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A generic method for rock mass classification

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ABSTRACT

Rock mass classification (RMC) is of critical importance in support design and applications to mining, tunneling and other underground excavations. Although a number of techniques are available, there exists an uncertainty in application to complex underground works. In the present work, a generic rock mass rating (GRMR) system is developed. The proposed GRMR system refers to as most commonly used techniques, and two rock load equations are suggested in terms of GRMR, which are based on the fact that whether all the rock parameters considered by the system have an influence or only few of them are influencing. The GRMR method has been validated with the data obtained from three underground coal mines in India. Then, a semi-empirical model is developed for the GRMR method using artificial neural network (ANN), and it is validated by a comparative analysis of ANN model results with that by analytical GRMR method.

1. Introduction

Engineering design associated with rock mechanics problems is a challenging issue due to the variation of rock strength properties. This is due to the presence of fractures (which govern the stability of surface structures) and in situ stress conditions (which govern the stability of deep structures) in rock masses. Furthermore, groundwater conditions, squeezing and swelling or stability conditions of rock masses, and filling materials in joints will scale their effects (Hudson and Harris, 1997; Panthee et al., 2016). In this regard, proper engineering design is one of the major concerns to avoid failure of engineering structures (Akin, 2013).

There are various schemes of rock mass classification (RMC) to characterize the rock mass strength properties (such as rock quality and rock mass deformability) and in situ conditions. In these RMC systems, each rock parameter is separately assigned with a value (so-called rating) depending on its weight on roof fall (based on the previous case studies). Finally, the ratings of all parameters are combined to obtain a final value used to classify the rock masses. It is observed that the influence of a rock parameter varies with its magnitude. Moreover, such variations are found to be nonlinear for almost all types of rock parameters. To overcome this limitation, the entire range of each rock parameter is divided into a number of zones. Thereby, it becomes quite easier to assign a rating value for each zone. Chances of assigning an appropriate rating to a rock parameter are of high risk if more number of zones is involved. But increasing the number of zones requires more experimental observations, and thus it makes the rock mass rating (RMR) system more complex. Therefore, finding an appropriate number of zones that divides the entire range of a rock parameter is critically important.

Among various RMC systems developed so far, RMR system suggested by Bieniawski (1993) (B-RMR) and Norwegian Geotechnical Institute (NGI) Q-system by Barton et al. (1974) (NGI-Q) are the most commonly used ones. Moreover, these two systems are also considered as the basis for developing many other systems for rock mass classification. Most of the parameters used by these two methods are found to be independent. Consideration of fewer rock parameters in a method implies that it reduces the classification complexity and minimizes the requirement of practical data measurements associated with the rock parameters. This is a quite logical compromise, provided that the criterion of choosing the influencing parameters is closer to the actual field parameter values. But in general, the most influencing rock parameters on site are actually less weighted or ignored in the RMR method. It suggests that a geologist or engineer should emphasize more on appropriate selection of a classification technique for the given rock mass site. This needs observations or huge trial-and-error tests that

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are definitely not the goal behind the approach using a few parameters. For this, there still remain questions about applicability of systems in highly fractured rock conditions. In a critique made by Palmstron and Broch (2006), it is suggested that NGI-Q system fails to properly consider joint orientations, joint aperture, joint continuity and rock strength. Bieniawski (1984) also advised that at least two classification systems may be adopted for practical problems when making a final decision. In spite of that, NGI-Q and B-RMR systems are found to be simplified and the most powerful tools for support design in underground excavations.

Considering the above problems, an attempt has been made to formulate a generic classification methodology for different rock masses. The proposed generic classification system considers the most possible rock load influencing the parameters that are found in a variety of rocks. This generic RMR (GRMR) classification method can be realized after examining the existing RMC systems, such as B-RMR system (Bieniawski, 1993), NGI-Q system (Barton et al., 1974), the system proposed by Central Mining Research Institute (CMRI), Dhanbad, India (CMRI-RMR) (Venkateswarlu et al., 1989), and the others (Sen and Sadagah, 2003; Aksoy, 2008). In order to establish and calibrate the RMR system, a huge number of databases referring to various rock structures are essential. Since it is very difficult to collect such enormous rock load data of different types of rocks, the statistical data related to roof fall are considered here for establishing the GRMR technique. The roof fall data were generated based on three RMR methods, i.e. B-RMR, NGI-Q and CMRI-RMR. Through literature review, it is evident that these three methods are widely used for different types of rocks across the world. The influence of each parameter on RMR classification is analyzed on a commonly used platform of rock load, in which the B-RMR, NGI-Q and CMRI-RMR are included. Variation of rock loads due to the varied rock parameter values in a given range was considered as the criterion to optimize the number of zones in the GRMR method. As for each rock parameter, a relative rating value was assigned based on a sensitivity analysis. The rating variations corresponding to different zones for any parameter associated with a single RMR method were done by a gradient analysis of rock load variation which is found in that RMR method. For parameters that are common in more than one RMR classification method, the rating variations were made by taking a mean value of rock load variations corresponding to those methods. Two rock load equations have been suggested for GRMR to evaluate the rock load that will be used for the purpose of making support design. By realizing the fact that rock structure is very complex in nature and the rock properties in a particular location may also change, an attempt was made here to construct an artificial neural network (ANN) model for the GRMR system (Khatik et al., 2017).

