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Height Prediction and Factor Analysis of Water Fracture Zone based on MNR

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Abstract

In the study of mine water hazard prevention and control,It is about a problem to predict the height of water - conducting fissure zone, This paper analyzes several influencing factors of the development of water diversion fracture zone.O coal seam thickness, uniaxial compressive strength of roof with strata and structural type of roof strata part, mining, the depth, thewire coefficient of hard rock lithology,5. Advancing speed. According to the actual production and the engineering geological theory of coal mine, the mining depth,The ratio coefficient of hard rock lithology,The mediator length of working face and the thickness of coal Seam are selected for analysis and research. 72 cases of 5-dimensional high-quality measured data are investigated-UsingThe Grey correlation analysis (GRA), the conclusion is that the mining height has the greatest influence on the development of the Water Fracture zone,And other factors are secondary factors. With the method of multiple regression analysis, the relationship between the height of water Fracture zone and each single factor is analyzed,And the fitting formula between the height of water Fracture zone and each factor is working with using the Multiple Nonlinear regression (MNR) analysis. Combined with the mining example of 3112 working face in Shandong Hongqi mine, the relative error is only 6.04%, which shows the sapplicability of the formula.

Keywords

Water-guided fissure band height; Influencing factors; Grey correlation analysis; Multiple regression analysis; Prediction.

1. Introduction

Among the five common disasters and accidents in coal mines, mine water disaster is always the second biggest accident that seriously threatens coal mine safety production. After coal mining, if the damage of the overlying strata on the roof of the coal seam extends to the underground aquifer or even to the surface, it is easy to form a water passage and make water (sand) enter the stope space (such as roadway, cutting hole and working face), thus causing mine safety accidents such as sand burst and water inrush[1].

In the theory of "Upper three Zones", the overburden after deformation and failure is divided into three zones: collapse zone, fracture zone and subsidence zone. The collapse zone and the fault zone are collectively referred to as the water-conducting fault zone. The water-conducting fracture zone progresses along with the working face and has a development process of rising, descending and stable from occurrence to maximum height. According to the final shape of the overburden failure range formed after the work is advanced to a certain extent, the vertical distance between the highest point of the water-conducting fracture zone and the upper limit of mining in the zone is taken as the maximum height of the water-conducting fracture zone, which is called the conductivity height[2].At present, the height prediction of the water-conducting fracture zone (straddling zone and fault zone,

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also known as "two zones") of the roof in China is based on "Regulations for coal pillar retention and Pressurized coal Mining in Buildings, water bodies, railways and main shafts" (hereinafter referred to as "Three lower" regulations) and "Mine hydrogeological regulations".However, there are many factors affecting the development height of the water-conducting fracture zone, and the geological conditions and mining conditions of different mining areas are very different, which leads to a large error between the height of the fracture zone and the results obtained by the prediction formula in the regulations.

Many scholars have studied the development height of mine drainage and water-conducting fracture zone to varying degrees[3~12], such as liu Yang[6] The numerical model of working face mining width was simulated and analyzed by using FLAC3D software, and the development height of water-conducting fracture zone was determined under different mining width conditions. Long-qing shi etc.[7]Based on the division theory of "upper four zones" in stope roof, the theoretical calculation formula of water-conducting fracture zone with multiple factors is deduced.At present, there are few quantitative researches on the height of "two zones", so it is a great challenge for engineering geology to accurately predict the height of water-conducting fracture zones.

In this article, through investigation and collecting 72 cases of 5 d high quality water flowing fractured zone as an example, combined with the water height of fractured zone with a variety of factors, determined by grey correlation analysis and main influence factors, through the SPSS regression and multivariate nonlinear regression research of the relationship between various factors and high conductivity, and get the regression empirical formula, the calculation of water conductivity and height of fractured zone of mine water inrush forecast and make the decision to provide important theoretical basis for mine flood prevention.

2. Factors influencing the height of water-conducting fracture zone

2.1 Research status and evaluation

The prediction of derivative height in the "three lower" regulation includes the following factors:

(1) Coal seam thickness M. Also known as mining thickness or mining height, it refers to the influence of the vertical height of underground mining on the stress redistribution, deformation and fracture range of roof rock body after mining, and it is one of the main indicators to predict the leading height.

