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Structure and deformation measurements of shallow overburden during top coal caving longwall mining

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ABSTRACT

Mining induced pressures are strong and overburden failure areas are large in top coal caving longwall mining, which constrains high production and safety mining. By employing the combination of the full view borehole photography technique and the seismic CT scanner technique, the deformation and failure of overlying strata of fully mechanized caving face in shallow coal seam were studied and the failure development of overburden was determined. Results show that the full view borehole photography can reveal the characteristics of strata, and the seismic CT scanner can reflect the characteristics of strata between the boreholes. The combined measurement technique can effectively determine the height of fractured and caved zones. The top end of the caved zone in Yangwangou coal mine employing the top coal caving longwall mining was at the depth of 171 m and fractured zone was at the depth of 106–110 m. The results provide a theoretic foundation for controlling the overburden strata in the shallow buried top coal caving panel.

1. Introduction

When the fully-mechanized top coal caving longwall mining method is applied to shallow buried coal seam, the mining induced pressures are strong and the failure and deformation areas in the overburden are large. These may damage the aquifers in the overburden, cause surface subsidence and destroy surface structures as well as environments. Therefore, it is important to detect the overburden failure and deformation [1–3].

Yin and Chang investigated the mining induced pressure in the panel of top coal caving longwall mining and obtained the interval of periodic weighting and caving height [4]. Liu analyzed the effect of mining depth on the strata behaviors in top coal caving longwall mining face [5]. Huang established a structure model of overburden movement in shallow buried coal seam with loose layers and analyzed the interaction between shields and surrounding rocks [6]. Lu et al. measured the maximum failure height and obtained the relationship between rock blocks and rock mass using back calculation method [7]. Mills et al. described the installation of the inclinometer between two survey stations, and considered that the detected results can provide a scientific basis for studying the overburden movement in longwall panels [8]. Cao et al. utilized the microseismic technique to study the characteristics of fracture development during mining [9,10]. Zhang et al. studied the fracture height of extra-thick coal seams in top coal caving longwall mining and used the VLF radar technique to study the overburden structures before and after mining, and validated it by the microseismic technique [11,12]. Wu et al. analyzed the dynamic change of caving zone based on the relation in electric parameters of the panel [13]. In this paper, the deformation and failure of overlying strata in the fully mechanized caving face in Yangwangou Coal Mine was detected using full view borehole photography technique and seismic CT technique.

2. Basic principle of the combined measurement technique

2.1. Full view borehole photography

In the full view borehole photography system, the probe with self-supply power source is used to observe, monitor and record the characteristics of rock strata. The information obtained from the borehole is processed either manually or via computer to quantitatively analyze the fracture width in the borehole. This system

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can be used to measure the integrity and intrinsic fractures of the overburden, and the fractured width, connectivity and failure condition of the fractured zone.

As shown in Fig. 1, the full view borehole photography system is made of probe, controller, hoisting support, cable and computer, which is capable of observing the 360 deg view of a borehole [14]. There is a camera at the center of the probe. As shown in Fig. 2, the camera photographs the borehole wall via the light reflecting cone lens, and then the collected data was processed, including conversion, interception and piece together in real time, to form a full borehole wall photo. The wall photo is pieced together based on buried depth in the vertical direction and spread in the N → E → S → W → N sequence in the horizontal direction. Every photo starts from the north in order to ensure correct piercing together. When the spread out photo is wrapped up and viewed in rotation, it becomes a virtual rock core [15].

2.2. Seismic CT measurement between boreholes

In the seismic CT measurement between boreholes, several signal emission points are set up at the left side and several signal receivers are installed in the borehole at the right side. The signal sources can be explosive, electric arc or hammering. The seismic CT system is used to generate a dense network of emission-receiving rays in the overburden strata, as shown in Fig. 3. Based on the density and resolution, the network is divided into cells and the linear simultaneous equations of the measured parameters are established. Proper ray tracking and inversion methods are selected to process these equations. And then, the distribution of seismic velocity in the measured areas will be created, which can be used to interpret the abnormal regions in the distribution of geological structures as well as fracture development [16]. The seismic velocity of the measured rock mass is relatively uniform in normal area, while the velocity is high in complete dense rock area, and is low in the loose and broken areas as well as in areas where the fractures is well-developed.

