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Determination of geological strength index of jointed rock mass based on image processing

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ABSTRACT

The geological strength index (GSI) system, widely used for the design and practice of mining process, is a unique rock mass classification system related to the rock mass strength and deformation parameters based on the generalized Hoek-Brown and Mohr-Coulomb failure criteria. The GSI can be estimated using standard chart and field observations of rock mass blockiness and discontinuity surface conditions. The GSI value gives a numerical representation of the overall geotechnical quality of the rock mass. In this study, we propose a method to determine the GSI quantitatively using photographic images of in situ jointed rock mass with image processing technology, fractal theory and artificial neural network (ANN). We employ the GSI system to characterize the jointed rock mass around the working in a coal mine. The relative error between the proposed value and the given value in the GSI chart is less than 3.6%.

1. Introduction

Generally, knowledge on the mechanical properties of rock mass is a prerequisite for the numerical simulation and the design of the underground structure, opening-up of mineral deposits and mining processes.

Since the early 1990s, many scholars (e.g. Hoek and Brown, 1997; Hoek et al., 2005, 2008, 2013; Hoek and Marinos, 2007) have proposed a variety of methods to determine the strength and deformation parameters of rock mass using geological strength index (GSI). The standard GSI chart considers qualitatively the surface condition and blockiness of a rock mass, and is used to estimate a value between 0 and 100 representing the overall geotechnical quality of the rock mass (Fig. 1). The GSI approach has been modified over the years and applied to characterizing the mechanical properties of rock mass by many authors (e.g. Sonmez and Ulusay, 1999; Cai et al., 2004, 2007; Sonmez et al., 2004; Bridean, 2005; Marinos et al., 2006).

The best outcomes can be achieved only by collaboration between experienced engineering geologists and geotechnical engineers. Quantifying estimates of GSI may provide a means of reducing inadvertent errors and inconsistencies by inexperienced practitioners in classifying a rock mass.

Bieniawski (1989) and Hoek and Brown (1997) suggested that GSI can be related to the modified rock mass quality index *Q* and rock mass rating (RMR), respectively. A recent paper by Hoek et al. (2013) proposed a method for quantifying GSI using the rock quality designation (RQD), the joint condition rating of the RMR system, and the joint condition factor ($JCond_{89}$) by Bieniawski (1989). Russo (2009) suggested a new approach for quantitative assessment of the GSI (Hoek et al., 1995) by means of the basic input parameters for the determination of the rock mass index (RMI), such as the elementary block volume and the joint conditions. A recent paper by Bertuzzi et al. (2016) provided data from four different rock masses to extend the case history proposed by Hoek et al. (2013). The correlation between the GSI qualitatively assessed from the standard GSI chart and the quantified GSI was found to be fair for the datasets from the four rock masses.

Akin (2013) estimated the GSI value using the back analysis method with shear strength parameters of a failure surface in heavily jointed rock masses on a slope. The shear strength parameters of a failure surface under a specific normal stress can be determined using the material constants of the Hoek-Brown failure criterion (m_b and s) as a function of the GSI value. Also, Tajdus (2010) proposed a back analysis method of the surface subsidence, which is based on the uniaxial compressive strength R_c of rock samples, as well as mining and geological conditions, to

