Advance Optimized Classification and Application of Surrounding Rock Based on Matter-element Extension Theory and Tunnel Seismic Prediction

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ABSTRACT
The geological conditions of tunnel engineering are complex and changeable, which leads to great difference between the surrounding rock classification in survey design stage and in construction stage. So a multi-index matter-element extension evaluation model for tunnel surrounding rock advanced optimization classification is established based on tunnel seismic prediction (TSP) and extension theory. Firstly, by collecting and collating information and results from the prediction data of a large number of typical TSP examples, the rock mass integrity index $K_v$, Young's modulus $E$, the longitudinal wave velocity $V_p$, Poisson's ratio $\mu$, and groundwater $W$ were selected as evaluation indexes of surrounding rock classification. According to seismic wave field response characteristics of various influence factors, the influence factors were divided in detail. Then, quantitative indicators were collected by using the TSP detection technology. Some main quantitative indicators with quantitative preprocessed were used to build the matter-elements. A simple correlation function is used to determine index weight for avoiding human subjective effect and making the results more objectivity. Lastly, the matter-element extension evaluation model is applied to the construction site of the Jinpingyan Tunnel and the evaluating results are compared against the site’s excavation situation. The results of the engineering practice turned out that the evaluation result is accordant with the excavation situation. The evaluation indices are facile to achieve and the evaluation results are accurate and reliable; thus, the model can provide scientific guidance for tunnel surrounding rock classification.
KEYWORDS: surrounding rock classification, tunnel seismic prediction, extension theory, engineering application.

1 INTRODUCTION

With the continued development of China’s economy, more and more attention has been paid to the development of tunnels and underground space. Engineering rock mass classification is an important part of rock mechanics research and project research. It can not only evaluate the structural characteristics and strength characteristics of rock mass, but also provide basic information for the selection of supporting schemes (Hassan and Hani, 2017; S. Takayama, 2008).

At present, quality evaluation methods of rock mass are frequently used including Engineering Rock Grading Standards, Q system, RMR system and RQD system. Qualitative and quantitative methods are adopted in Engineering Rock Grading Standards (The National Standards Compilation Group of People’s Republic of China, 1995), the combination of qualitative and quantitative methods to determine the grade of rock mass is consistent, and can further determine the grade of rock mass. Q system (Bieniawski, 1989) is a qualitative classification method with subjective randomness. RMR system (Barton et al., 1974) is a semi-qualitative and semi-quantitative method. RQD system is a rough method for measuring the degree of jointing or fracture in a rock mass. All these methods have a common shortcoming: due to the fixed evaluation factors and scoring methods, these methods all ignore the uncertainty, complexity and fuzziness of the quality classification of tunnel rock mass, which often lead to the fact that the evaluation results inconsistent with the actual (Martin et al. 2007; A. Salimi et al. 2017).

Therefore, domestic and international scholars have done a lot of research work on classification optimization methods of tunnel surrounding rock. Chen et al. (2011) selected rock integrity coefficient, friction coefficient of surface structure, coefficient of saturated rock firm and rock longitudinal wave velocity coefficient as influence factor of the surrounding rock classification, and applied support vector machine (SVM) to classify the surrounding rock stability. Chu et al. (2013) built up a gray correlation model based on analytic hierarchy process, the analytic hierarchy process is used to calculate weight value of the indices of classification and the improved calculation method of gray correlation is applied to determine the surrounding rock classification in the model. Shi et al. (2014) proposed an advance optimized classification model based on fuzzy analytic hierarchy process and tunnel seismic prediction, where the comprehensive assigning method was adopted to determine the weights of evaluation indices. Vitthal M and Arup Kr (2017) took into account the complexity of rock structure in nature and the variability of the rock properties in a particular location, and established a semi-empirical model for the generic rock mass rating method using artificial neural network. Jafar et al. (2010) illustrated the application of fuzzy set theory in the surrounding rock grade assessment processes and applied it to rock mass classification. Gioacchino and Mario (2016) proposed a new classification method of rock masses by adapting the rock engineering system method based on the local properties of the outcrops, the site conditions and the type of engineering work. Francisco et al. (2017) presented a new method for surrounding rock classification based on color and 3D laser based features. Each method mentioned above made some achievements and promote the progress of the classification of surrounding rock. However, every method has also their own some disadvantages (Aydin, 2004; Tzamos, 2006). For example, the grey model is with the characters of less data, high precision and without prior information, but there is a strong dependence on historical data, prediction, so it is difficult to make a long-term prediction. The artificial neural network requires a large number of training samples, and it is difficult to determine the network structure. The membership degrees and weights were difficult to calculate using fuzzy mathematical theory in the fuzzy mathematics system. SVM is a new learning method that has solid theoretical basis and requires small amount of sample. However,
its performance depends too much on the selection of parameters, and there is no reliable method to guide the selection of parameters. The quantitative data in the analytic hierarchy process (AHP) are too small to be convincing, and the accuracy of the AHP is mainly lie on the reliability of the risk recursive model. Therefore, practical evaluation models of the classification of surrounding rock should be studied systematically.

