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Study on prediction method of coal seam gas content based on principal component multiple regression

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Abstract: The gas content of coal seam is the basis of gas disaster control in coal mine. The accurate prediction of gas content of coal seam is directly related to the effect of gas precise control in coal mine. Weijiadi coal mine is a high gas mine in Gansu Province, the gas content of NO.1 coal seam is related to five factors, including burial depth, elevation of coal seam floor, vertical depth, thickness of coal seam and total thickness of coal seam. In order to avoid the problem that only one factor is taken into account in the statistical analysis and study of coal seam gas occurrence law and the one-dimensional linear model is not accurate in prediction, this paper determines the gas content of NO.1 coal seam through principal component analysis, the thickness and buried depth of coal seam are the main control factors of gas content in coal seam. The predicted value of gas content in coal seam is obtained by multiple linear regression analysis, and compared with the measured value, the predicted value is basically consistent with the measured value, which is of great significance for the prevention and control of gas disaster in coal mine.

1. Introduction

China is rich in coal resources, but the disasters are also serious. High gas mines account for more than 50% of the total amount of coal mines. Gas is the main factor affecting the safety of coal production[1], and the geological factors of coal fields are the main factor affecting the content of coal seams. Moreover, with the extension of the production level of coal mines, the geological structure is more and more complex, and gas disasters are more and more serious. Therefore, the study of coal mines It is of great theoretical value and practical significance to predict the gas content in coal seam and to control the gas disaster in coal mine[2-5]. Many scholars have put forward a variety of prediction methods, such as mine statistical method based on mathematical statistics, gas content method with coal seam gas content as the basic prediction parameters, gas geological mathematical model method, etc[6-9].

When using the mine statistical analysis to study the law of coal seam gas occurrence, if only considering the depth of coal seam or the elevation of coal seam floor, it is obvious that the prediction accuracy is not enough, and the obtained value will be greatly deviated. However, if considering many influencing factors and establishing multiple regression model, the solution process is complicated. In this paper, according to the actual situation of Weijiadi coal mine in Jingyuan, Gansu Province, multivariate linear regression is used to predict the gas content in different areas of the coal seam.

2. Parameter Selection and Data Acquisition Affecting Gas Emission in the Working Face

According to the data obtained during the geological survey, the parameters are selected as follows: ground elevation (m), floor elevation (m), vertical depth (m), minable thickness (m), coal seam thickness (m), total thickness of coal (m), etc., totaling 5 parameters. The first is the related parameters and gas content data of 17 boreholes in Weijiadi coal mine.

Table 1 Gas content of NO.1 coal seam and parameters of influencing factors

Name of coal seam	Drilling number	Ground elevation (m)	Floor elevation (m)	Vertical depth (m)	Recoverable thickness (m)	Total thickness of coal(m)	Gas content (m^3/t)
NO.1 coal seam	79	1602.40	1249.45	351.30	1.47	1.65	0.91
	224	1648.32	1203.00	443.36	0.88	1.96	0.31
	112	1608.74	1169.08	437.47	1.93	2.19	4.30
	212	1623.90	1078.79	542.11	3.00	3.00	1.74
	111	1619.54	1121.33	493.98	4.05	4.23	5.60
	Main hole	1637.50	1124.95	507.54	5.01	5.01	2.66
	198	1643.06	1073.01	563.37	5.91	6.68	2.22
	206	1618.99	1113.00	498.17	2.90	7.82	2.21
	214	1613.76	1099.26	505.97	8.43	8.53	7.73
	223	1634.54	1188.46	436.89	6.46	9.19	4.14
	201	1630.71	1107.28	512.24	10.35	11.19	10.39
	210	1667.38	951.93	702.08	11.34	13.37	4.35
	211	1612.65	1038.46	560.11	8.44	14.08	3.16
	100	1640.33	1266.66	358.06	13.27	15.61	1.74
	102	1613.00	1014.82	581.76	16.26	16.42	0.99
	197	1667.91	1242.07	405.31	19.38	20.53	3.04
	187	1651.02	1076.07	550.87	15.50	24.08	4.82

