

# **Experimental Studies of Acoustic Emissions during Deforming and Sliding of Typical Discontinuous Rocks**

**Supervisor: Ma Jin (Dr, & Prof)**  
**Candidate: Zeng Zhengwen (M. Eng)**  
**Major: Applied Tectonophysics**

**Graduate School  
University of Science and Technology of China  
&  
Institute of Geology  
State Seismological Bureau, People's Republic of China**

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# Abstract

With the rapidly increasing demands to natural resources, the scales of geotechnical engineering projects are expanding. On the other hand, people pay more and more attention to natural environments and wish to reduce the damage caused by geological disasters such as earthquakes, mine tremors, rock bursts, rock collapse and landslides. These two trends require geologists to monitor and forecast the stability of rockmasses at different dimensions. Thus it is essentially important to acquaint the dynamic behavior of rockmass during the process of deformation and failure.

Discontinuity is a basic property of natural rockmasses. Discontinuous structures are key factors controlling the stability of rockmasses. They are also important factors to affect the dynamic behavior of rockmasses.

The failure of rockmasses at different scales has different effects. Earthquakes are caused by the failure of vast rockmasses. Mine tremors, rock bursts, rock collapse and landslides are resulted in by the failure of mid-size rockmasses. Fractures and slips in laboratory and in-situ rockmass tests belong to small scale failures research results of solid mechanics, seismology, geophysics and other related sciences show that failures at micro-, meso- and macro- scales not only are similar to each other in phenomena, but also have common essences. From this point of view, the dynamic processes of natural rockmasses are failure in earthquakes, mine tremors; rock bursts, rock collapses and landslides are similar. And all of them may be simulated by the dynamic process of deformation and failure of laboratory rock mass models and described by the accompanied acoustic emission (AE) events.

Based on the results of former studies and combined theory of tectonics-physics with practice of engineering geomechanics of rockmass, deformational fracture and frictional slide experiments were carried out with typical discontinuous rockmass models. With a multi-channel digitalized AE acquisition system, full waveforms of more than 12,000 valid AE events were recorded in experiments. By analyzing more than 8,800 of the recorded AE events thoroughly, temporal and spatial characteristics of AE during the deforming and sliding processes of typical discontinuous rocks were obtained.

Energy sequence of AE events is important to describe the failure process of rockmass. It is found that type of energy sequence of AE events during the deformation and failure process of single-joint rockmass change with the joint angle  $\theta$ , the angle between the joint and the axial load. When  $\theta$  is relatively small, e.g.  $\theta = 30$  or  $35^\circ$ , AE energy distribution show a type of "main fracturing pattern". There are only a few AE events before rockmass failure. Most of the AE energy concentrated on the AE event occurred at the moment of failure. With the increment of  $\theta$ , e.g.  $\theta = 40, 45$  or  $60^\circ$ , AE energy distribution show a type of "group fracturing pattern". There are many AE events before failure. AE energy distributes in more AE events and more homogeneously. In relation to natural earthquake conditions, the former type of AE energy sequence corresponds to "main earth quake pattern" seismological model and the latter to "group earthquake pattern" seismological model.

AE b-value is a parameter to describe the dynamic features of rockmass deformation and failure, which was developed from the Gutenberg-Richter relation in seismology. The studies showed that during the deformation and failure of rockmass with

different structures, there are two types of AE b-value dynamic curves — the hill-shaped and the step-shaped. The hill-shaped b-value dynamic curves correspond to progressively stable fracturing of intact specimens, and the step-shaped b-value dynamic curves to abruptly unstable fracturing of specimens with planar discontinuities. On the other hand, AE b-value dynamic curves during rock frictional sliding may also be classified into two types —the saw-tooth –shaped and the plate-pillar-shaped. The saw-tooth-shaped b-value curves represent irregular stick-slips on rough sliding surfaces. The plate-pillar-shaped b-value curves correspond to regular stick-slips on smooth surfaces.

Traveling features of AE rays in discontinuous rockmass are not only important to the choice of adequate method for determination of AE event location, but also significant to properly understanding research results of seismic tomography (ST). By comparing the theoretically calculated relative delay times with the experimentally measured relative delay times of AE rays from different emitting points of regular single joint rockmass models before and after failure, it is found that traveling features of AE rays are influenced by pre-existing joint and post-generating fractures, with the pre-existing joint playing the dominant role. Due to the two effects, there are many differences between the calculated and the measured AE relative delay times. The sequence orders of calculated and measured AE relative delay time are different. Theoretical blind points and experimental blind points are not the same. In general, the effect of the pre-existing joint makes a large amount (about 50%) of practical AE rays travel faster, a few (about 10%) travel slower, and some (about 40%) remain no significant differences. On the other hand, the fracture effect makes most practical AE rays travel slower. But this effect is closely related to the orientation of the pre-existing joint. In the case of single joint models, the effect becomes more serious in small joint angle models. AE rays paralleling to the joint or passing through the joint with small angle travel faster. In contrast, AE rays that received at points far from the joint and emitted from points in dipping exposures of the joint or from points near the reviving points travel slower. AE location errors caused by these two effects are too large to accept in comparing with the dimensions of the model and the joint. So instant AE velocity fields are suggested to apply in determining locations of AE events occurred in the deformation and failure of jointed rockmass models. In case of inaccessible to instant AE velocity field, relative determination of AE locations are proposed in terms of the relative orders of AE arrivals with references to their waveforms in different channels.

Geometry and location of the fractured surface are fundamental in describing the failure features of discontinuous rockmass. With the results of relative location determination method, it is found that geometry of the fractured surfaces in single joint rockmass is controlled by the joint angle  $\theta$ . With the increment of  $\theta$ , the fracture mode of single joint rockmass change from sudden failure accompanying with locally concentrating of AE events to progressive failure with AE events dispersing through the whole joint layer. In correspondence, the fractured surfaces vary from simple continuous interface of rock-joint layer to complex discontinuous inner-joint layer sub-fractures. For complex jointed rockmass, the deformation and failure process are governed by a (set of) main discontinuity. AE events show temporal concentration on several spots (points). Strong AE events occurred at or near the crossing part of discontinuities.

Studies on the spatial distribution and migration of AE events during the process of frictional sliding of rock are significant to understanding the complexity of recurrence

and migration of continental natural earthquakes. According to the research results, strong and weak AE events show compensational characteristics. Areas distributed with more strong AE events on the sliding surface have less weak AE events. While local recurrence is the first tendency of all AE events they are governed by different factors in migration. Weak AE events are influenced by discontinuous structures and inner surface migration is the most favorable mode. Strong AE events are affected by distances and diagonal migration across the central sliding block is the easiest way. By defining the recurrence probability, PM, as the possibility to migrate certainly before occurring K events continually in the same area on the sliding surface, recurrence and migration of AE events during rock frictional sliding fit recurrence probability function as  $PR(K) = e^{-dk}$ , and migration probability function as  $pm(k) = 1 - ce^{-dk}$ , with statistical constants c and d showing opposite tendency in variation.