Numerical modelling of granular avalanches through a forest of deformable pillars

M2 Research Internship 2025

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Hosting Laboratory: ELAN team @ Grenoble (INRIA/LJK), `https://team.inria.fr/elan/`

Practical details: Paid internship (INRIA scale)

Context: Granular flows are frequently found interacting with deformable structures, either in natural settings such as snow avalanches in forests, or for industrial or risk-prevention purposes. In particular, the presence of slender fibres within a granular medium is known to strongly increase the strength of the resulting material (Maher and Gray, 1990), an effect which is crucial to stabilise soils and for example reduce the erosion of coastlines or mountain slopes.

While the rheology of granular materials has been extensively studied in the last decades (see Andreotti et al. (2013) for a review), much less is known about the behaviour of grains interacting with fibres, in particular regarding the flowing properties of such media, as most investigations have focused on the resulting static yield strength, with soil reinforcement applications in mind.

Investigating the flowing behaviour of grain-fibre mixtures is however essential to model the macroscopic rheology of the system, and better understand how the complex couplings between elasticity and friction at the micro-scale can affect the mechanical properties of the material.

Figure 1: Dunes in Vendée (France) are stabilised by plants of marram grass (image taken from `https://www.zoom-nature.fr/loyat-sculpteur-de-dunes`).

Objectives: The simple "inclined plane" shear experiment is among the most straightforward configurations to investigate the flow of granular materials and characterise their rheology as well as their yield properties (Pouliquen, 1999). It has notably been used recently by Darbois Texier et al. (2023) to examine how a forest of rigid pillars can impact granular flows, and in particular reduce the flow-rate of the material due to the additional drag forces created by the obstacles.

As a first step to investigate the rheology of grain-fibre mixtures, we propose to generalise the inclined plane setup by considering the downslope flow of a granular material through a forest of flexible fibres, and study how the elasticity of the fibres, as well as the frictional interactions between the grains and the fibres, can impact the granular flow. The goal of this project is thus to develop efficient numerical models to simulate large assemblies of grains in – frictional – interaction with clamped fibres, and use the resulting simulator to perform numerical experiments to characterise the rheological properties of the system. The numerical study will be supported by experimental measurements in the context of a collaboration with the FAST lab (Université Paris-Saclay).

The work will notably benefit from robust contact solvers for rigid bodies and Kirchhoff rods developed in the team (Crespel et al., 2024; Daviet et al., 2011; Bertails et al., 2006), and will explore direct discrete element approaches as a first step towards continuous modelling (Rousseau et al., 2023).

Required skills: Good skills in numerical analysis (modelling, numerical discretisation of ODEs and PDEs, finite elements, optimisation) as well as in algorithmics and computer programming (C/C++) are required. Curiosity and taste for applications in physics, mechanics and computer graphics would be appreciated.

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References

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