WILEY | Hindawi

Research Article

Geological Structural Surface Evaluation Model Based on Unascertained Measure

Kang Zhao [1,2] **Qing Wang,** [1] **Yajing Yan,** [1] **Junqiang Wang,** [2] **Kui Zhao,** [1] **Shuai Cao,** [3] **and Yongjun Zhang** [4]

[1]*School of Architectural and Surveying & Mapping Engineering, Jiangxi University of Science and Technology, Ganzhou 341000, China*
[2]*Lingbao Jinyuan Mining Company Limited, Lingbao 472500, China*
[3]*School of Civil and Resources Engineering, University of Science and Technology Beijing, Beijing 100083, China*
[4]*School of Civil Engineering, Qingdao University of Technology, Qingdao 266033, China*

Correspondence should be addressed to Kang Zhao; zhaok_666666@163.com

The surrounding rock structure plane survey is the basis for mine geological structure evaluation and stability of surrounding rock. On the basis of the unascertained measurement theory and scanline method, the surrounding rock stability of the underground geological structure plane in Lingbao Luoshan Gold Mine is evaluated. First, according to the structural plane five grading standards, the 9 single-index measure functions are constructed. Second, the information entropy is used to determine the weight of each indicator. Accordingly, a multi-index comprehensive measure evaluation vector is established. Finally, the confidence level is used to determine the structural plane stability level. Results show that surrounding rock grades of middle sections of R_1, R_2, and R_3 are Grades III, IV, and IV in Lingbao Luoshan Gold Mine, respectively. The evaluation grade is consistent with the actual situation of the mine, and strengthening the surrounding rock support for the middle sections of R_2 and R_3 is necessary. According to engineering practice, the evaluation model of the underground structure of metal mines established in this study has a practical value.

1. Introduction

The structural plane survey is the basis for understanding the geological structure, geostress analysis, and surrounding rock stability evaluation of mining areas. The structural face is a discontinuous surface with low or no tensile strength, including all geological separation surfaces. Different structural planes have different mechanical properties and scales, and common structural planes are divided into fractures, cleavage, unconformity, and folds. Rock mass discontinuity is caused by the existence of joints (faults, joints, and folds). On the one hand, when the rock mass is relatively complete, it can be analyzed by using the mechanical method of continuous media. On the other hand, when the rock mass has good integrity, it can be analyzed by using the mechanical method of the continuous medium. However, the majority of rock masses are discontinued bodies formed by cutting the plurality of structural planes and has anisotropy. The structural surface can be used to reflect the geological structure within the area because its presence reduces the strength of the rock mass. Soft mud and weak surface in the interlayer often cause remarkable harm in engineering [1] (as shown in Figure 1). Hence, investigating and analyzing structural planes in engineering are often necessary.

According to the classification standard of engineering rock mass, the structural plane scale is divided into five grades. The length of structural planes I, II, and III is several tens or even hundreds of meters and directly affects the stability of the entire engineering rock mass. Grades IV and V are mainly statistical structural planes. A structural plane

Figure 1: Collapsed highway slope.

destroys the rock mass integrity and affects the physical-mechanical properties and stress distribution state. The distribution of structural planes IV and V is random. Hence, statistical methods are needed to investigate the structural plane. Common survey methods include statistical window, borehole lithology, and scanline [2, 3]. Zhao et al. [4] used a detailed scanline method to investigate the structural plane of tungsten mines. García-Luna et al. [5] applied digital camera technology to structural surface analysis, thereby providing a new idea for structural surface investigation. As the distribution of structural planes is affected by many factors, randomness and uncertainty exist in its distribution. Therefore, Hekmatnejad et al. [6] evaluated the methods of statistical analysis of joint length and distribution utilization probability. Yang et al. [7] estimated the length and distribution of the joints by using the probabilistic method.

