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Linking fluid flow in a shear zone to the surrounding bulk with poroelastic boundary integral solutions

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A central problem in earthquake physics and fault mechanics is understanding the coupling of fluid and solid phases during fault slip. This coupling is mostly treated as a one-way coupled problem where the pore pressure is imposed as a perturbation in effective normal stress. However, more recent work indicates that the two-way coupling of a porous fluid-filled bulk and pressure changes in the shear zone significantly alters rupture properties. Further, a qualitative analysis of this problem in a poroelastic medium reveals that pore pressure inside an mm to micron thick frictional shear zone cannot be constant as slip dynamically evolves. This analysis calls into question the practice of imposing pore pressure as a perturbation to effective normal stress at an infinitesimal interface and raises fundamental questions regarding the interpretation of the effective stress principle. Here we explore two ways to couple shear zone processes on a mm-micron scale to the meter-kilometer scale bulk processes. Efficient coupling across these scales is achieved with a spectral boundary integral representation of a poroelastic bulk. Furthermore, the boundary integral representation reduces the dimension of the computational problem that needs to be discretized by one. In other words, it allows us to simulate 3D physics by only discretizing in 2D. We develop boundary integral solutions in 2D and 3D medium that are appropriate for modeling shear zone that can undergo pressure changes, expansion/contraction, and shear localization. First, we explore an efficient approach where shear zone properties are averaged and dimensionally reduced, thus with finite shear zone effects built into the boundary conditions of the bulk in 2D and 3D. Second, we show how a shear zone can be explicitly modeled, but the coupling to the surrounding bulk is done with a boundary integral representation. Thus, offering relatively efficient modeling of processes such as shear localization, dilatancy, thermal pressurization, and how such processes interact with the bulk. We suggest that such use of boundary integrals may be applied more generally to achieve two-way fluid-solid coupling at lower computation expense.