(2) Uniaxial compressive strength of roof strata. Based on the theory of engineering geology and rock mechanics, the uniaxial compressive strength of rock obtained by rock mechanics experiments is classified into three types: weak, medium and hard roof according to its size "three lower" rules and "hydrogeological rules". However, the uniaxial compressive strength obtained through experiments is affected by the rock itself, the experimental environment and the physical environment, and there are multiple layers of different types of rock strata within the guide height range, so the value is very fuzzy.

(3) Structure type of roof strata. With different roof strata structure, the fracture height is different due to the degree of damage after mining. After mining, the rock stratum is weak and broken, and the fracture height is relatively small. Hard intact layers are relatively large.

At present, only the above three factors are generally considered in the regulations, but the value of uniaxial compressive strength of roof strata is fuzzy and the roof type is not easy to be divided, so the prediction of guide height in practice is not comprehensive.

2.2 Multi-factor index analysis

According to the practical production of coal mine and the basic theory of engineering geology, the following aspects should be considered in influencing the development height of water-conducting fracture zone:

(1) Mining depth S. The stress of surrounding rock increases with the increase of depth, which makes the cracks between the unconnected roof rock appear interconnected, thus forming the water channel.

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This is caused by the mine pressure, which changes with the change of mining depth, so the mining depth can be analyzed as an influencing factor.

(2) Working face slope length L. Before the coal seam is fully started, the oblique length of the working face has a great influence on the development of water-conducting fracture zone, and the height will increase continuously with the tunneling of the working face. When the goaf area reaches the full mining of overburden, the oblique length of the working face has no obvious effect, and when the height of water-conducting fracture zone reaches the maximum, a typical arch will be formed[14].

(3) Propulsion velocity V. In the actual production process, the propulsion velocity obtained is the observation data after 2 months of working face propulsion, which reflects the basically stable height of water-conducting fracture zone development, with no obvious influence on the height, so it will not be studied in detail.

The above data are relatively easy to obtain in the geological exploration and design stage of coal mine, but for different types of roof rock, it is not easy to quantify the overall structural strength.

(4) Lithologic ratio coefficient B of hard rock.It refers to the ratio of hard rock and statistical height within the statistical height above the roof of coal seam (the height of water-conducting fracture zone).The coefficient can comprehensively reflect the characteristics of roof rock strength and structure combination, because the uniaxial compressive strength of roof and rock combination characteristics are the influencing factors of fracture zone development[12-13], which avoids the uncertainty problem of determining roof type according to uniaxial compressive strength in the current code, and is more convenient to obtain.

Grey theory holds that the objective system is complex in appearance, incomplete in information, discrete in data, but with latent law, and all the factors in the system are always interrelated[15、16]. Through Python, this paper firstly determines the parent factor and the sub-factor, and compares the contribution of sub-factors to the parent factor by calculating the grey relational degree. The development height of water-conducting fracture zone is taken as the parent factor, and the mining height, working face inclined length, hard rock lithologic ratio coefficient and mining depth are taken as the sub-factors. The higher the correlation degree is calculated, the greater the influence of sub-factors on the parent factor will be. The correlation degree data is obtained (Table 1).The mining height has the greatest contribution and the mining height has the greatest influence on the height development of water-conducting fracture zone.

Table 1 High correlation between the factors and the water-conducting fissure band

Factors affecting the	correlation
Mining height are broken	0.81
Lithologic ratio coefficient of hard rock	0.76
Inclined long	0.79
Mining depth	0.70

3. Data Collection

In order to comprehensively study the factors affecting the development height of water-conducting fracture zone, the data of some mine samples in several mining areas in China were investigated and analyzed by referring to literature[18-23], selection of similar geological conditions and mining conditions of mining area, including () areas in southwest of shandong province and neighboring provinces of anhui province and other regions, the data contains water fractured zone height H, coal seam buried depth of S, hard rock lithology ratio coefficient b, mining height are broken mined-out area length l, M, and the high quality of the 5 d sample data of 72 cases (table 2).

