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Experimental studies on pillar failure characteristics based on acoustic emission location technique

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Abstract: Acoustic emission (AE) technique is a useful tool for investigating rock damage mechanism, and is used to study the temporal−spatial evolution process of microcracks during the similar pillar material experiment. A combined AE location algorithm was developed based on the Least square algorithm and Geiger location algorithm. The pencil break test results show that the location precision can meet the demand of microcrack monitoring. The 3D location of AE events can directly reflect the process of initiation, propagation and evolutionary of microcracks. During the loading process, stress is much likely concentrated on the area between pillar and roof of the specimen, where belongs to danger zone of macroscopic failure. When rock reaches its plastic deformation stage, AE events begin to decrease, which indicates that AE quiet period can be seen as precursor characteristic of rock failure.

Key words: rock damage mechanism; pillar specimen; failure characteristics; temporal-spatial evolution; microracks; acoustic emission; location algorithm; quiet period

1 Introduction

Rock is a typical inhomogeneous and anisotropic material, and contains several natural defects with various scales, such as micro cracks, pores, fissures, joints inclusions, and precipitates. A great deal of acoustic emission (AE) events occurred when the rock specimen was subjected to a loading stage until failure. AE signal is associated with propagating of micro-cracks, and contains plentiful information of internal structure change on the rock. Therefore, the failure behavior could be interpreted by the AE results. More and more geotechnical engineering researchers have focused on the AE application into their studies [1,2].

The studies concerning microcracks temporal−spatial evolution process inside rock depends on the high-accuracy AE event location, and hence AE location algorithm becomes more important. The studies of AE location began in the 1960s. MOGI [3] had carried out line location and plane location by using analytic method based on the difference of P-wave arrival time detected by four sensors. SCHOLZ [4] had used the difference of S-wave arrival time and Least square algorithm to calculate the location of 22 large AE events, and pioneered the methods of AE location calculated by multi-channels signals. To date, many AE location algorithms have been developed. They can be classified into two different styles according to location theory, regional location and point location. Three types of sensor location approaches have been used, such as line location, plane location and 3-D location according to arrangement. Commonly used AE location algorithms include Least square algorithm [5], simultaneous inversion algorithm [6], relative location algorithm [7], Geiger location algorithm [8,9], and simplex location algorithm [10]. Based on these AE location algorithms, many research results of temporal-spatial evolution of microcracks within rock have been obtained [11−16].

In mines, there are lots of gobs that would cause stress concentration and result in pillar failure. Therefore, it is very meaningful to monitor pillar stability by using AE technique. But the precision of AE event location calculated by the above mentioned algorithms is not

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satisfactory when the fracture point is beyond the range of sensors array, and hence it cannot meet the requirement under complex mining conditions. In this work, a combined AE location algorithm based on the Least square algorithm and Geiger location algorithm after AE signal arrival time was determined by the Akaike Information Criterion (AIC) and Auto-Regression (AR) model was presented. In addition, pillar simulation experiment was carried out and major effort was considered into the current study. In particular, the AE concentrated characteristics and failure modes were identified during loading on pillar specimens.

2 Rock specimens and experimental techniques

2.1 Rock specimens

Granite and sandstone employed in the present study were prepared in accordance with the suggested methods by ISRM. PB1 and PB2 denote sandstone and granite, respectively. The cubic samples shown in Fig. 1(a) were performed the pencil break test. The granite samples PS1 and PS2 were used to carry out pillar simulation experiment shown in Fig. 1(b). The size and wave velocity of rock specimens are listed in Table 1.

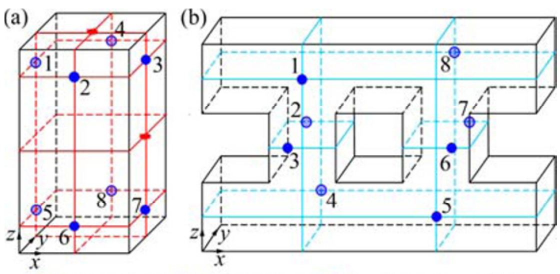

Fig. 1 Configuration of AE sensors: (a) Pencil break specimen; (b) Pillar specimen

Table 1 Specifications of rock specimens

Test item	Serial number	Dimension/mm	P-wave velocity/(m·s^{-1})
Pencil break test	PB1	109×100×198	3306
	PB2	70×70×146	4480
Pillar specimen	PS1	248×147×50	4660
	PS2	248×148×50	4080

2.2 Sensors arrangement

Eight Nano30 sensors with frequency sensitivity between 125 Hz to 750 kHz and a 40 dB pre-amplification (1220A-AST) were used in the AE system. These sensors were fixed on rock faces by gum band, and vaseline was used for coupling. Plastic cushions were sandwiched between steel platen and specimen to minimize noise generation due to friction. Figure 1 shows the arrangement of eight AE sensors.

2.3 Test equipment and loading way

A servo-controlled hydraulic testing machine with the maximum axial loading of 3000 kN was used in this experiment. The machine has a high sampling speed to record the load and displacement. In this work, uniaxial loading was applied and the loading rate was 20 kN/min. AE signals were real-time acquired using a multi-channel, high-speed AE testing and analyzing system, namely HUS (hyperion ultrasonic system). The temporal and spatial distribution of AE events within the specimen during loading was visually displayed in 3D by using a post processor. The threshold was set at 50 dB to gain a high signal/noise ratio. The sampling frequency was set at 2 MHz. Figure 2 shows the system of the experimental instruments.

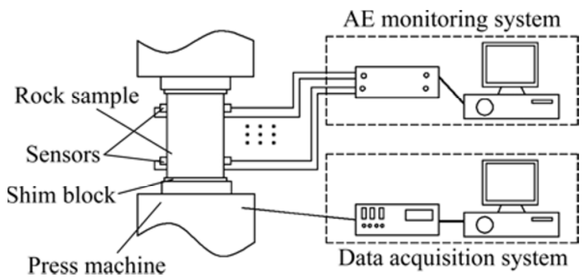

Fig. 2 Schematic diagram of AE and loading system

3 Location technique of AE events

3.1 Determination of P-wave arrival time

The determination of P-wave arrival time is based on assuming that waveform can be seen as normal state before and after arrival, and the best cut point is used as the time P-wave arrival time.

The data of waveform can be seen as a time series. The time series of *n* data are divided into two parts, one with the number of *k* data, and other with *n*-*k* data. For each value of *k*, auto-regression models (AR model) of *k* and *n*-*k* data were established and Akaike information criterion (AIC) was adopted to estimate the rationality of the models. The criterion, C_{ap}, is expressed as follows [2]:

$$C_{ap}=AIC_1+AIC_2=k\lg\sigma_1^2+(n-k)\lg\sigma_2^2+n(\lg 2\pi+1)+2(l_1+l_2+4) \quad (1)$$

where l_1, l_2, σ_1^2 and σ_2^2 are the degrees and variances of AR model of *k* data and *n*-*k* data, respectively. The value of C_{ap} of each *k* is calculated and the time to the minimum value of C_{ap} can be seen as P-wave arrival time (Fig. 3).

3.2 Location algorithm of AE events

The least square algorithm can only process one iteration whose location accuracy is much lower, but