Research on safety evaluation of bolt support based on analytic hierarchy process-entropy weight method

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Abstract: To evaluate the safety performance of bolt support scientifically, the factors affecting bolt support are systematically analyzed, the comprehensive evaluation index system is established from four aspects: support parameters, quality of bolt and fittings, construction management and monitoring level, and the safety evaluation model of bolt support is constructed; the AHP and entropy weight method are combined to determine the weight of each index, and the safety evaluation system of bolt support based on AHP-entropy weight method is established and its application program is developed. The safety evaluation method and application program proposed in this paper are applied to the safety evaluation of bolt support in a coal mine in Shanxi Province, and the results are in agreement with the actual situation. This article studies the correlation.

1 Introduction

As the main energy of our country, coal has made great contribution to the development of national economy. However, due to the frequent occurrence of coal mine accidents, more and more attention has been paid to coal mine safety. As the lifeline of coal enterprises, safety not only affects the health and family happiness of coal miners, but also directly affects the healthy development of national economy.

According to statistics, the coal accident rate is second only to the transportation industry, accounting for 60% of the domestic industrial death toll. From 2013 to 2017, there were 1945 coal mine accidents, with 3771 deaths [1]. Among these accidents, the incidence of roof accidents ranks first, which is 2.23 times of transportation accidents and 3.49 times of gas accidents. The specific values are shown in Table 1.

| Particular Year | Roof | Gas | Electromechanical | Flood | Transport | Blast | Other |
|-----------------|------|-----|-------------------|-------|-----------|-------|-------|
| 2013            | 274  | 59  | 59                | 21    | 109       | 16    | 81    |
| 2014            | 196  | 47  | 36                | 19    | 8         | 13    | 114   |
| 2015            | 134  | 45  | 31                | 12    | 62        | 7     | 59    |
| 2016            | 83   | 36  | 22                | 15    | 54        | 8     | 31    |
| 2017            | 73   | 31  | 20                | 12    | 32        | 8     | 43    |

It can be seen from the above table that the incidence rate of roof accidents is the highest. The prevention of roof accidents will greatly reduce the incidence of coal mine accidents. In order to effectively prevent roof accidents, it is necessary to improve the effectiveness and reliability of support. Bolt support is widely used in coal mining enterprises. It can not only effectively bear the ground pressure of surrounding rock, but also change the surrounding rock structure to optimize the mechanical state of surrounding rock [2-3]. Among them, the selection of bolt support scheme and bolt accessories material is the most important support. Therefore, effective evaluation of the safety performance of bolt support can take targeted measures to prevent roof accidents, which has important practical significance for coal mine safety production.

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2 Analysis of factors affecting bolt support

2.1 Technological parameters of bolt support

The process parameters mainly include anchor material, diameter, length and anchoring method, and anchor hole diameter, depth, anchor number, spacing, row spacing, angle, direction, arrangement mode and other anchor bolt layout parameters [4]. The selection of process parameters is conducive to the determination of support scheme, which is related to the support effect of the whole coal mine.

2.2 Supporting material

When the bolt support is carried out, the required accessories should also meet the corresponding requirements, such as drilling, anchor bolt and anchoring agent should ensure three diameter matching in actual use [5]. There are also certain requirements for the selection of bolt material, nut and anchoring agent. In the actual support, whether there are impurities in the borehole, whether the pre tightening force of the bolt is up to the standard, and whether the bond strength between the anchoring agent and the surrounding rock meets the standard are all important factors affecting the support effect.

2.3 Construction management level

Bolt support has very high professional requirements for workers, support must be professional support workers to operate, non professional personnel easily cause the support effect is not ideal, the construction quality does not meet the requirements, the technical measures and management are not in place, which also has an important impact on the support effect. In addition, the imperfect coal mine management system and training system will also cause the support workers' lack of safety awareness and affect the support effect of the whole coal mine. In the construction process, the construction quality should be strictly controlled, especially the installation quality of anchor rod, including the hole depth, exposed length, angle, quantity of anchoring agent, anchoring force, pre tightening force, etc. If the construction quality of anchor rod is unqualified, it must be re constructed [6].

2.4 Monitoring technology level

In the process of coal mining, geological form is very easy to change, and the in-situ stress will also change. The stability of surrounding rock affects the stability of the whole roadway. Whether the effect of bolt support is objective or not is often judged by the detection of mine pressure and the detection data of mine pressure to judge the effectiveness of bolt support. The monitoring of bolt support quality includes the monitoring of bolt and cable support engineering quality and the monitoring of roadway surrounding rock stability [7].

