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Correlations Between Various Rock Mass Classification Systems, Including Laubscher (MRMR), Bieniawski (RMR), Barton (Q) and Hoek and Marinos (GSI) Systems

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Abstract. Empirical rock mass classification systems are widely used in the practice of mining engineering, especially in the early stages of engineering design of mining infrastructure. This stage involves preliminary assessment of ground support needs for drifts and shafts, stability analysis of pillars and stopes, stability analysis of slopes in open pit mines, and others. During this preliminary stage of the design, mining engineers are required to consider different mining methods and mine designs, as well as underground and open pit alternatives. Crucial to design is the proper characterization of the rock mass, during and after the field data collection phase, in terms of available rock mass classification systems, such as Laubscher (MRMR), Bieniawski (RMR), Barton (Q) and Hoek & Marinos (GSI) systems. Because the rock mass characterization is normally done in terms of one (or rarely more than one) of these systems, and because different mechanical assessment tools used in this and later stages of mining design typically are expressed in any of the systems, it is important to be able to properly correlate rock mass classification ratings in the different rock mass classification systems. This process of correlating the ratings is not straight forward and has not been extensively treated in the literature. The aim of this paper is to address the problem of correlating rock mass classification information, and to propose new relationships for correlation of ratings, in particular, equations that allow to correlate the Laubscher and the Bieniawski systems, and the Barton and the Hoek Marinos systems.

Keywords. Rock mass classification systems. Correlation of systems. Laubscher (MRMR). Bieniawski (RMR). Barton (Q). Hoek and Marinos (GSI).

1. Introduction

Geotechnical exploration is an important phase done in the early stages of a mining project design. This phase has the purpose of collecting general information about the rock mass, which will be then used in specific geotechnical engineering analyses during the later phases of design of mining infrastructure. The collection of data has the purpose of characterizing the rock mass in different geological domains according to one or two of the available geotechnical classification systems used in geotechnical mining, namely, the $MRMR$ (Laubscher, 1990 [1]), the RMR or Rock Mass Rating (Bieniawski, 1989 [2]),

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the Q (Grimstd & Barton, 1993 [3]), and the GSI or Geological Strength Index (Hoek & Marinos, 2000 [4]).

These empirical classification systems are useful tools for mining design. For example, rock mass classification systems can assist in deciding the type of mining method to use, and to estimate needs of support required for the mining infrastructure (in case of underground mining, the required support for shafts, drifts, adits and others). Once a mining method has been selected, rock mass classification systems still allow to estimate other important characteristics of the implementation of the method itself. For example, when sublevel or block caving mining methods are used, empirical rock mass classification systems allow to estimate expected fragmentation of the rock during caving and whether conditions of easy or difficult caving exists.

Regularly, the field data collection is expressed in only one of the existing rock mass classification systems and frequently, the basic geotechnical parameters are expressed in terms of the final rating of this system only. This final rating is a (scalar) numerical value that results from the application of the system, and that results from the application of simple mathematical operations of several other partial ratings associated with the different characteristics of the rock mass accounted for by the classification system.

It usually happens that during later phases of the design mining infrastructure (e.g., when the mine is operating already and new developments are being considered), a method of geotechnical design that is intended to be used requires, as input data, the rating of a particular rock mass classification system that was not evaluated a priory. When the raw data (that would allow to compute ratings for any classification system) is not available, the only way to estimate the rating according to a new rock mass classification system is to try to correlate the rating of the available rock mass classification system with the target one. This correlation is not straight forward, and as a matter of fact, there seems not to exist much published bibliography that provides guidance on how to transform ratings from one system to another.

This paper fills that gap by presenting a case history with correlation formulas to relate ratings of the most popular systems mentioned earlier on, namely the $MRMR$, RMR, Q and GSI systems. Prior to discussing the proposed correlation formulas, a review published correlation guidelines and formulas is presented.

