EDITORIAL
published: 16 August 2022
doi: 10.3389/fmech.2022.954665

Check for updates

Editorial: Hydromechanical Instabilities in Geomaterials: Advances in Numerical Modeling and Experimental Techniques

Giulio Sciarra[1], Gioacchino Viggiani[2] and Frédéric Collin[3]*

[1]Nantes Université, Ecole Centrale Nantes, CNRS, GeM, UMR 6183, Nantes, France, [2]Université Grenoble Alpes, CNRS, Grenoble INP, 3SR, Grenoble, France, [3]Département ArGEnCo, Université de Liège, Liège, Belgium

Keywords: hydro-mechanical coupled instabilities, phase-field modeling (PFM), fingering, interfaces detection and tracking, digital image correlation, fluid-fluid displacement in porous media

Editorial on the Research Topic

Hydromechanical Instabilities in Geomaterials: Advances in Numerical Modeling and Experimental Techniques

Bifurcations and instabilities in geomaterials (soil, rock, and concrete) have attracted the interest of a scientific community that has become well-recognized in modern times. Several facets of this topic have been investigated in the past, from the experimental characterization of strain localization (shear bands, compaction bands) and the micromechanics of instabilities in granular materials, to the formulation of enriched continuum theories capable to provide the mathematical framework for treating loss of uniqueness and loss of stability of homogeneous solutions. Significant contributions have also been developed on numerical techniques able to capture the multiple (finite) solutions of a finite element discretized problem. The purpose of this Research Topic is to extend this fruitful combination of experimental, theoretical and numerical approaches to the study of coupled hydromechanical instabilities, where the notion of mechanical instabilities is enriched by the complementary (and not necessarily independent) notion of hydraulic instabilities, with a key role played by interfaces and coupled hydromechanical phenomena.

Geomaterials are intrinsically multi-phase, the porous network being typically saturated by a mixture of fluids. Therefore, instabilities can manifest both in the solid and fluid phases. As a consequence, localized or diffuse scale instabilities as well as grain reorganization, at the micro and mesoscopic scale of the porous skeleton, can obviously affect the behavior of the fluid phase, inducing heterogeneous and anisotropic fluid flow through the material. However, the reverse is also true: fluid instabilities, at different scales, such as Haines jumps, fluid pinch-off, fingering, etc., can affect the mechanical response of the solid phase inducing strain localization and heterogeneous remodeling. Investigating instabilities in geomaterials is therefore of paramount importance in order to understand the role of interfaces between the solid and fluid phases.

The six articles which are part of this Research Topic address the above-mentioned challenges from different angles and can be ordered into two main groups concerning experimental and numerical modeling research. They investigate the response of geomaterials both at the scale of pores and grains and at the scale of laboratory samples. The field of applications is wide and includes underground energy storage, CO_2 geological sequestration, fault reactivation, artificially induced and natural seismicity, nuclear waste disposal, etc.

Concerning the experimental research, the paper by Liu and Santamarina presents an interesting review of fluid-driven instabilities in granular materials providing examples of fluid instabilities at constant fabric

Edited and reviewed by:
Guoqiang Li,
Louisiana State University,
United States

***Correspondence:**
Giulio Sciarra
giulio.sciarra@ec-nantes.fr

Specialty section:
This article was submitted to Solid and Structural Mechanics, a section of the journal Frontiers in Mechanical Engineering

Received: *27 May 2022*
Accepted: *10 June 2022*
Published: *16 August 2022*

Citation:
Sciarra G, Viggiani G and Collin F (2022) Editorial: Hydromechanical Instabilities in Geomaterials: Advances in Numerical Modeling and Experimental Techniques. Front. Mech. Eng 8:954665. doi: 10.3389/fmech.2022.954665

and with fabric changes. The role of diffusion, advection, inertia, as well as viscous forces, capillary forces, and effective stresses is discussed in the first and in the second class of fluid instabilities, respectively. The focus is on the micro-scale positive feedback mechanisms that exacerbate initial perturbations and on the characterization of a set of dimensionless numbers associated with the considered instabilities.

Guevel et al. present experimental micro-scale measurements aiming at investigating the onset of Haines jumps during evaporation. In particular, the temporal evolution of capillary bridges, before and just after their rupture, is studied by using digital image correlation and varying the separation between the grains, the material properties, and the geometry. The temporal evolution of such micro-scale instabilities is found to be accurately described, as tertiary creep instabilities, by Voight's relation, similarly to field scale instabilities such as landslides and volcanic eruptions.