3 Research on safety evaluation method of bolt support based on AHP entropy weight method

Analytic hierarchy process (AHP) and entropy weight method are two kinds of system analysis methods with their own characteristics. Based on these two methods, this paper studies the safety evaluation method of bolt support. After the establishment of safety evaluation index system, the subjective weight and objective weight of each index are calculated by AHP and entropy weight method, and then the obtained weights are coupled and optimized to obtain the comprehensive evaluation method.

3.1 Establishment of safety evaluation index system

In general, the main reasons for the failure of bolt support are: unreasonable design parameters of bolt support, poor quality of bolt and its components, poor quality of monitoring and construction [8]. Therefore, in the evaluation of coal roadway bolt support, the design is analyzed from the above four aspects; according to the analysis of factors affecting the support effect, the index system of support safety evaluation is constructed from the support parameters, bolt and accessories quality, construction management level and monitoring level, as shown in Figure 1.
3.2 Analytic hierarchy process

The analytic hierarchy process (AHP) should first stratify and refine the research objects, so as to establish a multi-level analysis model, compare the importance of two factors, and then establish the importance judgment matrix to get the weight of each index. The index with the largest weight is regarded as the largest influencing factor.

1) Construct judgment matrix

In order to reduce the difficulty of comparing factors with different properties and improve the accuracy of final importance degree, the comparison method of factor pairwise is adopted according to the scale when constructing judgment matrix. The evaluation criteria are shown in Table 2.

| Factor I than factor j | Equally important | Slightly important | Strong and important | Strong importance | Extremely important | Intermediate value of two adjacent judgments |
|------------------------|-------------------|--------------------|---------------------|------------------|-------------------|---------------------------------------------|
| Quantized value        | 1                 | 3                  | 5                   | 7                | 9                 | 2.4.6.8                                     |

2) Weight calculation and consistency test

The eigenvector of the largest eigenvalue of the judgment matrix is obtained, and it is marked as w after normalization. If the analytic hierarchy process can be used, the consistency test is needed.

Eigenvalue calculation formula:

$$\lambda_{\text{max}} = \sum_{i=1}^{n} \frac{(BW_i)}{nW_i}$$

(1)

Consistency test formula:

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

(2)

In the formula, the consistency index is calculated by CI, and the smaller the CI value, the greater the consistency.

In order to measure the size of CI, random consistency index RI is introduced

$$RI = \frac{CI_1 + CI_2 + \cdots + CI_n}{n}$$

(3)

When testing whether the judgment matrix has satisfactory consistency, the test coefficient Cr is obtained by comparing CI with RI:

$$CR = \frac{CI}{RI}$$

(4)

If CR < 0.1, the judgment matrix has satisfactory consistency.

3) Hierarchical total ranking and consistency test

The calculated index weights are sorted by hierarchy and the consistency test is conducted. The method is the same as above.

3.3 Entropy weight method

Entropy is a measure of the disorder degree of a system; the smaller the information entropy of an indicator, the greater the amount of information provided by the indicator, the greater the role played in the evaluation, and the higher the weight accordingly [9-10].

1) Data standardization

Due to the differences in the measurement units of each index, it is necessary to standardize the indicators before calculating the objective weight [11]. The positive and negative indicators represent different meanings, so different methods should be adopted to standardize the positive and negative indicators. The specific calculation
methods are shown in formula (5) (6)

Positive indicators:

\[
X'_{ij} = \frac{X_{ij} - \min(X_{ij}, \cdots, X_{nj})}{\max(X_{ij}, \cdots, X_{nj}) - \min(X_{ij}, \cdots, X_{nj})} \quad (5)
\]

Negative index:

\[
X_{ij} = \frac{\max(X_{ij}, \cdots, X_{nj}) - X_{ij}}{\max(X_{ij}, \cdots, X_{nj}) - \min(X_{ij}, \cdots, X_{nj})} \quad (6)
\]

2) Calculate the information entropy of each index

The information entropy of a group of data is as follows:

\[
E_j = -\ln(n) \sum_{i=1}^{n} P_{ij} \ln P_{ij} \quad (7)
\]

Among them:

\[
P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \quad (8)
\]

If \(P_{ij}=0\), then:

\[
\lim_{P_{ij} \to 0} P_{ij} \ln P_{ij} = 0 \quad (9)
\]

3) Determine the weight of each index

The information entropy of each index is calculated according to formula (7), and the objective weight of each index is calculated by formula (10)

\[
W_{j} = \frac{1}{k-\sum E_i} (i = 1, 2, \cdots, k) \quad (10)
\]

3.4 Determination of comprehensive weight

In order to reflect the comprehensiveness of subjective and objective in the evaluation and make the weight value of each index more scientific and reasonable, a decision-making model is constructed based on the calculation of subjective and objective weights to keep the subjective and objective weights consistent with the preference coefficient. By coupling the subjective weight and objective weight, a more reasonable combination weight is obtained [12-13]. The calculation method is shown in formula (11).

\[
W_i = \beta W_{di} + (1-\beta) W_{bi} \quad \beta = 0.55 \quad (11)
\]

3.5 Determination of comprehensive evaluation method

After the comprehensive evaluation of the safety index of the coal mine, we can get the comprehensive evaluation of the safety index. The scoring grades are excellent, good, general, qualified and unqualified, and the corresponding assigned scores are 5, 4, 3, 2 and 1 [14].

