Minicolloque n° 11 ☐ **Oral**

A modified kinetic theory for sediment transport

Rémi Chassagne[a*], Raphaël Maurin[b], Philippe Frey[c] et Julien Chauchat[a]

a. Univ. Grenoble Alpes, CNRS, Grenoble INP, LEGI, 38000 Grenoble, France
b. IMFT, Univ. Toulouse, CNRS – 31000 Toulouse, France
c. INRAE, Univ. Grenoble Alpes, UR ETNA, St Martin d'Heres, France

* email : remi.chassagne@univ-grenoble-alpes.fr

Modelling natural granular flows, such as sediment transport, is of great importance for the understanding of geomorphological evolution. The associated scales are however so large that a continuum description of the granular phase has to be adopted.

In this context, a two-phase flow model for sediment transport, implemented in the SedFOAM code [1] is presented. The fluid phase is classically modeled as a turbulent fluid flow, with a mixing length approach, and interacts with the granular phase through drag and buoyancy forces. For the granular phase, a frictional-collisional approach is considered (Johnson & Jackson, 1987), i.e. the granular stresses are the sum of elastic stresses, due to enduring contacts, and kinetic stresses, due to fluctuating motion of particles and short collisions. While the former are computed with empirical closures from soil mechanics [2], the latter are based on the kinetic theory of granular flow. This requires the resolution of an additional conservation equation for the granular temperature, which closures are given by the Garzo & Dufty model for frictionless spheres [3].

The theory is compared with coupled fluid-Discrete Element Method (DEM), where frictional spherical particles are transported by a downslope flowing fluid. The DEM simulations show two points of departure from theory. First, the behavior of the dense part of the bed is highly influenced by inter-particular friction. Second, due to strong gradients at the bed surface, the kinetic theory fails at predicting the granular stresses in the dilute regime. Corrections are proposed to account for these discrepancies.

With the modifications, the continuum two phase flow model reproduces almost perfectly the fluid-DEM simulations for the whole range of packing fraction and for different values of restitution coefficient. The phenomenological mu(I) rheology is retrieved showing the relevancy of the proposed continuum model to represent such granular flows. The model is then tested against the sediment transport laboratory experiments of [4] and shows quantitative agreements with the data.

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[2] Johnson, P. C. and Jackson, R. (1987). Frictional–collisional constitutive relations for granular materials, with application to plane shearing. Journal of Fluid Mechanics, 176:67–93.
[3] Garzó, V. and Dufty, J. W. (1999). Dense fluid transport for inelastic hard spheres. Physical Review. E, Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics, 59(5 Pt B):5895–5911.
[4] Ni, W.-J. and Capart, H. (2018). Stresses and Drag in Turbulent Bed Load From Refractive Index-Matched Experiments. Geophysical Research Letters, 45(14):7000–7009.