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Research Article

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Research on the Layout of Microseismic Joint Monitoring Network Above and Below the Near-Horizontal Coal Seam

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Abstract: In order to prevent and control the dynamic disasters of rock burst in coal mines, my country's rock burst mines generally use microseismic monitoring technology for monitoring and early warning. For near-horizontal coal seam working faces, since microseismic sensors can only be arranged horizontally in the tunnel, the vertical error in locating the source is large, and the source parameters cannot be accurately calculated. In order to solve this problem, a joint microseismic monitoring technology for above and below the mine was proposed. At the same time, the layout of the ground microseismic monitoring station was determined by superimposing and dividing the impact danger area of the working face through the multi-factor coupling method, and field practice was carried out at the 31319-working face of a certain mine. Data analysis shows that after the installation of the ground network based on the multi-factor coupling method, the frequency of microseismic events and the energy receiving effect increased by 21% and 30.8% respectively; the distribution effect of the depth positioning of the epicenter of the microseismic event shows that the monitoring capability of the roof and the overlying goaf area has been improved, which provides a certain reference for the layout of the near-horizontal coal seam microseismic network.

Keywords: Rock burst; Near-horizontal coal seam; Microseismic monitoring above and below the well; multi-factor coupling method; Network layout

1. Introduction

Rock burst is a coal-rock dynamic phenomenon caused by the sudden release of elastic energy and deformation energy accumulated in coal and rock bodies during mining. When the energy is large enough, it will cause coal body ejection, roof subsidence, bottom drum and other tunnel damage. Microseismic monitoring can be used to monitor and predict coal-rock dynamic phenomena in mining areas [1-2]. Its main function is to automatically record the activities of coal and rock bodies in real time, locate the source and calculate the energy of dynamic phenomena, obtain the strength of rock burst activities in the mining area, and realize early warning of rock burst danger [3-5].

At present, underground microseismic monitoring technology is mostly used for early warning of mine rock burst disasters. [6-8] Near-horizontal coal seam mines are limited by the objective conditions of underground microseismic monitoring sensor layout, and the monitoring network cannot form a fully covered spatial stereoscopic monitoring network. While some mines have introduced underground microseismic monitoring stations, there is a problem of no reasonable layout plan for the underground network, resulting in inaccurate source location and early warning. For this reason, based on previous research, this paper studies the layout plan of the underground and underground microseismic joint monitoring network for near-horizontal coal seams and conducts field verification [9-10].

2. Analysis of Vertical Positioning Error of Earthquake Source in Near-Horizontal Coal Seams

Principle of microseismic positioning

The shortest propagation time from the earthquake source to the station can be described by equation (1):

$$t_i = t_0 + T_i\left(h, s_i\right) + \xi_i \tag{1}$$

Where t0 is the time when the earthquake occurred, $h = \left(x_0, y_0, z_0\right)$ and $s_i = \left(x_i, y_i, z_i\right)$ are the coordinates of the earthquake source and the i-th monitoring station respectively, ξ_i is the time error of the i-th station, Before the network is installed, it is usually assumed that the random errors of all stations in the network follow the same normal distribution $\xi_i \sim N\left(0, \sigma^2 I\right)$, I is the identity matrix, σ is the variance of the random error. For the uniform and isotropic velocity models, the travel time from the earthquake source h-th to the i-th station is:

$$T_i\left(h, s_i\right) = \frac{\sqrt{\left(x_i - x_0\right)^2 + \left(y_i - y_0\right)^2 + \left(z_i - z_0\right)^2}}{v_{\mathrm{p}}} \tag{2}$$

The source parameters t0 and $h = \left(x_0, y_0, z_0\right)$ can be estimated by minimizing the following functions:

$$\phi(\theta) = \sum_i \left| t_i - t_0 - T_i\left(h, s_i\right) \right|^p \tag{3}$$

