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Progressive mitigation method of rock bursts under complicated geological conditions

Wei-Yao Guo[a,b,*], Tong-Bin Zhao[a,b,*], Yun-Liang Tan[a,b], Feng-Hai Yu[a,b], Shan-Chao Hu[a,b], Fu-Qiang Yang[c]

[a] State Key Laboratory of Mining Disaster Prevention and Control Co-founded by Shandong Province and the Ministry of Science and Technology, Shandong University of Science and Technology, Qingdao 266590, China
[b] School of Mining and Safety Engineering, Shandong University of Science and Technology, Qingdao 266590, China
[c] Muchengjian Mine of Beijing Haohua Energy Resource Co., Ltd., Beijing 102304, China

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ABSTRACT

Jingxi Coalfield, which is called “China's Geological Encyclopedia”, has a complicated geological condition. As one its representative mines, Muchengjian Mine has witnessed nearly thirty rock bursts in the past decade. Considering geological structures, the in situ stress state, and the burst proneness of coal, one typical mining area in Muchengjian Mine is selected for analysis where nearly one-third of rock bursts occurred. This analysis lays the foundation for selecting mitigation strategies. Results indicate that the blasting disturbance plays an important role in the intensity and the scale of these rock bursts. Jingxi Coalfield has three types of rock burst mechanisms: I (high in situ stress rock burst), II (high mining-induced stress rock burst), and III (high in situ stress plus high mining-induced stress rock burst). Therefore, we follow two guidelines for rock burst control. One is to mitigate the high stress concentration, and the second is to control the disturbance stress. On the basis of these two guidelines, we designed a progressive mitigation method of rock bursts (PMMRB): first, the weak disturbance destress techniques (e.g., large-diameter drilling, water infusion) are applied to weaken the strength and the burst proneness of coal and to expand crack zones to reduce the stress concentration; and, second, the strong disturbance destress blasting is applied if the release of stress concentration is not sufficient. PMMRB is adopted in a similar mining area with a higher in situ stress, which indicates that PMMRB is applicable to the control of rock bursts and the reduction of rock burst intensity.

1. Introduction

Rock burst, a common dynamic disaster often accompanied with sudden, quick and violent ejection of coal or rock during exploitation of coal seam, often happens in complex ways under special conditions, even without warning signs.[1,2] Such a failure characteristic poses a great threat to the safety and efficiency of mining. Despite decades of researches, some aspects still need to be improved and its control remains a critical research point.

It is generally acknowledged that the frequency of rock bursts is related to intrinsic properties of coal, such as stiffness, strength, bursting energy, elastic strain energy, and duration of dynamic fracturing.[3] Apart from the intrinsic properties of coal, it also generally is known that high stress is related closely to the burst-prone condition, and is the main controlling factor of rock burst. Two main external aspects cause high stress.[2–5] One is the mining condition, such as coal pillars, the layout of mining faces, island mining faces (i.e., is a body of coal surrounded by previously mined faces), mining sequences, mining methods, and destress methods. The second is the geological condition, such as the large mining depth, hard roofs, folds, faults, and tectonic areas with facies change. Scholars have conducted significant work on the factors causing high stress.

Regarding research on mining conditions, theoretical analysis, numerical modeling, and field monitoring methods have been used to study rock bursts caused by the coal pillar and the island coal face.[6,7] Regarding research on the coal pillar, Haramy and Kneisley [8] confirmed that the yield pillars can effectively mitigate coal pillar bursts; Singh et al. [9] found that mining-induced stress during the pillar extraction may vary with the site-specific geological condition; Li et al. [10] studied the width-to-height ratio of yield pillars in a coal mine in China and concluded that decreasing the pillar width-to-height ratio from 2.67 to 1.67 can eliminate the rock bursts; Cording et al. [11]

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[*] Corresponding authors at: College of Mining & Safety Engineering, Shandong University of Science and Technology, 579 Qianwangang Road, Economic & Technical Developing Zone, Qingdao 266590, Shandong Province, China.
E-mail addresses: 363216782@qq.com (W.-Y. Guo), ztbwh2001@163.com (T.-B. Zhao).

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presented a design criterion to evaluate the overall stability of the pillars in mined gas storage cavers in shale formations; and Yu et al. [6] summarized the factors affecting coal pillar stability in detail and conducted stress and deformation monitoring to evaluate the performance of coal pillars. Regarding research on the island mining face, Li et al. [12] presented a method to predict rock-burst-threatened areas in an island mining face and put forward the corresponding mitigation measures; Jiang et al. [13] proposed an integrated approach for field tests and numerical investigations to assess the risk of rock bursts during extraction of an island mining face; Zhang et al. [14] investigated on the overall burst-instability of island coal pillars or mining faces by means of the possibility index diagnosis method to provide the width design of gobs and island coal pillars or mining faces; Feng et al. [15] set up the calculation model of abutment pressure in the island mining face, and established an evaluation method of rock burst hazard induced by overall instability of island mining face.