3. Principal Component Analysis of Influencing Parameters of Gas Emission in Working Face

3.1 Overview of mine gas

Weijiadi coal mine is located in Gansu Province, China, with a design production capacity of 1.5 million t/a, and then expanded to 3 million t/a, adopting the fully mechanized caving coal mining technology. The gas content of coal seam is 9.22-10.17m^3/t, the maximum pressure of gas is 1.88MPa, the maximum absolute emission of gas is 68.64m^3/min, and the maximum relative emission is 18.81m^3/t. The coal seam is dangerous to outburst. The mine field is a fold (or incomplete compound syncline) structure composed of No.1 anticline, No.2 syncline, No.3 syncline and No.4 syncline from West to East.

3.2 Basic principle of principal component analysis

Principal component analysis (PCA) is a multivariate statistical method which transforms many variables into a few principal components by dimension reduction technology[10]. These principal components can reflect most of the information of the original variables, usually expressed as the linear combination of the original variables, and the principal components are linearly independent. When many variables (parameters) are involved in the research, this method can be considered, so that it is easier to grasp the main contradiction of things and simplify the problem.

3.3 Selection of principal components

(1) Depth of coal seam

The deeper the coal seam is buried, the more difficult it is to move the gas to the surface, and the less the gas escapes. And the increase of the overburden with the buried depth is beneficial to preserve the gas, and the higher the gas content of the coal seam is. The burial depth of NO.1 coal seam in Weijiadi coal mine is from 350m to 620m, and the relationship between the coal seam gas content and the burial depth is shown in Figure 1. It can be seen that the coal seam gas content increases with the increase of the burial depth, and the correlation coefficient reaches 0.4826, which can be used as the main factor for predicting the coal seam gas content in the multiple linear regression model.

(2) Thickness of coal seam

According to the statistics of drilling data of geological exploration, NO.1 coal seam in the mine field is squeezed and superposed by fault group F_{1-2}, and the structural damage of coal seam is extremely serious. It is a typical structural coal, with a great change in thickness of coal seam, showing a trend of thicker in the East and thinner in the West. The thickness of coal seam changes between 0-38.88 m, with an average thickness of 7.34 m, containing 1-7 layers of unstable gangue, with a thickness of 0.32-7.01 m. The lower part of the layer is generally minable.

According to the correlation diagram 2 of coal seam gas and coal thickness, the larger the coal seam thickness is, the higher the coal seam gas content is, with a positive correlation coefficient of 0.3888, which can be used as a factor affecting the occurrence of coal seam gas.