Here, $\theta = \left(t0, x0, y0, z0\right)$ is the sum from 1 to the number of stations excited, an p=2 is taken. The estimated result is the optimal solution. The least squares iteration process can be described as follows:

$$\delta\theta_{(n)} = \left(A^T A\right)^{-1} A^T \delta r^n \tag{4}$$

$$A = \begin{bmatrix} 1 & \frac{\partial T_1}{\partial x_0} & \frac{\partial T_1}{\partial y_0} & \frac{\partial T_1}{\partial z_0} \\ 1 & \frac{\partial T_2}{\partial x_0} & \frac{\partial T_2}{\partial x_0} & \frac{\partial T_2}{\partial x_0} \\ \vdots & \vdots & \vdots & \vdots \\ 1 & \frac{\partial T_n}{\partial x_0} & \frac{\partial T_n}{\partial x_0} & \frac{\partial T_n}{\partial x_0} \end{bmatrix} \tag{5}$$

$$\frac{\partial T_i}{\partial Z_0} = \frac{z_0 - z_i}{v_p \sqrt{\left(x_0 - x_i\right)^2 + \left(y_0 - y_i\right)^2 + \left(z_0 - z_i\right)^2}} \tag{6}$$

For nearly horizontal coal seams, the underground microseismic probes are arranged approximately on the same horizontal plane, that is, $z_1 \approx z_2 \approx \cdots \approx z_i \approx \cdots \approx z_n$. Therefore, the first and fourth columns in the A matrix are not independent, causing A to be close to an irreversible singular matrix, and ultimately the correct solution cannot be iterated.

Theory of optimal design of D value

The selection of stations should depend on a value related to the given spatial layout. The optimal network spatial structure is defined by its minimum value, which should depend on the covariance matrix of the source parameter θ. The optimal network selection can be described as follows:

$$minf\left(C\theta(x)\right), x \in \Omega \tag{7}$$

Where the covariance matrix of the source parameter θ is $C\theta = \sigma^2(ATA)^{-1}$, is the coordinate of the microseismic station, and Ωx is the spatial domain of possible station locations.

Kijko believes that the choice of function f can be explained by the confidence ellipsoid of the source parameter θ. According to the D value optimal design theory, the eigenvalue of the covariance matrix reflects the uncertainty of the source parameter θ in the direction of each orthogonal eigenvector, so the determinant is a measure of the overall uncertainty of the source parameter θ. From a geometric point of view, the determinant of the covariance matrix is proportional to the volume of the parallelepiped circumscribed by the covariance confidence ellipsoid. The smaller the determinant, the smaller the volume of the confidence ellipsoid, and the smaller the overall uncertainty of the source parameter θ. Therefore, the microseismic station layout obtained by minimizing detCx is the optimal layout of D value.

Microseismic joint monitoring technology above and below the well

Most of the underground sensors in the near-horizontal coal seam working face are arranged in near-horizontal tunnels. The height difference between the sensors installed in the tunnels is small, which cannot meet the positioning accuracy requirements for the depth of the earthquake source. In order to improve the positioning accuracy of the microseismic sensors in the vertical direction, the ground monitoring station is introduced, combined with the underground microseismic monitoring system, to form a joint microseismic monitoring network above and below the well, which improves the vertical positioning accuracy of the earthquake source, optimizes the spatial three-dimensional network structure, and forms a good envelope effect for the monitoring area of the working face.

3. Multi-Factor Coupling Evaluation and Dangerous Area Division of Working Face

Working face overview

The 31319 working face of a certain mine is located in the south wing of the 3-1 mining area. The length of the working face is 5516.74m, the width is 285.8m, and the area is 1.5766 million m2. The southwest of the working face is the goaf, the northeast is the 31321 working face, the northwest is a horizontal east wing auxiliary transportation tunnel, and the southeast is the southern boundary of the mine field. The 3-1 coal seam where the 31319 working face is located is nearly horizontal mining, with a coal seam strike of 165°, a dip of 255°, and an inclination of 1° to 3°. The burial depth is 264.75 to 557.75m, the coal thickness is 0.30 to 7.45m, and the average is 4.54m.

