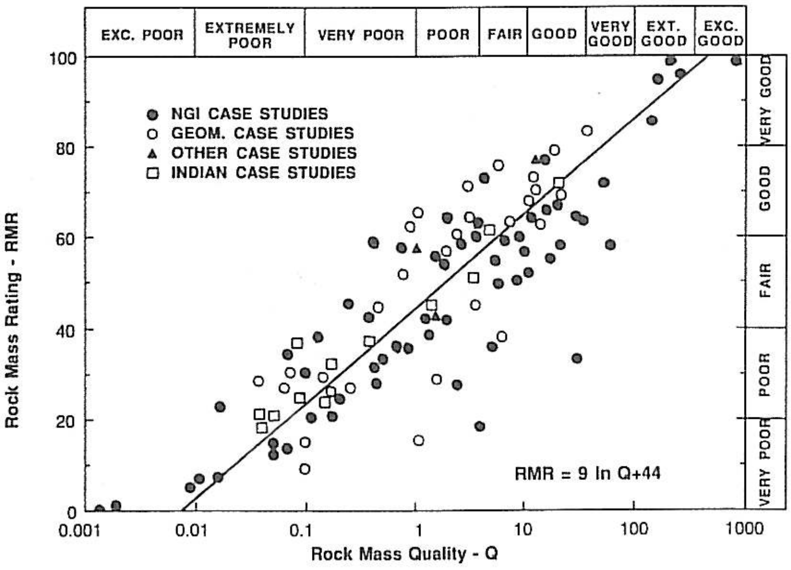

Figure 1: Correlation between *RMR* and *Q* (after Bieniawski, 1989).

Wide scattering of the data used for deriving correlations can be seen clearly from the *RMR-Q* plots provided by Abad *et al.* (1983), Kaiser *et al.* (1986) and Sheorey (1993). The possibility of obtaining different correlations for different rock mass conditions and wide scattering of the data used for deriving them means that the linking of the two methods by a single formula and conversion of the ratings between them could lead to significant errors.

4.2 CHOICE OF THE INDEPENDENT VARIABLE AND METHOD OF ANALYSIS

The relationships listed in Table 2 are based on least square linear regression analysis of *RMR* and *Q* values with *Q* as the independent variable (abscissa of the *RMR-Q* plot as in Figure 1). Kaiser *et al.* (1986) pointed out that the correlations developed using linear regression analysis should be viewed with caution because the results depend on the choice of the dependent variable. From the linear regression analysis of the data collected from the Wolverine West Tunnel in Canada, they derived two relationships; the first (Equation 11) used *Q* as the independent variable, and the second (Equation 27) used *RMR* as the independent variable.

$$RMR = 6.3\ ln\ Q + 41.6 \quad \textbf{(11)}$$

$$ln\ Q = 0.087\ RMR - 2.28 \quad \textbf{(27)}$$

Kaiser *et al.* demonstrated that despite the fact that the two relationships were derived using the same data set, they do not lead to the same result. For example, the first equation would predict an *RMR* value of 40 from a *Q* value of 0.8, while in turn the second equation would predict a *Q* value of 3.35 from a *RMR* value of 40. This clearly demonstrates the weakness of the conventional least square linear regression analysis. To overcome this weakness, Kaiser *et al.* (1986) used a probabilistic approach to determine a unique relationship, assuming that *RMR* and *ln Q* are normal variants and satisfy the central limit theorem of probability theory. Despite the use of a probabilistic approach, Kaiser et al. (1986) observed wide scattering of the data and therefore proposed two equations representing 90% confidence limits within which 90% of the data used for their study fall. However, Kaiser *et al.* noted that the range of values represented by the two equations is of little practical value as the range covers almost two RMR ground classes, as in the case of 90% confidence limits of Bieniawski (1976).

5 DIFFERENCES IN THE TWO RATING SYSTEMS

The presence of several different correlations and wide scattering of the data used in deriving them may be attributed to the fact that, the two methods have significantly different assessments of some of the rock mass parameters as discussed below:

- Intact rock strength (*IRS*) is a factor in the *SRF* term of the Q system, only if the excavation stability is affected by the *in situ* stress field. In contrast *IRS* is always included in the *RMR* value. If *IRS* changes while all the other parameters remain virtually the same, several *RMR* values are possible for a single *Q* value.