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Table 2 Measured values of water - guided fissure band height and the related influencing factors

Serial number	S/m	b	M/M	L/m	H/m	Serial number	S/m	b	M/M	L/m	H/m
1	412.40	0.09	2.20	157.00	35.40	21	367.00	0.47	7.50	173.50	22.61
2	489.00	0.47	4.50	160.00	54.79	22	403.20	0.10	1.80	120.00	22.00
3	86.10	0.50	4.60	170.00	53.90	23	125.00	0.06	3.00	150.00	53.70
4	472.50	0.53	4.50	132.00	57.45	24	665.00	0.19	7.50	222.00	70.30
5	336.40	0.12	2.00	76.00	27.25	25	433.00	0.52	7.00	168.00	47.55
6	89.00	0.95	2.03	69.00	45.86	26	434.10	0.35	3.00	145.00	38.41
7	424.42	0.26	3.40	120.00	45.10	27	290.00	0.37	2.60	168.00	62.50
8	590.00	0.51	9.00	220.00	76.37	28	485.00	0.36	4.80	175.00	43.43
9	290.00	1.00	2.60	168.00	46.22	29	265.00	0.60	2.60	147.00	50.34
10	290.00	0.18	2.60	168.00	39.14	30	269.00	0.68	2.80	156.00	58.50
11	420.50	0.52	3.00	209.00	52.01	31	387.50	0.55	4.50	175.00	48.90
12	357.00	0.38	7.53	170.00	61.90	32	441.97	0.36	3.40	120.00	28.63
13	649.10	0.23	3.00	186.00	42.99	33	437.17	0.05	3.40	120.00	86.40
14	475.20	0.28	3.90	209.00	49.05	34	463.00	0.62	7.60	116.00	22.61
15	568.60	0.65	3.65	132.00	60.14	35	403.10	0.08	2.00	136.00	57.49
16	557.25	0.45	5.80	186.00	65.25	36	476.40	0.63	3.65	132.00	55.00
17	320.00	0.81	5.00	122.00	67.70	37	515.70	0.35	4.50	147.00	86.80
18	412.55	0.08	2.20	157.00	35.20	38	450.00	0.72	8.00	170.00	51.40
19	312.00	0.24	5.30	145.70	44.20	39	283.90	0.63	5.70	177.90	54.79
20	679.00	0.46	2.10	180.00	44.54	40	499.90	0.47	4.80	150.00	45.00

Continue to list:

Serial number	S/m	b	M/M	L/m	H/m	Serial number	S/m	b	M/M	L/m	H/m
41	49	0.52	4.00	135.00	45.00	57	265.00	0.56	2.70	192.00	42.81
42	420.06	0.14	3.00	145.00	3.029	58	320.80	0.16	2.00	128.00	33.01
43	516.00	0.74	2.95	206.10	54.50	59	316.80	0.14	2.00	128.00	31.61
44	264.50	0.26	2.80	148.50	40.35	60	420.00	0.71	3.70	70.00	56.80
45	367.00	0.41	7.52	190.00	61.77	61	478.30	0.54	3.85	209.00	52.15
46	434.40	0.46	3.40	136.00	45.10	62	568.40	0.85	2.94	180.40	57.00
47	445.40	0.07	4.00	195.00	38.81	63	295.00	0.64	2.60	185.00	40.50
48	304.00	0.12	3.10	150.00	40.00	64	453.60	0.16	4.00	195.00	44.96
49	362.80	0.33	2.00	138.00	31.62	65	412.50	0.24	2.20	136.00	35.20
50	270.00	0.65	3.80	168.00	54.60	66	320.00	0.60	1.23	90.00	31.98
51	331.00	0.55	7.40	160.00	64.25	67	411.70	0.30	2.20	136.00	35.21
52	499.92	0.47	4.80	150.00	54.00	68	264.50	0.93	2.80	156.00	44.34
53	351.30	0.53	2.00	105.00	36.99	69	475.00	0.37	6.10	170.00	64.60
54	419.03	0.16	3.00	145.00	32.83	70	453.50	0.42	1.60	180.00	30.30
55	357.70	0.33	2.00	128.00	33.96	71	818.50	0.45	7.55	230.00	74.57
56	550.00	0.81	2.40	180.00	55.32	72	427.30	0.43	4.60	120.00	56.60

4. Research methods and process

4.1 Principle of multiple regression analysis

Multiple nonlinear regression is a method to study the nonlinear correlation between one dependent variable and several independent variables[24].

