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3D HIGHER ORDER X-FEM MODEL FOR HYGRO-MECHANICAL ANALYSIS OF CRACKED CEMENTITIOUS MATERIALS

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ABSTRACT

Numerical prognoses of durability of structures made of cementitious materials such as concrete require the consideration of moisture transport together with the hygro-mechanical couplings. The representation of highly accelerated moisture transport in cracks is important for the prediction of durability, e.g. as a major source for corrosive processes.

The hygro-mechanical response of porous materials is modeled in the framework of the BIOT-COUSSY theory [1], whereas moisture flow within cracks is accounted for by assuming POISEUILLE flow within the crack planes, taking the tortuosity and the crack width dependence of the liquid permeability within cracks into account [2,3]. For the discrete representation of cracks and moisture transport, the Extended Finite Element Method (X-FEM) [4,5] is employed. The spatial discretization of the displacement field as well as the fluid is based on an additive decomposition into a standard part and an enhanced part representing possible jumps of each field. To this end, the topology of the crack channel estimated from the enhanced part of the displacement field is incorporated in the weak formulation of the hygro-mechanical problem and its discretization. For modeling the moisture transport in concrete structures, different permeabilities are identified for the initial uncracked part depending on the liquid saturation S_l and the porosity ϕ and the evolving crack channel in which the moisture flow is increased depending on the crack width w

$$\mathbf{q}_l \;=\; k_\phi(\phi)\,/\,\mu_l\,\mathbf{k}_f(S_l)\,\nabla p_c\;, \qquad\qquad q_l^t \;=\; k^t_{crack}(w,S_l)\,/\,\mu_l\,\nabla^t p_c. \tag{1}$$

Considering 3D-X-FEM, a conflict between accuracy, applicability and the complexity of the numerical implementation arises. As an efficient numerical integration tool, cracked element are subdivided into fixed sub-tetrahedrons which are integrated separately [6] as shown in Figure 1. For each of these tetrahedrons, it is checked whether it is cutted or not. A tetrahedron can be either cutted by a triangular crack surface or by a quadrilateral one. According to the cracking pattern a sub-tetrahedron can be split into two tetrahedrons, two pentahedrons, a tetrahedron and a pentahedron or into a tetrahedron and a pyramid. In the present 3D-X-FEM implementation cracks may propagate elementwise. Within each element, the crack is represented by a plane of discontinuity. The cohesive characteristics of cracked concrete are considered by a softening traction-separation law. A weighted principal stress criterion is used as an indicator for the opening and for the propagation direction of new crack segments. To avoid

too strong restrictions concerning the kinematics of the crack surface, the C_0-continuity of the crack surface is replaced by a C_0-discontinuous crack propagation algorithm [8].

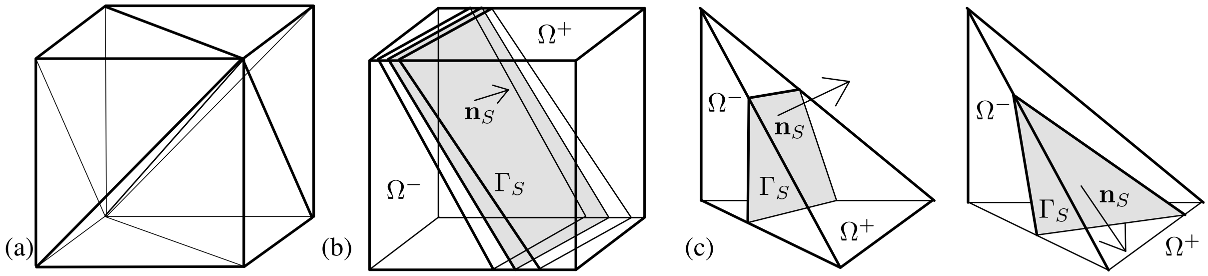

Figure 1: (a) Subdivision into sub-tetrahedrons, (b) Crack channel and crack surface, (c) Splitting of sub-tetrahedrons into two tetrahedrons or a tetrahedron and a pentahedron

In the proposed discretization concept 3D-p-multifield elements based upon a hierarchical anisotropic ansatz space are employed. The p-version of the finite element method has proven to be an efficient and powerful tool, in particular due to its ability to avoid locking effects that may occur when a non-adequate element kinematics is used. The performance of the proposed discretization concept is demonstrated by means of 2D and 3D numerical examples, including mechanical and hygro-mechanical analyses.

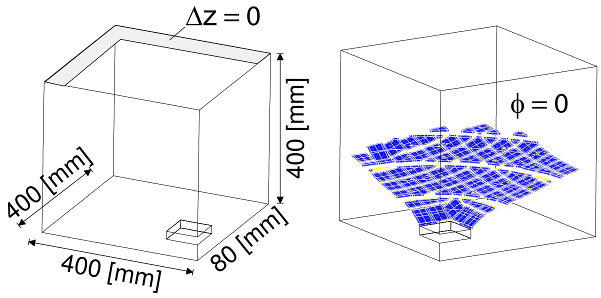

Figure 2: 3D anchor pull out test - Geometry and evolving crack surface

REFERENCES

[1] O. Coussy. “Poromechanics”. Chicester, England, 2004.

[2] N. Sukumar, N. Moës, B. Moran and T. Belytschko. “Extended finite element method for threedimensional crack modelling”. International Journal for Numerical Methods in Engineering, 48:1549-1570, 2000.

[3] M.-A. Abellan, R. de Borst and J.-M. Bergheau. “Analysis of discontinuities in fluid-saturated porous media”. International Conference on Fracture (ICF 11), Turin, Italy, 2005.

[4] S. Jox, C. Becker and G. Meschke. “Hygro-mechanical coupled analyses of cracked cementitious materials in the context of the extended finite element method including moisture transport”. FRAMCOS-6, Catania, Italy, 517-524, Taylor & Francis, 2007.

[5] C. Becker, S. Jox and G. Meschke. “Higher order spatial discretization methods for multi-field durability analyses. Part I: continuum modeling”. International Journal for Numerical Methods in Engineering, submitted, 2008.

[6] T.C. Gasser and G.A. Holzapfel. “Modeling 3D crack propagation in unreinforced concrete using PUFEM”. Comp. Meth. in Appl. Mech. and Eng., 194:2859-2896, 2005.