Slope-break Collisions: Comment on "Insight Into Granular Flow Dynamics Relying on Basal Stress Measurements: From Experimental Flume Tests" by K. Li et al.

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Key Points:

- Granular flow mobility increases when grain size decreases
- Granular flow mobility increases when particle agitation decreases
- There is no discrepancy between numerical simulations and laboratory experiments

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Abstract

Numerical simulations show that the positive correlation observed in laboratory experiments by Li et al. (2022) between an increase of grain size and particle agitation, on the one hand, and an increase of granular flow mobility, on the other hand, is not a valid cause-and-effect relationship. In other words, their mobility differential is not caused by a different energy dissipation rate that results from a different grain size content. Instead, the flows stop because of a head-on collision with the horizontal flume at the bottom of a steep 40º incline. Essentially, the slope-break jams the granular movement. Indeed, a combination of laboratory experiments and numerical simulations demonstrated that the mobility of unhindered dense granular flows increases as grain size and clast agitation decrease. Consequently, there is no evidence that the high mobility of large natural rock avalanches is due to an increase of particle agitation.

Plain Language Summary

The understanding of rock avalanche mobility is necessary for hazard mitigation efforts in mountain regions. However, given the difficulties of getting useful information in the field, the relationships between the variables (such as grain size) characterizing these dense flows and their mobility are investigated by means of numerical simulations and laboratory experiments. In these models, a functional relationship between grain size and mobility can be established only by comparing granular flows whose movement is unhindered by additional phenomena. This is not the case in the laboratory experiments by Li et al. (2022) where the flows collide with the horizontal flume at the bottom of a steep incline. The positive correlation between grain size and flow mobility observed by Li et al. (2022) is thus not a valid cause-and-effect relationship because it is instead determined by the collisions. Since these collisions were not reported by Li and coauthors, I illustrate them here by means of numerical simulations.

1. Introduction

Li et al. (2022) investigated a complex laboratory system where granular samples were released downslope. Since an additional phenomenon was overlooked, I must unfortunately disagree with their conclusion that an increase of grain size and particle agitation in dense granular flows causes an increase of flow mobility. Their experiments would model unsteady and dry granular flows of rock fragments such as rock avalanches (Hungr et al., 2014) if it was not for the fact that miniature flows underestimate the internal stresses of large-scale flows in nature (Bowman et al., 2010; Cagnoli, 2021).

2. Granular flow mobility depends on variables, initial conditions and additional phenomena

The mobility of granular flows of rock fragments is difficult to predict because it depends not only on a large number of variables, but also on many initial conditions and additional phenomena that a flow might experience. The main variables affecting flow mobility are grain size, flow volume, channel width, basal friction and stress level (i.e., flow scale). Their interplay modifies their effects to such an extent that the same variable can have opposite effects on flow mobility in different regimes. For example, an increase of flow volume causes a decrease of flow mobility at low stress level whereas it causes an increase of flow mobility at high stress level (Cagnoli, 2021). Initial conditions affecting flow mobility include the degree of compaction of the granular mass before release, its proportions of clast shapes (Cagnoli & Piersanti, 2015) and the boundary morphology (Delannay et al., 2007). Phenomena modifying flow mobility comprise the formation of a distal distribution of dispersed fragments (Cagnoli & Romano, 2012a) and obstacle collisions. Such complexity indicates that, since the effect on flow mobility of one variable can differ, the description of any such effect must include all occurring initial conditions and additional phenomena.

