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Simulation of rock dynamic failure using discontinuous numerical approach

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ABSTRACT

In this paper, an improved DDA method proposed by the authors is used to simulate the rock failure process under dynamic loading, and several SHPB tests on Brazilian discs with different angle pre-cracks are conducted for verification. The simulated main crack paths of different specimens agree well with the observations in the SHPB tests. In addition, the perforation process of a hard projectile into rock is also simulated, and some heavily discontinuous phenomena in impact failure are captured. It shows that the improved DDA method is able to simulate the failure behavior of rock under dynamic loading.

1. Introduction

The dynamic loading in rock engineering can be caused by earthquake, blasting, rockburst, mechanical vibration, among others. The mechanical properties and response of rock-like material are significantly different under quasi-static and dynamic loading. For example, numerous experimental studies have revealed that the compressive strengths of rock-like material phasely increase with the strain or loading rate. Rock mass inherently contains cracks or flaws which play an important role in dynamic failure, because the crack propagation and coalescence is the intrinsic mechanism of rock fracture. It is thus essential to understand the propagation behavior of crack and its influence on the failure process of rock mass subjected to dynamic loading.

With the development and wide application of split Hopkinson pressure bar (SHPB) test technique, extensive experimental and theoretical researches on the dynamic behavior of rock have been carried out. These researches mainly focus on the mechanical characteristic, failure criterion and constitutive model of rock under dynamic loading. In Ref. [1–10], the influence of strain rate on the strength or elastic modulus of rock, and the applicability of dynamic failure criterions have been investigated. Based on the dynamic experimental results of rock, the stress-strain relationship has been studied, and the overstress models have been established [11,12]. Besides, researchers have proposed some dynamic constitutive models of rock based on the fracture or damage mechanics, such as NAG-FRAG dynamic fracture model, BCM model, GK blasting damage model, and TCK model [13,14]. In these models, rock is assumed as homogeneous mass with cracks, but some vital parameters like the crack density are difficult to be determined due to the complexity of rock mass. Moreover, there are few researches on the correlation of macroscopic failure behavior of rock and microcrack growth process.

Compared with the laboratory experiment, the numerical simulation can trace the evolution of stress and strain state and analyze the influence of various parameters, and thus is considered to be an effective and powerful tool for the study on the dynamic response of rock. Lots of efforts have been contributed to the simulation of the dynamic failure process of rock, such as the work in the literatures [15–32]. For the continuum-based methods, such as finite element method and finite difference method, the common way to simulate the dynamic fracture of rock is to adopt element weaken algorithm or interface failure law associated with element apartment algorithm [15–23]. For instance, Zhu and Tang have studied the failure process of Brazilian discs subjected to dynamic loading by using RFPA (Rock Failure Process Analysis) code in which the elements are weakened in terms of elastic damage variable [22,23]. However, under the continuity and small deformation assumptions, the continuum-based methods are not capable for capturing the discontinuous spalling phenomenon in rock dynamic fracture. In contrast, the discrete medium methods including SPH method and discrete element method can reproduce the process failure of rock under high strain rate [24–32]. Nevertheless, in the discrete medium models, rock is treated to be completely discrete which is quite different with the real situation.

Actually, traditional continuum or discontinuum methods are not appropriate to describe the continuous-discontinuous evolution process of rock and meanwhile the large-displacement behavior after rock failure. Moreover, the dynamic failure mechanism of rock and the influence of internal cracks have still not been understood completely.

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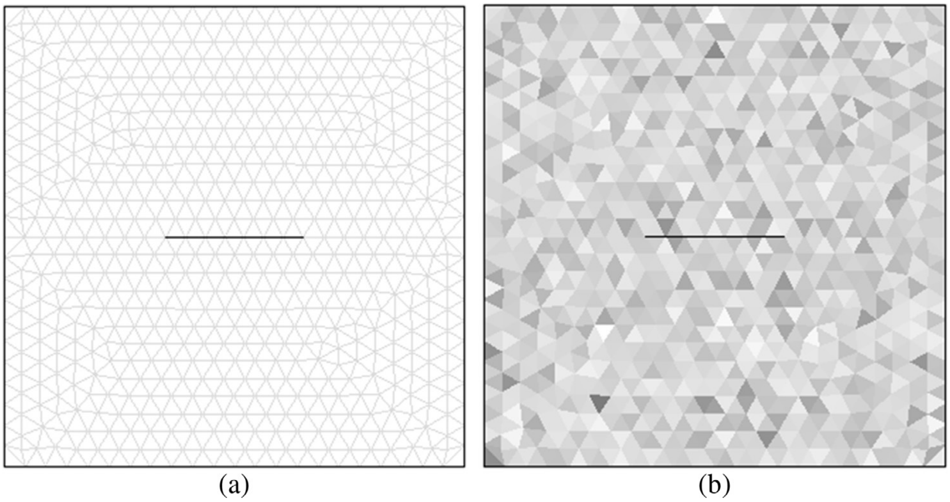

Fig. 1. The computational model of the improved DDA method.