The engineering rock mass classification standards commonly used in engineering mainly adopt the RMR classification [8] method and the Q classification method [9]. The RMR classification method is the uniaxial compressive strength (P1), rock quality index (P2), joint spacing (P3), joint condition (P4), groundwater condition (P5) of the rock block, and the orientation and foundation according to the joint plane, and the edge. The correction coefficient (P6) determined by the between the slope and the cavity is six signals as basic boundaries. According to the condition of the rock mass, the RMR total score of the rock mass quality can be obtained by scoring and adding one by one. With more influencing, such as groundwater, blast damage, stress changes, and other effects on the stability of surrounding rock, it is necessary to improve the RMR classification method. Barton et al. [9] proposed the Q grading method is based on the full strength of the rock, the shear strength of the chimeric rock mass, and the active stress product of the surrounding rock. Neither of these methods considers many uncertainties in the stability evaluation of surrounding rock. Uncertain measures can solve the uncertain reasons in the evaluation problem. The quantitative signals are used for analysis, and the weight of each is considered. Reduce the error of people's subjective evaluation. The unascertained mathematical theory established by Liu et al. [10] was based on the unascertained information and mathematical processing proposed by Professor Wang Guangyuan [11] in his earlier days. Unascertained information is defined as indeter-

minate information that is different from fuzzy, random, and gray information [12–14]. Unascertained measure theory is widely used in risk assessment in fields, such as slope risk assessment, urban environmental assessment, underground goaf collapse, enterprise innovation capability evaluation, and coal mine safety assessment [15–17].

In this study, on the basis of the unascertained measure theory, influencing factors and grading standards are determined based on the survey scanline structure and engineering rock mass grading standards. Influencing factors mainly include structural surface lithology, rock quality designation, rock integrity coefficient, joint mean track length, joint occurrence, joint spacing, joint roughness, joint opening degree, and water seepage on the rock surface. We investigate the structural plane by using the scanline method in the three production middle sections of Luoshan Gold Mine located in Lingbao City. This study establishes a single-indicator measure function and uses information entropy [18] to determine the weight of each indicator first. A multi-indicator measure function is then established. Finally, the confidence criteria to analyze the results are used. Research shows that the unascertained measure theory is suitable for structural plane evaluation. A new method is proposed for evaluating the stability of surrounding rock and performing support measures.

2. Unascertained Measure Theory

When n evaluation influencing factors exist in an evaluation object, these factors are recorded as $X_1, X_2, X_3, \cdots, X_n$, and the survey evaluation space is recorded as $X = \{X_1, X_2, \cdots, X_n\}$ $(i = 1, 2, \cdots, n)$. Each evaluation factor includes an m evaluation index, and the index space is recorded as $I = \{I_1, I_2, \cdots, I_m\}$ $(j = 1, 2, \cdots, m)$. x_{ij} represents the evaluation value of the jth indicator of the ith evaluation influencing factor. p levels exist in x_{ij}, and C_k is the evaluation level k as C_k $(k = 1, 2, \cdots, p)$. If the kth level is stronger than the $k + 1$th level, then this lever is recorded as $C_k > C_{k+1}$. If $C_1 > C_2 > \cdots > C_p$, then $\{C_1, C_2, \cdots, C_m\}$ is an ordered segmentation class of the evaluation space U.

2.1. Single-Index Unascertained Measure. If $u_{ijk} = u(x_{ij} \in C_k)$ represents the degree to which the observed value x_{ij} belongs to the kth evaluation level C_k, and it satisfies boundedness, normality, and additivity, then it can be expressed as the following relationship:

$$0 \le u(x_{ij} \in C_k) \le 1, \tag{1}$$

$$u(x_{ij} \in U) = 1, \tag{2}$$

$$u\left(x_{ij} \in \bigcup_{l=1}^{k} C_l\right) = \sum_{l=1}^{k} u_{ij}(x_{ij} \in C_l), \tag{3}$$

where u is the unascertained degree that is generally referred to as the measure. If u fails to satisfy Formulas

