Multi-scale multiphase modelling of granular flows

Krishna Kumar Soundararajan

Department of Engineering

University of Cambridge

This dissertation is submitted for the degree of

Doctor of Philosophy

King's College 2014

Multi-scale multiphase modelling of granular flows

Krishna Kumar Soundararajan

Geophysical hazards usually involve flow of dense granular solids and water as a single-phase system. The dynamics of a homogeneous granular flow involve three distinct scales: the *microscopic scale*, the *meso-scale*, and the *macroscopic scale*. Granular materials exhibit complex solid-like and/or fluid-like behaviour depending on how the grains interact with each other. Although soil flows are conventionally modelled as a continuum, recent studies have shown the limitations of continuum models to capture the in-homogeneities at the grain-scale level. In the present study, a multi-scale approach is adopted to understand the rheology of granular flows and the limitation of continuum models.

The Generalised Interpolation Material Point Method (GI-MPM), a hybrid Eulerian – Lagrangian approach is implemented in the present study to describe the continuum behaviour of granular flows. The Discrete Element Method (DEM) is used to model the micro-mechanics of granular flows. A two-dimensional collapse of a granular column on a horizontal surface is studied. The run-out distance of a granular column collapse exhibits a power law dependency with the aspect ratio of the column. For columns with small aspect ratios ('h/l' ≤ 2), both the approaches predict similar run-out behaviour. However, MPM predicts longer run-out distances for columns with larger aspect ratios ('h/l' > 2). The energy dissipation mechanism during the collapse reveals higher collisional dissipation in the initial free-fall regime for tall columns. The lack of collisional dissipation in MPM is found to be the reason for longer run-out distances for tall columns. The classical Mohr-Coloumb model has the ability to capture the rheology of granular flows in dense-granular and critical state flow regimes, such as run-out evolution of slopes subjected to impact loading, where the Inertial number $I < 0.1$.

The initiation and propagation of submarine granular flows depend mainly on the slope, density, and quantity of the material destabilised. The complex physical mechanisms that occur at the grain scale, such as the hydrodynamic instabilities and formation of clusters, have largely been ignored. A GPU paralellised two-dimensional Lattice Boltzmann LBM – DEM coupled technique is developed to understand the local rheology of a dense granular flows in a fluid. Granular materials of different permeabilities are simulated by varying the hydrodynamic radius of the grains. A parametric analysis is performed to assess the influence of the initial configuration, permeability, and the slope of the 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 the flow evolution in dry and immersed granular flows. Voronoi tesselation is used to capture the meso-scale behaviour such as the evolution of local density and water entrainment at the flow front.