2. Published correlations

Among the best known existing correlation equations for rock mass classification systems is, perhaps, the following equation

$$RMR = 9 \ln Q + A \tag{1}$$

Equation (1) allows to correlate the RMR rating by Bieniawski [5] and the Q rating by Barton et al. [6]. The correlation, which was proposed by Bieniawski [5], is based on the analysis of 111 case histories of rock mass characterization, including 62 cases from Scandinavia, 28 cases from South Africa, and 21 cases from the United States, Canada, Australia and Europe. In equation (1), the variable A varies between 26 and 62 (with a mean value of 44), where 26 represents the 90% confidence limit –see Bieniawski [5].

Abad et al. [7] analyzed 187 drifts in coal mines in Spain, and based on equation (1), suggested the following equation for correlation between the RMR system and the Q system

$$RMR = 10.5 \ln Q + 42 \quad (2)$$

Other authors also looked at the relationship for correlating RMR and Q systems. For example, adopting again the equation (1), Kaiser et al. [8] proposed that the value 9 in the first term of the right side of the equation ranges from 5 up to 13.5, while Afrouz [9] proposed the following more involved form of correlation equation, based on the original one proposed by Bieniawski [5]

$$RMR = x^a \ln Q + y^b \quad (3)$$

In equation (3), the set of variables (x, y, a, b) are constants that depend upon the type of rock and the condition of the joints. Afrouz [9] also provided some ranges for the relationship existing among the variables (x, y, a, b) as follows

$$x^a = 5 \; to \; 13.5$$
$$y^b = 26 \; to \; 62$$

Correlations between the Bieniawski RMR and the Hoek & Marinos GSI systems were discussed in Hoek & Karzulovic [10]. The Authors suggested that for rock masses of poor quality and better $(RMR > 25)$, the GSI value can be estimated directly from the 1976 version of the Bieniawski RMR system, considering a dry rock mass (the water rating set to 10) and the adjustment for joint orientation set to 0 (very favorable). They also suggested that if the 1989 version of the Bieniawski RMR system is used, then the Geological Strength Index should be considered as $GSI = RMR_{89} - 5$, with the groundwater rating (in the Bieniawski RMR system) set to 15 and the adjustment for joint orientation set to 0. Hoek & Karzulovic [10] also noted that for very poor quality rock masses $(RMR < 25)$, the above-mentioned correlations have proved to be unreliable and should never be used. In those cases, GSI values should be estimated directly from the GSI charts.

Hoek [11] mentioned that, in general, geologists and engineering geologists are comfortable with the qualitative estimation from GSI charts, whereas, many engineers feel the need for a more quantitative estimation of GSI. Accordingly, different methodologies to estimate GSI values in a more quantitative way have been published in the literature in the past.

For example, Sonmez and Ulusay [12] proposed a quantification of the entry 'block size' in the GSI chart by introducing the Structure Rating (SR) coefficient, which can be computed based on the Volumetric Joints (J_v) coefficient as follows

$$SR = -17.5 \times \log J_v + 79.8 \quad (4)$$

Sonmez and Ulusay [12] also proposed a quantification of the entry 'joint condition' in the GSI chart by introducing the Surface Condition Rating (SCR), using the following equation:

$$SCR = R_r + R_w + R_f \quad (5)$$

In equation (5), R_r is the Roughness Rating, R_w is the Weathering Rating and R_f is the Infill Rating of the discontinuities (the total rating is calculated as the average of individual ratings for each joint set).

Cai et al. [13] proposed a quantification of the entry 'block size' in the GSI chart by considering the spacing and block volume associated with a set of joints. They 'block volume' coefficient V_b is calculated according to the following equation

$$V_b = \frac{S_1 S_2 S_3}{\sin(y_1)\sin(y_2)\sin(y_3)} \quad (6)$$

In equation (6), S_i and y_i are the joint spacing and the angle between joint sets, respectively (see Figure 1).

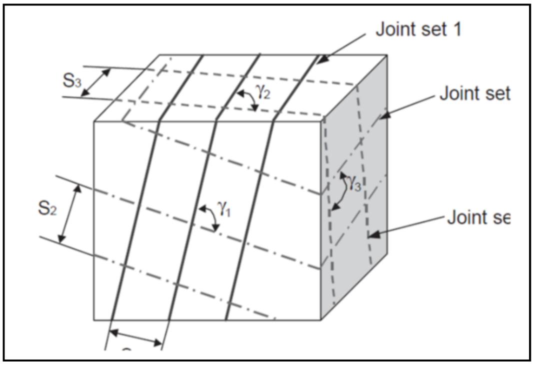

Figure 1. Rock mass with three joint sets –after Palmstrom [14].

