International Journal of Energy
ISSN: 2957-9473 | Vol. 3, No. 3, 2023

Stability Classification of Roadway Surrounding Rock Cased on Fuzzy Comprehensive Evaluation

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Abstract: In order to effectively predict the stability of roadway surrounding rock, a reasonable and effective support scheme was proposed. Fuzzy clustering analysis was introduced to classify the stability of roadway surrounding rock. Based on the data processing of 7 classification indexes, the weight and subordination degree of surrounding rock indexes of roadway are established. The results show that the upper roadway of No. 111070 is a Class IV unstable roadway. The research results can provide a certain reference for the subsequent determination of the stability classification of roadway surrounding rock.

Keywords: Surrounding Rock Stability; Fuzzy Comprehensive Evaluation Method; Roadway Support.

1. Introduction

The stability of roadway surrounding rock is affected by many factors, such as the nature of surrounding rock, surrounding rock structure, structure and failure condition, surrounding rock stress, groundwater, location of roadway, shape and size of roadway section, roadway support mode, etc., and it is also affected by mining. Therefore, it is necessary to adopt multi-index classification. Cluster analysis can be used to study the degree of affinity between samples and the classification of categories. Many scholars have used different methods to classify the stability of coal roadway surrounding rock. Guo Wenbing [1] proposed a fuzzy cluster analysis method based on fuzzy equivalence relation. Mu Lei [2] explored the stability of surrounding rock through theoretical analysis and numerical simulation. Wang Maosheng[3] and Duan Zhenrong [4] used the fuzzy clustering method to classify the stability of roadway surrounding rock. Chen Junmin[5] used the fuzzy classification method to complete the surrounding rock stability classification through statistical support design and analysis. Xu Xinghui [6] established a mathematical model of fuzzy comprehensive evaluation to predict the stability of roadway surrounding rock. These studies provide theoretical basis and guidance for roadway support and help to improve my safety.

Fuzzy comprehensive evaluation method is based on evaluation criteria and measured values, after fuzzy transformation, to make a general evaluation of things or phenomena affected by many factors. The stability category set of roadways surrounding rock is taken as the evaluation set, and the fuzzy comprehensive evaluation method is used to classify the stability of roadway surrounding rock. Therefore, it is more perfect to use fuzzy cluster analysis to classify the stability of mining roadway surrounding rock, and it is closer to the actual situation.

2. Classification Index of Roadway Surrounding Rock

Taking the upper roadway face of No.11070 mine as the engineering background, the main factors affecting the stability of roadway surrounding rock are analyzed. The strength of the roof, the strength of the coal seam and the strength of the floor are selected to represent the strength index of the surrounding rock. Burial depth represents the index of self-weight stress. The first caving step of the direct roof represents the structure and structure index of the rock mass. The ratio of direct roof thickness to mining height and the width of pillar to protect roadway represent the mining influence index. The values of the seven classification indicators are as follows:

2.1. Three Surrounding Rock Indexes

The strength of surrounding rock refers to the unidirectional compressive strength of surrounding rock, and the unit is MPa. The strength of the roof is the weighted average of the strength of the rock strata within the range of 1.5 times the height of the roadway, and the strength of the floor is the weighted average of the strength of the rock strata within the range of 1 time the height of the roadway. Combined with the field geological data and mechanical test results, the unidirectional compressive strength of coal seam is 0.24MP, roof is 38.43MP and floor is 32.07MP.

2.2. Burial Depth

The buried depth H of the roadway refers to the depth from the surface of the roadway (unit: m). According to the actual measurement results, the average buried depth is selected as 570m.

2.3. Rock Integrity Index

The rock mass integrity index D is expressed by the first caving step of the direct roof l, and the unit is m. According to the ore pressure observation results of the upper roadway of No. 11070, the average first caving step of the direct roof is 12m.

2.4. Ratio of Direct Roof Thickness to Mining Height

The thickness of the direct roof can be measured directly from the geological column chart, but the range of the direct roof should be analyzed according to specific conditions. Direct top is directly located on the coal seam (or false top), the strength is less than 60 ~ 80 MPa, generally with the return column and collapse rock. When the ratio of direct top thickness to mining height N>4, N=4, N value has no dimension. According to the field geological data, the mining

influence index of this section is finally determined to be N=2.147.

2.5. Width of Coal Pillar for Roadway Protection

Pillar width X refers to the actual width of coal on one side of the mining roadway, and the unit is m. When there is solid coal on both sides of the roadway, X=100m; When there is no pillar to protect the roadway, X=0 is taken. When there is solid coal on both sides of the roadway at the upper roadway face of No. 11070, X=70m is taken.

