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Automated tunnel rock classification using rock engineering systems

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ABSTRACT

At present, rock mass classification in tunnel construction basically depends upon geologist's knowledge, and normally suffered from bias judgments. Based on rock engineering system and computer programming technology, an approach to automated zonation and classification of rock mass is presented in this paper. Seven parameters are considered and parameter interaction intensity and weighting of each parameter have been analyzed. Discontinuity property is found to be the most important factor influencing rock mass quality. The rock mass quality index, which is the weighted summation of each selected parameter, is put forward for rock mass classification. A computer-aided automated classification system is then developed and used for the Dazhushan tunnel. The classification results show good agreement with that by RMR, indicating that the proposed system can work precisely, with its powerful function for data management and fast implementation.

1. Introduction

Rock mass classification is an essential step for implementation of rock engineering (Ramamurthy, 2004). The classification system is gradually developed from the early stage with a single factor, to the present stage with multiple qualitative and/or quantitative factors. Since rock quality designation (RQD), which is suggested by Deere (1964), researchers have been working in this dependency to achieve an efficient method for rock mass quality assessment (Wickham et al., 1972; Bieniawski, 1973; Barton et al., 1974). Intact rock strength, joint properties (roughness, orientation, aperture, seepage and infilling etc.) and groundwater have been gradually been taken into account in addition to RQD. Wickham et al. (1972) proposed a rock structure rating system (RSR) for tunnel support design. Bieniawski (1973) further developed the RSR to a portion-rating system, called rock mass rating (RMR). Rock tunneling quality index (Q), another system closely related to RMR, was proposed by Barton et al. (1974) and has been widely utilized in tunnel construction. Later on, mathematical algorithms, such as Analytic Hierarchy Process by Saaty (1980) and the fuzzy Delphi method by Kaufmann and Gupta (1988) were also employed for rock mass classification.

However, the first step to assess a rock mass quality is zoning the overall rock profile. And this is always done with the geologist's experiences in practice. Approaches (e.g., RMR and Q system) are then adopted to evaluate the rock mass within each zone and classify it into different categories. However, rock mass classification is usually time-consuming in engineering practice. Fan et al. (2003) put forward a new method to analyze the structural homogeneity of rock mass based on discontinuity density, which has been successfully applied for zoning the rock mass in some large hydropower projects in Southwest China. However, the available zonation methods need to build a complex model, which is normally requested to be further tailored and modified for specific conditions. Meanwhile, with the implementation of western development strategy of China, construction of long, large and deep tunnels for railway and expressway has been progressing at a great speed in mountainous areas than ever. It is, therefore, of great importance to identify the factors, which have influences on zonation and classification of rock mass during tunnel construction. In addition, the relative importance (weighting) of each parameter is another issue to be addressed for actually evaluating the subjected rock mass. Rock engineering system (RES), put forwarded by Hudson and Harrison (1992), is one of the most powerful methods in rock engineering to deal with complex engineering problems from a holistic point view, with its preferential characteristics, such as comprehensiveness, adaptability, repeatability, efficiency and effectiveness. The present paper tends to propose an automated rock mass classification method for tunnel engineering based on the RES method and computer programming technology. The aim is set to provide quick and accurate information of rock mass for tunnel support design.

The Dazhushan Tunnel in Baoshan region, Yunnan province, is employed to illustrate the operation of this newly proposed method. Seven parameters are considered as the main factors for zonation and classification. Their degree of interaction intensity is obtained based on site investigation, engineering expertise, theoretical and numerical analyses, and retrievable archives. The weighting of each selected

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parameter is determined, based on which the rock mass quality index (QI) for rock mass classification is put forward. The automated procedures have been programmed for achieving a feasible and quick rock mass evaluation system for tunnel engineering.

2. Methodology

In tunnel construction, rock mass classification is the fundamental for rock mass stability evaluation and tunnel support design. This is usually achieved by means of semi-quantitative approach combined with expert experiences (Shen and Guan, 1998). Particularly, the zonation of tunnel profile depends, to a large extent, upon the available information of the geological condition and the expert's knowledge. One would probably get totally different and even contradictory results from others for the similar situations, since nobody can completely understand the underground geological conditions. There is, therefore, urgent requirement for a suitable approach with quantitative and theoretical foundation to optimize the zonation and classification of rock mass. RES (Hudson, 1992) is one of the examples to meet the above requirements.

The interaction matrix is the basic analytical device used in the RES approach for considering all variables and mechanisms relevant to a particular engineering problem (Hudson and Harrison, 1992). In RES, all parameters affecting the rock mass quality are arranged along the leading diagonal of the interaction matrix. The corresponding off-diagonal position is the influence degree of each individual factor to any other factor, called as the off-diagonal terms. As shown in Fig. 1, Subject A represents a certain influential factor, which is placed in one of the leading diagonal boxes of the matrix. Subject B, as one of other factors, is placed in a different leading diagonal box. As the leading diagonal is laid from top left to bottom right, we consider the influences of A on B and B on A with a clockwise convention (Figure 1).

