Risk Assessment Based on Combined Weighting-Cloud Model of Tunnel Construction

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Abstract: In order to reduce the tunnel construction accidents and ensure the safety of personnel, a comprehensive assessment method of tunnel construction risk based on combination weighting and cloud model is constructed according to the characteristics of tunnel construction. The risk assessment index system is established based on researches on engineering geological condition, natural environmental condition, Tunnel engineering design scheme and construction management. On this basis, the tunnel risk is divided into 4 levels and the index risk level standard is proposed. In order to improve the rationality of weighting, a weight calculation method based on AHP, entropy method and Lagrange multiplier method is constructed. Finally, the normal cloud generator is used to form comparison pictures of risk clouds and standard clouds, which demonstrates the risk status of the evaluation indexes at all levels. With reference to Deda Tunnel of Sichuan-Tibet Railway engineering of high integrated risk level, management decision-making is required. The evaluation results are basically consistent with engineering practices, proving that the method has good feasibility and applicability.

Keywords: cloud model; combination weight; risk assessment; tunnel construction

1 INTRODUCTION

Railway is the backbone of the comprehensive transportation system. With the in-depth advancement of the "One Belt, One Road" strategy, China has vigorously accelerated the pace of railway construction. Due to the complex structure and difficult construction technology of railway tunnel engineering, the risk factors in the construction process are intertwined and complicated. Tunnel construction projects in the complex and dangerous areas, represented by the Sichuan-Tibet Railway, are confronted with geological hazards such as collapse, landslide, debris flow, inrush of clay and water, high ground temperature, rock bursts, and large deformations of soft rocks from deep-buried tunnels [1, 2]. The proportion of tunnels on the entire Sichuan-Tibet Railway is relatively high and there are many ultra-long and deep buried tunnels, so safety accidents are prone to occur during construction [3]. Therefore, in order to ensure the high-standard and high-quality safe construction of tunnel engineering, it is necessary to conduct risk analysis of tunnel construction, so as to avoid risks, improve risk management and control capability, and achieve the purpose of reducing accidents and casualties.

Modern risk management is generally acknowledged to have originated in Germany. In 1987, Sorrell of the UK first proposed the concept of risk engineering [4]. He believed that risk assessment should consider the common influence of multiple factors. After that, Einstein introduced the risk theory into tunnel engineering and studied the risk assessment theory of tunnel construction from the perspective of risk management [5]. Risk assessment methods have been widely used in the construction of tunnels and other underground projects [6]. Hyun et al. [7] considered the impact of risk probability and used FTA and AHP to evaluate and analyze the construction risk of shield tunnel. Hadi et al. [8] used FAHP to analyze and evaluate the uncertain factors during the tunnel construction. Marian [9] demonstrates that Bayesian Belief Networks (BBNs) can be used as D-DSM to assess and manage risks and finally select best response decisions. Andreotti [10] used a comprehensive numerical method to evaluate the seismic risk of mountain tunnels and demonstrated it with two cases. Bjelland, H. & Aven, T. [11] assessed the risks of the undersea tunnel and provided ideas on how to assess the uncertain risks. Clarke, J. A. & Laefler, D. F. [12] proposed a holistic risk assessment method before construction in view of the ground settlement that may be caused by tunnel construction. McFeat-Smith, I. & Harman, K. W. [13] proposed a risk assessment system consisting of 33 risk types based on the risk analysis of more than 50 tunnels in Asia. Nezarat et al. [14] used FAHP to evaluate and classify the geological risks of tunnels, and sorted them out. In addition, Bayesian network method [15-17], FAHP [18], FNA [19], etc., has also been applied in the risk assessment of tunnel construction.

Cloud model can realize the bidirectional uncertainty mapping from evaluation value to evaluation domain, measure the fuzziness and randomness of evaluation index, and realize the conversion between qualitative concept and quantitative expression. Risk assessment methods based on cloud model have been applied in many fields [20-22]. Wu, H. W. [23] used cloud model and improved evaluation method to construct the second-level index system of urban rail transit operation safety evaluation, which provided reference and theoretical basis for urban rail transit operation safety planning and management. W. Dong [24] used the cloud model mixed entropy method - AHP to determine the weight, and finally determined the result after repeated simulation. The result showed that the evaluation result of the evaluation method based on the cloud model was better than other evaluation methods. Ma, X. Y. [25] applied the cloud model method to realize the multi-criterion assessment of rock fall risk in a tunnel portal section, and provided practical guidance for tunnel safety construction of similar projects.