In the present study, an optimized classification method of advanced surrounding rock is proposed based on matter-element extension theory and TSP203 system. The influential factors that are closely related to the type of surrounding rock and closely related to TSP203 results are selected based on TSP203 detection results (Pooyan, 2006). A model of surrounding rock classification with five factors is constructed by matter-element extension theory. The comprehensive weighting method is used to gain the reasonable weight of each evaluation index and the fuzzy comprehensive evaluation method is used to predict the rock level in front of the tunnel face. It not only overcomes the subjectivity of the weight calculation in the extension theory but also solves the inaccuracy of the rock grade of the single TSP detection. At the same time, the effective utilization of the data of TSP203 detection is strengthened. Moreover, the evaluation model was applied to Jinpingyan Tunnel in China. The study results show that the evaluation result agreed well with the actual construction situation, which effectively improves the effective utilization of TSP detection data, avoids the shortcomings of the previous classification method of surrounding rock, and enhances the accuracy of the discrimination of surrounding rock grade. The evaluation model can also be used in seismic wave detection of other projects, such as tunnels, water diversion tunnels, etc.

2 ANALYSIS OF INFLUENCE FACTORS BASED ON TSP203

2.1 TSP principles and TSP detection results

Tunnel Seismic Prediction 203 (TSP203) system is a new generation of geological prediction system. Some (generally less than 24) specific blasting hole are arranged in the vicinity of the side wall in the tunnel face, then the seismic waves are artificially excited in these holes. When the seismic waves encounter formation interface, joint interface, and unfavorably geological interface such as fault fracture zone, karst cave and underground river, some of the seismic waves will be reflected and received by the receiver, and they are recorded by host (Qiu et al., 2010; Xu et al., 2013; Mohammadreza et al., 2017). The system is capable of forecasting exactly the circumstances of the wall rock in front of 100 to 250m of the tunnel, which can provide guidance for rapid and safe construction of the tunnel (Andisheh et al. 2008; Supattra et al. 2016). Schematic diagram of the working principle of TSP is shown in Figure 1.
In the process of excitation, the seismic waves will be transmitted to electronic sensor in the form of direct and reflected waves. The longitudinal wave velocity $V_p$ and the shear wave velocity $V_s$ can be calculated based on the parameters obtained by the TSP03. Due to the anisotropy of the rock mass, the wave equation of elastic medium is used to describe motion equations of various vibrational physical systems. These equations of motion can be expressed by partial differential equations.

$$\frac{\partial^2 u}{\partial t^2} = v^2 \frac{\partial^2 u}{\partial x^2}$$  \hspace{1cm} (1)

Where the $t$ is the propagation time of reflection wave, $v$ is the propagation velocity of stress wave, $x$ is the component of the Cartesian coordinate system, $u$ is a function of $x$ and $t$.

Motion equations of the elastic wave introduced by the Laplace operator $\nabla^2$ can be written as the following form in three-dimension cases.

$$\begin{Bmatrix}
(\lambda + G) \frac{\partial \varepsilon}{\partial x} + G \nabla^2 u_x + \rho X = \rho \frac{\partial^2 u_x}{\partial t^2} \\
(\lambda + G) \frac{\partial \varepsilon}{\partial y} + G \nabla^2 u_y + \rho Y = \rho \frac{\partial^2 u_y}{\partial t^2} \\
(\lambda + G) \frac{\partial \varepsilon}{\partial z} + G \nabla^2 u_z + \rho X = \rho \frac{\partial^2 u_z}{\partial t^2}
\end{Bmatrix}$$  \hspace{1cm} (2)

Where the $\lambda$ is the wavelength of the seismic wave, $G$ is the shear modulus of rock, $\varepsilon$ is a function of $x, y$ and $z$, $\rho$ is the density of rock.

