International Journal of Mining Science and Technology 24 (2014) 237–244

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Prediction of rock mass rating using fuzzy logic and multi-variable RMR regression model

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ARTICLE INFO

Article history:
Received 22 September 2013
Received in revised form 20 October 2013
Accepted 10 November 2013
Available online 18 February 2014

Keywords:
Fuzzy set
Fuzzy inference system
Multi-variable regression
Rock mass classification

ABSTRACT

Rock mass rating system (RMR) is based on the six parameters which was defined by Bieniawski (1989) [1]. Experts frequently relate joint and discontinuities and ground water conditions in linguistic terms with rough calculation. As a result, there is a sharp transition between two modules which create doubts. So, in this paper the proposed weights technique was applied for linguistic criteria. Then by using the fuzzy inference system and the multi-variable regression analysis, the accurate RMR is predicted. Before the performing of regression analysis, sensitivity analysis was applied for each of Bieniawski parameters. In this process, the best function was selected among linear, logarithmic, exponential and inverse functions and finally it was applied in the regression analysis for construction of a predictive equation. From the constructed regression equation the relative importance of the input parameters can also be observed. It should be noted that joint condition was identified as the most important effective parameter upon RMR. Finally, fuzzy and regression models were validated with the test datasets and it was found that the fuzzy model predicts more accurately RMR than regression models.

1. Introduction

The main purpose of classification systems is to group objects or events using the general scales and terms to simplify the communication of information, the guide of detailed investigations, the prediction of their properties, and the behavior or establishment relationships. The design of an appropriate classification for the prediction behavior of rock mass rating (RMR) involves using both the qualification and the quantification parameters. This in turn leads to the development of many empirical design systems which involves the rock masses. Rock mass classification systems are developed by many researchers. Some of the most commonly used rock mass rating system consist of RMR and Q.

In this study, the latest edition of the rock mass rating system, Bieniawski is used as the reference classification structure (Table 1) [1]. Bieniawski developed a RMR system based on six parameters: the uniaxial compressive strength of intact rock (UCS), the rock quality designation (RQD), the joint or discontinuity spacing (JS), the joint condition (JC), the ground water condition (GW), and the joint orientation.

He assigned statistical rating significances to all these factors [2]. The arithmetic amount of these ratings which correspond to the input values of the five main parameters is referred to as "the total RMR" (Fig. 1). The engineering quality or rock mass rating is represented by "the total RMR", which is acquired by adjusting "the basic RMR" to the influence of joint orientation to the tunnel axis.

The relative contribution of rating factors form of each criterion to the engineering quality of rock masses is emphasized over arithmetic. In rock mass classification processes, subjective uncertainties result in the use of linguistic terms (as the input value of some criteria) whose connotation disagree from one educationalist to another, predetermined and sharp class boundaries, whereas the rock quality is gradational in nature. Linguistic terms are generally preferred by engineers and engineering geologists. How can we make the most of these linguistic terms in expert opinion and decision process? Fuzzy inference system (FIS) reveals not only the basis for specialists' assessments but also makes them more objective, particularly through the process of setting weighting intervals of their perception. FIS enables a flexible classification approach to account the uncertainties by allowing the experts to determine the weighting for qualification terms. As the fuzzy models can cope with the complexity of problematical systems in a flexible and consistent way, in the recent years, various models have been devised for the simulation of empirical classification.

Classification systems are based on the geological characteristics and linguistic terms made in the field. Nguyen and Ashworth

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http://dx.doi.org/10.1016/j.ijmst.2014.01.015
2095-2686/

Table 1
Rock mass rating system, classification parameters and their ratings [1].

