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Original Research Article

Experimental study on uniaxial mechanical properties and crack propagation in sandstone containing a single oval cavity

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ABSTRACT

The geometry and orientation of cavities in a rock mass has a significant influence on the failure mechanism and fracture propagation. The theoretical study of these behaviors is of great importance to enable fundamental understanding of unstable failure in rock mechanics. A very limited number of experimental studies have been conducted for sandstone specimens containing oval cavities. Sensitive parameters include the short axis (*b*) to long axis (*a*) ratio. Here, we enhance the present understanding of crack coalescence behavior around an oval cavity by applying uniaxial compression tests to sandstone cores containing manually inserted single oval cavity, combined with photographic and acoustic emission monitoring. The *b*:*a* ratio was varied from 1/4 to 1/1, thus the cross-sectional cavity shape evolved from oval to a fully circular opening. The experimental results showed that the stress–strain curves of specimens containing cavities exhibited multiple stress reductions prior to peak strength, which led to a sudden increase in the accumulated AE count-rate. As the *b*:*a* ratio was increased, the uniaxial compressive strength, crack initiation stress and peak strain of cavity specimens all decreased linearly. Tensile fractures, shear fractures, and compound shear-tensile fractures were all observed to emanate from the cavities. Compared to the intact specimen, the failure mode of cavity specimens comprised a mixture of tensile and shear cracks, emanating from the tips (or surfaces) of the oval cavity. For specimen with a cavity angle of 45°, when the *b*:*a* ratio was below 1/2, no tensile crack from the surface of short axis was initiated, whereas tensile crack was observed clearly after *b*:*a* = 1/2. This study not only increases our understanding of mechanical failure behavior in fractured rock, but also enhances our knowledge of underground tunneling or roadway stability.

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1. Introduction

Rock often contains either pre-existing or man-made cavities (fissures, joints, faults, etc.) [1]. The presence of cavities in a rock mass has a significant influence on its strength and deformation behavior according to the previous experimental and numerical results reported by Wang et al. [2]; Park and Bobet [3]; Lee and Jeon [4]; Cao et al. [5] and Yang et al. [6]. In these cases, the failure of rock usually begins with the initiation of the first crack at the perimeter of cavities. Fig. 1a shows a pillar fracture induced by the crack coalescence between two inclined fissures at a relatively low pillar stress [7]; Fig. 1b shows a step-path failure in the rock slope of the Xiaowan hydropower station, China [8]; Fig. 1c shows a typical wedge failure along the fault in a steep slope at the Three Gorges Project, China [9].

Extensive studies of crack initiation, propagation and coalescence behavior have been carried out on rock or rock-like specimens containing pre-existing cavities. On the one hand, for specimens with crack-like cavities [10] (see Fig. 2a), on the basis of laboratory experiments or numerical simulations performed by Wasantha et al. [11]; Fujii and Ishijima [12]; Wong and Einstein [13]; Sahouryeh et al. [14]; Li et al. [15]; Yang et al. [16]; Liang et al. [17]; Manouchehrian et al. [18]; Lu et al. [19] and Wong et al. [20], one can conclude that the fissure geometry (such as fissure angle, fissure length, inclusions) dominated the mechanical properties and failure process of rock. The main types of newborn cracks propagating from the tips of fissures were tensile wing crack, secondary shear crack and anti-wing tensile crack. It also reveals that specimens containing a longer fissure had lower strength, while the fissure angle had a non-linear relationship with peak strength. On the other hand, for specimens that contained hole-like cavities, the types of micro cracks [21], failure process [22], stress distribution [23], crack evolution [24], acoustic emission (AE) [25] and displacement field [26] around the pre-existing cavities have been investigated. When specimens prepared with man-made cavities were loaded under compression, the cracks always first initiated from the cavity perimeter. In accordance with the point of initiation and the propagation direction of the crack, the new cracks were identified as primary fractures at the tensile stress concentration zone, secondary fracture at positions inside the rock abutments, and sidewall slabbing at the concentration of compressive stress [27] and their locations were controlled by the cavity size and the confining pressure [28].

