Simulating debris flows in the laboratory

Summary: The objective of this subproject was to gain physical insight into the dynamics of highly concentrated particulate flows by conducting “dam-break” experiments. The experimental setting is the idealization of debris flows involving saturated poorly consolidated materials. The dam-break experiment consists in releasing a fixed volume of material and tracking the subsequent motion. The experimental facility is made up of a flume and a reservoir, from which the material is released. Using high-speed cameras and special image processing techniques, we were able to measure the flow features (such as the flow depth profile over time) together with the flow inner structure (e.g., velocity and density profiles). In our experiments, the particle concentration was close to the maximum packing fraction and we observed that minutes changes in this concentration caused tremendous changes in flow dynamics. For concentrations in excess of a critical value (0.59 for our suspensions), stick-slip motion was observed (succession of resting and flowing phases), which confirmed the role of pore pressure. For lower solid concentration, the debris flow took the appearance of a highly viscous flow.

Methods
Flow visualization is essential to understanding how complex fluids organize when flowing in the form of a ‘rapid’ surge down a flume. Going inside the flow requires special techniques. First, the fluids had to be made transparent; we used PMMA particles mixed with various fluids to obtain transparent suspensions that looked like saturated granular soils. Second, particle imaging techniques were employed to measure the velocity (and perhaps density profiles) inside the flow, far from the sidewall. Additional sensors (bottom pore pressure, flow depth profile) were also used.

Important results
We found that the solid concentration is a key parameter that controls flow dynamics. For solid concentration in excess of a critical values (close to 0.59 with our suspensions), flow is unstable and characterized by stick-slip motion. This observation is consistent with Schaeffer and Iverson’s theory [Steady and Intermittent Slipping in a Model of Landslide Motion Regulated by Pore-Pressure Feedback, SIAM J. Appl. Math. 69, 769–786 (2008)] and shows how important the excess pore pressure is in causing material ‘liquefaction’. For lower solid concentrations, we retrieved a viscous flow behavior, as documented by other authors [e.g., Bonnot et al., Inclined plane rheometry of a dense granular suspension, J. Rheol. 54 65-79 (2010)]. Some features are noteworthy. For instance, as reported on the figure thereafter, the front position scales as a power function of time, but the exponent \( n = 0.41 \) differs from the value found for dilute suspensions \( n = 1/3 \). The reason for this mismatch is still unclear.

Major outcome
The facility built within the framework of the TRAMM project is unique in that it allows to visualizing what occurs inside the flow (without disturbing flows). Although many teams in the world have conducted dam-break experiments with various flumes and materials, there is no other instance where both details of the inner flow structure (e.g., particle arrangement, velocity and density profiles) and bulk flow features (e.g., flow depth profile) can be measured at the same time. The experimental protocol was delicate to define, but after many trials and errors, we are now able to run experiments on the laboratory scale, which mimic the behavior of flows on larger scales, with the great advantage that a wealth of information can be measured in our setup.
Further reading

A paper is in preparation for the *Journal of Fluid Mechanics*.

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