- *In situ* stress field is not accounted for in the RMR system in classifying a rock mass. In the Q system it is a factor in the *SRF* term if excavation instability is stress driven. Thus for a rock mass with a given *RMR* value, several different *Q* values are possible depending on the *SRF* value used. As pointed out by Baczynski (1983), the *RMR* versus *Q* correlations are stress-dependent. The relationship will be significantly altered if different *SRF* values are assumed in the determination of the *Q* rating.
- Joint spacing (*JS*) is a key parameter in the RMR system; the closer the *JS* the lower the *RMR* value and the wider the *JS* the higher the *RMR* value. This is not so in the Q system. As pointed out by Milne *et al.* (1998), if three or more joint sets are present and the joints are widely spaced, it is difficult to get the Q system to reflect the competent nature of a rock mass. For widely spaced jointing, *Jn* in the Q system appears to unduly reduce the resulting *Q* value (Milne *et al.*, 1998). Thus for a single *Q* value several *RMR* values are possible depending on *JS*.
- *RQD* is used in both methods, and is a function of joint spacing *JS*, albeit it does not fully represent its true nature. In addition to *RQD*, as mentioned above, *JS* is also a key parameter in the RMR method. In the Q system, although the number of joint sets is taken into account, their spacing is not considered directly. This means the joint spacing is counted twice in the RMR method, while Q system uses it indirectly only once.
- In the RMR method joint orientation is accounted for directly through *RA* by allocating a rating between 0 and -12. In the Q system this is considered implicitly, but what is meant by adversely oriented discontinuities is not defined and the selection of the most critical discontinuity set is user dependent. In any case no rating is given to *RA* in the Q system. Thus for a given *Q* value different *RMR* values are possible depending on the orientation of the excavation relative to the discontinuity set orientation.
- Rating scale: The rating scales in the RMR method have been changed several times as shown in Table 1, while Q remained unchanged for nearly 20 years until 1993. For a rock mass with a given *Q* value, different *RMR* values can be obtained depending on the RMR version used. Since 1993, the *SRF* parameter of the Q system has been given a rating scale of 1 to 400 for competent rock with rock stress problems. As mentioned earlier, depending on the *SRF* value used, different *Q* values can be obtained for a rock mass with a given *RMR* value. With the 1 to 400 range of *SRF* values, the difference in the *Q* value can be more than two orders of magnitude. By setting the *SRF* value to 1 in deriving the *Q* values, this problem may be overcome if the *SRF* term represents only stress. But, it is not strictly a stress factor. It also represents weakness zones, which are rock mass parameters.

From the foregoing it is clear that there is unlikely to be a universally applicable single formula for linking *RMR* and *Q* values. Any relationship will be specific to the rock mass from which the data were obtained, the potential failure mode assumed in deriving the *Q* values and the orientation of the excavation considered for the *RMR* values. It is also noteworthy that the data used for deriving the *RMR* and *Q* correlations listed in Table 2 were obtained by applying different versions of the RMR system. For instance, the correlation given in Equation 3 was obtained using the pre 1976 version(s) of RMR, while the subsequent correlations may be based on either pre or post 1976 versions. Since different versions of the RMR method use somewhat different ranges of ratings, it is important to state which version is being used when correlating the *RMR* and *Q* values. The lumping of the ratings assigned using different RMR versions to compare and correlate them with the *Q* values has a very limited scientific basis.

Sheorey (1993), Goel *et al.* (1996) and Kumar *et al.* (2004) attempted to reduce data scattering and obtain better correlations using truncated versions of the RMR and Q methods. They defined RMR_{mod} (also called *RCR* – rock condition rating) as *RMR* without *IRS* and *RA* and Q_{mod} (also denoted as *N*) as *Q* with *SRF*=1. By regression analysis of the truncated versions of the two methods, Sheorey (1993), Goel *et al.* (1996) and Kumar *et al.* (2004) obtained the relationships given by Equations 28, 29 and 30, respectively.

$$RCR = 9.5\ ln\ N + 31 \qquad \textbf{(28)}$$

$$RCR = 8.0\ ln\ N + 30 \qquad \textbf{(29)}$$

$$RCR = 8.0\ ln\ N + 42.7 \qquad \textbf{(30)}$$

Despite the relatively high correlation coefficients (r^2=0.87, 0.92 and 0.88, respectively) of these equations, the relevant data plots show that the data are still scattered around the regression lines of the three equations. For instance, according to the data provided by Goel *et al.* (1996) when N is 3, the corresponding RCR can be between 25 and 45. Further, Sari and Pasamehmetoglu (2004) found that regression analysis of RCR and N values does not always yield high correlation coefficients. Their RMR-Q correlation (Equation 26) with r^2=0.86 is better than their RCR-N correlation given as Equation 31 with r^2=0.65, showing a distinction from the three equations given above.

$$RCR = 1.7\, ln\, N + 51.5 \tag{31}$$

Based on their analysis, Sari and Pasamehmetoglu stated that the correlation between RCR and N cannot be generalised.