Regarding aspects of geological condition, scholars have reached consensus that geological structures are generated by geodynamic movement, and that their characteristics directly influence occurring conditions of rock bursts or other dynamic disasters.[3,7,16–18] For research on the hard roof, Jiang et al. [19] put forward the concept that the spatial structure of strata can be divided into four types including θ-shaped, O-shaped, S-shaped and C- shaped structures; Tan et al. [20] investigated the rock burst and acoustic emission (AE) pattern induced by three types of roof structure, including brittle-thick-hard roof, flexible-thick-hard roof and fault activation; Lu et al. [21] revealed the multi-parameter precursory characteristics and the source distribution evolution rules pre- and post-rock burst based on a rock burst hazard induced by hard roof; Zhao [22] and Jiang et al. [23] concluded that the seismic activity caused by hard roof failure easily can lead to rock burst based on the analysis of the micro-seismic data from two working faces, which were characterized by the hard roof and hard coal seam. Regarding research on the fold, Tan [24] analyzed the relationship between the occurrence of rock bursts and the tectonic stress of fold; Wang et al. [25] got the stress distribution rule in the core of syncline and anticline by numerical method; Zhang et al. [26] found that the core of a fold syncline had more intense tectonics than other positions, causing the concentration of local in situ stress, from four extremely intense rock bursts; and Gu et al. [27] studied the formation mechanism of an anticline structure and its disaster mechanism of rock burst by theoretical analysis and UDEC numerical simulation. Regarding research on the fault, Liu et al. [28] established a mechanical model of fault-slip and proposed the pattern recognition of signal for fault-slip rock burst; Li et al. [29] used mechanical analysis of a roof rock-mass balanced structure and numerical simulation to study the rules of rock burst caused by faults, and found that the risk of fault-slip rock burst is higher when the longwall face advances from footwall to the fault itself than when the face advances from hanging wall to the fault; Jiang et al. [30] used numerical simulation to research the fault activation rule under the mining influence, and had similar results; Cai et al. [31] studied the mechanical genesis of the Yima (China) thrust nappe structure comprehensively using geomechanics, fault mechanics, elastic mechanics, and Coulomb's law of friction; and Sainoki and Mitri [32,33] established the dynamic modeling of fault slip induced by a variety of factors that might exert an influence on the fault slip and studied the dynamic behavior of mining-induced fault slip through numerical simulation. Regarding research on the tectonic area with facies change, Sun [34] arrived at in situ stress distribution law in the variable region of coal seam thickness through numerical simulation; Zhao et al. [4] researched the mechanics mechanism of rock burst for mining in the variable region of coal seam thickness; and Zhai et al. [35] concluded that the variation of coal seam thickness has a significant control effect on rock burst based on case studies.

As a consequence of this research, in addition to the intrinsic bursting proneness of coal, the two main external aspects causing high stress have been determined, and the meaningful results provide good reference for a better understanding the mechanisms of rock burst induced by various factors. Comparatively speaking, case studies of rock bursts are not enough, but they are very valuable. According to incomplete statistics, rock bursts near geological structures account for nearly 70% of the total rock bursts in China.[36] Jingxi Coalfield, which is called “China's Geological Encyclopedia”, has a complicated geological condition. As one of its representations, Muchengjian Mine, which has witnessed more than thirty rock bursts during the past ten years, is rich in geological structures, with notable faults, folds, and tectonic areas with facies change. The analysis and study of these rock bursts can build a foundation for understanding, predicting, providing early warning, and especially preventing rock bursts in similar kinds of complicated geological underground projects.

Researchers have done a lot of work on the mitigation techniques of rock bursts except for the factors causing high stress. The commonly used mitigation methods include destress blasting performed in coal seams and compete rock layers, water infusion of coal seam, and destress drilling.[37,38] Among these methods, destress blasting has become one of the most popular procedures. Li [39] and Wang et al. [40] found that blasting is a good method to reduce the risk level of rock burst during stoping or tunneling. For example, this method has been performed satisfactorily in the Czech part of the USCB since 1990 to prevent rock bursts, and more than 2000 destress blastings occurred in this region between 1990 and 2010.[41] Rock burst, as a type of dynamic disasters, is caused by excavation, however, and the response of the surrounding rock may differ depending on destress methods.[42] Obviously, the mitigation of rock bursts needs to focus on the details of the destress technique selection, especially for destress blasting, which often is severe. Xie and Li [43] confirmed that blasting disturbance is not only a significant factor for rock burst control but also is an important triggering factor for rock burst occurrence. Wang and Huang [44] also found that the blasting disturbance seriously affected the scale of rock bursts. Intense rock bursts occurred during the exploitation when using destress blasting in Muchengjian Mine from 2005 to 2013, which seriously affected production efficiency. Therefore, a new mitigation strategy needs to be put forward to improve stress concentration condition and to avoid blasting induced rock bursts.

Because of the large number of rock bursts, it is not practical to describe every event. Thus, allowing for geological structures, the in situ stress state, and the burst proneness of coal in one typical mining area, we selected for this research an area where rock bursts account for one third of the total rock bursts. First, we present the rock burst distributions, the related spatial and temporal characteristics, and the geological characteristics. Second, we propose a rock burst mechanism through the analysis of these representative rock bursts. Third, on the basis of this mechanism, we propose a progressive mitigation method of rock bursts (PMMRB). Last, we confirm the validity of PMMRB by field application in a similar mining area.

2. Engineering geological characteristics and in situ stress field

2.1. Overview of Jingxi Coalfield

Jingxi Coalfield is located in Mengtougou and Fangshan Districts in Beijing with a length of 45 km from east to west and a width of 35 km from south to north. The mineable zone is about 1019 km^2. This area has three major coal-producing underground mines, including Muchengjian Mine, Datai Mine, and Da’anshan Mine (Changgouyu Mine was closed in 2016). This area is under compression from the southeast to northwest.[45] The area also has five major syncline folds and one large-scale faul. From west to east, these structures are the Baihuashan, Tiaojishan-Miaoanling, Jiulongshan-Xiangyu, Shijingshan and Beijing synclines, and Babaoshan Fault, as shown in Fig. 1.[3] Because of these coal-bearing synclines influenced by tectonic movement and sedimentary environment, the dip angle of strata is steep in