Cai et al. [13], also proposed a quantification of the entry 'joint condition' in the GSI chart by introducing the Joint Condition Factor (Jc), which is computed with the following equation

$$J_C = \frac{JwJs}{Ja} \quad (7)$$

Where, in equation (7), J_w and J_s are the ratings for waviness and the smoothness, and J_a is the joint alteration rating (for details, see [3] and [13]).

Recently, Hoet et al. [15] proposed different methods to quantify GSI, based on the Rock Quality Designation (RQD) and the 'joint condition' entry in either Bieniawski or Barton systems, according to the following relationships

$$GSI = 2JCond_{76} + RQD/2 \quad (8)$$

$$GSI = 1.5JCond_{89} + RQD/2 \quad (9)$$

$$GSI = \frac{52J_r/J_a}{1+J_r/J_a} + RQD/2 \quad (10)$$

In equations (8) and (9), $JCond_{76}$ and $JCond_{89}$ are 'joint condition' entries from the original Bieniawski 1976 [5] system, and from the updated Bieniawski 1989 [2] system, respectively. In equation (19), J_r and J_a are the 'joint roughness' and the 'joint alteration' entries, respectively, from Barton Q System [2]. As mentioned above, in equations (8) through (10), RQD is the Rock Quality Designation.

3. Proposed correlations

As mentioned in Section 2, various correlations have been proposed in the literature to transform ratings from one rock mass classification system to another. Among others, correlations exist to transform RMR ratings to Q and GSI ratings, respectively. In addition, several equations have been proposed in the literature to quantify GSI.

This section presents correlations developed by the authors using a database of rock mass classification information corresponding to drill cores from actual mining development projects. In particular, correlations are presented to relate $MRMR$, RMR, Q and GSI systems. A procedure to quantifying GSI (alternative to that mentioned in Section 2) is also presented.

A rock mass classification database has been developed by SRK Consulting Chile based on information collected during two exploration drilling campaigns for underground mining projects in Chile. The first drilling and logging campaign has involved 62,000 m of drill core in a porphyry copper deposit of 'good' to 'very good' geotechnical rock mass quality. The second drilling and logging campaign has involved 81,000 m of drill core in an epithermal gold deposit of 'poor' to 'fair' geotechnical rock mass quality.

The information obtained from both campaigns (i.e., from evaluation of 143,000 m of drill core) has been merged into a single database that includes information for the full spectrum of rock mass (geotechnical) quality. Along the full length (143,000 m) of drill core, a total of 35,137 intervals have been identified. For each interval, RQD and FF/m (per-meter fracture frequency) have been estimated. Also, each interval has been evaluated in terms of $MRMR$, RMR, Q and GSI systems. With this regard, logging and application of rock mass classification systems has followed a rock mass characterization procedure developed by SRK Consulting Chile. The philosophy of the procedure focuses on extracting all (possible) basic geotechnical parameters from cores, required to apply all four different classification systems.

The information collected from the 143,000 m of drill core, has been analyzed in various stages. First, the consistency of data has been verified by plotting collected RQD and FF/m values, as suggested by Priest and Hudson [16]. Next the correlation between Bieniawski (RMR) and Barton (Q) has been analyzed, and the resulting parameters to use in equation (3) have been computed. Figure 2 shows that there existed a good correlation between RQD and FF/m values. Figure 3 also shows that there existed good correlation between RMR and Q systems (the computed values of the parameters for equation 3 are shown in the legend of the diagram).

