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Mixed mode crack simulation using Virtual Crack Extension and a normal/shear cohesive crack model within a meshless discretization

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The discrete modeling of crack propagation with arbitrary crack paths is still a field for many researchers because of the required discretization update of the domain. By using standard finite elements, an adaptive remeshing of the structure is necessary, which is very complex for higher order elements. A recent technique was developed to overcome this problem, the Extended Finite Element Method, wherein cracked elements are enriched by additional jump functions without remeshing. Both methods require an adaptation of the integration point arrangement around the moving crack tip including a state variable transfer. Due to the discontinuous stress distribution over the edges of the finite elements this procedure is not straightforward. An alternative possibility to model discrete cracks is given by meshless interpolation methods, where a predefined mesh is not required and the interpolation function depends only on the node positions. Most meshless interpolation functions can represent continuous stress distributions almost everywhere, which makes the transfer of stress depending history variables much easier.

In this study the Natural Neighbor Interpolation is used in the framework of a Galerkin approach [1]. This methods shows several advantages compared to the Element-free Galerkin Method, like the automatic fulfillment of the essential boundary conditions. To model the cohesive crack behavior of concrete the Fictitious Crack Model is applied [2], where a force transmission over micro cracks is assumed. This force transmission is realized by placing finite interface elements automatically between the crack surfaces during the crack growth simulation. In this paper an energy-based crack criterion using the Virtual Crack Extension technique [3] is presented, which was already successfully applied for adaptive finite element calculations. The adaptation of this concept for the Natural Neighbor Galerkin Method will be demonstrated. In Fig. 1 the principle of this method, where an existing crack tip is shifted for an infinitesimal distance along the crack line from the last increment, is shown. From this virtual extension of the crack the energy release rates G_I and G_{II} for Mode-I and Mode-II, respectively, are determined and the criterion for crack growth which given as

$$G_I + G_{II} - \mathbf{u}^T \frac{\partial \mathbf{f}}{\partial A} = 0, \tag{1}$$

will be evaluated. $\mathbf{u}$ denotes the displacement vector, $\mathbf{f}$ the cohesive force vector and A the area of the cohesive crack. In previous applications of this concept [3],[4],[5] the cohesive model represents in general the relation between the normal crack opening and the normal stress, which is assumed with an exponential softening function, independently from the shear stresses in tangential direction. The cohesive forces $\mathbf{f}$ have been calculated only from the normal stresses. In [6] a improved model was developed using a coupled relation between the normal and shear damage based on an elastoplastic constitutive formulation. In Fig. 2 the development of an initial cohesive yield surface (0) during a normal crack opening (1) and following shear displacements is shown. The resulting Coulomb's friction surface (2) represents the state where the complete interlocking between the crack surfaces is destroyed. This model also represents the effect of shear traction induced crack opening. The adaptation of the crack criterion in Eq.1 for this cohesive model will be shown and the presented algorithms will be verified on several numerical examples. For this purpose several experiments published through the IALAD network [7] will by simulated numerically and the obtained results will be compared and discussed in view of the experimental results.

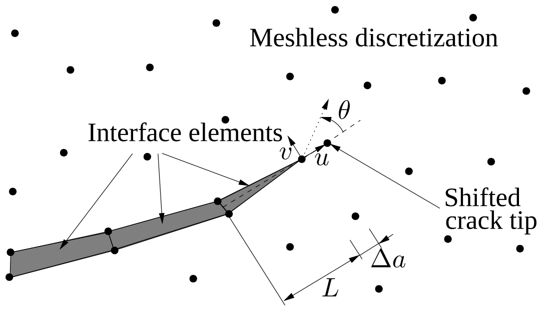

Figure 1: Virtual crack extension Δa at an cohesive crack tip with interface elements

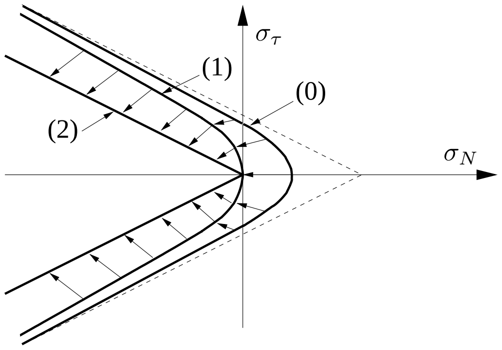

Figure 2: Cohesive yield surface development during normal and shear traction

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