STUDY ON EVOLUTION CHARACTERISTICS OF OVERBURDEN CAVING AND VOID DURING MULTI-HORIZONTAL SECTIONAL MINING IN STEEPLY INCLINED COAL SEAMS

by

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In this paper, the evolution characteristics of overburden caving and void during multi-horizontal sectional mining in steeply inclined coal seams are studied. Based on the typical engineering background of steeply inclined coal seams mining in Wudong Coal Mine, the physical simulation model is build. The evolution characteristics of overburden caving and void during multi-horizontal sectional mining is systematically studied, combined with the monitoring data of overburden infrared thermal image, void ratio, void network fractal dimension, and peak mine pressure. It is showed that, during multi-horizontal sectional mining in steeply inclined coal seams, the movement rule of overburden is extremely complicated, and the temperature changes in infrared thermal image were significant.

Key words: *steeply inclined coal seams, multi-horizontal sectional mining, infrared image, void, binary image*

Introduction

Xinjiang is the 14th large-scale coal base, approved and build by China, with a capacity of 100 million tons. In the base, the resources of steeply inclined coal seams are abundant, and the mining technical conditions are complex [1-3]. Under the condition of multi-horizontal sectional (12.0-27.0 m) mining, large-scale production mines with an annual output of 10 million tons represented by Wudong Mine has been build. However, with the large-scale mining of coal resources and the continuous improvement of mining level, overburden disasters, floods, fires, and serious damage occurred frequently, which have severely affected the production security [4-7].

The coal mining inevitably causes redistribution of internal stresses in the overburden, deformation and destruction of different properties in different layers. Xie *et al.* [8], Li *et al.* [9], and Xue *et al.* [10] used fractal dimension to describe the disordered phenomena and behaviors in nature. The research showed that the fracture distribution of mined rock masses has fractal characteristics. Based on a large number of simulation studies and field tests, the *three zones* height of the shallow buried coal seam in Yushenfu was obtained in [11]. Zhang *et al.* [12] sys-

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tematically studied the movement and fracture development rules of mining overburden with different occurrence structure types in typical mining areas in northwestern China, and constructed a cooperative change model of upper water barrier-median barrier layer-lower basic roof structure. A method for predicting the height of the water conduction fracture zone based on the position of the key layer was proposed in [13]. The model of dumping mechanics of roof broken for steeply inclined coal seam horizontal section fully mechanized caving roof was established in [14]. It revealed two failure modes of the dumping type of the upper section and the slipping type of the lower section. The rock burst control technology of large dip angle multi-layer thick coal seam with the core of cross peak pressure regulation, blasting roof cutting and strong support, was put forward in [15]. This effectively prevents the occurrence of rock burst during the mining process of the fully mechanized caving face. However, there are few studies on the evaluation of overburden caving characteristics, fracture development degree, connectivity and water permeability under the disturbance of multi-horizontal sectional mining in steep coal seams. According to the actual geological conditions and mining methods, the main target of the paper is to show that the evolution characteristics of overburden caving and voids in multi-horizontal sectional mining of steeply inclined coal seams are systematically studied by establishing physical simulation model.

Model construction of physical simulation experiment

The evolution characteristics of overburden caving and void during multi-horizontal sectional mining in steeply inclined coal seams were extremely complicated. It was difficult to conduct field exploration and depiction. Based on the simulation theory, the similar characteristics were used to study the development characteristics of overburden breaking in this physical simulation experiment. Thus, the forming and mechanism of overburden caving and void in multi-horizontal sectional mining in steeply inclined coal seams can be measured and described intuitively and reliably [16-18]. Wudong Coal Mine was a typical mining with steeply inclined coal seams. The 43# coal seam is one of the main mining coal seams. Its coal bearing stratum belongs to the Xishanyao Formation of the Middle Jurassic, and the strata are distributed from northeast to southwest. The dip angle of 43# coal seam is 45°, and the thickness of coal seam is 40 m.

Model design

Taking the actual geological conditions and mining methods of Wudong mine as the engineering background, the physical simulation experiment was constructed using the 2-D experiment platform of Xi'an University of Science and Technology. According to the theory of simulation, the geometric simulation ratio (model: experiment) was 1: 200, and the pavement size of the similar simulation experiment model was 2.0 × 0.3 × 1.75 m. Based on the lithology of the overburden 43 # coal seam in Wudong Coal Mine Geological Exploration ZK007 drilling histogram, the experimental system design and the original stratum were simplified to the stratum profiles, shown in fig. 1. Based on similar principles, river sand, white powder, plaster of gypsum, water, and fly ash were used for pavement according to a certain ratio.

