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A multi-domain continuum scale model for hierarchically structured porous media

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Structural hierarchy is a fundamental characteristic of natural porous media. Yet, it provokes one of the grand challenges for the modeling of fluid flow and transport since pore scale structures and continuum scale domains often coincide independent of the observation scale. Common approaches to represent structural hierarchy build either on a multi-domain continuum or on the coupling of Stokes equations with Darcy's equation. The former, however, does not consider the pore structure in explicit ways. Here, we present a combination of these two approaches to model a uniform flow for both domains and explicitly considering the structure of large scale features without using Stokes equations. Specifically, we include the pore space morphology to fully parameterize the flow according to Darcy's law in combination with the law of Hagen-Poiseuille inside pore scale structures. Continuum scale parts are modeled as commonly done using effective parameters. We compare our approach to solutions of Stokes equation on a synthetic domain to illustrate its fitness. The resulting flow fields of both approaches are practically identical. Furthermore, we applied the model employing X-ray μ-CT data of columns with a hierarchically structured porous medium built from solid glass beads and microporous glass pellets. The resulting simulated flow field was used to predict the breakthrough of a conservative solute via particle tracking, which was then compared to the experimental breakthrough of NaCl. The excellent agreement of observations and simulations confirms the suitability of the presented approach and the validity of the model assumptions at laminar flow regimes. In this way, a multi-domain modeling approach was found that might also be useful on larger scale simulations typically represented by solutions of Stokes-Brinkman equations.