Therefore, calculation formula of the longitudinal wave velocity $V_p$ and the shear wave velocity $V_s$ are shown as follows.

$$V_p = \sqrt{\frac{\lambda + 2G}{\rho}}$$  \hspace{1cm} (3)

$$V_s = \sqrt{\frac{G}{\rho}}$$  \hspace{1cm} (4)

The time profile of P wave, depth migration profile, rock reflection layer, various rock parameters (Poisson's ratio, density, etc.) and two-dimensional and three-dimensional distribution of reflection layer, etc. can also be obtained by TSPwin software. The geological conditions in front of the tunnel face can be predicted based on the above information, such as karst caves, soft rock, faults, fractures and rich water, etc. The geological conditions provide a reference for the correct selection of excavation method, support measures, optimization of engineering design and construction scheme.

### 2.2 Analysis of influencing factors

At present, there are many classification methods of surrounding rock. The classification indexes of each classification method are not exactly the same. So the most important and influential factors should be selected based on the principles of scientificity, rationality, operability, and representativeness (Xu et al., 2008; T. Li et al., 2009; Saengsuree et al., 2016). So, the rock mass integrity index $K_v$, Young's modulus $E$, the longitudinal
wave velocity $V_p$, Poisson's ratio $\mu$, and groundwater $W$ were selected as evaluation indexes of the classification of surrounding rock. In this paper, the grade of surrounding rock is divided into five grades, i.e., grade I, grade II, grade III, grade IV and grade V, representing lower risk, low risk, medium risk, high risk and higher risk respectively.

2.2.1 Physical and mechanical parameters of rock

Rock physical and mechanical parameters that affect rock mechanics properties include Poisson's ratio, Young's modulus and so on. The Poisson's ratio can be calculated directly by the P-wave velocity and S-wave velocity and Young's modulus can be calculated directly by the rock density, the P-wave velocity and S-wave velocity. Therefore, Poisson's ratio and Young's modulus are selected as the evaluation index, which are easy to obtain and representative in the process of TSP203 processing. The Poisson's ratio, Young modulus of the tunnel can be calculated by the following formula so as to make the prediction of the unfavorable geology before the tunnel face.

$$
\nu = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)}
$$

$$
E = \rho V_s^2 \left(\frac{3V_p^2 - 4V_s^2}{V_p^2 - V_s^2}\right)
$$

2.2.2 The integrity coefficient of rock mass

Rock mass integrity refers to various fissures in rock geological interface development degree. The integrity coefficient of rock mass reflects the integrity of the rock mass, which is the most direct and important index to evaluate the surrounding rock level. The calculation formula is as follows:

$$
K_v = \left(\frac{V_p}{V_s}\right)^2
$$

2.2.3 Groundwater

Groundwater is an important index affecting the stability of tunnel surrounding rock. Groundwater will corrode soluble cement and small particles of filling rock and structural surface, soften and reduce the strength of the surrounding rock. When the quality of rock mass is good, without water content or with less pressure water, the influence of groundwater on the surrounding rock is small. When the quality of rock mass is poor, and there is a gushing water and the water pressure is great, the groundwater is lager affected the surrounding rock (Shi et al. 2013). Therefore, the role of ground water should be fully considered. The development of groundwater is a qualitative index, and is quantified based on Table 1.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Value</th>
<th>Detailed description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very strong</td>
<td>0.8-1.0</td>
<td>S-wave reflection energy is obviously stronger than that of P-wave. S-wave has a wide reflection bandwidth and a good extension. $V_p/V_s$ or Poisson's ratio increases greatly.</td>
</tr>
<tr>
<td>Strong</td>
<td>0.6-0.8</td>
<td>S-wave reflection energy is obviously stronger than that of P-wave. $V_p/V_s$ or Poisson's ratio increases</td>
</tr>
<tr>
<td>Medium</td>
<td>0.4-0.6</td>
<td>S-wave reflection energy is obviously stronger than that of P-wave.</td>
</tr>
<tr>
<td>Small</td>
<td>0.2-0.4</td>
<td>S-wave reflection energy is stronger than that of P-wave.</td>
</tr>
<tr>
<td>Very small</td>
<td>0.0-0.2</td>
<td>The data does not show the aquifer characteristics.</td>
</tr>
</tbody>
</table>
The influence factors are divided into several intervals according to the influence of each factor on the surrounding rock. These factors are divided and quantified based on a large number of statistical data and theoretical calculation. The index grade division is shown in Table 2.

