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Extended Abstract

Enriched Element-Free Galerkin Method for Numerical Simulation of Cohesive Crack Propagation and Normal Contact in Porous Media

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Abstract

This study addresses the numerical simulation of cohesive crack propagation and the normal contact in porous media. The penalty method is used to enforce essential boundary conditions. The strong discontinuity in the deformation field is effectively modeled by exploiting the partition of unity property of element-free Galerkin shape functions and employing an external enrichment strategy. To account for both crack initiation and propagation behavior in mode I, occurring under tensile stresses, as well as the compressive behavior at the edges of a closed crack in compression, the cohesive crack theory and the penalty method are incorporated into the existing computer program prepared for simulating porous media using the enriched element-free Galerkin method. The resulting algebraic system of equations is highly non-linear. Therefore, an appropriate approach must be employed to linearize and solve the equations. The Newton-Raphson technique is utilized in this study for this purpose. The results obtained from solving the problems of tensile cracks and cracks under compression (i.e., the contact of two crack edges) demonstrate the capabilities of the numerical formulation and the prepared computer program. Extending the developed numerical model allows for the modeling of crack growth issues in porous media in the presence of fluids, as observed in processes like hydraulic fracturing.

1. Introduction

Linear Elastic Fracture Mechanics (LEFM) is applicable for modeling crack growth when the nonlinear region at the crack tip is negligible compared to the crack length. However, this does not hold true for quasi-brittle materials like rocks and soil. Therefore, Barenblatt [1] proposed the cohesive crack model as an alternative to linear elastic fracture mechanics for modeling crack growth in quasi-brittle materials.

The nonlinear behavior of the material in the cohesive crack model is captured by applying cohesive forces to the crack edges along the fracture process zone.

Various numerical methods have been employed for modeling cohesive crack growth. Finite element methods have been predominantly used. For instance, Bažant and Li [2] used finite element methods to model cohesive crack growth in viscoelastic materials. Some researchers have utilized the enriched element-free Galerkin method for cohesive crack growth modeling. For example, Iranmanesh and Pak [3] used the enriched element-free Galerkin method for modeling hydraulic cohesive crack growth and investigated heat conduction and convection effects in hydraulic crack growth [4].

The primary goal of this research is to develop a computational framework for cohesive crack growth modeling. Furthermore, the normal contact is introduced briefly for potential future applications.

2. Formulation

The overall linear momentum equilibrium equation for the system is considered in the following form:

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$$\sigma_{ij,j} + \rho g_i = 0 \qquad (1)$$

Where σ_{ij} is the total stress tensor, ρ is the mass density and g_i is the acceleration of gravity. In order to model strong discontinuities in the deformation field, the Heaviside function is utilized for enriching the displacement field and the penalty method has been employed to enforce the normal contact constraint.

3. Results and Conclusions

To assess the program's performance in modeling cohesive crack growth, a well-known problem originally solved by Wells and Sluys in 2001 has been considered [5]. Geometry and boundary conditions for this problem are illustrated in Figure 1. the young modulus is 100 *MPa*, the tensile strength is 1.0 *MPa* and the fracture energy is 100 *J/m*.

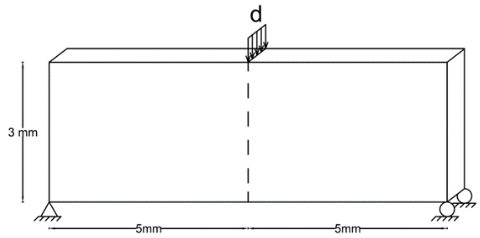

Fig. 1. Geometry and boundary conditions for the problem of cohesive crack growth

As crack initiate and propagate, the load-carrying capacity of the beam gradually diminishes. This trend is prominently evident in the force-displacement curve as shown in Figure 2.

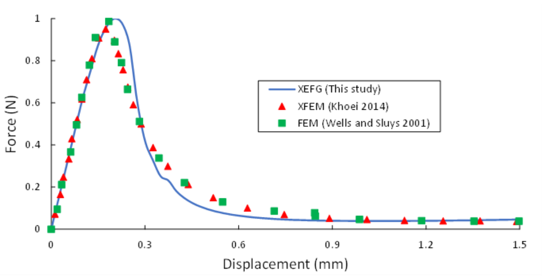

Fig. 2. The force-displacement diagram of the examined beam.

Also, to investigate the performance of the program in normal contact problems, the example which has previously been solved by Liu and Borja [6] using the finite element method is considered. A square domain with linear elastic behaviour with a horizontal crack in the middle of the domain's height and its entire length is considered. The upper surface of the domain is displaced vertically downward by 10 centimetres.. Therefore, the crack edge surfaces along their entire length will be under normal contact. The material's elastic modulus is assumed to be 104 *MPa*, and the Poisson's ratio is 0.3.

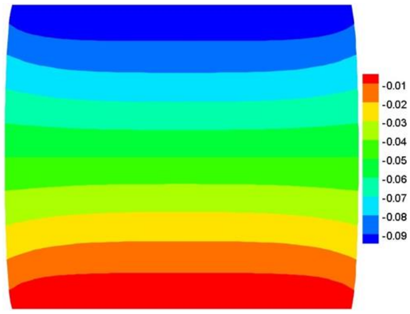

Fig. 3. Vertical displacement contour

Figure 3 illustrates the vertical displacement contour which shows the capability of the produced program in modelling normal contact problems with the developed element-free Galerkin method and penalty technique.

4. References

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