(1) to (3), then the value of u cannot guarantee its correctness. $(u_{ijk})_{n*p}$ is a single-index evaluation matrix that uses a linear unascertained measure function and can be expressed as

$$\left(u_{ijk}\right)_{n*p} = \begin{bmatrix} u_{i11} & u_{i12} & \cdots & u_{i1p} \\ u_{i21} & u_{i21} & \cdots & u_{i2p} \\ \cdots & \cdots & \cdots & \cdots \\ u_{in1} & u_{in2} & \cdots & u_{inp} \end{bmatrix}. \tag{4}$$

2.2. Determining the Weight of Indicators.
Let w_j be the weight of X_j, and w_j denotes the relative importance degree of the measurement index x_{ij} compared with other indicators, $0 \le w_j \le 1$, $\sum_{j=1}^{n} w_j = 1$, where $w = \{w_1, w_2, \cdots, w_n\}$ is called the index weight vector. By using the information entropy [16] theory to determine the index weight, we obtain

$$v_j = 1 + \frac{1}{\lg p} \sum_{k=1}^{p} u_{jk} \lg u_{jk}, \tag{5}$$

$$w_j = \frac{v_j}{\sum_{i=1}^{m} v_i}. \tag{6}$$

As the evaluation matrix of a single-index measure is known, the weight w_j of each index can be obtained by using Formulas (5) and (6).

2.3. Multi-Index Comprehensive Measure Evaluation Vector.
If $u = u_0$ $(R \in C_k)$ indicates the degree to which the evaluation target R belongs to the kth evaluation level, then

$$u_{ik} = \sum_{i=1}^{n} w_j u_{ijk}, \tag{7}$$

where w_j is the weight of the indicator I_j that satisfies

$$0 \le w_j \le 1,$$
$$\sum_{j=1}^{m} \omega_j = 1. \tag{8}$$

u_{ik} satisfies the following relationships:

$$0 \le u_{ik} \le 1,$$
$$\sum_{k=1}^{p} u_k = 1. \tag{9}$$

u_k is the uncertainty degree determined by using Equation (4). $u_k = (u_1, u_2, \cdots, u_k)$ is a multi-index comprehensive measure evaluation vector of the evaluation object.

2.4. Confidence Recognition Criteria.
Use the confidence recognition criteria, confidence λ (normally $\lambda = 0.6$ or 0.7), for the sequence $C_1 > C_2 > \cdots > C_p$ to satisfy the following formula:

$$k_o = \min \left\{ k : \sum_{i=1}^{k} u_i > \lambda, k = 1, 2, \cdots, p \right\}. \tag{10}$$

Then, the evaluation object belongs to the k_o evaluation level grade C_k.

3. Steps in the Structural Surface Evaluation Analysis Based on Unascertained Measure

(1) Determine the influencing factors and classification criteria for structural surface evaluation. The main influencing factors of structural plane survey based on the scanline method include lithology, rock quality designation, rock integrity, joint track length, joint occurrence, fracture roughness, joint opening degree, and rock moisture content

(2) Determine the single-index unascertained measure function of the structural plane evaluation according to the grading standard

(3) Determine the evaluation matrix according to measured structural surface indicators and the single unascertained measure function

(4) By using information entropy to determine the weight of the evaluation index, the multi-index measure evaluation vector is obtained via Formula (7)

(5) Evaluate the structural plane level by using the confidence criteria

4. Case Study

The Luoshan Gold Mine at Lingbao City is located in the Xiaoqinling District in the southern margin of the North China Platform. The lithology of the mining area is mainly composed of black cloud slanted gneiss, mixed gneiss, and mixed granite. Fault structures are well developed in the mining area. An ore-controlling structure is a set of ductile shear zones and faults that are distributed near the east-west direction. This structure generally occurs near the east-west direction and slightly inclined to the north. The majority of inclination angles are gently inclined between 30° and 40° with a few steeply reaching 60°.