Cloud model has been applied and developed to deal with the fuzziness and randomness of various indexes to a certain extent. Applying cloud model to the risk assessment of tunnel construction is beneficial to improve the accuracy of the assessment results. In order to solve the limitation of single subjective or objective weighting, the risk assessment results were further optimized, and the evaluation method based on the combined weighting cloud model was proposed, so as to provide decision-making suggestions for the risk level evaluation of tunnel construction.
2 BASIC THEORY OF CLOUD MODEL

On the basis of traditional fuzzy mathematics theory and probability statistics, Academician Li Deyi proposed the uncertainty conversion model between qualitative concepts and quantitative values in the cloud model. The cloud model mainly reflects the vagueness and randomness of the concept of uncertainty, and integrates the two together to form a qualitative and quantitative mutual mapping. The cloud model has universal adaptability and is applied to decision analysis, risk assessment, image processing and other fields.

Set $U$ as the universe of concrete numbers, $X$ as a qualitative concept of $U$. If the quantitative value $x \in U$, and $x$ is a random implementation of the qualitative concept $X$, where $y = UX(x)$ is the degree of certainty of $x$ to $X$ and $UX(x) \in (0, 1)$, then the distribution of $x$ on the universe $U$ is called the cloud model.

Expectation $Ex$, entropy $En$, and excess entropy $He$ are three indicators that reflect the digital characteristics of the cloud model, as shown in Fig. 1. $Ex$ represents the central distribution position of cloud droplets in the space of the argument domain, which reflects the stability and unity of the cognition of a certain qualitative concept, and can most directly reflect the qualitative characteristics of the evaluation object. Entropy $En$ represents the dispersion degree of cloud droplet, which reflects the degree of ambiguity of qualitative concept. The higher entropy is, the more obvious uncertainty is. Excess entropy $He$ is the entropy of entropy, representing the dispersion degree of entropy, which is intuitively expressed as the thickness of cloud [26].

The cloud model achieves qualitative and quantitative conversion through two cloud generators. A certain number of cloud drops can be calculated by the forward cloud generator, and the three digital characteristics of the cloud can be determined by the reverse cloud generator ($Ex, En, He$). The specific calculation method is shown in Eq. (1), [27].

$$
\begin{align*}
E_x &= \frac{1}{q} \sum_{k=1}^{q} x_k \\
En &= \sqrt{\frac{1}{2} \times \frac{1}{q} \sum_{k=1}^{q} |x_k - Ex|} \\
He &= \sqrt{S^2 - En^2} \\
S^2 &= \frac{1}{q-1} \sum_{k=1}^{q} (x_k - Ex)^2
\end{align*}
$$

The risk is unacceptable, and certain risk control measures are required within a reasonable range.

Where, $q$ is the number of samples; $x_k$ is the score value of the No. $k$ expert; $S^2$ is the sample variance.

3 RISK ASSESSMENT MODEL OF TUNNEL CONSTRUCTION

3.1 Index System for Assessment of Tunnel Construction Risk

The influencing factors of tunnel construction accidents are complex and diverse. In order to fully consider the information that characterizes the safety status of tunnel construction and the interrelationship of factors affecting construction risk, follow the principles of science, completeness, and hierarchy. From engineering geology, natural environmental conditions, tunnels engineering design plan and construction management technical level are studied, and establish the tunnel construction evaluation index system shown in Tab. 1.

### Table 1 Risk assessment index system for tunnel construction

| First-level index | Second-level index |
|-------------------|-------------------|
| Engineering geology $U_1$ | Basic quality grade of rock mass $U_{11}$ |
|                    | Underground seepage volume $U_{12}$ |
|                    | Rock weathering degree $U_{13}$ |
|                    | Fault fracture zone situation $U_{14}$ |
| Natural environmental conditions $U_2$ | Earthquake intensity $U_{21}$ |
|                    | Annual rainfall $U_{22}$ |
| Tunnel engineering Design scheme $U_3$ | Tunnel depth $U_{31}$ |
|                    | Tunnel span $U_{32}$ |
|                    | Measurement Scheme $U_{33}$ |
| Construction Management and Technology $U_4$ | Emergency rescue level $U_{41}$ |
|                    | Disturbance of surrounding rock $U_{42}$ |
|                    | Effect of the support scheme $U_{43}$ |

### 3.2 Classification of Risk Levels

Combining the characteristics of tunnel construction and the requirements of relevant assessment guidelines, the risk levels of tunnel construction indicators are divided into four levels, creating comment set:

$$
V = (V_1, V_2, V_3, V_4)
$$

The definition of risk level is shown in Tab. 2.