3. The Solution Steps of Fuzzy Comprehensive Evaluation Method

Since the classification is a numerical classification of multiple factors and indexes, there are fuzziness in the selection limit of classification indexes and the determination of index values, so fuzzy cluster analysis method is chosen to classify the stability of surrounding rock of mining roadway. In the process of solving the fuzzy comprehensive evaluation matrix, the emphasis is on determining the degree of membership between the evaluation samples and various clustering centers, and the Euclidean distance method is used to determine the degree of membership. The specific steps to solve the fuzzy comprehensive evaluation matrix are as follows:

1.Raw data linearization preprocessing

In order to simplify the relationship between the stability of roadway surrounding rock and its influencing factors, this relationship is converted into a linear relationship as far as possible, and the original data of classification indicators are not directly applied in the classification or prediction of roadway categories, but are preprocessed. Table 1-2 shows the methods for preprocessing the original data of the seven classification indicators.

Table 1. Raw data preprocessing methods

Raw data	The pre-processed data
σ_1'	$\sigma_1 = 1/\sqrt{\sigma_1'}$
σ_2'	$\sigma_2 = 1/\sqrt{\sigma_2'}$
σ_3'	$\sigma_3 = 1/\sqrt{\sigma_3'}$
N	N; N≤4
H	H
X	$W_1 = e^{-2.6[(X-B/3)/B]^2}$
	$W_2 = e^{-3.6[(X-B/3)/B]^2}$
	$W_3 = (0.3 \sim 0.4)/W_2$
D	D

Note: B is the width of coal pillar to maintain a stable state; W is the coal pillar coefficient, and foot marks 1, 2 and 3 respectively indicate that the strength type of surrounding rock is soft, stable and hard. The unidirectional compressive strength of soft surrounding rock is less than 30 MPa, stable surrounding rock is 30 ~ 80 MPa, and hard surrounding rock is greater than 80 MPa.

Referring to the calculation process of the treatment method in Table 1, the pretreatment linearization matrix of each factor of the upper roadway face of No. 11070 is obtained.

The cluster center is the core of all the roadway surrounding rock samples, which reflects the characteristics of this kind of index. According to the standard sample clustering centers of 5 categories, see Table 2. This model is used for pattern recognition and can be used to classify the predicted roadway.

Table 2. Clustering centers of various indicators

Class of roadway	σ_1	σ_2	σ_3	N	H	W	D
I	0.1035	0.2073	0.1296	0.025	266.3	0	24.3
II	0.1491	0.2335	0.1728	2.355	297.5	0	14.9
III	0.182	0.2821	0.2869	3.1	412.1	0	10.3
IV	0.1384	0.243	0.1834	2.656	340.8	0.799	11.9
V	0.1726	0.2978	0.29	3.19	365.5	0.826	9.7

2.Data standardization

The purpose of data standardization is to eliminate the impact of the difference between the categorical index dimension and the absolute value. Since the dimensions and magnitude of the variables studied may be different, direct calculation with the original data of the classification index will highlight those variables with large absolute values and reduce the role of those variables with small absolute values. At the same time, in order to satisfy the fuzzy clustering operation, the index value needs to be compressed between 0 and 1. Therefore, to solve the problem of data standardization before fuzzy cluster analysis, it can be carried out in two steps:

(1) Non-dimensional, the calculation formula is:

$$X' = \frac{X - \overline{X}}{C} \tag{1}$$

X' —No quantified raw data;

$\overline{X}$, C —Mean and standard deviation of the original data;

X —Raw data.

In reference (1), the preprocessing results and the clustering centers of various indicators are dimensionless. The standard deviation matrix of each index parameter of the roadway is obtained:

$$[0.3613 \quad 2.0392 \quad -0.4526 \quad -0.0848 \quad 1.7997 \quad 0.9306 \quad -0.3408]$$

.

Standard deviation normalization matrix of each index parameter in clustering center:

$$R' = \begin{bmatrix} -1.6949 & -0.47 & -1.1622 & -1.9121 & -1.0084 & -0.9127 & 1.9249 \\ -0.073 & -0.4342 & -0.5098 & 0.0943 & -0.72 & -0.9127 & 0.1934 \\ 1.0972 & -0.3677 & 1.2137 & 0.7358 & 0.3397 & -0.9127 & -0.6539 \\ -0.4536 & -0.4212 & -0.3496 & 0.3535 & -0.3196 & 0.8735 & -0.3592 \\ 0.7629 & -0.3462 & 1.2606 & 0.8133 & -0.0912 & 09339 & -0.7645 \end{bmatrix}$$

(2) Compress the data to between 0 and 1, the calculation formula is

$$X'' = \frac{X' - X'_{\min}}{X'_{\max} - X'_{\min}} \tag{2}$$

X'' —Undimensionalized raw data compressed to between 0 and 1;

$X'_{\max}$、$X'_{\min}$ —The maximum and minimum raw data without dimensionalization.

