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Characterization of jointed rock masses for geotechnical classifications utilized in mine shaft stability analyses

İ. Özkan [a,*], B. Erdem [b], A. Ceylanoğlu [b]

[a] Selçuk University, Mining Engineering Department, Konya, Turkey
[b] Cumhuriyet University, Mining Engineering Department, Sivas, Turkey

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ABSTRACT

In the Divriği open-pit iron mine in Turkey, extracted ore is initially crushed in an underground chamber. This chamber was previously located 54 m below the bottom level of the mine, which was linked by a vertical shaft. Because of the progression in the mine operations, the mine management decided to shift the chamber to a depth of 264.15 m below the surface. A borehole called as YNK-3, which was no closer than 15 m to the existing shaft that was 4 m in diameter and 54 m in length, was drilled to a vertical distance of 264.15 m. Although the first 54 m was drilled in a coreless manner, the drill cores obtained from the remaining 210.15 m were used in the rock mass characterization studies for the design of the shaft support. The rock formations encountered during shaft sinking, which were generally jointed rock masses, were classified into structural regions and domains for geological and geotechnical definition. Initially, the original rock mass rating (RMR) and quality (Q) systems were used for rock mass characterization, but difficulties were experienced in determining a number of input parameters required, particularly by the RMR system. A comprehensive examination of the drawbacks encountered directed us to the modified RMR (M-RMR) system. In this paper, the original (RMR and Q) and modified (M-RMR) rock mass classification systems are compared in a detailed discussion of our results. In addition, the classification results were tested using the Hoek-Brown failure criterion to compare the ratings presented by classification systems.

1. Introduction

Mine management expects safe and economically operated underground mine openings. However, these expectations can only be realized with improved understanding of the rock mass conditions. The rock mass classification systems provide more insight into the rock mass conditions. Today, two scientific approaches, one empirical and one numerical, are widely used in support design studies of underground mine openings. Whereas empirical design is based on rock mass classifications, such as the rock mass rating (*RMR*) and quality (*Q*) systems, the numerical design approach uses various failure criteria and the properties of intact rock material, such as uniaxial compressive strength (*UCS*, σ_{ci}), Young's modulus (E_i) and Poisson's ratio (ν). However, numerical approaches developed during the last two decades utilize failure criteria, which include rock mass material properties (m, s, a, etc.), modulus of elasticity (E_m), and uniaxial compressive strength (*UCS*, σ_{cm}) of rock mass that are defined by rock mass classification systems. It was revealed from case studies that some numerical approaches, which use outcomes of classification systems, worked well in the support design. Therefore, the numerical design approach can be satisfactorily used in complex rock masses consisting of geological components, such as joints and heavy stratification. For this reason, project engineers tend to prefer numerical approaches that utilize outputs of rock mass classifications for designing underground mine openings and tunnels.

Rock mass characterization systems are essentially empirical approaches used during the preliminary design stage. There are several models available, although the ones usually applied are *RMR* and *Q*, both of which demand plain and straightforward input parameters. However, in their original form, they can only be applied to a limited range of rock mass types for specific purposes. The characterization of intricate rock mass conditions, based on the original ratings suggested by these systems, could be misleading when design decisions are made. Therefore, the original *RMR* and *Q* systems were often modified by including various new parameters.

In this study, the rock formations encountered along a borehole drilled in the Divriği mine were first evaluated with the original *RMR* and *Q* systems. Drill cores obtained from a 210.15 m borehole were used for rock mass characterization. Difficulties were experienced in determining some of the input parameters for geotechnical evaluation,

* Corresponding author. Tel.: +90 332 2232097; fax: +90 332 2410635.
E-mail address: ozkani@selcuk.edu.tr (İ. Özkan).

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such as the strength, the joint condition, and the orientation of the discontinuity. The *M-RMR* system was used in an attempt to overcome these difficulties. General information of the rock mass classification systems, which are used in this case study, is presented in the following subsections.

2. A critical review of the rock mass classification systems used in this study

2.1. Rock mass rating system: RMR

Rock mass rating (*RMR*) was developed by Bieniawski [1] based on in situ measurements and observations obtained in 351 different underground mines. The system consists of six input parameters: (i) uniaxial compressive strength (*UCS*) or the point load strength index (*PLS*); (ii) rock quality designation (*RQD*); (iii) joint spacing (*JS*); (iv) joint condition (*JC*); (v) groundwater (*GW*); and (vi) joint orientation (*JO*). Because these parameters have different rating values, the *RMR* score ranges between 0 and 100. The guidelines suggested for the calculation of the basic and design RMR scores are given by the *RMR* system. The *JC* parameter used in the original *RMR* system [1] was subsequently modified by Bieniawski himself [2] by further evaluating outcomes obtained from numerous applications of the *RMR*. Bieniawski [2] also suggested graphs to determine the ratings for the following parameters: *UCS*, *RQD*, and *JS*. The basic *RMR* score can be calculated using the following equation:

$$RMR = [I_{UCS}] + [I_{RQD}] + [I_{JS}] + [I_{JC}] + [I_{GW}] + [I_{JO}] \quad (1)$$

where I_{UCS}, I_{RQD}, I_{JS}, I_{JC}, I_{GW}, and I_{JO} are the index values of the *UCS*, *RQD*, *JS*, *JC*, *GW*, and *JO* parameters, respectively.