### Table 2 Risk level description

| Grade | Comment collection | Grade definition |
|-------|--------------------|------------------|
| $V_1$ | Low risk | The risk can be ignored and no control measures are required |
| $V_2$ | Medium risk | Risks are undesirable and need to strengthen supervision and management |
| $V_3$ | High risk | Risk is undesirable and must be controlled within a reasonable range |
| $V_4$ | Very high risk | The risk is unacceptable, and certain improved control measures must be implemented for the risk |

In the evaluation index system shown in Tab. 1, the magnitudes and dimensions of different indexes are quite different and unable to calculate uniformly. Therefore, the evaluation index is quantified to $[0, 10]$, and divided into 4 levels according to the evaluation set. The specific quantification standard of the evaluation index is shown in Tab. 3.
### Table 3 Quantification Standard of Evaluation Index

| Evaluation index                                     | Quantitative score |
|------------------------------------------------------|--------------------|
| Basic quality grade of rock mass                    | 0~3 (Ⅰ)           |
|                                                      | 3~5 (Ⅱ)           |
|                                                      | 5~7 (Ⅲ)           |
|                                                      | 7~10 (Ⅳ)          |
| Underground seepage volume                           | 1 × (min x 10 m)−1 |
|                                                      | 25~50              |
|                                                      | 50~100             |
|                                                      | 100~125            |
|                                                      | ≥ 125              |
| Degree of rock weathering                            | unweathered        |
|                                                      | medium weathered   |
|                                                      | strong weathered   |
|                                                      | fully weathered    |
| Fracture condition of fault / m                      | <10                |
|                                                      | 10~30              |
|                                                      | 30~50              |
|                                                      | ≥ 50               |
| Earthquake intensity                                 | I, II              |
|                                                      | III, IV            |
|                                                      | V, VI, VII         |
| Annual rainfall / mm                                 | < 400              |
|                                                      | 400~800            |
|                                                      | 800~1600           |
|                                                      | ≥ 1600             |
| Tunnel buried depth / m                              | <10                |
|                                                      | 10~40              |
|                                                      | 40~60              |
|                                                      | ≥ 60               |
| Span / m                                             | <9                 |
|                                                      | 9~14               |
|                                                      | 14~18              |
|                                                      | ≥ 18               |
| Monitoring measurement plan                          | The frequency is more reasonable |
|                                                      | The frequency is reasonable |
|                                                      | The frequency is low |
|                                                      | The frequency is very low |
| Emergency rescue level                               | Good               |
|                                                      | Fair               |
|                                                      | Poor               |
|                                                      | Very Poor          |
| Disturbance of surrounding rock                      | No disturbance     |
|                                                      | Micro disturbance  |
|                                                      | Disturbance        |
|                                                      | Severe disturbance |
| Effect of the support scheme                         | Good               |
|                                                      | Generally good     |
|                                                      | Poor               |
|                                                      | Worse              |

### 3.3 Weight Determination Based on the Combination Weighting Method

#### 3.3.1 AHP

The analytic hierarchy process is a method of subjective weighting obtained by experts based on empirical judgments. It decomposes complex issues into a hierarchical structure and uses a judgment matrix to analyze the importance of various factors. The core idea is to assess the importance of each factor based on the expert's experience. The judgment matrix of the indicator is scored to obtain the attribute weight.

1) Construct judgment matrix of criterion layer and calculate the weight. The experts themselves compare the criterion levels and score according to the 1-9 scale method to judge the relative importance of the indicators. The judgment matrix is shown in Eq. (3). The assignment method is shown in Tab. 4.

\[
C = \begin{pmatrix}
c_{11} & c_{12} & \cdots & c_{1n} \\
c_{21} & c_{22} & \cdots & c_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
c_{n1} & c_{n2} & \cdots & c_{nn}
\end{pmatrix}
\]  

(3)

where: \(c_{ij}\) is the comparison between index \(i\) and index \(j\), which is the important value of the criterion layer.