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Multiple linear regression analysis is used to analyze the correlation between N independent variables and dependent variables. Its basic model is:

$$Y = beta._0 + beta._1 x_1 + beta._2 x_2 + ... Beta._n x_n$$

The least square method is used to find the regression coefficient$_0$, beta,$_1$, beta,$_2$And..., beta,$_n$, the process is as follows:

$$F\ (x_i(y) = \Sigma_i - y_i)^2 = \Sigma\ (y_i - beta._0 - beta._1 x_{1i} - beta._2 x_{2i} - ... - beta._n x_{ni})^2 = min$$

Where the independent variable is x_{1i}, x_{2i}And..., x_{ni}, the dependent variable y_i Are specific known observations for the regression coefficient on $_0$, beta,$_1$, beta,$_2$And..., beta,$_n$ Take the derivative and set its first derivative to be 0, then:

$$\begin{cases} L_{11}Beta._1 + L_{12}Beta._2 + ... + L_{1n}Beta._n = L_{1y} \\ L_{21}Beta._1 + L_{22}Beta._2 + ... + L_{2n}Beta._n = L_{2y} \\ ... \\ L_{21}Beta._1 + L_{22}Beta._2 + ... + L_{2n}Beta._n = L_{2y} \end{cases}$$

One of them. $Lij = Lji = \sum(x_{ij} - \bar{x}_i)\ (x_{ij} - \bar{x}_j)$; $L_{iy} = \sum(x_{ij} - \bar{x}_1)(y_i - \bar{y}_1)$

Due to the L $_{i1}$, L_{i2}And..., L_{in}, L_{iy}(I = 1, 2,...N) is given, that is, x_{ij}, y_i(I =1,2...$\bar{x}_j\bar{x}_i\bar{y}_i$,n) is known,$_1$, beta,$_2$And..., beta,$_n$ Is n unknowns and n equations. Therefore, the determinant or elimination method can be used to solve for beta $_1$, beta,$_2$And..., beta,$_n$And find beta$_0$.

Regression coefficient$_n$(0,1...After the solution, the regression model needs to be further tested to determine the reliability of the model. Generally, RMSE and R determination coefficient are used to determine the reliability of the model^{2}The smaller the RMSE, the R^2The closer to 1, the more accurate the interpretation of the model to the data and the better the fitting degree.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

$$R^2 = \frac{\sum(\hat{y}_i - \bar{y})^2}{\sum(y_i - \bar{y})^2}$$

4.2 Single-factor regression analysis

SPSS software was used to analyze the correlation between research height and various factors, and to carry out statistical analysis from simple statistical description to complex multiple regression factors.In univariate analysis, for example, to avoid the influence of other factors, in the case that other influencing factors are similar, representative data are selected and the most relevant unitary regression model is obtained through curve regression analysis.

In the case that the ratio coefficient of hard rock lithology, the mining depth and the inclined length of goaf are similar, the correlation and function types of leading-mining height and mining height (Figure 1, Table 3).

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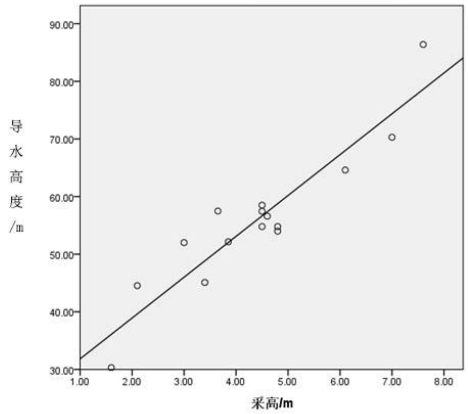

Figure 1 Correlation between water height and high extraction

Table 3 Selection of Height and Guide Function Types

Function types	R^2	Fitting the sorting
Y = ax + b	0.866	1
Y = alnx + b	0.812	2
Y = aebx	0.829	3

When the mining depth, mining height and the inclined length of goaf are similar, the correlation and function types of guide height and the ratio coefficient of hard rock lithology (Figure 2, Table 4).

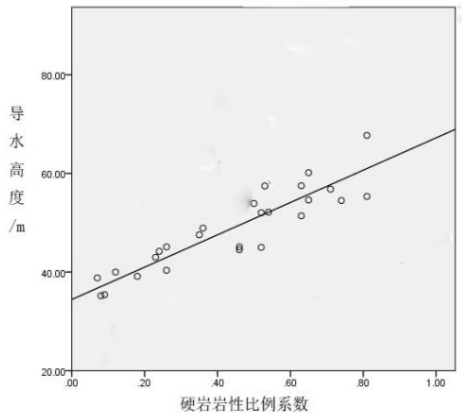

Figure 2 Correlation between the water height and the scale coefficient of hard rock

Table 4 The ratio coefficient of hard rock and The type of The guide function

Function types	R^2	Fitting the sorting
Y = ax + b	0.914	1
Y = alnx + b	0.858	3
$Y = ae^{bx}$	0.872	2

In the case of similar mining height, hard rock lithologic ratio coefficient and mining depth, the correlation and function types between the inclined length of goaf and leading height (Figure 3, Table 5).

