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Research Article

Quantitative Identification of Grouting Effect of Working Face Floor with Multifactor Set

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The deep coal mining in the North China type of coalfield is generally threatened by the underlying limestone water of Taiyuan Formation and Ordovician. The occurrence of water inrush can be avoided effectively by applying grouting reinforcement technology to the coal floor. However, the reinforcement treatment of the coal floor belongs to underground concealment engineering, and it is of great significance for the safe production of the coal mine by scientifically and comprehensively evaluating the technical method of the grouting effect on the working face floor. In this study, the optimal transfer matrix is used to construct the judgment matrix that meets the consistency requirements; the analytic hierarchy process is improved; and the grouting effect of the working face floor is evaluated by fuzzy comprehensive evaluation based on several factors of the grouting effect. Taking the grouting engineering of the 15092 working face of the Guhanshan Mine as an example, the evaluation of the grouting effect based on four evaluatory indices have been refined: dynamic hydrological features, grout amount, grouting inspection hole, and geophysical prospecting have been refined. Based on the improved analytic hierarchy process (AHP), the result of the grouting effect can be divided into four levels: distinction, good, average, and poor. The study would play a very important role in the evaluation of the grouting reinforcement of the working face floor and the practice of coal mine production safety.

1. Introduction

With complex hydrogeological conditions, the coal-bearing strata in the North China type of coalfield are mainly the Permian Shanxi Formation and the Lower Shihezi Formation [1]. As coal resources in the shallow part of coalfields are exhausted, the threat to the mining of lower coal groups threatened by confined karst aquifers is increasing, and the danger of mine water inrush is gradually increasing [2, 3]. The mining of the lower coal seams of the Shanxi Formation is generally seriously threatened by the limestone water of the underlying Taiyuan Formation and the Ordovician limestone water [4–6]. The Ordovician water pressure on the coal seam floor of many mines has exceeded 10 MPa, and the risk of Ordovician limestone inrush into the coal seam floor is increasing [7]. In order to mine the lower coal group safely, the coal seam floor must be grouted and reinforced, which can increase the thickness of the effective water-resistant layer and eliminate or reduce accidental karst water inrush accidents [8, 9]. However, grouting on the coal seam floor is an underground concealed project. Furthermore, grouting mainly considers the weak water content within the water barrier, the depth of bottom plate mining damage, and the development of bottom plate fissures, but the premise ensures that the water control by-laws are within the safety factor of water burst, and cannot be measured by the head pressure size alone. The scientific and effective evaluation of the grouting effect is related to the success or failure of the grouting project [10–13]. Therefore, it is of great significance to carry out grouting effect evaluation research.

In recent years, the evaluation of the grouting effect on the coal floor has mainly focused on various detecting methods, including water quantity, water temperature, post-grouting pressure, water absorption, *P-Q* curve analysis, coring inspection, and geophysical exploration results. Based on the fact that the permeability and mechanical strength of the rock mass are important parameters reflecting the grouting effect of the rock mass, Liu et al. [14] proposed the high-pressure water pressure test method for the quantitative evaluation of the grouting effect of plugging the Taiyuan formation limestone. On the basis of carrying out the single-hole water discharge experiment, Li et al. [15] combined it with the dominant surface theory of water inrush to put forward the floor classification grouting technology. Based on the data set of grouting drilling, Xie et al. studied the case of water inrush in the grouting reinforcement of the working face and the data at the point of mine water inrush and combined it with the study of factors such as geological structures, hydraulic pressure of underlying water, floor water-conducting properties, and grouting amounts, and established the risk evaluation for floor water inrush in the grouted working face [16–18]. The novel technique of evaluating grouting techniques such as the artificial neural network (ANN) is also used for consolidation grouting quality assessment of dam foundation [19]. But the evaluation system of dam foundation is different from grouting of the working face floor. There is a certain limitation to the grouting effects evaluatory methods because these evaluatory methods were either based on a single evaluatory factor [3, 5] or did not contain the different evaluatory factors which covered the whole of grouting engineering [9]. Even though a combination of several factors is used, if the weight of each factor is not settled scientifically, it will lead to a low reliability of the overall evaluation as a result. It is dangerous to make a decision concerning coal mine production based on a wrong or an incomplete grouting evaluatory result.