2) Calculate the maximum eigenvalue \(\lambda_{max}\) of the judgment matrix \(S\) and its corresponding eigenvector and normalize it.

Using the approximate method of finding the eigenvector of the judgment matrix, add the normalized matrix by row:

\[
\eta = \frac{1}{n} \sum_{j=1}^{n} a_{ij}
\]  

(5)

The subjective weight of each indicator is:

\[
\eta = \frac{\eta_i}{\sum_{i=1}^{n} \eta_i}
\]  

(6)

Calculate the largest characteristic:

\[
\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} (C \eta)_i
\]  

(7)

3) Consistency inspection

In order to avoid the subjective bias of experts and ensure reasonable weight distribution, the consistency of the judgment matrix should be verified. Conformity ratio \(CR\) is:

\[
CR = \frac{CI}{RI}
\]  

(8)

In the formula, \(RI\) is the random consistency index of \(S\), \(CI\) is the consistency index of \(S\), as shown in Eq. (9).

\[
CI = \frac{\lambda_{max} - n}{n - 1}
\]  

(9)

When \(CR < 0.1\), the judgment matrix is considered to be consistent and the weights are valid.

#### 3.3.2 Entropy Method

Entropy is mainly used to measure uncertainty. The information entropy value of an evaluation indicator is inversely proportional to the amount of information. The smaller the value of information entropy, the greater the amount of information contained in the indicator, and the
corresponding weight of the indicator is also big. Entropy weight method is an objective weighting method. In the weighting process, with the help of the variation process of the index, the entropy weight is calculated according to the information entropy of the index, and the objective information can be used to calculate the weight to the greatest extent. The calculation process is as follows.

Construct a judgment matrix, set \( m \) items to be evaluated, \( n \) evaluation indicators to form the original judgment matrix \( R = (r_{ij})_{m \times n} \), and calculate the entropy value of the No. \( j \) indicator is:

\[
\begin{align*}
\omega_{ij} &= \frac{p_{ij}}{\sum_{i=1}^{m} r_{ij}} \\
\ln m &= 1 \\
e_{j} &= -k \sum_{i=1}^{n} p_{ij} \ln p_{ij}
\end{align*}
\]

where \( r_{ij} \) is the evaluation value of the No. \( i \) item under the No. \( j \) index, and \( e_{j} \) is the entropy value of the No. \( j \) index.

Calculate the entropy weight of the No. \( j \) index.

\[
\lambda_{j} = \frac{1-e_{j}}{\sum_{j=1}^{n} (1-e_{j})}
\]

### 3.3.3 Combination Weighting

According to the analytic hierarchy process and entropy weighting method, the subjective weight and the objective weight are calculated. Subjective weighting and objective weighting have their own advantages and disadvantages. It is more reasonable to combine the objective internal laws of indicators and the decision-making of expert experience.

From the subjective weight \( \eta_{j} \) and the objective weight \( \lambda_{j} \) of each evaluation index to solve the combined weight \( \omega_{j} \), the spatial distribution of \( \omega_{j} \) must be as close as possible to \( \lambda_{j} \) nd \( \eta_{j} \). According to the principle of minimum information entropy, it can be obtained:

\[
\begin{align*}
\min F &= \sum_{j=1}^{m} \omega_{j} (\ln \omega_{j} - \ln \lambda_{j}) + \sum_{j=1}^{m} \omega_{j} (\ln \omega_{j} - \ln \eta_{j}) \\
\sum_{j=1}^{m} \omega_{j} &= 1 (\omega_{j} > 0, j = 1,2,...,m)
\end{align*}
\]

Solve the optimization problem according to the Lagrangian multiplier method and get the comprehensive weight:

\[
\omega_{j} = \frac{\lambda_{j} \eta_{j}}{\sum_{i=1}^{m} \sqrt{\lambda_{i} \eta_{i}}}
\]

### 3.4 Risk Cloud

Experts are invited to quantify the 12 secondary evaluation indicators with reference to the quantification standards in Tab. 1, and score each evaluation indicator with a precision of 0.1. The inverse cloud generator is used to generate the three characteristic numbers of the secondary sub-risk cloud, which are recorded as \( R_{ij} = (Ex_{i}, En_{i}, He_{i}) \).