The paper by Couture et al. extends experimental investigation of immiscible fluid flow instabilities from 2D and 3D idealized porous media to a 3D real porous rock (Fontainebleau sandstone), using three-dimensional full-field measurements from x-ray tomography. A laboratory experimental system, specifically designed to study the evolution of immiscible fluid fingering in natural sandstone samples, allows for qualitatively understanding the mechanisms at the basis of the propagation of vicious fingers in natural settings, suggesting also some conclusions concerning the role of pore scale and sample scale heterogeneities.

Finally, Al Nemer et al. report experimental evidence of fluid instabilities accompanied by fabric changes, as mentioned in the paper by Liu and Santamarina In particular, using a new biaxial setup endowed with a high-resolution optical system, drainage experiments are carried out by injecting air into a water-saturated sand sample. Strains induced by air invasion are measured using digital image correlation. The effect of the heterogeneous infiltration of gas through an initially saturated granular medium, in terms of induced strain localization, is quantitatively characterized.

Concerning the numerical modeling research, recently developed approaches to the study of fluid instabilities in granular media are based on the use of a phase field model of a multi-phase flow within the porous network, see e.g., Sciarra (2016); Ommi et al., 2022a, Ommi et al., 2022b, endowed with energetic terms in the gradient of the phase field parameter. The finite element numerical implementation of the corresponding governing equations passes through a mixed formulation allowing to rephrase higher order partial differential equations (PDE) into a system of second order PDE, giving rise to a kind of multi-physics problem.

The paper by Ferronato et al. introduces a unifying framework for the development of preconditioning techniques in multi-physics problems, specifically in coupled poromechanics. The application of such a framework can help to identify a unique basic idea underlying different strategies and make it easier to generalize the algorithms to a multiplicity of problems, possibly including an increasing number of physical processes. Three approaches, namely explicit, implicit, and reverse, are considered and compared in real-world challenging benchmarks.

Finally Ommi et al., on the basis of the experimental evidence reviewed by Liu and Santamarina, proposed a model to describe "open-mode discontinuities" in geomaterials under compressive effective stress when subjected to forced drainage or drying boundary conditions. The fracturing of the granular medium, considered as a local grain reorganization, is hypothesized to be caused by the forced invasion of the pore network by a non-wetting fluid. Abandoning the purely mechanistic approaches proposed in the literature, see e.g., Peron et al. (2009, 2013), to explain the formation of desiccation cracks in soils, an alternate capillarity-driven mechanism is proposed at the continuum scale.

We hope that readers will enjoy reading the carefully selected papers on the growing and exciting research area of coupled hydromechanical instabilities in geomaterials.

AUTHOR CONTRIBUTIONS

GS drafted the initial manuscript. GS, GV, and FC edited the manuscript.

FUNDING

The authors would like to acknowledge the support of the French National Research Agency (ANR), project STOWENG (Project-ANR-18-CE05-0033).

REFERENCES

Ommi, S. H., Sciarra, G., and Kotronis, P. (2022b). A phase field model for partially saturated geomaterials describing fluid–fluid displacements, part ii: Stability analysis and two-dimensional simulations. *Adv. Water Resour.* 164, 104201. doi:10.1016/j.advwatres.2022.104201

Ommi, S. H., Sciarra, G., and Kotronis, P. (2022a). A phase field model for partially saturated geomaterials describing fluid–fluid displacements. part i: The model and one-dimensional analysis. *Adv. Water Resour.* 164, 104170. doi:10.1016/j.advwatres.2022.104170

Peron, H., Hueckel, T., Laloui, L., and Hu, L. B. (2009). Fundamentals of desiccation cracking of fine-grained soils: Experimental characterisation and mechanisms identification. *Can. Geotech. J.* 46, 1177–1201. doi:10.1139/T09-054

Peron, H., Laloui, L., Hu, L.-B., and Hueckel, T. (2013). formation of drying crack patterns in soils: A deterministic approach. *Acta Geotech.* 8, 215–221. doi:10.1007/s11440-012-0184-5

Sciarra, G. (2016). Phase field modeling of partially saturated deformable porous media. *J. Mech. Phys. Solids* 94, 230–256. doi:10.1016/j.jmps.2016.04.018

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.