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A multiscale multi-permeability poroplasticity model linked by recursive homogenizations and deep learning

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Abstract Many geological materials, such as shale, mudstone, carbonate rock, limestone and rock salt are multi-porosity porous media in which pores of different scales may co-exist in the host matrix. When fractures propagate in these multi-porosity materials, these pores may enlarge and coalesce and therefore change the magnitude and the principal directions of the effective permeability tensors. The pore-fluid inside the cracks and the pores of host matrix may interact and exchange fluid mass, but the difference in hydraulic properties of these pores often means that a single homogenized effective permeability tensor field is insufficient to characterize the evolving hydraulic properties of these materials at smaller time scale. Furthermore, the complexity of the hydro-mechanical coupling process and the induced mechanical and hydraulic anisotropy originated from the micro-fracture and plasticity at grain scale also makes it difficult to propose, implement and validate separated macroscopic constitutive laws for numerical simulations. This article presents a hybrid data-driven method designed to capture the multiscale hydro-mechanical coupling effect of porous media with pores of various different sizes. At each scale, data-driven models generated from supervised machine learning are hybridized with classical constitutive laws in a directed graph that represents the numerical models. By using sub-scale simulations to generate database to train material models, an offline homogenization procedure is used to replace the up-scaling procedure to generate cohesive laws for localized physical discontinuities at both grain and specimen scales. Through a proper homogenization procedure that preserves spatial length scales, the proposed method enables field-scale simulations to gather insights from meso-scale and grain-scale micro-structural attributes. This method is proven to be much more computationally efficient than the classical DEM-FEM or FEM^2 approach while at the same time more robust and flexible than the classical surrogate modeling approach. Due to the usage of bridging-scale technique, the proposed model may provide multiple opportunities to incorporate different types of simulations and experimental data across different length scales for machine learning. Numerical issues will also be discussed.

Keywords dual-porosity, data-driven modeling, directed graph, embedded discontinuity, recurrent neural network, multiscale method

1 Introduction

Many geological materials are porous media with a pore size distribution that spans several orders in magnitude. For instance, a crystalline rock may contain micro-pores filled with brine inclusion inside each crystal grain, while precipitation may exist in between grain boundaries. However, the initiation, propagation and coalescence of flaws, defects and cracks may also produce larger pores that become flow conduits. Natural geological process or human activities such as CO_2 storage or hydraulic fractures may also induce

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