Postdoctoral position

Modeling and numerical simulations of dense and fluidized granular flows. Application to pyroclastic density currents.

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Salary : the gross salary is 2690 € per month (net income 2238 €).
Starting date : between september 2022 and january 2023.
Duration : 17 months.
Application procedure : candidate must send a resume and a motivation letter. Recommendation letters are welcome but not mandatory.

Scientific context. Dense granular flows involved in some pyroclastic density currents (PDCs) during explosive volcanic eruptions are inherently complex and the physical mechanisms involved are still poorly understood. It is now widely recognized by the vulcanological community that PDCs, consisting of a mixture of gas, rock fragments and ash, are vertically stratified in density [1]. Most of these flows consist of a dense basal flow, with particle volume concentrations of the order of 30-50%, overlain by a dilute turbulent part in which clusters of intermediate concentrations can feed the basal flow. Concentrated gravity flows of gas-particle mixtures remain poorly understood due to the complexity of the physical mechanisms. The concentrated part of PDCs behaves like a fluid and can travel distances that in some cases exceed 100 kilometers on almost horizontal slopes [2]. These flows are major natural hazards that can cause extreme human and material damage and have environmental consequences on a continental or even global scale. Understanding the mechanisms that control the run out distance of pyroclastic flows and modeling these devastating natural phenomena is a major challenge for fundamental research and for the study of natural hazards.

Fluidization due to pore gas pressure, which strongly reduces interactions between solid particles, is a mechanism that allows flows to propagate over large distances [3]. Collapse experiments of fine-grained columns ($< 100\,\mu m$) conducted at the Laboratoire Magmas et Volcans (LMV) have demonstrated the essential role of pore gas (air) pressure : a column initially fluidized by vertical injection of air at its base and then released propagates over a distance about twice as long as that observed for an non-fluidized column [3]. Moreover, these experiments have highlighted that PDCs have an interface, which separates a static part (the basal deposit) and a moving upper part, and which migrates upwards in time [3] and controls the deposition rate of the particles. These results were reproduced by numerical simulations in [4], using a two-dimensional model based on the incompressible Navier-Stokes equations with the μ(I)-rheology [5] and taking into account the pore gaz pressure. The use of a non-averaged model is essential here to study the internal dynamics of these flows. In [4] (see also [6]), the μ(I)-rheology is rewritten as a visco-plastic constitutive law. This formulation reveals a mathematical difficulty due to the non-differentiable definition of the deviatoric stress tensor. We have solved this problem by introducing a projective formulation of the plastic tensor. We thus obtain a bi-projection scheme [7] which was initially developed, analyzed and implemented in the context of Bingham fluids.

This approach suffers from several shortcomings and limitations although it captures the essential features of these flows. Indeed, as the volume fraction of particles in the granular medium is assumed to be constant, dilation/compression effects cannot be taken into account, restricting the study to dense compacted flows. The aim of this project is to enrich the model to simulate weakly diluted PDCs that are highly present in nature.

Research project. A parallel code, written in Fortran 90 and using the PETSC and MPI libraries, has been developed at LMBP to simulate the collapse of dense granular columns. Fluidization can be used by applying a constant flow of air from below during the collapse of the granular column. The code produced the results presented and analyzed in [4]. One phase is Newtonian while the other is visco-plastic, with a space and time varying viscosity and a Drucker-Prager plasticity criteria. The plastic part of the stress tensor for the granular flow is computed with a bi-projection scheme [7]. The interface between the two phases is tracked with a level set method. A friction law is applied to the walls in contact with the granular material. The effect of the gas (air) on the solid particles in the granular medium is taken into account by a pore pressure diffusion equation. Indeed, by using the Jackson's equations [8] to model the air/particle mixture and invoking the law of perfect gases, a time evolution equation for the pore gas pressure can be derived.

The postdoctoral fellow will contribute to the development and implementation of a model that takes into account dilation/compression effects of granular flows. More precisely, the Roux and Radjai dilation model [9] will be considered. As a consequence, the granular flow is no longer incompressible. Nevertheless, a bi-projection method [7] can still be written. Related mathematical issues such as the existence of an energy equation and the stability of the numerical scheme will be studied. The model and its implementation will be evaluated by comparing numerical simulations of the collapse of weakly expanded granular columns with the results of experiments conducted at LMV [2]. As in [4] and [6], experimental measurements of the front velocity, flow shape and internal dynamics as well as the length of the final deposit in the collapse configuration of a dense, fluidized and weakly expanded granular column will be used.

Bibliography

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