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ACOUSTICS OF STRUCTURALLY INHOMOGENEOUS SOLID MEDIA. GEOLOGICAL ACOUSTICS

Detection of Cracking and Damage Mechanisms in Brittle Granites by Moment Tensor Analysis of Acoustic Emission Signals[1]

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Abstract—An acoustic emission (AE) testing of rock cracking was performed under uniaxial loading conditions by precut varisized circular holes in selected brittle granites. Based on AE-source location technique and AE-theory for moment tensor analysis, rules of the temporal–spatial evolution of micro-cracks in different failure mechanisms were explored and types of micro-cracks were analyzed as well. The results revealed that the micro-cracks are uniquely easy to generate in the positions where stress are concentrated. Tensile fractures are easy to form on the roof and floor of a circular hole, while shear fractures are easy to be found on both sides. The locations of initial cracks generated around the holes in the loading process are the direction or vertical direction of maximum principle stress. Macroscopic crack orientation agrees with the direction of maximum principle stress approximately. As the size of circular opening increases and the relative size of pillar decreases, shear cracks are dominant with the percentage more than 45%, tension cracks are fewer, accounted for less than 40% of the total events, and mixed-mode cracks represent a minimum proportion, despite the decrease of percentage of shear cracks. The findings of this work can serve for supporting design of tunnel or roadway to avoid collapse.

Keywords: rock, circular hole, AE, moment tensor, fracture mode

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1. INTRODUCTION

Currently, more and more underground engineering are being designed and constructed in brittle rocks of high stress. Underground excavation in such high stress areas would alter the mechanics, hydraulics and geological characteristics of the rock mass around the excavation body, form excavation damage zone and even cause collapse of the excavation body. The formation and development of excavation damage zone are serious threats to the safety of underground engineering. Therefore, the mastery of development characteristics of damaged areas surrounding a circular chamber is of great significance to the design of mining drifts and underground nuclear waste storage chambers.

However, as a complex natural geologic body, rocks will inevitably contain a wide variety of internal defects such as micro-cracks and micro-damages, which presents more challenges for the study of excavation damage zones surrounding deep high-stress circular chambers.

Formation of damage zones surrounding circular excavation body has been extensively studied by many scholars. To our knowledge, stress redistribution, excavation damage process and geological process of groundwater are three major causes of fractured zones [1–3]. And stress redistribution, as a consensus among all researchers, is believed to have the greatest damaging impact on the surroundings of circular excavation body. Haiqing Yang deemed that micro-cracks generated by local stress concentration around the circular excavation body should be responsible for the damaged area [4]. Shen and Mitaim found that the formation of damage zone was very sensitive to the development and propagation of micro-cracks [5, 6]. Chang presented that when there is an energy imbalance induced by unbalanced stress distribution, the generation and penetration of micro-cracks may contribute to the failure of rock or even rock mass [7]. Therefore, the study of evolution behavior of formation, propagation and penetration of micro-cracks inside the rock and of interactions among micro-cracks has an important role to the analysis and prevention of the forming of damage zones around a circular excavation body.

Right now many methods are available for studying cracks development in rock failure process, of which infrared thermal imaging, scanning electron microscopy, CT-technique and AE-technique are typically common [8–17]. However, despite the fact that pres-

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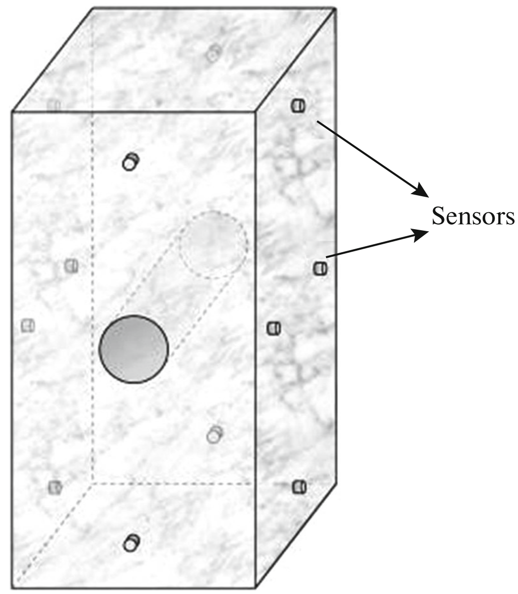

