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Analysis of concrete fracture using a novel cohesive crack method

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A R T I C L E I N F O

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A B S T R A C T

Numerical analysis of fracture in concrete is studied with a simplified discrete crack method. The discrete crack method is a meshless method in which the crack is modeled by discrete cohesive crack segments passing through the nodes. The cohesive crack segments govern the non-linear response of concrete in tension softening and introduce anisotropy in the material model. The advantage of the presented discrete crack method over other discrete crack method is its simplicity and applicability to many cracks. In contrast to most other discrete crack methods, no representation of the crack surface is needed. On the other hand, the accuracy of discrete crack methods is maintained. This is demonstrated through several examples.

1. Introduction

The fracture process of structures made of quasi-brittle materials such as concrete is characterized by the formation of microcracks that eventually coalesce and lead to the formation of continuous macrocracks. Though methods exists that smear treat cracking in a smeared sense [1–15], it is believed that many applications require the description of discrete cracks. Crack propagation in concrete materials is associated with localization of the strain field, which, in case of fully open macrocracks becomes singular across the crack. Obviously, numerical analyses of this class of problems require robust models which adequately represent the discontinuous character of the fracture process. For the modeling of the non-linear material behavior in the vicinity of the crack tip cohesive crack models [16–25], which take into account a gradual transition from full material strength to zero material strength, are generally adopted. This is necessary for materials with strain softening since the use of pure continuum models lead to mesh dependent results [26].

Since the mid of the 1960s considerable progress has been made in developing models to describe the evolution of cohesive cracks in quasi-brittle materials using continuum-based approaches such as plasticity or damage formulations, rotating or fixed crack models, which, since the mid of the 1980s, have been enhanced by means of adequate regularization techniques (see, e.g. [1,27–29] for a smeared representations of cracks). At the same time, models allowing for a discrete representation of cracks have been developed by introducing cracks as separate entities directly into the discretization. Meshless methods have become popular for these applications since thanks to the absence of a mesh, discrete cracks can easily be inserted into the discretization [2,30–40]. Though these methods can handle arbitrary crack propagation, they are usually restricted to a few number of cracks due to computational efficiency. One major difficulty of discrete crack models is representation and cracking of crack surface that becomes cumbersome when number of cracks increase. However, concrete

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structures generally undergo excessive cracking before failure. Therefore, numerical methods are needed that can handle many cracks. We propose a method based on an idea developed in [41] that can handle many cracks and simultaneously maintain the accurate character of discrete crack models. That method was successfully used for a variety of problems [42–47]. Such methods are urgently needed to model and understand cracking phenomena in concrete materials.

We present a meshless method for cohesive cracks. The meshless method is based on local partition of unity in order to model the crack. In contrast to most other methods, the crack is described by a set of discrete crack segments through a node. Cohesive zone models are applied at the interfaces of these crack segments in order to take into account the energy dissipation during cracking. The main advantage of the method is its simplicity. There is no need for tracking the crack path. This makes the method well suited for simulation of many cracks as they occur in concrete materials.

2. The methodology – a flow chart

This paragraph briefly outlines the basic steps of the method. One of the key ingredients of the method is the element-free Galerkin method, Section 3, that is capable of modeling arbitrary crack growth. The crack is modeled via local partition of unity enrichment. Therefore, discrete cohesive crack segments are introduced into the element-free Galerkin method through a simple enrichment scheme, Section 4, once a certain cracking criterion is met that is explained in Section 5. The cohesive crack segments are required to pass through the entire domain of influence of a node and the orientation is determined by the cracking criterion, Section 5.

The cohesive force term, Section 6, is introduced as external force into the governing equations, Section 7, and takes into account the energy dissipation during the fracture process avoiding spurious mesh-dependence. The cohesive traction depends on the jump in the displacement field that is given through the partition of unity enriched meshfree method. A flow chart is given in Fig. 1.

3. Element free Galerkin method

The element-free Galerkin (EFG) method [48] is derived from moving-least-squares (MLS) approximation, that can be written in terms of a polynomial basis $\mathbf{p}(\mathbf{x})$ and unknown coefficients $\mathbf{a}(\mathbf{x})$:

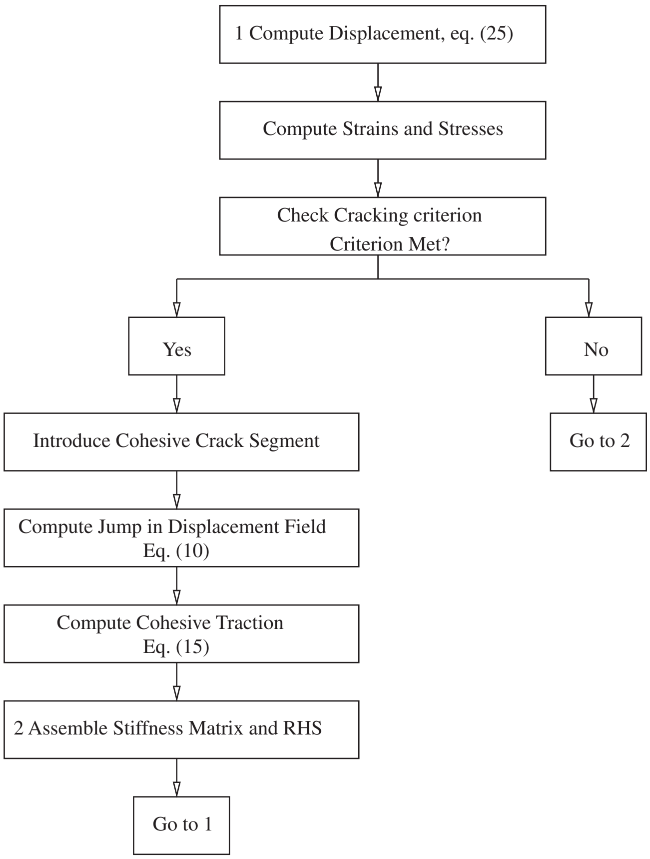

Fig. 1. Flow chart of the proposed method.