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An interface method for the coupling of dissimilar Finite Element Meshes for the simulation of partially saturated soils

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ABSTRACT

The presentation is concerned with the coupling of dissimilar Finite Element (FEM) meshes for the numerical simulation of partially saturated soils. In the proposed model partially saturated soil is described as a triphasic material within the framework of the Theory of Porous Media (TPM) considering the soil skeleton, water and air as separate phases (see [1] for details). Mesh coupling has to be applied if independently meshed and therefore dissimilar FE subdomains have to be connected. This may be the case if continuous meshing of a complex structure is impossible or would lead to an unnecessary fine mesh, while using independent meshing of subdomains would achieve well structured Finite Element meshes. The present work has been performed in the context of the development of a FEM software for the simulation of shield tunnelling, where the detailed consideration of the construction process and the sourrounding soil lead to a complex model geometry [2].
For the coupling of independently meshed sub-continua for single phase materials mortar and penalty methods are frequently used (see e.g.[3,4]). A method for the coupling of incompatible FE-meshes for the simulation of partially saturated soils by a triphasic formulation has not been presented so far.
Within this model the penalty method has been used to couple the incompatible subdomains $\Omega^1 \cup \Omega^2 = \Omega$. Coupling between the interfaces $\Gamma^i_{coupling} \in \Omega^i$ requires continuity of the primary variables

$$\boldsymbol{d}^1 = \boldsymbol{d}^2 \;\forall\; \boldsymbol{x} \in \Gamma^i_{coupling} \text{ with: } \boldsymbol{d}^i = \left[\boldsymbol{u}^{s^i}, p^{w^i}, p^{a^i}\right]^T . \tag{1}$$

Between the surfaces $\Gamma^i_{coupling}$ an interface $\Gamma^\star$, which can be meshed independently, is introduced. For this interface the constraint condition (1) is re-written as

$$\boldsymbol{d}^1 = \boldsymbol{d}^\star \text{ and } \boldsymbol{d}^2 = \boldsymbol{d}^\star \;\forall\; \boldsymbol{x} \in \Gamma^i_{coupling}. \tag{2}$$

Expressed in terms of the penalty method fulfilment of the constraints (2) is identical to the minimisation of the potential

$$\Pi \quad = \quad \Pi^{int,ext} + \sum_i^2 \frac{1}{2} \int_A \gamma \left(\boldsymbol{d}^\star - \boldsymbol{d}^i\right) d\Gamma^\star \tag{3}$$

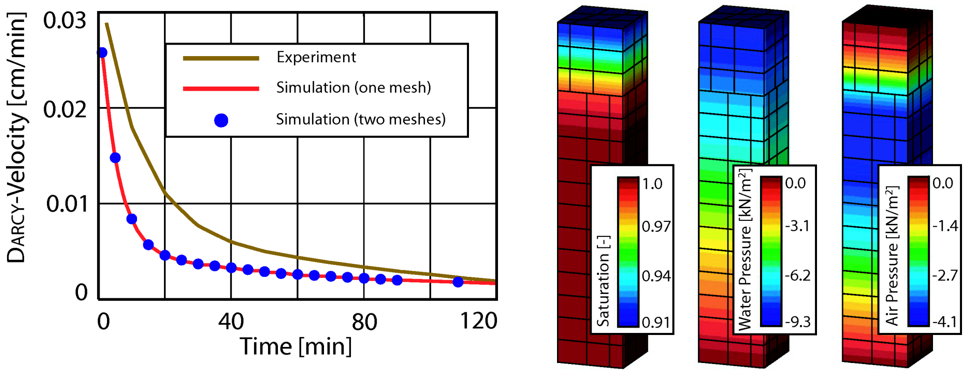

Figure 1: Comparison of measured and computed water outflow over bottom face of the sand column (left), water saturation, water and air pressure simulated with two dissimilar meshes after 2h (right)

for $\gamma \rightarrow \infty$, where γ denotes the penalty parameter. The problem is solved through its variational form $\delta\Pi = \delta W_{int,ext} + \delta W_{coupling} = 0$. Therein the integrals in $\delta W_{coupling}$ are integrated by subdividing the facets of elements of $\Gamma^\star$ similar to the method presented in [4]. This quadrature method minimises the integration error induced by mesh inequalities between $\Gamma^\star$ and Γ^i.
The back-analyses of the dewatering of a sand column tested in laboratory [6] demonstrates an excellent agreement of the results from a simulation with the proposed mesh coupling method, experimental results and results from a simulation with continuous meshing (see Figure 1). The proposed method will be used within a simulation model for shield tunnelling to offer the possibility of independent meshing of the components connected with the tunnel construction and the layers of the surrounding soil.

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