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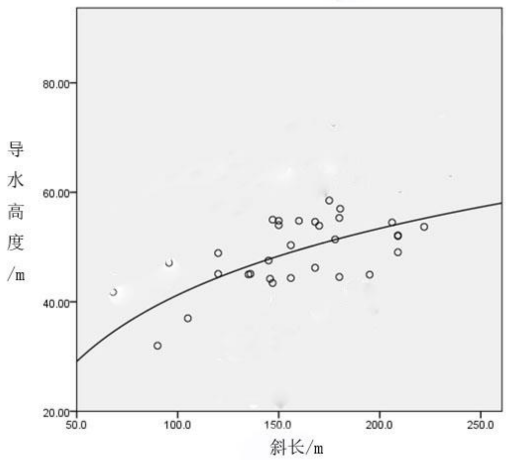

Figure 3 Correlation between the water height and slope length

Table 5 Slope Length and Guide Function Type Selection

Function types	R^2	Fitting the sorting
Y = ax + b	0.8962	2
Y = alnx + b	0.9367	1
Y = aebx	0.8621	3

In the case of similar mining height, lithologic ratio coefficient of hard rock and inclined length of goaf, the correlation and function types of guide height and mining depth (Figure 4, Table 6).

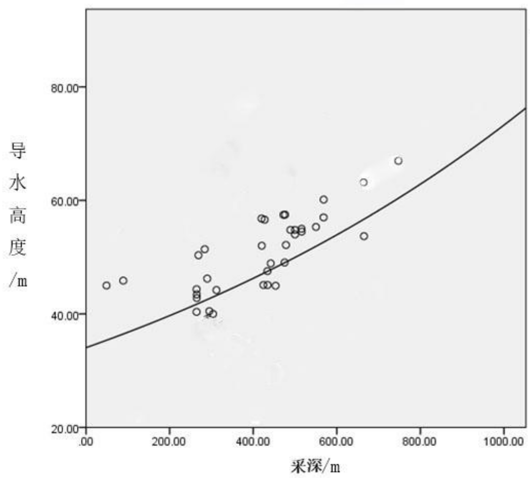

Figure 4 Related relationship between water height and depth of extraction

Table 6 Selection of depth and high-conducting Function Types

Function types	R^2	Fitting the sorting
Y = ax + b	0.923	2
Y = alnx + b	0.712	3
Y = aebx	0.934	1

To sum up, through the linear regression analysis of single factor, function types between single factor and can be determined (Table 7).

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Table 7 Function Type between Single factor and Leading Height

Factors affecting the	Function types
Mining height are broken h	linear
Lithologic scale coefficient B of hard rock	linear
Working face slope length L	logarithmic
The depth of coal seam is M	index

4.3 Construction of multiple nonlinear regression model

Guide high growth prediction is a complex nonlinear problem, which affected by many factors, our country's at present commonly used water fractured zone height are expected to reach "three under" rules of empirical formula method, but because of its influence factor considering single, roof classification, roughly calculated results error is bigger, need according to actual conditions and the existing mining technology timely correction. In this paper, on the basis of integrating 72 groups of high-quality sample data shown in table 2 above, aiming at the deficiencies of the existing empirical formula of procedures, on the basis of single factor analysis of leading to high development, a multiple nonlinear regression model reflecting the comprehensive effect of multiple factors was established by using training sample data.

On the basis of single factor analysis, a multiple nonlinear regression model can be established[20]:

$$H = \beta_0 + \beta_1 M + \beta_2 b + \beta_3 \ln l + \beta_4 e^{(\beta_5 + \frac{\beta_6}{s})} + \varepsilon \tag{1}$$

The regression fitting formula between the derivative height and various factors is obtained through analytic fitting:

$$H_f = 4.92M + 28b + 0.897 \ln l + 4.619 \exp\left(1.722 - \frac{551.853}{s}\right) + 6.117 \tag{2}$$

The fitting effect and relative error of regression formula (Figure 5, Figure 6).

