Pore-scale modeling tools for three-phase sediment transport processes

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Key words: Multiphase Flow, Level Set, Immersed Boundary, Discrete Element Method, Finite Element Method

Introduction

A better understanding of sediment erosion and deposition processes is critical to the mission of the US Army Corps of Engineers and many other organizations concerned with flood protection, navigation, and riverine and coastal water resources. Long-term engineering of the Mississippi river, beach nourishment projects for coastal communities, and design of levees, breakwaters, and dunes for storm protection are just a few areas that turn on the interaction of fluids with granular materials. Hunter Rouse, "the father of modern hydraulics" wrote in 1939 that, "neither mathematical tools nor physical understanding of their use can be considered sufficiently far advanced to cope with so intricate a problem at the present time" [3]. Today, the state of practice in computational modeling of sediment dynamics still relies heavily on empirical relationships.

In recent decades, however, much progress has been made on the development of numerical methods capable of obtaining accurate solutions of fluid-grain dynamics at the microscale as well as on rigorous methods for obtaining practical computational models at larger scales. Perhaps soon mathematical tools and physical understanding will be sufficiently advanced to cope with the intricate problem of sediment dynamics. This presentation will describe a combination of level set [1, 2] and immersed/embedded boundary methods [4, 5] for simulating microscale air-water-solid dynamics using finite element methods for incompressible flow of the fluid phases and discrete element methods for the dynamics of the solid grains.

Approach

Level set methods have been used for decades to model two-phase incompressible flows because, among other reasons, the provide a robust method for dealing with topological change [6]. Due to the geometric content inherent in the level set interface representation, the resulting framework naturally also allows inclusion of the surface tension force and provides the continuum field variables and geometric quantities for common filtering and averaging approaches. The same representation can be used for the fluid-solid boundaries, but enforcement of proper jump conditions at the fluid-solid interface than the fluid-fluid interface. The additional difficulty is partly due to the fact that the solid phase physics is described as a system of interacting rigid bodies and the continuity of velocity at the interface must be modeled as a no-slip condition on the fluid. Immersed and embedded boundary methods provide methods for specifying the no-slip condition. The combination of level set and immersed boundary methods allows topological changes through out the multiphase domain, that is bubbles, droplets, and solid separation/contact as shown in the simulation in figure 1. Conveniently, X-ray

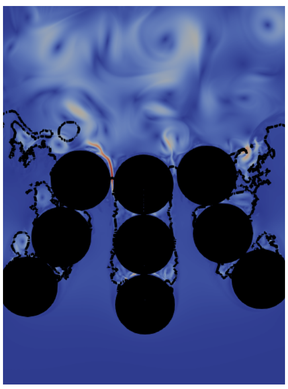

Figure 1: Simulation of solid spherical grains falling through air and water

micro-tomography (CT) can now provide experimental results of air-water-sediment systems as shown in figure

2. In addition to the computational methods above we have developed a workflow for generating granular

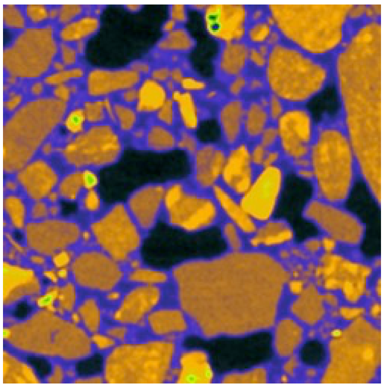

Figure 2: Detail of CT scan of moist soil. Using these high-resolution CT scans of moist soils, we can identify and characterize the pore fluid distribution (blue regions) within the solid matrix (orange regions). This allows us to construct realistic virtual samples with fluid infiltration.

material based on the output of the CT scans 3. In this presentation we will describe these approaches in

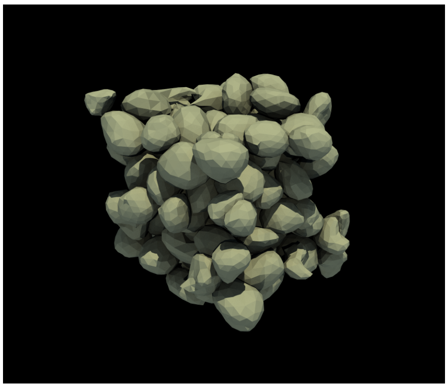

Figure 3: Virtual grains generated from CT scans of a soil sample. We have developed a workflow that generates virtual soil samples to facilitate a one-to-one correspondence between physical and numerical experiments to improve model calibration and process upscaling.

more detail and provide an update on this ongoing area of research and development at the US Army Engineer Research and Development Center.

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