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From the new Austrian tunneling method to the geoengineering condition evaluation and dynamic controlling method

Yanjun Shang [a,*], Kun Li [a], Wantong He [a], Chunbo Sheng [b]

[a] Key Laboratory of Engineering Geomechanics, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[b] Shanxi Branch, China State Construction International Holdings Limited, Yangquan 045000, China

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ABSTRACT

The new Austrian tunneling method (NATM) is widely applied in design and construction of underground engineering projects. When the type and distribution of unfavorable geological bodies (UGBs) associated with their influences on geoengineering are complicated or unfortunately are overlooked, we should pay more attentions to internal features of rocks grades IV and V (even in local but mostly controlling zones). With increasing attentions to the characteristics, mechanism and influences of engineering construction-triggered geohazards, it is crucial to fully understand the disturbance of these geohazards on project construction. A reasonable determination method in construction procedure, i.e. the shape of working face, the type of engineering support and the choice of feasible procedure, should be considered in order to mitigate the construction-triggered geohazards. Due to their high sensitivity to groundwater and in-situ stress, various UGBs exhibit hysteretic nature and failure modes. To give a complete understanding on the internal causes, the emphasis on advanced comprehensive geological forecasting and overall reinforcement treatment is therefore of more practical significance. Comprehensive evaluation of influential factors, identification of UGB, and measures of discontinuity dynamic controlling comprises the geoengineering condition evaluation and dynamic controlling method. In a case of a cut slope, the variations of UGBs and the impacts of key environmental factors are presented, where more severe construction-triggered geohazards emerged in construction stage than those predicted in design and field investigation stages. As a result, the weight ratios of different influential factors with respect to field investigation, design and construction are obtained.

1. Introduction

The main concerns for engineering geologists worldwide include the evaluation of engineering geological conditions, the comparison and suggestion of engineering site selection, the forecast of key geological problems and the dynamic adjustment of design and construction items. In China, many kinds of geological and geomorphological environments are commonly observed, and the complex engineering geological conditions are the challenging issues and disputations up to now.

In the stages of field investigation and design, some complex engineering geological conditions often have problems confusing engineers or researchers, possibly making them misunderstand or miscalculate. In the stages of project planning or layout setting, the site selection or project spatial alignment can mostly cause unreasonable strategic decisions or problematic designs when unfavorable geological bodies (UGBs) are not well identified. As a result, multiple influential factors associated with unknown weight ratios and thresholds should be considered as the key issues in following analysis process. As deformation or failure modes of rock mass are not adequately understood, there are potential risks in the excavation or reinforcement schedules. Thus, a synthetic method is needed to address above-mentioned problems.

In this regard, the authors propose a geoengineering condition evaluation and dynamic controlling (GEDC) method. The GEDC method includes engineering geological evaluation, comparison of engineering site locations, identification of UGB, and dynamic controlling of removal of rock mass fragments during construction. The GEDC is significantly different from the new Austrian tunneling

* Corresponding author. Tel.: +86 10 82998634.
E-mail address: jun94@mail.igcas.ac.cn (Y. Shang).
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method (NATM) which is based on displacement monitoring and reinforcement of shotcrete and rockbolt with elapsed time, as well as preliminary and secondary support at different steps. The self-stability of rocks grades I–III basically can be guaranteed, while for fractured rock mass of grades IV and V, reinforcement must be employed, depending on variations of structural model and parameters used. In this paper, the GEDC is introduced and a case study of landslide is presented for the purpose of validation.

2. Program and methods

The GEDC can be regarded as an engineering geological program consisting of three key steps:

(1) Synthetic evaluation of engineering geological conditions by means of interaction matrix of multiple influential factors, analytic hierarchy process (AHP), expert scoring method, etc.
(2) Identification of UGBs by means of field investigation, analogical analysis, etc.
(3) Dynamic controlling of rock mass structures with the aid of back analysis using monitoring results or of forecast using index thresholds as deformation rate ratio criterion (DRRC), etc.

2.1. Synthetic evaluation of engineering geological conditions

In the earlier stages of project plan and design, assessment of engineering geological conditions associated with comprehensive analysis methods should be considered. According to the engineering geomechanical meta-synthesis system methods (EGMS) (Yang, 1993) and/or the meta-synthesis in the engineering geology (Wang, 2011), three components, i.e. the associated theories, expert group experience, in situ observation and monitoring, are combined to constitute an approach to solve problems in association with huge open complex system of engineering geomechanics. Some scholars, e.g. Hoek et al. (1995), have already mentioned the importance of theoretical models where above three components for a synthetic evaluation of engineering geological conditions should be combined.

