International Journal of Rock Mechanics & Mining Sciences 94 (2017) 123–138

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

A zoning model for coal mining - induced strata movement based on microseismic monitoring

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ARTICLE INFO

Keywords:
Microseismic monitoring
Strata movement
Vertically zoning method
Horizontally zoning method
Displacement angle

ABSTRACT

A microseismic monitoring technique is adopted to investigate the distribution regularity of microseismic events released by the coal mining - induced roof rock mass along the vertical and horizontal directions in combination with mine geological data. On the basis of the quantity and energy distributions of the microseismic events recorded using the microseismic monitoring technique, a zoning method is first established for the roof strata movement in the vertical and horizontal directions. The vertically zoning method is then applied to analyze the microseismic monitoring results obtained in the Dongjiahe Coal Mine, which divides rock mass into six zones along the vertical direction, i.e. the caved zone, the block zone, the vertical fracture through-going zone, the vertical fracture zone, the separation zone and the continuous zone. The horizontally zoning model divides the roof strata movement into three zones, i.e. the calm zone, the generation zone impacted by working face and the historical generation zone. After that, based on the horizontally zoning model, a method is developed to determine the displacement angle using the microseismic monitoring data, which has been verified in the Dongjiahe Coal Mine.

1. Introduction

In recent years, as a three-dimensional space monitoring technology for monitoring rock mass micro-fracturing, microseismic monitoring technology has achieved rapid development. The microseismic monitoring technology mainly monitors time, space and intensity as well as related microseismic source parameters of micro-fracturing ocurred in brittle rock mass under external force. With constant development and improvement of monitoring hardware and software, the microseismic monitoring technology has now been widely used in mines subjected to high ground stress both nationally and internationally, and has become an important means for ground pressure research and management in deep mines [1]. Li et al.[2] established a microseismic monitoring system for studying impact ground pressure in Fankou Lead-zinc Mine using Canadian equipment. Based on the microseismic monitoring system produced by Commonwealth Scientific and Industrial Research Organization, Jiang et al.[3] developed a microseismic monitoring system for early warning mine disasters in coal mines. Lu et al.[4] introduced a microseismic monitoring system developed at Poland Mining Research Institute, and installed it in dozens of mines with impact ground pressure. Tang et al.[5] installed a microseismic monitoring systemt from South Africa to monitor rock burst disasters in Dongguashan Copper Mine. Since 2004, Liu et al.[6] adopted Canadian microseismic monitoring equipment to carry out research on dynamic disasters such as water inrush, impact ground pressure and gas outburst in Hongtoushan Copper Mine, Zhangmatun Iron Mine, Shirengou Iron Mine, Yuejin and Qianqiu Coal Mines as well as Xinzhuangzhi Coal Mine. Besides, Mendecki [7], Tang [8] and Liu et al.[9] carried out research on common statistical parameters of the microseismicities monitored in coal mines. As can be seen from the review above, although the microseismic monitoring technology has been implemented in various applications in coal mines, systematic research has not been conducted to study the distribution regularity of microseismic events in rock mass.

Many researchers [10–11] carried out research on the correlation between the stress-strain curves of rock mass and acoustic emission events, and deemed that acoustic emissions we closely related to stress and deformation of rock mass, which, correspondingly, indicates there is a correlation between the distribution regularity of microseismic events in the roof and the stress and deformation state of rock mass in roof. On the other hand, the strata movement theory is often based on the distribution of stress and deformation in the roof. Thus, there exists a certain relationship between the strata movement and the distribution regularity of microseismic events.

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http://dx.doi.org/10.1016/j.ijrmms.2017.03.001
Received 22 June 2016; Received in revised form 19 February 2017; Accepted 6 March 2017

The strata movement refers to the phenomena and processes of the movement, deformation and fracture of overlying strata caused by coal mining. As one of several basic problems in coal mines, the strata movement has a relatively greater impact on important issues such as surface deformation, underground support, gas drainage and water inrush disaster. Thus, it is necessary to study the strata movement caused by coal mining. However, present research on the strata movement mainly focuses on that in the vertical and horizontal directions and, correspondingly, the so-called vertical zoning model [12–14] and horizontal zoning model [15–17] are proposed for roof strata movement by various researchers. However, few scholars carry out research on the relationship between the strata movement and the distribution regularity of microseismic events.

This paper takes the No. 22517 working face in the Dongjiahe Coal Mine as an example to investigate the distribution regularity of microseismic events caused by roof strata movement in both vertical and horizontal directions using the microseismic monitoring technology in combination with mine geological data. On the basis of the obtained results, the correlation between the distribution regularity of the microseismic events and the vertical zoning model of roof strata movement is then discussed. After that, the distribution characteristics of the microseismic events in the horizontal direction are discussed in terms of their application in controlling rock mass. Finally a method is developed to establish a zoning model for rock mass along the vertical direction and determine the strata displacement angles based on the microseismic monitoring technology.