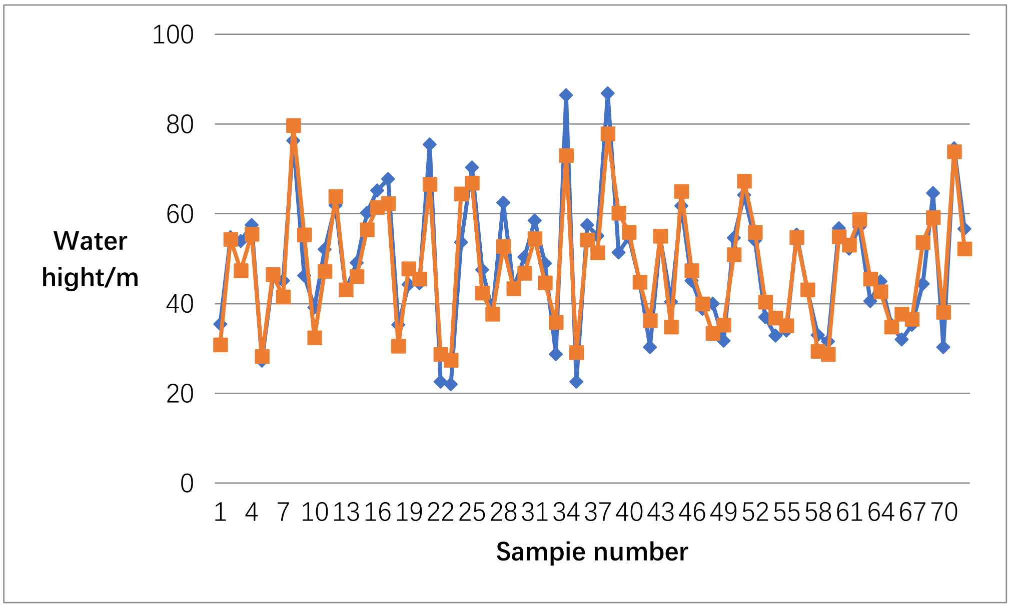

Figure 5 MNR model fitting effect

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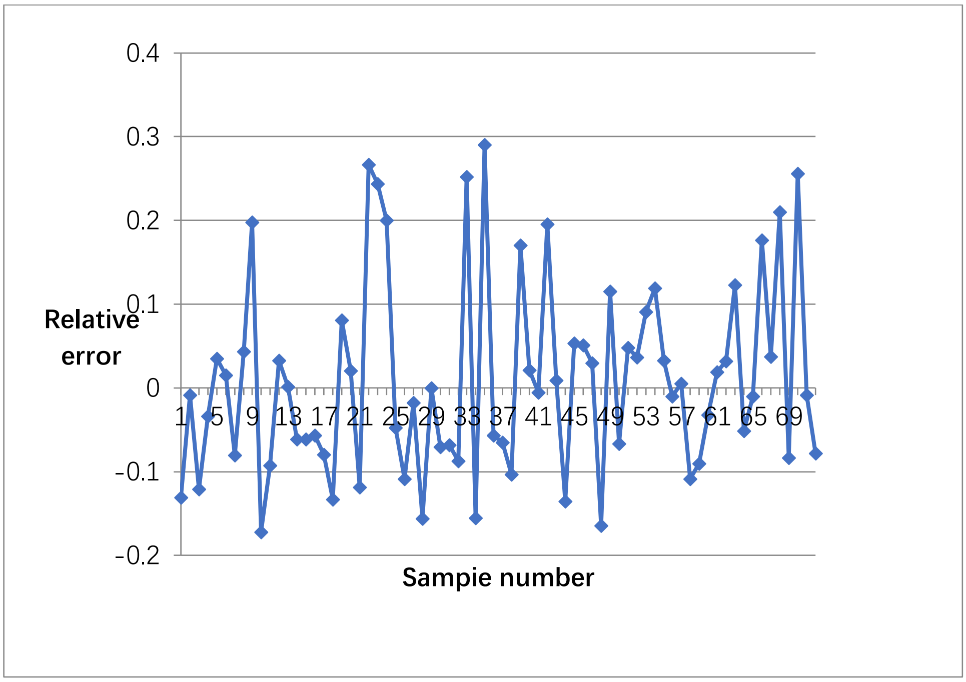