Fuzzy comprehensive evaluation is a fuzzy concept with multiple indicators and levels, which is an effective way for evaluating targets affected by multifactor. It has been widely used in many fields, such as the safety management of petrochemical company, medicine, construction, urban development. and the environment, quality supervision, water quality assessment, and feed safety assessment. The analytic hierarchy process (AHP) is a decision analysis method that combines qualitative and quantitative methods. It is good at solving complex problems with multiple goals. The weight of each evaluatory factor can be calculated by the analytic hierarchy process method, and the comment set and evaluatory results can be gotten by fuzzy concepts [20, 21]. By combining the two methods, more scientific and reliable evaluatory results can be obtained.

In order to overcome the shortcomings of evaluating the grouting effect by a single index, this paper classifies major evaluatory indices of the grouting effect. With the improved analytic hierarchy process, the fuzzy comprehensive evaluation method for the evaluation of the grouting effect of the working face floor is studied. The grouting effect of the 15092 working face floor of the Guhanshan Mine of the Coking Coal Group has been evaluated by the studied method, and the science and validity of the studied method have been verified.

2. Calculation Method and the Study Area

2.1. Improved AHP Method. The analytic hierarchy process (AHP) is a practical multischeme or multiobjective system analysis and decision-making method which was proposed by Professor Thomas L. Saaty, an operations researcher at the University of Pittsburgh in the United States. AHP method combines qualitative and quantitative analyses. The goal of the combined weight of each level is calculated through the establishment of a hierarchical structure or model, the construction of a judgmental matrix, single-level ordering, total level ordering, a consistency check, etc. and is a systematic method of objective and optimized decision-making [22–24].

The consistency of the judgmental matrix established by the analytic hierarchy process must be tested. There are some difficulties in the consistency test of the judgmental matrix, and the standard $CR < 0.1$ for testing lacks a scientific basis. In order to solve the problem, this research improves the method of constructing the judgment matrix and uses complementary ideas for its construction, which can automatically meet the consistency requirements of the judgment matrix.

2.2. Constructing a Complementary Judgment Matrix. Constructing a complementary judgment matrix Q based on the importance of impact factors, that is,

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1m} \\ q_{21} & q_{22} & \cdots & q_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix}. \quad (1)$$

The elements in matrix Q meet the following condition:

$$q_{mn} = q_{mk} - q_{nk} + 0.5, \quad (2)$$

where m represents the number of factors involved in the evaluation, $0 \le q_{mn} \le 1$, $q_{mn} + q_{nm} = 1$, q_{mn} represents the importance of membership that the factor q_m has when compares to q_n. The higher the q_{mn} shows that q_m is more important than q_n. q_m and q_n have the same importance when q_{mn} equals 0.5.

2.3. Calculating the Complementary Consistent Judgmental Matrix. Fuzzy complementary matrix $Q = (q_{ij})_{n\times n}$, summed by line, marked as

$$b_i = \sum_{k=1}^{n} q_{ik}, i = 1, 2, \cdots, n, \quad (3)$$

then the following further transformation

$$b_{ij} = \frac{b_i - b_j}{a} + 0.5, \quad (4)$$

where $a = 2 * (n - 1)$ and $B = (b_{ij})_{n\times n}$ is the complementary consistent judgmental matrix.

2.4. Weighting Calculation. Weighting calculation formula:

$$w_i = \frac{\beta^{(1/n)\sum_{j=1}^{n} r_{ij}}}{\sum_{k=1}^{n} \beta^{(1/n)\sum_{j=1}^{n} r_{kj}}}, \quad (5)$$

where w represents weight and β is the parameter used for adjusting the resolution. The value is a positive integer greater than 1, and the larger the value of β, the higher the resolution of the weight calculated by formula (5).

In the general analytic hierarchy process (AHP) method, when constructing the pairwise comparison judgmental matrix, the fuzziness of human judgment is usually not considered. Experts often give some fuzzy amount, so the fuzzy comprehensive evaluation theory is introduced.

2.5. Fuzzy Comprehensive Evaluation Method. The fuzzy mathematics theory is the basis of fuzzy comprehensive evaluation, applying the principle of fuzzy relationship synthesis, quantifying some difficult quantitative factors, and comprehensively evaluating the status of the evaluated affairs by multiple factors.

2.6. Determining the Domain of Factors of the Evaluated Object. According to the evaluatory research of the grouting effect, the evaluatory factors $U = \{$dynamic hydrological characteristics of grouting holes, grouting characteristics, inspection holes, geophysical prospecting$\}$.

