

Editorial

Damage and Fracture Behavior of Rock

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Received 26 March 2019; Accepted 26 March 2019; Published 2 May 2019

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Underground excavation will lead to stress redistribution, and stress redistribution will also cause the stress of surrounding rock near the excavation area to increase several times or even tens of times [1, 2]. Then, stresses easily exceed the microcrack initiation stress level inside the rock mass. Increased stress in surrounding rock can easily induce brittle failure of rock mass, and the existing literature also shows that brittle failure is a typical failure form of deep well engineering rock mass. At the same time, a large number of engineering practices show that deep ground pressure disasters such as rock burst, floor lag water inrush, and roof fall are all caused by crack propagation and connection in rock mass [3]. In fact, the sudden change of instability of deep well rock mass is the result of crack initiation, propagation, and macroscopic failure surface formation. Therefore, rock fracturing is also the starting point of disaster breeding in deep rock engineering. As far as the characteristics of rock mass are concerned, it is not isotropic material. After hundreds of millions of years of geological action, there are a large number of discontinuities in its interior. Discontinuities weaken the basic mechanical properties of rock mass to a great extent. However, after excavation, the effect of high stress makes the tip of primary crack in a state of high stress concentration, which is easy to induce crack initiation and propagation damage.

The nonlinear deformation behavior of geotechnical materials is induced by the propagation and coalescence of cracks and joints under external loads [4–6]; hence, the mechanical characteristics and failure patterns of the rock

mass are difficult to predict. Study on the damage and fracture behavior of rock will promote the understanding of crack propagation, coalescence, and failure modes of brittle materials with fissures. The failure process of rock mass is very complicated because it involves the combined effects of loading, joint geometry, environment effect, and size. The understanding of the crack initiation, propagation in complex stress condition, interactions between discontinuities, and excavation activities are actual challenging topics.

Over the past decades, a large number of studies on “Damage and Fracture Behavior of Rock” have been made in physical testing [7], numerical modeling [8, 9], and theoretical studies. And the experimental research is mostly common used. Recently, with recent rapid developments in computer science, many numerical methods have been suggested to simulate crack initiation and coalescence, and most of the simulation results show good agreement with experimental results. In this special issue, a series of papers where contemporary research in nature rock mass or brittle fractured rock-like materials was done are presented. The influences of joint/fissure geometry parameters, environment effect, loading condition, and size effect on strength and failure characteristics of jointed rock/rock-like specimens are evaluated. Moreover, the new equipment for rock fracturing recognition has also been discussed in this issue.

The discontinuities have a great influence on the mechanical behavior of rock mass. Most engineering cases, such as roadway excavation, rock slope, and pillars in deep mining activities, often require the estimation of the strength

and failure characteristics of a rock mass that contains a large number of discontinuities [10]. The influences of joint/fissure geometry parameters on failure mechanism of jointed rocks are developed in some papers of this special issue: "Cracking and Failure in Rock Specimen Containing Combined Flaw and Hole under Uniaxial Compression" (X. Fan et al.), "Dynamic Indentation Characteristics for Various Spacings and Indentation Depths: A Study Based on Laboratory and Numerical Tests" (J. Liu et al.), and "An Experimental Study on Mechanical Behavior of Parallel Joint Specimens under Compression Shear" (F. Wang et al.). In the above articles, many kinds of joint geometry parameters have been considered, such as combined joint (flaw and hole), joint spacing, indentation depth, nonoverlapping length, and inclination angle. The strength parameters and failure characteristics have also been analyzed and discussed. Moreover, in order to investigate the failure behavior of jointed rock mass under different stress environment, scholars have conducted a series of experimental or numerical research studies; the influence of loading condition on mechanical behavior jointed rock mass is analyzed in the following papers: "The Effect of Confining Pressure and Water Content on Energy Evolution Characteristics of Sandstone under Stepwise Loading and Unloading," "Mechanical Behavior of Shale Rock under Uniaxial Cyclic Loading and Unloading Condition," "Effects of Cyclic Loading on the Mechanical Properties of Mature Bedding Shale," and "Experimental Study on the Shear Behavior of Bolted Concrete Blocks with Oblique Shear Test."

The failure mechanism of jointed rock mass is regulated not only by joint geometry parameters but also by the environment conditions. With the change of environmental factors (such as thermal environment, freezing-thawing cycles, and dry-wet cycles), the failure characteristics of jointed rock mass will exhibit big difference when compared to those in nature condition. In this issue, the environment factor has also been considered. For example, the effect of thermal environment on the mechanical behaviors of rocks was investigated by H. Su et al., and the details are covered in their paper "Effect of Thermal Environment on the Mechanical Behaviors of Building Marble." H. Deng et al. have done a series of experiments to investigate the damage characteristics of sandstone under coupled effect of freezing-thawing cycles and acid environment ("Damage Characteristics of Sandstone Subjected to Coupled Effect of Freezing-Thawing Cycles and Acid Environment"). The results show that coupled effect of acid corrosion and recurrent freezing-thawing cycling causes much more serious deterioration to sandstone samples than acid corrosion. In the paper "Constitutive Model and Damage Evolution of Mudstone under the Action of Dry-Wet Cycles (M. Hu et al.)," a customized model test container and a novel test method are applied to study the decay rate of mudstone under different temperatures and over multiple dry-wet cycles. S. Li et al. investigated the influence of acid solution and immersion time on the physicomaterial properties of sandstone, and the corrosion mechanism of sandstone attacked by the acid