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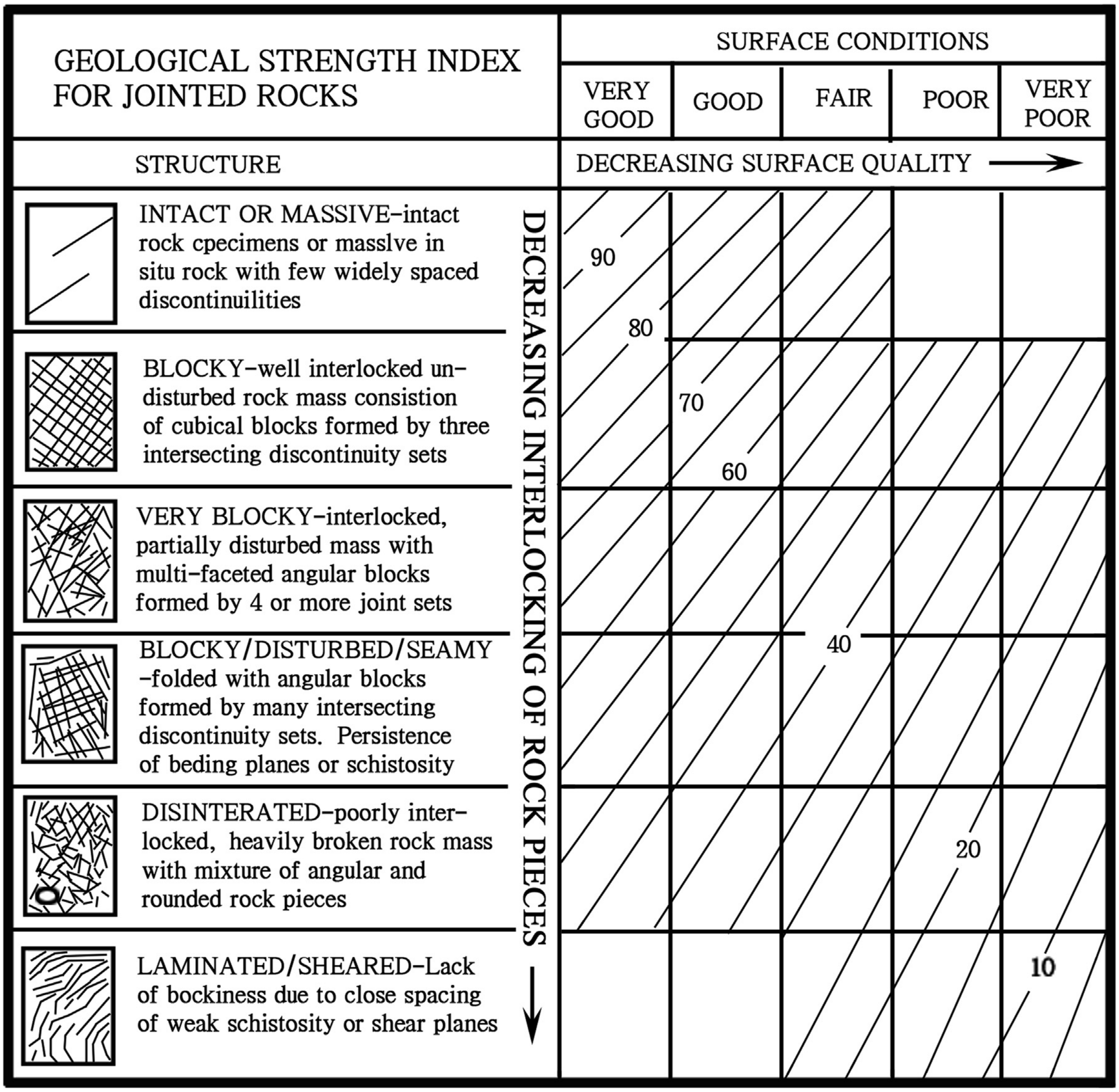

Fig. 1. Chart for determining GSI of jointed rock mass (Hoek and Brown, 1997).

determine the GSI values of a rock mass disturbed by underground exploitation.

In recent years, several authors such as Han et al. (2014), Poulsen et al. (2015) and Wang et al. (2015a) have also suggested many methods to determine the strength and deformation parameters of rock mass using GSI. All of the above-mentioned papers focused on quantifying the GSI chart to facilitate use of the system especially by inexperienced practitioners.

Many researchers (e.g. Crosta, 1997; Castleman, 2002; Hadjigeorgiou et al., 2003; Lemy and Hadjigeorgiou, 2003; Lato et al., 2009) have investigated digital face mapping as a practical tool to characterize rock masses, which can significantly reduce the time required in the field and avoid exposure to potentially unsafe conditions.

The digital rock mass rating (DRMR) developed by Monte (2004) uses basic image processing procedures and calculations to estimate a classification rating from digital images of rock masses. The rating system incorporates fracture information collected from a discontinuity trace map (e.g. length, spacing, large-scale, roughness, rock bridge percentage, and block volume).

In this paper, we propose a method to quantitatively determine the GSI by first detecting the joints in two-dimensional (2D) photographs of a rock mass surface using the image processing technology, then determining the fractal dimension, and finally predicting the GSI using artificial neural network (ANN). The applicability of the method proposed is verified through stability analysis of the working in a coal mine.

2. Joint detection on the rock mass surface using image processing

Fig. 2 shows the schematic flowchart for detecting joints on the rock mass surface via image processing. The detailed steps for joint detection on the rock mass surface are described as follows.

(1) Converting the color image of rock mass to black and white one

To detect the joints on the image of jointed rock mass, the contrast of the image should be analyzed. We convert the natural