2.7. Determining the Comment Set. Determining the comment set is essential to the grade division of the grouting effect, which can generally be divided into four grades. The comment set is $V = \{$distinction, good, average, poor$\}$.

2.8. Constructing the Fuzzy Complementary Consistent Judgmental Matrix. Since the judgmental matrix is not complementary and consistent, the fuzzy complementary consistent judgmental matrix B is further established by formula (4):

$$B = \begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{11} & b_{22} & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{m1} & b_{m2} & \cdots & b_{mn} \end{pmatrix}, \quad (6)$$

where $b_{ij} (i = 1, 2, \cdots, m\,; j = 1, 2, \cdots, n)$ represents the degree of membership of b_i to b_j.

(1) Determining the fuzzy weight vector of the evaluatory factor

Using the weight calculation formula (3), the weight factor $w_i\,(i = 1, 2, \cdots, m)$ is calculated based on the judgmental matrix, w_i meets the conditions, which are $w_i \geq 0$ and $\Sigma w_i = 1$. The weight set W consists of a fuzzy set of weights. With the second-level weight vector and the single-factor evaluatory matrix, the second-level evaluation matrix E can be obtained.

(2) Fuzzy comprehensive evaluation by multifactor

The fuzzy synthesis operator of the matrix is used to synthesize the first-level weight factor W and the second-level evaluatory matrix E. The fuzzy comprehensive evaluatory vector can be calculated by

$$A = W \circ E = (w_1, w_2, \cdots, w_m) \begin{pmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ e_{21} & e_{22} & \cdots & e_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ e_{m1} & e_{m1} & \cdots & e_{mn} \end{pmatrix} = (a_1, a_2, \cdots, a_n). \quad (7)$$

In formula (7), ° is a fuzzy operator, and a_j represents the degree of membership of the rated object to the fuzzy subset element v_j of the evaluatory level as a whole. The principle of maximum degree of membership is adopted to process the fuzzy comprehensive evaluatory vector, that is, if the fuzzy comprehensive evaluation result vector $A = (a_1, a_2, \cdots, a_n)$, if $a_r = \max_{1\leq j\leq n}\{a_j\}$, the evaluating result is the rth level as a whole.

2.9. Geological Profile. The Guhanshan Mine is located in the eastern section of the Jiaozuo Coalfield and is under the jurisdiction of Xiuwu County, Jiaozuo City, 15 km south of Xiuwu County, and 42 km east of Huixian City. The minefield is 15 km south of the Xinjiao Railway, and the mine is connected to the Daiwang Station of the Xinjiao Line by the special coal mine railway. The transportation is convenient, and the regional geological structure is complex. The large faults around the minefield include the Jiulishan Fault, the Mafangquan Fault, and the Fenghuangling Fault, which are shown in Figure 1.

The main mining strata of the Guhanshan Mine is the II_1 coal in the lower part of the Shanxi Formation. The coal thickness is 2.79-9.13 m, with an average of 4.86 m. The roof is gray to dark gray mudstone, sandy mudstone, and fine-grained sandstone or partial siltstone. The floor is gray-black to dark gray mudstone, sandy mudstone, or siltstone. According to the bed thickness, lithology, water-bearing conditions, and water yield properties, the aquifers in the study area could be divided into three types: (1) The Ordovician limestone aquifer is the sedimentation base of the coal measure strata. The osmotic coefficient of the aquifer is 1-30 m/d. (2) The Carboniferous limestone aquifer, which is mainly composed of the Taiyuan Formation limestone and the L_2 and L_8 limestone. The osmotic coefficient is 1-3 m/d. The thickness of the aquiclude between the aquifer and the II_1 coal seam is relatively stable, with an average of 35.55 m. There is an aquiclude (aluminous mudstone) between the Ordovician limestone and L_2 aquifers. The direct water-filled rock layer on the floor is the L_8 limestone fissure-karst aquifer in the upper part of the Carboniferous Taiyuan Formation. The L_2 limestone and Ordovician

