Homogenization and Numerical Model Reduction of Fine-Scale Poroelasticity towards a Poro-Viscoelastic Substitute Model

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ABSTRACT

This contribution deals with Variationally Consistent Homogenization and Numerical Model Reduction (NMR) of fluid transport and pressure diffusion in heterogeneous poroelastic media. Exposed to a macroscopic loading, the heterogeneity of the material leads to local (i.e. on a scale much smaller than the macro-scale) fluid pressure gradients which are equilibrated via local pore fluid redistribution until a stationary regime is reached. Due to locality of the process, a macroscopic observer is not able to measure the redistribution process directly, but he senses the intrinsic attenuation of a material with apparently poro-viscoelastic properties.

The aim of this contribution is to establish a numerically efficient computational homogenization method to identify the poro-viscoelastic properties of the macroscopic substitute model. We establish an NMR procedure that is inspired by the Nonuniform Transformation Field Analysis [1, 2]. Starting point is the additive decomposition of the pore pressure field p into a stationary part p_{stat} and a fluctuation part $\tilde{p}^{\mu}$,

$$p(\mathbf{x},t) = p_{\text{stat}}(\mathbf{x},t) + \tilde{p}^{\mu}(\mathbf{x},t) \text{ with } \tilde{p}^{\mu}(\mathbf{x},t) \approx \sum_{a=1}^{M} \hat{p}_a(\mathbf{x})\, \xi_a(t),$$

where $\hat{p}_a(\mathbf{x})$ and $\xi_a(t)$, $a = 1, 2, \ldots, M$, are called pressure modes and mode activity coefficients. For computational efficiency, M should be a finite, preferably small, number. It turns out that the mode activity coefficients $\xi_a(t)$ represent internal variables that define the viscoelastic contribution to the macroscopic substitute model. The pressure modes $\hat{p}_a(\mathbf{x})$ may be identified in terms of a Proper Orthogonal Decomposition of snapshots stemming from ("offline") training computations executed on Representative Volume Elements. We show that this data basis enables us to derive the material properties of the poro-viscoelastic substitute model in a reliable way. Altogether, we establish a reduced FE^2 procedure to solve macroscopic initial boundary value problems in a numerically highly efficient fashion.

The proposed method is validated in several numerical experiments.

REFERENCES

[1] Jänicke, R., Larsson, F., Steeb, H., and Runesson, K. Numerical identification of a viscoelastic substitute model for heterogeneous poroelastic media by a reduced order homogenization approach. *Comp. Meth. Appl. Mech. Eng.* (2016) **298**:108–120.

[2] Jänicke, R., Quintal, B., Larsson, F., and Runesson, K. Identification of viscoelastic properties from numerical model reduction of pressure diffusion in fluid-saturated porous rock with fractures. *Comp. Mech.* (2018) DOI 10.1007/s00466-018-1584-7.