

Meso-macro numerical approach to macroscopic permeability of fractured concrete

X. Jourdain, J.-B. Colliat, C. De Sa, F. Benboudjema and F. Gatuingt

LMT-Cachan

(ENS Cachan/CNRS/UPMC/PRES UniverSud Paris)

61 avenue du Président Wilson, 94235 Cachan Cedex, FRANCE

Email: jourdain@lmt.ens-cachan.fr, web page: <http://www.lmt.ens-cachan.fr>

ABSTRACT

Mass transfers computations within fractured cement-based materials are a major issue dealing with numerous engineering domains such as geological CO₂ storage or civil nuclear industry. For the latter, many countries – among which France, Germany, USA – aim at extending their nuclear plants lifetime to face the increasing electricity demand. In order to prevent leaks due to concrete aging or in case of an accident (e.g. LOCA = Loss-Of-Coolant-Accident), it is important to compute the flow going through concrete structures under different kind of loading: static or dynamic loads, temperature gradients during hydration, drying shrinkage, etc.

We present such a coupled flow model within the framework of a sequential multi-scale numerical method. Such framework requires both a fine scale analysis (coupling mechanical non-linear behaviour to the mass transfers) and a macro-scale transfer model. The latter is based on porous media flow theory [1] and requires the definition of a macroscopic permeability tensor which components are usually quite difficult to link to the structure mechanical behaviour, especially when dealing with smeared crack models such as plasticity or damage. Here the key point is to consider, at the fine scale level, displacements (“strong”) discontinuities in order to represent meso-scale cracks. On the FE point of view those discontinuities can be seen as kinematics enhancements [2] and lead to compute cracks opening in a straightforward fashion. Thus, based on these meso-scale cracks openings, the meso-scale mass transfer problem can be formulated according to a “double porosity” way. Mass transfers take place both inside very small porosities (leading to an isotropic and homogeneous permeability tensor) and within meso-scale cracks. The latter is evaluated thanks to Poiseuille flow, both for incompressible and compressible fluids, between two planes which gap is equal to the crack opening. Considering a macroscopic cracks pattern made of a large number of meso-scale cracks with different orientations and openings, macroscopic tortuosity as well as percolation issues are both naturally solved, which is one of the main benefit for the multi-scale method.

In the spirit of sequential multi-scale numerical analysis, specific boundary conditions are applied at the meso-scale in order to identify macroscopic quantities such as permeabilities. Here we consider “linear pressure boundary conditions” which lead to constant macroscopic pressure gradients. Three simulations are thus required in order to compute the nine components of the 3D macroscopic permeability tensor. We show those components for “perfect” cracks (along different directions and several crack openings) and link the induced anisotropy to the cracks patterns. We also deal with several failure patterns due to macroscopic loading paths (pure tension and compression, shear, 2D compression) and stress on the difference between compressible and incompressible fluids.

REFERENCES

- [1] J. Bear, “Dynamics of fluids in porous media”, *Dover Publications*, 1989.
- [2] N. Benkemoun, M. Hautefeuille, J.B. Colliat and A. Ibrahimbegovic, “Failure of heterogeneous materials : 3D meso-scale FE models with embedded discontinuities”, *Int. J. Num. Meth. Engng*, **82**, 1671-1688, 2010.