2. Vertically zoning model for roof strata movement

2.1. Introduction to vertically zoning model

Nowadays, most researchers agree the three-zone theory of overburden strata movement which means the overlying strata movement caused by the longwall mining can be divided into three zones [13], i.e., the caved zone, the fractured zone and the continuous zone, as shown in Fig. 1a. Moreover, some scholars [14] further divided the overlying strata movement into four zones, namely, the caving zone, the fractured zone, the dilated zone and the confined zone, as shown in Fig. 1b. According to the three-zone theory, the fractured zone above the caved zone can be further divided into three zones such as the fragmented rock blocks zone, the vertical fracture propagating-through zone and the horizontally separated zone [13].

It is essential to determine the height of each zone (especially the height of the fractured zone) in the strata movement zoning theory since the height of the strata movement zone dominates the layout of gas drainage hole and the height of water conducted zone [18]. Till now, the methods of determining the height of the strata movement zones include empirical methods [12,19–21], geophysics methods [22], vertical borehole observation methods [23–25], numerical simulations [26] and similar material simulation experiments [27–28]. Table 1[19] lists the empirical formula widely used to determine the height of the fractured zone, especially in China, which indicates the height of the fractured zone depends on the strength of the overlaying strata. However, most researchers [12,21] agreed that the height of the caved zone could reach 3–12 times of the mined coal seam thickness. Nevertheless, the height of the fractured zone may range from 20 to 100 times of the mined coal seam thickness [20] if the overlying strata is weak, in which the separation between the strong strata and the weak strata can reach 0.4 m.

These methods have greatly helped us to understand rock mass and deformation as well as fracture characteristics in each zone of the zoning theory. However, certain issues still exist among these methods: for example, the empirical methods are short of theoretical basis, while the similar material simulation experiments and the numerical simulation methods largely simplify actual situations, which makes it is very hard to apply the obtain results in fields. The vertical borehole observation method has three major disadvantages. Firstly, due to budget limitation, very few boreholes are equipped with roof delamination observation, which may cause inaccurate borehole monitoring results. Secondly, the borehole observation method is limited to mainly observe macro-cracks instead of micro-fracturing nucleation. Thirdly, the drilling process of the borehole observation method liberates the rock cores from the original stressed state to the unstressed state, which may intensify the deformation and fracture of the drilled rock cores and thus cause deviations. Besides, as an immature method of characterizing rock mass in the zoning theory, the accuracy of the geophysical methods is often poor.

2.2. Relationship between the zoning theory and monitoring methods

No matter the zoning theories divide the roof strata into three zones[13], four zones[14] or five zones[13], they are all developed based on the deformation and failure characteristics of overlying rock mass. When a coal seam is mined, the stress around the stope is redistributed, which makes the roof rock mass deform and fracture. The deformation and fracture in two adjacent strata may differ greatly because of the layered overlying rock mass strata with uneven thickness and unequal strength, which may lead to different zones of roof strata movement. Thus, it is reasonable to develop the zoning theory on the basis of deformation and failure characteristics of roof rock mass. The zoning theory deems that the deformation or fracture state of rock mass in a zone is mainly under a certain range.

Based on the discussion above, the zoning theory of roof rock strata movement is closely related to measuring methods. It can be seen from the five-zone model[13] that, different monitoring methods are suitable to measure different objects. If the measured objects are closer to the variables used to differentiate the zoning phenomena in a zoning model, the zoning model may become more detailed and accurate. At present, there are mainly three methods for measuring the deformation and failure of rock strata in roof, i.e. the geophysics methods, the vertical borehole observation methods, and the microseismic monitoring. The disadvantages of the vertical borehole observation method and the geophysical method have been described in the above. The microseismic monitoring technology, as a powerful means for monitoring rock mass micro-fracture, can monitor the microseismic events generated from the deformation to failure stages of rock mass under loads. Thus, the microseismic monitoring technology, as a more advanced observation method, is of great importance for the research on the zoning theory of roof rock mass movement.

2.3. Key stratum theory

In recent years, the key stratum theory has enjoyed a great progress[28–29]. According to the key stratum theory, when there are multiple layers of hard rock mass in the overburden rock strata, the stratum playing a decisive role in the stability of all (the primary key stratum) or part (the inferior key stratum) of rock masses is called the key stratum[28–29]. The key stratum of the overburden strata in a stope has the following five features[28–29]: I. geometric features, i.e. the key stratum is thicker than other strata. II. Lithology features: compared with other strata, the key stratum is relatively harder, i.e. with a larger modulus of elasticity, and a higher strength. III. Deformation features: when the key stratum sinks and deforms, the subsidence of all or part of its overlying strata synchronizes with it. IV. Fracture feature: the fracture of the key stratum may cause the collapse of all or part of the overlying strata, arousing strata movement within a large scope. V. Support feature: before fracture, the key stratum acts as a bearing body of all or part of strata, in the structural form of plate (or simplified beam).

The physical-mechanical parameters of sedimentary rock are non-homogeneous in the vertical direction, which may lead to the zoning phenomena of rock mass when the underlying coal seam is mined. The