Biot-Bažant Conference, June 1-3, 2021
Northwestern University, Evanston, IL

Incompressible fluid flow in a deformable frame

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Abstract:

Everyday experience shows that fluid mass can be squeezed out of a porous medium by suitably deforming the porous frame. When fluid is transported through a porous medium, it is likely that the flow is incompressible. In the Biot theory, the porous frame is deformable, however, the fluid flow regime is not immediately apparent. When the Biot theory is constructed from the pore-scale equations via volume averaging, one finds that this macroscopic theory accounts for compressible flow only. This is also corroborated by the fact the diffusion constant depends on the fluid bulk modulus. However, the more plausible scenario of incompressible fluid flow is beyond the scope of Biot's theory. We examine the diffusion process predicted by the de la Cruz-Spanos (dCS) poroelasticity theory when the flow is incompressible[1]. Crucial in our analysis is the role of the pore-interface motion. In the incompressible flow limit the fluid-solid interaction is unidirectional (Figure 1). We find that the diffusion constant appearing in the diffusion equation for the increment of fluid content does then depend on the drained porous frame elastic properties but not on the fluid bulk modulus. For low-porosity materials, this diffusion constant can be two orders of magnitude larger than the corresponding diffusion constant in the Biot theory.

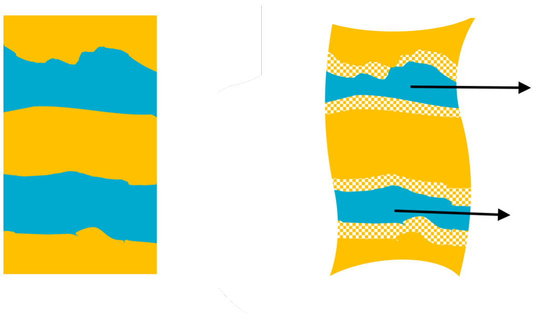

Figure 1: Schematic of flow out of a control volume (left) driven by the deformation of the solid phase (right) due to injection of fluid at a distant source point. During infinitesimal deformation of the solid phase the pore boundary moves and sweeps away a certain pore volume $\Delta V_{\rm p}$ (hatched region). At macroscale, the dilatational part of the interfacial strain is interpreted as the change of porosity. To guarantee fluid incompressibility, the amount of fluid volume expelled from a control volume is exactly given by $\Delta V_{\rm p}$. The flow direction vector (black arrows) is pointing away from the source, where a continuous supply of fluid is provided.

[1]Sahay, P. N. and T. M. Müller (2020). *Diffusion in deformable porous media: Incompressible flow limit and implications for permeability estimation from microseismicity. Geophysics, 85(2),A13–A17.*