

Correlation between Rock mass rating, Q-system and Rock mass index based on field data

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Abstract. Throughout the last decades, many authors have published empirical correlations between rock mass classification systems that have arisen from a series of measurements and observations with the special conditions of the work site; this means that the validity of these expressions is strongly dependent on the knowledge of the original data from which they were deduced. Consequently, none of these expressions are universal nowadays.

In recent years, the principal corps B3 “CPB3” of IMITER mine area has witnessed massive mining activities involving a large amount of underground excavation, the rock mass characteristics are undoubtedly the essential requirements for empirical design and numerical modeling. Therefore, the research carried out aims to provide a new specific inter-relation between the most widespread Quality Indexes, Bieniawski’s RMR Quality Index, Barton’s Q Quality Index and Palmström’s R_{Mi} Mass index utilizing the data gathered from the jointed volcano-sedimentary rock mass of the “CPB3”.

The “CPB3” mining level is located in Imiter silver mine, eastern Anti-Atlas, Morocco, at a depth of 500m. A total of 128 rock blocks were examined for the rock mass quality using the three characterization systems, the outcrop mapping was carried out on freshly parallel exposed faces in the horizontal south to north direction. After processing and plotting the in-situ measured data, several equations of the three indexes has been investigated using regression modeling to analyze the obtained results and find the most suitable equation with the highest correlation coefficients. These relationships were then compared with those reported in the literature.

The proposed regression models reveal strong correlations between RMR, Q and R_{Mi} indexes with high values of accuracy coefficients so that they can be used to estimate the “CPB3” underground rock mass quality for the range of RMR between 30% and 80%. The developed mathematical formulations of the geomechanical indexes will certainly offer an effective tool to geologist and geotechnical professionals in the decision-making process, preliminary design phase, stability problems and suggestions of the required supporting system and techniques without the expense of more resources or time.

Key Words: Rock Mass Classification, RMR, R_{Mi}, Q-System, Correlation, Regression, Geomechanics

Table 1. Nomenclature used in this study

CPB3	Principal Corps B3	σ_c	Uniaxial compressive strength of intact rock
RMR	Rock mass rating	JP	Jointing parameter
R _{Mi}	Rock mass index	jC	Joint condition factor
Q	Rock mass quality	V _b	Block volume, measured in m ³
RQD	Rock quality designation	jL	Joint size
RA	Rating adjustment for joints orientation	jR	Joint roughness
J _n	Joint set number	jA	Joint alteration
J _r	Joint roughness number	MAE	Mean absolute error
J _a	Joint alteration number	RMSE	Root mean squared error
J _w	Joint water reduction factor	MAPE	Mean absolute percent error
SRF	Stress reduction factor	Eq No	Equation number

1 Introduction

The last five decades have witnessed the advent of several rock mass classification systems that became a very common practice in underground engineering to make an estimation of the geomechanical characteristics and provides input for stability analysis of the excavated zone to establish the appropriate support system.

Past experience with field examinations and monitoring has provided fairly good correlations with quantitative classifications and these may be used to predict engineering behavior of rock masses with reasonable accuracy. This is the reason that quantitative classifications have become very popular all over the world.

Nowadays, the most widely used classifications are Bieniawski's RMR Quality Index, Barton and al. Q-system, and Palmström's Rock mass index.

2 Rock mass classification systems

2.1 The Rock Mass Rating 1989

Rock mass rating (RMR) was developed by Bieniawski [1], it is an index of rock mass competency based on the rating of six parameters:

- A₁ Intact rock strength (IRS)
- A₂ Rock quality designation (RQD)
- A₃ Joint spacing (JS)
- A₄ Joint surface condition (JC)
- A₅ Groundwater condition (GW)
- RA Rating adjustment for discontinuity orientation

The first five parameters represent the basic parameters in the classification system. Each of these parameters is given a value. All the values are algebraically summed for the first five given parameters and then adjusted by the sixth parameter depending on the joint and excavation orientation as shown in the following equations:

$$RMR_{basic} = \sum_{i=1}^5 A_i \quad (1)$$

$$RMR_{89} = RMR_{basic} + RA \quad (2)$$

The RMR value ranges from 0 to 100.

2.2 The Q-system 1993

Barton and al. (1974) of the Norwegian Geotechnical Institute (NGI) proposed a Tunnelling Quality Index (Q) as a classification system for estimating rock support in tunnels [2,3]. It is a quantitative classification system based on a numerical assessment of the rock mass quality. Later, Barton and al. have published several papers on the Q system aiming at extending its applications.

