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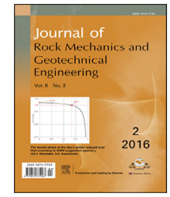

Full length article

Prediction and prevention of rockburst in metal mines – A case study of Sanshandao gold mine

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ABSTRACT

Rockburst is a kind of artificial earthquake induced by human activities, such as mining excavations. The mechanism of rockburst induced by mining disturbance is revealed in terms of energy in this context. For understanding the rockburst mechanism, two necessary conditions for the occurrence of rockburst are presented: (1) the rock mass has the capability to store huge amount of energy and possesses a strong bumping-prone characteristic when damaged; and (2) the geological conditions in the mining area have favorable geo-stress environments that can form high-stress concentration area and accumulate huge energy. These two conditions are also the basic criteria for prediction of rockburst. In view of energy analysis, it is observed that artificial and natural earthquakes have similar regularities in many aspects, such as the relationship between the energy value and burst magnitude. By using the relationship between energy and magnitude of natural earthquake, rockburst is predicted by disturbance energy analysis. A practical example is illustrated using the above-mentioned theorem and technique to predict rockburst in a gold mine in China. Finally, the prevention and control techniques of rockburst are also provided based on the knowledge of the rockburst mechanism.

1. Introduction

Metal mine rockburst, mining-induced seismicity, and coal burst in coal mines are basically regarded as shock bump which is characterized by dynamic hazards induced by mining excavations. With increasing mining depth, the intensity and frequency of rockburst occurrence are becoming higher, which have imposed serious threats to the safety of mining production (Cai, 2001).

The earliest rockburst recorded in the world was in the Kolar gold mine of India in 1900. In USA, the first rockburst record in Atlanta copper mine was reported in 1904, which led to the closure of this mine due to serious damages induced by rockburst.

From the 1950s, rockbursts occurred in many copper-nickel mines in Sudbury area in Canada, with the largest magnitude of ML3.8. In Ontario, 217 rockburst events in mines with the largest burst magnitude of ML4.0 were reported from 1984 to 1985, leading to some mines being closed consequently.

Most rockburst events were recorded in the gold mines of South Africa. Six hundred and eighty rockburst events were reported in 31 gold mines, which killed 73 workers in 1975. At the moment, the maximum mining depth in the gold mines of South Africa was larger than 4000 m. These mines were all subjected to the experience of rockburst with the maximum burst magnitude of ML5.1. In 1984–1993, 3275 workers died during mining damage hazards in the gold mines of South Africa, due to the lack of adequate mining techniques suitable for rockburst control below the depth of 2000 m (Gurtunca, 1997; Feng and Wang, 1998). In China, various rockburst events occurred in Hongtoushan copper mine in Liaoning Province in 1999, with the maximum burst intensity equal to 500–600 kg explosive (Shi, 2000).

Since the beginning of the 21st century, the mining depth in a number of Chinese metal mines has been increased continuously and reaches 1000 m or more. For example, the mining depths of Huize lead-zinc mine in Yunnan Province, Jiapigou gold mine in Jilin Province and Hongtoushan copper mine in Liaoning Province have reached 1500 m, 1400 m, and 1300 m, respectively.

Most of large-scale underground metal mines, which are now under construction in China, belong to deep mines. For example, Dataigou iron mine and Sishanling iron mine in Benxi City of Liaoning Province have the mining depths of 1200–1600 m and 800–1600 m in association with ore reserves of 3 billion and 2.5 billion tons, respectively. The designed production capacity of these two mines is 20–30 million tons per year.

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Moreover, two large-scale gold deposits were discovered few years ago at the east of Shandong Province. They are Xiling gold deposit in Sanshandao gold mine and Sizhuang gold deposit in Jiaojia gold mine, both at the depth of 1200–2000 m. In this circumstance, mining excavation in depth will be a common issue for future metal mining engineering, and rockburst will be the major threat to mining safety.

Prediction and control of rockburst are also challenging issues across the world. Although, the study of rockburst can be dated back to the early 20th century, it receives close attention in rock mechanics research community until the 1970s. During the past 3 decades, many theories about the mechanism of rockburst are proposed, such as the stiffness theory, strength theory, energy theory, instability theory, but most of them are assumptive or empirical. In addition, many methods are proposed and developed for monitoring or prediction of rockburst, such as micro-gravity inspection method, drilling scrap inspection method, acoustic emission method, and electromagnetic radiation method; however, few methods are always reliable. The main reason is the lack of understanding of the rockburst mechanism and suitable prediction technology of rockburst tendency associated with mining excavation (Pan et al., 2003; Jiang et al., 2014). In this regard, the study of rockburst should focus on prediction and control of rockburst, rather than the judging criterion. In addition, developing reliable techniques for monitoring, prediction, forecast and prevention of rockburst is needed to ensure safely and highly efficient production of metal mines in deep mining. For this purpose, the author tries to develop the theory and technique for understanding the rockburst mechanism, prediction and prevention of rockburst caused by mining excavation based on the analysis of disturbance energy.

