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Editorial

Special Issue on Experimental Investigation and Numerical Modeling of Rock Brittle Failure Behavior under High Stress Conditions

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1. Introduction

To meet the demands of the mining, hydropower, and transportation industries, deep rock mass engineering in China has rapidly developed. As the excavation depth increases, the stress environment in which the rock mass is located becomes particularly complex and diverse. Correspondingly, problems, such as excavation disturbance, blasting, seepage, and water heat coupling, can lead to increasingly serious deformation and damage accidents in rock engineering, thereby posing a threat to normal operations. The lack of comprehensive understanding of the brittle failure behavior and mechanical properties of deep rock masses seriously hinders the effective prevention and control of deep catastrophic accidents. Conducting research on the brittle failure and mechanical behavior of rock masses under high-level stress is still a comprehensive challenge, and it is of great significance for the stability assessment of deep rock mass engineering. This was the reasoning behind publishing this special feature on Experimental Investigation and Numerical Modeling of Rock Brittle Failure Behavior under High-level Stress Conditions.

This Special Issue was introduced to collect the latest research on related topics. More importantly, the failure mechanism and mechanical behavior of rock mass under high-level stress conditions were investigated to provide a reference for the design and construction of deep rock mass engineering. Thirty-one papers were submitted to this Special Issue, and thirteen papers were accepted (i.e., 42% acceptance rate). Looking back on the Special Issues, various topics were addressed, mainly on the failure behavior and mechanical characteristics of microscopic, macroscopic and engineering rock masses under statics, dynamics, seepage and high-temperature conditions.

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2. Failure Behavior of Microscopic and Macroscopic Rock Masses

Due to the emergence and development of CT scanning low-field nuclear magnetic resonance (LF-NMR) and scanning electron microscopy (SEM), research on the microscopic and macroscopic mechanical properties and failure mechanisms of rock masses has dramatically developed. The damage evolution law and failure mechanism of mudstone under uniaxial compression were carried out by Duan et al. [1] using high-resolution CT scanning equipment. Combining digital core technology and the digital volume image correlation method, the 3D characterization of the mesostructure and the evolution process of the localized damage of mudstone were analyzed. The results showed that the aggregated mineral zone was prone to local deformation under loading, and the final propagation shape of cracks was very consistent with the propagation shape of the mineral zone. The progressive fracture process and mechanical behavior of multi-scale rocks, considering the microstructure, mesostructure, and macro joints, were estimated using a failure process analysis (RFPA) simulator and digital image processing technology [2]. The effects of shale fractures, mineral spatial distribution, and joints on the fracture formation process were studied for Brazilian splitting and joined rock masses, respectively. The results showed that the multi-scale, micro-to-macro failure process of brittle materials be estimated using the finite element parallel computing simulation method and digital images. The effects of saturation and impact loading on the dynamic mechanical behavior of frozen red sandstone were investigated using a low-temperature split Hopkinson pressure bar system (LT-SHPB) [3]. The dynamic strength, elastic modulus, and brittleness index of the frozen sandstone under impact loading tended to increase, and then decreased with saturation. However, the ultimate deformation capacity of the frozen sandstone showed the opposite trend. Additionally, the energy dissipation capacity of the frozen sample first increased, and then decreased with increasing saturation. The dynamic strength, elastic modulus, and peak strain of the frozen sandstone showed a significant strengthening effect, while its brittleness index gradually decreased at full saturation as the impact load increased. The dynamic evolution of the microstructure of the frozen sandstone due to changes in saturation was estimated using low-field nuclear magnetic resonance (LF-NMR) and scanning electron microscopy (SEM).

3. Failure Behavior and Mechanical Characteristics of Rock Mass under Complex Stress Conditions

To understand the tensile strength of macroscopic rock masses, three respective scholars studied the failure behavior and mechanical properties of conventional, frozen, and temperature–water coupling rock samples. The effect of layer orientation on strength and failure patterns of the layered rocks under direct and indirect tension via experimental and numerical tests were discussed by Gao et al. [4]. The results showed that the tensile strength, failure patterns, and progressive deformation of the layered rocks were significantly affected by the dip angle of the bedding planes. Moreover, the tensile strength obtained in the direct tension test was more accurate than that of the Brazilian disc test. The modified Single Plane of Weakness (MSPW) failure criterion was proposed to predict the tensile strength of layered rocks based on the failure modes of direct tension. The effectiveness of the failure criterion was verified. The original rock specimens were mined and processed in Yulong Copper Mine, and artificially frozen fractured marble specimens were made. Based on physical experiments and numerical simulations, the failure mechanism and mechanical properties of the Brazilian splitting of frozen rocks were studied by Wang et al. [5]. The test results indicated that frozen rock samples exhibited typical brittle failure characteristics. The tensile strength of frozen rock gradually decreased with the increase in the width and length of the ice-filled crack. It first decreased, and then increased with the increase in the ice-filled crack angle. The dynamic tensile properties of annular sandstone specimens under the influence of temperature and water were studied by Ping et al. [6]. The variation in the mass, volume growth rates, density growth rate, dynamic compressive strength, average strain rate, and peak strain with water temperature was evaluated. The results showed that the changes in the dynamic properties of sandstone specimens were not due to their own material composition, but due to the damage to their structure caused by the temperature–water coupling effect.

