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Towards understanding coupled fluid-granular deformation during shear

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The deformation of coupled fluid -granular matter is a fundamental physical problem, with many practical implications: from shearing of a fluid-filled gouge zone, to earthquake induced liquefaction, and to formation of debris flows. The basic picture is a porous skeleton made of contacting grains, with fluid-filled pores. The skeleton may deform elastically or in a poro-plastic manner (e.g. pore collapse). Such changes of pore structure and volume may affect the pore fluid pressure. The fluid pressure in turn exerts a force affecting grain motion and network evolution. In order to study such coupled deformation of saturated granular material in response to forcing, we developed a generic analytical framework, based on first principles of mass and momentum conservation, for both phases, the granular one and the interstitial fluid one. This formulation captures basic coupling mechanisms leading to generation of high pore pressure. The formulation then serves as a basis for a general two-level two-phase model, suitable for simulating irreversible and finite matrix deformation: the grains are modeled at the grain scale using a granular dynamics model, while fluid is simulated on a coarser Darcy porous flow scale.

The analytical and numerical models are used to understand the physics of pore pressure elevation during shear of granular matter. Initial results from our model already provide insights. First an analytical formulation for coupled solid-fluid deformation was developed. The formulation reveals two processes by which pore pressure evolves: when drainage is relatively poor, pore fluid pressurization is correlated to fluid compressibility which is thus proven to be essential (in contrast to what was previously thought), and when drainage is relatively good, pore pressure may rise as a result of a coupling between granular deformation and Darcy flow. In the latter case, pore pressure elevation to high values may take place even when initially dense granular packing is sheared, in contrast to the common conception that pore fluid pressurization occurs only in initially loose packing. We also use the model to calculate expected pore pressure rise induced by elastic and poro-plastic deformation of the granular skeleton during shear, and compare these predictions with existing theories and experiments.