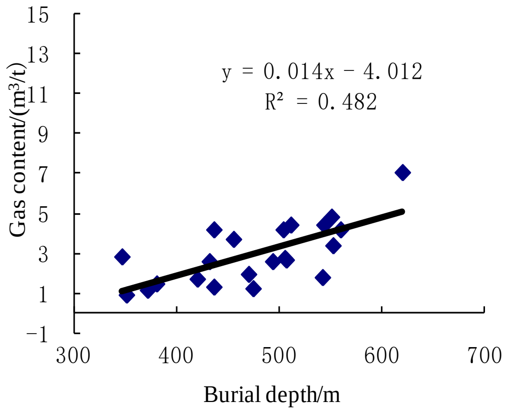

Fig. 1 Relationship between gas content and buried depth

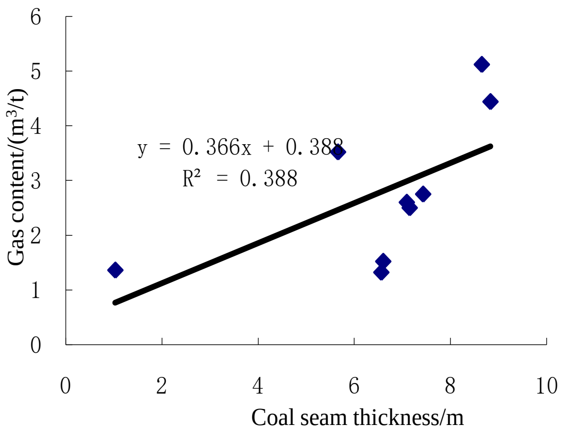

Fig.2 Relationship between gas content and thickness

4. Multivariate Linear Regression Mathematical Model Based on Principal Component

4.1 Definition of multiple linear regression

Multiple linear regression[11], that is, under the condition of linear correlation, a dependent variable is determined by two or more independent variables, which is called multiple linear regression model.

Set a dependent variable Y and m independent variables $x_1, x_2, \dots, x_m$ satisfied relation:

$$Y = a_0 + a_1 x_1 + a_2 x_2 + \cdots + a_m x_m + \varepsilon \tag{1}$$

$$\varepsilon \sim N(0, \delta_2)$$

Where: a_0, a_1, a_2, $\dots, a_m$, δ_2 and x_1, x_2, $\dots, x_m$ are unrelated unknown parameter, m>1, then there is a linear correlation between Y and x_1, x_2, $\dots$, x_m. Equation (1) is called m-element normal linear regression model.

4.2 Least square estimation of regression model parameters

In order to facilitate the solution, formula (1) is changed to the matrix expression of M random equations as follows:

$$Y = Xa + \varepsilon \tag{2}$$

Where, $Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$, $A = \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_n \end{bmatrix}$

In formula (2), if $rank(X) = k+1$, $X^T X$ is a $k+1$ square matrix of order, so $X^T X$ is the inverse matrix of full rank, then it can be calculated by least square estimation.

$$X^T X = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ x_{11} & x_{21} & \cdots & x_{n1} \\ \vdots & \vdots & & \vdots \\ x_{1m} & x_{2m} & \cdots & x_{nm} \end{bmatrix} \begin{bmatrix} 1 & x_{11} & \cdots & x_{1m} \\ 1 & x_{21} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ 1 & x_{n1} & \cdots & x_{nm} \end{bmatrix} = \begin{bmatrix} n & \sum_{i=1}^{n} x_{i1} & \cdots & \sum_{i=1}^{n} x_{im} \\ \sum_{i=1}^{n} x_{i1} & \sum_{i=1}^{n} x_{i1}^2 & \cdots & \sum_{i=1}^{n} x_{i1} x_{im} \\ \vdots & \vdots & & \vdots \\ \sum_{i=1}^{n} x_{im} & \sum_{i=1}^{n} x_{im} x_{i1} & \cdots & \sum_{i=1}^{n} x_{im}^2 \end{bmatrix} \tag{3}$$

$$X^T Y = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ x_{11} & x_{21} & \cdots & x_{n1} \\ \vdots & \vdots & & \vdots \\ x_{1m} & x_{2m} & \cdots & x_{nm} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_{i1} y_i \\ \vdots \\ \sum_{i=1}^{n} x_{im} y_i \end{bmatrix} \tag{4}$$

From formula (3) and (4), we can get:

$$\hat{A}=\begin{bmatrix}\hat{a}_0\\ \hat{a}_1\\ \vdots\\ \hat{a}_m\end{bmatrix}=(X^TX)^{-1}X^TY\ \hat{a}=(X'X)^{-1}X'Y \tag{5}$$

By substituting the least square estimate of the parameters a_0, a_1, a_2, …, a_m ,the linear regression equation of m-element can be obtained.

$$y=a_0+a_1x_1+a_2x_2+\cdots a_nx_n \tag{6}$$

5. Multi Factor Regression Prediction and Result Analysis of Gas Content in Coal Seam

5.1 Selection of samples and establishment of regression model

Considering the influencing factors of coal seam gas content, it can be seen that the depth and thickness of coal seam are the two main determinants of gas content. Based on this, a binary regression model is established

$$y=a_0+a_1x_1+a_2x_2 \tag{7}$$

Where: x_1 is the thickness of coal seam; x_2 is the depth of coal seam.