Gold ore bodies, produced in ductile shear zones and faults, are strictly controlled by fault structures. The main surrounding rock is composed of fragmented mixed granite. In recent years, the frequent occurrence of ground pressure activities is caused by the formation of a large number of goafs via stratified caving. Mining pressure activities remarkably threatens the safety of mining workers. Mining methods need to be optimized to ensure safe production in mines.

Structural planes of the three middle operations (R_1, R_2, and R_3) are evaluated from top to bottom. Sections R_1 and R_2 are mainly composed of mixed granite, and section R_3 is mixed with gneiss.

4.1. Structural Surface Evaluation Indicators and Grading Standards.

Line surveying method is mainly used for statistical investigation of microstructural planes of Grades IV and V. Based on investigation and experimental results, the rock uniaxial compressive strength Rc, engineering rock quality index RQD, rock integrity coefficient Kv, joint trace length L, and joint occurrence (strike angle θ_1 and dip angle θ_2, where θ_1 and θ_2 are calculated by using the dominant structural plane, and strike angle θ_1 represents the strike difference between joint and roadway), fracture roughness coefficient JCR, joint opening degree B, and rock moisture content ω are the main parameters that represent the rock mass quality. According to the engineering rock mass quality grading standards [19], Table 1 lists the structural surface grading standards. Table 2 presents the parameters of each middle section.

4.2. Single-Index Measure Function Model.

On the basis of the evaluation criteria of the rock structural plane, the single-index measure function of uniaxial compressive strength Rc, rock quality designation RQD, rock integrity coefficient Kv, joint trace length L, joint occurrence (strike θ_1 and dip angle θ_2), fracture roughness coefficient JCR, joint opening degree B, and rock moisture content ω was established as shown in Figures 2–10.

The parameters in Table 2 show that the evaluation matrix of each middle section is obtained from the graph. Taking middle section R_1 as an example, the evaluation matrix is calculated as follows:

$$\left(u_{1jk}\right)_{9\times5} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0.6 & 0.4 & 0 \\ 0 & 0 & 0.75 & 0.25 & 0 \\ 0 & 0.875 & 0.125 & 0 & 0 \\ 0 & 0 & 0 & 0.4 & 0.6 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0.231 & 0.769 & 0 \\ 0.25 & 0.75 & 0 & 0 & 0 \end{bmatrix}. \quad (11)$$

4.3. Multi-Index Comprehensive Measure Evaluation Vector.

Information entropy is used to determine the weight of each indicator. From Equations (5) and (6), the weight vector of middle section R_1 is $W = \{0.145, 0.145, 0.084, 0.094, 0.111, 0.084, 0.145, 0.096, 0.094\}$. The specific calculation process is as follows:

$$
\begin{aligned}
v_1 &= v_2 = v_7 = 1 + \frac{1}{\lg 5}(1 \lg 1 + 0) = 1, \\
v_3 &= v_6 = 1 + \frac{1}{\lg 5}(0.6 \lg 0.6 + 0.4 \lg 0.4) = 0.582, \\
v_4 &= v_9 = 1 + \frac{1}{\lg 5}(0.75 \lg 0.75 + 0.25 \lg 0.25) = 0.651, \\
v_5 &= 1 + \frac{1}{\lg 5}(0.875 \lg 0.2 + 0.125 \lg 0.125) = 0.766, \\
v_8 &= 1 + \frac{1}{\lg 5}(0.231 \lg 0.231 + 0.769 \lg 0.769) = 0.664, \\
v &= v_1 + v_2 + v_3 + v_4 + v_5 + v_6 + v_7 + v_8 + v_9 = 6.896, \\
w_1 &= w_2 = w_7 = \frac{v_1}{v} = \frac{1}{6.896} = 0.145, \\
w_3 &= w_6 = \frac{v_3}{v} = \frac{0.582}{6.896} = 0.084, \\
w_4 &= w_9 = \frac{v_4}{v} = \frac{0.651}{6.896} = 0.094, \\
w_5 &= \frac{v_5}{v} = \frac{0.766}{6.896} = 0.111, \\
w_8 &= \frac{v_8}{v} = \frac{0.664}{6.896} = 0.096.
\end{aligned}
\quad (12)
$$