The numerical value of the index Q is defined by six parameters and the following equation:

$$Q = \left(\frac{RQD}{J_n}\right) \times \left(\frac{J_r}{J_a}\right) \times \left(\frac{J_w}{SRF}\right) \quad (3)$$

The symbols in the expressions above represent:

- RQD Rock quality designation
- J_n Joint set number
- J_r Joint roughness number
- J_a Joint alteration number
- J_w Joint water reduction factor
- SRF Stress reduction factor

2.3 The RMi system 1995

The rock mass index is a volumetric parameter indicating the approximate uniaxial compressive strength of a rock mass, it was first presented by Palmström (1995) [3]. It 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:

$$RMi_{jointed\ rock} = \sigma_c \times JP = \sigma_c \times 0.2 \sqrt{jC} \times Vb^D \quad (4)$$

$$jC = jL \times \frac{jR}{jA} \quad (5)$$

$$D = 0.37 jC^{-0.2} \quad (6)$$

The symbols in the expressions above represent:

- σ_c Uniaxial compressive strength of intact rock
- JP Jointing parameter
- jC Joint condition factor
- Vb Block volume, measured in m³
- jL Joint size
- jR Joint roughness

3 Review of previous researchers

Throughout the last decades, many authors have published empirical correlations. The most widely used examples are given in Table.2

Table 2. Equations correlating geomechanical classifications from previous works

Approach	Relation	Eq
RMR-Q		
Bieniawski (1984) [5]	$RMR = 9. \ln(Q) + 44$	(7)
Rutledge and Perston (1978) [6]	$RMR = 5,9. \ln(Q) + 43$	(8)
Cameron Clarke and Budavari (1981) [7]	$RMR = 5. \ln(Q) + 60,8$	(9)
Abad and al. (1984) [8]	$RMR = 10,5. \ln(Q) + 41,8$	(10)
RMR-RMi		
Kumar and al. (2004) [9]	$RMR = 5,4. \ln(RMi) + 54,4$	(11)
Hashemi and al. (2009) [10]	$RMR = 7,5. RMi + 36,8$	(12)
RMi-Q		
Kumar and al. (2004) [9]	$RMi = 0,5. Q^{0,93}$	(13)

Hashemi and al. (2009) [10]	$RMi = 1,082 \cdot Q^{0,4945}$	(14)
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Each of the previous expressions has arisen from a series of specific data that is related to a certain rock mass type.

4 Methodology and case study

The study area is located in Imiter silver mine, eastern Anti-Atlas, Morocco, at a depth of 500m.

- The common rock types in the "CPB3" are volcano-sedimentary rock
- There are prominent foliations over all the rock mass in Est-West direction.
- There are multiple discontinuity sets, many of which intersect each other.

A total of 128 rock blocks were examined for the rock mass quality using the characterization systems from the previous discussion, the outcrop mapping was carried out on freshly exposed faces in the horizontal south to north direction.

After processing and checking the accuracy of the proposed expressions, several types of mathematical equations such as linear, exponential, logarithmic, and power were derived with regression analysis to find the most suitable expression with the highest correlation and lowest error coefficients.

5 Statistical processing

To analyze the results obtained, the R coefficient (Pearson's coefficient for correlation) was used. This coefficient provides information about the degree of relationship between two variables (RMR, Q, and RMi in this case). The mathematical formula for computing R is:

$$R = \frac{n \sum x_i y_i - (\sum x_i) (\sum y_i)}{\sqrt{n(\sum x_i^2) - (\sum x_i)^2} \sqrt{n(\sum y_i^2) - (\sum y_i)^2}} \quad (15)$$

where, x_i is the input parameter, y_i is the output parameter and n is the number of data.

In order to check the representativeness of the proposed relationships, the Coefficient of Determination (R^2) is used to analyze the results, for example, if a certain correlation has a Coefficient of Determination of X%, it means that the X% of the RMR Index is in direct relation to the Q-Index. So, it represents the proportion of the shared or explained variability.

MAE measures the average magnitude of the errors in the set of rock quality predictions, without considering their direction where all individual differences have equal weight. and is defined by the following expression:

$$MAE = \frac{1}{n} \sum_{i=1}^n |A_t - F_t| \quad (16)$$

where, A_t is the actual value and F_t is the forecast value of the output variable.