### Table 2 Grade division of evaluation index

<table>
<thead>
<tr>
<th>Level</th>
<th>$K_v$</th>
<th>$\nu$</th>
<th>$E$</th>
<th>$V_p$</th>
<th>$W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$&gt;0.75$</td>
<td>$&lt;0.2$</td>
<td>$&gt;45$</td>
<td>$&gt;4.5$</td>
<td>$0.0-0.2$</td>
</tr>
<tr>
<td>II</td>
<td>$0.75-0.55$</td>
<td>$0.2-0.25$</td>
<td>$45-25$</td>
<td>$4.5-3.5$</td>
<td>$4.5-3.5$</td>
</tr>
<tr>
<td>III</td>
<td>$0.55-0.35$</td>
<td>$0.25-0.3$</td>
<td>$25-12$</td>
<td>$3.5-2.5$</td>
<td>$0.4-0.6$</td>
</tr>
<tr>
<td>IV</td>
<td>$0.35-0.15$</td>
<td>$0.3-0.35$</td>
<td>$12-3.5$</td>
<td>$2.5-1.5$</td>
<td>$0.6-0.8$</td>
</tr>
<tr>
<td>V</td>
<td>$&lt;0.15$</td>
<td>$&gt;0.35$</td>
<td>$&lt;3.5$</td>
<td>$&lt;1.5$</td>
<td>$0.8-1.0$</td>
</tr>
</tbody>
</table>

2.3 Normalization of evaluation indicators

In order to compare and summarize different evaluation indexes conveniently, each index should be normalized and non-dimensionally preconditioned. Normalization is a dimensionless processing method, which is an effective way to simplify the calculation and reduce the value. If the rock level increases with the index value, the Eq. (6) is used to calculate the boundary value. On the other hand, the Eq. (7) is used to calculate the boundary value. The normalized evaluation index is shown in Table 3.

$$
c_i' = \frac{c_i - c_{i\min}}{c_{i\max} - c_{i\min}}
$$  \hspace{1cm} (6)

$$
c_i' = \frac{c_{i\max} - c_i}{c_{i\max} - c_{i\min}}
$$  \hspace{1cm} (7)

### Table 3 Normalized standard of classification

<table>
<thead>
<tr>
<th>Level</th>
<th>$K_v$</th>
<th>$\nu$</th>
<th>$E(GPa)$</th>
<th>$V_p(km/s)$</th>
<th>$W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.75-1.00</td>
<td>0.60-1.00</td>
<td>0.53-1.00</td>
<td>0.69-1.00</td>
<td>0.80-1.00</td>
</tr>
<tr>
<td>II</td>
<td>0.55-0.75</td>
<td>0.50-0.60</td>
<td>0.29-0.53</td>
<td>0.54-0.69</td>
<td>0.60-0.80</td>
</tr>
<tr>
<td>III</td>
<td>0.35-0.55</td>
<td>0.40-0.50</td>
<td>0.14-0.29</td>
<td>0.38-0.54</td>
<td>0.40-0.60</td>
</tr>
<tr>
<td>IV</td>
<td>0.15-0.35</td>
<td>0.30-0.40</td>
<td>0.04-0.14</td>
<td>0.23-0.38</td>
<td>0.20-0.40</td>
</tr>
<tr>
<td>V</td>
<td>0.00-0.15</td>
<td>0.00-0.30</td>
<td>0.00-0.04</td>
<td>0.00-0.23</td>
<td>0.00-0.20</td>
</tr>
</tbody>
</table>