The multi-index comprehensive measure evaluation vector of the middle segment of R_1 can be obtained from the weight vector W and Formula (11) as follows:

$$u_1 = \{0.024, 0.313, 0.302, 0.165, 0.195\}. \quad (13)$$

4.4. Evaluation Result Analyses.

The confidence is introduced in this section to evaluate the result with a confidence value of $\lambda = 0.6$. From the multi-index comprehensive evaluation vector and confidence criterion evaluation, $k_0 = 0.024 + 0.313 + 0.302 = 0.639 > \lambda$ exist from large to small, and the structural plane evaluation level of middle section R_1 is Grade III. However, $k_0 = 0.195 + 0.165 + 0.302 = 0.769 > \lambda$ exist from small to large, and the evaluation level is also Grade III. Therefore, the two judgment results are consistent, and the structural plane evaluation level of the R_1 middle section is Grade III.

Similarly, the same method is used to evaluate the middle sections of R_2 and R_3, and the surrounding rock stability evaluation results of the middle sections of R_2 and R_3 are all Grade IV.

From an overall view of the three middle sections, the entire area of the mining area is mainly composed of mixed granite, and the rock is broken. Joints with a trace dominant length of approximately 1 m and the dominant occurrence that substantially differs from the roadway direction have a major impact on the surrounding rock stability. These features are the main reason for the poor evaluation of the structural surface. Other major factors affecting the structural plane include lithology, rock integrity, joint trace length, and joint occurrence.

TABLE 1: Structural plane evaluation classification standard.

Influencing factor indicator	Classification criteria				
	I grade (C_1)	II grade (C_2)	III grade (C_3)	IV grade (C_4)	V grade (C_5)
Uniaxial compressive strength Rc (MPa)	>150	150~120	120~80	80~30	30~0
Rock quality designation RQD (%)	100~90	90~80	80~60	60~30	30~0
Rock integrity coefficient Kv	0.75~1	0.55~0.75	0.35~0.55	0.15~0.35	0~0.15
Joint trace length L (m)	0~0.3	0.3~0.5	0.5~0.8	0.8~1.2	1.2~1.5
Strike θ_1 (°)	90~75	75~60	60~45	45~30	30~0
Dip angle θ_2 (°)	0~30	30~45	45~60	60~75	75~90
Fracture roughness coefficient JCR	20~12	12~8	8~4	2~4	2~0
Joint opening degree B (mm)	0~0.2	0.2~1.0	1.0~2.0	2.0~5.0	>5
Rock moisture content ω (%)	0~20	20~30	30~45	45~65	65~100

TABLE 2: The middle section structural surface parameters.

Middle section	Rc (MPa)	RQD (%)	Kv	L (m)	θ_1 (°)	θ_2 (°)	JCR	B (mm)	ω (%)
R_1	120	25	0.37	0.7	54	66	8	1.2	26
R_2	95	35	0.33	0.8	67	72	6.5	2	43
R_3	100	28	0.20	1.1	43	63	5	2.5	58
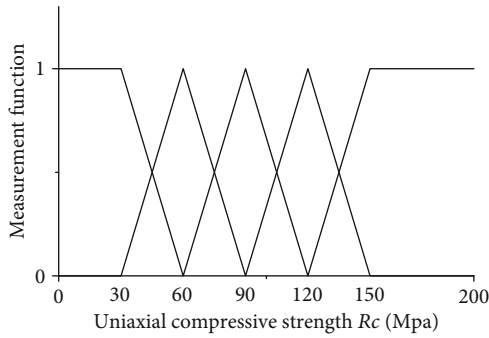
FIGURE 2: Uncertainty measurement function of Rc.