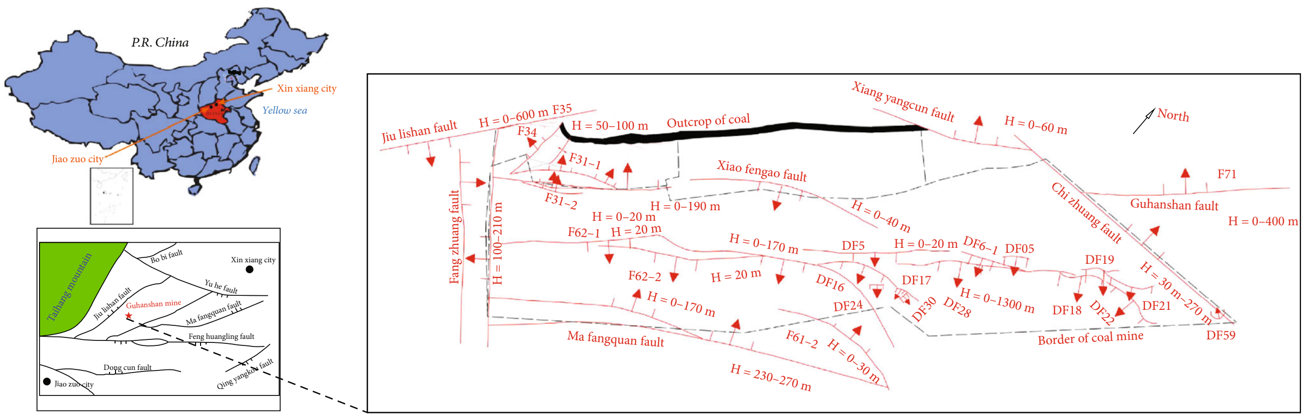

Figure 1: Regional tectonic profile and sketch of mine geological structure.

limestone karst water aquifers in the lower part of the Carboniferous Taiyuan Formation are indirect water-filled aquifers mined in the II_1 coal seam, with strong water-bearing aquifers, as shown in Figure 2. Due to the thin layer of the L_8 aquifer and the long-term regional drainage effect, it is not harmful to the coal mining of the II_1 coal seam. If the lower L_2 limestone aquifer is recharged, the risk of water inrush will increase. (3) the Quaternary porous aquifer is mainly consist of the sandy gravel layer or fine sand layer. The supply sources of the water are atmospheric precipitation and infiltration from canals and rivers.

The 15092 working face has a strike length of 984 m, an inclination width of 127.7 m, a coal seam strike of 50°, an inclination of 140°, an inclination angle of 12-15°, an average of 13°, an average coal thickness of 2 m, and a recoverable reserve of 396,000 tons. The geological conditions of the 15092 working face are relatively simple. The coal seams are stable and fold in a wide and gentle manner. The occurrence of the strata changes slightly under the influence of faults. The hydrogeological conditions of the working face are simple.

3. Evaluation of Grouting Effect on the Working Face Floor

3.1. Index System Construction. The impact indicator of the grouting effect evaluatory grade is complex are interrelated but poorly correlated. Therefore, based on the analysis of the influence of each factor on the effect evaluation, combined with the characteristics and construction requirements during the grouting construction period, the grouting effect evaluatory hierarchy is established, as shown in Figure 3. In this paper, a comprehensive evaluation of the grouting at the working face of the Jiaozuo coalfield is carried out, and four first-level index evaluatory systems, namely, $U = \{u_1, u_2, u_3, u_4\}$, are constructed for the dynamic hydrological characteristics of grouting holes, grouting characteristics, inspection holes, and geophysical prospecting, respectively.

According to the requirement of coal mine production safety, the grouting effect evaluatory level is divided into four evaluatory sets: distinction, good, average, and poor. The grouting effect evaluation set is shown in Table 1.

4. Factor Weight Determination

Weight is a measure of the relative importance or contribution of a specific evaluatory factor in determining the set of reviews. In the fuzzy comprehensive evaluation, the weight has an important influence on the final evaluatory result, and different weights will even lead to completely different conclusions. At present, the main methods for determining weights are the weighted average method, the analytic hierarchy process, the expert survey method, the eigenvalue method, etc. The analytic hierarchy process has the characteristics of strong objectivity and strong reliability of the evaluatory results, which ensure the judgmental matrix. In this study, the improved analytic hierarchy process was used to determine the weight of the evaluatory factor. The weight setting is shown in Table 2.