Figure 6 MNR Model Phase Error Distribution

Table 8 Experience Computing formula of height of water flowing Fracture zone

The lithology	The calculation formula is one over m	Formula 2 /m
hard	$H_f = \frac{100\sum M}{1.2\sum M + 2.0} \pm 8.9$	$H_f = 30\sqrt{\sum M} + 10$
In the hard	$H_f = \frac{100\sum M}{1.6\sum M + 3.6} \pm 5.6$	$H_f = 20\sqrt{\sum M} + 10$
weak	$H_f = \frac{100\sum M}{3.1\sum M + 5.0} \pm 4.0$	$H_f = 10\sqrt{\sum M} + 5$
Very weak	$H_f = \frac{100\sum M}{5.0\sum M + 8.0} \pm 3.0$	

Table 9 Error between the height prediction Value of the partial water-guided Fissure band and the measured value

Serial number	Measured water conductivity height /m	Fitting formula		Under the three rules of	
		Forecast/m	Relative error /%	Forecast/m	Relative error /%
1	61.90	63.92	3.26	53.72	13.12
2	61.77	65.04	5.31	53.71	13.05
3	42.99	43.04	0.14	24.98	41.89
4	67.70	62.31	7.96	71.40	5.47
5	54.60	50.95	6.67	44.86	17.84
6	50.34	46.78	7.06	40.25	20.04
7	43.43	43.40	0.05	39.11	9.95
8	40.35	34.86	13.59	24.47	39.36
9	38.41	37.71	1.80	39.11	1.82
10	64.25	67.35	4.83	53.53	16.68
11	57.00	58.82	3.20	62.08	8.91
12	54.50	55.00	0.92	41.06	24.66
13	44.54	45.45	2.05	35.77	19.69
14	53.70	64.45	20.03	30.55	43.11

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It can be seen from the figure that the relative error range is 0.05% ~ 29.05%, the average relative error is 7.05%, the number of samples with the absolute relative error greater than 20% is very small, after calculation, RMSE =4.1925, the determining coefficient R^2= 0.786.

14 groups of sample data were selected to compare the regression fitting formula (2) and the empirical formula in the "three lower" procedure (Table 8) to calculate the error between the predicted value and the measured value (Table 9).

Table 8 Empirical formula for the height of water-conducting fracture zone under "three times" regulation

It can be seen from the above table that the predicted value error obtained by the regulation formula is large, while the predicted value error obtained by the fitting formula is relatively small, which also indicates that the more factors are considered in the prediction of derivative height, the more consistent the predicted value will be with the actual value.

5. Application examples of formula

The parameters of the 3112 working face of Hongqi Coal Mine in Shandong province are as follows: mining height 4.6m, lithologic ratio coefficient of hard rock 0.43, working face oblique length 120m, mining depth 427.3m, and measured water conductivity height 56.60m.

By substituting the values of the four influencing factors into the fitting formula (2), the predicted derivative height is calculated to be 53.18m, and the relative error is only 6.04%. The difference between the predicted value and the measured value is very small, indicating that the obtained empirical formula of multi-factor prediction of derivative height is in line with the reality and has certain applicability.

6. Conclusion

(1) According to the gray correlation analysis, mining height has the greatest influence on the development of guide height, followed by mining depth, hard rock lithologic ratio coefficient and working face slope length.

(2) Through the single-factor correlation analysis, the function types of each factor and the derivative height are obtained, and the derivative height is related to the natural logarithm function of working face slope, the index function of mining depth, and the lithological coefficient of mining thickness and hard rock.

(3) On the basis of the single-factor correlation analysis, the regression empirical formula between the derivative height and multiple factors is obtained through the multivariate nonlinear regression analysis. The relative error is 6.04%, which is in good agreement with reality, and can provide scientific basis for roof water damage prediction and prevention.

(4) According to the prediction results in Table 9, the relative error of the fitting formula is smaller than that of the regulation formula, which is of high reference value. However, due to the numerous influencing factors of the height of the water-conducting fracture zone and the different mining conditions, the error of the prediction results will also be large. Therefore, the prediction of the height of water-conducting fracture zone plays a certain auxiliary role in the prevention and control of mine water damage. In order to ensure the safety of coal mine production, the study of geological conditions and mining conditions should be done well, and the emergency prevention measures should be improved.

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