RMSE is a quadratic scoring rule that also measures the average magnitude of the error and tells how concentrated the data is around the line of best fit. The equation is given by:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (A_t - F_t)^2} \quad (17)$$

MAPE is the measure of accuracy in statistics. It usually expresses accuracy as a percentage, and is defined by the following formula:

$$MAPE = \frac{1}{n} \sum_{i=1}^n \left| \frac{A_t - F_t}{A_t} \right| \quad (18)$$

6 Correlation results between the rock mass classification systems

6.1 RMR-Q correlation

The possibility of interrelating RMR and Q Indexes is studied using different types of mathematical expressions that are presented in Table.3

Table 3. Comparison of various regression trendlines between RMR and RMi

Trend-line	Expression	R ²	Eq. No
Linear	$RMR = 1,4906Q + 45,73$	0.29	(19)
Multi Linear	$RMR = 0,24RQD - 0,73Jn + 7,66Js - 0,2Ja + 17,17Jw + 19,83$	0.79	(20)
Exponential	$RMR = 44,953 \cdot e^{0,0304 \cdot Q}$	0.27	(21)
Logarithmic	$RMR = 5,614 \cdot \ln(Q) + 49,395$	0.70	(22)

After testing different types of formulae for fitting, it could be concluded that the multilinear (Eq.20) and logarithmic (Eq.22) models fit well to the available data. By correlating the two sets of Q values with the relevant RMR values, we obtained the figure.1

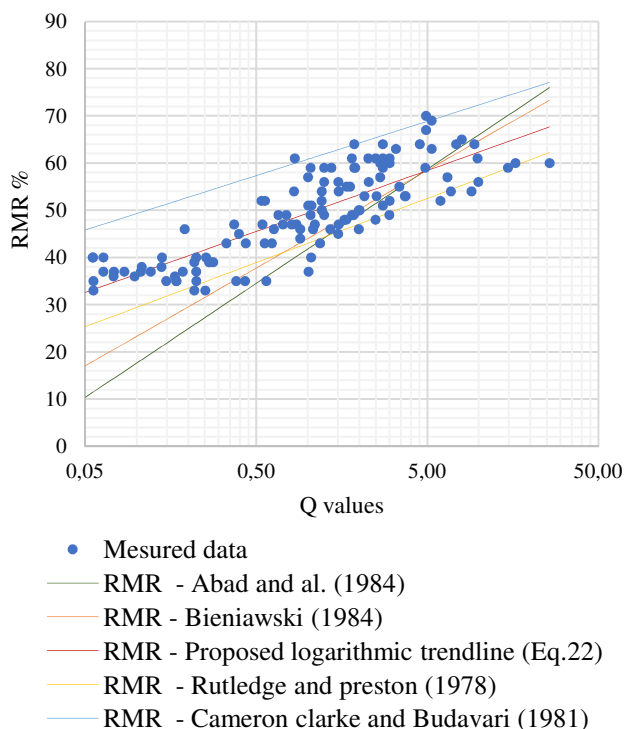


Figure 1. plot of correlations between RMR and Q-system in this case and available literature

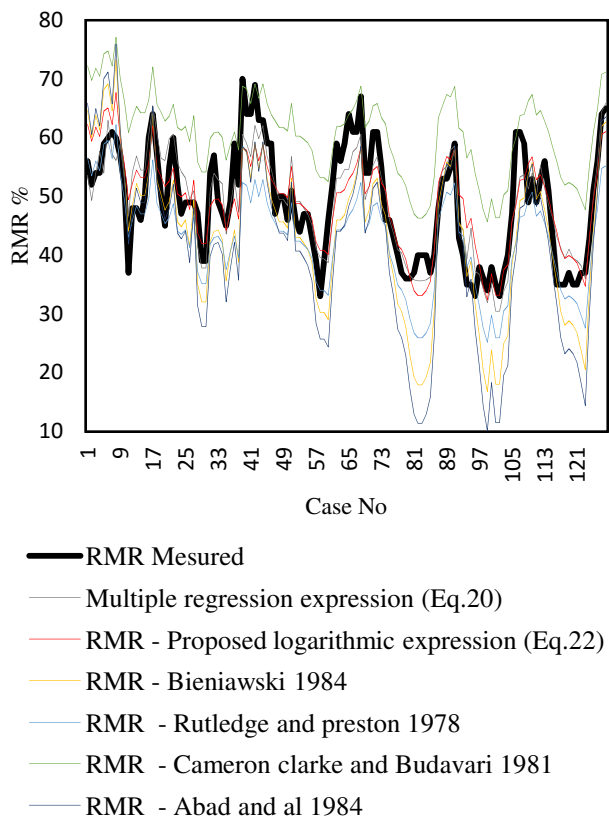


Figure 2. Evaluation of various Correlations between RMR and Q in this case and available literature (128 cases)