3 MATTER-ELEMENT EXTENSION MODEL

3.1 Extension evaluation processes

Extension method is an original subject founded by Cai in 1983 (Cai, 1983, 1990, 1994). Normalization is a dimensionless processing method, which transforms the absolute value of the physical system value into a relative value. In order to completely evaluate things, extension method has established a multi-index evaluation model, which provides a new way to solve the problem of evaluation (Arendacká et al., 2007). The extension evaluation processes of surrounding rock classification is shown in Figure 2.
3.2 Construction of extension evaluation model

3.2.1 Classical field, festival field and matter-element

Suppose the number of influencing factors of surrounding rock grade is \( m \), which include \( c_1, c_2, \ldots, c_m \).

Based on these indices, divide the surrounding rock level into 5 grade, and construct the classical matter-element matrix:

\[
R_j = [N_j, C, V_j] = \begin{bmatrix} N_j & c_1 & V_{1j} \\ c_2 & V_{2j} \\ \vdots \\ c_m & V_{mj} \end{bmatrix} = \begin{bmatrix} N_j & c_1 & \langle a_{1j}, b_{1j} \rangle \\ c_2 & \langle a_{2j}, b_{2j} \rangle \\ \vdots \\ c_m & \langle a_{mj}, b_{mj} \rangle \end{bmatrix}
\]  

(8)

In the matrix, \( R_j \) represents the matter-element model when surrounding rock grade is in the level of \( j \); \( N_j \) represents the surrounding rock grade in the level of \( j \); \( V_{ij} = \langle a_{ij}, b_{ij} \rangle \) represents the value range of the index which is number \( m \) in the level of \( j \) in the evaluation of surrounding rock grade; \( j=1,2,\ldots,m \).

In the evaluation of surrounding rock grade, the matrix that is formed by the range of the value of each factor is called festival matter-element matrix.

\[
R_P = [P, C, V_P] = \begin{bmatrix} P & c_1 & V_{1P} \\ c_2 & V_{2P} \\ \vdots \\ c_m & V_{mP} \end{bmatrix} = \begin{bmatrix} P & c_1 & \langle a_{1P}, b_{1P} \rangle \\ c_2 & \langle a_{2P}, b_{2P} \rangle \\ \vdots \\ c_m & \langle a_{mP}, b_{mP} \rangle \end{bmatrix}
\]  

(9)

In the matrix, \( P \) represents the overall level of the surrounding rock grade, \( V_{ip} = \langle a_{ip}, b_{ip} \rangle \) represents the range of the index \( c_n \) whose number is \( m \) in \( P \), \( V_{ij} \in V_{ip} \) (\( i=1,2,\ldots,n; j=1,2,\ldots,m \)).

Using the following matter-element extension matrix to represent the data obtained by analyzing and evaluating the surrounding rock grade.
counting the evaluating index of the tunnel to be evaluated:

\[ R = \begin{bmatrix} P & c_1 & v_1 \\ c_2 & v_2 \\ \vdots & \vdots \\ c_m & v_m \end{bmatrix} \]  \hspace{1cm} (10)

In the matrix, \( P \) represents the level of the surrounding rock grade of the tunnel to be evaluated; \( v_i \) represents the evaluating value of the index \( c_i \) whose number is \( i \) in the tunnel to be evaluated (\( i = 1, 2, \ldots, m \)).

### 3.3 Index weight

Suppose

\[ r_y = \begin{cases} 
\frac{2(v_i - a_y)}{b_y - a_y}, & v_i \leq \frac{a_y + b_y}{2} \\
\frac{2(b_y - v_i)}{b_y - a_y}, & v_i \geq \frac{a_y + b_y}{2}
\end{cases} \]  \hspace{1cm} (11)

Where \( i = 1, 2, 3, \ldots, m, \) \( j = 1, 2, 3, \ldots, m \).