Model excavation and monitoring

The multi-horizontal sectional mining was adopted based on the actual mining situation of the 43 # coal seam over the years. From the +742 level to the current mining level of +575, and downward to the +550 and +525 levels, a total of 11 levels have been mined. During the experiment, Fluke Ti300 thermal imaging camera was used to monitor infrared thermal radiation characteristics in real time during the process of overburden breakage and caving.

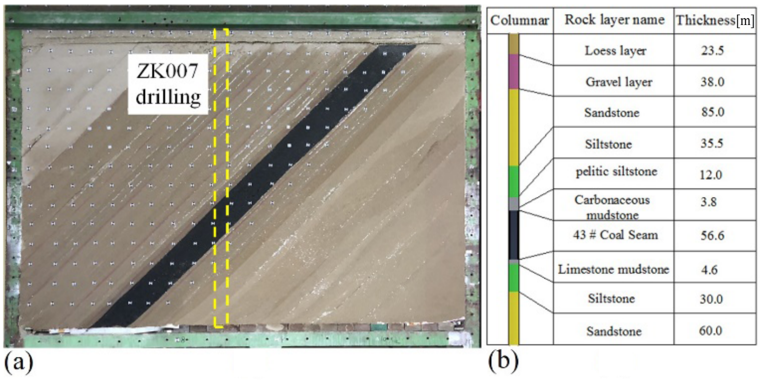

Figure 1. Physical simulation model (a) test model and (b) rock layer histogram

The SD500 digital camera was fixed 2 m in front of the model. After the mining of each layer is finished and the overburden caving is stable, the whole physical simulation model is photographed. At the same time, 59 pressure sensors were laid along the inclined floor of the coal seam to monitor the characteristics of floor stress changes in real time during mining.

Movement and failure characteristics of overburden rock

Movement characteristics of overburden rock

Being different from the horizontal coal seams mining, the overburden rock was mainly moved along the vertical direction. The overburden rock during multi-horizontal sectional mining in steeply inclined coal seams had many forms, such as gravity subsidence, moving close to normal floor, sliding along the floor and so on. After mining in each section, the collapsed coal and rock mass which has been mined will slide downward. As the mining level extends to the lower part, a larger range of rock was collapsed. The damage range of the rock layer further expands upward along the roof direction, and finally reaches the surface. During the experiment, it was found that under the natural collapse state, mining generally takes 2-3 levels, and a large rock movement occurs. After each big move, there was a relatively stable period. The goaf of each section and the original goaf form a total goaf, with large range of strata movement, strong dynamic. It easily leads to form the impact load. The goaf formed by the mining of steeply inclined coal seams was a continuously expanding and moving V-shaped goaf. Typical collapse characteristics of overburden at different mining levels were shown in fig. 2.

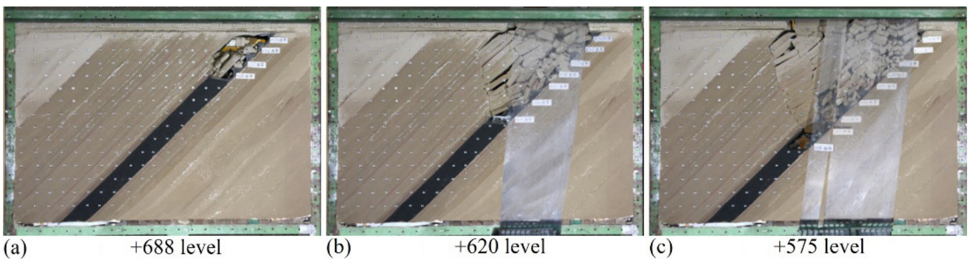

Figure 2. Typical overburden caving characteristics at different mining levels

Infrared thermal imaging characteristics of overburden rock

Thermal infrared imagers have been applied to analyze the thermal imaging characteristics of overburden activities under different mining levels. Typical infrared thermal image characteristics of different mining levels were shown in fig. 3. The results showed that the breaking of the overburden was accompanied by energy concentration and release. The chromatic aberration of infrared thermal image temperature was obvious. When the rock layer was disturbed by excavation, high temperature areas appear. The coal mass produces stress relief after mining disturbance. The more complete the energy release, the lower the corresponding temperature. With the extension of the mining level, the relatively high temperature range of the disturbance-affected area continues to expand. The overburden caving structure was transformed from a shallow *inclined arch* structure to a *cantilever beam and articulated beam* structure. Due to the collapse structure, stress concentration was generated. The infrared thermal image showed abnormal temperature, which was in phase with the high temperature area.