From the view point of engineering construction, circular and oval shapes are cross-sectional structures that appear in association with drilling for coal mine [29], rock mine [30] and

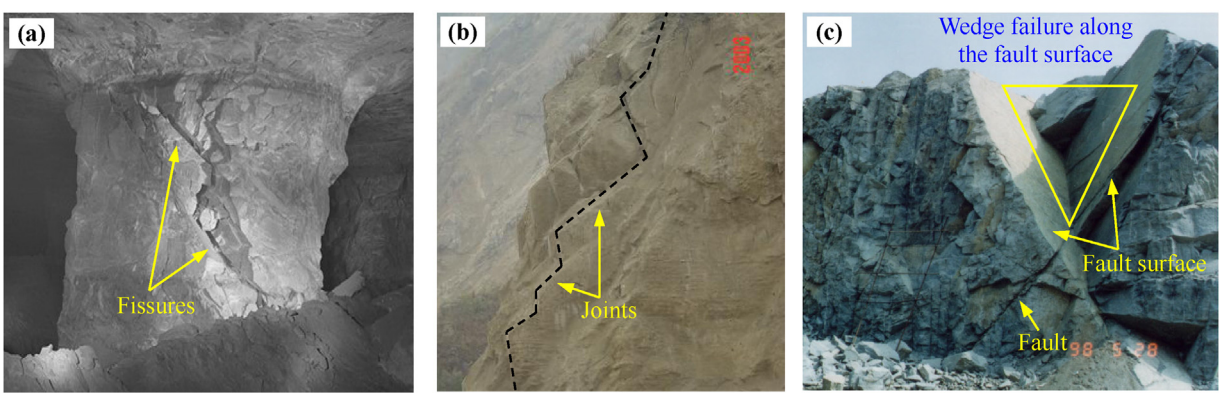

Fig. 1 – Photographs of rock engineering failure along cavities. (a) Unstable pillars failure in underground stone mines within the Eastern and Midwestern United States [7], (b) rock slope failure in Xiaowan hydropower station, China [8], and (c) a steep slope failure at the Three Gorges Project, China [9].

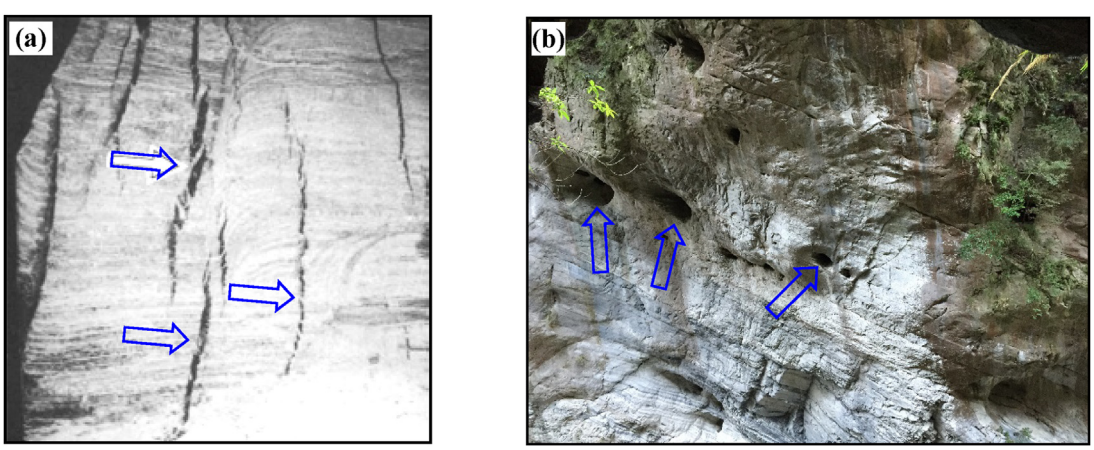

Fig. 2 – Photographs of rock containing different types of cavities. (a) Crack-like cavities [10] and (b) oval cavities [34].

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