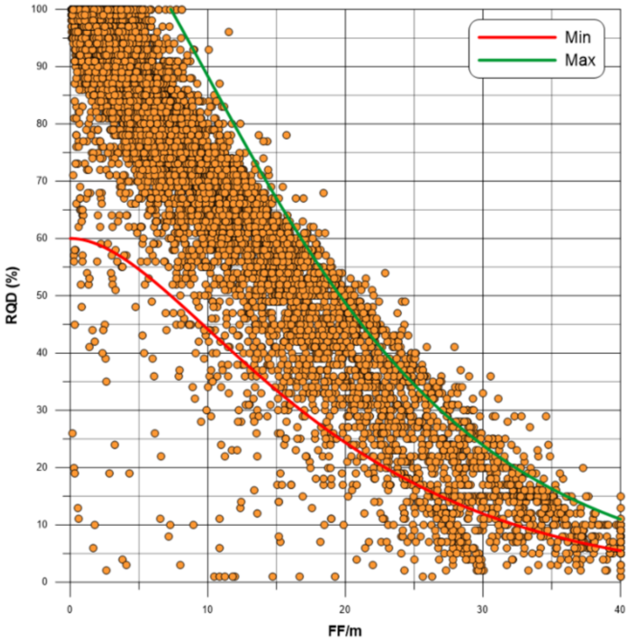

Figure 2. RQD vs. FF/m correlation. Most of the data are in the confidence range defined by Priest & Hudson [16].

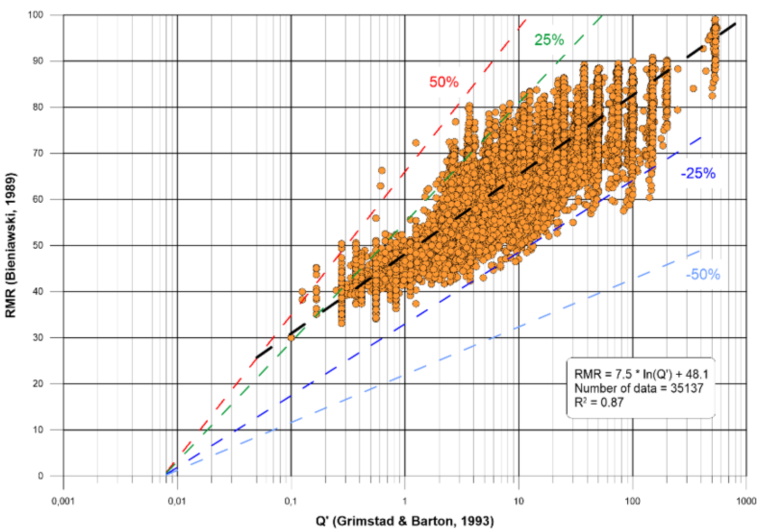

Figure 3. Bieniawki RMR [2] vs. Q System [3] correlation.

Laubscher $MRMR$ [1] has been estimated using RQD and joint spacing to obtain a better correlation with RMR, Q and GSI classification systems [2,3,4]; this was done because all these systems are using RQD as one of the main parameters. Figures 4, 5 and 6 show the correlations obtained between different systems. The following equations have been obtained by performing a least square fitting of the data represented in Figures 4, 5 and 6.

$$RMR_L = 1.3RMR_B - 33.8 \qquad (Valid\ for\ RMR_B > 30) \tag{11}$$

$$RMR_L = 10.3\ln(Q') + 27.9 \qquad (Valid\ for\ Q' > 0.1) \tag{12}$$

$$GSI = 36.9\ln(RMR_L) - 78 \qquad (Valid\ for\ RMR_L > 10) \tag{13}$$

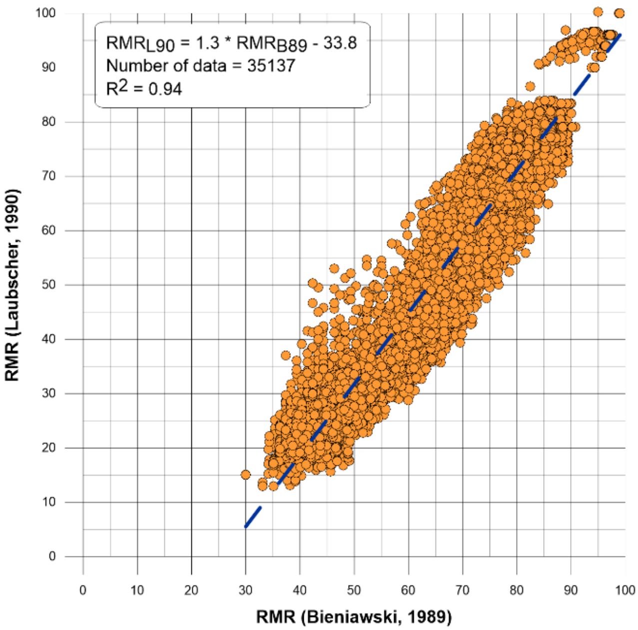

Figure 4. Laubscher RMR [1] vs. Bieniawki RMR [2] correlation.