2. Rockburst mechanism, prediction and prevention techniques based on disturbance energy

Rockburst is one of the dynamic hazards induced by mining excavation, a process of accumulation, evolving and sudden release of energy. This process is basically controlled by in situ stresses of rock strata. Before mining, the rock mass in the mining area is in an equilibrium status. Mining excavation can break the equilibrium status and in situ stress will be released in a form of energy to the free face of rock masses during excavation. The released stress is usually called “equivalent released load”, as shown in Fig. 1, which is the fundamental load applied to surrounding rocks with respect to stress redistribution.

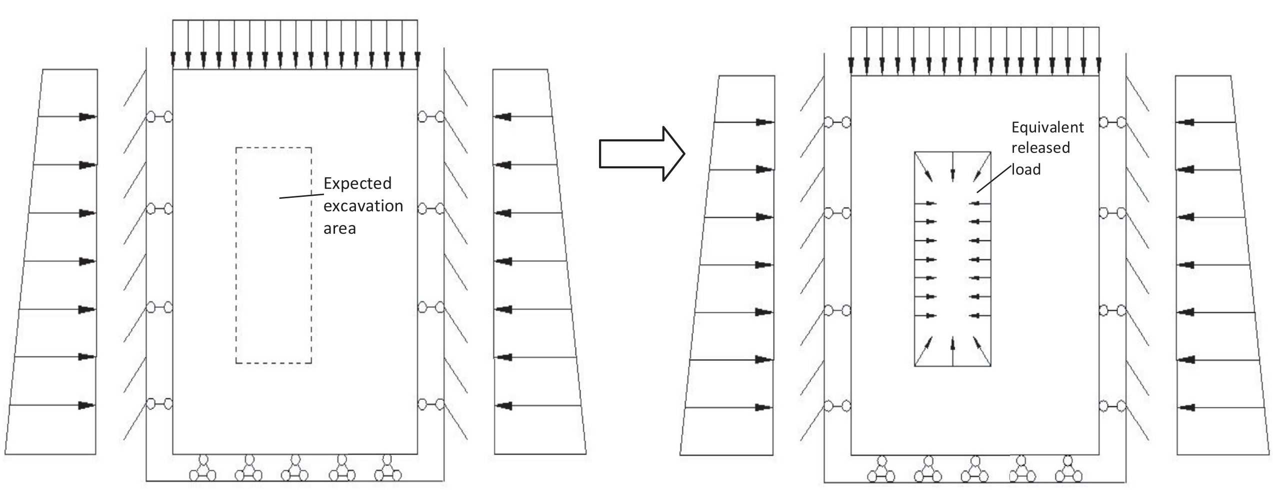
2.1. Mechanism of rockburst

In high in situ condition, strong stress concentration and large deformation can be observed in rock mass, which means that high energy will be accumulated in rock mass in a form of strain energy. In the theory of elasticity, the product of stress multiplied by strain is the main item in the formula to calculate strain energy, e.g. the strain energy stored in a unit volume of rock mass can be expressed as $W = \frac{1}{2}(\sigma_1\varepsilon_1 + \sigma_2\varepsilon_2 + \sigma_3\varepsilon_3)$,where σ_1, σ_2 and σ_3 are the major, intermediate and minor principal stress components; ε_1, ε_2 and ε_3 are three principal strain components in the unit rock mass. The accumulated strain energy will be released abruptly under the condition that rock mass is broken by high stress applied or along the weak plane in rock mass. This is the initiation of rockburst. So, rockburst is considered to be the shock bump of strain energy type.

2.2. Principles for prediction and prevention of rockburst

Based on the above-mentioned mechanism of rockburst induced by release of strain energy, rockburst prediction should be continuously updated in association with mining process. According to mining scheme, including volume, position, depth and procedure, the magnitude of rockburst, initiation time, distribution of the disturbance energy in rock mass induced by mining excavation can be calculated quantitatively using numerical modeling, mathematical statistics and other analytical methods. Then, with the knowledge of seismology on the relationship of magnitude and related energy as shown in Section 3.4 (see Eq. (9)), prediction and spatio-temporal-strength regularity of rockburst induced by mining excavations can be quantitatively made (Cai et al., 2005).

Similarly, for prevention and control of rockburst, the most essential steps are considered and listed as follows: (1) using proper mining methods, (2) optimizing mining layout and excavation sequence, (3) avoiding large stress concentration in rock mass, and (4) using suitable supporting measures. Following the above-mentioned steps, accumulation of disturbance energy in rock mass induced by mining excavation can be effectively controlled. The stress concentration and large displacement in rock



(a) Before excavation. (b) After excavation.

Fig. 1. Process of equivalent released load induced by excavation in rock mass.