FIGURE 4: Uncertainty measurement function of rock integrality coefficient.
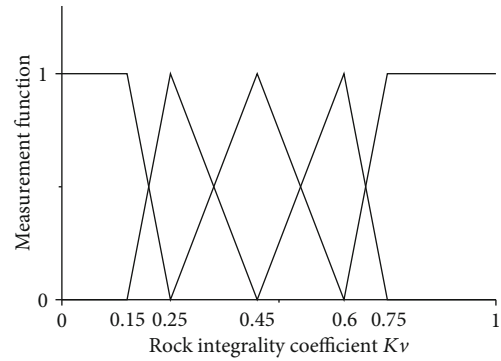

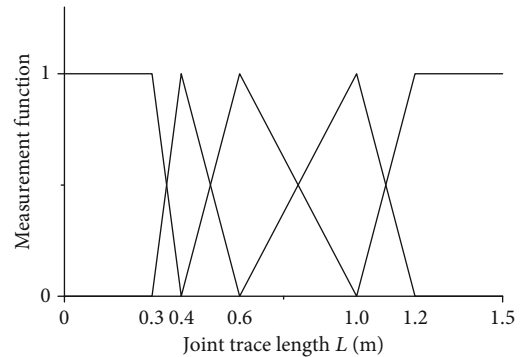FIGURE 3: Uncertainty measurement function of RQD.

FIGURE 5: Uncertainty measurement function of joint trace length.

Looking at the relevant data of the mine, the rock in middle section R_1 is relatively dry, and the roadway surface in middle sections R_2 and R_3 is mildly to severely wet. The groundwater of middle section R_1 penetrates along the joint surface and into middle sections R_2 and R_3 because middle sections R_2 and R_3 are mined. A large amount of groundwater weakens the strength and reduces the stability of sur-

rounding rock, making the surrounding rock in middle sections R_2 and R_3 vulnerable to failure. Therefore, strengthening the support of middle sections R_2 and R_3 and improving the hydrophobic drainage of the lower middle section in time are necessary. The design of the main transportation
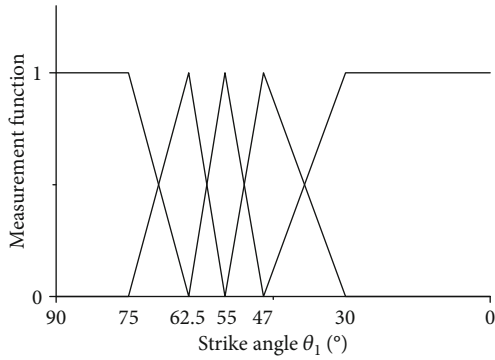
FIGURE 6: Uncertainty measurement function of joint strike angle.
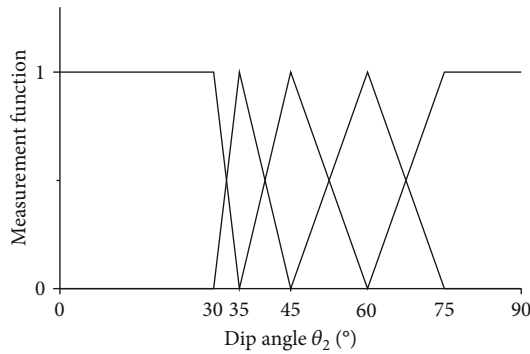

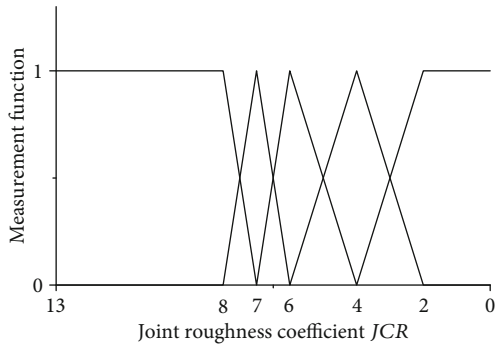FIGURE 7: Uncertainty measurement function of joint dip angle.

