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Numerical simulation on rockburst of underground opening triggered by dynamic disturbance

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ABSTRACT

The dynamic disturbance, which is termed as the time-dependent loading such as explosion, vibration, stress impact from neighboring rockbursts, earthquakes, may trigger the rockbursts around the underground opening at depth. A numerical model capable of studying the dynamic failure process of rock under coupled static geo-stress and dynamic disturbance is proposed, and it is implemented into the Rock Failure Process Analysis (RFPA), a general finite element package to analyze the damage and failure process of engineering materials such as rock and concrete. Based on the consideration of the static geo-stress, the RFPA-Dynamics is used to simulate the rockburst that is deemed to be triggered by dynamic disturbance around the deep underground opening. The effect of lateral pressure coefficient and dynamic disturbance waveform on the development of failure zone around the underground opening is numerically simulated. The numerical results indicate that the dynamic disturbance is one of the most important mechanisms that trigger the rockbursts around underground opening. Therefore, it is of theoretical and practical significance to investigate the effect of dynamic disturbance on the rockbursts of underground opening, especially for the underground excavation at depth where the surrounding rockmass is highly stressed. The numerical results also reveal that the contribution of the dynamic disturbances is closely pertinent to both the static geo-stress condition and the waveforms of the dynamic disturbance. In general, dynamic disturbance brings about the greater influences on the stability of underground opening with its increasing magnitude and prolonged duration. However, with regard to the specific static geo-stress condition and characteristics of dynamic disturbance, the contribution of dynamic disturbance to trigger the rockbursts must be examined based on numerical analysis according to the specific geo-stress conditions and characteristics of the dynamic disturbance.

1. Introduction

The term “rockburst” has been defined in an impressive variety of ways. Rockbursts or “bumps” in underground mines are characterized by the spontaneous release of elastic energy, which is largely transformed into kinetic energy, thus resulting in abrupt displacements and unpredictable rock failures (Müller, 1991). Rockbursts may cause severe devastation and endanger operation in mine. From a practical standpoint, the definition widely used in US mines is that, the rockburst is a sudden and violent failure of overstressed rock resulting in the instantaneous release of large amounts of accumulated energy (Whyatt et al., 2002). Kaiser et al. (1998) stated that a rockburst is a seismic event that is associated with damage to a mine opening. In this paper, the expansive definition proposed by Kaiser et al. (1998) is adopted, and therefore the rockburst is extensively termed as the damage and failure around a mine opening as a result of a seismic event.

The rockbursts described in deep-level mining are very different from that in tunnels, because the former is usually pertinent to the mining excavations. Based on the classification of Ortlepp and Stacey (1994), in this study, the strainbursting and the rock ejection are two rockburst mechanisms that will be illustrated in the numerical simulations. Therefore, in this study, the term “rockburst” is applied to the damage that occurs during underground mining as results of a dynamic disturbance, or which is directly associated with a dynamic disturbance.

In the past several decades, a vast majority of work related to mechanism of rockbursts had been undertaken. It is deemed that a detailed understanding of the damage mechanisms and the application of this knowledge to the mining and support of underground opening will lead to a reduction in the hazard posed by rockbursts (Durrheim et al., 1998). It has also been deemed that the individual rockbursts cannot be accurately predicted. However, changes in mining-induced seismicity can provide insight into changes in rock mass conditions and geologic structures, which can affect the likelihood of a rockburst (Whyatt et al., 2002). The deterministic model of seismological parameters as pre-monitors

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of rockbursts, although not free from certain limitations at present, has been applied to predict rockburst activity with some success (Srinivasan et al., 1997). Up to now, apart from a number of methods describing the stress state in the rock mass, it is rather difficult to give universal and practical rockburst criteria. Most of their methods are based on static calculations and therefore only the potential onset of a rockburst can be evaluated (Müller, 1991). Zubelewicz and Mroz (1983) think that the rockburst occurs when the static stability conditions of the rock mass are violent and the dynamic failure process proceeds starting from the equilibrium state. Huang and Wang (1999) analyzed the rockburst mechanism induced by dynamic disturbance using numerical simulation based on an example from a hydropower station in China. In the past two decades, many theoretical and numerical models and technical means were developed to analyze the occurrence of rockbursts (Müller. 1991; Linkov, 1996; Mansurov, 2001; Wang and Park, 2001; Lee et al., 2004), and considerable progress in controlling rockbursts hazards has been made in the intervening 60 years. However, understanding, predicting and controlling the rockbursts still pose a considerable challenge for underground mining.

The occurrence of rockbursts is associated with many factors such as the geological structures of the rockmass, the geo-stress conditions, rockmass strength, the excavation method and excavation size, rock blasting and earthquake (Wang and Huang, 1998; Mansurov, 2001; Wang and Park, 2001; Lee et al., 2004). It is general accepted that the rockbursts occur due to the violent release of a large amount of elastic energy stored in the rock mass. This can explain why rockbursts are more likely to occur in more massive rock type that is highly stressed. However, the possession of the highly accumulated elastic energy in the rockmass is only a prerequisite for rockburst occurrence, the external disturbance may be the one of the necessarily key factors to trigger the rockbursts around the underground opening at depth. As proposed by Blair (1995), as well as Huang and Wang (1999), during underground mining, there are many such external disturbances, e.g. explosion, vibration, stress impact from neighboring rockbursts, earthquakes, etc., all of which can be considered to involve dynamic disturbance.

