Study on attenuation coefficient characteristics of the in-seam seismic wave in fault and collapse column

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Abstract. Various types of geological structures exist in the working face of coal mine stope. Failure to identify the structural development in advance could defer the timely implementation of reasonable management measures, which may eventually affect production safety and connectivity. As a matter of fact, fine detection and interpretation problems of in-seam seismic wave caused by different types of geological anomalies such as faults and collapse columns can exist simultaneously in the working face of mining. In view of these problems, forward modeling research of three-dimensional seismic wave fields on geological models with fault and collapse column are carried out in this study. Meanwhile, in combination with the imaging results of in-seam seismic wave attenuation coefficient of the exposed fault and collapse column, the characteristics of in-seam seismic wave were analyzed. Following comparative analysis, we found the attenuation coefficient anomaly of the fault is generally banded and weakens at both ends of the fault. The attenuation coefficient of the collapse column presents as an irregular ellipse. The energy of the smaller collapse column has a relatively small attenuation, while the energy of the larger collapse column shows a significantly obvious attenuation.

1. Introduction

Recently, with the continuous improvement seen in mechanized coal mining technology, the scale of working face in well mining is getting larger and the super-long working face is gradually increasing. At the same time, different degrees of latent geological structure can be seen in the working face. Generally speaking, during the mining process, once the working face gets exposed and causes geological hazards, the results can range from affecting the normal coal mining of working face and reducing the efficiency of production to gas accumulation or penetration of the aquifer, causing safety accidents and eventually resulting in huge economic losses or even casualties. In addition, due to the complex geological conditions of some mines, latent faults, collapse columns, crushing zones, coal-rock variation zones and stress concentration zones existing in the working face have become important factors restricting the safe production of coal mines [1,2].

For interior geological structure of mine working face, the detection techniques mainly include the following: surface three-dimensional earthquake, underground radio wave perspective (pit penetration),
underground in-seam seismic wave earthquake and traditional drilling[3]. As for the surface 3D earthquake, subject to the influence of technical conditions, construction environment constraints and buried depth, its detection of the small structure inside the working face may lead to a large deviation and low accuracy of the inversion results. Radio wave perspective is relatively mature in China. However, its resolution is relatively low and obvious response cannot see to faults and fracture zones. As for traditional drilling methods, it is difficult to cover the entire working surface, which means the detection of local structures might be forgotten. In contrast, in-seam seismic wave earthquakes can be used to detect the working face at a closer range and in all directions, thus obtaining seismic signals with high signal-to-noise ratio and rich information. At present, in-seam seismic exploration is one of the most promising geophysical exploration methods for mine structure exploration[4].

In this study, a geological model with faults and collapse columns is established, and a three-dimensional seismic wave field is simulated. In addition, combined with a case exploring transmission channel wave and the validation of mine practical situation, a comparative study was conducted on seismic wave field with geologic abnormal areas, such as fault and collapse column, and an analysis was carried out on the changing characteristics of channel wave attenuation coefficient in the different types of geologic abnormal body, thus providing references for future channel wave seismic data processing and interpretation.

2. Characteristic Analysis of Fault Attenuation Coefficient

2.1 Forward Modeling of Fault Model and Characteristics Analysis of Wave Field

First, it is necessary to establish a fault model (Figure 1), which has a length of 600m, a width of 300m, and a depth of 100m, and a total of 5 rock formations are designed. Secondly, the thickness of coal is 5m, the velocity of longitudinal wave is 2000m/s, the velocity of shear wave is 1200m/s, and the density is 1300kg/m³. In addition, the roof and floor of the coal seam are both argillaceous sandstone, with the velocity of longitudinal wave being 3500m/s and the velocity of transverse wave being 2200m/s, and the density being 2300kg/m³. Finally, the designed fault is a dip type fault with an angle of 60° to the roadway and a fault with a distance of 2.5m.

Forward modeling method of wave equation is applied to simulate the numerical value and the single shot record is obtained through this process[5]. CT imaging of attenuation coefficient was performed by using SIRT algorithm (see Figure 2)[6,7]. Analysis shows that the overall morphology of the fault at an angle of 60° with the roadway is characterized by banded abnormal, which is consistent with the location of the designed fault. In fact, the center of the anomaly corresponds to the location of the designed fault, and the influence range of the anomaly on both sides of the fault is about 10-15m. In addition, the abnormal is strongest at the position of the fault, and gradually weakens on both sides, and slightly weakens near the roadway.
2.2 Analysis Characteristics of Fault Attenuation Coefficient Exposed on Site

