Modelling of rock materials subjected to dynamic loading using a particle-based numerical manifold method

X. Li[1,2], Q.B. Zhang[1], J. Zhao[1,2]

Department of Civil Engineering, Monash University, Clayton, VIC 3800, Australia
School of Architecture, Civil and Environmental Engineering, Ecole Polytechnique Fédérale de Lausanne, Switzerland

Abstract

A particle-based numerical manifold method (PNMM) is proposed and implemented to simulate dynamic behavior of rock materials. By introducing the concept of particle presentation into the numerical manifold method (NMM), the PNMM inherits the flexibility in fracturing simulation from the NMM and gains the ability to simultaneously represent the microstructure and macroscopic behavior of rock. The basic idea of PNMM is to represent the microstructure of rock materials with a group of particles and simulate the macroscopic behavior of rock masses through polygonal elements. This is carried out by a dual-level discretization system. The first discretization is in the manner of the FEM, reducing the infinite degrees of freedom of a continuum to the finite degrees of freedom of polygonal elements. Then, each finite element is further discretized into a group of particles with varying diameters and material properties. The latter discretization does not further influence the degrees of freedom of the model, and the behavior of internal particles are obtained from the mechanical fields of their governing element. Benefiting from this characteristic, the degrees of freedom of the model is separated from the simulation of the microstructure of rock materials. Similar to the NMM, a dual-layer-cover system, i.e. the mathematical cover and the physical cover, is adopted in the PNMM. As the result of such a cover system, interpolation fields are free from the shape of modeling domain, so that fractures, especially those with complex geometry, can be naturally represented and conducted. In PNMM, microcracks can be induced at the micro-level between particles, based on the Mohr-Coulomb with a tensile cut-off criterion. And the coalescence of microcracks is to simulate the initiation and propagation of fractures on macroscopic level. A modified Johnson-Holmquist-Beissel (JHB) material model is incorporated into the PNMM to simulate the behavior of rock materials at high strain rates and pressures. In the original JHB model, a damage model with an analytical failure strain represents the material from an intact state to a failed state. The modifications to the JHB model are carried out by associating the damage coefficient with the number of microcracks. Numerical simulations show a good agreement with experimental results concerning the same conditions conducted by a split Hopkinson pressure bar and a plate impact facility.

Keywords: Rock Materials, Particle-Based Numerical Manifold Method, Johnson-Holmquist-Beissel Material Model, Strain-Rate Dependent Behavior