Developments in a Coupled Thermal-Hydraulic-Chemical-Geomechanical Model for Soil and Concrete

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Abstract

In the broad context of geotechnical and geo-environmental problems, the study of coupled thermal-hydraulic-chemical-mechanical behaviour of natural soils and engineered materials has attracted tremendous interest amongst scientific community and industry. This is especially the case in the study of feasibility, design, construction and long term performance of nuclear waste disposal facilities. From the point of view of deep disposal studies, the main research questions typically investigated are (i) saturation time, (ii) peak temperature in the near field, (iii) duration of thermal phase, (iii) geomechanical stability and (iv) chemical stability of the barriers and host soil/rock. Similar questions are investigated in the case of near surface disposal facility but mainly for cementitious materials under isothermal conditions, with specific attention to long term concrete degradation. In order to address these, Belgian nuclear research institute has already accomplished significant advances and further research is being actively pursued.

In this context, the paper describes current progress in the implementation of a framework in COMSOL Multiphysics®-MATLAB® environment within which the coupled thermal-hydraulic-chemical-geomechanical behaviour of soil and concrete can be studied (Figure 1). Governing equations are based on mechanistic approach combining mass conservation, energy conservation, stress-strain equilibrium and thermodynamics, including cross couplings between primary variables: pore water pressure, pore gas pressure, temperature, chemical concentration and displacements (small strain). Four most powerful features of COMSOL have been employed for this purpose: PDEs for flow and transport, built in nonlinear structural mechanics module for geomechanical implementation, built in chemical species transport module and LiveLink™ for MATLAB® to couple with an external geochemical reaction module.

Due to the complex coupling involved and resultant large number of parameters, coefficients, constitutive laws and internal features, a stepwise approach has been taken to verify/validate different combinations of physics in order to gain confidence in the implementation and quality assurance. In this paper, the presentation is limited to two important validation studies based on previously published literatures. The first validation concerns simulation of an isothermal experiment on unsaturated bentonites, requiring unsaturated flow and poroelastic features with extensions to include swelling behaviour in the effective stress definition. The second simulation

concerns a large in-situ thermo-hydro-geomechanical experiment at the HADES laboratory, Mol, Belgium, requiring saturated flow, thermal flow and poro-plasticity implemented within the built in general plasticity feature. Both these models are solved in 2D-axisymmetric frame.

Results in the form of moisture content, pore water pressure, temperature, stresses and displacements have been compared with experiments where available and alternative codes. The results show good comparisons thus improving confidence in the implementation. Further work is ongoing to carry out validations involving other components of the coupled model such as chemo-osmotic, thermal diffusion and chemo-mechanical behaviour. Finally, some constraints experienced during the model development will be highlighted.

Figures used in the abstract

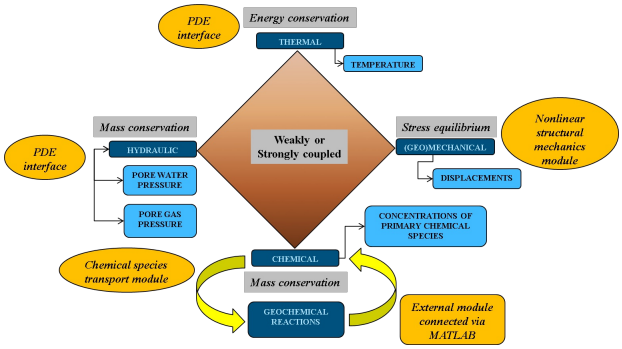

Figure 1: Implementation strategy for the coupled thermal-hydraulic-chemical-mechanical model.