Multi-factor coupling evaluation of working face

1) During the initial mining of the 31319 working face, the calculated initial pressure step distance was 43.42m. During the initial collapse of the old sandstone roof, the possibility of rock burst was high, and the nearby area had moderate stress concentration.
2) When the working face is mined to a distance equal to the length of the working face from the cutting eye, it reaches the initial "square" stage of the working face, and high-energy vibrations are prone to occur, thereby inducing impact ground pressure accidents. Therefore, there is moderate stress concentration within 50m before and after the square of the working face, and there is weak stress concentration within 50m before and after the periodic square.
3) The width of the coal pillar in the gob-side tunnel section between the 31319 working face and the 31317 working face is 30m, and there is weak stress concentration in the area near the coal pillar.
4) Due to the goaf formed by the mining of the upper coal seam of 2-2, the 31319 fully mechanized mining face of the 3-1 coal seam will be affected by the boundary of the upper goaf of 2-2. The mine pressure will be strong, which may cause abnormal pressure when mining the 3-1 coal seam below. There will be moderate stress concentration in the area.
5) The statistical analysis results show that rock burst often occurs under the condition of hard and thick roof and roof rock thickness parameter $L_{st} \geq 50$. The characteristic parameter of the roof thickness of the 3-1 coal seam is calculated to be 86.91 (greater than 50), so the structural characteristics of the roof rock of the coal seam are the main influencing factors of the rock burst hazard of the 3-1 coal seam.
6) The average uniaxial compressive strength of 3-1 coal is 11.09 MPa, and the average elastic energy index is 3.50. The impact tendency of 3-1 coal and roof and floor plates increases the possibility of rock burst accidents in the 3-1 coal working face and is one of the main influencing factors of the impact hazard of the 3-1 coal working face.

Division of dangerous areas of working face

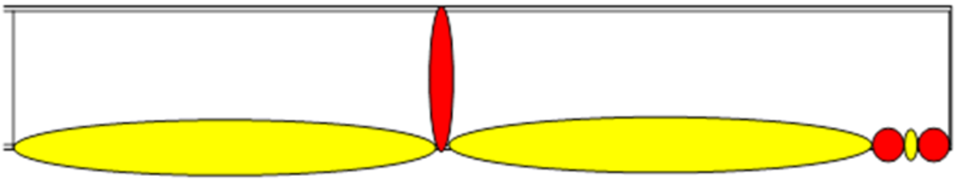


Figure 1: Schematic diagram of impact hazard area division

Field Application

Microseismic monitoring station layout plan

In order to reduce errors as much as possible, obtain useful information, cover current key areas and take into account potential dangerous areas, based on the overview of the existing mine, based on the results of the dangerous area division of the working face, combined with the current production and mining situation and mining continuity, the optimized design of the network ground layout plan is shown in Figure 3-1.