3. Grain size has a multifaceted effect on granular flow mobility

Both laboratory experiments (Cagnoli & Romano, 2010) and numerical simulations (Cagnoli & Piersanti, 2015, 2017; Johnson & Campbell, 2017) demonstrated that a decrease of grain size (all other features the same) causes an increase of flow mobility. More specifically, flow mobility is inversely proportional to grain size at low stress level, whereas it is inversely proportional to grain size squared at high stress level (Cagnoli, 2021). The inverse proportionality is due to the fact that a decrease of grain size results in a decrease of particle agitation per unit of flow mass and, consequently, a decrease of energy dissipation per unit of travel distance (Cagnoli & Romano, 2010; Cagnoli & Piersanti, 2015). This is so because particle agitation is generated in contact with the rough subsurface and its upward propagation increases when the number of particles in the flow decreases (Cagnoli & Romano, 2012a), i.e. the grain size becomes larger (all other features the same). Indeed, in flows on a relatively smooth subsurface grain size has no effect on flow mobility (Cagnoli, 2021). This explanation is equivalent to that where mobility is a decreasing function of shear rate (Campbell et al., 1995) because particle agitation increases as shear rate increases. Moreover, clast agitation and shear rate decrease (and consequently mobility increases) when the rock avalanche becomes bigger (Campbell et al., 1995; Cagnoli, 2021). Also the μ(I)-rheology friction of steady flows increases as grain size and shear rate increase (Jop et al., 2006). However, when the solid volume fraction at the flow front decreases so much that a smaller number of dissipative solid-solid interactions occurs there per unit of time, an increase of grain size can cause an increase of the overall mobility (Cagnoli, 2021). All these effects of grain size pertain to unsteady and nonuniform flows experiencing identical initial conditions and additional phenomena and that, after an initial downslope acceleration, slow down and stop on a subsurface with a continuous profile function (i.e., without slope-breaks) so that their energy dissipation differential is only due to the variables whose effect is investigated.

4. Flow mobility in the experiments by Li et al. (2022) is affected by many causes

In laboratory experiments, Li et al. (2022) released sands from the top of a steep, 2.5-m-long, 0.2 m wide, straight ramp that sloped at a 40º angle from the horizontal flume into which the granular masses plunged (sidewalls were vertical). Since there was no gradual slope change between incline and horizontal flume, the flows came to an abrupt stop when colliding with the flume. This collision constitutes an additional phenomenon that Li and coauthors did not describe or mention. Numerical simulations illustrate it here in section 5.

In the different experimental runs, initial conditions also differed in unknown degrees and for unknown reasons. The five same-mass (up to 12 kg) granular mixtures whose mobility was compared had the same range of grain sizes from 0.25 to 7 mm but different proportions of the five intervals into which the range was divided. This range was so wide that vertical segregation occurred (their figure 4b). Segregation is a phenomenon that is impossible to prevent (Cagnoli & Romano, 2013) and it very likely occurred also when the granular mixtures were introduced behind the gate before release. The consequent different internal structure of the five mixtures probably resulted in different amounts of energy dissipation during the initial deformation after the gate removal and when impacting the horizontal flume. By means of a tilting test (i.e., independently from granular flow motion), the authors also assessed that as the proportion of coarser grain sizes increases in the granular mixtures, their basal friction coefficient decreases from 0.62±0.005 to 0.554±0.005 (their table 1). Since this different basal friction is probably due to other factors, it can increase the velocities and consequently the mobility of coarser grain size flows for reasons other than grain size. Indeed, static friction is not affected by grain size (Lambe & Whitman, 1969).

5. Numerical simulations of slope-break collisions

5.1. Method

I have carried out numerical simulations to illustrate the collision of granular flows that plunge into a horizontal flume after their release from the top of a 2.5-m-long, straight ramp with an inclination of 40º (g=9.8 m/s^2). Channel base and the 6-cm-apart vertical sidewalls are flat but relatively rough because of a 0.62 friction coefficient (the maximum value in Li et al., 2022) in all simulations. The Discrete Element Method is implemented by using software EDEM (Cagnoli and Piersanti, 2015). Clasts (2700 kg/m^3) are angular with cubic shape. The mobility of two flows with the same mass (1.7 kg) but different grain size is compared: one with 2 and the other with 4 mm cubes. These two simulations are repeated on the same channel where only its slope-break portion is replaced by a continuous curved surface that seamlessly merges with the same ramp and horizontal flume (insets Figure 1). All granular masses form before release the same prism (Figure 1) with always identical bulk density and center of mass (CM). This granular prism collapses because of gravity (no gate is used to avoid unnecessary frictions). The reciprocal of mobility is measured by the apparent friction coefficient $\mu_{CM} = h_{CM}/l_{CM}$, where h_{CM} is the vertical drop of the CM of the granular material and l_{CM} is its horizontal distance of travel (the CM is the only point whose mobility depends on the energy dissipation of all particles). All clasts are considered when computing μ_{CM} because the removal of the distal ones (as in Li et al., 2022) can be arbitrary. Animations of simulation flows are provided as supporting information.

