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Evaluation on strength and deformation behavior of red sandstone under simple and complex loading paths

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ABSTRACT

Triaxial compression experiments were carried out for red sandstone to investigate its strength and deformation failure behavior under simple and complex loading paths. In this research, tested confining pressure is in the range from 5 to 35 MPa. Under simple loading path, the peak strength, residual strength and critical damage threshold of red sandstone all increase with the confining pressure, which are in good agreement with the linear Mohr–Coulomb criterion. To investigate the re-fractured mechanical behavior of pre-cracked red sandstone with different post-peak stress drops, two complex loading paths with only one specimen are put forward to obtain the strength and deformation parameters of red sandstone. The differences of strength and deformation parameters of red sandstone between simple and complex loading paths are evaluated detailed. The elastic moduli of red sandstone under simple and complex loading paths all increase nonlinearly with the confining pressure. It is suggested and recommended to predict the peak strength of rock under simple loading path by adopting complex loading path A (increasing gradually the confining pressure) not complex loading path B (reducing gradually the confining pressure). On the basis of the linear Mohr–Coulomb criterion, a kind of new method is put forward to revise the peak strength of red sandstone under complex loading path A, which is testified to be right and reasonable. The investigated conclusions are very significant for ensuring the stability and safety of deep underground rock engineering.

1. Introduction

The strength and deformation behavior of rock material are dependent to the loading path, which have been widely investigated in the past decades to understand and explore the fracture mechanism of various rock engineering (such deep underground rock engineering, and tunnel rock engineering, etc.) under different loading paths (Jaeger, 1967; Swanson and Brown, 1971; Crouch, 1972; Yao et al., 1980; Xu and Geng, 1986; Ferfera et al., 1997; Lee et al., 1999; Cai, 2008; Wang et al., 2008; Yang et al., 2011; Yang et al., 2012).

In the previous studies, two kinds of loading paths, i.e. conventional triaxial compression (Path I) and confining pressure reduction (Path III) (Figure 1) (detailed definition can be referred in the paper (Yang et al., 2011)), are often adopted to analyze the strength and deformation behavior of all kinds of rock material. On the influence of the loading path on the strength of rock, there are two kinds of contradictory opinions. One opinion regarded that the strength of the rock was independent to the stress loading path by carrying out triaxial compression experiment for granite and norite (Swanson and Brown, 1971; Crouch, 1972). Another opinion regarded that the loading path had a significant influence on the loading path. Xu and Geng (1986) studied the various loading paths causing strength, deformation and failure in hard and soft rocks. His results showed that the effect of two loading paths (Paths I and III) on the peak strength was related to lithologic character. Wang et al. (2008) thought that the cohesion of marble under Path III was distinctly lower than that under Path I, but the internal friction angle of marble under Path III had no obvious difference with that under Path I. But on the influence of the loading path on the deformation behavior of rock, Yao et al. (1980) carried out triaxial experiment for gabbro and marble under Paths I and III, which showed that the gabbro under Path III was more brittle than that under Path I, but marble under Path III could appear some brittle fracture even though under higher confining pressure.

As it is well-known to all, sandstone is a kind of typical sedimentary rock, which is widely distributed in all kinds of underground engineering. Up to now, some experiments on the influence of loading path on strength and deformation behavior of sandstone material have been performed in previous studies (Bésuelle et al., 2000; Baud et al., 2004; Feng et al., 2004; Charalampidou et al., 2011; Yang and Jing, 2011; Yang et al., 2012), but designed loading paths are mainly some simple loading paths, e.g. uniaxial compression and tension; Paths I and III. Shen et al. (2003) performed triaxial test of red sandstone under different loading paths, which analyzed the effect of different loading paths on the deformation of rock specimens. He concluded that the deformation of rock under different loading paths

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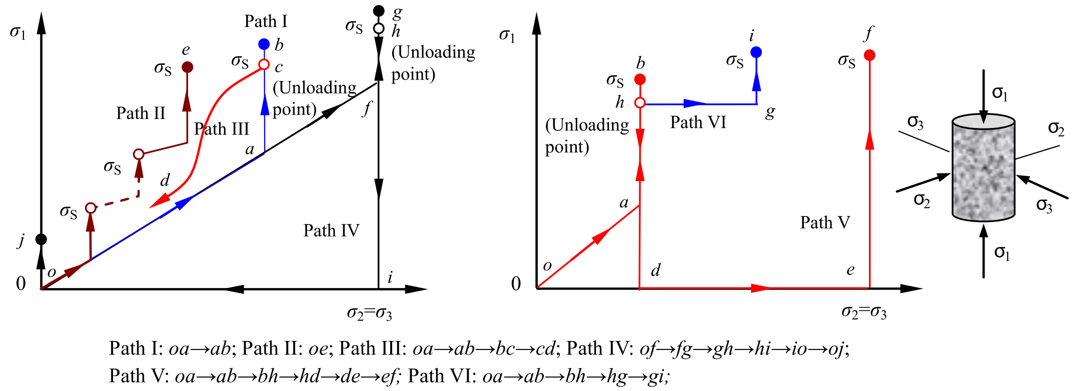

