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Technical Note

The relationship between vertical stress gradient, seismic, and electromagnetic emission signals at Sanhejian coal mine, China

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1. Introduction

In recent years, along with the innovation of coal mining process and equipment in China, such as the advanced combined support system composed of pre-tensioned bolting and bracing, wire mesh and cable anchor, no coal pillar mining technology with reused roadway, as well as the high-strength and high-resistance hydraulic support equipment application, etc, the large-scale and strong-mining working face has been possible. However, the ability of the mine disaster prevention and mitigation to adequately characterize the geotechnical environment and keep up with changing geologic conditions severely lags the advance rate of mining equipment and process.

The rapid advance rates of today's highly productive mechanized methods, particularly longwall mining, can cause rapid stress buildup near the face area and shorten the time available for mine management to address changing geologic conditions and associated abnormal stress concentration field problems. The higher and static stress concentration accompanied with the dynamic stress wave caused by key strata strenuous movement and fracture in coal pillar area can easily trigger the strong mining tremor (even rockburst disaster).

Geophysical techniques such as seismic, electromagnetic emission (EME) and ground penetrating radar have obtained some success in expanding the knowledge of coal and rock dynamic hazards before and after excavation. Especially, seismic methods are widely applied to monitor and warn coal and rock dynamic hazards in coal mines due to its abundant spectrum and broadband character, which can monitor the fracturing form of surrounding coal and rock, roof falls and the high-stress concentration distribution. Seismic important parameters such as the initial arriving time, amplitude, duration, and spectrum can be applied to analyze the nature and location of source.

In the past, most mining-related seismic researches always focused on the location and mechanism of source, the statistical rules of energy and event count, as well as the indexes for evaluating rockburst danger according to the events such as production blasts from quarries, roof falls, and rock fractures. For example, Durrheim et al. [1] discovered the seismic event resulted from failure of the remnant with attendant movement into the workings. Poplawski [2] gave a new method, “departure indexing” of seismic signal, was being developed to provide a robust tool for rockburst hazard evaluation in the longer term. Eneva et al. [3] revealed the seismic response of rock mass to blasting and its relevance to the evaluation of rockburst potential using ISS seismic data. Hanson et al. [4] gave an overview of the theories and processes involved in seismic tomography applicable to coal mine. Abdul-Wahed et al. [5] established a close correlation between the location of seismic activity and induced stresses in the ground surface of the working areas. Ge et al. [6] developed an in-seam seismic (ISS)-based void detection and stress distribution identification technique at Penn State University. Murphy et al. [7] found a relation to correlate the relative radiated seismic energy to the size of the explosion from underground explosions. Chen et al. [8]

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found that seismic energy and event count steadily increased accompanied with stress increased. Guy et al. [9] found that SH-wave seismic reflection surveys can be applied to diagnose mine-induced subsidence potential. Friedel et al. [10] found that high-velocity regions were indicative of elevated levels of compressional stress by an active 3-D seismic tomographic investigation. Lesniak and Isakow [11] demonstrated the potential of the clustering technique in evaluation of the increment of the seismic hazard over a limited area. Holub et al. [12] revealed the decrease of seismic wave amplitudes with distance from rockburst foci. Murphy et al. [13] determined that the attenuation and duration measurements could give insight into future seismic signatures. Srinivasan et al. [14] established linear empirical relations between the seismic energy released due to a rockburst, total tonnage of ore mined out and total number of rockbursts, as well as seismic events. Boler et al. [15] determined source parameter and seismic energy using four of the University of Utah three-component stations. Fujii et al. [16] established a method to predict failure in coal and rock mass by using numerical stress analyses, and found the positive relationship between the stress concentration level and rockburst danger. Nalbant et al. [17] found locations of large earthquakes were consistent with the stress interactions by advance-to-failure. Friedel et al. [18] established the relationships between P-wave velocity, stress, and in attempts to evaluate ground stability hazards. Shen et al. [19] found that seismic and roof stress signals appeared to provide warnings for the imminent roof falls earlier than the roof displacement signals.

As a consequence of the above, in addition to the conducted researches on the seismic wave velocity in terms of stress state, and the statistical relations between seismic activity and total tonnage of ore mined out, as well as rockburst danger evaluation, little or no effort has been focused on revealing the quantitative relationship between seismic, EME signals and the abnormal vertical stress gradient value in a strong rockburst coal mine. An aim of our study is to discover this relationship.

This paper described progress in the consistent relationship between vertical stress gradient, seismic and EME signals, as well as drilling bits volume by on-site observation data. An attempt has been also made towards the early warning of rockburst danger using seismic and EME monitoring. Based on numerical simulation analysis, by identifying the locations of the abnormal vertical stress concentration and gradient values before excavation, steps can be taken appropriately to mitigate rockbursts danger in time.

