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The Rosetta Stone Project – Integrating experimental results on debris flow mechanics across the scales: next results

Elisabeth T. Bowman[1*], *Amanda* Fawley[2], *Roland* Kaitna[3], *Shuai* Li[4], *Brian* McArdell[5], *Jim* McElwaine[6], *Nicoletta* Sanvitale[7], *W. Andrew* Take[2], *Lisa* Tauskela[2], *Alex* Taylor-Noonan[2], and *Yuting* Zhao[1]

[1]Department of Civil & Structural Engineering, University of Sheffield, Sheffield, United Kingdom
[2]Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada
[3]Institute of Mountain Risk Engineering, University of Natural Resources & Life Sciences, Vienna, Austria
[4]Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu, China
[5]Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland
[6]Department of Earth Sciences, Durham University, Durham, United Kingdom
[7]Department of Civil, Chemical, Environmental, and Materials Engineering, University of Bologna, Bologna, Italy

Abstract. We present the combined efforts of a research network designed to address the many challenges in the experimental modelling of debris flow phenomena. The approach has been to use apparatuses of different functional arrangement and at different scale with identical and commonly sourced flow materials from the highly idealised (dry, coarse and uniform) to the highly complex (well graded, segregating, fluid saturated). Here we briefly present some key findings of the network and point to the research questions that are currently being addressed. This complementary view of experimental debris flows helps to constrain methodological artefacts/scale effects and to identify key processes responsible for the diverse appearance and often high mobility of debris flows.

1 Introduction

Debris flows consist of poorly sorted (polydisperse or well-graded) solids that are generally fluid saturated, however, the majority of flume tests conducted in the laboratory focus on much more simple arrangements – at the extreme these may be dry granular flows of uniformly sized particles. This reticence to test fluid saturated flows is understandable as these flume tests pose significant additional challenges, including complex pore pressure effects due to coupled stress-dilatancy effects (e.g. negative or positive excess pore water pressures during shearing), often contradictory or confusing basal pore pressure measurement data, and the potential for a greater influence of scale effects over experiments conducted on dry material.

The Rosetta Stone International Experimental Network on Debris Flows commenced in August 2017 [1] as a partnership between five institutions (The University of Sheffield, UK, Queen's University, Canada, IAN-BOKU, Austria, WSL, Switzerland and Durham University, UK.) with the objective to use the complementary expertise and experimental facilities available (flumes of varying size, a vertical drum, and a highly instrumented field site) to explore and address the challenges of physically modelling of fluid saturated flows over a range of pore-sized materials and geometric scales.

The core idea of the network was that every participating laboratory would have their own approach to analysing the data (e.g. geotechnical engineering, fluid mechanics, granular physics), but would test identical materials purchased in the same lot from a single supplier, to act as a 'Rosetta Stone' to translate between viewpoints, notation, and approaches. Over the past five years the network has worked together to explore saturated granular flows in materials of increasing complexity, commencing with the most simple of material arrangements and proceeding to the most complex that can be accommodated in the apparatuses, informed by the field condition as presented at the well-instrumented and documented Illgraben site in Switzerland [1] – (i) dry, uniform, particles of relatively large size, (ii) saturated, uniform particles of the same size, (iii) saturated well-graded flows at specified water content, (iv) variable water content tests of both uniform and well graded flows.

The objective of this extended abstract and associated presentation is to provide an overview of the findings of the network, including highlights describing advances in experimental testing methods targeting both dry and fluid saturated granular flows, before exploring the observations of complex pore pressure effects in saturated granular flows, and concluding with outstanding research questions.

2 Experiments

2.1 Advances in experimental testing required for saturated flows

2.1.1 Release Box

The typical arrangement of laboratory flumes include a release box with a rotating or vertically lifting gate at the top of the flume to expose an unsupported height of the source volume to initiate landslide motion (Fig. 1a). In saturated materials, particularly comprising particles of

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* Corresponding author: e.bowman@sheffield.ac.uk

fine sands or silts, the initial packing of the saturated granular material is of extreme importance. If the void ratio of the soil is denser than the critical state void ratio, the shearing of the soil upon release can result in a dilatant response, leading to negative excess pore water pressures to such an extent that the saturated material does not release. Saturated dam break tests in transparent soil conducted by [2] to explore this phenomenon has shown that the behaviour of dilatant columns is limited by the pore air entry value and hence, the particle size of the soil, and is particularly problematic for finer and more densely packed soils. The limit equilibrium model of stability proposed by [2] illustrates that the size of the flume (e.g. the unsupported height of the release box) and the particle size of the material have significant impacts on the initial triggering of instability.