Fig. 2 illustrates the coding of a multiple-dimensional interaction matrix. A problem, containing N factors, has an interaction matrix of N rows by N columns. The column passing through P_i represents the influence of other factors on parameter P_i, while the row through P_i represents the influence of P_i on the rest factors. According to Hudson and Harrison (1992), the 'expert semi-quantitative' (ESQ) method is most commonly used in engineering practice for coding the matrix in Fig. 2, and the interaction between parameters are ranked by a numerical scale, shown in Table 1. After coding the matrix, the sum of each row and column can be calculated. The summation of row values for each parameter is termed as 'cause' value (C_i), and the summation of column values is named as 'effect' value (E_i). Thus, a cause–effect graph can be plotted by the summarized information of coordinates (C_i, E_i), which helps to understand the relative importance of each parameter within the system (Jiao and Hudson, 1995). The other information will be described in detail below together with an application example.

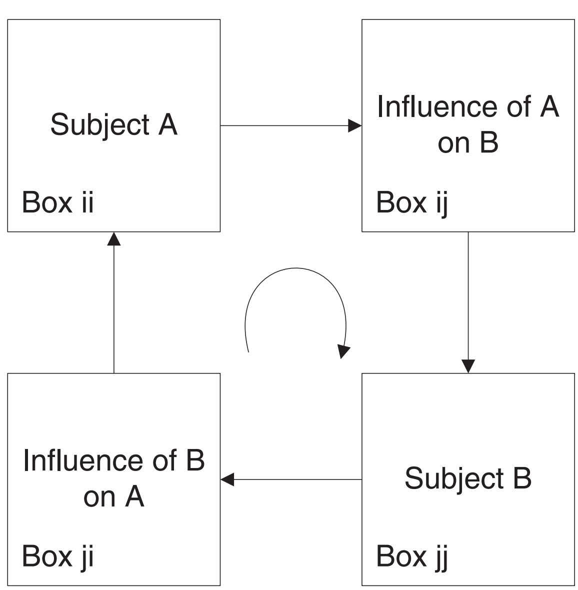

Fig. 1. The principle of the interaction matrix (Hudson, 1992).

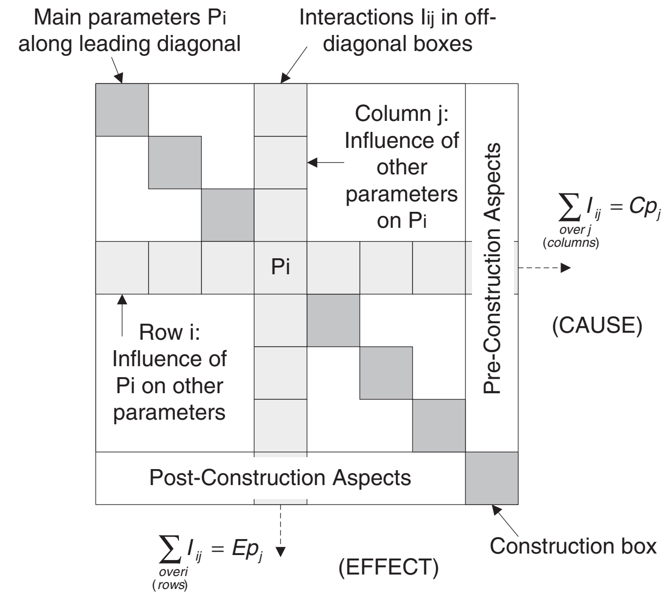

Fig. 2. Summation of coding values in the row and column through each parameter to establish the cause and effect coordinates (Hudson and Harrison, 1992).

3. Example of application

To demonstrate the application of the above-mentioned method for zonation and classification of rock mass for tunnel engineering, the Dazhushan Tunnel is selected as a case study, which is a long, deep-buried tunnel on the under-construction Dali-Ruili railway (Figure 3).

Fig. 3 shows the location of the Dazhushan tunnel. The tunnel is 14.5 km long, and the maximum depth is approximately 1010 m. The entrance is located on the steep face of the river valley, at an elevation of 1450 m above sea level. The exit on the other side is at an elevation of 1700 m. The area is principally located in the active NW-trending Lancangjiang River fault zone. The regional structural features are shown in Fig. 4, such as the Wulishao fault, Yijingshui fault and Yangjiashan overturned anticline. Almost all kinds of geological structure can be found in this region, and the lithology is rather complicated. The typical rocks are sequences of purplish red sandstone, thick-layered gray limestone and fuchsia mudstone. In addition, charcoal gray slate with sericite, shale, basalt and diabase can be found in some other parts of the region.

Table 1
Expert semi-quantitative method for coding the interaction matrix.

Code value	Significance
0	No interaction
1	Weak interaction
2	Medium interaction
3	Strong interaction
4	Critical interaction