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Advance optimized classification and application of surrounding rock based on fuzzy analytic hierarchy process and Tunnel Seismic Prediction

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ABSTRACT

An advance optimized classification method is proposed to accurate predict the surrounding rock classification based on Fuzzy Analytic Hierarchy Process (FAHP) and Tunnel Seismic Prediction (TSP). Several factors that greatly affect rock mass classification are selected as evaluation indices of FAHP based on analysis of numerous TSP data. Evaluation indices are divided into five grades according to its response characteristics of seismic wave field, and their membership functions are proposed by using frequency statistical method. Comprehensive assigning method is adopted to determine the weights of evaluation indices, and a FAHP model is established for optimized classification of surround rock. Engineering application of Shimenya Tunnel of Yi-Ba Highway is taken as a case study, and proved that the evaluation indices are easy to obtain and the evaluation results are accurate and reliable. The FAHP-TSP method can be further used for other tunnel engineering.

1. Introduction

The engineering quality classification of tunnel rock is an important part of rock mechanics and engineering basic work. The classification of tunnel rock structural characteristics and strength properties provides basic data for the support program selection [1,2].

The rock classification methods in the application of rock engineering are mainly "Engineering Rock Grading Standards", Q system and RMR system. The focuses of all three methods are not the same. The Q system is a qualitative classification method. The RMR method is a semi-quantitative, semi-quantitative method. The "Engineering Rock Grading Standards" uses a combination of qualitative and quantitative methods. Both qualitative and quantitative methods to determine the rock level are consistent, and we can further determine the rock mass level [3–7].

In addition, these methods have some inadequacies, ignoring the impact of tunnel rock mass quality classification of uncertainty, complexity and ambiguity features, and often lead to inconsistency with the actual results of the assessment [8–12]. Therefore, the fuzzy mathematics theory is introduced to engineering application to effectively avoid the problem above and make the evaluation results more accurate [13–17].

TSP (Tunnel Seismic Prediction) is the most widely used method in tunnel long-distance detection. This method predicts through a long distance (100 to 150 m), impacts little on the construction and doesn't occupy the tunnel face. TSP method predicts the unfavorable geology (joints, fissures, faults and fracture zone), which is perpendicular to the tunnel axis more accurately [18,19]. However, in the surrounding rock classification, TSP is only based on the single factor judgment of the longitudinal wave velocity, and leads to less accurate results [20,21].

According to the above problems, this paper presents a surrounding rock optimized classification method based on TSP203 and FAHP. This method enhances the effective use of the TSP detection data and the prediction accuracy of the surrounding rock classification. It can be extended to other projects, such as tunnel, roadway and diversion tunnel.

2. Effect factor analysis of the surrounding rock classification based on TSP

2.1. The principle of TSP

TSP is an underground reflection seismic wave technology for geological condition advance prediction before the tunnel face. In Fig. 1, the seismic waves are excited by some (generally less than 24) small-scale artificial blasting in specific blasting point and received by electronic sensor. When the seismic incident waves encounter formation interface, joint interface, and especially unfavorably geological interface such as fault fracture zone, karst cave and underground river, the reflected waves are generated and received by the receiver, and they are amplified, outputted, recorded by digital recorder [18–21].

The calculation formula of longitudinal wave velocity V_P is:

$$V_P = \frac{L_1}{T_1} \tag{1}$$

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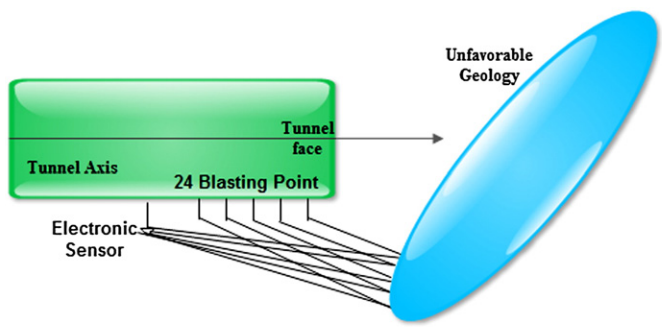

Fig. 1. The principle of TSP.

where L_1 is the distance from the seismic source and sensor, and T_1 is the transmission time of the first wave arriving at the sensor.