Figure.2 summarizes the obtained estimated RMR values from Q compared to other approaches shown in a graphical way

Table 4. Evaluation of correlation and accuracy Coefficients for existing and proposed RMR-Q relations

Approach	R	MAE	RMSE	MAPE (%)	Eq No.
Bieniawski (1984)	0,72	7,5	9,07	22,6	(7)
Rutledge and Perston (1978)	0,72	6,91	8,3	17,14	(8)
Cameron clarke and Budavari (1981)	0,72	11,48	12,62	19,42	(9)
Abad and al. (1984)	0,72	9,67	11,75	37,88	(10)
Proposed regression model	0,72	4,34	5,26	8,81	(22)
Proposed multiple regression model	0,89	3,55	4,37	7,34	(20)

The results of accuracy analysis Table.4 show a satisfactory R and MAPE values for (Eq. 20) and (Eq. 22), the proposed RMR-Q relationships are given by:

$$RMR = 0,24RQD - 0,73Jn + 7,66Js - 0,2Ja + 17,17Jw + 19,83 \quad (20)$$

$$RMR = 5,614 \cdot \ln(Q) + 49,39 \quad (22)$$

6.2 RMR-RMi correlation

The possibility of interrelating RMR and RMi Indexes is studied using different types of mathematical expressions that are presented in table.5

Table 5. Comparison of various regression trendlines between RMR and RMi

Trend-line	Expression	R ²	Eq. No.
Linear	$RMR = 8,2667 \cdot RMi + 41,77$	0,60	(23)
Multi Linear	$RMR = -0,52F - 6,32Js - 0,04Ja + 0,19jL + 5,96Vb + 3,13jC - 84,86D + 107,62$	0,87	(24)
Exponential	$RMR = 41,519 \cdot e^{0,1671 \cdot RMi}$	0,58	(25)
Logarithmic	$RMR = 7,71 \cdot \ln(RMi) + 54,441$	0,83	(26)

Based on the analysis of the coefficient of determination, the most approximate formulas are the multi-linear (Eq.24) and logarithmic (Eq.26) models.

The obtained results from the correlation between RMi and RMR values are shown in an analytical way by figure.3

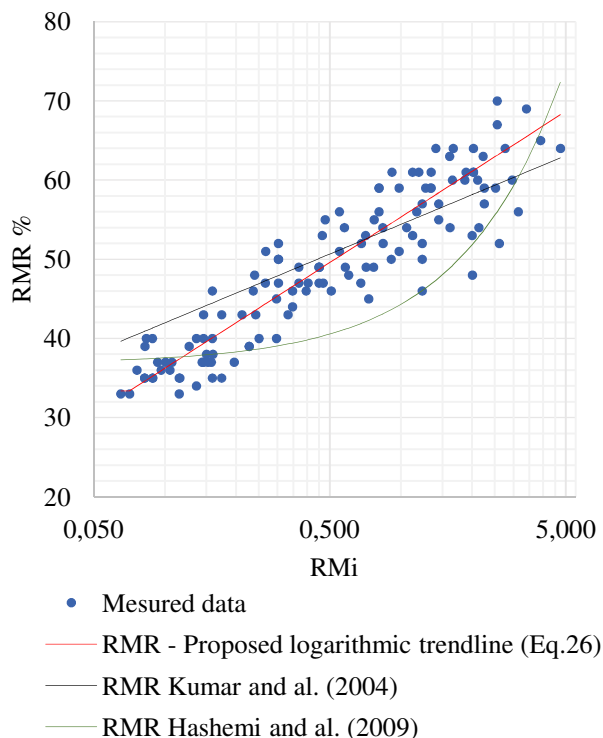


Figure 3. plot of correlations between RMR and RMI in this case and available literature