5. Determination of the Weight of the Primary Evaluation Factor

First-level evaluation factor set $U = \{u_1, u_2, u_3, u_4\} = \{$ dynamic hydrological characteristics of grouting hole, grouting feature, inspection hole, geophysical prospecting$\}$, considering that the weight difference of the first-level evaluation factor should not be too large, take $\alpha = 810$, $\beta = 100$, from Table 2 and considering the importance membership degree between factors, the judgment matrix is obtained:

$$Q = \begin{pmatrix} 0.5 & 0.6035 & 0.7675 & 0.7906 \\ 0.3965 & 0.5 & 0.7403 & 0.7675 \\ 0.2325 & 0.2597 & 0.5 & 0.664 \\ 0.2094 & 0.2325 & 0.336 & 0.5 \end{pmatrix}. \quad (8)$$

Based on Q, constructing a fuzzy complementary consistent judgment matrix according to formula (4):

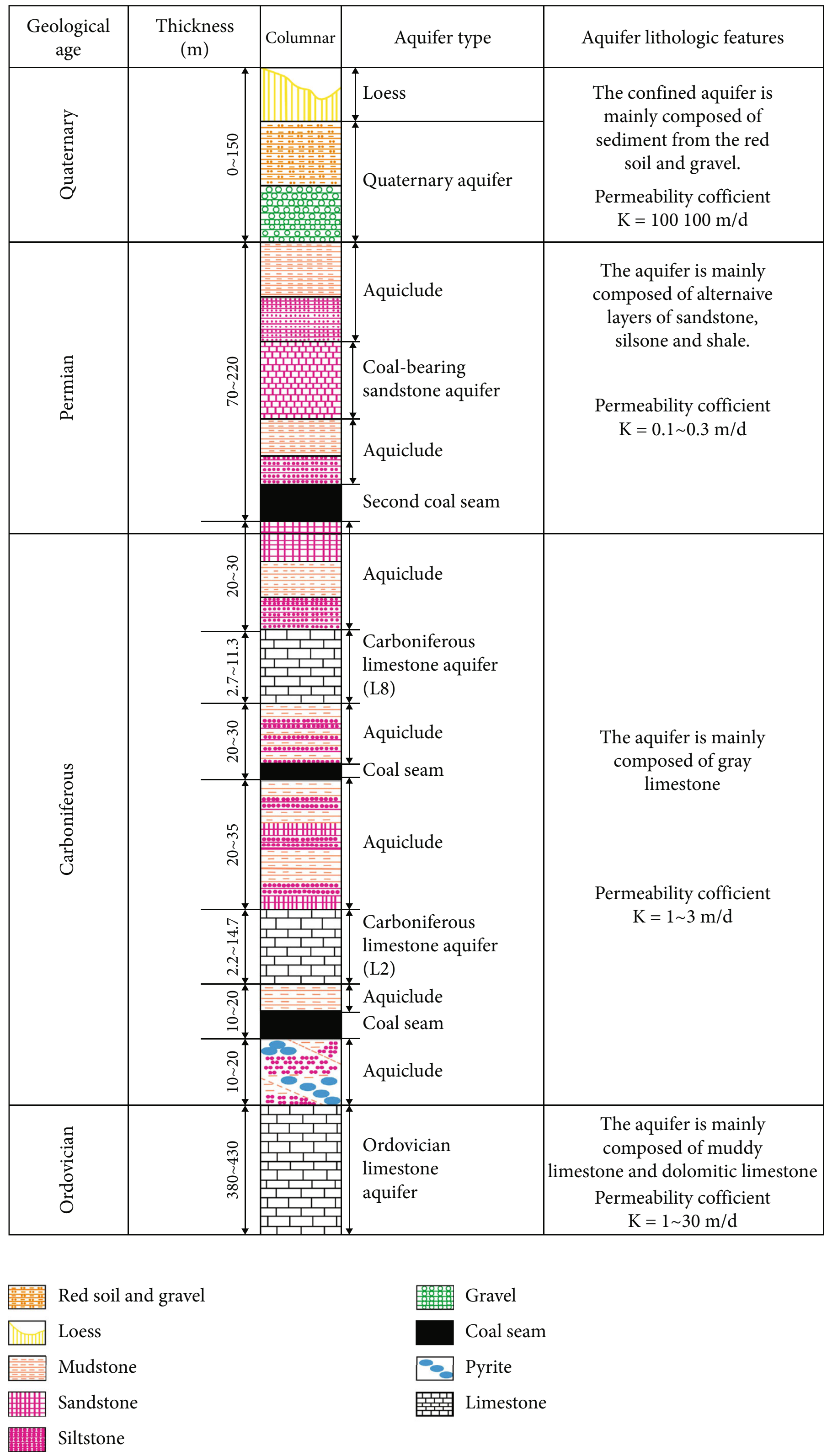

FIGURE 2: Stratigraphic histogram of the upper Ordovician.