\[
\begin{align*}
Ex &= \sum_{i=1}^{n} \omega_{i} \times Ex_{i} \\
En &= \sum_{i=1}^{n} \omega_{i} \times En_{i} \\
He &= \sum_{i=1}^{n} \omega_{i} \times He_{i}
\end{align*}
\]

where \( Ex_{i} \), \( En_{i} \), \( He_{i} \) are the expectation, entropy, and super-entropy of the first-level index \( U_{i} \) risk cloud, respectively; \( Ex_{ij} \), \( En_{ij} \), \( He_{ij} \) are the expectation, entropy, and super-entropy of the second-level \( U_{ij} \) risk cloud respectively.

### 3.5 Standard Cloud

The cloud model is used to describe the four evaluation criteria of the tunnel construction risk comment set, where the No. \( j \) subinterval is expressed as \([C_{imin}, C_{imax}]\), and the standard cloud inverse generator is used to generate the standard cloud characteristic number \( S = (Ex, En, He) \), standard Cloud digital features are calculated as follows:

\[
\begin{align*}
Ex &= (C_{min} + C_{max})/2 \\
En &= (C_{min} + C_{max})/6 \\
He &= k
\end{align*}
\]

where, \( Ex, En, He \) are the expectation, entropy, and excess entropy of the standard cloud, respectively; \( k \) reflects the randomness of subjective evaluation, and the value should not be too large, and \( k = 0.1 \).

The digital characteristics of the standard cloud are shown in Tab. 5, and the standard cloud is shown in Fig. 2.

### Table 5 Standard cloud digital characteristics

| Evaluation grade     | Score   | Standard cloud digital features |
|----------------------|---------|---------------------------------|
| Low risk \( (F_{1}) \) | (0, 3)  | \( (1.5, 0.5, 0.1) \)          |
| Medium risk \( (F_{2}) \) | (3, 5)  | \( (4.0, 0.33, 0.1) \)          |
| High risk \( (F_{3}) \)   | (5, 7)  | \( (6.0, 0.33, 0.1) \)          |
| Very high risk \( (F_{4}) \) | (7, 10) | \( (8.5, 0.5, 0.1) \)          |

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3.6 Risk Cloud Picture

Use Matlab to program the forward cloud generator to generate standard cloud diagrams and risk cloud diagrams. Observe the position and shape of the risk cloud to determine the risk status of the evaluation object. It is expected that $Ex$ falls within a certain standard cloud interval, and the risk level is the standard cloud level; the greater the entropy $En$ and the hyper-entropy $He$, the greater the span of the risk cloud, the thicker the cloud, and the greater the dispersion and randomness of the evaluation index.

4 ENGINEERING APPLICATIONS

4.1 Engineering Background

Deda Tunnel is located in the hinterland of western Sichuan Plateau and Ganzi Tibetan Autonomous Prefecture of Sichuan province. It is adjacent to Heni Township of Litang County in the east, Deda Township of Batang County in the west, and Bogoxi Township of Batang County in the south. The average annual precipitation in this region is about 1000~1200 mm, mostly in June–September. The entry mileage pile number of Deda Tunnel is CK603 +250, the exit mileage pile number is CK636 +280, and the center mileage pile number is CK619 +765. The length of the tunnel is 33030 m, which is in human slope, and the maximum buried depth is about 1230 m. Most of the tunnel trunk is yanshaniammonio granite and syenogranite. Fault breccia, cataclastic rock and fault gouge are developed in the tensile brittle fault zone, with width ranging from 2 to 10 meters. The tunnel is located in the Yidun-Shaluli late Triassic island areal belt between jinsha River suture zone and Litang suture zone, with 17 large fractures. We assess the construction risk of a section of the Deda tunnel. The segment of tunnel crossing the fault fracture zone, the grade of surrounding rock to III area drainage tunnel site of jinsha river tributary stream. The groundwater types are as follows: the groundwater is dominated by structural fissure water and carbonate karst erosion fissure water; the second is fissure water in weathered zone network; and the distribution of pore water is limited. Through comprehensive analysis, the normal water inflow of the tunnel was predicted to be 114,669 m$^3$/d, and the maximum water inflow in the wet period was 172.003 m$^3$/d. The ground motion peak acceleration of 0.20 g, the ground motion response spectrum feature period of 0.40 s, its corresponding basic earthquake intensity is VIII degrees. The geological environment of Deda tunnel is very complex, which has great influence on tunnel construction.

