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The impacts of silts and clays on mobility of a scaled debris flow physical model

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ABSTRACT: Debris flows are high speed landslides that contain a mix of water and granular material in a range of particle sizes. For flow to travel downslope under gravity, it must shear to dissipate energy. While coarser particles interact frictionally and through collisions, smaller diameter particles, the 'fines', remain in constant suspension due to the agitated environment. During shearing the pore space expands and shrinks, as flow layers dilate and contract. This means the fluid in the pores must move in and out of voids as a response. If the motion of the fluid contained in the pore space is restricted, this leads to a build-up of pore pressure and reduced interparticle friction. Therefore, flow mobility increases. As the fluid contains fine particles, the reaction to shearing is also governed by the type of fines present. While both silts and clays are included in the 'fines' category due to their small diameters, their impact on fluid properties is very different. Clay suspensions are viscous and shear-thinning, whereas silt suspensions are Newtonian. Currently it is unclear how this difference will affect the efficiency of fluid moving within the pore space network and therefore overall flow mobility. In response to this, a small-scale instrumented flume is used to investigate the influence of either kaolinite clay or silica silt in uniform gravel debris flows.

1 INTRODUCTION & BACKGROUND

Debris flows undergo shearing caused by variable frictional resistance in the flow depth. Any obstruction, such as from the presence of suspended fine particles, or slowing of this process can lead to an excess in pore pressure (Kaitna *et al.*, 2016). This shearing also contributes to phase separation between the coarse granular material and the fluid suspension, thus producing a commonly seen dry granular front (Bowman and Sanvitale, 2009).

It has been observed that fines in debris flows have potential to increase both mobility and pore pressures above hydrostatic (De Haas *et al.*, 2015; Kaitna *et al.*, 2016). Existing theories have discussed the influence of fines on: permeability (Bowman and Sanvitale, 2009; Cabrera *et al.*, 2015), the timescale of large particle motion, and changes to fluid resistance (Kaitna *et al.*, 2016). However, samples used in the existing research often have a wide particle size distribution (PSD) with mixed fines mineralogy. Basal stresses are also not always measured. Thus, it is unclear which theory, or group of theories, are appropriate to apply for different types of fines. This is because while both silts and clays are classed as fines, and will reduce the flow matrix permeability, (Bowman and Sanvitale, 2009), a clay suspension also increases fluid viscosity (Bougouin *et al.*, 2022). However, it is still unclear how significant this change is to the shearing processes in a debris flow.

The following extended abstract describes the initial data collection to better critique these theories, by comparing flows with different fines mineralogy, and investigating excess pore pressure magnitude.

2 METHODS

2.1 Equipment & analysis

Figure 1 shows the small scale instrument flume used to release the well-mixed sample.

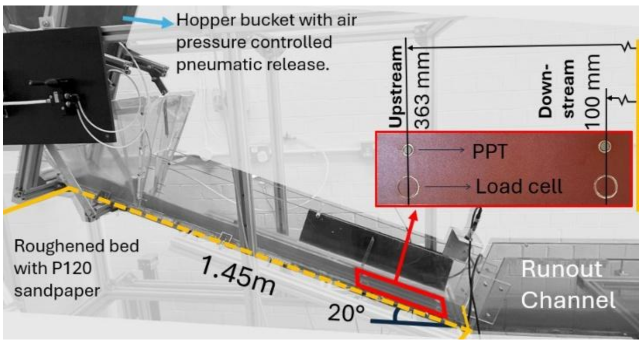

Figure 1. Flume apparatus with sensor locations.

To measure the extent of excess pore water pressure generation, if any, the liquefaction ratio (LR) is used (Kaitna *et al.*, 2016):

$$LR = \frac{u}{\sigma} \quad (1)$$

where u (kPa) is the pore pressure, and σ (kPa) is the total basal stress. If LR is ≈ 0.5 hydrostatic conditions are present, if LR > 0.5 positive excess pwps are being generated (Kaitna *et al.*, 2016).

2.2 Sample details

Each scaled debris flow used Denstone® 2000, with a mean diameter 3.85 mm, to represent coarse particles (NorPro, 2017), and a water content of 45% by mass. To investigate the influence of fines mineralogy, 10% of the solid Denstone® was replaced with either silt (S10) or kaolin (K10). A further test was carried out to examine the role of flocculation of the clay on its viscous shearing response within the flow (DfK10). To disperse and remove the effect of flocculation of the clay, sodium hexametaphosphate was added to a kaolin fines test. The concentration used was 4 g in 900 ml. All fines suspensions were soaked for 1 hour prior to vigorous mixing and combination with the coarse fraction in the flume hopper.

3 RESULTS & CONCLUSIONS

Figure 2 shows the liquefaction ratios using filtered total stress and pore pressure data. These cover the duration for tests with different fines mineralogy at both sensor locations, labelled on Figure 1. These are also zeroed prior to sample arrival.

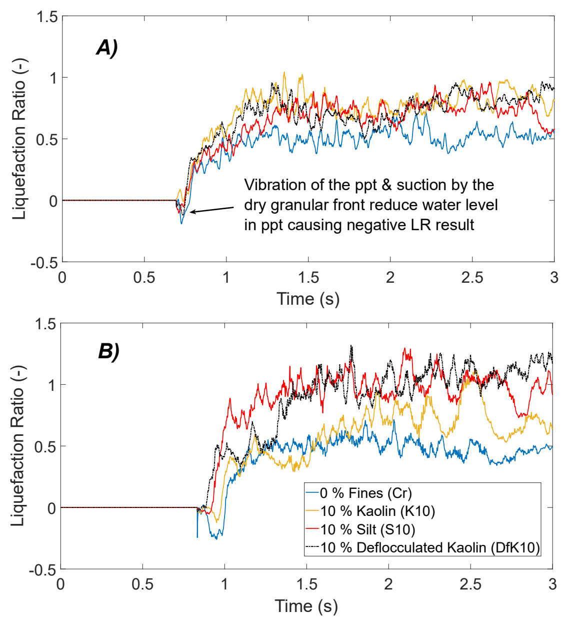

Figure 2. Liquefaction ratio over time.
A) Upstream position B) Downstream position

As expected, based on the existing literature, tests with no fines (CR), displays hydrostatic behaviour (LR <= 0.5), whereas all other samples are able to achieve LRs > 0.5 (Kaitna *et al.*, 2016); this indicates generation of excess pore pressure. However, in the downstream position, K10 and S10 differ, where S10 reaches a state of full liquefaction, K10 appears to be less liquefied. However, when the clay is deflocculated (DfK10), the response downstream also suggests full liquefaction, like the results from the S10 test. The difference in LR values between K10 and DfK10 highlights that when fine particles are allowed to interact with each other via variable electrostatic charges (K10), the balance of stresses within the flow depth can be significantly affected. This shows the importance of considering the fluid's properties on the shearing process and thus flow mobility.

Overall, these results show that the mineraology of fines is a key parameter in affecting debris flow mobility, and that fluid viscosity is potentially significant.

ACKNOWLEDGEMENTS

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