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Segregation induced fingering instabilities in granular avalanches

Anthony Thornton (1), Mark Woodhouse (2), Chris Johnson (2), Peter Kokelaar (3), and Nico Gray (2)

(1) Department of Applied Mathematics and Department of Mechanical Engineering, University of Twente, 7500 AE, Enschede, Netherlands (a.r.thornton@utwente.nl), (2) School of Mathematics and Manchester Centre for Nonlinear Dynamics, University of Manchester, Oxford Road, Manchester, M13 9PL, U.K., (3) Department of Earth and Ocean Science, University of Liverpool, 4 Brewnlow Street, Liverpool, L69 3GP, U.K.

It is important to be able to predict the distance to which a hazardous natural granular flows (e.g. snow slab avalanches, debris-flows and pyroclastic flows) might travel, as this information is vital for accurate assessment of the risks posed by such events. In the high solids fraction regions of these flows the large particles commonly segregate to the surface, where they are transported to the margins to form bouldery flow fronts. In many natural flows these bouldery margins experience a much greater frictional force, leading to frontal instabilities. These instabilities create levees that channelize the flow vastly increasing the run-out distance.

A similar effect can be observed in dry granular experiments, which use a combination of small round and large rough particles. When this mixture is poured down an inclined plane, particle size segregation causes the large particles to accumulate near the margins. Being rougher, the large particles experience a greater friction force and this configuration (rougher material in front of smoother) can be unstable. The instability causes the uniform flow front to break up into a series of fingers.

A recent model for particle size-segregation has been coupled to existing avalanche models through a particle concentration dependent friction law. In this talk numerical solutions of this coupled system are presented and compared to both large scale experiments carried out at the USGS flume and more controlled small scale laboratory experiments.

The coupled depth-averaged model captures the accumulation of large particles at the flow front. We show this large particle accumulation at the head of the flow can lead to the break-up of the initially uniform front into a series of fingers. However, we are unable to obtain a fully grid-resolved numerical solution; the width of the fingers decreases as the grid is refined.

By considering the linear stability of a steady, fully-developed, bidisperse granular layer it is shown that the governing equations, while not ill-posed, are linearly unstable to arbitrarily small perturbations. It should be noted similar stability characteristics are found for shallow layer fluid flows on an inclined plane, with small wavelength perturbations stabilized by the inclusion of empiral frictional drag and viscous dissipation. Furthermore, depth-averaged models for roll waves on a monodisperse, shallow granular layer released on an inclined plane have a similar problem with high wave-number modes remaining linearly unstable. In this case the high wavenumber instability can be suppressed by the inclusion of (phenomenological) viscous dissipation. It is possible that by including similar rheological terms in our depth-averaged model the small wavelength modes can be stabilized and a well defined finger width can be predicted.

This is the first model to describe the break-up of a uniform front of granular material, and it represents a crucial step forward in obtaining a mathematical model of this process. However, the current model is not complete and remains linearly unstable to arbitrarily small wavelength perturbations. We anticipate that these small wavelength instabilities can be stabilized by including additional physical effects, and this remains an active avenue of investigation.