6 CONCLUSIONS

The rock mass classification systems, such as RMR and Q, despite their limitations, will continue to be used for underground excavation support design, particularly in the early stages of projects as they provide a useful means of transferring previous experience to new projects. Since both methods have limitations, it is advisable to apply both simultaneously if they are to be used as a design tool. However, it is not implied that by applying both methods all possible rock mass problems can be adequately dealt with.

The review of the published RMR and Q correlations showed that each one is different and the data used in deriving them are often widely scattered. The main reasons for this are the differences in the parameters and the rating methods used, and the manner in which the final RMR and Q values are computed.

It is clear from the available information that a different relationship can be obtained for each case study and that each relationship is applicable only to that particular rock mass and project conditions from which the relationship was obtained. Even for the same rock mass, if the data used are widely scattered, such relationships are of very little practical value and their use for transforming the ratings between the two methods could lead to errors. Further, Kaiser *et al.* (1986) showed that the results of correlations depend on the choice of the dependent variable. From the foregoing, it is apparent that there is no sound scientific basis to assume a universally applicable linear relationship between the two systems.

When both methods are to be applied to a project, which is desirable, each should always be applied independent of the other, without attempting to convert the ratings of one method to that of the other using the relationships published in the literature. Such relationships, bearing in mind their obvious limitations, may be used as a crude guide for checking the general accuracy of the ratings derived by the two systems.

7 DISCLAIMER

The views expressed in this paper are those of the two authors and not necessarily of their respective employers.

8 REFERENCES

Abad,J., Celad, B., Chacon, E., Gutierrez, V. and Hidalgo, E. (1983) Application of geomechanical classification to predict the convergence of coal mine galleries and to design their supports. Proc 5th Int. Congr. Rock Mech., ISRM Melbourne, Vol. 2, pp. E15-E19.

Asgari, A. R. (2001) New correlation between "Q & RMR" and "N & RCR". Proc 5th Iranian Tunnelling Conference, Tehran (in Persian), English abstract is available on http://www.civilica.com/EnPaper-ITC05-003_0871148829.html.

Baczynski, N. R. P. (1983) Application of various rock mass classifications to unsupported openings at Mount Isa, Queensland: A case study. Proc 3rd Aus-NZ Conf on Geomech, Wellington, 12–16 May 1980, Vol. 2, pp. 137–143. New Zealand Inst Eng, Wellington.

Barton, N. (1976) recent experience with the Q System in tunnel support design. Proc Sym Exploration for Rock Engineering, Johannesburg, Ed. Z.T. Bieniawski, Vol. 1, pp. 107-115.

Barton, N. (1995) The influence of joint properties on in modelling jointed rock masses. Keynote lecture, 8th ISRM Congress (Tokyo), Balkema, Rotterdam.

Barton, N. and Bieniawski, Z. T. (2008) RMR and Q – setting records. Tunnels & Tunnelling International, February 2008, pp. 26-29.

Barton, N., Lien, R. and Lunde, J. (1974) Engineering classification of rock masses for the design of rock support. *Rock Mechanics*. 6, pp. 189–236.

Barton, N., Lien, R. and Lunde, J. (1977) Estimation of support requirements for underground excavations. Design Methods in Rock mechanics. Proc 16th Symp on Rock Mech, Univ of Minnesota, ASCE 1977, pp. 163-177.

Barton, N., Loset, R., Lien, R. and Lunde, J. (1980) Application of Q-system in design decisions concerning dimensions and appropriate support for underground installations. In Subsurface Space 2, 1980 (ed. M Begman), Pergamon, New York, pp. 553-561.

Bieniawski, Z. T., 1973. Engineering classification of jointed rock masses. Trans South African Inst of Civil Eng. Vol.15, pp.335-334.

Bieniawski, Z.T. (1974) Geomechanics classification of rock masses and its application in tunneling. In: *Proceedings of the Third International Congress on Rock Mechanism*, ISRM, Denver, pp. 27–32.

Bieniawski, Z.T. (1975) Case Studies: Prediction of rock mass behaviour by the geomechanics classification. 2nd AusNZ Conf on Geomech, Brisbane, 1975, Inst Eng Australia, pp. 36-41.

Bieniawski, Z.T. (1976) Rock mass classification in rock engineering. Proc Symp for Exploration for Rock engineering. Z.T. Bieniawski and.A.A. Balkema eds, AA Balkema, Rotterdam. pp. 97-106.