The calculation method of comprehensive score is shown in formula (12)

\[
F = Q^T P = \sum_{k=1}^{n} q_k P_k \quad (12)
\]

In the formula, \(F\) represents the comprehensive evaluation results, \(P\) represents the scoring matrix of each factor, and \(PK\) represents the on-site scoring results.

4 Coal mine bolt support safety evaluation application program and example application

4.1 Development of safety evaluation application

In order to carry out the safety evaluation of coal mine bolt support and solve the problem that one person scoring needs to recalculate, according to the above calculation index weight method and the complete safety evaluation method, this paper develops an application program, which inputs the weight of each factor and scoring results, and then obtains the comprehensive results of coal mine bolt support safety evaluation. The specific flow of the application is shown in Figure 2.
4.2 Application of evaluation method

In a coal mine in Taiyuan City, Shanxi Province, the main roadway and the mining face mostly use bolt support. Whether the bolt support is safe or not seriously affects the production of the coal mine. Five personnel from the safety department and the technical department are invited to score each index according to the scoring standard and construct the judgment matrix. According to the judgment scale table, the elements are compared and the judgment matrix of each index is obtained as follows:

\[
A = \begin{bmatrix}
1 & 2 & 3 & 4 \\
1/2 & 1 & 2 & 4 \\
1/3 & 1/2 & 1 & 3 \\
1/4 & 1/4 & 1/3 & 1
\end{bmatrix}
\]

\[
B_1 = \begin{bmatrix}
1 & 2 & 3 & 4 \\
1/2 & 1 & 2 & 3 \\
1/2 & 1/2 & 1 & 2 \\
1/3 & 1/2 & 1/2 & 1 \\
1/4 & 1/3 & 1/3 & 1
\end{bmatrix}
\]

\[
B_2 = \begin{bmatrix}
1 & 2 & 3 & 3 \\
1/2 & 1 & 2 & 3 \\
1/3 & 1/2 & 1 & 2 \\
1/3 & 1/3 & 1/2 & 1 \\
1/2 & 1 & 2 & 3 \\
1/3 & 1/2 & 1/3 & 1
\end{bmatrix}
\]

\[
B_3 = \begin{bmatrix}
1 & 2 \\
1/2 & 1
\end{bmatrix}
\]

According to the above steps, the subjective weight, objective weight and comprehensive weight of each index are calculated by Excel, and the results are shown in Table 3.

**Table 3** Weight Results of Safety Evaluation Index of Bolt Support

| Middle layer index | Subjective | Objective | Comprehensive |
|--------------------|------------|-----------|--------------|
|                    |            |           |              |

Figure 2 Flowchart of security assessment applications
Ten technicians of the coal mine enterprise are invited to score the influencing factors of bolt support, and then the scores of each factor are input into the safety evaluation application program to obtain the safety evaluation results of bolt support. The evaluation calculation process of the application program is shown in Figure 3.

By calculating the average value of the final scores of ten technicians, it is concluded that the comprehensive score of the coal mine bolt support is 4.15, and the evaluation result is excellent, which is consistent with the actual safety production situation of the coal mine. In the process of the safety evaluation of the coal mine bolt support, the safety evaluation application program can effectively save the workload of the evaluation calculation and improve the work efficiency of the coal mine safety evaluation.

5 Conclusion

In order to reasonably and effectively evaluate the safety of bolt support in coal mine, this paper establishes the support safety evaluation index system, and optimizes the subjective weight calculated by AHP and the objective weight calculated by entropy weight method, obtains the comprehensive weight of evaluation index, and forms a perfect bolt support safety evaluation method; in order to reduce the workload of calculation and scoring and facilitate the practical application to develop its matching evaluation application program. The main conclusions are as follows

(1) Combining the partial subjective AHP with the partial objective entropy weight method, the comprehensive weight of each index is obtained by reasonable method, which avoids the shortcomings of a single method, reflects the characteristics of optimization of evaluation methods, and the weight obtained is more accurate and effective.

(2) The above evaluation method is applied to the safety production practice of coal mine production site, and the results of evaluation are consistent with the actual production situation of the coal mine.
actual safety situation of coal mine enterprises, which
demonstrates that the safety evaluation method proposed in this
paper is reasonable and effective.

(3) The application program of safety evaluation
developed in this paper can easily carry out the safety
evaluation of bolt support in coal mine, and improve the
evaluation efficiency.

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