When the seismic waves are traveling in the strata, the travel time is a function of wave velocity $V(x, y)$ and traveling roadway. For the ith ray, if the travel time is t_i, then the following integral exists [18]:

$$t_i = \int_{R_i} \frac{1}{V(x,y)} ds = \int_{R_i} A(x,y) ds \tag{1}$$

where $V(x,y)$ is velocity distribution function, m/s; R_i the travel roadway for the ith ray, m; and $A(x,y)$ the slowness distribution function, s/m.

After dividing the photo into several regular cells, the Eq. (1) can be transformed into the following discrete linear simultaneous equations:

$$t_i = \sum_{j=1}^{N} d_{ij} \cdot x_j \quad i = 1, 2, \ldots, N \tag{2}$$

where t_i is the travel time for the ith ray, s; d_{ij} the length for the ith ray to travel through the jth cell, m; x_j the slowness for the jth cell, s/m; M the number of rays; and N the number of cells.

The Eq. (2) can be written as matrix form:

$$[T] = [D][X] \tag{3}$$

where $[T]$ is a vector of M dimension; $[X]$ is an unknown vector of N dimension; and $[D]$ is the $M \times N$ matrix.

Eq. (3) is the inversion equation for constructing the layer-by-layer linear structure model. Fig. 4 shows the flow sheet for seismic layer-by-layer photo inversion. In the photo forming process, it must emphasize several constraints conditions during inversion, including digital spacing, boundary conditions, number of iterations, cell discretizing and the initiation model.

3. Measurement of overburden failure and deformation

3.1. Mine site description

Yangwangou coal mine is located in Jungar mine area of Inner Mongolia, China. The major mining coal seam is the 6# seam and its thickness is 9–11 m with an average thickness of 10 m. The geology is uniform with the whole structure in syncline structure. The coal seam is buried at 170–200 m and with thin bedrock. The immediate roof is mainly sandstone and claystone, while the floor is mainly sandy claystone and fine-rained sandstone with local coarse-grained sandstone.

The fully mechanized caving panel 6204 is located in the south of mine field. There is no railroad, bridges and rivers over this panel. While, there are a water storage pond and two highways leading to the mine. Due to the influence of adjacent panel, panel 6204 was divided into two sections. As shown in Fig. 5, the A section was 86.4 m in width by 222 m in length, while the B section was 126.5 m in width by 371 m in length. The mining height is 3 m with top coal caving 7.0 m. So, the mining-to-caving ratio was 1:2.3. Large mining height creates large failure area in the overburden and increases the mining induced pressure. Therefore, the full view borehole photography and seismic CT scanner were used to monitor the failure and deformation in the overburden.

3.2. Borehole layout and monitoring operation

Considering the requirements for operating the full view borehole photography and seismic CT techniques, the boreholes was drilled at the center of panel 6204, about 150 m from the open-off cut along the advancing direction. The first borehole ZK01

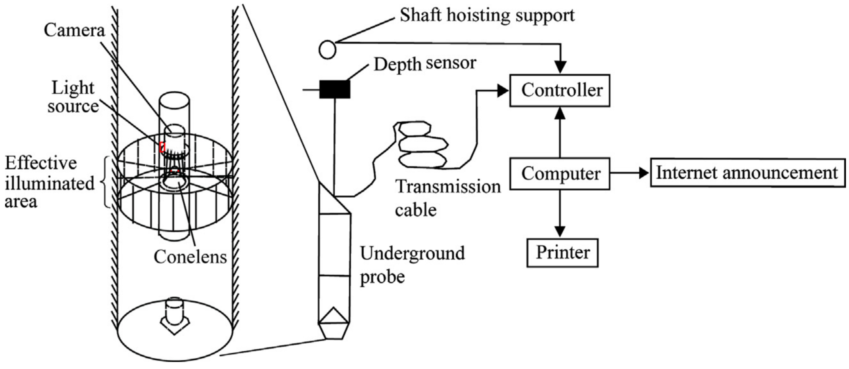

Fig. 1. Components of the full view borehole photography.

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