Title: A probabilistic thermo-hygro-mechanical approach for concrete modeled as a random heterogeneous porous medium

Supervisor: Prof. Fekri MEFTAH – INSA Rennes – France – Fekri.Meftah@insa-rennes.fr

Keywords: Civil Engineering – Finite Element Modeling - Homogenization / Upscale Modeling – Cementitious Materials – Concrete – Durability Mechanics – Thermo-Hygro-Mechanical couplings – Heterogeneous Random Porous Medium – Mesoscopic approach – Probabilistic approach

Project details:

The behavior of cementitious materials still remains under investigation, especially in some particular engineering applications: tightness of dams and storage structures, safety evaluations during fire in tall buildings and in tunnels, particular scenarios of thermo-hydraulic loading in pipes and other containment structures. In such situations, a complexity in assessing concrete behavior comes from its microstructure, which needs to be sketched as a deformable heterogeneous chemically reactive porous matrix, partially saturated with water and/or other fluids.

Indeed, during the above-mentioned scenarios, not only mechanical processes are involved, but also other physical, complex and strictly correlated phenomena related to the multiple phases composing concrete. They mainly concern flow of fluids (dry air, liquid and vapor water filling the porous network) due to concentration and pressure gradients, diffusion, capillary effects (due to surface tension), sorption/desorption effects, water phase changes (evaporation/condensation), chemical transformations, etc. All these phenomena lead to an alteration of the material microstructure that in turn modifies its transfer properties, i.e., phenomena are coupled.

Furthermore, a satisfying description of the heterogeneous microstructure should take into account not only porosity but also cracks, i.e., micro-cracks provoked by internal stresses due to autogenous shrinkage restrained by the aggregates and cracks due to external loadings. Indeed, their inevitable presence weakens the porous matrix resistance and constitutes a preferential flow path for fluids, gas and pollutants: material durability and long-term behavior are therefore seriously affected.

Given the complexity of the problem, it is essential to rely on numerical tools capable to design and evaluate the resistance and the tightness of the material and of the whole structure under serviceability and limit state loadings.

The thermos-hygro-mechanical (THM) modeling of concrete as a partially saturated porous medium is now a widely admitted approach for assessing not only its mechanical performances but also issues related to its durability and long-term behavior [1,2].

Nevertheless, usual approaches are based on macroscopic homogeneous deterministic descriptions (average models) while material heterogeneity plays an important role in the overall behavior (e.g. scale effects) that should be taken into account for properly understanding the material behavior.

Heterogeneity can be described either by representing explicitly the microstructure morphology at the mesoscale or by an implicit probabilistic representation of this morphology at the macroscale. This latter allows for significantly reducing computational cost of numerical simulation and therefore for analyzing large-scale problems.

Recently, a proposed model [3] has allowed integrating the heterogeneous and random nature of the microstructure of the material by mean of a probabilistic approach with spatially non-correlated material parameters. The proposed project aims at further developing this approach. Morphological heterogeneity of the material microstructure will be described by an equivalent spatially correlated probabilistic approach that accounts for the finite size of heterogeneities. Therefore, correlation lengths should be properly determined in order to provide a reliable distribution of the involved physical phenomena. In particular, fluctuations of significant fields (stresses, strains, micro-cracks, temperature, saturation, pore pressure) will be investigated. For this purpose, an existing mesoscopic THM approach will be used to simulate local fields fluctuations. Note that the mesoscopic approach provides a rich description of concrete microstructure: aggregates and cement paste are treated as individual components. Each component has its own geometry and its own thermo-hygral and mechanical behavior, thus allowing exploring local phenomena (e.g. influence of aggregate grains on micro-cracking and on moisture transport). Then, the information provided by a mesoscopic description can provide the link for including this microstructural information at the upper (macroscopic) scale through the probabilistic approach. Inverse analysis techniques will be then developed to properly upscale the information obtained via the mesoscopic approach to the macroscopic numerically efficient THM approach, enriched with random properties distributions. Based on spatial correlations of the considered parameters, the proposed approach will allow to determine the proper correlation lengths and to assess scale effects related to the size of statistical unit volumes and their convergence towards a representative elementary volume.

This study will be accompanied to a sensitivity analysis on random parameters, which should result in a simplified, averaged model, well adapted to the structural scale. The developed stochastic approach will be therefore employed to perform reliability/residual-life analyses of concrete structures.

References

[1] F. Meftah, S. Dal Pont, Staggered Finite Volume Modeling of Transport Phenomena in Porous Materials with Convective Boundary Conditions, Transport in Porous Media, 82/2, 275-298, 2010

[2] S. Dal Pont, F. Meftah, B.A. Schrefler, Modeling concrete under severe conditions as a multiphase material, Nuclear Eng. and Design, 241/3, 562-572, 2011

[3] F. Meftah, S. Dal Pont, B.A. Schrefler, A three-dimensional staggered finite element approach for random parametric modeling of thermo-hygral coupled phenomena in porous media, Int.J. Num.Anal.Meth.Geom. Vol.36/5, pp.574-596, 2012