Generally speaking, when faults exist in the working face, the signals of in-seam seismic waves can be blocked by faults, which results in energy attenuation. Different distances of fault show different degrees of attenuation. In case of a relatively small fault drop (generally less than 1/3 of the coal thickness), the in-seam seismic wave signal shows insignificant attenuation; In case when fault drop ranges between 30% and 70% of the coal thickness, some signals will be blocked and the transmitted in-seam seismic waves will be weaker. In the case of a large fault drop (generally over 2/3 of the coal thickness), the transmitted in-seam seismic wave signal will be significantly attenuated. In case the fault drop is greater than the thickness of the coal seam, the in-seam seismic wave signal will be completely blocked, and generally speaking, the transmitted in-seam seismic wave can’t be received.

Figure 3 is an example of detecting a working face. One fault is actually exposed in the mining. In the cloud map of attenuation coefficient, the fault often presents as a long and narrow abnormal (the red area in the figure refers the abnormal area). Gradual extinction occurs at both ends of the fault, and the attenuation of in-seam seismic wave signals is also gradually weakened. Therefore, anomalies tend to be gradually weakened at both ends of the fault.

In the case of a dip fault (with a large angle to the roadway), only the excitation and receiving points on both sides of the fault are blocked by in-seam rays. Rays on the same side of the fault receives no influence. Significant difference shows between the two sides of the fault, and the transverse resolution is relatively high in the inversion. Therefore, transmission in-seam waves can be used to detect dip faults.

3. Attenuation Coefficient Characteristics of Collapse Column

3.1 Forward Modeling of Collapse Column Model and Characteristic Analysis of Wave Field

First, a collapse column model (Figure 4) is established. The model has a length of 600m, a width of 300m and a depth of 100m. The thickness of the coal is 5m, the velocity of the longitudinal wave is
2000m/s, shear wave, 1200m/s, and the density is 1300kg/m³. The roof and floor of the coal seam are both argillaceous sandstone. The velocity of the longitudinal wave is 3500m/s, the velocity of the shear wave is 2200m/s, and the density is 2300kg/m³. The collapse column passes through the coal seam with a long axis of 40m.

The forward modeling method of wave equation is used to simulate the geological model of collapse column numerically and the single shot record is obtained through this process. Meanwhile, CT imaging of attenuation coefficient is performed by using SIRT algorithm (see Figure 5). Analysis shows the overall shape of the collapse column is elliptic anomaly, which is consistent with the position of the designed collapse column. In fact, the center of the anomaly corresponds to the center of the designed collapse column. The strongest anomaly exists at the center of the collapse column, while anomaly at the surrounding area gradually weakens.

3.2 Characteristic Analysis of Attenuation Coefficient of Collapse Column Exposed on Site

In the working face with a collapse column, and after the in-seam seismic wave signals are transmitted to the edge of the collapse column, they no longer constrained by the roof and floor of the coal seam and form a total reflection. Seismic signals are gradually diffused outward, obviously attenuating the energy. In the case of a small-sized collapse column (with general diameter less than 30 m), some in-same seismic wave signals can be transmitted and diffracted to the opposite roadway. At this time, relatively small energy attenuation will occur. In the case of a large-sized collapse column (generally larger than 50 m in diameter), the energy attenuation is significantly obvious, so generally speaking, no effective in-seam seismic wave signals can be received.

Figure 6 shows an example of detecting collapse column in the working face. In the figure, the influence range of the exposed collapse column is basically consistent with the CT imaging results of attenuation coefficient. Meanwhile, the collapse column shows relatively obvious elliptic anomaly on
the cloud map of attenuation coefficient (red area refers to the abnormal region). In addition, due to the influence of collapse column, the surrounding coal and rock mass sometimes develops along with the fracture zone, leading to a slightly enlarged range of anomalies.

Figure 6. Feature of Attenuation Coefficient of the Actual Exposed Collapse Column.

4. Conclusions
Through forward modeling and case analysis, it can be concluded that the in-seam seismic wave anomalies of faults and collapses column are relatively obvious. Meanwhile, the tomographic imaging method of in-seam seismic wave attenuation coefficient can effectively detect different types of geological anomalies.

(1) For dip faults, the detection of the attenuation coefficient of the transmitted in-seam seismic wave delivers good results. Most of them show long and narrow anomalies, which generally weaken gradually at both ends of the fault.

(2) Elliptic anomalies can be seen in most of collapse columns. Small collapse columns show small energy attenuation, while larger collapse columns show significant energy attenuation. Generally speaking, the abnormal range of collapse column’s impact on the surrounding coal and rock mass is slightly larger.

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