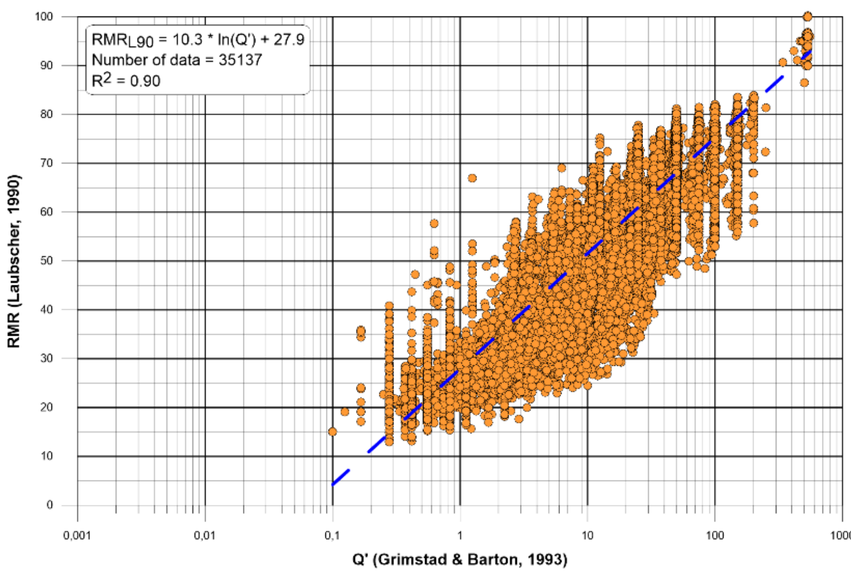

Figure 5. Laubscher RMR [1] vs. Q System [3] correlation.

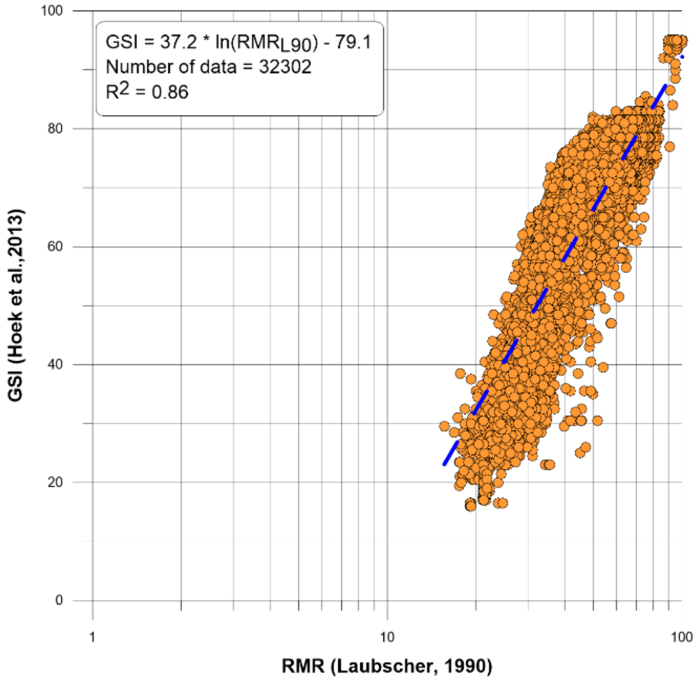

Figure 6. Laubscher RMR [3] vs. GSI [5] correlation.

