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Numerical Simulation of Granite Plates Containing a Cylindrical Opening in Compression

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Abstract

In this paper, a numerical investigation of uniaxial compressive tests on prismatic specimens with single cylindrical pre-existing cavities in brittle rock is performed. To investigate the rock fracture around cavities and to assess the potential of the numerical model to simulate this behaviour, published laboratorial physical models on granite are simulated numerically with a Bonded-Particles Model (BPM) by using a distinct elements code. The numerical models are presented and the calibration of the BPM micro-parameters is described. Then, the calibrated numerical models are used to investigate the potential of the BPMs to simulate the fracture initiation and propagation of the physical specimens. It is concluded that the laboratory and the numerical observations are in good agreement.

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Keywords: BPM; Numerical simulation;Granite; Rock fracture

1. Introduction

The bonded-particle model BPM [1] has extensively been used over the past decade to simulate the mechanical behaviour and fracture of rock under a variety of loading configurations. In the BPM, the intact rock is represented by a dense packing of rigid spheres (in 3D) or disks (in 2D) bonded together at their contacts. The model is implemented in the Particle Flow Code PFC [2]. The BPM has been extended by Potyondy (2010) [3] to form the Grain Based Model (GBM) in order to simulate a rock grain structure of deformable, breakable or not, polygonal

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grains, cemented along their adjoining sides. The GBM has been successfully used to describe the crack initiation, crack damage and peak strength of Dionyssos marble specimens under uniaxial compression [4]. However, more computational effort and extended calibration procedures are normally required to match the macroscopic rock behavior with the GBM. With the recent addition of the Flat-Joint contact logic in the BPM [5] particle interlocking and friction resistance at the contact are imposed, restricting the relative movement of particles, and thus attaining the advantages of simulating the rock structure.

In this study, the BPM is used to model the fracture initiation and damage around cylindrical openings in compression (e.g. [6-8]). Published laboratorial physical models on granite [6] are simulated numerically with the two-dimension Particle Flow Code PFC2D by using the flat-joint contact model.

During a uniaxial compression test on the aforementioned physical models, three (3) phenomena should be appeared. First, the primary fractures (denoted in Fig. 1 with red colour) initially start from the upper or lower hole's boundary, extending upwards or downwards respectively. These fractures initiate due to the tensile stress concentration of the upper and lower regions of the hole's boundary. Then, remote fractures (denoted in Fig. 1 with blue colour) away from the hole are formed on regions with high stress concentration, extending upwards and downwards. The angle of their formation and appearance is depended of the examined material's characteristics. Finally, slabbing initiation (denoted in Fig. 1 with green colour) on the inner surface at the left and right hole's boundary is observed, due to the high compressive stress concentration on these regions. The more the material is brittle, the more apparent are the V-shaped notches at the left and right of the hole.

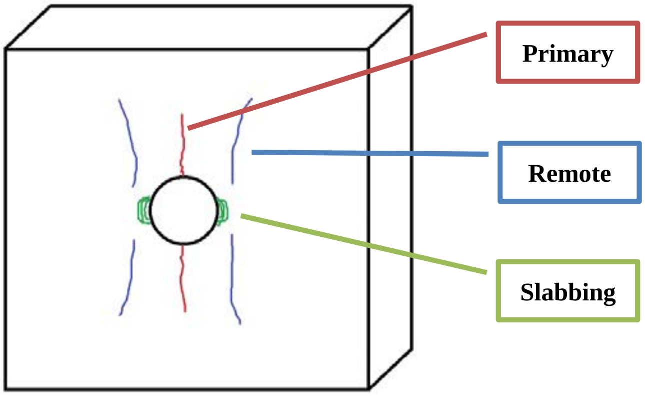

Fig. 1. The three (3) fracture types: primary fractures (red), remote fractures (blue) and slabbing (green).

Dzik & Lajtai (1996) [6] performed stress-controlled uniaxial compression experiments on prismatic granite specimens with circular holes of 20 mm, 40 mm, 60 mm, 80 mm and 100 mm diameter. These researchers noted that the specimen's dimensions were maintained with at least a 10:1 width to cavity radius ratio and at least a 15:1 height to cavity radius ratio. The formation of the first (primary) fracture was deduced from the output of strain gauges placed in the nucleation positions. The researchers note that Lac du Bonnet granite is a linear material, so the deflection of the stress-strain curves, deduced from strain gauge measurements, could only be the result of fracture nucleation. Under this assumption, a deflection of the load-strain curve, following the linear part of elastic deformation, is attributed to the arrival of the crack tip. For the larger radii cavities ($R > 20$ mm), the researchers attached a strain gauge to the interior curved face of the cavity. For the smaller cavities, the point of nucleation was interpreted from the first gauge which was fixed on the face of the block, just above the boundary perimeter. For primary fracture and slabbing, the fracture initiated at the perimeter of the cavity. According to Dzik & Lajtai (1996) [6], the fracture nucleation stress for all three fracture types, was size-dependent with size sensitivity being more pronounced in the small radius range ($R < 10$ mm).

In order to examine the effect of the boundary conditions, Dzik & Lajtai (1996) [6] performed a set of tests on three (3) identically sized blocks of granite: a) with the steel loading plates in direct contact with the specimen, b) by inserting teflon on the interface between the steel plates and the granite sample, and c) by implementing a granite plate on the interface between the steel plates and the specimen. All three tests concluded that the primary fractures propagated through the samples at similar stress levels, which means that boundary influences were