Multiscale Multiphase Modelling of Granular Flows

Krishna Kumar Soundararajan

Department of Engineering

University of Cambridge

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Geophysical hazards, such as avalanches, debris flows and submarine landslides, involve rapid mass movement of granular solids, water and air as a single-phase system. The momentum transfer between discrete and continuum phases significantly affects the dynamics of the flow. The dynamics of a granular flow involve at least three distinct scales: the *microscopic scale*, which is characterized by contact between soil grains, the *meso-scale*, which represents micro-structural effects such as grain rearrangement, and the *macroscopic scale*. This study aims to understand the ability of continuum models in capturing the micro-mechanism of granular flow dynamics. The initiation and propagation of granular flows depend mainly on the initial density, slope, and the quantity of material destabilised.

Collapse of a granular column on a horizontal surface is a simple case of granular flow, however, the mechanism of collapse and the flow dynamics is yet to be fully understood. In the present study, multi-scale modelling, i.e. discrete-element and continuum analyses, of quasi-two dimensional collapse of granular columns are performed. Material Point Method (MPM), a hybrid Lagrangian and Eulerian approach is used to describe the continuum behaviour of granular column collapse, while the micromechanics is captured using Discrete Element Method (DEM).

The run-out distance exhibits a power law dependency with the aspect ratio of the column. Discrete-element approach predicts transition behaviour in the run-out distance with increase in the aspect ratio of the granular column. The run-out profile predicted by the continuum simulations matches with DEM simulations for columns with small aspect ratios (‘h/l’ ≤ 2), however MPM predicts longer run-out distances for columns with higher aspect ratios (‘h/l’ > 2). Energy evolution study in DEM simulations reveals higher collisional dissipation in the initial free-fall regime for tall columns. The lack of collisional energy dissipation mechanism in MPM simulations results in longer run-out distances. In DEM simulations, Voronoi tesselation is used to evaluate the development of shear bands and evolution of local packing density. Studies on granular collapse with different initial densities reveal the same critical density at the end of the flow. A sliding flow regime is observed above the distinct passive zone at the core of the column. Stress profiles obtained from both the scales are compared to understand reason for a slow flow run-out mobilization in MPM simulations.

Certain macroscopic models are able to capture simple mechanical behaviours, however the complex physical mechanisms that occur at the grain scale, such as hydrodynamic instabilities, the formation of clusters, collapse, and transport, have largely been ignored. In order to describe the mechanism of saturated and/or immersed granular flows, it is important to consider both the dynamics of the solid phase and the role of the ambient fluid. In particular, when the solid phase reaches a high volume fraction, it is important to consider the strong heterogeneity arising from the contact forces between the grains, the drag interactions which counteract the movement of the grains, and the hydrodynamic forces that reduce the weight of the solids inducing a transition from dense compacted to a dense suspended flow. Hence, it is important to understand the mechanism of underwater granular flows at the granular scale. A pending research issue is the parameterisation of interactions between the water phase and the sediment phase. Owing to the number of flow variables involved and measurement imprecision, estimating such parameters from laboratory experiments remains difficult.

In this study, two-dimensional sub-grain scale numerical simulations are performed to understand the local rheology of a dense granular flows in a fluid. The Discrete Element Method (DEM) is coupled with the Lattice Boltzmann Method (LBM) for fluid-grain interactions, to understand the evolution of immersed granular flows. The fluid phase is simulated using Multiple-Relaxation-Time LBM method for better numerical stabilities. The Eulerian nature of the LBM formulation, together with the common explicit time step scheme of both LBM and DEM makes this coupling strategy an efficient numerical procedure for systems dominated by both grain–fluid and grain–grain interactions. The D2Q9 Model in LBM is used to simulate the fluid phase. In order to simulate interconnected pore space in 2D, a reduction in radius of the grains is assumed during LBM computations. Granular materials of different permeabilities are simulated by varying the reduction in radius of the grains. A parametric analysis is performed to assess the influence of the grain sample characteristics (initial configuration, permeability, slope of inclined plane) on the evolution of flow and run-out distances. The effect of hydrodynamic forces and hydroplaning on the run-out evolution is analysed by comparing the mechanism of energy dissipation and flow evolution in dry and immersed granular flows. Voronoi tesselation was used to study the evolution of local density and water entrainment at the flow front. A parameteric analysis is performed to assess the influence of the grain sample characteristics (initial configuration) and the fluid properties (e.g., viscosity) on the evolution of flow and run-out distances. The effect of hydrodynamic forces on the run-out evolution is analysed by comparing the mechanism of energy dissipation and flow evolution in dry and immersed granular flows.