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FINITE ELEMENT FORMULATION OF UNILATERAL BOUNDARY CONDITIONS FOR UNSATURATED FLOW IN POROUS SOLIDS

*** A. Abati[1], C. Callari[2]**

[1] Università di Roma "Tor Vergata"
00133 Roma, Italy
abati@ing.uniroma2.it

[2] Università del Molise
86039 Termoli (CB), Italy
carlo.callari@unimol.it

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ABSTRACT

In civil and environmental engineering problems involving partially saturated porous media, the geometric locus of zero pore pressure often intersects a boundary in contact with atmosphere. Different responses are then typically observed on the two boundary portions located above and below this intersection: the interstitial pressure is lower than the atmospheric value in the upper part and an outflow is observed in the remaining portion. The locus of zero fluid pressure is not a priori known and it evolves with time in presence of unsteady fluid flow. Hence, in the analysis of these interfaces between porous solid and atmosphere, the boundary condition to be applied may change between imposed-pressure and imposed-flow types during problem evolution. A common approach to the numerical treatment of these problems considers the switching of the boundary type in an incremental-iterative solution, that is, the application of the so-called "variable" boundary conditions [4]. However, these boundary conditions can be considered in the more general framework of unilateral constraints, leading to a more effective numerical formulation, especially for those frequent cases where large boundary regions are almost instantaneously subjected to the aforementioned switch of condition type. In Reference [1], we employ both penalty and augmented Lagrangian methods to treat fluid-flow unilateral boundaries in the finite element formulation for coupled unsaturated porous solids presented in [2,3]. The performance of such regularization techniques is thoroughly investigated by the analysis of steady one-dimensional problems, assessing the analogy between the mechanical contact problem and the proposed fluid-flow boundary conditions, not only from a formal point of view, but also in terms of numerical algorithm performances. We also employ the proposed unilateral constraints to simulate multidimensional and strongly non-linear transient problems, such as the infiltration in a partially saturated ground during rainfall events and the progressive partial saturation of a concrete dam due to reservoir operations.

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