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Closure laws for dry granular avalanche flows

Thomas Weinhart, Anthony R Thornton, Onno Bokhove, and Stefan Luding
University of Twente, The Netherlands (t.weinhart@utwente.nl)

Gravity-driven free surface flows are common in both the natural geophysical environment and industry at different orders of magnitude. Common examples range from rock slides, containing upwards of 1000 m3 of material, to the flow of sinter, pellets and coke into a blast furnace for iron-ore melting, down to the flow of sand in an hour-glass.

The properties of granular avalanches depend on the inclination as well as the roughness of the basal material: for large inclinations and a rough base, the flow is essentially fluid-like and may accelerate due to gravitational forces. However, due to dissipation at the particle contact level, the flow remains steady for smaller inclinations, and for very small angles the flow arrests and becomes static. For very smooth bases, the flow can be oscillatory. As the base becomes smoother, the flow arrests at lower inclinations and the range of angles for which steady flow is observed decreases.

Simulations are done using the Molecular Dynamics (MD) algorithm which is an extremely powerful tool to investigate the effects of granular flows. With the rapid recent improvement in computational power the full simulation of a million particles is now obtainable.

However, the full MD simulation of real geophysical flow will, probably, never be possible. Continuum shallow-water style models are able to simulate the volume of real geophysical flows, but have to make averaging approximations reducing the properties of a huge number of individual particles to a handful of averaged quantities.

To obtain closure laws for the shallow-layer model, we study small simulations of steady flow for varying flow height, chute angle, and basal roughness. The resulting closure relation agrees well with the Pouliquen model for rough bases. We use the MD data sets to obtain the fictional closure law for varying basal roughnesses, showing a transition from classical Coulomb- to Pouliquen-style behaviour. The closed continuum model will be validated against full MD simulations.

For more complex scenarios, we anticipate the tabulated closure law to fail; in this situation, closure will be achieved by a heterogeneous multi-scale method, coupling the shallow-layer model with small MD simulations. The first problem considered is the flow through a contraction.