FIGURE 8: Uncertainty measurement function of joint roughness coefficient.
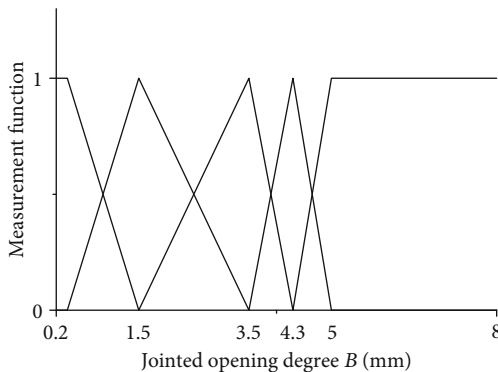

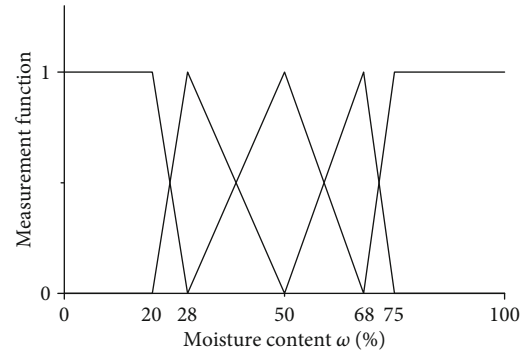FIGURE 9: Uncertainty measurement function of jointed opening degree.

FIGURE 10: Uncertainty measurement function of rock moisture content.

lane direction should be kept as small as possible considering the dominant surface of the structural plane to avoid wider damage areas.

5. Conclusion

(1) On the basis of the structural plane investigation via the scanline method, the evaluation factors and grading standards of the structural plane are determined. Quantitative analysis of the evaluation by using the scanline method overcomes the shortcomings of the original qualitative evaluation criteria. On the basis of the mine example, the unascertained measure theory is used in the evaluation and analysis of underground structural planes. The models of single- and comprehensive-index functions are constructed. Information entropy is used to determine the weight, whereas the confidence recognition criterion is used to evaluate the structural surface level

(2) From the three middle section survey results of the mine, the unascertained measure theory is suitable to evaluate the structural plane. The evaluation results show that the structural evaluation grades of R_1, R_2, and R_3 are Grades III, IV, and IV, respectively. Therefore, middle sections R_2 and R_3 should establish a strengthened support to ensure safe operation. The unascertained measure theory provides a new method for structural plane evaluation by using the scanline method

(3) As the geological structure surface is affected by many factors, further selecting accurate and reasonable underground structural surface parameters and grading standards in the future is necessary to ensure the reliability of the evaluation survey

Data Availability

The test data used to support the findings of this study are included within the article. Readers can obtain data supporting the research results from the test data table in the paper.
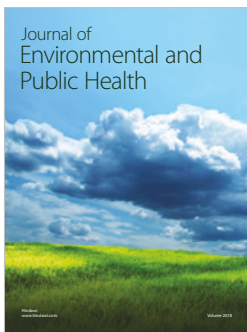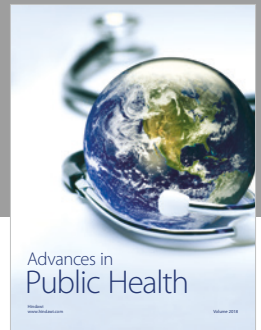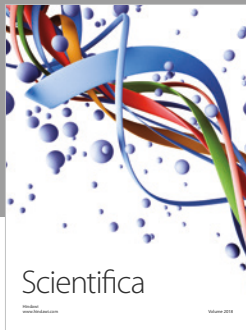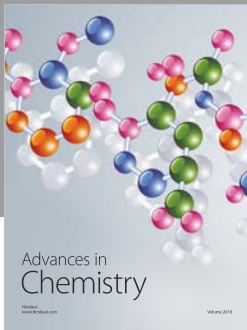
Conflicts of Interest

No potential conflicts of interests were reported by the authors.