The influence on the rock mass arising from blasting (A_b), in-situ stress (A_s), and major faults (S) is taken into consideration by the *RMR* system. The design *RMR* score can be found by multiplying the basic *RMR* score and appropriate adjustment factors (A_b, A_s and S).

2.2. Rock mass quality system: Q

The original *Q* system for rock mass classification was developed in Norway in 1974 by Barton, Lien, and Lunde of the Norwegian Geotechnical Institute [3]. The system was proposed after the evaluation of 212 tunnel case histories in Scandinavia. The *Q* system is based on six different parameters: (i) *RQD*; (ii) number of joint sets (*Jn*); (iii) roughness of the most unfavorable joint or discontinuity (*Jr*); (iv) degree of alteration or filling along the weakest joint (*Ja*); (v) water inflow (*Jw*); and (vi) stress conditions (*SRF*). The *Q* value, which can range between 0.001 and 1000, can be determined using the following equation:

$$Q = \left(\frac{RQD}{Jn}\right)\left(\frac{Jr}{Ja}\right)\left(\frac{Jw}{SRF}\right) \quad (2)$$

2.3. Modified rock mass rating system: M-RMR

The *RMR* and *Q* systems were used for the design studies of thirteen mines in Turkey between 1986 and 2013. While borax, coal, copper, antimony, galena, and trona were extracted in the six underground mines, the others were produced in surface mines. In all of the mines, the rock masses encountered were of weak, stratified, clay-bearing and jointed character. Experience obtained from rock mass classification studies, in which *RMR* and *Q* systems were increasingly utilized for approximately 28 years in Turkey, has raised a variety of concerns in the adequacy of addressing the role played by rock strength, weathering-roughness-aperture-continuity-filling of discontinuity, groundwater damage, and orientation of discontinuities in weak, stratified, clay-bearing and heavily jointed rock masses. Difficulties were encountered in determining the ratings for a number of input parameters required by the *RMR* and *Q* systems, as explained in detail elsewhere [4–15]. A new classification system with new intervals and ratings, designated *M-RMR*, was developed by Unal and Ozkan [5] to mitigate certain shortcomings of the previous characterization systems. Consequently, the basic *M-RMR* score can be calculated as

$$M-RMR = F_c[I_{PLS} + I_{RQD} + I_{JC}] + [I_{JS}] + [I_{GW}] + [I_{JO}] \quad (3)$$

where the input parameters shown in Eq. (3) are the index values for the weathering coefficient (F_c), *PLS*, *RQD*, *JC*, *JS*, *GW* and *JO*. The suggested intervals and ratings associated with the input parameters are presented in Fig. 1 and Table 1.

The design *M-RMR* score is determined by multiplying the basic *M-RMR* score by two adjustment factors, which reflect the effect of blasting (A_b) and the major weakness planes (A_w) [10,15].

Ulusay [16] demonstrated that for rock masses with lower *RMR* ratings ($RMR < 40$), *M-RMR* deviates significantly from *RMR*. Bieniawski [17] also suggested that the *M-RMR* system be used for rock masses with *RMR* ratings lower than 20. In addition, in a tool developed for *GSI* to better characterize poor and very poor rock masses, both *ICR* and *BSTR* concepts utilized in the *M-RMR* system were used by Osgoui et al. [18].

3. General information about the study region

The Divriği open-pit mine is located east of the city of Sivas, mid-eastern Anatolia. The mine site consists of two main ore bodies, the A-Head and the B-Head, which are magnetite and hematite ore bodies, respectively. The magnetite body is the main mineral deposit, which is fitted into an alteration zone and a tectonic structure; it has a massive character and is therefore brittle. The rock units encountered at the site are syenites, crystallized limestones, serpentinized ultramafics, contact metamorphic rocks, altered serpentines, silicified and carbonated serpentines, and felsic serpentines.

The Divriği open-pit mine is the largest open-pit iron mine currently operating in Turkey. Ore is produced by drilling and blasting; before being transferred to a nearby processing plant, the ore is crushed in an underground chamber, which is connected to the open-pit bottom through a vertical shaft. The crushed ore is then carried to the processing plant via a conveyor-belt transportation system mounted in an underground mine roadway. The processed ore is hauled by railroad to three large domestic iron–steel plants, which are known as Kar-Demir, Er-Demir, and İs-Demir.

4. Geotechnical evaluation of borehole YNK-3

A fully cored geotechnical borehole, YNK-3, was drilled by the Divriği iron mine management to deepen the existing production shaft by 264.15 m, which was originally 54 m long with a 4 m diameter. Drilling started 15 m from the existing shaft and extended to 264.15 m. Although the first 54 m was drilled in a coreless manner, drill cores obtained from the remaining 210.15 m were used in rock mass characterization studies for the design of the shaft support. Conventional single-tube core barrels with diamond surface set bits were used to cut the cores. The cores were 47 mm in diameter up to a depth of 174 m; the diameters of the cores in the subsequent sections of the borehole were 36 mm. This borehole was evaluated based on its lithological units and geotechnical logging [14].

4.1. Lithological units

The rock units present in the borehole were serpentinite, ultramafics, syenite, and ultramafic pyroxenite. These rock units,