As mentioned in Section 2, Hoek et al. [15] have proposed a quantification of GSI based on RQD and Bieniawski/Barton joint condition. When designing mines using block or sublevel caving methods, the Laubscher $(MRMR)$ rock mass classification system is the preferred one, because this system allows to evaluate expected cavability characteristics of the rock mass. In the case of mines using caving methods, design tools expressed in terms of Bieniawski or Barton classification systems are not available. To fill the gap, the authors have developed a correlation equation for quantifying GSI based on RQD and Laubscher Joint Condition parameter $JCond_{90}$ (Laubscher, 1990 [1]). The correlation equation, which uses a similar approach as that proposed by Hoek et al. [15] (i.e., considers the rock mass to be dry), is as follows

$$GSI = 1.25JCond_{90} + RQD/2 \tag{14}$$

Equation (14) has been applied to each geotechnical interval of the (143,000 m length) drill core to estimate GSI values, and the resulting values have been compared with values estimated according to the formula (8). A good correlation has been obtained with both methods, as shown in Figure 7 (note that coefficients of the linear regression equation and resulting coefficient of determination are shown in the legend of the figure) The good correlation shown in Figure 7 suggests that equation (14) can be used as an alternative means to computing the Geological Strength Index (GSI) from RQD and $JCond_{90}$.

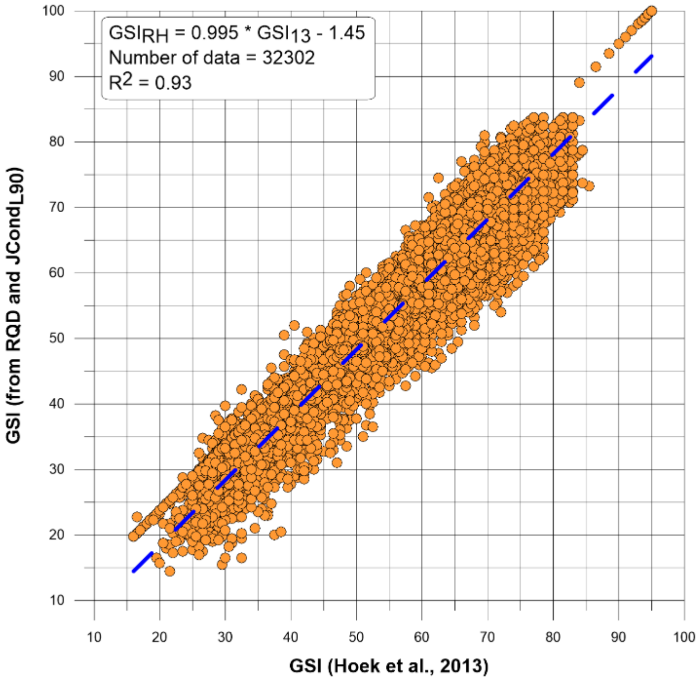

Figure 7. Correlation graph between GSI estimated from RQD and joint condition $JCond_{90}$ from Laubscher and GSI from Hoek et al. [15].

4. Final comments

This paper has reviewed existing correlations and presented a new set of correlation equations that allow to relate ratings obtained with different rock mass classification systems, namely, the $MRMR$, RMR, Q and GSI systems. In addition, the paper has presented a new equation to correlate GSI and RQD and $JCond_{90}$ values.

The authors consider that although new and existing correlation equations are useful in some instances (e.g., when not all input information is available to apply a particular rock mass classification system) there is no better replacement to doing a proper estimation of ratings for each of the different systems using the original raw data (i.e., data coming from logging or field mapping). The authors also consider that for new mining developments projects, and when possible, it is always important to characterize the rock mass in terms of several (and possibly all) systems used in this paper. This is because geotechnical tools that are used in the design of the different components of a mine may require input information (i.e., ratings/indexes) coming from different rock mass classification systems. With this regard, it needs to be recognized that in contrast to design done for civil engineering infrastructure (which once finished, typically remains 'as is' throughout the life-span of the infrastructure), design done for a mine is an 'ongoing' process that happens until the mine is closed. This is because new drifts, shafts, caverns, etc. need to be designed and constructed as the mine expands.

Therefore, a complete characterization of the rock done at initial stages of design of the mine will certainly be of use at the later stages of design, throughout the life-span of the mine.

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