Granular flows over obstacles using smooth and non-smooth discrete element methods

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Abstract

This study investigates the interaction between granular flows and obstacles, a critical topic for
designing protective structures and mitigating natural disasters. Traditionally, researchers have used
two types of discrete numerical methods to model granular flows in quasi-static (solid-like), dense
inertial (liquid), or dilute (gas) states: smooth and non-smooth Discrete Element Method (DEM).
In this study, we perform numerical simulations of a two-dimensional (2D) granular flow down an
incline passing over an obstacle, with the help of both smooth and non-smooth DEMs.

The main objective is to validate a granular fluid model by applying both methods to the same
geometry and examining key phenomena, such as the μ(I)–rheology, the formation of "dead zones"
upstream of obstacles, and the forces exerted on these obstacles. Smooth and non-smooth DEM
differ significantly in their definitions of contact laws. Smooth DEM requires explicit, differentiable
contact laws and small time steps to maintain stability and accuracy, often relying on numerical
damping. This method has been used by Faug et al. (1) to obtain results in the specific case we
consider here. Non-smooth DEM, on the other hand, can use an implicit approach with piecewise
functions for contact laws, allowing it to capture discontinuous interactions without the need for
small time steps and damping. This method was used by Azéma & Radjaï (2) to decipher the

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different contributions to effective friction in the context of the μ(I)–rheology for tree-dimensional flows. Direct comparisons between these two methods are rare. Saint-Cyr et al. (3) proposed one for the quasi-static state but, to date, no comprehensive study has yet established the equivalence of results between them for a highly non-uniform flowing state, particularly for the case considered here when a granular flow impacts an obstacle.

After calibrating the mechanical parameters of the contact law, we examine the influence of time step size and numerical damping parameters specific to each method, providing insights into their sensitivity and stability. We use YADE (4) for smooth DEM and Siconos (5) for non-smooth DEM, with computational times being comparable (simulation of 25000 spheres over 3 seconds in 2D). Through these simulations, we compare the two approaches across various parameters, finding consistency in volume fraction, velocity profiles, and stress tensors.

Overall, this study aims to provide a detailed comparison of smooth and non-smooth DEMs, highlighting the strengths, limitations, and optimal application scenarios of each method in granular flow modeling. Finally, we discuss the validation of μ(I)–rheology using both smooth and non-smooth DEM, in zones far from the obstacle and near the obstacle. Around the obstacle, a dead zone forms upstream and co-exists with a fluid-like zone above, while a much more gaseous jet forms downstream: this complicated mechanism may raise questions about the validity of the μ(I)–rheology everywhere inside the bulk of the granular medium.

References

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