In this approach, the interaction matrix of multiple influential factors, AHP, and expert scoring method is necessary where the input and output can be visibly obtained.

2.1.1. Interaction matrix of multiple influential factors

The interaction matrix analysis method was initially proposed in rock mechanics analyses (Hudson and Harrison, 1992) and was further developed for engineering geology evaluations (Shang et al., 2000). In this method, the main influential factors at different levels are first selected and compared. Then, an asymmetric matrix is constructed with the factors array at main diagonal line, and their interaction degree codes (generally from 0 to 4) are input spatially clockwise, i.e. for one couple of adjacent factors in the diagonal line, the cause (initiative) action codes are arrayed at rows, while the effect (passive) action codes are at columns. Finally, the sum of each row and column is calculated, respectively, and the weight of any influential factor is equal to the ratio of its cause adding effect values to the sum quantity. On the other hand, the function rating code actually depends on the active degree of factors in site, and the rating codes of $N = 0, 1, 2$ indicate non-active, active, and intense active, respectively. The sum of the weight ratio associated with the rating code is equal to the total actual assessment values of factors W_i:

$$W_i = \frac{N\alpha_i}{2} \tag{1}$$

where W_i is the actual weight ratio of factor i, ranging from 0% to 100%; N is the rating code from the actual function of factors in site, $N = 0, 1, 2$; α_i is the weight ratio of factor i in one region or obtained from the interaction matrix, and α_i = 0%–100%.

2.1.2. Analytic hierarchy process (AHP)

The AHP is commonly used in engineering for comparison of priority of various factors at different levels. The AHP is regarded as one level-structural mathematical model. First, the level analytical model is set up. Then, a judgment matrix $\boldsymbol{A}$ is organized with codes 1–9. Next, the calculation is carried out step by step to obtain different evaluation results with math checks (Saaty, 2008). The random consistency index CI is used to check the logic trueness of the judgment matrix:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

where λ_{max} is the maximum value of eigenvalue of the matrix $\boldsymbol{A}$, and n is the number of eigenvalue in the matrix $\boldsymbol{A}$.

Generally, if $CI \le 0.1$, it can be noted that the judgment matrix is consistent, and the calculated value of weight ratio W is acceptable.

The random index RI is

$$RI = \frac{\lambda'_{max} - n}{n - 1} \tag{3}$$

where λ'_{max} is the average value of the maximum eigenvalue of the matrix $\boldsymbol{A}$. The RI is an experimental value depending on the number of eigenvalue, n.

Finally, the total level array and consistency are checked. Priority of each parameter C_i to the highest target level A, through level B_i in terms of A/C_i, is represented as $W(A/C_i)$ for overall priority of the consistency ratios of random arrays:

$$CR_2 = CR_1 + \frac{CI_2}{RI_2} = CR_1 + \frac{\sum_{i=1}^{n} CI_{2i} W(A/B_i)}{\sum_{i=1}^{n} RI_{2i} W(A/B_i)} \tag{4}$$

In this way, the total random consistency ratio CR values of parameters in level C can be obtained.

2.1.3. Expert scoring method

The results using expert judgment system are scored for different parameters with various weight ratios and ratings. Various parameters values are summarized and represented through expert assessment in a way of semi-quality and semi-quantity. The factors constituting the engineering geological conditions are determined based on relative standards or specifications. Practically, the expert scoring method based on experiential judgment of interactions and synthetic evaluation of geo-engineering conditions is widely applied in engineering practice but mostly qualitatively. Thus, it should be noted that the weight ratio of expert judgment results is theoretically different, so the selection of expert, who is familiar with the actual engineering geological situations and has the mandatory knowledge of corresponding theory, is critically important.

2.2. Identification of UGB

Classification and zonation are the main approaches for identifying various site-specific UGBs. Classification of UGBs and corresponding measurements associated with different kinds of UGBs are illustrated in Fig. 1.

The UGB can be divided into 3 types, i.e. soft rock and hard soil, karst cavern, and weak discontinuity, each composed of different media and components. In sites, risks and geohazards have a close relationship with UGB (see Fig. 1), where the scientific adjustment