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Couple analyzing the acoustic emission characters from hard composite rock fracture

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Abstract: Rock mass is fractured media. Its fracture is a nonlinear process. The accumulation of acoustic emission (AE) is closely related to the degree of damage. The dynamics problem is simply described based on the non-equilibrium statistical theory of crack evolvement, trying to use the hybrid analysis of the statistical theory and scan electron microscopy (SEM), the characters of AE signals from rock damage in a mined-out area is synthetically analyzed and evaluated. These provide an evidence to reverse deduce and accurately infer the position of rock fracture for dynamical hazard control.

Key words: couple analysis; acoustic emission; scan electron microscopy (SEM); non-equilibrium statistics; large scale mined-out area

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1 Introduction

The effects of discontinuities on rock mechanics properties include increased deformability, decreased strength, increased permeability, anisotropy, scale effect, and additional kinematic possibility. It is clear that not all discontinuities play equal roles in the behavior of rock mass. Physically minor discontinuities and geological features may sometimes be more critical to design than major (large scale) features. These minor features, however, are often overlooked. Based on the practical view, it is not clear what represents a critical or major feature, and it is often determined in a very subjective method. To a large-scale mined-out area, the investigation of a limestone pillar failure has been evaluated, especially, the stress-strain process and application of fracture mechanics approach have been achieved [1]. In the case of testing on fracture toughness, there exists an ISRM-suggested method, and two estimating methods are described, the Chevron bend specimen and the short rod specimen, respectively [2]. The acoustic emission (AE) sequences generated by loading hard rock samples (at a constant stress rate and up to fracture) have been analyzed [3, 4]. That estimation on the stability of under-ground structural engineering by an acoustic emission system and in-situ monitoring 255 Main Transport Roadway of Linglong Gold Mine in Shandong province of China has been synthetically finished [5]. It mainly includes the following: 1) An advanced rock AE monitor system; 2) Solid and fluid flow couple numerical simulation. Numerical simulations are carried out in order to study the change in stress and the deformation distribution during the failure process. It provides a new insight on the formation mechanism of failure zones and the development of cracks; 3) SEM experiment. Laboratory tests have been carried out to study the fractural effect on two types; 4) In situ application and feedback; 5) Data mining on AE signals, *etc.* It was observed that, close to the limiting values of the stress state of the rock, the AE values as well as the associated autocorrelation coefficients change significantly. Further experiments have extended the validity of previously obtained results on granites, and also to a different type of loading regime. It was shown that these parameters of statistical distributions of the AE (*e.g.* dynamic damage series, magnitude-frequency distribution) are not random. Parameters of the AE distribution are compatible with the strain stage of the loaded samples. The precursor properties of sudden rock-failure are based on deformational data analysis and the transfer properties of loaded rock samples analysis. Using an advanced multi-channel system, the continual monitoring and analysis of AE was ensured.

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2 Instable fracture analysis

Geology, the site rock mechanical characterization, must be addressed when developing sampling plans for site characterization, and be incorporated during the design process. Laboratory testing to determine relevant physical parameters must reflect the geological conditions as well. Scaling relations are an integral component of rock mass models. Especially, the physical value that gleaned from experiment involves a degree of uncertainty due to the time and space scaling. For example, smaller scale processes may be inherently different from large scale processes. Testing at the geologic scale is not always possible, so the question becomes how to use the smaller scale information to determine large scale performances. For example, the in-situ monitoring and stability couple analysis and prediction of subsiding area of 255 Main Transport Roadway have been successfully finished [6]. The corresponding critical values of acoustic emission of rock damage are presented in the **table 1**.