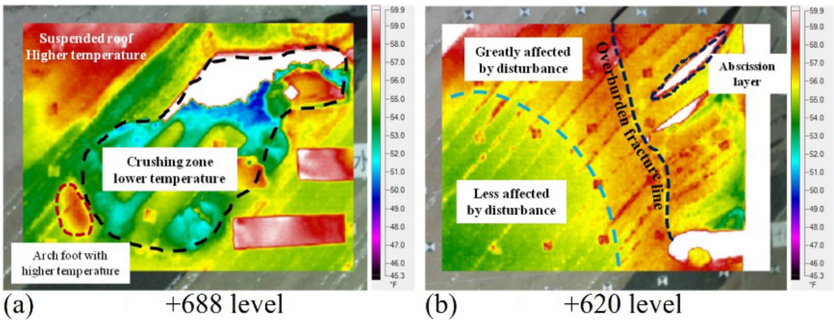

Figure 3. Typical infrared thermal image characteristics of overburden at different mining levels

Overburden void distribution and evolution characteristics

The image was an important information carrier and can be widely used in remote sensing, medicine, artificial intelligence and other fields [19, 20]. According to the images of overburden voids obtained from physical simulation experiment, the evolution characteristics of overburden voids in multi-horizontal sectional mining was systematically studied, combined with different mining levels, fractal geometry theory, floor pressure, and other monitoring data.

Relationship between overburden void and mining level

The development degree of overburden voids after multi-horizontal sectional mining in steeply inclined coal seams was an important indicator of the structural stability of overburden, which has a very important influence on the overall stability of rock masses [21, 22]. The MATLAB software was used to binarize the overburden graphics of each mining level. The binary image of the distribution of overburden voids in typical different mining levels was shown in fig. 4. The black area in the figure was the distribution of overlying voids.

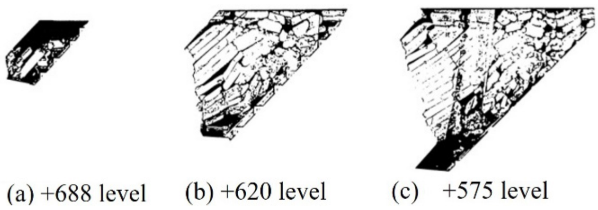

Figure 4. Typical binary distribution image of overburden voids at different mining levels

From the binary image analysis of overlying voids, it can be seen that the distribution of voids changes dynamically as the mining level extends downward. The overburden voids distribution status of the previous mining level was superimposed on the overburden voids of the next mining level. The void distribution of the overburden layer was more complicated. Not only were new voids created one after another, but the original voids have undergone a series of expansions, closures, and openings. In addition, the distribution area of voids gradually expands to the upper rock strata, thus continuously generating new rock mass structures. The binary image of the distribution of overburden voids in typical different mining levels was shown in fig. 4.

The apparent void ratio index is introduced to the degree of void development, that is, the percentage of void area divided by the area of the whole analysis area. It can be expressed:

$$\eta = \frac{G_W}{G_T} \tag{1}$$

where η was the apparent surface void ratio, G_W – the area of all voids in the image, and G_T – the area of the overall analysis area of the image.

The black area in the area and the percentage of the entire model area were analyzed, and the corresponding program was compiled using MATLAB software. The calculation results of the apparent void ratio of each level of overburden in the physical similar simulation experiment were shown in fig. 5.

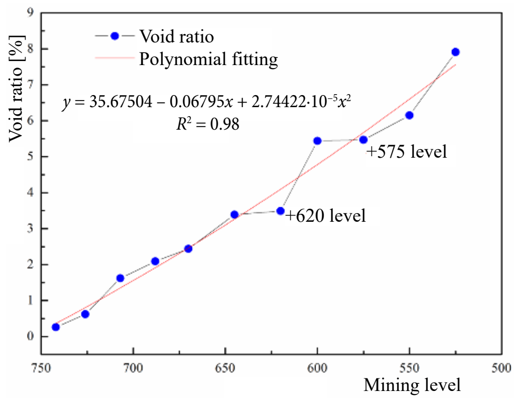

Figure 5. Apparent surface void ratio of overburden rock at different mining levels