These results indicate that the preparation of a loose source volume (i.e. contractive on shearing) is essential for flume tests on fluid saturated flows. Two approaches were developed in the network to achieve this, depending on the scale of the flume. In small scale flume testing (e.g. University of Sheffield flumes with volumes up to 8L) it is possible to ensure that saturated soils remain loosely packed by careful stirring by hand. In large scale testing (e.g. Queen's University flume with volume up to 1 m^3) it is not possible to do this. In the latter case, an upward hydraulic gradient system has been developed for the flume release box to liquefy the sand following placement to ensure it is in a contractive state following reconsolidation prior to the opening of the release box.

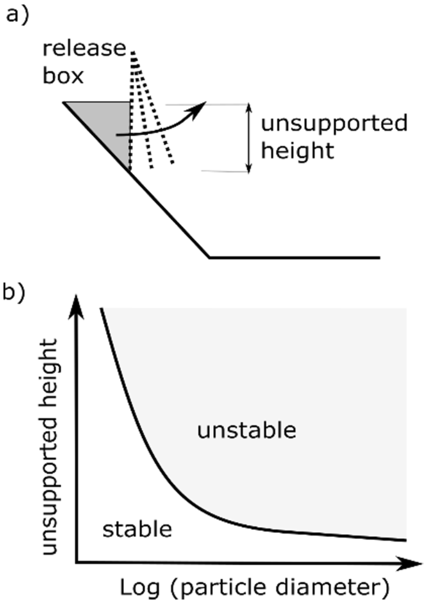

Fig. 1. Potential release issues in saturated debris flow experiments: (a) release box arrangement (b) stability of unsupported face for dense soil as a function of particle size.

2.1.2 Measurement of basal pore pressure

Pore pressure is notoriously difficult to measure in a shearing saturated granular flow. Fig. 2 shows typical indicative responses of pore pressure transducers to such an overriding flow. As illustrated in this cartoon, pore pressure responses of replicate sensors installed at the same location of the flume can yield highly contradictory and internally-inconsistent responses. In the extreme example depicted in Fig. 2, sensors may diverge between recoding a positive or negative pore pressure despite being at the same nominal location in the flow. Research is underway to examine the reasons behind this behaviour – and to devise a method by which the "true" pore pressure response may be captured with confidence.

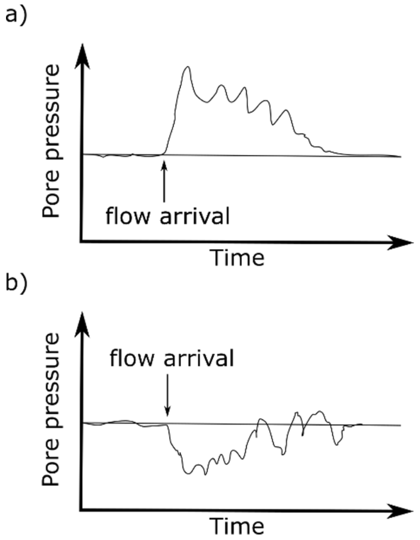

Fig. 2. Schematic of pore pressure response of basal transducers under shearing flow.

2.1.3 Image processing

Granular flow profiles are able to be determined at the sidewalls in experimental flumes, drums and conveyors, via the analysis of images taken at sufficiently high speed and resolution to obtain measures such as flow velocity and granular temperature. Typical image processing methods include Particle Image Velocimetry (PIV) – in which interrogation regions of image "texture" are followed between frames to establish displacements (Fig. 3 – top) and Particle Tracking Velocimetry (PTV) in which particle centroids are identified via thresholding and then tracked between frames.

In general, the success of the different techniques in measuring velocity profiles is well established, however, there are problems with the majority of methods in the correct determination of granular temperature [3] – with both over and underestimation possible. Within the network, research has been conducted to develop a method that benefits from the unique strengths of both PIV and PTV and avoids their weaknesses [4]. The new method, termed "hybrid PIV" uses the texture (PIV) of individual particles (PTV) to follow their motion discretely (Fig 3 – bottom). Comparison with numerical results shows that this method is better able to capture the correct granular temperature of shearing granular systems across both flume and drum experiments.