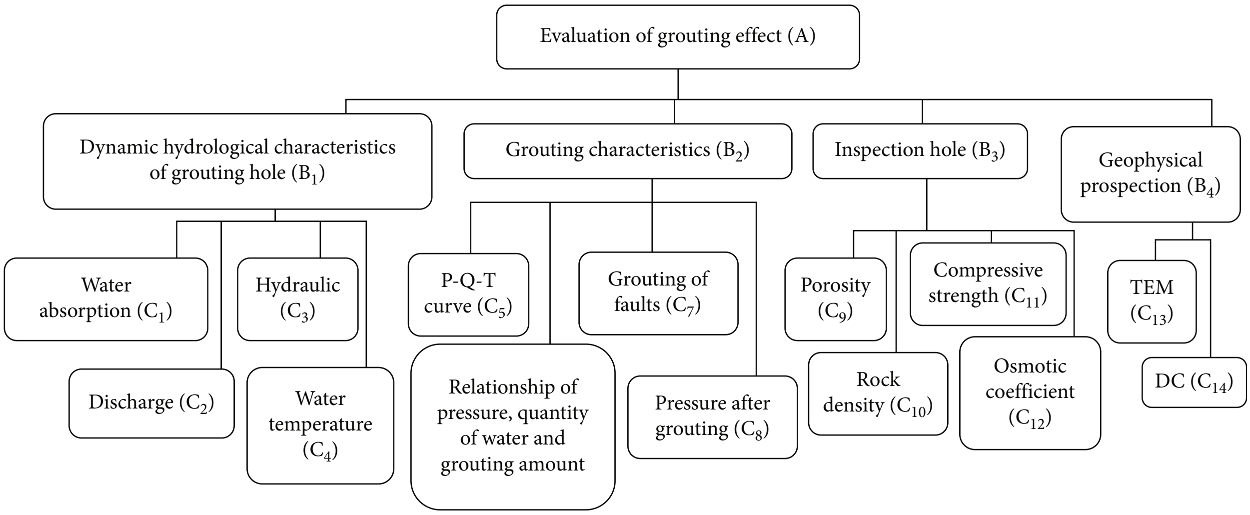

Figure 3: Architecture of multilayered evaluatory factors.

Table 1: Fuzzy comment set.

Level	Distinction	Good	Average	Poor
Value	$0 < v \leq 0.25$	$0.25 < v \leq 0.5$	$0.5 < v \leq 0.75$	$0.75 < v \leq 1$

$$B = \begin{pmatrix} 0.5 & 0.5429 & 0.6676 & 0.7306 \\ 0.4571 & 0.5 & 0.6246 & 0.6877 \\ 0.3324 & 0.3753 & 0.5 & 0.5631 \\ 0.2694 & 0.3123 & 0.437 & 0.5 \end{pmatrix}. \tag{9}$$

From the calculation formula of the weight vector, the resolution of the combined factor, the β value is 100, then the weight of each factor:

$$W = (0.38, 0.31, 0.18, 0.13). \tag{10}$$

6. Determination of the Weight of Secondary Evaluation Factors

The secondary evaluation factor of the judgmental matrix of the calculation process and the fuzzy complementary consistent judgmental matrix is omitted. Due to limited space, the result of the fuzzy complementary consistent judgmental matrix is directly given. The calculation process and parameter settings are the same as the primary evaluation factor.

The evaluatory matrix of the dynamic hydrological characteristics of the grouting hole is

$$B_1 = \begin{pmatrix} 0.5 & 0.5072 & 0.4861 & 0.6448 \\ 0.4928 & 0.5 & 0.4789 & 0.6376 \\ 0.5139 & 0.5211 & 0.5 & 0.6587 \\ 0.3552 & 0.3624 & 0.3413 & 0.5 \end{pmatrix}. \tag{11}$$

Weight vector $W_1 = (0.28, 0.27, 0.30, 0.15)$.