In this regard, the rockbursts may occur when the rock mass is firstly thought to be under the high static stress induced by the geo-stress and excavation, and is secondly triggered by a dynamic disturbance. For instance, the control of rockburst hazards with blasting practices is started with the recognition that roughly 75% of rockbursts occur with, or in the hour following, a blast (Whyatt et al., 2002). The rock mass at depth is subjected to highly confined vertical and horizontal static stress before the instability triggered by the dynamic disturbance arising from blasting and boring. As the underground mining goes deeper, the more elastic strain energy accumulated in the rock mass, the rockbursts become even more severe as one of the mining catastrophes. The rockmass may behavior differently compared to the situation subjected separately to either static stress or dynamic loading (Li et al., 2008). Therefore, it is of great significance to consider the dynamic disturbance as a key factor to trigger the rockbursts in deep underground mining.

2. Numerical simulator description

The simulator RFPA (abbreviated from Rock Failure Process Analysis) is a two-dimensional code that can simulate the fracture and failure process of rock under static or dynamic loading conditions. To model the failure process (or rockbursts), the rock medium is assumed to be composed of many mesoscopic elements whose material properties are different from one to another and are specified according to a Weibull distribution (1951). The finite element method is employed to obtain the stress fields in the mesoscopic elements. Elastic damage mechanics is used to describe the constitutive law of the meso-scale elements when the maximum tensile strain criterion and the Mohr–Coulomb criterion are utilized as damage thresholds (Zhu and Tang, 2006).

RFPA has been recognized internationally in simulating the failure process of rock under static loading (Zhu and Tang, 2004; Zhu et al., 2005). From year 2003 on, this code is extended as the RFPA-Dynamics when the new FEM solver is employed and more universal boundary conditions are implemented to consider the dynamic loading regime, which makes it capable for studying the failure process of rock under dynamic loading (Zhu and Tang, 2006).

2.1. The fundamental of RFPA

2.1.1. Assignment of material properties

In RFPA, the solid or structure is assumed to be composed of many mesoscopic elements with the same size, and the mechanical properties of these elements are assumed to conform to a given Weibull distribution as defined by the following probability density function:

$$f(u) = \frac{m}{u_0}\left(\frac{u}{u_0}\right)^{m-1} \exp\left(-\left(\frac{u}{u_0}\right)^{m}\right) \tag{1}$$

where u is the mechanical parameter of the element (such as strength or elastic modulus); the scale parameter u_0 is related to the average of the element parameters and the parameter m defines the shape of the distribution function. From the properties of the Weibull distribution, a larger value of m implies a more heterogeneous material and vice versa. Therefore, the parameter m is called the homogeneity index in our numerical simulations. In the definition of the Weibull distribution, the value of the parameter m must be larger than 1.0. Using Eq. (1), in a computer simulation of a medium composed of many mesoscopic elements, one can numerically produce a heterogeneous material. The computationally produced heterogeneous medium is analogous to a real specimen tested in the laboratory, so in this investigation it is referred to as a numerical specimen.

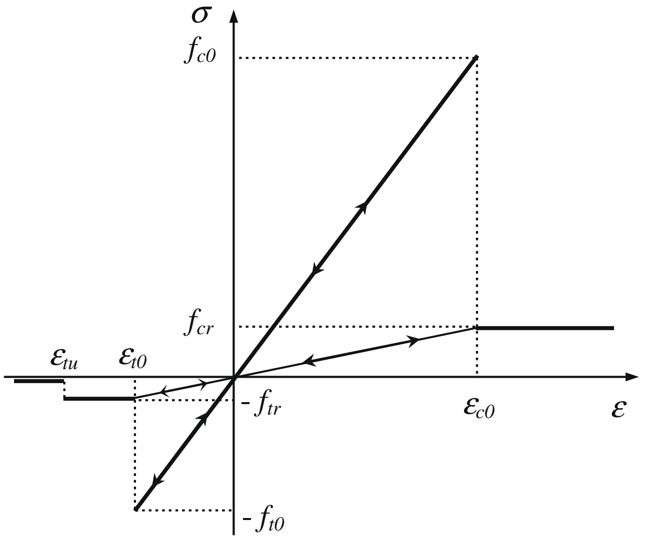

Fig. 1. Elastic damage constitutive law of the element under uniaxial stress state (here f_{t0} and f_{tr} are dynamic uniaxial tensile strength and residual uniaxial tensile strength of element, respectively, and f_{c0} and f_{cr} are dynamic uniaxial compressive strength and residual corresponding strength of element, respectively).