Analysis and Research on the Comprehensive New Index of Bursting Liabilitys in Yima Coalfield

Enbing Yi 1,2,3*

1 School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo 454000, Henan, China
2 State Key Laboratory of The Gas Disaster Detecting, Preventing and Emergency Controlling, Chongqing 400037, China
3 China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing 400037, China
*Corresponding author’s e-mail: 112002010011@home.hpu.edu.cn

Abstract. Aiming at the phenomenon that the impact energy index, the elastic energy index and the dynamic failure time are contradictory in the process of the impact tendency identification experiment, it is impossible to accurately distinguish the strength of impact tendency. This paper adopts the method of principal components analysis to confirm indexes weight and makes full use of experimental data, and a preliminary judgement is made that the value of the samples more than 0 is strong bump proneness, the other is weak bump proneness. The result agrees with the coal seam bump proneness of practical situation in Yima coalfield, namely strong bump proneness in Yima coalfield. The method of comprehensive new principal components analysis will judge the bump proneness very well and provides a new method to judge the bump proneness.

1. Introduction

Bursting liability refers to the property of coal rock mass which has accumulated deformation energy and can produce impact type damage. Bursting liability is the inherent property of the coal rock mass which occurs rock burst, and determines the ability of the coal rock mass to appear rock burst[1]. The study of bursting liability is an important part of the study of rock burst mechanism, and it is the foundation for the prediction and prevention of rock burst[2].

Domestic and foreign common indicators for the evaluation of coal seam bursting liability are elastic energy index, bursting energy, dynamic failure time, elastic deformation, the surplus energy release rate index, the stiffness ratio index, microcrystalline parameter index, coefficient of creep compliance, physical phase, etc[3-5]. The commonly used bursting liability indicators in China have dynamic damage time $D_r$, elastic energy index $W_{ET}$ and bursting energy index $K_e$, etc[6-7]. The bursting liability of coal seam is divided into three types: strong bursting, weak bursting and non-bursting in China.

2. The necessity of comprehensive new index analysis

China’s current bursting liability index of coal seam mainly includes: elastic energy index, bursting energy index, dynamic damage time. In the physical sense, the elastic energy index is the ratio of the accumulated elastic energy of coal seam to the plastic deformation energy, indicating the magnitude of the deformation elastic energy of coal rock, reflecting the ability to absorb energy. The bursting energy...
The index is the ratio between the deformation energy accumulated before the peak and the residual deformation energy after the peak, indicating the magnitude of residual energy in the process of coal rock failure, and the bursting liability of coal rock is revealed from the energy aspect. The dynamic failure time indicates the time of the coal rock failure and the inherent law of the bursting liability of the coal rock from time aspect. In essence, coal seam bursting liability should be influenced by time and energy. The above three indexes respectively reflect the magnitude of the bursting liability from the Angle of energy and time, and are not comprehensive enough. And three indicators used at the same time, the result is often inconsistent. At this point, how to determine the magnitude of the impact bias is often based on the subjective experience of the judge, so it is necessary to comprehensively analyze the above indicators.

3. Principle and procedure of principal component analysis

The principal component analysis can recombine the original number and the related indexes into a new few independent comprehensive indexes under the premise of loss or little loss of original information. It is a method of mathematical transformation to transform a given set of related indicators (n objects, p indicators) into another set of unrelated indicators by linear transformation. These new indicators are arranged in descending order of variance. In the mathematical transformation, the total variance of the index is invariant, so that the first index has the largest variance, which is called the first principal component. The variance of the second finger is large, and it is not related to the first index, which is called the second principal component, and so on. If the cumulative contribution rate of the former k (k<p) principal components has reached more than 80%, the former k main components can reflect more information of the original indexes.

The specific calculation procedure are as follows:

The original variable matrix X is set up with n samples. Each sample has p indicator variables to form the data matrix: \( X = (X_{ij})_{n \times p} \). Where \( i = 1,2,\ldots,n, j = 1,2,\ldots,p \), \( X_{ij} \) represents the jth index value of the ith sample.

Standardized processing the original data, because the dimension, size and evaluation index of each factor in principal component analysis are very different, the comparability is poor, so the standardization is first carried out to make it have good comparability. Using the principle of extreme difference standardization to make dimensionless, its operation is:

\[
X'_{ij} = \frac{x_{ij} - \bar{x}_j}{R_j} \quad i = 1,2,\ldots,n, j = 1,2,\ldots,p
\]

Where \( R_j = \max(x_{ij}) - \min(x_{ij}) \), \( \bar{x}_j = \frac{1}{n} \sum_{i=1}^{n} x_{ij} \) is the average of the JTH variable.

