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Local adaptive refinement method for the fracture of heterogeneous materials

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Summary In the frame of nuclear safety research program of the french ‘Institut de Radioprotection et de Sûreté Nucléaire’ (IRSN), a micromechanical approach is developed to predict the fracture of concrete containment structures in nuclear power plants. A problem in studying crack propagation within these structures is the computational cost related to spatial discretization of each relevant scale. A way to reduce the computational cost without any significant loss of accuracy is to perform local adaptive refinement. The refinement method presented in this paper is called CHARMS, and is based on the splitting of elements in a region of interest of an existing mesh. This refinement method is applied to the recent ‘Eigen-Erosion’ method allowing crack propagation based on a killing element-type method with respect to the Griffith’s criterion.

Adaptive mesh refinement devoted to crack propagation problems rely on an adjustment of the spatial resolution in the region of interest of the discretized domain in order to achieve higher accuracy. Two main issues arise from such a spatial refinement: increase of the computational cost and possible decrease of the shape quality of some elements located in the coarse-to-fine transition region. A solution consists in adjusting the density of the mesh by performing local *refinement* (resp. *unrefinement*) of an existing mesh. In this work, the CHARMS method (Conforming Hierarchical Adaptive Refinement MethodS [1]) is investigated to perform such a refinement and coupled to the recent ‘Eigen-Erosion’ method proposed by Pandolfi and al. [2] to simulate crack propagation.

The refinement method (CHARMS) is based on the refinement (resp. unrefinement) of the basis functions rather than the refinement of the finite elements and thus allows non conformities. These non conformities are geometrical and not linked to spatial discretization: the approximation spaces remain H^1 -conform. The fundamental property of this method is, given that the approximation spaces are nested, $X_J \subset X_{J+1}$ with $J \geq 0$, any basis function in the approximation space basis B_j , $j \in \llbracket 1, J \rrbracket$, can be written as a linear combination of finer basis functions in B_{j+1} (see Figure 1). These linear combinations define child-parent relationships between basis functions of two consecutive refinement levels.

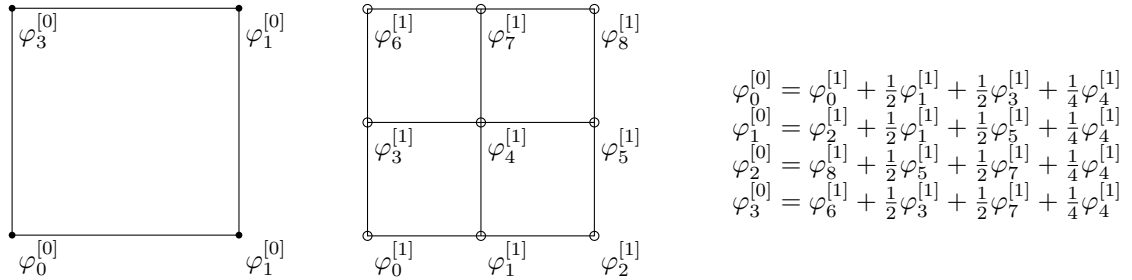


Figure 1: Example of refinement equations for a linear \mathbb{Q}_1 element, φ represents the basis functions of refinement level [0] and [1].

The ‘Eigen-Erosion’ method is based on energetics criteria and enables to simulate crack propagation using an accurate killing-element technic. This method relies on a variational approach of fracture mechanics and offers two main advantages: a low computational cost and a mesh independent crack path [3].

The CHARMS method and the ‘Eigen-Erosion’ method have been implemented in the software Xper [4] and enable to simulate the crack propagation in refined regions. The test case presented in Figure 2 has been performed by using a simple geometrical criterion to refine the region of interest. Other refinement criteria may be used.

Figure 4(a) shows that the cracks obtained with a fine uniform mesh (blue crack) and with a refined mesh (red crack) are similar, and both cracks are comparable to the one obtained by the experiment in Figure 4(b). The difference between the two simulations is the computational cost.

Another refinement criterion based on the elastic energy will be presented.

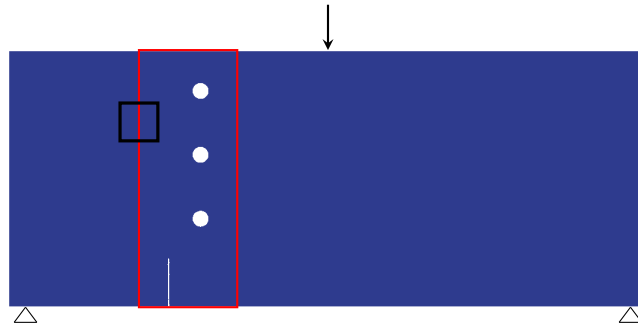


Figure 2: Example of a three holes bending beam proposed by [5] and using a geometrical criterion for refinement. The red rectangle is the region selected for refinement and where the crack will propagate and the black one shows the transition region for each meshes in Figure 3.

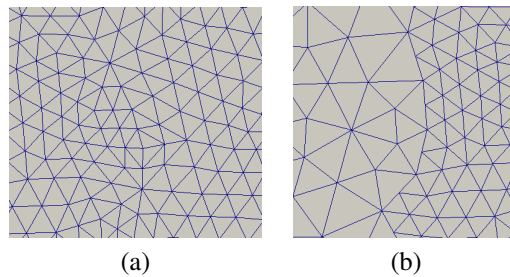


Figure 3: Transition regions for (a) the fine uniform mesh and (b) the refined mesh where we can see the geometrical non-conformities.

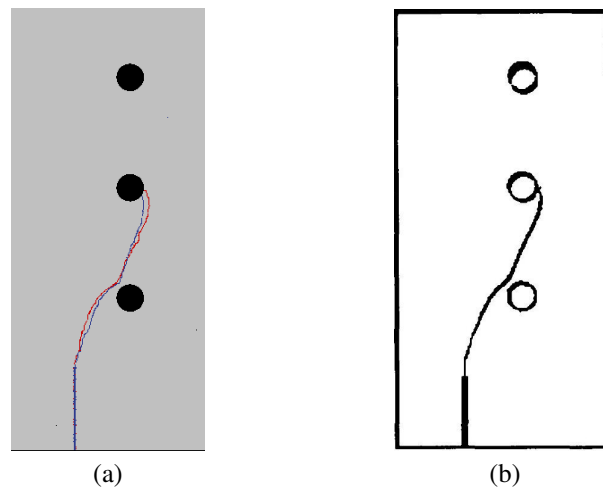


Figure 4: Cracks obtained by (a) the simulation and (b) the experiment in [5]. In (a), the blue crack is obtained with a fine uniform mesh in 14H (1 087 710 cells) and the red one with a refined mesh in 1H (195 976 cells). The element size of the fine uniform mesh is the same than the one of the refined region.

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