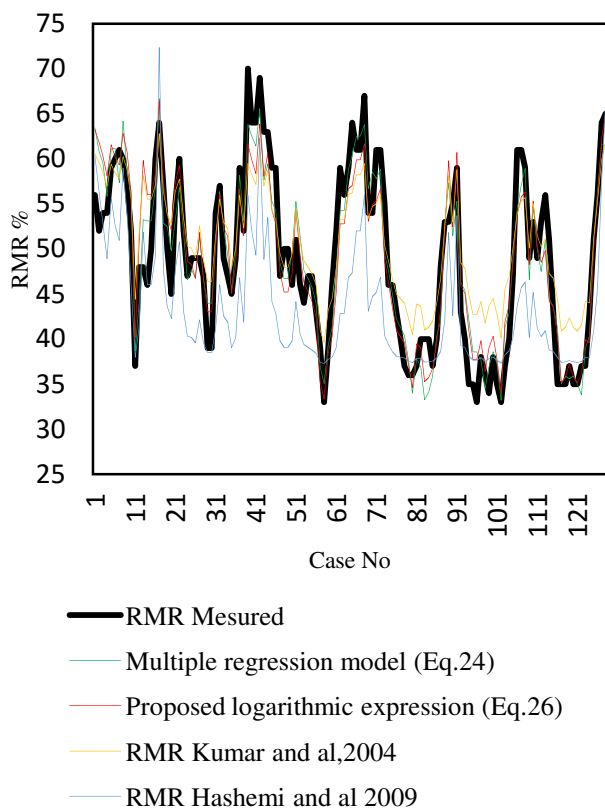


Figure 4. Evaluation of various Correlations between RMR and RMI in this case and available literature (128 cases)

Figure.4 summarizes the obtained estimated RMR values from RMI compared to other approaches shown in a graphical way

Table 6. Evaluation of correlation and accuracy Coefficients for existing and proposed RMR-RMI relations

Approach	R	MAE	RMSE	MAPE (%)	Eq No.
Kumar and al. (2004)	0,89	4,2	4,95	8,56	(11)
Hashemi and al. (2009)	0,81	6,77	8,2	15,47	(12)
Proposed regression model	0,89	3,09	3,99	6,17	(26)
Proposed multiple regression model	0,93	2,88	3,49	5,93	(24)

It can be seen clearly in Table.6 that the estimated value of RMR from RMI using logarithmic and multi-Linear expressions shows one of the biggest values for R and lowest MAPE, the resultants equations for the regression are:

$$RMR = -0,52F - 6,32Js - 0,04Ja + 0,19jL + 5,96Vb + 3,13jC - 84,86D + 107,62 \quad (24)$$

$$RMR = 7,71 \cdot \ln(RMI) + 54,44 \quad (26)$$

6.3 RMI-Q correlation

The possibility of interrelating RMI and Q Indexes is studied using different types of mathematical expressions that are presented in table.7

Table 7. Comparison of various regression trendlines between RMI and Q

Trend-line	Expression	R ²	Eq. No
Linear	$RMI = 0,1962Q + 0,444$	0.55	(27)
Multi Linear	$RMI = 0,021RQD - 0,054jn + 0,445Js - 0,129Ja + 0,065Jw + 0,674$	0.71	(28)
Exponential	$RMI = 0,3121 \cdot e^{0,2092 \cdot Q}$	0.41	(29)
Logarithmic	$RMI = 0,5073 \cdot \ln(Q) + 0,9122$	0,63	(30)
Power	$RMI = 0,5195 \cdot Q^{0,7202}$	0,82	(31)

Likewise, a similar analysis was performed for RMI and Q correlation, it could be concluded that the power model (Eq.26) model fits well to the available data.

RMI-Q Correlated data from the "CPB3", along with the other correlations available in the literature, are presented in Figure. 5

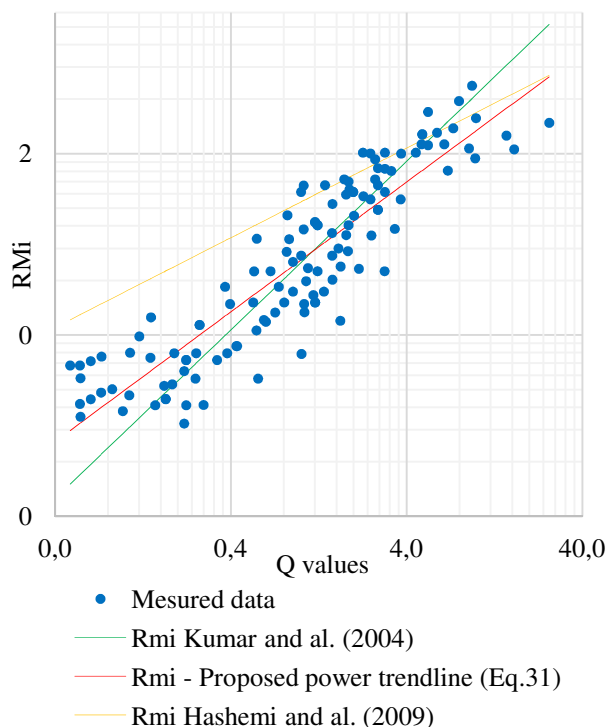


Figure 5. plot of various correlations between Rmi and Q-system in this case and available literature