Calculate the correlation coefficient matrix \( R \) of standardized data. Find the characteristic roots and eigenvectors of the correlation coefficient matrix \( R \), determine the principal component to find the characteristic root(\( \lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \)) of the correlation matrix \( R \), it’s the variance of the principal component, indicating the magnitude of the action of each principal component in describing the object being evaluated. The corresponding eigenvectors are obtained according to each characteristic root. \( L_g = l_{g1}, l_{g2}, \ldots, l_{gp} \) (g=1,2,\ldots,p). Convert the standardized indicator variables to the main components: \( Y_g = l_{g1}X_{1g} + l_{g2}X_{2g} + \cdots + l_{gp}X_{pg} \) (g=1,2,\ldots,p), \( Y_1 \) is called the first principal component, and \( Y_2 \) is called the second principal component, ..., \( Y_p \) is called the Pth principal component.

According to the cumulative variance contribution rate, the number of principal components is determined, that is selected based on the ratio of variance to the total variance \( \alpha = \sum_{g=1}^{P} \lambda_g / \sum_{g=1}^{P} \lambda_g \) (generally taken \( \alpha \geq 80\% \)). P is the number of principle components. Establish the principal component equation and calculate the principal component value.

4. Test data analysis and processing

4.1. Establish factor gathers

A set of factors that affect the bursting liability of the entire yima coalfield is established based on the
experimental data of the bursting liability in the four mining areas of Yima Changcun, Gengcun, Yuejin and Qianqiu. It is important to note that in the sample, there is an uncalculated index value which is replaced by the average value of the mining area.

4.2. Principal component analysis
Calculate standardized data and its correlation coefficient matrix. The impact test data of Yima mining area was standardized and the correlation coefficient matrix was calculated, as shown in Table 1.

| Factors             | Elastic energy index | Shock energy index | Dynamic failure time /ms |
|---------------------|----------------------|--------------------|--------------------------|
| Elastic energy index| 1                    | 0.507              | -0.074                   |
| Shock energy index  | 0.507                | 1                  | -0.0731                  |
| Dynamic failure     | -0.074               | -0.073             | 1                        |

Find the characteristic roots and eigenvectors of the correlation coefficient matrix and determine the principal component. According to the data in Table 1, the eigenvectors and their corresponding eigenvectors are obtained, as shown in Table 2.

| principal component | feature vector $L_c$ | Characteristic root | Contribution rate /% | Cumulative contribution rate /% |
|---------------------|----------------------|--------------------|-----------------------|---------------------------------|
| $Y_1$               | Elastic energy index | 0.196              | 1.527                 | 50.917                          |
|                     | Shock energy index   | 0.972              | 0.980                 | 83.567                          |
|                     | Dynamic failure time /ms | 0.001         | 0.493                 | 100.000                         |

From Table 2, the first principal component $Y_1$ and the second principal components $Y_2$ accounted for 83.567% of total variance, which can reflect the bursting liability of coal seam 83.567% of all information, so using the two principal components in analysis can meet the requirements.

Establish the principal component equation. According to the above results, the cumulative contribution rate of the first principal component $Y_1$ and the second principal component $Y_2$ is 83.567%, over 80%, so the equation of the first principal component and the second principal component is established:

$$
\begin{align*}
Y_1 &= -0.704X_1' - 0.704X_2' + 0.196X_3' \\
Y_2 &= 0.135X_1' + 0.136X_2' + 0.972X_3'
\end{align*}
$$

$X_i'$ is the standardized test data. According to equation (1), the first and second principal component values can be calculated.

4.3. Establishment and analysis of comprehensive new index
The first principal component $Y_1$ accounted for 50.917% of the total variation. Its elastic energy index and bursting energy index have a higher absolute value, which can be considered to be controlled by elastic energy index and bursting energy index, as is shown in Figure 1. The higher the elastic energy index and the impact energy index, the stronger the coal seam bursting liability. Therefore, the first principal component also reflects the degree of coal seam bursting liability. Because the coefficient of its elastic energy index and impact energy index is negative, that is, the smaller the component value, the stronger the bursting liability of coal seam, and vice versa.
The second principal component $Y_2$ accounts for 32.650% of the total variation, and the dynamic damage time coefficient is the largest and positive. It can be considered that the second main component mainly reflects the dynamic failure time, as is shown in figure 2. The smaller the dynamic damage time, the stronger the coal seam bursting liability. Therefore, the second principal component also reflects the degree of bursting liability of coal seam, that is, the smaller the component value, the stronger the bursting liability of coal seam, and vice versa.

In order to comprehensively reflect the physical significance of each of the three shocks, the following main components $Y^*$ are proposed:

$$Y^* = -\frac{\lambda_1 Y_1 + \lambda_2 Y_2}{\lambda_1 + \lambda_2}$$

In the formula, $\lambda_1$ is the first eigenvalue, and $\lambda_2$ is the second eigenvalue, $Y_1$ is the first principal component value, and $Y_2$ is the second principal component value. Substitute the parameter values and get the new index $Y^*$ value of the main components.

