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Finite deformation modeling of cone penetration tests in saturated structured clays

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The complex coupled deformation and flow processes occurring in the soil around a CPTu penetrometer during the execution of a test in structured natural clays are investigated by means of an advanced numerical simulation tool. The objective is to gather useful information in order to attempt a more rational way to interpret CPTu results.
In the test simulations, the Particle Finite Element Method has been used to deal with the large displacements and deformations induced by the cone penetration. The PFEM implementation adopted incorporates a fully coupled hydro-mechanical formulation, based on low-order linear strain triangles. To avoid locking problems and instabilities associated to the equal order of approximation for both displacement and pore pressure fields, a mixed stabilized formulation has been used, incorporating the Jacobian J as an additional unknown field.
To capture the relevant features of the mechanical response of natural structured clays, the soil behavior has been described using a finite deformation version of the non-associative elastic-plastic model for this class of geomaterials, referred as FDMilan model. The model formulation is based on a multiplicative decomposition of the deformation gradient and on the adoption of an elastic response based on the existence of a suitable free energy function. Two bonding-related internal variables, quantifying the effects of structure on the yield locus, are incorporated to provide a macroscopic description of mechanical destructuration effects. In order to deal with strain localization phenomena, typically observed in bonded geomaterials upon yielding, the model has been equipped with a non-local version of the hardening laws, which has demonstrated capable of regularizing the pathological mesh dependence of PFEM solutions in the post-localization regime.
To investigate (i) the effects of the ratio between the characteristic times of the consolidation process and the cone tip advancement and (ii) the impact of the mechanical destructuration on the observed macroscopic results, a numerical simulations program varying the soil permeability and the initial amount of bonding has been performed. The numerical model developed has demonstrated capable of capturing: 1) the development of plastic deformations induced by the advancement of the cone tip; 2) the destructuration associated with such plastic deformations; 3) the space and time evolution of pore water pressure as the cone tip advances; 4) the effect of soil permeability on predicted excess pore water pressures; and 5) the effect of soil bonding on predicted values of cone tip resistance.