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Waves in Porous Media

Guest Editorial of the Special Issue of Transport in Porous Media on Experiments, Theory, and Numerical Modeling of Waves in Heterogeneous Porous Media

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Understanding and interpreting the physics of propagating seismic and/or electromagnetic waves in the earth is still a challenge nowadays because of various heterogeneities and interacting phases on multiple scales. In recent years, e.g., multi-phase models based on extensions of the classical Biot-theory have been proposed to predict propagating bulk/surface waves in heterogeneous fully and partially saturated rocks in the range of seismic frequencies and above. Furthermore, theoretical models for interacting electromagnetic and seismic waves in fully saturated porous media have been proposed and experimentally validated. All these continuum models predict higher order bulk waves modes in certain frequency ranges and show a distinct dispersive behaviour. Nevertheless, questions addressing the role of involved nonlinearities, property gradients, concepts of coarse-graining in space/time, multi-phase saturation, and the efficiency/reliability of numerical algorithms (finite differences, finite element methods, TVD, for example) are still challenges, which are not answered satisfactorily. To bring together scientists from various fields like continuum modelling, scientific computing, and laboratory and field experimental investigation, to exchange novel concepts and exchange ideas, a Mini-Symposium was organized on **Experiments, Theory, and Numerical Modeling of Waves in Heterogeneous Porous Media,** as part of the 4th European Conference on Computational Mechanics (ECCM in Paris, France, May 17–21, 2010.

The papers in this issue represent the state of the art in research on wave propagation in porous media, where a fine mix between experimental and theoretical contributions is achieved. Selected contributions were subsequently invited for full paper contributions to this Special Issue of Transport in Porous Media: **Experiments, Theory, and Numerical Modeling of Waves in Heterogeneous Porous Media.**

The contributions underwent a full reviewing process resulting in papers on fracture effects on wave propagation (Berryman; Fan and Smeulders), experimental shock tube

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applications (Britan et al.; Fan and Smeulders), innovative theoretical and computational modeling (Pazdniakou and Adler; Boutin; Serrano), and novel wave coupling phenomena (Schakel and Smeulders). The following contributions are acknowledged:

A. Pazdniakou and Pierre Adler extend existing Lattice Spring Models (LSM) to study elastic waves through dry porous media. They demonstrate that this method constitutes a simple and robust method to calculate the (linear) elastic properties of porous media predicting elastic wave propagation.

H. Fan and D. Smeulders demonstrate that an experimental technique based on shock-induced linear wave propagation in porous cylinders is capable to detect existing fracture zones in borehole configurations. The new experimental results are underpinned by existing predictions from literature.

M. Schakel and D. Smeulders present new experimental and theoretical results on the coupling between seismic and electromagnetic waves in porous materials. This coupling is induced by the existence of an electric boundary layer on the nano-scale at the solid–grain interface, characterized by the so-called zeta-potential. Their theory is based on the linear combination of the Biot and Maxwell relations.

A. Britan and co-workers prepared particulate foam consisting of particles of coal fly ash added to a mixture of fire-fighting surfactants and tap water. The foam was tested in a shock tube set-up to test blast wave mitigation effects. A nonlinear system of equations is used to predict pressure wave propagation, which is compared with experimental results.

James Berryman presents an algorithm for inverting laboratory or field data for the drained constants of an orthotropic fractured poroelastic system. The fluid in the fractures tends to mitigate the weakening effect by the fractures themselves. His analysis quantifies these effects and shows that the key physical variable to account for them is the so-called Skempton's second coefficient, which is always between zero and one. Also relations between fracture aspect ratio and Skempton's coefficient are discussed.

Claude Boutin investigates sound propagation in air-saturated rigid porous media, which generally have frequency-dependent properties (e.g., permeability and compressibility). This means that the so-called non-locality in time is inferred. Correspondingly, for smaller wavelengths or for double porosity systems, also a non-locality in space in introduced, where pressure gradients in adjacent Representative Elementary Volumes (REVs) influence the pressure gradient in the unit cell under consideration. To study this, the homogenization method of periodic media is adapted for weak non-local corrections.

Segio Serrano improves the Adomian method of decomposition for nonlinear waves in porous media. Nonlinear wave propagation in porous media is traditionally approached via numerical solutions of the governing differential equations, but these may generate instabilities and require linearization steps. The Adomian method has the advantage of both analytical and numerical procedures, but was still limited in the coordinate direction. In this paper, extensions of the method to boundary conditions imposed on all coordinate axes are considered, thus allowing a more comprehensive nonlinear transient analysis of groundwater flow.