The transmission time of the reflected wave T_2 can be calculated as follows:

$$T_2 = \frac{(L_2 + L_3)}{V_P} = \frac{(2L_2 + L_1)}{V_P} \tag{2}$$

where L_2 is the distance from the blasting hole to the reflector, and L_3 is the distance from sensor to the reflector.

The sensor can receive the reflected wave information, and present the characters and occurrence related to the interface by different dates. The Poison's ratio (Eq. (3)), Young modulus (Eq. (4)) etc. of the tunnel can be obtained by the following formula so as to make the prediction of the unfavorable geology before the tunnel face.

$$\nu = \frac{V_P^2 - 2V_S^2}{2(V_P^2 - V_S^2)} \tag{3}$$

$$E = \rho V_S^2 \left(\frac{3V_P^2 - 2V_S^2}{2V_P^2 - V_S^2} \right) \tag{4}$$

Where V_s is the shear wave velocity, V_p is the longitudinal wave velocity and ρ is the rock density. An attribute synthetic assessment system consists of three components: single index attribute measure analysis, multiple indices synthetic attribute measure analysis and attribute recognition analysis.

2.2. Analysis of effect factors

(1) The rock physical and mechanical parameter
The accurate V_P can be obtained from the result of TSP. Other parameters are obtained by V_P and empirical formulas. Therefore, V_P is selected as the indicator of rock physical and mechanical parameter (Table 1).

(2) The integrity coefficient of rock mass
The integrity coefficient of rock mass reflects the integrity degree of rock mass, and the K_v can be calculated as follows:

$$K_v = \frac{{V_{pm}}^2}{{V_{pr}}^2} \tag{5}$$

where V_{pm} is the longitudinal-wave velocity of rock mass and V_{pr} is the longitudinal-wave velocity of the rock. K_v can be obtained based on V_p by TSP 203 and V_{pr} (Table 2).

(3) The surface state of discontinuous structure
Combined with the experience of the TSP prediction, the grade division is shown in Table 3.

(4) Groundwater
Groundwater affects the surrounding rock stability greatly. The grade division of groundwater is shown in Table 4.

(5) Main-structure surface and the angle of tunnel axis
The main-structure surface and the angle of tunnel axis also affect the surrounding rock stability greatly. The grade division of groundwater is shown in Table 5.

Table 1
Grade division of V_p.

Grade	V_P (km/s)
V	<0.15
IV	0.15–0.25
III	0.25–0.35
II	0.35–0.45
I	>0.45

Table 2
Grade division of K_v.

Grade	K_v
V	<0.15
IV	0.35–0.15
III	0.55–0.35
II	0.75–0.55
I	>0.75

3. FAHP evaluation model

First proposed by T.L. Saaty [22–24], the analytic hierarchy process (AHP) is suitable for dealing with complex systems related to making a choice from several alternatives and provides a comparison of the considered options,. To improve the AHP method and to determine the relative weight of criteria of risk assessment, this study applies the fuzzy analytic hierarchy process (FAHP) and expresses the comparative judgments of decision-makers with trapezoid fuzzy numbers [25–30].

3.1. Establishment of factor set

This paper selects five main effect factors to establish the following factor set.

$$U = (u_1, u_2, u_3, u_4, u_5) \tag{6}$$

Where u_1 is the rock physical and mechanical parameter; u_2 is the integrity coefficient of rock mass, u_3 is the surface state of discontinuous structure, u_4 is the groundwater and u_5 is the main-structure surface and the angle of tunnel axis. The grade division of factors is shown in Table 6.

Table 3
Grade division of discontinuous-structure surface.

Grade	Detailed description
Very strong	The P-wave negative reflection is very strong, and the positive and negative reflection layers in reflection zone are abundant and mussy. The P-wave and S-wave velocities decrease and change frequently.
Strong	The P-wave negative reflection is strong, and the single reflection has a wide bandwidth and a good extension.
Medium	The P-wave negative reflection is obvious.
Small	The P-wave negative reflection is weak.
Very small	The P-wave negative reflection is not obvious.