Seepage Forces and Their Effects on the Development of Faults and Hydraulic Fractures

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Seepage forces result from fluid flow through a porous medium, in response to an overpressure gradient, according to Darcy's Law. As the fluid flows past each grain or element of the solid framework, frictional drag and a local difference in pore pressure impart a seepage force to the grain. This contributes to the local balance of forces and modifies the effective stress in the solid framework. The critical factor is neither the rate of Darcy flow, nor the permeability, but the magnitude of the overpressure gradient. Over the past few years, experiments on fluid flow through porous granular materials have demonstrated the importance of seepage forces, especially at high values of overpressure, close to the overburden stress. By modifying the effective stresses, seepage forces may cause shear faults and tensile fractures to nucleate in various orientations.

1. In a thrust belt or a large gravity slide, where overpressure ramps up across a sealing layer of low permeability, incipient shear faults have listric shapes and curve into a layer-parallel detachment. This has major consequences for the structural development of deltas.

2. In strike-slip zones, where overpressure comes from a deep source, seepage forces have significant horizontal components, as well as vertical ones. The horizontal components reduce the frictional resistance on the main strike-slip zone and produce through-going faults, instead of oblique Riedel shears.

3. In cohesive materials, fluid overpressure may result in internal hydraulic fracturing. The vertical gradient of overpressure may attain or exceed the overburden stress. In basins, which are subject to no horizontal tectonic stress, hydraulic fractures may initiate in horizontal attitudes, rather than the more conventional vertical attitudes.

4. Non-cohesive layers may fluidize and the resulting material may intrude more cohesive layers, forming sand injectites, or may extrude at the free surface, forming gravity flows.

5. In composite materials, which consist in part of grains that can melt or transform to a liquid phase, heating from below may result in loss of support within the solid framework. The settling of grains through the pore fluid then results in seepage forces, which set up an overpressure gradient in the pore fluid. This in turn may lead to horizontal hydraulic fracturing, migration of the liquid fraction, and extrusion at the surface.