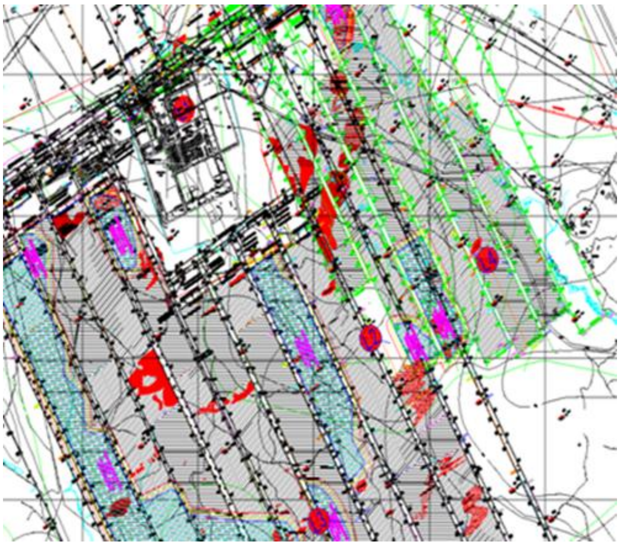
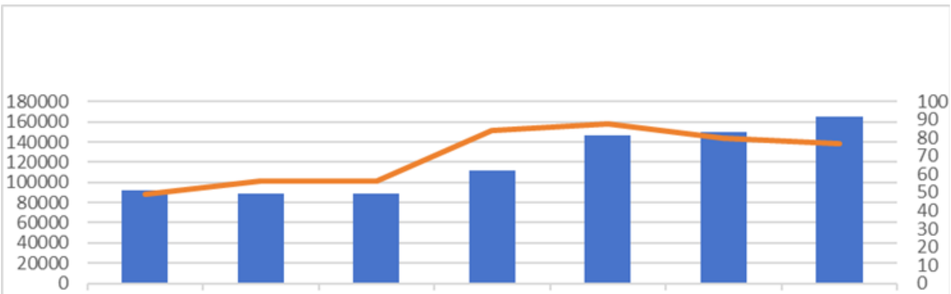


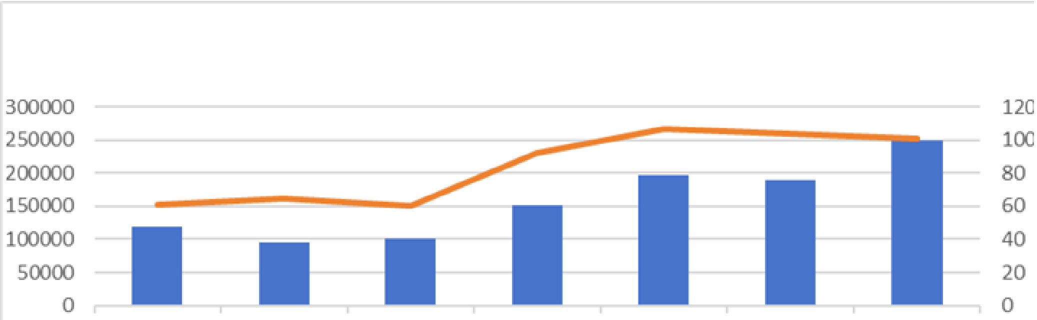
Figure 2: Ground station network layout

On-site data analysis

(1) Figure 3-2 counts the microseismic events that occurred from September 2, 2024 to September 8, 2024. Among them, the underground microseismic sensor system alone received 490 microseismic events, with an average daily total energy of 120,400 J; the underground and underground microseismic joint network received 593 microseismic events, with an average daily total energy of 157,600 J. Compared with the underground microseismic system, the monitoring capability of the frequency of microseismic events increased by 21%, and the monitoring capability of the energy of microseismic events increased by 30.8%.