The evaluatory matrix of grouting characteristics is

$$B_2 = \begin{pmatrix} 0.5 & 0.5791 & 0.5413 & 0.3797 \\ 0.4209 & 0.5 & 0.4622 & 0.3006 \\ 0.4587 & 0.5378 & 0.5 & 0.3384 \\ 0.6204 & 0.6994 & 0.6616 & 0.5 \end{pmatrix}. \tag{12}$$

The weight vector of the grouting feature $W_2 = (0.23, 0.16, 0.20, 0.41)$.

The evaluatory matrix of the inspection hole is

$$B_3 = \begin{pmatrix} 0.5 & 0.5134 & 0.3597 & 0.3107 \\ 0.4867 & 0.5 & 0.3463 & 0.2973 \\ 0.6403 & 0.6537 & 0.5 & 0.451 \\ 0.6894 & 0.7027 & 0.549 & 0.5 \end{pmatrix}. \tag{13}$$

The weight vector of the inspection hole $W_3 = (0.16, 0.15, 0.31, 0.38)$.

The evaluatory matrix of the geophysical method is

$$B_4 = \begin{pmatrix} 0.5 & 0.436 \\ 0.564 & 0.5 \end{pmatrix}. \tag{14}$$

The weight vector of the geophysical method $W_4 = (0.43, 0.57)$.

7. Evaluation of Grouting Effect

7.1. Constructing Single-Factor Evaluatory Matrix. Based on the actual grouting data of the 15092 working face of Guhanshan Mine, multiple experts independently voted on each index of evaluating the grouting effect. The number of

Table 2: The meaning of membership degree of fuzzy uniform matrix and its comparison table.

Degree of membership	Definition	Semanteme
0.5	Equal importance	The importance of two index to the goal is equal
$\log_\alpha 3 + 0.5$	Slight importance	The importance of two index to the goal is that index 1 is slight importance to index 2
$\log_\alpha 5 + 0.5$	Obvious importance	The importance of two index to the goal is that index 1 is obvious importance to index 2
$\log_\alpha 7 + 0.5$	Strong importance	The importance of two index to the goal is that index 1 is strong importance to index 2
$\log_\alpha 9 + 0.5$	Extreme importance	The importance of two index to the goal is that index 1 is extreme importance to index 2
$\log_\alpha i + 0.5, i = 2, 4, 6, 8$	Compromise value of adjacent scale	Represents the degree of membership when adjacency factor compromising
The degree of membership of the above is complementary	Complementation	The degree of membership of scheme A_i to scheme A_j is r_{ij}, otherwise $1 - r_{ij}$

experts' votes for each index is used as the evaluation of the factor, as shown in Table 3.

7.2. Single-Factor Evaluatory Matrix. Combining the voting results of the experts in Table 3, the normalized value of the votes obtained by each secondary evaluatory factor is used as the element in the corresponding single-factor evaluatory matrix. Thus, the single-factor evaluatory matrix of four first-level evaluation factors u_1, u_2, u_3, and u_4 can be obtained as

$$E_1 = \begin{pmatrix} 0.3 & 0.4 & 0.2 & 0.1 \\ 0.5 & 0.3 & 0.1 & 0.1 \\ 0.4 & 0.4 & 0.1 & 0.1 \\ 0.3 & 0.3 & 0.3 & 0.1 \end{pmatrix},$$
$$E_2 = \begin{pmatrix} 0.3 & 0.4 & 0.2 & 0.1 \\ 0.4 & 0.3 & 0.2 & 0.1 \\ 0.3 & 0.3 & 0.3 & 0.1 \\ 0.4 & 0.3 & 0.2 & 0.1 \end{pmatrix},$$
$$E_3 = \begin{pmatrix} 0.4 & 0.5 & 0.0 & 0.1 \\ 0.2 & 0.4 & 0.2 & 0.2 \\ 0.3 & 0.3 & 0.1 & 0.3 \\ 0.4 & 0.3 & 0.1 & 0.2 \end{pmatrix},$$
$$E_4 = \begin{pmatrix} 0.3\,0.3\,0.2\,0.2 \\ 0.4 \quad 0.2 \quad 0.2 \quad 0.2 \end{pmatrix}. \tag{15}$$