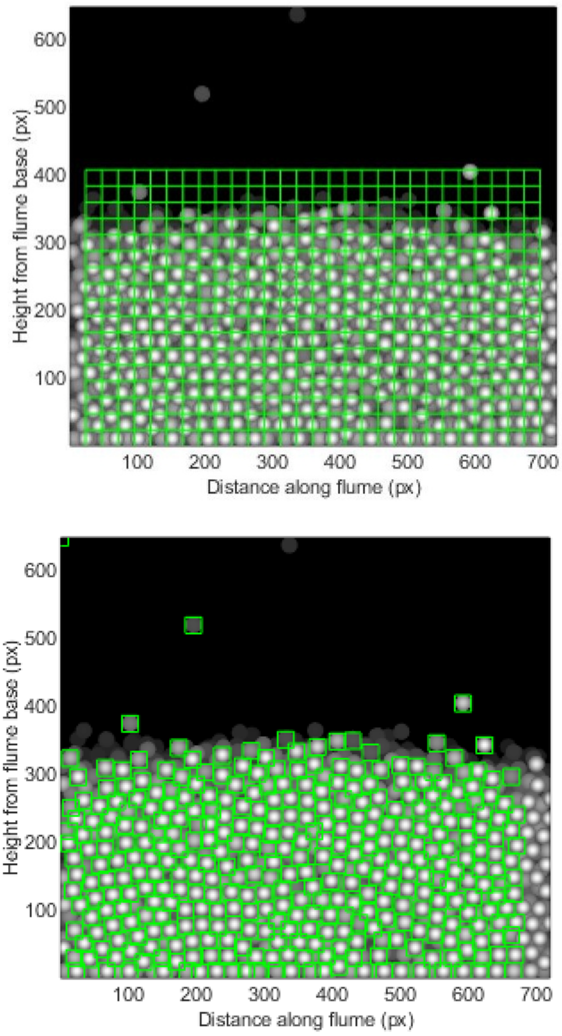

Fig. 3. Regular grid-type PIV (top) tracking; Hybrid PIV tracking (bottom).

3 The importance of pore pressure

In providing a valuable critique of laboratory modelling of debris flows compared with field scale processes Iverson (2015) has stated [5] that "similarity of form does not imply similarity of process". That is, it may be expected that larger flows will develop and sustain pore pressures that in turn reduce interparticle friction and thereby produce longer runout under Coulomb resistive friction than smaller flows, which may instead, be expected to develop resistance due to fluid viscosity, surface tension and particle cohesion.

The veracity of this idea can be addressed by examining differences in behaviour of flows at different scale (e.g. large and small flumes) and materials.

3.1 Mobility and water content

Flume testing allows the measurement of "mobility" as described by travel angle (arctan H/L), where H is the height of the centre of gravity of the commencement of flow release to the length L of the centre of gravity of the deposit.

The influence of water on the mobility of flows is not clear. It has been suggested that excess pore pressures are key to the high mobility of field scale debris flows (e.g. [1]), however these may not exist in smaller laboratory flows [5]. In addition, the travel angle of non-fluid saturated natural flows (rock and snow avalanches) is shown to vary with volume [6].

Here, parametric studies on both coarse, uniform materials under dry and wet (variable moisture content) conditions and at different scales (large and small flumes with variable source volumes) allows the influence of pore pressure to be systematically examined. Fig. 4 shows the possibilities – with comparison made against the well-defined results of dry flows. That is, (i) the travel angle of a dry granular flow may not be expected to vary significantly with volume; (ii) the addition of fluid could have no effect on the travel angle due to the large particle size, or (iii) could have a potentially non-linear monotonically increasing response due to positive pore pressure, or indeed capillary effects may be induced which could dominate at small scale, and then be eliminated at large scale resulting a non-monotonic effect. These possibilities are being examined via systematic variation of water content in small flume experiments.

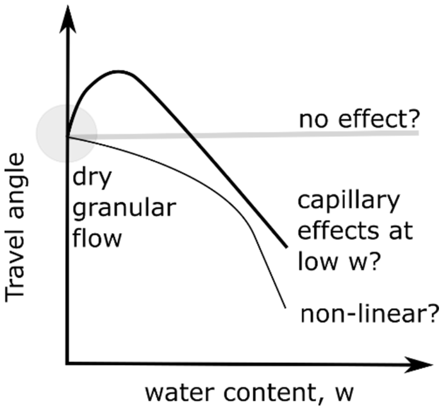

Fig. 4. Potential response of travel angle to variation in water content.