Bieniawski, Z.T. (1979) The geomechanics classification in rock engineering applications. 4th Intnl Conf on Rock Mech, vol 2, ISRM, Montreux, pp.41-48.

Bieniawski, Z.T. (1989) Engineering rock mass classifications, John Wiley & Sons, New York, 251 p.

Bieniawski, Z.T. (1993) Classification of rock masses for engineering: The RMR system and future trends, Comprehensive Rock Engineering, Principles, Practice and Projects, Editor in Chief J. A. Hudson, Pergamon, Vol. 3, pp.553-573.

Cameron-Clarke, L. S. and Budavari, S. (1981) Correlation of rock mass classification parameters obtained from borecore and in situ observations, Engineering Geology, Elsevier, Vol. 17, pp.19-53.

Celada Tamames, B. (1983) Fourteen years of experience on rock bolting in Spain. In Proceedings International Symposium on Rock Bolting, Abisko 1983, (ed. O Stephansson), pp. 295-311.

Choquet, P. and Hadjigeorgiou, J. (1993) The design of support for underground excavations. Comprehensive Rock Engineering, Principles, Practice and Projects, Editor in Chief J. A. Hudson, Pergamon, Vol. 4, pp. 313-348.

Grimstad, E. and Barton, N. (1993) Updating the Q-system for NMT, in Proc Int. Sym on Sprayed Concrete, Norwegian Concrete Assoc, Oslo. pp. 46-66.

Jethwa, J. L., Dube, A. K., Singh, B. and Mithal, R. S. (1982) Evaluation of methods for tunnel support design in squeezing rock conditions. Proc 4th International Cong of International. Assoc Eng Geol, Delhi, 1982, Vol 5, pp. 125-134.

Kaiser, P. K., MacKay, C. and Gale, A. D. (1986) Evaluation of rock classification at B. C. Rail Tumbler Ridge Tunnels. Rock Mech and Rock Eng, Vol. 19, pp. 205-234.

Kumar, N., Samadhiya, N. K. and Anbalagan, R. (2004) Application of rock mass classification systems for tunnelling in Himalaya, India. SYNOROCK2004 Symposium Paper 3B14, Int. J Rock Mech. Min. Sci. Vol. 41, No. 3, CD-ROM.

Milne, D., Hadjgeorgiou, J and Pakalnis, R. (1998) Rock mass characterization for underground hard rock mines. Tunnelling and Underground Space Tech. Vol.13, No. 4, pp. 383-391.

Moreno Tallon, E. (1982) Comparison and application of geomechanics classification schemes in tunnel construction. Tunnelling 82, 3rd Intl. Sym. The Inst. Min. Met., pp. 241-246.

Palmstrom, A. (2009) Combining the RMR, Q and RMi classification systems. Tunnelling & Underground Space Technology, Elsevier, Vol. (in press).

Rawlings, C. G., Barton, N., Smallwood, A. and Davies, N. (1995) Rock mass characterisation using the Q and RMR systems. 8th ISRM Congress (Tokyo), Balkema, Rotterdam. Vol. 1, pp. 29-31.

Rutledge, J. C. and Preston, R. L. (1978) Experience with engineering classifications of rock. Proc Intnl Tunnelling Symp, Tokyo, 1978, pp. A3.1-A3.7.

Sari, D, and Pasamehmetoglu, A. G. (2004) Proposed support design, Keletepe tunnel, Turkey, Engineering Geology, Elsevier, Vol. 72, pp. 201-216.

Sheorey, P. R. (1993) Experience with the application of modern rock classifications in coal mine roadways. Comprehensive Rock Engineering, Principles, Practice and Projects, Editor in Chief J. A. Hudson, Pergamon, Vol. 5, pp.411-431.

Sunwoo, C. and Hwang S, (2001) Correlation of rock mass classification methods in Korean rock mass. Frontiers of Rock Mechanics & Sustainable Development in 21st Century, 2nd ARMS, Proc of the 2001 ISRM Intnl Symp, Beijing, China, Balkema, pp. 631-633.

Tugrul, A. (1998) The application of rock mass classification systems to underground excavation in weak limestone, Ataturk dam, Turkey. Engineering Geology, Elsevier, Vol. 50, pp. 337-345.

Udd, J E. and Wang, H. A. (1985) A comparison of some approaches to the classification of rock masses for geotechnical purposes. In Proceedings 25th U.S. Symposium on Rock Mechanics, Rapid City, SD, (Ed. E. Ashworth), Balkema, Rotterdam, pp. 69-78.