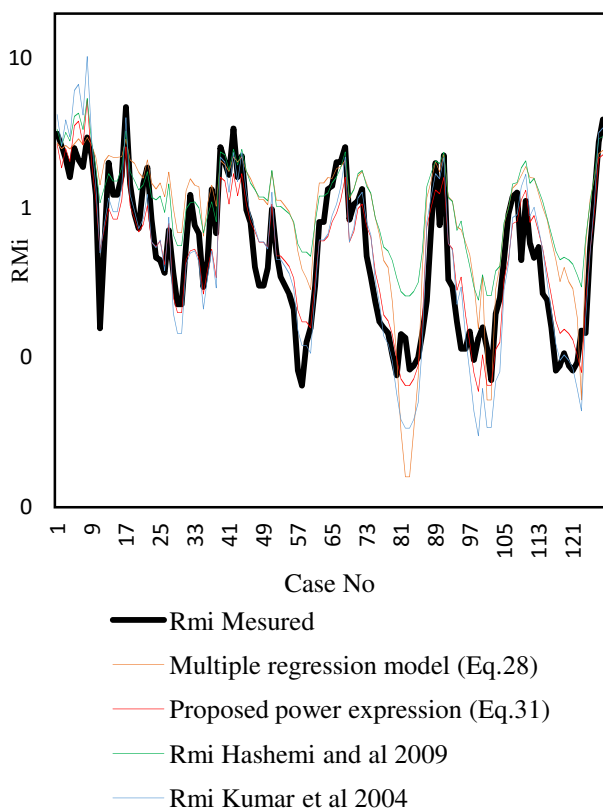


Figure 6. Evaluation of various Correlations between Rmi and Q in this case and available literature (128 cases)

Figure.6 summarizes the obtained estimated Rmi values from Q compared to other approaches shown in a graphical way

Table 8. Evaluation of correlation and accuracy Coefficients for existing and proposed Rmi-Q relations

Approach	R	MAE	RMSE	MAPE (%)	Eq No.
Kumar and al. (2004)	0,93	0,52	0,66	47,93	(13)
Hashemi and al. (2009)	0,72	0,39	0,94	53,21	(14)
Proposed regression model	0,98	0,33	0,53	43,01	(31)
Proposed multiple regression model	0,84	0,52	0,63	60,40	(28)

From a statistical point of view, the power law approximation gives a quite acceptable level of certainty Table.8, we have got the following equation:

$$Rmi = 0,5195. Q^{0,7202} \tag{31}$$

Table 9. The recommended relations based on the "CPB3" data

Expression	R	Eq No.
RMR – Q		
$RMR = 0,24RQD - 0,73Jn + 7,66Js - 0,2Ja + 17,17Jw + 19,83$	0.89	(20)
$RMR = 5,614. \ln(Q) + 49,395$	0.72	(22)
RMR – Rmi		
$RMR = -0,52F - 6,32Js - 0,04Ja + 0,19jL + 5,96Vb + 3,13jC - 84,86D + 107,62$	0.93	(24)
$RMR = 7,71. \ln(Rmi) + 54,441$	0.89	(26)
Rmi – Q		
$Rmi = 0,5195. Q^{0,7202}$	0.98	(31)

7 Conclusion

Most of the available relationships between indexes of rock mass quality have been derived using geological data of Europe, America and Oceania region. In recent years, the “CPB3” of IMITER site has witnessed massive mining activities involving a large amount of underground excavation. Therefore, there is a need to develop specific correlations between the most prevalent rock mass classification indexes for the special conditions of the working site.

The systematic plotting of the graphs using the available relationships reveals a strong potential correlation between RMR, Q and Rmi indexes. The proposed regression equations have high-reliability coefficient Table.9 so that they can be used to estimate the “CPB3” underground rock mass quality for the range of RMR between 30% and 80%.

After a preliminary comparison of the different solutions, we recommend using these correlations with extreme prudence at initial stages of a project, being extremely cautious about the origin, compatibility and rating range of the initial data.

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