7.3. Single-Factor Evaluation. According to the improved analytic hierarchy process, using the fuzzy evaluatory theory to calculate the weight of the secondary evaluation factor is

$$\begin{aligned} W_1 &= (0.28, 0.27, 0.30, 0.15), \\ W_2 &= (0.23, 0.16, 0.20, 0.41), \\ W_3 &= (0.16, 0.15, 0.31, 0.38), \\ W_4 &= (0.43, 0.57). \end{aligned} \tag{16}$$

The fuzzy operator $F(\cdot, \oplus)$ is used to get the secondary evaluatory matrix:

$$E = \begin{pmatrix} W_1 \circ E_1 \\ W_2 \circ E_2 \\ W_3 \circ E_3 \\ W_4 \circ E_4 \end{pmatrix} = \begin{pmatrix} 0.384 & 0.358 & 0.158 & 0.1 \\ 0.357 & 0.323 & 0.22 & 0.1 \\ 0.339 & 0.347 & 0.099 & 0.215 \\ 0.357 & 0.243 & 0.2 & 0.2 \end{pmatrix}. \tag{17}$$

7.4. First-Level Comprehensive Evaluation. The weights of the first-level evaluatory factors u_1, u_2, u_3, and u_4 are

$$\begin{aligned} A = W \circ E = (a_1, a_2, a_3, a_4) &= (0.38, 0.31, 0.18, 0.13) \\ &\circ \begin{pmatrix} 0.384 & 0.358 & 0.158 & 0.1 \\ 0.357 & 0.323 & 0.22 & 0.1 \\ 0.339 & 0.347 & 0.099 & 0.215 \\ 0.357 & 0.243 & 0.2 & 0.2 \end{pmatrix} \\ &= (0.37 \quad 0.33 \quad 0.17 \quad 0.13). \end{aligned} \tag{18}$$

Finally, the first-level evaluation vector is obtained: $(0.37, 0.33, 0.17, 0.13)$.

According to the criterion of the maximum degree of membership, the largest of the comprehensive evaluatory vector A is the final evaluation result, that is, the grouting effect of the 15092 working face of the Guhanshan Mine is good.

Table 3: The weight of the grouting evaluation on the 15092 coal workface of Guhanshan mine.

Evaluation factor of first level	Weight	Evaluation factor of second level	Weight	Distinction	Good	Average	Poor
Dynamic hydrological characteristics of grouting hole	0.38	Water absorption	0.28	3	4	2	1
		Water inflow	0.27	5	3	1	1
		Water pressure	0.30	4	4	1	1
		Water temperature	0.15	3	3	3	1
Grouting characteristics	0.31	Curve of P-Q-T	0.23	3	4	2	1
		Dynamic relationship of water pressure, quantity of water, and grout amount	0.16	4	3	2	1
		Grouting characteristics of fault	0.19	3	3	3	1
		Pressure after grouting	0.40	4	3	2	1
Inspection hole	0.18	Porosity	0.16	4	5	0	1
		Rock mass density	0.15	2	4	2	2
		Compressive strength	0.31	3	3	1	3
		Osmotic coefficient	0.38	4	3	1	2
Geophysical prospecting	0.13	TEM	0.43	3	3	1	2
		DC	0.57	4	2	2	2

8. Conclusion

(1) The method of judgmental matrix construction of the analytic hierarchy process has been improved. The evaluatory result is divided into four grades: distinction, good, average, and poor. According to the method, the grouting effect of the coal floor in the 15092 working face of Guhanshan Mine in the Jiaozuo Coalfield was evaluated and classified

(2) The evaluation of the grouting effect of the working floor is an important issue for the safety of coal mine production. The use of the fuzzy evaluatory method to quantitatively study the grouting effect is an active attempt in the evaluation of the grouting effect. Compared to single-factor or multifactor qualitative evaluation, this evaluatory method is simple, easy to implement, and convenient to guide the practice of grouting effect evaluation. The coal mining production shows that the evaluatory result is reliable

(3) This study has extracted four first-level evaluation factors and fourteen second-level evaluatory factors from the grouting effect evaluation indicators. The scientific nature of the weight setting of the corresponding index factors needs to be further verified by more engineering practices

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no competing interests.

Authors' Contributions

Zhenwei Yang and Junchao Yue designed the evaluation project. Xinyi Wang and Shuitao Guo devised the evaluation method and collected the grouting data. Zhenwei Yang analyzed the data and wrote the main manuscript text.

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