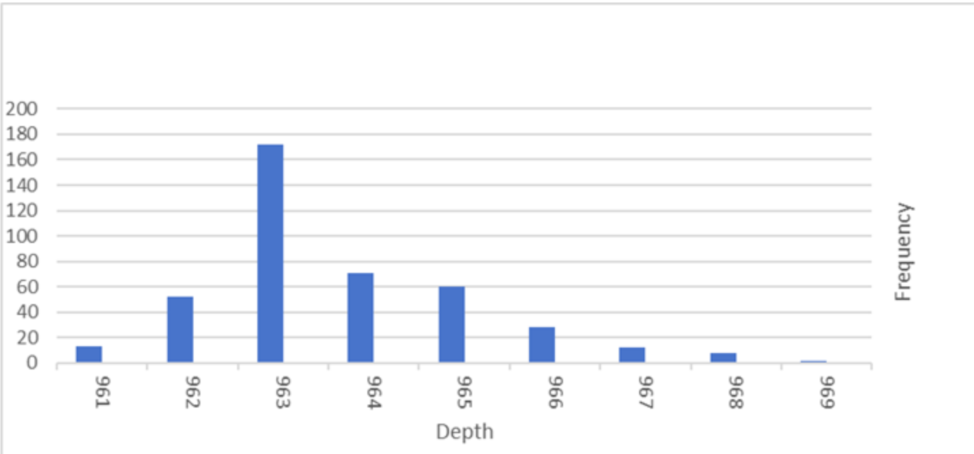
(a) Downhole microseismic sensor only



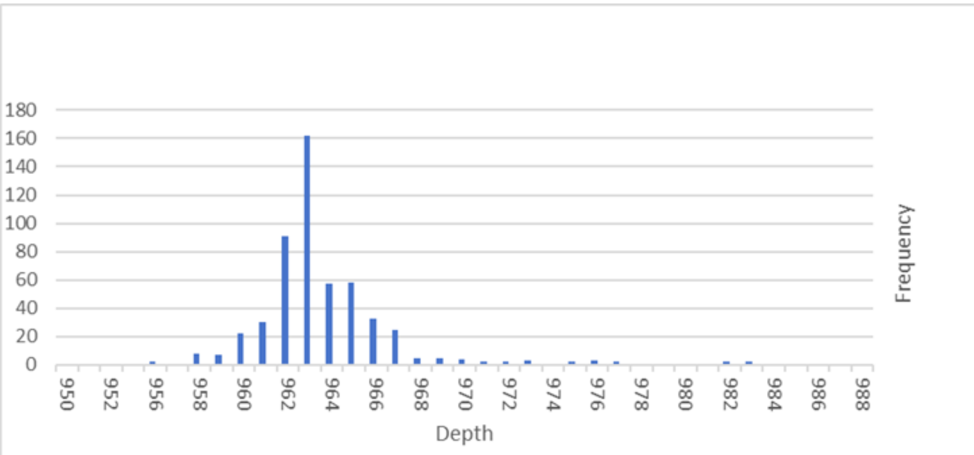
(b) Joint microseismic network above and below the well

Figure 3: Microseismic event energy frequency statistics

(2) The quantitative statistics of the epicenter depth under two conditions, the underground microseismic system of the 31319 working face and the underground and underground microseismic joint monitoring network, are shown in Figure 3-3. As can be seen from Figure 3-3 (a), when only the underground microseismic system is positioned alone, the microseismic events are distributed around 15 meters in the coal seam. As shown in Figure 3-3 (b), the monitoring results of the underground and underground microseismic joint monitoring network can accurately show the occurrence layer of microseismic events. Microseismic events are mainly distributed within 40 meters of the coal seam. Compared with a single underground monitoring system, the positioning accuracy of large energy events in the overlying goaf is significantly improved.



（a）Downhole microseismic sensor only



(b) Joint microseismic network above and below the well

Figure 4: Statistics of epicenter depth of microseismic events

4. Conclusion

(1) Based on the principle of microseismic location, it is analyzed that the partial differential matrix of the source parameters of the near-horizontal coal seam is close to an irreversible singular matrix, which leads to errors in the solution of the source height.

(2) Based on the geological structure and mining conditions of the working face, the impact danger area of the working face was divided using the multi-factor coupling method, the layout of the microseismic network above and below the well was optimized, and the positioning accuracy of the microseismic monitoring network in the vertical direction was improved, which is particularly suitable for near-horizontal coal seam working faces.

(3) By analyzing the frequency, energy and depth of microseismic events of the combined above-and-below microseismic monitoring network at the near-horizontal coal seam working face of a mine in Inner Mongolia, it can be seen that the positioning accuracy of the combined above-and-below microseismic monitoring network is significantly improved compared with the traditional single underground microseismic system.

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