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Four-way coupling of a three-dimensional debris flow solver to a Lagrangian Particle Simulation: method and first results

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Debris flows are dense flowing mixtures of water, clay, silt, sand and coarser particles. They are a common natural hazard in mountain regions and frequently cause severe damage. Modeling debris flows to design protection measures is still challenging due to the complex interactions within the inhomogeneous material mixture, and the sensitivity of the flow process to the channel geometry.

The open-source, OpenFOAM-based finite-volume debris flow model debrisInterMixing (von Boetticher et al, 2016) defines rheology parameters based on the material properties of the debris flow mixture to reduce the number of free model parameters. As a simplification in this first model version, gravel was treated as a Coulomb-viscoplastic fluid, neglecting grain-to-grain collisions and the coupling between the coarser gravel grains and the interstitial fluid.

Here we present an extension of that solver, accounting for the particle-to-particle and particle-to-boundary contacts with a Lagrangian Particle Simulation composed of spherical grains and a user-defined grain size distribution. The grain collisions of the Lagrangian particles add granular flow behavior to the finite-volume simulation of the continuous phases. The two-way coupling exchanges momentum between the phase-averaged flow in a finite volume cell, and among all individual particles contained in that cell, allowing the user to choose from a number of different drag models. The momentum exchange is implemented in the momentum equation and in the pressure equation (ensuring continuity) of the so-called PISO-loop, resulting in a stable 4-way coupling (particle-to-particle, particle-to-boundary, particle-to-fluid and fluid-to-particle) that represents the granular and viscous flow behavior of debris flow material.

We will present simulations that illustrate the relative benefits and drawbacks of explicitly representing grain collisions, compared to the original debrisInterMixing solver.