Reference formula (2) normalizes the above dimensionless results by extreme difference. The normalized matrix of standard deviation of each index parameter of the roadway is obtained:

[0.3267 1 0 0.1476 0.9039 0.5551 0.0449].

Normalized matrix of standard deviation of each index parameter in cluster center:

$$R''=\begin{bmatrix} 0.074 & 0.1444 & 0.1693 & 0 & 0.1459 & 0.2922 & 1 \\ 0.506 & 0.353 & 0.3444 & 0.5265 & 0.3062 & 0.2922 & 0.5395 \\ 0.8178 & 0.74 & 0.8082 & 0.6949 & 0.8949 & 0.2922 & 0.3142 \\ 0.4047 & 0.4287 & 0.3879 & 0.5945 & 0.5286 & 0.8184 & 0.3926 \\ 0.7287 & 0.865 & 0.8208 & 0.7182 & 0.6555 & 0.8362 & 0.2848 \end{bmatrix}$$

(3) Fuzzy comprehensive evaluation matrix solution

The fuzzy relationship matrix is solved by calculating the distance between the standard deviation normalization matrix of each index parameter in the roadway and the standard deviation normalization matrix of each index parameter in the cluster center. The specific calculation process is processed in the following steps:

1)The relative Euclidean distance d_{ij} was used for calibration

$$d_{ij}=\sqrt{\frac{1}{m}\sum_{k=1}^{m}(x''_{ki}-x''_{kj})^{2}}=\left|x''_{ki}-x''_{kj}\right| \tag{3}$$

m—Index number;

x''_{ik} —i sample k index;

x''_{jk} —j sample k index.

2) Euclidean proximity:

$$r'_{ij}=1-d_{ij} \tag{4}$$

3) Normalization process:

$$r_{ij}=\frac{r_{ij}}{\sum_{j=1}^{7}r'_{ij}} \tag{5}$$

The comprehensive evaluation discriminant matrix is obtained after transposing:

$$\underline{R^{*}}=\begin{bmatrix} 0.2078 & 0.2282 & 0.1415 & 0.2563 & 0.1662 \\ 0.057 & 0.1395 & 0.2924 & 0.1694 & 0.3417 \\ 0.3364 & 0.2654 & 0.0777 & 0.2479 & 0.0726 \\ 0.2928 & 0.2133 & 0.1555 & 0.1899 & 0.1485 \\ 0.0804 & 0.1336 & 0.3291 & 0.2074 & 0.2496 \\ 0.201 & 0.201 & 0.201 & 0.2009 & 0.1961 \\ 0.0167 & 0.1876 & 0.2713 & 0.2422 & 0.2822 \end{bmatrix}$$

4. Evaluation Results of Roadway Surrounding Rock Stability

In the fuzzy cluster analysis, to distinguish the influence of these indicators on the stability of surrounding rock, each indicator needs to be weighted. The specific implementation method of weighting is to multiply the corresponding weight value of the data after the standard processing of each index. The weights of classification indicators in our country are shown in Table 3.

Table 3. Weights of classification indicators

Roof strength	Coal strength	Floor strength	Mining influence coefficient	Roadway depth	Roadway pillar width	First caving step of direct roof
0.11	0.03	0.21	0.11	0.122	0.3	0.118

(1) The set of weights of each classification index can be obtained as

A=[0.11 0.03 0.21 0.11 0.122 0.3 0.118]

(2) Calculation of the set of comments

$$B=A*\underline{R}^{*}$$

= [0.1995 0.2072 0.1902 0.2204 0.1827]

(3) No. 11070 upper roadway face surrounding rock classification results

The above index parameters respectively represent the degree of subordination of No. 111070 to all kinds of roadway surrounding rocks. It can be seen from the review set that among the five categories of the work face of No.11070, the membership degree of the surrounding rock of class IV is the largest. Therefore, the stability type of surrounding rock of upper roadway No. 11070 belongs to class IV and is an unstable roadway.

5. Conclusion

According to the fuzzy comprehensive evaluation method, the subordinate degree of No. 11070 upper roadway work facing 5 types of roadways surrounding rock is as follows [0.1995 0.2072 0.1902 0.2204 0.1827] ,Among them, the subordination degree of Class IV surrounding rock is the largest, so the working face of No.11070 upper roadway is Class IV unstable roadway.

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