Safety Assessment of Water Inrush from Roof and Floor of Coal Seams

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Abstract: The paper uses the theory of fuzzy comprehensive evaluation to solve the problem about the safety assessment of water inrush from roof and floor of coal seam, and studies its feasibility. The paper introduces how to establish the evaluation model of water inrush from coal floor, and focuses on using the analytic hierarchy process to determine the weight of different valuation factors. Finally, the evaluation results we obtained can provide a reference and basis for developing preventive measures of water inrush from roof and floor of coal seam.

Keywords: water inrush from roof and floor of coal seam; fuzzy comprehensive evaluation; analysis of hierarchy process

1. Introduction

The frequent occurrence of mine water damage accident makes a very bad impression. Especially the problem about water inrush from roof and floor of coal seam is an outstanding and common issue in the coal mine of our country. It is an open question how to control the mechanism of water disasters and evaluate it timely and accurately.

The problem about water inrush from roof and floor of coal seam is a complex issue involving many factors, such as hydrogeology, engineering geology, mining method and impermeable layer of roof and floor. Currently, the interaction between these factors can’t be described by precise mathematical language, and the relationship between the randomness of these factors that appears and disasters shows fuzziness. On the one hand, some factors can’t be accurately described using precise number, on the other hand, there are not exist a one-to-one correspondence function between the change of various factors and disasters. Therefore, it is impossible to establish accurate mathematical models, while there are unique effects using the fuzzy theory to deal with these issues. Now, the fuzzy evaluation of the safety evaluation in the coal mine has gradually been widely used. [1-4]

2. The Fuzzy Comprehensive Evaluation Theory

The fuzzy comprehensive evaluation is a semi-quantitative analysis method for analyzing the multi-factor incident. It can express the qualitative description and subjective judgments in a magnitude form and it can determine the accident risk rating of the system by fuzzy operation. It can reduce the subjective effects to a certain degree and let the analysis more scientific. The facts of water inrush from roof and floor of coal seam are determined multifactorially, and the whole system can be decomposed into a number of units or factors using the fuzzy comprehensive evaluation method. Basing on determining the risk and weight of the different factors, it can make a comprehensive evaluation to the accident risk of water inrush from roof and floor of coal seam.

3. The Facts of Water Inrush from Roof and Floor of Coal Seam

3.1. The Geological Structure

Geological structure is the main factor causing water inrush. More than 80% water inrush accidents are associated with rock fracture according to the information we knew. Fracture can not only storage water, but also guide water. As the fracture reduce the strength of the water-resisting layer in roof and floor strata, and the dislocation can make the ledge and the aquifer closer, even opposite joint, then it makes the water-resisting layer partly or wholly loss its confining effect and effluent water, especially in the ends of the fault, the crossing, fold axis, and the fracture zone of stress concentration.

3.2. The Geohydrologic Condition

Geological structure is the main factor causing water inrush. More than 80% water inrush accidents are associated with rock fracture according to the information we knew. Fracture can not only storage water, but also guide water. As the fracture reduce the strength of the water-resisting layer in roof and floor strata, and the dislocation can make the ledge and the aquifer closer, even opposite joint, then it makes the water-resisting layer partly or wholly loss its confining effect and effluent water, especially in the ends of the fault, the crossing, fold axis, and the fracture zone of stress concentration.
the water inrush. After forming the channels of water inrush, the main role of water pressure is to overcome the resistance of water inrush channel. If the water pressure is great, water is rich and the channel is open, the risk of water inrush would be greater. Besides, it is a basic for the large quantity outstanding that the Karsts aquifer is in good condition or the water supply is strong.

3.3. The Conditions of the Impermeable Layer in the Roof and Floor

The water inrush occurs or not depends on weather the strength and the weight of roof and floor can resist the aquifer water pressure and ground pressure, while the strength and the weight of roof and floor depends on its thickness and rock properties. If the water-resisting layer is very thick and hard, it will be relatively safe. Therefore, most of the water inrush occurred in the areas, where the aquifuge is thinner and the rock is broken and soft.

3.4. The Coal Mining Activities

The water inrush accident is closely related to the space of hanging roof area, which is direct related to the different coal-mining method. In some mining area with the water inrush risk, we can change the coal-mining method to avoid or reduce the risk of water inrush, such as using short-Face mining, banded mining, room-and-pillar working, or mining with stowing. The main factors related to mining activities are working thickness, mining depth, the face length in the tendency and the long. They influence the size of the depth of mining damage and the distribution of mine ground pressure.