Table 1 Critical value of AE's characteristic parameters of rock damage

Rock-mass stability type	I	II	III	IV	V
Large event / (times·min^{-1})	—	≥4	≥4	≥1	—
Total event / (times·min^{-1})	—	≥11	≥10	≥9	—
Energy rate / (energy unit·min^{-1})	—	≥750	≥350	≥150	—

3 Scan electron microscopy (SEM) experiment

While constitutive models and numerical codes are available, there still exists uncertainty about the influence of rock properties on strength-related features such as fracture counts and micro-structural aspects. Rock mechanics engineer can predict the damage behavior and build structures in fractured media. Behavior in response to various loading situations can be anticipated and can interact with the structure. Our ability to test rock specimens of significant and important size is limited, and most engineering is based on the results from small intact pieces of rock mass tested in laboratory. The change observed in the above parameters mainly reflects the critical deformational state of the sample. The agreement in the recorded results for different types of experiment indicates more general properties of the investigated parameters, which are also independent of the rock types tested.

The quantitative description of rough surfaces and interfaces has an important challenge for many years. More recently, it has been realized that fracture geometry and scaling concepts can considerably simplify this task for a quite wide range of system. With the development of rock mechanics and mining science, the method to describe phenomena in precise, and quantitative terms has frequently led to important advances in understanding. This certainly seems to be true in the case of surface toughness and growth (crack growth). In order to probe into the acoustic emission's character of hard composite rock supporting material fracture, the breakpoint and different fracture stages of the Linglong granite and relating to the crack evolvement of granite on the fractural surface can be observed by SEM. A comparison between the distributions of growth factors can be measured. In the process of rock fracture due to loading, the crack can be statistic by terms of a non-linear equation based on a digitized image. The crack growing patterns have been described distinctly [7, 8]. These provide an effective evidence to calculate the in-situ acoustic emissions in order to identify the dangerous region. Finally, some measurements would be given to strengthen the support and rock mass. **Figure 1** demonstrates the crack evolvement of granite on the fracture surface. **Figure 2** illustrates the crack evolvement of rock composite material. It obviously described the crack evolvement of composite granite material which embodies a little impurity at different magnifying times and resolution.

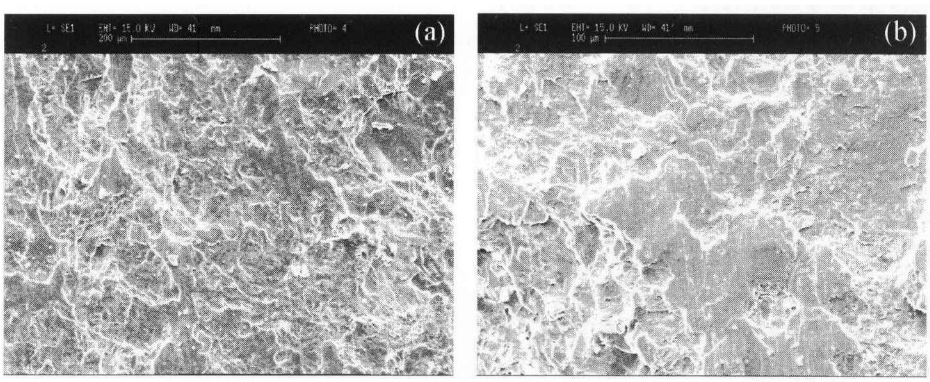

Figure 1 Crack evolvement of granite on the fractural surface.

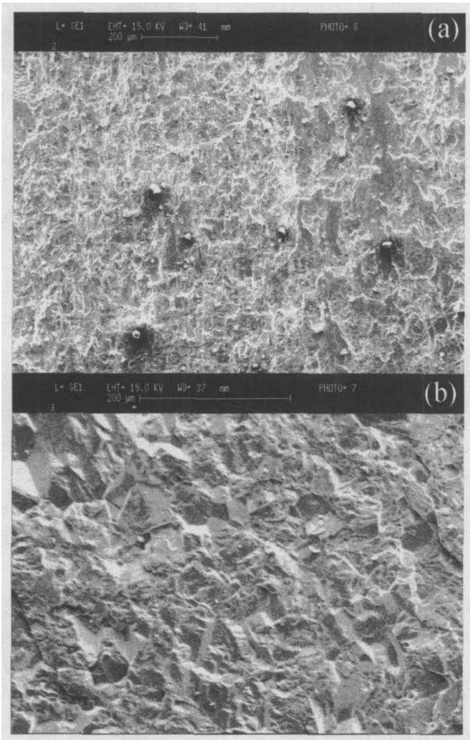

Figure 2 Crack evolvement of rock composite material.