	Parameter		Range of value						
1	Strength of intact rock material (MPa)	Point-load Strength index	>10	4–10	2–4	1–2	For this low range uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250	100–250	50–100	25–50	5–25	1–5	<1
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90–100	75–90	50–75	25–50	<25		
	Rating		20	17	13	6	3		
3	Spacing of discontinuities (m)		>2	0.6–2	0.2–0.6	0.06–0.2	<0.06		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces, not continuous, no separation, unweathered wall rock	Slightly rough surfaces, separation<1 mm, slightly weathered walls	Slightly rough surfaces, separation<1 mm, highly weathered walls	Slicken sided surfaces or gouge<5 mm thick or separation 1–5 mm, continuous	Soft gouge>5 mm thick, or separation>5 mm, continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	<10	10–25	25–125	>125		
		Joint water press/major principal σ	0	<0.1	0.1–0.2	0.2–0.5	>0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating	15	10	7	4	0			

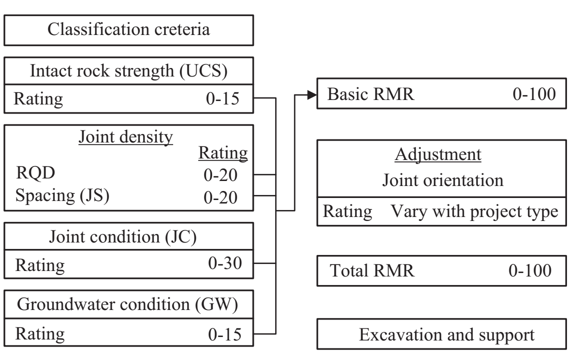

Fig. 1. RMR classification for characterization and design purposes [3].

employed the fuzzy set for obtaining a rock mass classification rating from the CSIR classification system with the incorporation of expert knowledge [4,5]. Similarly, Habibagahi and Katebi used the fuzzy set theory to develop an approach for rock mass classification by maintaining the logic behind the RMR proposed by Bieniawski [6,7]. A rock mass classification method was put forward by Aydin which is based on the notion of partial fuzzy sets representing the variable significance of each parameter in the universal domain of rock mass quality [3]. Juang and Lee's fuzzy classification method is based on Dong and Wong's FWA (fuzzy weighted average) algorithm and aggregates the individual (fuzzy) ratings of different criteria into an overall classification rating [8,9]. The earlier classification methods explained the potential of the modifications of RMR classification structure, universal domains and class intervals, membership functions, and aggregation and defuzzification procedures. This probably demonstrates their failure to achieve support as practical tools. Unlike the earlier approaches, the proposed method addresses the matter of capability of RMR criteria by constructing weighting intervals for linguistic terms. The proposed weighting intervals concept was shown in order to demonstrate the capability of expressing inconsistency of rock quality conditions as well as a specific geological setting by the subjective opinion of the expert. The proposed weights adapted to different geological and engineering environments and of tackling intrinsic uncertainties in the classification process.

This study established a method for fuzzification of descriptive criteria that develops FIS for predication of RMR. Also a multi-variable regression was established with these weighting intervals and was compared with the result of the Mamdani fuzzy inference system. Before implementation of regression analysis, sensitivity analysis was performed based upon the main dataset to determine the best relationship between each parameter and RMR. The proposed approach is based on the weighting intervals that were introduced for JC and GW. It should be noted that the results are strongly controlled by the subjective conclusion of the expert. In this study, to validate the obtained results from prediction of regression analysis and Fuzzy inference system, input data from three case studies were considered into account. So, datasets were collected through an extensive field investigation from selected sites, named; Almas, Dehdasht and Ziaran sites, which are located in center of Iran. It should be noted that in this paper, two different datasets are used. The first series which called main dataset, is applied for constructing fuzzy inference system and regression equation and the second series, called test dataset, is used for assessing the performance of these models.

Fig. 2a shows the outcrop of Aasmari formation at south western of anticline in Almas site. The rose diagram of bedding planes along the Almas tunnel is displayed in Fig. 2b. Fig. 2c shows the discontinuities joint set patterns at Dehdasht site. The rock formation along the main tunnel axis (located at Almas site) are formed by clay limestone and grey marls. In some sections along the tunnel axis, rock formations are divided by several minor faults.