Taking the measured data of seventeen boreholes of coal seam $(y_i;x_{i1},x_{i2})$ as samples, $i=1,2\cdots 9$, substituting (7) formula, the multiple linear regression equation of NO.1 coal seam is obtained by SPSS software.

$$y=-4.631+0.705x_1+0.008x_2 \tag{8}$$

5.2 Regression results and analysis

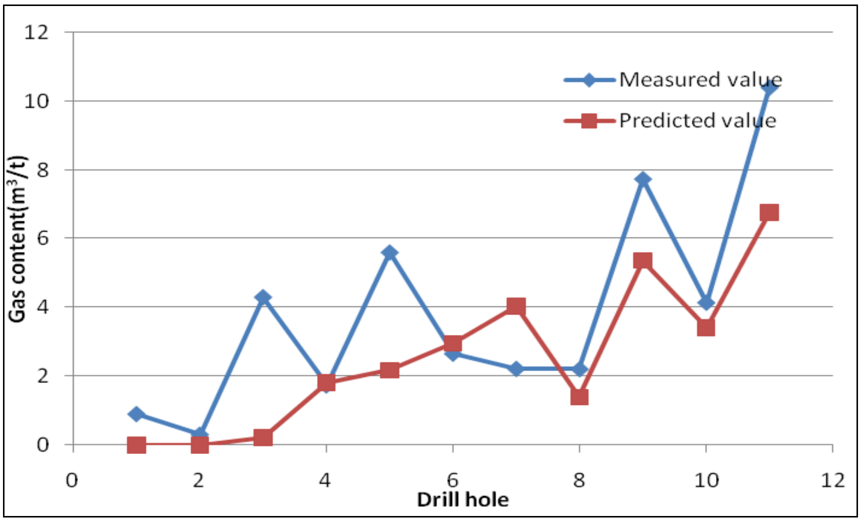

Fig. 3 Relationship between measured value and predicted value of coal seam gas content

Through the collection of index data of seventeen geological exploration boreholes in the mine field, the prediction value is obtained by using multiple linear regression equation. From the significance test method of F regression equation, it can be seen that NO.1 coal seam multiple linear regression equation is significant, the predicted value is close to the measured value, and the prediction degree is high. The line chart of the relationship between the measured value of coal seam gas content and the predicted value is shown in Figure 3, which shows that the two discounting basically overlap, it shows that the prediction is reliable.

Table 2 Measured value and predicted value of NO.1 coal seam drilling

Serial number	Coal seam thickness/m	Buried depth of coal seam/m	Gas content(m^3/t)	
			Measured value	Predicted value
79	1.47	351.30	0.91	0
224	0.88	443.36	0.31	0
112	1.93	437.47	4.30	0.23
212	3.00	542.11	1.74	1.82
111	4.05	493.98	5.60	2.18
Main hole	5.01	507.54	2.66	2.96
198	5.91	563.37	2.22	4.04
206	2.90	498.17	2.21	1.4
214	8.43	505.97	7.73	5.36
223	6.46	436.89	4.14	3.42
201	10.35	512.24	10.39	6.76
210	11.34	702.08	4.35	8.98
211	8.44	560.11	3.16	5.8
100	13.27	358.06	1.74	7.59
102	16.26	581.76	0.99	11.49
197	19.38	405.31	3.04	12.27
187	15.50	550.87	4.82	10.7

6. Conclusion

(1) Through the principal component analysis of the influencing factors of the gas content in the No. 1 coal seam of Weijiadi coal mine, it is concluded that the coal seam buried depth and buried depth are the main controlling factors of the gas content in the coal seam.

(2) As the main control factor of gas content in coal seam, the depth and thickness of coal seam are predicted by multiple regression analysis, and the predicted value is basically consistent with the measured value, which provides a theoretical basis for gas control in coal mine.

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