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The analysis of rock damage process based on the microseismic monitoring and numerical simulations

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A B S T R A C T

In mining process, the mechanical parameters of rock mass are deteriorating continuously. Fixed mechanical parameters were usually selected when using numerical simulation to analyze the damage process of rock mass, which led to the simulation results difficult to meet the actual situation. Microseismic monitoring system is an effective means to monitor the evolution of rock mass damage. It is of great significance to effectively combine the monitoring data with numerical simulation to correct rock mass parameters. In order to study the relationship between source parameters and rock mass damage, microseismic events of No. 15–16 exploratory line were analyzed from the project of Shirengou iron mine. Location verification was carried out on the established microseismic monitoring system and the microseismic events with larger errors were eliminated. The damage and failure characteristics of rock mass in this area were preliminarily analyzed based on the analysis of the temporal and spatial change of microseismic events and source parameters. In addition, based on the study of isotropic releasable strain energy, the damage model of rock mass was established by using the relationship between source parameters and releasable strain energy. The microseismic monitoring results were used as input of numerical simulation through FISH language existing in FLAC^{3D}. Source parameters were used to modify rock mechanical parameters, so as to analyze the damage process of rock mass. Through the analysis of microseismic activity, the damage degree of rock mass and the change of plastic zone, the unstable areas were located, furthermore corresponding preventive measures were put forward.

1. Introduction

Rock mechanical parameters are essential for analysis and design of rock mass engineering (such as slope and tunnel). The research on rock mass stability is an important task which urgently needs to be studied at present. Mechanical parameters of rock mass depend on the development degree of discontinuities and properties, meanwhile influenced by mining damage (Wittke, 2014). Affected by excavation blasting and mining unloading extending downward with goaf, rock mass damage is becoming more serious. Therefore, how to correctly select mechanical parameters of rock mass is the fundamental problem in rock mechanics, and also a difficulty in solving rock mass engineering.

The stability of rock mass engineering structure is influenced by the reliability of rock mass mechanical parameters. When dealing with practical engineering problems by numerical calculation, there is an inconsistency of the calculation results with the actual field situation, which is related to the selection of rock mass mechanical parameters (Sonmez and Ulusay, 1999). Many factors will cause the weakening of mechanical parameters, such as the inaccuracy of the mechanical parameters of rock mass due to the less detailed geological survey results of faults and discontinuities, a variety of mining activities, blasting disturbance and underground water. Therefore, it is difficult to simulate the actual in-site mechanical behavior based on static parameters. It is necessary to continuously revise the mechanical parameters of rock mass in simulation calculation. The most accurate method to obtain the mechanical parameters is to carry out in-site rock mass test (Okada et al., 2006), which can accurately obtain the deformation and strength characteristics of rock mass. However, it is difficult to carry out a large number of experiments because it will cost much time and money (Liu and Chen, 2007). Reasonable estimation of rock mass strength based on the laboratory rock mechanics test and comprehensive consideration of the effect of joint fracture, scale effect and ground water has become an important research topic in rock mechanics (Yang et al., 2015). At present, the methods of obtaining rock mass parameters include grading system analysis, empiric formula analysis and etc (Mendecki, 1997; Cai et al., 2001). But most of them are obtained by reduction or statistical analysis of the mechanical indexes obtained from the laboratory tests. However, this only considers the static factors of rock mass failure such

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as water, in-situ stress and so on, and ignores the dynamic triggering factor such as blasting vibration, engineering excavation and etc. Therefore, it is necessary to take into account the dynamic triggering factor and the rock mass damage degree in order to obtain the reasonable mechanical parameters of rock mass.

With the increasing mining engineering, rock burst, goaf collapse, landslide, geological defect activation and other disasters have become increasingly prominent, and traditional means cannot satisfy the requirements of safety monitoring. The information of rock mass damage such as failure location, failure scale and occurrence time can be effectively monitored by microseismic monitoring technique based on the development of geophysics (Gibowicz and Kijko, 1994). In recent years, microseismic monitoring technology is widely used in mines (Mendecki, 1993, 1997; Zhang et al., 2016), hydropower (Dai et al., 2017a,b), tunnels (Cai et al., 2001; Ma et al., 2015), slopes (Xu et al., 2011; Zhang et al., 2015), oil and gas exploration (Ma et al., 2016; Zhuang et al., 2017). It can be seen from the research that the microseismic monitoring has become an effective method for analysis of rock mass stability. Under the action of internal and external force or temperature change, the local elastic–plastic energy concentration will occur internally. When energy accumulated to a critical degree, it will cause the initiation and propagation of cracks. This process is accompanied with the release of elastic waves, which is called microseismic in seismology (Mendecki, 1997; Xiao et al., 2015). Rock mass failure is a process of initiation, extension, and gathering of micro fracture and a process from disorder to order. The microseismic monitoring can well monitor the whole process. Microseismic monitoring has become an effective method for rock damage evolution, through this method, further dynamic analysis of rock damage degree has been carried out, which has important scientific value and practical significance to realize the real time calibration of rock mass strength. However, there is lack of research on this work. Yang et al. (2013) proposed dynamic calibration method for strength parameters of rock mass by introducing the number of events, the energy and the distance between events. Xu et al. (2014) have analyzed the slope stability of Jinping first stage hydropower station by trying to combine the microseismic monitoring data with RFPA numerical simulation. The thought is correct and the method is reasonable, but still in the initial exploration stage and existing some problems, which need to be improved and resolved. Such as: how to get correct influence extent and influence range of microseismic events are the key to establish the relationship between microseismic monitoring and numerical simulation; how to establish correct dynamic damage model based on microseismic monitoring data is also vital.