Fig. 1. Sample with precut holes and the arrangement of sensors.

ently the formation and penetration mechanisms of micro-cracks on the rock surface may be well observed by infrared thermal imaging and scanning electron microscopy, observation of internal cracks is very difficult to realize with the above two methods. In the electron microscopy-adopted studies of rock fracture, the fracture surfaces were all scanned after the rock failure, and a real-time monitoring of the temporal–spatial evolution process of the micro-cracks still cannot be realized. On the other hand, even though a real-time observation of the failure process of inner micro-cracks may be made by CT-technology, almost all current CT-devices adopt medical technology and cannot satisfy the requirements of large scale loading equipment in terms of scanning space.

As a nondestructive testing method, AE-technology, which can reveal the deformation and failure process of the material by utilizing AE location technology to realize a continuously and real-time monitoring of inner micro-cracks, has attracted many international mechanics researchers attention and has been widely applied in experimental study and field monitoring [15, 16]. Only the location where the micro-cracks are produced is not enough for the research of the formation of excavation damage zone around circular hole – the type and sliding orientation of cracks are also needed. Moment tensor analysis method, which shows promising application perspective in the future, offers a better way to do research on the interaction and evolution of cracks, along with the development of AE location equipment [18–22].

Although many significant researches have been carried out on the failure mechanism of micro-cracks by moment tensor theory analysis, these studies are mainly performed on integrated samples. However, some tunnels or drifts with high vertical stress can be seen as uniaxial loading because of the existence of a large number of underground engineering. In view of this, by selecting coarse-grained granites from Hongtoushan Copper Mine, this paper not only studies the AE temporal–spatial evolution behavior of varisized circular-hole rock samples during their failure process, but also the fracture types of micro-cracks and mechanisms of interaction among precut holes by moment tensor analysis method. The results of this work may serve as a basis for monitoring the stability of engineering rock mass.

2. TEST MATERIALS AND THE TEST

The object under study was coarse-grained granite, which is composed chiefly of quartz and plagioclase, usually with lesser amounts of one or more other minerals, such as biotite or hornblende. It is usually light gray, hard and firm. The rock samples are with rectangular shape 200 × 100 × 100 mm. A total of 9 samples were divided into 3 groups, in which circular holes of 20, 27 and 38 mm were cut respectively (Fig. 1). Three measurements of P-wave velocity were carried out in the intact area of rock samples before experiment, of which the results are listed in the table:

The loading system of this test is a servo-controlled machine with high stiffness and of maximum uniaxial loading of 3000 kN, and its rate is up to 40 kN/min. As for the AE monitoring system, the test adopted Sensor Highway II (SH-II) AE-system manufactured by the American Physical Acoustics Corporation. It is designed with 18-bit A/D conversion scheme for a real-time acquisition of the transient waveforms of AE and a simultaneous extraction of the signal characteristics of AE, completely meeting the test requirements. The main amplifier, threshold value, sampling frequency and sampling length of the monitoring system were set as 100, 50 mV, 2.5 MHz and 8 k respectively for a high-precision time-of-arrival of AE-signal.

This test utilized twelve Nano-30 sensors for AE-signal acquisition, with a frequency response range of ~125–750 kHz; and each sensor was configured with a preamplifier. In order to improve the signal reception qualities, the sensors were fixed with rubber belts; vaseline was also applied on the interface between sample and sensor for coupling. Meanwhile, polytetrafluoroethylene sheets are sandwiched between the specimens and the pressure heads to reduce friction noise. The arrangement of sensors is shown in Fig. 1. This test used arrival time difference among sensors to locate AE-events [23].