4.2 Data Processing

We invited 8 experts with rich experience in construction risk management to quantify the evaluation index system, and the specific quantitative scores are shown in Tab. 6.

| Total index | First grade indexes | Second grade indexes | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ | $x_8$ |
|-------------|---------------------|---------------------|------|------|------|------|------|------|------|------|
| $U_1$       | $U_{11}$            |                     | 3.5  | 4    | 4.5  | 5    | 3.5  | 4.8  | 5    | 5    |
|             | $U_{12}$            |                     | 3.4  | 4    | 4.8  | 5    | 3.8  | 4.7  | 5    | 5    |
|             | $U_{13}$            |                     | 5.8  | 6    | 6.4  | 6.6  | 6.5  | 6    | 5.5  | 6    |
|             | $U_{14}$            |                     | 5.9  | 6.2  | 6.5  | 6    | 9.5  | 9    | 8.5  | 10   |
|             | $U_{15}$            |                     | 8    | 6.5  | 6.5  | 5.5  | 6.5  | 6    | 7    | 6    |
|             | $U_{16}$            |                     | 8    | 9    | 9.5  | 9    | 8.8  | 9    | 10   | 9.5  |
| $U_2$       | $U_{21}$            |                     | 8.5  | 9    | 9.2  | 9    | 8.5  | 9    | 9.5  | 10   |
|             | $U_{22}$            |                     | 1    | 5    | 1    | 2    | 2.5  | 2.8  | 3    | 2.5  |
|             | $U_{23}$            |                     | 5    | 4.5  | 5    | 5.5  | 6    | 4.5  | 4.8  | 3.5  |
|             | $U_{24}$            |                     | 3    | 3.5  | 3    | 3    | 2.8  | 3    | 2.5  | 3    |
|             | $U_{25}$            |                     | 2    | 2    | 1.5  | 2.5  | 2    | 2.6  | 2.6  | 3    |
| $U_3$       | $U_{31}$            |                     | 0.38 | 0.32 | 0.32 | 0.38 |      |      |      |      |
|             | $U_{32}$            |                     | 0.12 | 0.17 | 0.12 |      |      |      |      |      |
|             | $U_{33}$            |                     | 0.25 | 0.16 | 0.15 |      |      |      |      |      |
|             | $U_{34}$            |                     | 0.24 | 0.37 | 0.35 |      |      |      |      |      |

In order to improve the rationality of index weight calculation, the combination weighting method is used to calculate the weight. The analytic hierarchy process is used to calculate the subjective weight of each index. Entropy weight method is used to calculate the objective weight of each index. The comprehensive weight obtained from Eq. (13) is shown in Tab. 7 and Tab. 8.

| First grade indexes | Subjective weight | Objective weight | Comprehensive weight |
|---------------------|-------------------|-----------------|---------------------|
| $U_1$               | 0.38              | 0.32            | 0.38                |
| $U_2$               | 0.12              | 0.17            | 0.12                |
| $U_3$               | 0.25              | 0.16            | 0.15                |
| $U_4$               | 0.24              | 0.37            | 0.35                |

Applying the reverse cloud generator to process the quantization value of the second-level evaluation index, the second-level sub-risk cloud is obtained. Eq. (14) is applied for calculation to obtain the digital characteristics of the first-level sub-risk cloud, and then the digital characteristics of the comprehensive risk cloud. The specific results are shown in Tab. 9.

| Second grade indexes | Subjective weight | Objective weight | Comprehensive weight |
|----------------------|-------------------|-----------------|---------------------|
| $U_{11}$             | 0.425             | 0.285           | 0.516               |
| $U_{12}$             | 0.352             | 0.316           | 0.277               |
| $U_{13}$             | 0.220             | 0.195           | 0.345               |
| $U_{14}$             | 0.100             | 0.152           | 0.072               |
| $U_{21}$             | 0.710             | 0.518           | 0.656               |
| $U_{22}$             | 0.415             | 0.355           | 0.344               |
| $U_{23}$             | 0.680             | 0.515           | 0.628               |
| $U_{24}$             | 0.425             | 0.386           | 0.372               |
| $U_{25}$             | 0.324             | 0.258           | 0.323               |
| $U_{26}$             | 0.300             | 0.200           | 0.240               |
| $U_{27}$             | 0.256             | 0.148           | 0.165               |
| $U_{28}$             | 0.255             | 0.245           | 0.272               |

