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FE MODELLING OF COUPLED ELECTROKINETIC CONSOLIDATION PROCESSES IN UNSATURATED SOILS

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ABSTRACT

The prevention of contaminant migration from waste disposal facilities or contaminated sites with different kinds of barriers is one of the main issues in environmental geomechanics. For newly designed waste disposal sites, this problem is typically dealt with using engineered containment systems employing compacted clay liners and/or geomembrane liners. For sites where no adequate control measures have been implemented or in polluted areas, it might be necessary to design remedial measures to limit the pollution of the surrounding environment according to local regulations. Such remedial measures may include the installation of vertical cut-off walls like cement-bentonite or soil-bentonite slurry walls, whenever the extraction of the contaminants is not technically or economically convenient. In both cases, the underlying design principle is to isolate the contaminated zone from the surrounding environment.

A quite promising approach to circumvent some of the limitations of the currently adopted technologies is represented by the so-called ”electrokinetic barriers” [1–3], a highly effective active containment system which exploits the possibility of moving both polar and non-polar contaminants by applying a low intensity DC current across the clay soil layer constituting the barrier.

The quantitative prediction of the different phenomena occurring in the soil upon the activation of the electric field is of paramount importance for the evaluation of the barrier effectiveness and for its proper design from both the technical and the economical point of view. This in turns requires the analysis of several mutually coupled deformation and conduction processes including: 1) hydraulic and electric conduction processes; 2) multicomponent mass transport processes for the different species present in the liquid phase; 3) deformation of the solid skeleton, due to both the changes of pore water pressures in the liquid phase and the chemical composition of pore-water fluid.

A relevant role in these processes can be played by the variations of the degree of saturation of the clayey barrier system, as it is well known that the degree of saturation may affect to a large extent, the stiffness, strength, hydraulic conductivity and electrical conductivity characteristics of a unsaturated soil. As a matter of fact, typical compacted clay liners are cast in place to water contents well below the saturated conditions. Moreover, previous studies on electrokinetic barriers and electrokinetic fences have shown

that the electrolysis reactions at the electrodes give rise to the production of a significant amount of gas, which cannot be eliminated easily [4]. A reduction of the degree of saturation close to the electrodes is thus to be expected after some time of treatment. Finally, several experimental observations indicate that, even in an open flow arrangement, the development of significant suctions in the pore water can occur upon sustained electric field [5,6].

The objective of the present work is to provide a contribution to the numerical modelling of coupled electrokinetic consolidation processes occurring in electrokinetic barriers or electrokinetic fences, focusing on the effects induced by the changes of the degree of saturation on the evolution with time of the electric field, pore water and pore gas pressures and solid skeleton deformations. Following the previous work of refs. [7,8], a coupled hydro–mechanical elastic-plastic model with generalized hardening function is adopted for the soil skeleton, in order to describe the hardening effects associated to both the development of plastic strains and the changes in the degree of saturation. Electro–osmotic flow is simulated in unsaturated conditions, taking into account: i) gas production at the electrodes; ii) gas dissolution in water; and, iii) gas transport through the porous medium. The results obtained in a series of parametric studies allow to assess the influence of the partial saturation on the dynamics of the conduction processes and the evolution with time of the stress and strain fields in the solid skeleton.

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