Prevention and Control of Rockbursts in Dongguashan Copper Mine

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ABSTRACT: A seismic monitoring system was installed in 2005 at Dongguashan Copper Mine, the deepest metal mine in China. Based on the seismic events monitored in situ, the possibility of rockburst prediction and prevention is investigated in this paper. We analyzed the spatial-time distribution of hypocenters of the seismic events, the apparent stress and displacement induced. The characteristics of space-time-intensity of mining-induced seismicity and the seismic response to mining are studied in detail using the seismic data in Dongguashan Mine. A conceptual model and a criterion of assessment of hazard seismic nucleation are proposed for Dongguashan Mine. In this model, the mine seismic stiffness method is adopted for rockburst prediction within the framework of the unstable failure theory. To analyze rock failure cases in Donggaushan Mine, the rate of the ratio of stiffness of rock in nucleation area to its surrounding area is proposed as a criterion for rockburst prediction.

1 INSTRUCTION

Dongguashan Mine, near the Tongling City in Anhui province of China, is a large deep-level hard rock copper mine. The production of the mine started in the fourth quarter of 2005. For safe and sustainable production, a rockburst monitoring system was deployed before production. The current main objective is to make middle-term prediction of rockbursts during mining activities. This rockburst control technique is based on the monitoring of the seismicity and thus predicting the stress change and deformation of rock mass. This way, areas with potential rockburst hazards are identified, and the rockburst potentials are predicted by analyzing the characteristics of seismicity time series in these areas.

The rockburst event has a nucleation phase. It is thus important for rockburst prediction to investigate the variation of seismicity in time and space. It has been demonstrated that there is good correlation between the heterogeneity of seismicity and the properties of rock mass. This heterogeneity of seismicity bears important information for rockburst nucleation for mining engineering structure under the mining condition (Aki, 1984, Tang et al., 1997, Lei et.al., 2004, Mendecki, 1997). Many attempts have been made to quantify the mechanisms of rockbursts using seismic parameters and rock mechanics methods. Some seismological based theories and methods for rockburst prediction have been proposed. Among these methods, mine stiffness theory that was studied preliminarily using data from some mines in South Africa, is attractive and thus will be used here (Cook, 1966, Amidzic, 2005, Van aswegan, 2005).

This paper will discuss the model of seismic nucleation based on the theory of seismic heterogeneity. Using the in-situ micro-seismic data from Dongguashan Mine, the rockburst prediction is made using the criterion based on the mine stiffness theory.

2 GEOLOGIC AND MINING CONDITIONS

Dongguashan copper deposit is at 1000 m beneath the surface and it is controlled by an anticline (Figure 1). The strike of the deposit is NE350°-400° and the dip along the strike is about 100° northeast. The two wings of the ore-body dip northwest and southeast respectively. The average dip angle is about 20°. Its horizontally projected length is 1820 m and its horizontally projected width varies from 204 m to 882 m. The maximum thickness of the ore-body is 85 m and the average thickness is about 40 m. The ore-body is mainly composed of cupriferous skarn, with direct roof rock marble and siltstone and quartz diorite floor. There are few large faults and dense joints in the ore-body. The maximum in-situ stress, σ_1 is 30 ~ 35 MPa, approximately parallel to the strike direction of the ore-body; the minimum in-situ stress, σ_3 is 9~16 MPa. The ore and its major surrounding rocks are very hard and thus are prone to rockburst during mining operation (Tang et al. 2002, Tang et al. 2006).



Figure 1 (a) Occurrence of Dongguashan copper deposit and (b) a typical vertical section perpendicular to the strike of the ore body.



The ore-body is divided into panels along its strike, with the length of each panel being equal to the horizontal width of ore-body and the width being 100 m. Panel barrier pillars of 18 m in width are kept temporarily between the two neighboring panels. The stopes are arranged along the long axis of the panels. Each stope is of 78 m or 82 m in length and 18 m in width. The stope is mined and backfilled with cemented tailings afterwards, this is followed by the excavation and backfill of the pillars.

3 SEISMIC MONITORING SYSTEM

The Dongguashan rockburst monitoring system is composed of a seismic monitoring system and a conventional stress and deformation monitoring system. The seismic monitoring system is the ISS system by Integrated Seismic System International (South Africa). The system was tuned and optimized for the geologic and mining conditions of the Dongguashan Mine (Kanamori, 1978). It has 24 channels and 16 sensors. All signals are transmitted by copper twist cables to the monitoring control centre underground, and then transmitted by an optical cable to the monitoring centre on the ground surface as well as the safety and production management offices of the mine. Currently, the area of monitoring is the first stage mining area that has four panels, which include area between the #52 exploratory line and the #60 exploratory line and the surrounding rock mass. The monitoring area will be extended the entire mine.