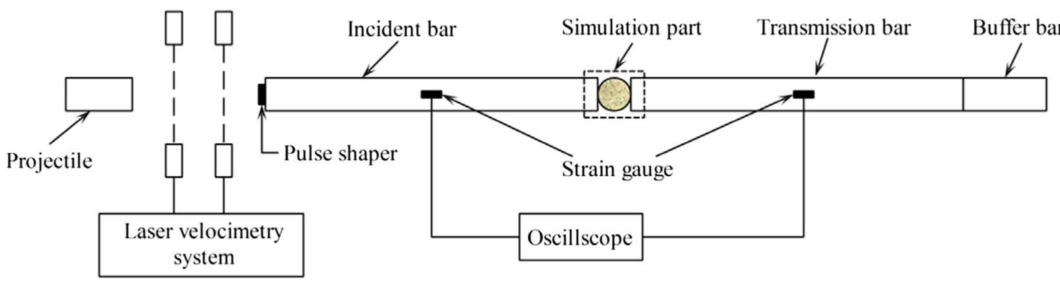

Fig. 2. Sketch of SHPB experimental setup.

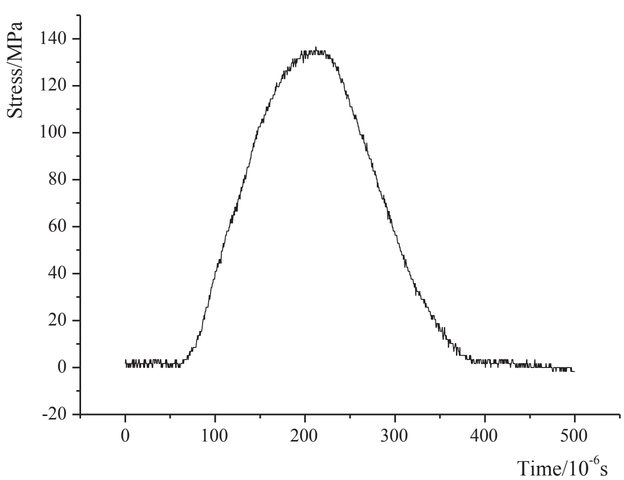

Fig. 3. The typical incident stress wave in SHPB experiment.

Therefore, further work is needed. In this paper, an improved DDA method proposed by the authors is introduced firstly. This method is capable for simulating the failure process of rock by applying the cohesive-fracture algorithm on the artificial joint. Then, the SHPB tests of Brazilian disc specimens with single pre-crack are performed, and the fracture process of specimens are simulated by the improved DDA method. Finally, the proposed method is used to simulate the perforation process of a hard projectile into rock.

2. Brief introduction of the improved DDA method

2.1. The computational model

The improved DDA method is established on the DDA algorithm proposed by Prof. Shi [33]. In the improved DDA method, the concept of artificial joint is introduced into the computational model. The interest area is discretized into a large number of triangular blocks, and the block boundaries in continuous region are defined as artificial joints. As shown in Fig. 1(a), the black block boundaries represent real joints, while the gray ones represent artificial joints. The triangular blocks are assigned different values of Young's modulus and Poisson's

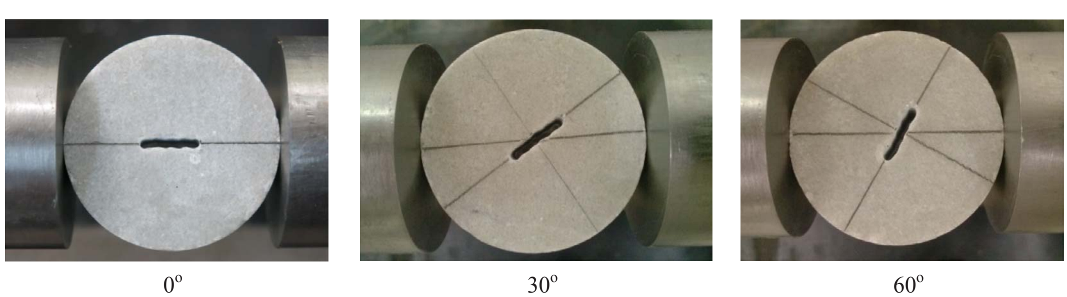

Fig. 4. Photograph of the pre-crack specimens.