2. Geological conditions and seismic system

2.1. Geological and mining conditions of 9202 working face

Sanhejian coal mine (SCM) of Xuzhou coal mining group (XCMG) is one of the most serious rockburst coal mines in China, and the destructive rockburst has occurred more than twenty-five times until now. Especially, a rockburst hazard happened in 7204-3 working face on Dec 6, 1998, which destroyed 500 m long roadway, resulted in closing the working face and 4 fatalities. Therefore, rockburst has been one of the major coal and rock dynamic disasters in SCM.

The mining main seams of SCM are 7# and 9# coal, respectively, and the vertical interval between two seams is about 25–30 m. The average depth of 9202 working face in 9# seam is 840 m, and the original in situ vertical stress is 21 MPa. 9202 working face locates in the west wing of SCM field, neighbored by abandoned 9112 working face, and the gob of 7# seam including the residual coal pillars of 7202 working face is vertically above 9202 working face. When 9202 working face mined below the residual coal pillars, vertical stress concentration was very intensive. 9202 working face, therefore, belongs to the deep and high stress area, and 9# seam belongs to strong rockburst tendency by experimental identification. The residual coal pillar district of 7202 working face can be approximately divided into 1# coal pillar (100 m $\times$ 70 m) and 2# coal pillar (72 m $\times$ 35 m), which locate above 9202 working face headentry. Fig. 1 shows the plane diagram of 9202 working face and the residual coal pillar district. Fig. 2 shows the simplified schematic diagram and its corresponding size parameters of the residual coal pillar district.

The thickness of 9# seam in 9202 working face is 1.4–3.66 m with average thickness of 2.2 m, and the dip angle is 11–28°with an average of 22°. The uniaxial compressive strength of 9# seam is 37.7 MPa by experimental tests [20]. The immediate roof is 1.2 m thick siltstone, the main roof is 9.3 m thick medium sandstone, and the main floor is 8.9 m thick silt sandstone. The strike longwall retreating advancing, as well as the conventionally-mechanized mining process was used. The complete caving method for roof control was adopted. The whole mining period of 9202 working face was from May 9, 2003 to Apr 25, 2004, in which advancing at the edge of 1# coal pillar, junction and the edge of 2# coal pillar was on Nov 26, 2003, Feb 20, 2004 and Apr 16, 2004, respectively. Fig. 3 shows the composite columnar section of 9202 working face.

Rockburst mainly appeared floor shock and sudden heave during the period of 9202 working face roadway driving, which

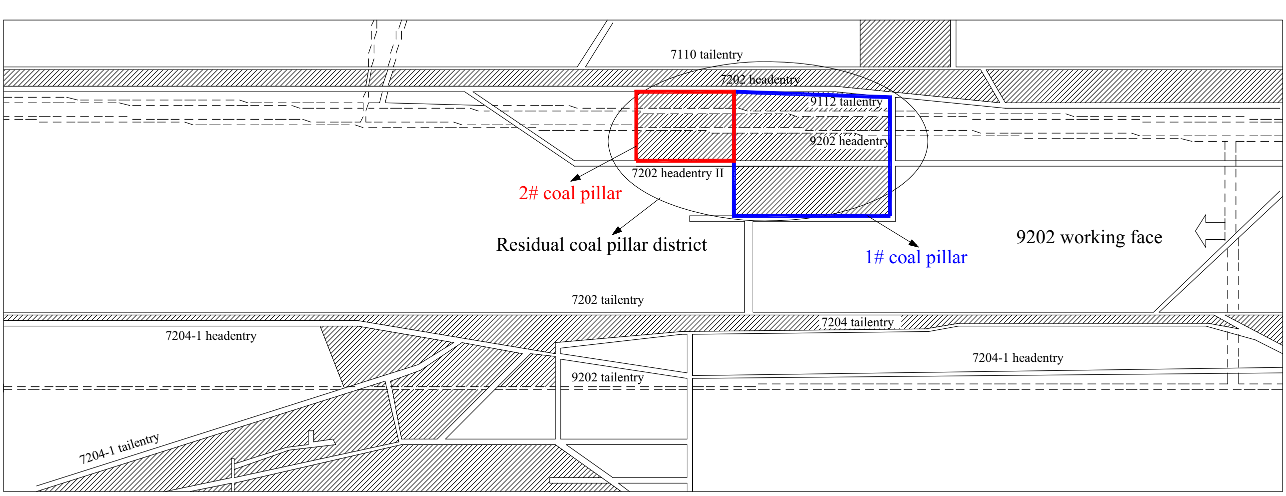

Fig. 1. Schematic plane diagram of 9202 working face and the residual coal pillar district. *Note*: the shaded area is the residual coal pillars of 7# coal seam.