4 SEISMIC RESPONSE TO MINING

4.1 The spatial-time distribution of hypocenters

In spatial volume ΔV and time period Δt , seismic events are plotted in 3D with coordinates being the hypocenters of seismic events (Figure 2). The change of the spatial aggregations can be analyzed by comparing the spatial distribution of events during different time periods. For example, it can be seen in Figure 2 that there are nine areas of aggregated events in the first stage mining area, from December 25, 2005 to January 26, 2006. Among these areas, the area 1, 2, 3, 4 and 8 are induced by the driving of draw shafts, the area 5, 6 by development of drifts, and the area 7 by the extracting of a stope. However, the area 9 is far from the mining area, the mechanism in this area is believed to be the slip of one pre-existing fault, activated by blasting.



Fig.2 (a) Scenograph of seismic events and (b) delineation of horizontal projection of relative aggregating areas initial mining area (2005-12~2006-1)

Analyzing the data from the first stage mining area from September 1, 2005 to August 30, 2008 reveals that the events induced by driving shafts and developing drifts are located near these mining sites, and they are sensitive to these mining activities. On the other hand, the extracting of stope can induce seismicity in a much larger area. Generally speaking, aggregating events are located at temporary pillars and panel barrier pillars.

4.2 Apparent stress and displacement of seismic events

Apparent stress and displacement in different time periods can be used to describe the variation of stress state. Using the occurrence of Dongguashan deposit and the layout of the mining engineering structure, apparent stress and displacement at different levels are appropriate to describe the spatial distribution of stress and deformation in the initial mining area. Therefore, a series of nephograms of displacement, u, and contour maps of logarithm of the apparent stress, $\log(\sigma_A)$, at different levels are plotted for Dongguashan Mine. Figure 4 shows the apparent stress contour and displacement nephogram of -730m level and -760m level, respectively, during the same time period as in Figure 3. Areas of stress concentration and deformation are clearly showed in Figure 4.

Figure 4 also shows some stress concentration areas that are not located at the aggregation areas of events. For example, development of single drift usually does not cause obvious stress concentration and deformation, despite of the aggregations of events occurring in these areas. It is also seen that, under the condition of stope extracting or many drifts drilling, stress and deformation concentration occurs in the neighboring area of aggregation areas of events. Also important are cases where the stress is not positively related to the deformation. It is manifest from the discordance between area of seismic apparent stress concentration and of deformation (Figure 4a). If the mining scale is small, activities do not affect each other and mining structures are independent, the areas of stress concentration usually correlate well to the area of deformation. However, the correlation may not exist if the activities are far away from each other. Because seismic apparent stress and displacement are independently calculated in seismology [4], relative rate of change between the seismic apparent stress and deformation at the same space reflects the mechanical property of rock mass.



b. -760m level

Figure 4 Apparent stress contour map and displacement nephogram at different levels (2005-12~2006-1)

4.3 Conceptual model and the criterion for hazard seismic nucleation

Because there are no obvious large scale geological discontinuity surfaces such as dykes and faults in this mine, the dominant factor that controls the heterogeneity of rock mass is the mining engineering structure and mining activities. Panel barrier pillars and many temporary pillars are formed between hanging wall and foot wall with mining. These pillars restrain relative deformation of the walls, which can be roughly considered as compression-shear. In the framework of the theory of asperity in seismic source mechanism (Aki, 1984, Funk, 1997), these pillars can be considered as asperities where seismic nucleation may occur. Therefore, we can develop a conceptual model of seismic nucleation at Dongguashan Mine, as shown in Figure 5, in which the areas enclosed by red dashed curve are considered approximately the potential areas of the seismic nucleation. Figure 5a is the section along the strike of ore body, and Figure 5b is the section perpendicular to the strike.



Figure 5 conceptual model of seismic nucleation

Figure 6 is the apparent stress and displacement on the section along strike of 52-6# stope (perpendicular to the strike of the ore-body), in which rectangles are stopes designed and the panel barrier pillars are between these stopes. It is seen that concentration of stress and deformation are located in panel barrier pillars and their surrounding rocks. These areas work as asperities on faults. This fact demonstrates that the conceptual asperity model can be used as for analyzing potential areas for hazard nucleation. However, due to interaction between mining activities, aggregation of events and distribution of stress and deformation are too complicated to be included in the conceptual model.