If \( v_i \in V_{ip} \) then,

\[ r_{ij_{\max}}(v_i, v_{ij_{\max}}) = \max_j \{ r_y(v_i, v_j) \} \]  \hspace{1cm} (12)

If the greater the grade of the \( c_i \), the greater the weight of the index, then,

\[ r_j = \begin{cases} 
\max \left( j_{\max} \times (1 + r_{ij_{\max}}(v_i, V_{ij_{\max}})), r_{ij_{\max}}(v_i, V_{ij_{\max}}) \right), & r_{ij_{\max}}(v_i, V_{ij_{\max}}) \geq -0.5 \\
0.5, & r_{ij_{\max}}(v_i, V_{ij_{\max}}) < -0.5
\end{cases} \]  \hspace{1cm} (13)

If the greater the grade of the \( c_i \), the smaller the weight of the index, then,

\[ r_j = \begin{cases} 
(m - j_{\max} + 1) \times (1 + r_{ij_{\max}}(v_i, V_{ij_{\max}})), & r_{ij_{\max}}(v_i, V_{ij_{\max}}) \geq -0.5 \\
(m - j_{\max} + 1) \times 0.5, & r_{ij_{\max}}(v_i, V_{ij_{\max}}) < -0.5
\end{cases} \]  \hspace{1cm} (14)

So the weight of the index \( c_i \) can be calculated by Eq. (12).

\[ a_i = \frac{r_i}{\sum_{i=1}^{n} r_i} \]  \hspace{1cm} (15)

### 3.4 Correlation function value

\[ K_j(v_i) = \begin{cases} 
-\rho(v_i, V_{ij}), & v_i \in V_{ij} \\
\frac{\rho(v_i, V_{ij})}{\rho(v_i, V_{ij}) - \rho(v_i, V_{ji})}, & v_i \notin V_{ij}
\end{cases} \]  \hspace{1cm} (16)

Where the
\[
\rho(v_i, v_j) = \frac{a_{ij} + b_{ij}}{2} - \frac{a_{ji} - b_{ji}}{2} 
\]

(17)

\[
|\rho| = |b_{ij} - a_{ij}|
\]

(18)

\[
\rho(v_i, v_j) = \frac{a_{ij} + b_{ij}}{2} - \frac{a_{ji} - b_{ji}}{2}
\]

(19)

3.5 Grade evaluation of surrounding rock

The correlation degree of tunnel surrounding rock to be evaluated can be calculated by Eq. (17).

\[
K_j(p) = \sum_{i=1}^{n} a_{ij} K_j(v_i)
\]

(20)

Where the \( K_j(p) \) is relational grade of surrounding rock grade \( J \).

If

\[
K_{j0}(p) = \max_{j \in \{1, 2, \ldots, m\}} K_j(p)
\]

(21)

Then \( P \) belongs to grade \( j_0 \).

Suppose

\[
\tilde{K}_j(p) = \frac{K_j(p) - \min_{j \in \{1, 2, \ldots, m\}} K_j(p)}{\max_{j \in \{1, 2, \ldots, m\}} K_j(p) - \min_{j \in \{1, 2, \ldots, m\}} K_j(p)}
\]

(22)

\[
j^* = \frac{\sum_{j=1}^{m} j \cdot \tilde{K}_j(p)}{\sum_{j=1}^{m} \tilde{K}_j(p)}
\]

(23)

Where the \( j^* \) is variable eigenvalue of \( P \).

4 ENGINEERING APPLICATION

4.1 Engineering background

The Jinpingyan Tunnel along the Tibetan Plateau is located in Sichuan Province, which are prone to produce geological disasters. The Jinpingyan Tunnel is one of the control engineering projects along that entire route. The length of the tunnel, which starts from D2K201+558 and extends to D2K203+988, is 2400 m. The bottom level of the tunnel is about 2410–3260 m, and the maximum depth is 600 m. Jigongling Tunnel is located in the Tibetan Plateau, which shows some intermixed existence of rock of various lithology. The overlying strata in the Jinpingyan Tunnel area consists of Holocene series, including the mass rock and soil (Q4de1), alluvium (Q4d1+co1), diluvium (Q4a1+p1), accumulation horizon (Q4sef) and elurium (Q4d1+e1). The bedrock in the Jinpingyan Tunnel area consists of the Triassic Period (T3l), including the Luokong Group (T3X), Xinduqiao Group (c1sp), Zhuwo Group (T3zh).
4.2 TSP203 detection