4. The Evaluation System about the Water Inrush from Roof and floor of coal seam

4.1. The Model of the Security Assessment

1) Quantitative description of risk about the roof and floor of coal seam water inrush

The risk about water inrush (R) is decided by two factors: the probability of happening of water inrush (p) and the danger of water inrush (d). In other words, the risk is a function of the probability of happening and the danger, \( R=f(p,d) \)

Because it is difficult to calculate the probability, the accident risk generally refers to the accident rate of water inrush from roof and floor, which is the possibility of accident. The dangers of water bursting from roof and floor generally include the damage, which should include direct damage and indirect losses, personal casualty and social impact.

2) The comprehensive evaluation of the accident risk

The comprehensive evaluation is composed by three levels two-stage evaluating indicator, as shown in the figure 1.

4.2. The Possibility of Water Inrush

We make a analysis and calculation about the coal mine which water inrush occurred, and here is the analysis and calculation.

1 ) Establish a evaluation grade set \( V \), \( V=\{v_1,v_2,v_3,v_4,v_5\} \). The likelihood of the water inrush from roof and floor of coal seam in this mine is divided into five levels and in turn increase. \( V=\{ \text{Grade I, Grade II, Grade III, Grade IV, Grade V} \} \)

2 ) Establish a factor sets, \( U=\{u_1,u_2,u_3,u_4\} \). The factor sets of the water inrush from roof and floor of coal seam are \( U=\{ \text{the geological structure, the geohydrologic condition, the water-resisting layer, the coal mining activities} \} \)

In this paper we used expert scoring method, and had consulted four experts: universities and research institutes professors, scholar, mine safety management, mine engineering and technical personnel, the workers with years of work experience. According to their views and opinions about water inrush control experience, they rated each factor about water inrush in the mine. We statistic count the scores of every experts, and obtained the fuzzy relation matrix with single factor.

3 ) Determine the weight vector of evaluation factors \( A, A=\{a_1,a_2,a_3,a_4\} \). Generally speaking, different evaluation factors are not equally important to the evalu-

\[
R = \begin{bmatrix}
0.12 & 0.16 & 0.18 & 0.18 & 0.36 \\
0.18 & 0.17 & 0.13 & 0.32 & 0.20 \\
0.22 & 0.10 & 0.45 & 0.15 & 0.18 \\
0.35 & 0.20 & 0.15 & 0.17 & 0.13 \\
\end{bmatrix}
\]
-ation object, and their impacts on the overall performance of the system are different. Therefore, we should determine and normalize A, the weight vector of evaluation factors, before carrying out fuzzy transform.

Now, there are many ways to determine the weight vector of evaluation factors. The AHP (analytic hierarchy process) is an effective method. We determine the weight vector of evaluation factors using the AHP and structure the matrix using the scale proposed by the professor Saaty, as shown in the table 1.

### Table 1. The matrix using the scale proposed by the professor Saaty

<table>
<thead>
<tr>
<th>The scale</th>
<th>The definition</th>
<th>The explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equally important</td>
<td>Compared with the two factors, they are of equal importance</td>
</tr>
<tr>
<td>3</td>
<td>Somewhat important</td>
<td>Compared with the two factors, one factor is slightly more important than the other</td>
</tr>
<tr>
<td>5</td>
<td>Obviously important</td>
<td>Compared with the two factors, one factor is obviously more important than the other</td>
</tr>
<tr>
<td>7</td>
<td>Very important</td>
<td>Compared with the two factors, one factor is much more important than the other</td>
</tr>
<tr>
<td>9</td>
<td>Absolutely important</td>
<td>Compared with the two factors, one factor is absolutely more important than the other</td>
</tr>
<tr>
<td>2, 4</td>
<td></td>
<td>The median between the adjacent case</td>
</tr>
<tr>
<td>6, 8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The multi-factor evaluation results about the water inrush from roof and floor of coal seam given by the experts as shown in the table 2.

### Table 2. The possibility matrix of the water inrush

<table>
<thead>
<tr>
<th>A</th>
<th>B₁</th>
<th>B₂</th>
<th>B₃</th>
<th>B₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>B₁</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>B₂</td>
<td>1/2</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>B₃</td>
<td>1/3</td>
<td>1/3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>B₄</td>
<td>1/5</td>
<td>1/4</td>
<td>1/3</td>
<td>1</td>
</tr>
</tbody>
</table>

The step of calculating the index weight in criteria level and element level:

1. Calculating the product of the scores in each line in the matrix: \( M_{ij} = \prod_{k=1}^{4} B_{jk} \) i=1,2,3,4
2. Calculating the M’s 4-th root: \( M_i = \sqrt[4]{M_{ij}} \).