Furthermore, the seepage characteristics, failure mechanism, and mechanical behavior of rock masses under seepage and dynamic loads were analyzed. Firstly, the seepage characteristics during the stress–strain process of limestone under high water pressure were assessed in an experimental test by Bao et al. [7]. A tool to predict the formation of the seepage channel, namely, acoustic emission positioning technology, was proposed. The results suggested that the sudden drop in the stress–strain curve after its peak indicated the full formation of shear fractures and seepage paths. The dynamic and real-time development of microfractures can be monitored with acoustic emission technology and via seepage monitoring. Then, experiment research was conducted on soft siltstone specimens under a combination of dynamic and static loads by Dong et al. [8]. The mechanical properties and acoustic emission characteristics of soft rocks were quantitatively revealed using a creep disturbance impact loading system and acoustic emission system. The results indicated that the deformation of siltstone specimen increased with the increase in the initial average stress. As the initial average stress increased, the maximum load first decreased, then increased, and finally decreased. Moreover, the influence of the elastic modulus of each loading step on the damage evolution of the specimen under dynamic disturbance was analyzed using RFPA. The wave form characteristics during the damage of the specimens were analyzed by extracting signals at the key points. Finally, the influence of the angle on the dynamic crack propagation behavior under stress wave action was investigated by Zhang et al. [9]. The dynamic propagation behavior of cracks and new cracks around the blast hole were analyzed using AUTODYN's numerical analysis software. The stress wave theory was successfully used to analyze and predict the dangerous area after failure, proving that cracks ranging from 45° to 90° will induce characteristic cracks, which will accelerate the instability of the model.

4. Discussion on Failure Behavior and Mechanical Problems of Engineering Rock Mass

Currently, the reduction of crustal stress, stability analysis, and control technologies for engineering rock masses are hot research topics. The intelligent inverse method combining a particle swarm optimization (PSO) algorithm with a back propagation (BP) neural network was applied to the inverse analysis of crustal stress by Yan et al. [10]. The application was carried out using an underground powerhouse of Shuangjiangkou Hydropower Station as an example. The results indicated that the method improved the stability and accuracy of the inversion results. Referring to existing tunnel projects, nonelectronic equipment and electronic detonators were used for blasting tests and determining the impact of blasting construction on the range of rock loosening zones and the degree of rock fragmentation, respectively [11]. The results indicated that the range of loose rock circles around the tunnel, the decrease in wave velocity of loose rock masses, and the degree of rock fragmentation caused by normal blasting with nonelectronic detonators were larger than those caused by electronic detonators. Then, the surrounding rock stability of the excavated geologically weak section of the #2 diversion tunnel in the Xulong Hydropower Station was assessed by Qian et al. [12] using a numerical model. The results indicated that during the excavation process, the surrounding rock of the tunnel section was most significantly damaged near the arch crown and corner of the side wall with tensile failure. As the excavation progressed, the number of microseismic events at the corners of the arch and side walls gradually increased, and the energy of acoustic emissions steadily accumulated. Therefore, the likelihood of a collapse and rock burst in the area increased. Furthermore, the effect of the fracture geometric parameters on the failure mechanism and mechanical parameters of engineering rock mass in the dam site area of Lianghekou Hydropower Station were investigated using the ShapeMetriX^{3D} system and RFPA^{3D} in an uniaxial compression test [13]. The results showed that the fractured rock mass mainly represented a compressive–shear composite. Moreover, the influence of the fracture geometric parameters on the uniaxial compressive strength was greater than that of the elastic modulus.

5. Future Development

Although the Special Issue is closed, researchers still require a deeper understanding of the failure mechanism of deep rock masses during construction. In this case, this Special Issue will receive more attention, facilitate in-depth discussions, and encourage outstanding research.

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