4 Non-equilibrium statistics of rock fracture

Rock fracture process and acoustic emission's character are complex. The analytical method refers to random process statistics, non-linear dynamics, unstable time serial, *etc.* To site hard rocky composite material, due to containing steel fiber, it can release discriminative acoustic emission signals comparison with the general rocky material in the process of fracture and damage. There is not an effective method to analyze and evaluate the unstable serial time signal tendency. We try to present methods that extend the evaluation of rock mass stability to the use of non-equilibrium statistical theory based on AE time series. The concept and method stems from the non-equilibrium statistical theory and is applied to the solid fracture [9]. The analysis of AE event time-space distributions could also contribute to the physical explanation of the fracturing process.

5 Statistical regular and analysis

Complicating rock mass characterization is the fact that many processes (*e.g.*, thermal, hydraulic, chemical, mechanical, temporal and engineering perturbations) may be coupled, and small perturbations may have large effect. Without signification (linearization), this is a non-linear problem, which imposes a paradigm shift in modeling and site property determination. New approaches and tools should be investigated, perhaps taken from the physics of quantum mechanics, neural networks, chaos, complexity theory, self-organized system fields [10-13]. It is shown that the statistical regular of AE's character at the rock fractural damage (three stages) is different. M. Cai *et al.*, have proposed four discriminating patterns [14]: 1) Ascending pressure-stable pattern (I); 2) Ascending pressure-stable pattern (II); 3) Descent pressure-stable pattern; 4) Descent pressure-instable pattern. **Figure 3** illustrates the curve of AE's characteristic parameters comparing with the pressure. It shows that when the pressure is descended, the sum of acoustic emission's total events is rising. It mainly indicates that the rock-mass strength is weakened and fractured or damaged seriously. Especially, the phenomenon will occur when the rock mass and fluid flow interact in the heavy raining season. So the reinforcing measurement in situ would be proposed effectively.

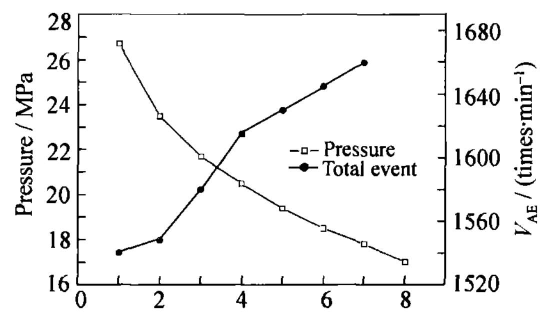

Figure 3 Curves of AE's characteristic parameters (total event rate) *vs.* pressure.

The analysis of the characteristic of individual monitored AE signals, especially, the changes in the frequency-amplitude spectra of these events are related to the sample load value. The AE event regular analysis includes time sequences and energy-frequency patterns, AE's characteristic parameters (large event, total event rate, energy, rate, *etc.*) *vs.* pressure and spatio-temporal relations.

6 Conclusions

(1) The rock mass is fractured media. Its fracture is a nonlinear process. The accumulation of acoustic emission is closely related to the degree of damage. The in-situ monitoring shows that the method can predict fairly well. Experimental results about the AE characteristics of hard composite rock failure can provide failure development both in the pre- and post-peak region. AE records can be used in determining the different stress levels when the cracks appear.

(2) The couple method could enhance risk assessment and management and reduce risk and uncertainty. Hybrid applying experiment, numerical simulations and in-situ monitoring, the stability of large scale of mined-out area is evaluated. It provides new insight

into the mechanism of failure zones and crack development. There would be the foundation of quantitative predicting risk and controlling in time.

(3) This series of research can give more insight into the mechanism of failure behavior of rock. Furthermore, improving the technique of acoustic emission itself, including noise control, accuracy improvement and analogue tests *etc.*, will certainly enhance the quality of experimental results. Lastly, it can provide evidence that the acoustic emission monitoring is an appropriate technology to predict the dynamical hazard in coal mine.

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