The purpose of this study is to explore the method of designing microseismic monitoring range based on numerical simulation and proofreading numerical simulation based on microseismic monitoring data. As mentioned above, from the project of Shirengou iron mine, the determination of unstable areas and key protected areas through field geological survey (structural surface scanning and actual investigation), and a microseismic monitoring system was established for this area. Through the data processing module in microseismic system, the microseismic waveform is processed in real time, and the location events and the source parameters are obtained. Combined with the actual construction situation, the spatial-temporal analysis of microseismic events and source parameters were carried out, and the damage process of rock mass was analyzed. In addition, by using the relationship between source parameters and rock mass mechanics parameters, the rock damage model was established. This model was used as input of the three-dimensional numerical software to constantly modify rock mass parameters, perform numerical calculation, analyze damage process, determine damage degree, delineate unstable area, and then provide treatment scheme. Coupling analysis of microseismic monitoring and numerical simulation results aimed at providing a reference both for next mining design and next setting of microseismic monitoring area.

2. Isotropic releasable strain energy considering damage

The failure of rock mass can be described as an instability phenomenon under the energy driven (Xie et al., 2009). The process of rock damage, strength weakening and rock failure experience the accumulation, dissipation and release of energy (Zhang et al., 1999). In recent years, many scholars have made an important contribution to the analysis of rock mass damage by energy (Mikhalyuk and Zakharov, 1997; Sujatha and Kishen, 2003). It can be seen that the study of the relationship between the energy change in the process of rock mass damage and the mechanical properties of rock mass is beneficial to reflect the change of rock mass strength and the overall damage behavior.

Rock will experience a variety of deformation mode from initial loading to final failure. Each deformation mode corresponds to one or more forms of energy. Such as: elastic energy W_E produced by recoverable deformation after unloading, plastic energy W_p corresponding to the difference value between total strain energy and recoverable strain energy, surface energy W_Ω corresponding to the initiation and propagation of crack, radiation energy W_m and kinetic energy W_v during the failure of rock and the energy dissipated in other forms W_x. Although the total energy during rock mass deformation process is conserved, it is not the superposition of all the energy listed above. Because W_E, W_p, W_Ω, W_m, W_v and W_x can be transformed into each other, existing in a coupled state. There is a functional relationship between them and the total energy W_F, which can be expressed as formula (1). In this paper, W_p, W_Ω, W_m, W_v, W_x are attributed to dissipation energy.

$$W_F = f(W_E, W_p, W_\Omega, W_m, W_v, W_x) = W_E + W_D \tag{1}$$

Xie et al. (2009) summed up the energy expression relationship of rock mass system. Per unit volume of rock mass is assumed to be a closed system, according to the first law of thermodynamics:

$$U = U^d + U^e \tag{2}$$

where U is the total energy done by outside on rock mass unit, U^d is the dissipation energy of rock mass unit and U^e is the releasable strain energy of rock mass unit. The relationship between U^d and U^e in rock mass unit is shown in Fig. 1.

During rock failure process, the elastic energy stored in rock unit was released. This released elastic energy can be transformed into the kinetic energy, radiation energy and etc., which provides the energy for rock mass damage. In the later stage of stress, when rock disaster occurred, elastic energy was released from the inside of the rock, and transformed into different forms of energy. In fact, the energy released by rock failure is the elastic strain energy stored in early stage and is the drive of rock disaster. According to the elastic mechanics, total energy of rock

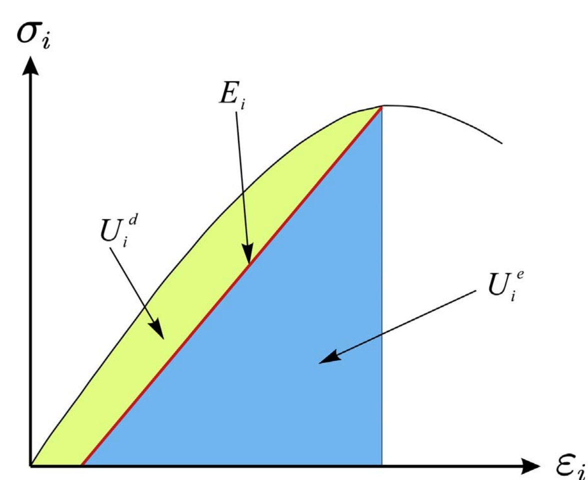

Fig. 1. The relationship between releasable strain energy and dissipation energy.