Acknowledgments

References

[1] M. Koopialipoor, D. Jahed Armaghani, A. Hedayat, A. Marto, and B. Gordan, "Applying various hybrid intelligent systems to evaluate and predict slope stability under static and dynamic conditions," *Soft Computing*, vol. 23, no. 14, pp. 5913–5929, 2019.

[2] M. Mauldon, W. M. Dunne, and M. B. Rohrbaugh Jr., "Circular scanlines and circular windows: new tools for characterizing the geometry of fracture traces," *Journal of Structural Geology*, vol. 23, no. 2-3, pp. 247–258, 2001.

[3] G. H. Davis, S. J. Reynolds, C. F. Kluth, and C. Kluth, *Structural Geology of Rocks and Regions*, John Wiley & Sons, 2011.

[4] K. Zhao, K. Zhou, J. Zhang, X. Tu, and K. Zhao, "Analysis of structure plane characteristic for rock mass of a tungsten mine," *Metal Mine*, vol. 12, pp. 1–5, 2017.

[5] R. García-Luna, S. Senent, R. Jurado-Piña, and R. Jimenez, "Structure from motion photogrammetry to characterize underground rock masses: experiences from two real tunnels," *Tunnelling and Underground Space Technology*, vol. 83, pp. 262–273, 2019.

[6] A. Hekmatnejad, X. Emery, and J. A. Vallejos, "Robust estimation of the fracture diameter distribution from the true trace length distribution in the Poisson-disc discrete fracture network model," *Computers and Geotechnics*, vol. 95, pp. 137–146, 2018.

[7] C. Yang, H. Bao, G. Wang, and T. Mei, "Estimation of mean trace length and trace midpoint density of rock mass joints," *Yanshilixue Yu Gongcheng Xuebao/Chinese Journal of Rock Mechanics and Engineering*, vol. 25, no. 12, pp. 2475–2480, 2006.

[8] Z. T. Bieniawski, "Classification of rock masses for engineering: the RMR system and future trends," in *In Rock Testing and Site Characterization*, pp. 553–573, Elsevier, Pergamon, 1993.

[9] N. Barton, R. Lien, and J. Lunde, "Engineering classification of rock masses for the design of tunnel support," *Rock Mechanics*, vol. 6, no. 4, pp. 189–236, 1974.

[10] K. Liu, Y. Lin, and L. Yao, "Informational uncertainties and their mathematical expressions," *Kybernetes*, vol. 30, no. 4, pp. 378–397, 2001.

[11] G. Y. Wang, "Uncertainty information and its mathematical treatment," *Journal of Harbin University of Civil Engineering and Architecture*, vol. 23, no. 4, pp. 1–9, 1990.

[12] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, no. 3, pp. 338–353, 1965.

[13] G. Matheron, *Random Sets and Integral Geometry*, Wiley, New York, 1975.

[14] D. Ju-Long, "Control problems of grey systems," *Systems and Control Letters*, vol. 1, no. 5, pp. 288–294, 1982.

[15] S. C. Li, J. Wu, Z. H. Xu, and L. P. Li, "Unascertained measure model of water and mud inrush risk evaluation in karst tunnels and its engineering application," *KSCE Journal of Civil Engineering*, vol. 21, no. 4, pp. 1170–1182, 2017.

[16] C. Huang, S. Tian, Q. Li, and J. Huang, "Evaluation of rock quality of tunnel wall rock based on rough set theory and unascertained measurement theory," *Mathematical Problems in Engineering*, vol. 2018, 10 pages, 2018.

[17] Y. Z. Chang and S. C. Dong, "Study on evaluation model of international trade in agricultural products based on unascertained measure," *Chemical Engineering Transactions*, vol. 51, pp. 673–678, 2016.

[18] A. Shamilov, "Generalized entropy optimization problems and the existence of their solutions," *Physica A: Statistical Mechanics and its Applications*, vol. 382, no. 2, pp. 465–472, 2007.

[19] V. M. Khatik and A. K. Nandi, "A generic method for rock mass classification," *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 10, no. 1, pp. 102–116, 2018.