2. Existing methods of rock mass classification

2.1. Rock mass properties

Unlike intact rock, it is difficult to illustrate the strength properties for fractured rocks (Noorian Bidgoli et al., 2013), due to the limitations in complete theories and difficulties in practical measurements associated with fractured rocks (Hudson and Harris, 1997). Also, limited geotechnical data cause restriction on exact mathematical modeling of the relation among rock quality and rock properties. The solution to this problem is to adopt empirical methods such as RMR systems which are based on the condition of rock masses with various properties. These rock properties are the inputs to RMR systems, and hereafter mentioned as rock parameters. The consideration of rock parameters plays a key role in fractured rock masses for arriving to some strength clues. Among various methods available, the one with the highest number of rock parameters provides a closer view to the actual field condition. Fifteen rock parameters were sorted (presented in Table 1) whose values can be measured quantitatively, and all together present a similar nature to actual rock mass conditions. Details about these parameters can be found in the respective references.

2.2. Existing methods of RMR systems

It was observed that the choice of a method for RMC is highly dependent on which parameters are (most) sensitive in actual site. The RMR method which considers those sensitive parameters is chosen for classification. The three most commonly used RMR systems are discussed in the following sub-sections.

2.2.1. B-RMR system

With additional case histories, the RMR system or geomechanics classification has been revised several times (basic principle remained the same) (Bieniawski, 1989). The B-RMR method considers six rock parameters (first six parameters in Table 1). To find out the RMR value using B-RMR system, the rock mass is divided into a number of regions such that certain features are more or less uniform within each region (Bieniawski, 1989). The classification parameters are then measured at each region of rock masses. Each parameter is assigned to an empirical rating, R, corresponding to its actual value according to Table 2 presented in Bieniawski (1973). In this method, the discontinuity presented in rock masses is the most important factor in rock mass classification. Discontinuity spacing and conditions (e.g. roughness and separation) have given 50% weight together. When the number of discontinuity set is less than 3, the rating for discontinuity spacing may be increased by 30%. The strike and deep orientation of discontinuities are considered as separate parameters which also depend on the type of application like tunnel, mine, slope or foundation. The RQD and strength of intact rocks have given weight of 20% and 10%, respectively. The groundwater rating accounts for 15% of total ratings. The final RMR value of the rock is calculated as follows:

$$RMR = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 \tag{1}$$

where R_1, R_2, …, R_6 are the ratings corresponding to six rock parameters as depicted in Table 2. The calculated RMR value lies between 0 and 100. A higher RMR value shows good quality of rock. The B-RMR system has wide areas of applications such as tunnels, chambers, mines, slopes and foundations (Bieniawski, 1989). Nevertheless, the critical rock mass conditions, with large faults, weakness zones, and highly stressed conditions, should be handled with care. From the RMR value, the rock load and rock support can

Table 1
Various rock parameters.

No.	Rock parameter	Source
1	Uniaxial compressive strength (UCS)	Bieniawski, 1974
2	Rock quality designation (RQD)	Deere et al., 1967; Zhang, 2016
3	Spacing of discontinuity (SOD)	
4	Joint roughness value (COD)	
5	Water inflow rate and pressure (GWP)	
6	Orientation of discontinuity (OOD)	
7	Weatherability (WD)	
8	Layer thickness (LT)	
9	Faults in rocks (SF)	
10	Stresses in rocks (RS)	NIRM, 2008
11	Number of joints (NOJ)	
12	Filler material in joints (AOJ)	
13	Swelling and squeezing of rocks (S&S)	
14	Number of weakness zones (NOWZ)	
15	Depth of excavations (DOW)	