D2K201+620-D2K201+700 is selected as the TSP detection section, the depth migration diagram and the 2D results of the observations are shown in Figure 3 and Figure 4, respectively. In Figure 3, S-wave reflection is stronger than P-wave reflection and S-wave negative reflection energy is stronger than P-wave negative reflection energy near D2K201+620-D2K201+660. In Figure 4, the P-wave and S-wave velocity ratio and Poisson's ratio all sharp increase near D2K201+630-D2K201+660 (Vp/Vs increases from 1.85 to 2.34 and Poisson's ratio increases from 0.19 to 0.41). Rock density $\rho$ and young modulus $E$ decline (rock density declines from 2.86 g/cm$^3$ to 3.15 g/cm$^3$ and $E$ declines from 61 GPa to 32 GPa). According to the geological conditions and prediction results, it is inferred that the strength of the surrounding rock is reduced, the joint fractures in the rock mass are developed and the water content is increased.

Figure 3: Maps of depth migration
4.3 Selection of parameters

The influence factors of the surrounding rock grade assessment are determined based on TSP detection results and response characteristics of various influencing factors. It is sometimes difficult to make a quantitative judgement on the groundwater, and the parameter values given are subjective. Therefore, the following methods can be used in the evaluation: (1) the upper and lower values of measured values of groundwater factors $W$ are taken and arranged and combined; (2) comprehensive analysis of evaluation results to determine the grade of surrounding rock. In this project example, the groundwater index of the evaluation sample S is strong, so the value $W$ taken 0.6 and 0.8 for S, respectively. The parameters of each evaluation object are shown in Table 4.

Table 4 Factors parameters of D2K201+630-D2K201+660 section

<table>
<thead>
<tr>
<th>Influence</th>
<th>Sample (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
According to the Eqs. (8) - (9), the classical field and festival field of the evaluation can be obtained as follows,

\[
R_j = \begin{bmatrix}
N_j & c_1 & \{a_{i,j}, b_{i,j}\} \\
& c_2 & \{a_{i,j}, b_{i,j}\} \\
& c_3 & \{a_{i,j}, b_{i,j}\} \\
& c_4 & \{a_{i,j}, b_{i,j}\} \\
& c_5 & \{a_{i,j}, b_{i,j}\}
\end{bmatrix}
\]

\[
R_p = \begin{bmatrix}
P & c_1 & \{0,1\} \\
& c_2 & \{0,1\} \\
& c_3 & \{0,1\} \\
& c_4 & \{0,1\} \\
& c_5 & \{0,1\}
\end{bmatrix}
\]

Where the \(j = 1, 2, 3, 4\) and 5, respectively, the value range of \(c_1, c_2, c_3, c_4\) and \(c_5\) is shown in Table 3. According to the Eq. (14), the eigen element of the surrounding rock level is obtained as follows,

\[
R_p = \begin{bmatrix}
P & c_1 & S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \\
& c_2 & 0.38 & 0.38 & 0.31 & 0.31 & 0.34 & 0.34 \\
& c_3 & 0.34 & 0.34 & 0.41 & 0.41 & 0.52 & 0.52 \\
& c_4 & 0.05 & 0.05 & 0.05 & 0.05 & 0.05 & 0.05 \\
& c_5 & 0.40 & 0.20 & 0.40 & 0.20 & 0.40 & 0.20
\end{bmatrix}
\]

### 4.5 Weight calculation

The greater the grade of the ci, the greater the weight of the index. According to the Eqs. (11) - (14), the weight of each index can be obtained as shown in Table 5.
4.6 Correlation functions values

According to the Eq. (15), the correlation function value of each grade of the surrounding rock level can be calculated.

\[
K(v_j) = \begin{bmatrix}
-0.30 & 0.05 & -0.02 & -0.32 & -0.48 \\
-0.37 & -0.24 & -0.05 & 0.20 & -0.17 \\
-0.36 & 0.21 & -0.13 & -0.37 & -0.47 \\
-0.93 & -0.91 & -0.87 & -0.78 & 0.22 \\
-0.75 & -0.67 & -0.50 & 0.00 & 0.00
\end{bmatrix}
\]