The forward cloud generator is applied to generate a comparison diagram of comprehensive risk cloud and standard cloud, as shown in Fig. 3. In order to observe the
risk state of the first-level index tunnel engineering design scheme, a comparison diagram of $U_3$ risk cloud and standard cloud is generated, as shown in Fig. 4. To observe the seismic intensity risk status of the second-level index layer, a comparison chart of $U_{21}$ risk cloud and standard cloud is generated, as shown in Fig. 5.

![Comprehensive Risk Cloud and Standard Cloud](image)

**Table 9 Evaluation Index Risk Cloud Digital Characteristics**

| Overall Performance | Integrated Risk Cloud | First Grade Indexes | First Level Risk Cloud | Second Grade Indexes | Second Level Risk Cloud |
|---------------------|-----------------------|---------------------|------------------------|----------------------|-------------------------|
| Tunnel Construction Risk Assessment System $U$ | (5.18, 0.4, 0.08) | Engineering Geology $U_1$ | (4.80, 0.45, 0.07) | Rock Mass Grade $U_{10}$ | (4.41, 0.50, 0.08) |
| &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; | &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; | Natural Environment $U_2$ | (8.11, 0.44, 0.11) | Earthquake Intensity $U_{21}$ | (9.12, 0.53, 0.12) |
| &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; | &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; | Tunnel Engineering Design Scheme $U_3$ | (9.07, 0.35, 0.12) | Tunnel Depth $U_{31}$ | (9.11, 0.38, 0.14) |
| &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; | &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; &nbsp; | Construction Management and Technology $U_4$ | (3.16, 0.37, 0.06) | Tunnel Span $U_{32}$ | (9.00, 0.30, 0.08) |

![Risk Cloud and Standard Cloud](image)

4.3 Assessment Results Analysis

As can be seen from Fig. 3, the comprehensive risk level of Deda tunnel construction is high and the risk is unacceptable, so management and decision should be made to avoid the risk. According to the comprehensive analysis shown in Fig. 4 and Fig. 5, the seismic condition risk level of the tunnel is ultra-high, and the buried depth risk and span risk level of the tunnel engineering design scheme are ultra-high. Deda tunnel is located in the seismically active area, and the secondary geological disasters caused by high intensity earthquake, such as rock fall, collapse, landslide and debris flow, may constitute a major hazard to the safety of tunnel construction. For the seismically active and strong, the construction of Deda tunnel should be increased to meet the seismic requirements. The Deda tunnel is located in the hinterland of the Western Sichuan Plateau, with complicated geological conditions and great topographic difference, which increases the difficulty and requirements of the tunnel design scheme, and the construction of the tunnel with large burial depth and span and the health security of the construction personnel are all faced with extremely high risks. Therefore, we suggest that construction units should attach importance to the safety supervision of the construction of tunnels. As for possible accidents, relevant emergency units should start the emergency plan as soon as possible, take safety protection measures, reduce the working time in areas with frequent geological activities as much as possible, and do a good job in the construction risk management and control.

5 CONCLUSION

(1) According to the characteristics of tunnel construction, a tunnel construction risk assessment index system is constructed, which includes four first-grade indexes including engineering geology, natural environmental conditions, tunnel engineering design scheme and construction management, and 12 second-grade indexes. The randomness and fuzziness of evaluation indexes are treated synthetically by cloud model theory, and the transformation between qualitative concept and quantitative expression of security level is realized.

(2) Based on cloud model theory, this paper proposes a risk assessment method for tunnel construction. The cloud model evaluation results are presented in the form of contrast cloud picture to intuitively reflect the risk status of tunnel construction. The weight calculation method based on AHP, entropy weight method and Lagrange multiplier method, achieves the comprehensiveness of calculating the
weight of the tunnel construction evaluation index, and improves the reliability of the model.

(3) This paper applies cloud model to evaluate the construction risk of a section of Deda tunnel of Sichuan-Tibet Railway and the evaluation results are in agreement with the engineering practice. It proves that the method is accurate and can be operated, which has certain reference value for the research of tunnel construction risk assessment.

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