solution is discussed with the results of SEM tests (Experimental Study on Physicomaterial Properties of Sandstone under Acidic Environment). The results showed that the deformation characteristics of sandstone samples under acid attack are characterized by the softening of rock, and the softening degree gradually increases with the increase of the acidity and the soaking time. In the paper "Damage Features of Altered Rock Subjected to Drying-Wetting Cycles," Z. Qin et al. conducted a series of experimental tests, and the effects of drying and wetting cycles on the mechanical parameters of pit rock were investigated. It was found that uniaxial compressive strength and elastic modulus decreased as the number of dry/wet cycles increased. At the same time, an exponential function was established to describe the quantitative relationship between the mechanical parameters and the number of dry/wet cycles.

In recent years, with the development of laboratory testing technology, more and more new technologies have been applied to the study of rock crack propagation or damage recognition. Then, testing technology has also been highlighted in this issue. The papers "Use of Acoustic Emission for the Detection of Brittle Rock Failure under Various Loading Rates" and "Researches on Damage Evolution and Acoustic Emission Characteristics of Rocks" (Y. Chen et al.) used the technique of acoustic emission to investigate the damage evolution of rocks. In their paper, a statistical damage model has been established to formulate analytical constitutive relations for deformation behavior. Moreover, comparisons between predicted results and experimental data also show a good agreement. J. Li et al. (in their paper "An NMR-Based Experimental Study on the Pore Structure of the Hydration Process of Mine Filling Slurry") used low-field nuclear magnetic resonance (LF-NMR) to study the evolution of porosity in the process of filling slurry hydration. And the results showed that the higher the mass concentration of the filling slurry, the slower the hydration reaction, the smaller the average size of the pores, the higher the proportion occupied by harmful pores, and the lower the proportion occupied by multiharmful pores. Recently, the DICM has been widely used to identify the crack nucleation and propagation in brittle materials, and the new cracks can be well described by the displacement gradient evolution corresponding to time and space. Based on DICM, H. Kong et al. conducted a series of experiments, and the movement and fracturing process of the overlying strata during excavation are observed and studied (Application of DICM on Similar Material Simulation Experiment for Rock-Like Materials). The results also indicated that the DICM is entirely feasible to use in the large-scale full-field deformation measurement on complex rock structures, and it is of theoretical importance for testing for rock-like materials.

Compared with the in situ test and laboratory test, the numerical simulation is an economical and practical method to simulate the failure process of jointed rock masses. Overall, most of the numerical results show good agreement with experimental results. In this special issue, several kinds

of numerical methods will also be discussed in papers. Hydraulic fracturing is one of the most important factors affecting the safety of earth and rockfill dam. And more and more research studies have paid attention to the safety design of high rockfill dams. In the paper “Numerical Simulation of Hydraulic Fracturing in Earth and Rockfill Dam Using Extended Finite Element Method,” E. Ji et al. used the extended finite element method (XFEM) to simulate the hydraulic fracturing behavior in an actual high earth and rockfill dam. The possibility of hydraulic fracturing occurrence is discussed and analyzed, and the critical crack length is obtained when hydraulic fracturing occurs. A comparison between the hybrid FDEM and continuous techniques has been done by N. Vlachopoulos and I. Vazaios (The Numerical Simulation of Hard Rocks for Tunnelling Purposes at Great Depths: A Comparison between the Hybrid FDEM Method and Continuous Techniques). The finite element method (FEM) and hybrid finite-discrete element method (FDEM) are used to model the failure behavior of jointed rock mass during excavation, respectively. And the results indicated that the FDEM is more capable of capturing the highly damaged zone (HDZ) and the excavation damaged zone (EDZ) compared to results of continuum numerical techniques in such excavations. In the paper “Numerical Tests Research on Mechanical Parameters of Rockmass considering Structural Plane Combination Characteristics,” J. Wei et al. conducted the triaxial numerical test through the discrete element method, and the size effect of rock mass was also studied by using the characteristics of the numerical test. Notably, in this issue, apart from the numerical methods that have been mentioned above, there are also other methods developed by scholars and been used to model the failure process of rocks or rock-like materials.

The influence factors for damage and fracture behavior of rock include but not limited to the above aspects. At the same time, the new experimental testing technology or numerical methods for fracturing recognition are not fully presented. Many excavation activities like deep mining have to face the crack propagation and coalescence in rock mass. For deep mining, with the increase of mining depth, the in situ stress increases. At the same time, the geological environment becomes more complex. Then, the crack initiation and propagation become more complex and unpredictable. So, there are still more unknowns in this field waiting to be explored and discovered in the future.

Conflicts of Interest

The editors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

The editors would like to thank all colleagues who have paid attention to this topic and have submitted manuscripts to this special issue. The editors have been able to do this, thanks to the excellent works from the authors. At the same time, they also would like to thank all the

reviewers for their contribution in reviewing the submitted manuscripts.

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