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Size Effect, Fracture Toughness, and Process Zone in Numerical Simulation of Rock Fracture

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Abstract

A bonded particle model is used in three point bending simulation of rock fracture to investigate whether size of fracture process zone is an intrinsic material property. Different sample sizes are used. The normal bond between particles at contact points is assumed to follow a softening behavior. The slope of the linear softening is considered a material property. An extensive numerical analysis is conducted to obtain the nominal tensile strength, apparent fracture toughness, and width of the process zone. It is shown that the apparent fracture toughness is a function of the specimen size and that the change in nominal tensile strength with specimen size can be captured by Bazant's size effect law. In addition, the numerical results suggest that inverse of width of crack tip process zone has a linear relationship with inverse of specimen size. The numerical results show a stronger relationship between width of process zone and specimen size for a material with a small brittleness number. On the other hand, for a more brittle material, specimen size has a small or no impact on size of process zone; process zone can be considered a material property when the brittleness number is greater than 10.

Keywords: Process zone, fracture toughness, size effect, numerical modeling

1. INTRODUCTION

Application of linear elastic fracture mechanics to quasi-brittle materials like rock and concrete, usually leads to imprecise prediction of the intact rock failure and safe design of structures. This inapplicability is proven to be caused by the existence of a localized damage zone prior to failure in quasi-brittle materials that is significant compared to the structure size. This nonlinear region affects both strength and stability of a rock structure. Therefore the study of process zone is an important subject in the fracture study of rocks and other quasi-brittle materials.

Several experimental studies have been conducted to investigate the size of process zone. Despite the general consensus on the existence of a micro-fracture or process zone at a notch or crack tip, it is not clear yet if size of process zone is a material property. Zietlow and Labuz [1] conducted some three-point bending tests on rocks using acoustic emission. They noted that the size of process zone does not differ significantly with the change in the beam size with the exception of the Rockville Granite leading them to refer to the process zone as an intrinsic property of the material. On the other hand, some researchers like Jankowsi and Stys [2] reported that the extent of the fracture process zone is of the same order as the cross section dimensions of the tested specimen.

Another arguable topic regarding the fracture of rock, involves the size dependency of fracture toughness. Peng and Johnson [3] reported that the fracture toughness of Chelmsford Granite is a physical property of the material. Also Schmidt and Lutz [4] came up with a similar result concluding that the fracture toughness of Westerly Granite for different specimen configuration is constant and should be considered as a material property of the rock. On the other hand, Palmer and Baker [5] claimed that the fracture toughness for a low cement refractory increases with the increase in specimen size. Khan and Al-Shayea [6] investigated the size dependency of fracture toughness of limestone. They concluded that the specimen diameter greatly influences the fracture toughness. As the specimen diameter increases, the toughness increases too.

The objective of this paper is to investigate the size dependency of the fracture process zone and fracture toughness by a comprehensive discrete element numerical simulation. Three point bending tests on notched specimens will be conducted. A softening bond model is used to mimic the damage zone around the notch tip. Different synthetic materials ranging from brittle to ductile will be used in the simulations.