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Detection and monitoring of hydromechanical instabilities in geomaterials: fingering and strain localization

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Abstract:

Injection-withdrawal cycles from underground aquifer reservoirs can be responsible for gas leakage, instabilities of the tight caprock, fault reopening, induced seismicity and subsidence. The study of microstructure rearrangement due to fluid propagation is barely mentioned in literature even if a large number of studies have been devoted to the investigation of this kind of fluid instabilities[1]. In order to improve the understanding of the response of geomaterials during fluid injection, a new study has been elaborated at the laboratory scale. A new biaxial apparatus, adapted to unsaturated soils and endowed with high resolution and high speed cameras, has been designed in GeM laboratory at Ecole Centrale Nantes. Being capable to impose hydromechanical loadings on a ($5\times4\times1.1$ cm^3) sample, it is characterised by two transparent windows which allow the cameras, installed on both sides of the sample, to film the fluid propagation and the rearrangement of the soil microstructure. In order to identify the occurrence of fluid instabilities, a saturated sand sample is put in contact with a pressure-controlled gas source, so as to induce gas injection into the sample (drainage process). Depending on the flow rate and the properties of the defending and the injected fluids, viscous fingering can be observed[2]. During the drainage process, the full field measurements of displacements and deformations of the sample are determined using digital image correlation (DIC) combined with Virtual Image Correlation (VIC). While the injected fluid (air) propagates through the saturated sample, it induces contrast changes inside the sample (dry and saturated parts). The VIC procedure is developed to capture the current position of the fluid front and therefore to catch the triggering and the propagation of fingering instabilities. It's based on the idea of deforming a virtual band of grey level transition, to fit the real interface[3]. So it allows the detection of the moving bi-phase front and characterises it by a geometrical description. The finite element based DIC method[4], allows to construct the full field deformation maps. The latters are calculated using an adapted mesh, constructed in the partially saturated transition zone which is detected by the VIC method, in order to avoid having elements constitued of mixed grey levels. The novely of this work is therefore to combine the fluid propagation to quantitative displacement and strain maps of the material during a pressure controlled hydromechanical loading. The results show that during fluid propagation, localized deformations at the moving interface emerge and are characterised by compaction surmounted by swelling zones. A parametric study for different values of the macroscopic pressure gradient and corresponding induced flow rate is presented.

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