3. The vector \( \mathbf{M}_A \) is normalized to get the weight vector \( \mathbf{A}_1 = (a_1, a_2, a_3, a_4) \).

Based on the above steps, we can calculate using the data in Table 2, \( \mathbf{A}_1 = (0.44, 0.30, 0.14, 0.12) \)

Using the fuzzy composite operator to get the evaluation vector.

In order to better reflect the prominent role of weight, the operator \( M = (V, \cdot) \) is selected for the major factors.

### 4.3. The Analysis of Accident Hazard

1. Same as the above, establish a evaluation grade sets \( V = \{v_1, v_2, v_3, v_4, v_5\} \). The harmfulness of the water inrush from roof and floor of coal seam in this mine is divided into five levels and in turn increase. \( V_2 = \{\text{Grade I, Grade II, Grade III, Grade IV, Grade V}\} \)

2. Establish a factors sets \( U = \{u_1, u_2, u_3\} \). The evaluation factor sets is \( U_2 = \{\text{the personal casualty, the property loss, the social impact}\} \). Same as the above, it can be got the result \( R_2 \) using expert rating method:

   \[
   R_2 = \begin{bmatrix}
   0.11 & 0.20 & 0.42 & 0.16 & 0.16 \\
   0.12 & 0.12 & 0.58 & 0.10 & 0.08 \\
   0.14 & 0.25 & 0.41 & 0.11 & 0.09
   \end{bmatrix}
   \]

3. Same as the above, it can be can determine the weight vector of evaluation factors using the AHP \( \mathbf{A}_2 = (a_1, a_2, a_3) = (0.35, 0.4, 0.25) \)

   \[
   R_2 = \begin{bmatrix}
   0.11 & 0.20 & 0.42 & 0.16 & 0.11 \\
   0.12 & 0.12 & 0.58 & 0.10 & 0.08 \\
   0.14 & 0.25 & 0.41 & 0.11 & 0.09
   \end{bmatrix}
   \]

   \[
   B_1 = A_1 \times R_1 = (0.44, 0.30, 0.14, 0.12) \times \begin{bmatrix}
   0.14 & 0.18 & 0.18 & 0.22 & 0.28 \\
   0.18 & 0.17 & 0.13 & 0.42 & 0.10 \\
   0.22 & 0.10 & 0.45 & 0.15 & 0.18 \\
   0.35 & 0.20 & 0.15 & 0.17 & 0.13
   \end{bmatrix} = (0.062, 0.079, 0.079, 0.126, 0.123)
   \]

   By normalized \( B_1 \), we get \( B_0 = (0.13, 0.17, 0.17, 0.27, 0.26) \), which tell us the possible memberships of water inrush in this mine from grade I to grade V are 0.13, 0.17, 0.17, 0.27, 0.26. According to the principle of maximum membership, the possible memberships of water inrush in this mine is grade IV, which means a great possibility of accidents.

### 4.4. The Fuzzy Comprehensive Evaluation of Risk

We divided the accident risk into five levels, and we can derive the fuzzy matrix Layer according to the
computing result about criteria layer:

\[
R_j = \begin{bmatrix}
0.13 & 0.17 & 0.17 & 0.27 & 0.26 \\
0.11 & 0.16 & 0.51 & 0.13 & 0.09 \\
\end{bmatrix}
\]

The experts gave out the possibility and danger weight of water inrush accidents 0.53 , 0.47, so

\[
A_3 = (0.53, 0.47)
\]

\[
B = A_3 \times R_j \times \begin{bmatrix}
0.13 & 0.17 & 0.17 & 0.27 & 0.26 \\
0.11 & 0.16 & 0.51 & 0.13 & 0.09 \\
\end{bmatrix}
\]

\[
= (0.0689, 0.0901, 0.2397, 0.1431, 0.1378)
\]

By normalized \( B_3 \), we get \( B_3 = (0.10, 0.14, 0.35, 0.21, 0.20) \). According to the principle of maximum membership, the accident risk memberships of water inrush in this mine is 0.35, which is Intermediate risk.

5. Conclusion

That using the fuzzy comprehensive evaluation method to evaluate the accident risk about water inrush from roof and floor of coal seam is the application of security engineering in the mining security. It can make accident prevention and control measures more scientific, reasonable and effective. But now the AHP-FUZZY is not perfect in the mining safety assessment, and needs further development and improvement.

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References