4.7 Classification results and analysis of surrounding rock

According to Eqs. (15) - (23), the grade of surrounding rock and the correlation degree of grade \( j \) can be obtained. More method was used for further testing and verifying the matter-element extension model. Results derived from the matter-element extension model, genetic and support vector machine method (GA_SVM), attribute mathematics method and the field-observed results were compared. The results show that the matter-element extension model is more convenient to acquire evaluate data with the TSP detection, the process of evaluation is more simple and faster. The evaluation result is more accurate, reasonable and detailed (For example, \( J^* = 4.8 \) means that the grade of surrounding rock is grade four to grade five, which is closer to grade five.). The matter-element extension model based on TSP provides a powerful tool for systematically assessing the grade of tunnel surrounding rock and the proposed model has practical guiding implication and can be applied in further engineering.

As shown in Figure 5. (a), the working face appears water gushing and the surrounding rock grade of working face becomes worse when the tunnel is excavated to D2K201+630 and D2K201+650. As shown in Figure 5. (b), the working face appears fissure water, and the surrounding rock fissure is developed when the tunnel is excavated to D2K201+660. The excavation results are in good agreement with the evaluation results.

Table 6 The sample of comprehensive extensive evaluation

<table>
<thead>
<tr>
<th>Sample</th>
<th>Correlation degree</th>
<th>Matter-element extension model</th>
<th>Attribute mathematics Method</th>
<th>GA_SVM Method</th>
<th>Rock in tunnels</th>
<th>Design value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( K_1 )</td>
<td>( K_2 )</td>
<td>( K_3 )</td>
<td>( K_4 )</td>
<td>( K_5 )</td>
<td>( J^* )</td>
</tr>
<tr>
<td>S1</td>
<td>-0.68</td>
<td>-0.53</td>
<td>-0.48</td>
<td>-0.31</td>
<td>-0.05</td>
<td>4.10</td>
</tr>
<tr>
<td>S2</td>
<td>-0.66</td>
<td>-0.49</td>
<td>-0.48</td>
<td>-0.38</td>
<td>-0.05</td>
<td>4.07</td>
</tr>
<tr>
<td>S3</td>
<td>-0.69</td>
<td>-0.54</td>
<td>-0.49</td>
<td>-0.30</td>
<td>-0.06</td>
<td>4.12</td>
</tr>
<tr>
<td>S4</td>
<td>-0.68</td>
<td>-0.51</td>
<td>-0.48</td>
<td>-0.35</td>
<td>-0.07</td>
<td>4.08</td>
</tr>
<tr>
<td>S5</td>
<td>-0.65</td>
<td>-0.50</td>
<td>-0.45</td>
<td>-0.28</td>
<td>-0.04</td>
<td>3.96</td>
</tr>
<tr>
<td>S6</td>
<td>-0.63</td>
<td>-0.45</td>
<td>-0.49</td>
<td>-0.31</td>
<td>-0.05</td>
<td>3.95</td>
</tr>
</tbody>
</table>
5 CONCLUSIONS

(1) According to the hydrology and geological conditions and the results of previous studies, the rock mass integrity index $K_v$, Young's modulus $E$, the longitudinal wave velocity $V_p$, Poisson's ratio $\mu$, and groundwater $W$ were selected as the evaluation indexes of surrounding rock classification. These indicators have universality and applicability in engineering practice. According to a lot of forecast experience and the seismic wave field response characteristics of main factors, these evaluation indexes are quantitatively described, which made the evaluation results of surrounding rock grade more objective.

(2) The selected quantitative indices affecting the classification of surrounding rock are closely related to the interpretation results of TSP. According to the matter-element extension theory, a multi index evaluation model based on tunnel seismic wave detection was established. The weight of each index is calculated by the simple correlation function method, which overcomes the subjectivity of the previous artificially determination of the weights of indexes and make the evaluation result more reasonable and reliable.

(3) The classification of surrounding rock of Jinpingyan Tunnel was evaluated based on the established matter-element extension model, and comparisons were made between the results derived from the proposed model and other methods. The excavation verification shows that the evaluation results are reasonable and feasible. The grade of rock mass proposed by the matter-element extension model is more accurate, and it is in good agreement with the exposure results.

6 ACKNOWLEDGEMENTS

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