Figure 3 shows the relationship trend diagram of $Y_1$, $Y_2$, and $Y^*$ values. Figure 4 shows the relationship trend diagram between $Y^*$ value and bursting energy index and elastic energy index. Figure 5 shows the relationship trend diagram between $-Y^*$ value and dynamic failure time. The following conclusions can be drawn from figure 3-5:

As can be seen from formula (2) and figure 3, the comprehensive new index of principal component is the weighted average value of the first principal component value and the second principal component value, and the $Y^*$ value is negatively correlated with the $Y_1$ and $Y_2$ values. The first principal component $Y_1$ and the second principal components $Y_2$ accounted for 83.567% of total variance, which can reflect
the bursting liability of coal seam 83.567% of all information. The first principal component values reflect the information carried by the elastic energy index and the bursting energy index. The second principal component value mainly reflects the information carried by dynamic damage time. Therefore, the comprehensive index of the principle components can reflect the comprehensive information of elastic energy index, bursting energy index and dynamic failure time, and then it is reasonable and feasible to evaluate the bursting liability of coal seam with this index.

As shown in figure 4 and figure 5, \( Y^* \) is positively correlated with bursting energy index and elastic energy index, and negatively correlated with dynamic failure time. Therefore, the comprehensive new index of main components reflects the bursting liability of coal seam, namely, the higher the value \( Y^* \), the stronger the bursting liability of coal seam.

Fig. 3 The trend map of the relationship of \( Y_1 \), \( Y_2 \) and \( Y^* \)

Fig. 4 The trend map of the relation between \( Y^* \), impact energy index and elastic energy index
5. Conclusions

The principal component value is a comprehensive reflection of the elastic energy index, impact energy index and dynamic failure time of each sample. That is, the principal component value comprehensively describes the bursting liability of each sample. So it is reasonable to give the weight of each sample with the principal component value.

First, the \( Y_1 \) and \( Y_2 \) principal component values are weighted and averaged, and then the weight of each sample is calculated. Finally, the comprehensive index values of the impact tendency of the Yima coal field coal seam are: elastic energy index 11.43, impact energy index 6.82, dynamic failure time is 134ms, and the new principal component comprehensive index value is 0.050.

The first principal component \( Y_1 \) and the second principal components \( Y_2 \) accounted for 83.567% of total variance, which can reflect the bursting liability of coal seam 83.567% of all information, so using the two principal components in analysis can meet the requirements. Specifically, \( Y_1 \) accounted for 50.917% of the total variation, which reflected the elastic energy index and impact energy index. The smaller the component value, the stronger the bursting liability of coal seam. \( Y_2 \) accounted for 32.650% of the total variation, which reflected the dynamic failure time. The smaller the component value, the stronger the bursting liability of coal seam.

According to the test data of the impact tendency of yima coal field, the initial determination of the bursting liability of the sample with \( Y^* \) value greater than 0 is strong, and the sample bursting liability with \( Y^* \) value less than 0 is weak. The determination of the critical value also requires a lot of tests and engineering examples to better guide the engineering practice.

Using principal component comprehensive index \( Y^* \), it is concluded that the results of coal seam bursting liability in whole yima coalfield is consistent, is more consistent with the actual situation, that is the bursting liability of whole yima coalfield is strong bursting. The impact tendency is weak by means of average comprehensive evaluation, because the average value ignores the weight of each sample in judging the bursting liability of coal seam in the whole coal field. Therefore, it is not reasonable to judge the bursting liability of coal seam in the whole coalfield by means of average.

Acknowledgments

We gratefully acknowledge the financial support for this work provided by the National Key Research and Development Program of China(2017YFC0804208).

References

[1] Hao, X.J., Yuan, L., Li,Y.L. (2018) Lateral deformation characteristics of coal with bump tendency based on uniaxial compression experiment. Journal of China University of Mining & Technology, 47: 129-136.
[2] Cai, W., Dou, L.M., Han, R.J. (2011) Lateral deformation characteristics of coal with bump tendency based on uniaxial compression experiment. Journal of China Coal Society, 36: 346-352.

[3] Wang, Y.H., Zhao, Y.Z., Peng, X.C. (2017) Continuous monitoring and warning theory and technology of rock burst dynamic disaster of coal. Journal of China Coal Society, 36:122-123.

[4] Song, Z.Y., Ji, H.G., Sun, L.H. (2015) Advances in Evaluation Indices and Experiments for Bursting Liability of Coal and Rock. Chinese Journal of Underground Space and Engineering, 11:401-406.

[5] Li, L., Zhang, Y. (2017) Experimental research on bump proneness of simulated layered rock specimens. Chinese Journal of Rock Mechanics and Engineering, 36:4025-4035.

[6] Wang, H.W., Jiang, Y.D. (2017) Investigation on the inducing factors of coal bursts under complicated geological environment in Yima mining area. Chinese Journal of Rock Mechanics and Engineering, 36:4085-4091.

[7] Zhang, X.Y., Feng, G.R., Kang, L.X. (2009) Method to determine burst tendency of coal rock by residual energy emission speed. Journal of China Coal Society, 34:1165-1168.