An alternative approach to constrain the effect of fluid on the mobility of debris flows is to conduct experiments in a re-circulating drum environment. Such tests with dry and saturated granular materials enable an examination of the influence of moisture on the flow geometry, resistance to flow (via total stress and pore pressure measurements at a section and via overall torque) and internal shearing behaviour (via image analysis at the side walls) to be undertaken. The advantage of this approach is that the steady flow of different material volumes can be observed over a long period of time and measured flow parameters can be statistically analysed.

A metric to compare the mobility of drum flows with experiments of identical material in straight flume configurations is the deviation angle of the centre of mass from the vertical (Fig. 5). Our observations focus on the pore pressure in coarse uniform flows, compared to well-graded (poorly sorted) flows; and how this moderates flow resistance. We also examine the scale dependence of dilation of the flows in both wet and dry conditions.

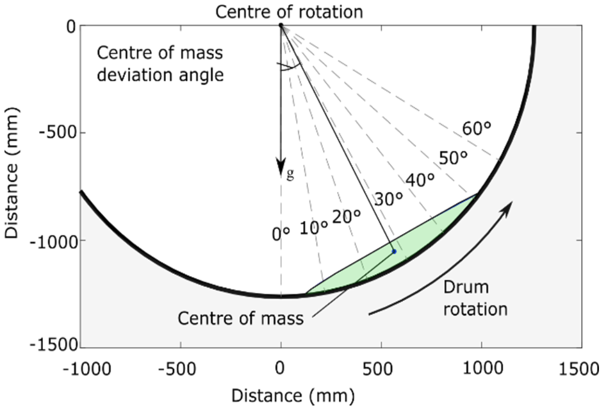

Fig. 5. Schematic of BOKU drum with typical granular flow arrangement – centre of mass varies with drum rotation speed, soil type, fluid content and overall mass

3.2 Mobility and scale

Flume tests of a similar configuration (30° slope angle, fixed basal roughness) conducted at large scale (2 m wide, 8.7 m long) and small scale (100 mm wide, 1.4 m long) with otherwise the same materials, enable scale influences on mobility to be assessed for both coarse granular flows (under dry and saturated conditions) and well graded materials. Scale effects may exist due to volumetric responses (soil dilation, suction, and viscosity influences) for tests conducted on a given flume and between apparatuses of different scale.

Fig 6 shows how the travel angle might be expected to change with the source volume for large and small flumes. Results on monodisperse (uniform) coarse flows within large flume experiments are available in [7] – and these indicate a clear dependency of travel angle with fluid content for these larger flows. Comparison with smaller flume flows is also underway.

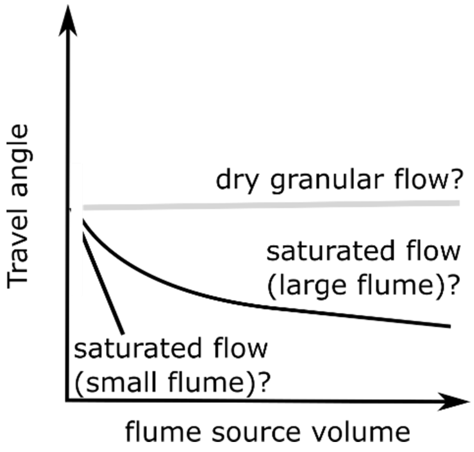

Fig. 6. Potential response of travel angle to variation in source volume.

4 Conclusions

Over the past five years the Rosetta network [8] has worked together to explore granular flows in materials of increasing complexity, commencing with the most simple of material arrangements (dry, uniform, coarse) to the most complex (fluid saturated, well-graded, at a range of specified water contents).

We present highlights that describe advances in experimental testing methods targeting both dry and fluid saturated granular flows, and explore the observations of complex pore pressure effects in saturated granular flows. Outstanding research questions are:

- How can we ensure that the measurement of pore pressure in laboratory and field tests are accurate (Fig. 2)?
- What is the influence of water content on the mobility of debris flows and how is this affected by the material composition (Fig. 4)?
- How does source volume – both expressed as a variation in flow mass within a given experimental flume and as differences between flumes of different scale – affect the mobility of debris flows and how is this linked to pore pressure response in saturated flows (Fig. 6)?

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