Figure 5 shows that the apparent void ratio of overlying strata in multi-horizontal sectional mining in steeply inclined coal seams extends with the mining level. The variation range of apparent void ratio of overburden at different mining levels was different. The voids development degree showed an overall upward trend. The apparent void ratio increased from 0.26% to 7.91%. Combined with the physical similar simulation experiment process, it can be seen that when the slope of the curve was large, the overburden has hanging roof phenomenon and the goaf has large hanging roof space. When the slopes of the void ratio curves of the +620 and +575 levels overburden rock were gentle, the overlying rock will collapse as a whole. A series of new expansion, closure, and opening changes will occur on the basis of the original void, resulting in a reduction in the overall void ratio change.

Relationship between overburden void and fractal dimension

Geometric fractal can be used to describe the irregular and disordered phenomena and behaviors in nature. Therefore, combined with the geometric fractal theory, the box dimension calculation method was used to calculate the fractal dimension of the overburden void network for the binary image of the overburden at each mining level. The calculation result was shown in fig. 6. As the mining level extends to the lower part, the development degree of the voids in the overburden was consistent with the overall trend of the change of the fractal dimension of the void network, both of which show an upward trend. Due to the collapse of the overburden as a whole, a series of expansions, openings and closures occurred on the basis of the original voids. But the change of the overall void ratio decreased and the fractal dimension reduction phenomenon appeared.

Relationship between overburden voids and peak mine pressure

The coal seam mining causes the movement, destruction and collapse of overburden layers. During this process, the stress in the rock mass was continuously redistributed. There must be a certain relationship between the degree of void development in the overburden and the mine pressure. With the excavation of the coal seam, the stress in the floor of the mined-out area reduced, and the peak stress appears in the lower coal body. Figure 7 shows the relationship between the void ratio and the peak stress corresponding to different mining levels. It can be seen from the figure that with the increase of the void ratio of the overburden, the peak stress generally shows an upward trend. But under local conditions, the peak stress decreases. When the void ratios were 2.44% and 5.44%, the peak values of the stress corresponding to the mining levels of +670 and +620, respectively, appear to decrease. It can be seen from the experiment that after the corresponding mining level overburden suspended roof structure was unstable, the overall collapse occurs. The stress concentration was released, and the rock mass was redistributed, causing the peak stress dropping down. Therefore, there was a non-linear relationship between the void ratio and the peak pressure of the mine.

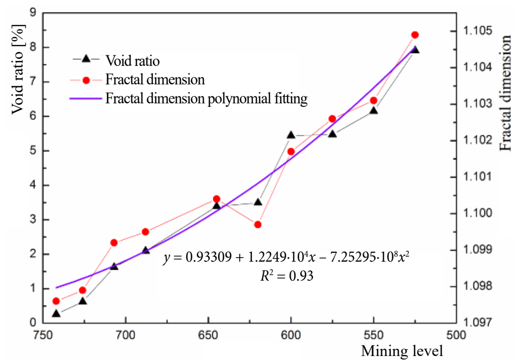

Figure 6. Relationship between mining level, void ratio and fractal dimension

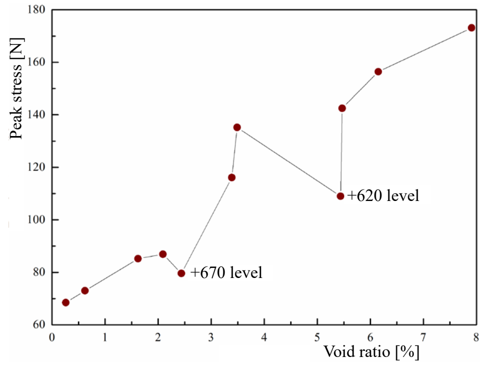

Figure 7. Relationship between void ratio and peak stress

Conclusion

In the present work, the temperature field of the disturbed overlying strata changes significantly in the multi-horizontal sectional mining of steeply inclined coal seams, when the overburden caving structure was formed, the temperature was abnormal, and the relatively high temperature area appeared. After the stress of the rock mass in the fall zone was released, the local area was subject to high temperature due to friction and compression. Due to collapse of the rock mass, the overall temperature was relatively low. With the extension of the mining level, the formation, expansion, and distribution of overburden voids become more complicated. The damage scope, damage degree and irregularity increase significantly.

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