Fig. 1. Six different loading paths presented in the principal stress space (σ_3, σ_1) (Yang et al., 2011).

had nonlinear property, which was unlike the test results under Path I. Lee et al. (1999) preformed a series of hollow cylindrical triaxial tests to investigate the potential effect of loading path on the mechanical behavior of the Pei-Tou sandstone. His results showed that Kim and Lade's model was shown to be more accurate than the Mohr–Coulomb theory in predicting the failure surface according to the limited test data. Yang et al. (2012) performed the experimental study on red sandstone under Paths I and III, which analyzed the influence of confining pressure and loading path on the strength, deformability, failure behavior and acoustic emission locations of red sandstone.

However, real engineering rock mass experienced by loading path is more complex, which makes that mechanical behavior of rock under complex loading paths more and more significant (Xiong and Zhou, 2006; Yang et al., 2011). The re-fracture strength and deformation behavior of fractured rock mass are not clear under complex loading paths; therefore it is necessary to explore the strength and deformation failure behavior of rock under complex loading path, which is helpful to controlling the unstable failure of underground rock engineering structures. Yang et al. (2011) designed three complex loading paths (Paths IV–VI) (Figure 1) to investigate the re-fracture mechanical behavior of flawed coarse marble. He found that peak strength and deformation failure mode of flawed coarse marble depended on the loading paths. And then he analyzed the effect of complex loading path on strength, deformation and failure behavior of flawed coarse marble under different confining pressures; Xiong and Zhou (2006) carried out in-situ true triaxial tests on rock mass under complex loading paths, i.e. (1) σ_1 decreased, σ_2 and σ_3 maintain constant in the same course; (2) σ_1 decreased, σ_2 maintain constant and σ_3 decreased in the same course; (3) σ_1 decreased, σ_2 maintain constant and σ_3 increased in the same course. The results showed that when a principal stress decreased and another one increased in the same process, the deformation is nonlinear and anisotropic.

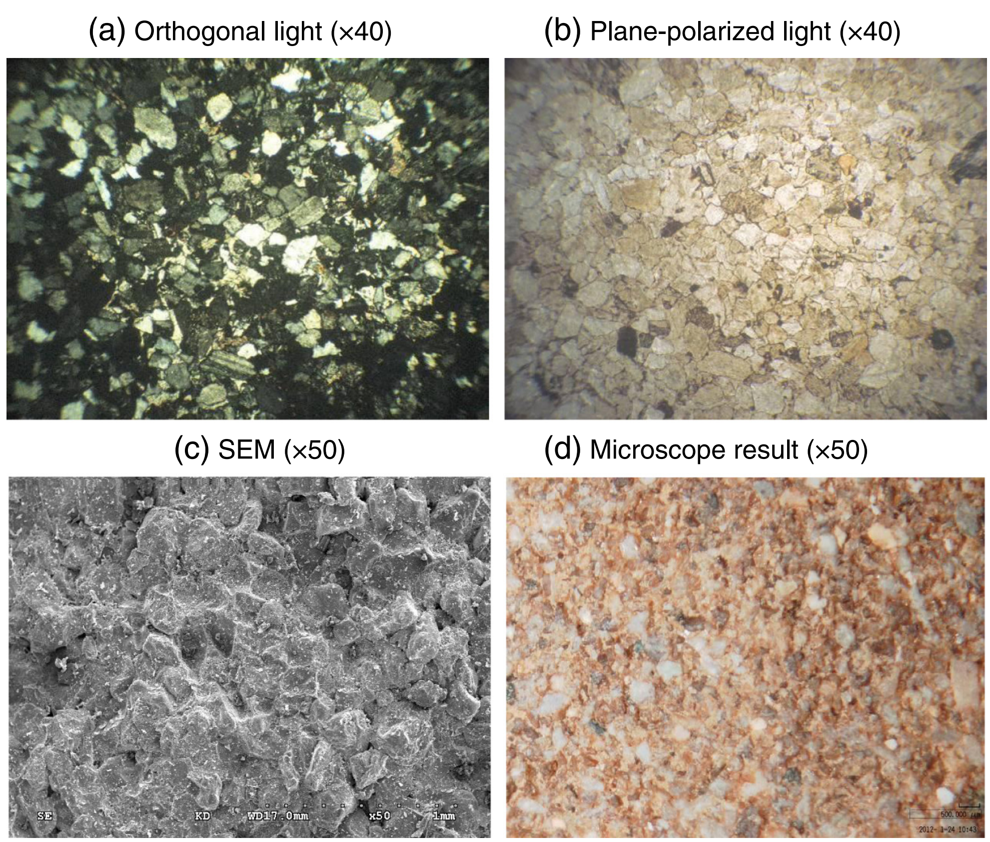

Fig. 2. Microscopic structure of red sandstone in the present study.