Figure 6 (a) The apparent stress and (b) the displacement on the section of initial mining area along strike of 52-#6 stope (Jun.1~Jul. 30, 2006)

5 MINE SEISMIC STIFFNESS METHOD FOR ROCKBURST PREDICTION

5.1 Measure of Parameters for Unstable Failure

According to the mine stiffness theory, the rock burst occurs if the stiffness of rock in the seismic nucleation area is larger than that of the rock mass outside the nucleation area. Using the definition of seismic apparent stress, σ_A , and its relation to the stress drop, $\Delta\sigma$, of an event Mendecki, 1997, the ratio of the release energy of an event, E, to seismic moment, M, can be used to express the stiffness of the event. Because there are many events in a nucleation area during a time period, Δt , we can take advantage of a fitting method to determine the average stiffness of this area in a given time period. The scatter diagram of logE and logM of events can be drawn and a relation of E-M is given below in Equation (1) from fitting (Amidzic, 2005):

$$\log E = c + d \log M \tag{1}$$

where c and d are fitting constant, with given ΔV and Δt . The slope, d, is the stiffness of nucleation area. d increases with the increase of stiffness (Amidzic, 2005). If M is constant, a steeper slope d indicates a larger energy release; if d is constant, c increases with the increase of stress

The surrounding rock mass outside the nucleation area should be considered as mine loading system, whose stiffness is called mine stiffness. To determine the mine stiffness, some statistical and fitting methods are used. In the seismic prediction, b value in the G-R relation has been used extensively. The G-R relation is:

$$\log N(\ge m) = a - bm \tag{2}$$

It has been demonstrated that b value is affected by the heterogeneity of rocks and stress, stress level and stiffness of loading system. The b value decreases with the decrease of stiffness of the loading system [12, 13].

5.2 A criterion for rockburst prediction

We analyzed the a, b, c and d parameters using the data recorded at Dongguashan Mine to predict rockburst using seismic stiffness. A typical case is shown in this paper. From Sept. to Oct. 2006, a few rock failures occurred in surrounding rocks of drifts under the panel barrier pillar along the #54 exploratory line. Figure 7 is the distribution of the stress and displacement on the vertical section along midline of this panel barrier pillar. In Figure 7, the time period for analysis is from Jun. to Nov. 2006.



Figure 7 Stress and displacement in panel barrier pillar along #54 exploratory line

The area where rock failure occurred is recognized as the seismic nucleation area, where the concentration of stress and deformation is identified. Some rocks located in area outside the nucleation area are selected as the loading system rock. For nucleation area, we plot the scatter diagram of logE and logM to determine c and d; for load system rock, we plot the frequency of events vs magnitude of events to determine a and b. The time period for analysis is from April, 2006 to April, 2007. Every two months is used as the time interval for analysis and the parameters a, b, c and d are determined for every time interval, and shown in Figure 8 and Figure 9.



Figure 8 The c and d in nucleation area Figure 9 The a and b in load system area

Figure 8 shows decrease of c from Sep. to Oct. 2006, which indicates that the rock failures reduce the stress. During the same time period, d decreases only slightly, which shows that rock failures result in slight decrease of stiffness in this area. Figure 9 shows that a value increased and b value decreased monotonously from April 2006 to April 2007, and furthermore, b value decreased steeply fast from Sep. to Oct. 2006. This is because that from April 2006 to April 2007, stopes at two sides of the panel barrier pillar was being extracted, and backfill started shortly after. As a result, rock deformation and damage increased gradually. Therefore, the change of b value represents the change of the stiffness of loading system rock.

Theoretically, we can make rock burst prediction by comparing relative change between d and b (Figure 10). However, it is difficult to identify sizable changes from this Figure. Furthermore, we cannot get the absolute values of the stiffnesses. To solve this problem, we proposed the change of the ratio of d in the nucleation area to b in the loading system to measure the change of the relative stiffness of bath areas, and further to determine the possibility of rock burst. The ratio of d to b is defined as S below:

$$s = d/b \tag{3}$$

The curse of S with time period is shown in Figure 11. The change of S reflects the relative change of the stiffness of nucleation area to that of the load system area. Therefore, we defined the dS/dt as a rock burst prediction criterion in mine, i.e., increase of possibility of rock burst if dS/dt > 0, decrease of possibility of rock burst if dS/dt < 0.



6 CONCLUSIONS

1) By analysing the spatial-time distribution of hypocenters, apparent stress, and displacement of seismic events, the characteristics of space-time-intensity of mining-induced seismicity and the seismic response to mining are studied with the data of seismicity in Dongguashan Mine. The relationships between seismicity and size and property of excavation are discussed. A conceptual model of hazard seismic nucleation is proposed for Dongguashan Mine according to the conditions of this Mine, which provides a method for the locating areas of hazardous seismicity in the mine.

2) A mine seismic stiffness method of rockburst prediction is proposed on the basis of mine stiffness theory and the analyses of rock failure cases in Dongguashan Mine. The variable rate of ratio of stiffness of rock mass in nucleation area to its surrounding rock's is used as a criterion of rockburst prediction.

3) The studies in this paper are preliminary. With accumulation of data recorded and extension of scale of mining in the mine, further investigation on these results will be developed through analysing more cases of rock bursts and rock failures in this mine.

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