5.2. Results

On the continuous subsurface (Figure 1a), the finer grains size flow (μ_{CM} = 0.7875) is more mobile than the coarser grains size flow (μ_{CM} = 0.8000) as in Cagnoli (2021). On the slope break

(Figure 1b), the finer grains size flow (μ_{CM} = 0.8553) is less mobile than the coarser grains size flow (μ_{CM} = 0.8526) as in Li et al. (2022). The first mobility differential corresponds to +9 cm, the second to –1 cm (Table S1). These μ_{CM} values show that the slope-break collision prevents the granular masses from being as mobile as they could be without slope-break. When the granular flows stop, they form a talus cone (Turner & Schuster, 1996) where the incoming granular material travels over a dead zone (Ng et al., 2017) of motionless clasts collected by the slope-break (Figure 1c).

6. Discussion

The numerical simulations focus on the phenomenon defining the Li et al. laboratory experiments by comparing granular flow mobility on subsurface profiles with and without slope-breaks. The simulations are not meant to reproduce their μ_{CM} values that are affected by all problems aforementioned. Importantly, the lack in my simulations of the fractal grain size distribution (FGSD) adopted by Li and coauthors does not change the sign of the mobility differential due to grain size on the slope-break. There is therefore no discrepancy between simulation and experiment results. Moreover, the finer the FGSD of columns collapsing on horizontal flumes, the more mobile the flows (Lai et al., 2017). Thus, subsurface geometry alters mobility.

As expected, scaled particle agitation $\Delta\sigma_i/\bar{\sigma}_i$ in Li et al. (2022) exhibits before the slope-break collision (their figure 14b) an increase as grain size increases (Cagnoli & Romano, 2012b; Cagnoli & Piersanti, 2018). But, although their equation 7 (i.e., $\Delta\sigma_i/\bar{\sigma}_i$) is identical in meaning and aim to equation 5 by Cagnoli and Romano (2012b), no reference was cited. Critically, the numerical simulations reveal that the slope-break hinders the mobility because of the collision with the horizontal flume (both μ_{CM} values are larger on the slope-break than on the continuous subsurface). Since in both simulations and experiments, the final CM is always located after the slope-break interaction, the Li et al. mysterious velocity variation before the slope-break cannot be solely responsible for mobility. Slope-breaks prevent mobility from being as large as it would be if the energy dissipation was due to grain size and clast agitation only. As expected, dead zone and consequently μ_{CM} grow larger as flow mass increases (their figure 14b). Although, it is worth modelling rock avalanches hitting slope-breaks, it is on a continuous subsurface, where there is no impediment, that finer granular flows can be shown to have a smaller energy dissipation per unit of travel distance (Cagnoli, 2021).

7. Conclusions

The collision with the horizontal surface at the bottom of the steep incline in the flawed laboratory experiments by Li et al (2022) prevents the mobility of the center of mass from being governed by the dissipation rate due to grain size and clast agitation. Therefore, the positive correlation (their figure 14b and conclusions) proposed by Li and coauthors between grains size and particle agitation, on the one hand, and flow mobility, on the other hand, is not a valid cause-and-effect relationship. Indeed, correlation does not imply causation. Numerical simulations and laboratory experiments demonstrated instead that, with unhindered dense granular flows, mobility increases when grain size and clast agitation decrease. There is thus no evidence that the high mobility of large natural rock avalanches is due to an increase of particle agitation.

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The x, y and z coordinates of the centers of mass of the deposits used to compute μ_{CM} are available in Table S1 as supporting information. The software Altair EDEM version 2021.2 used to carry out the simulations is accessible under license at https://www.altair.com/edem/. The animations of the four numerical simulations discussed here are also available as supporting information.

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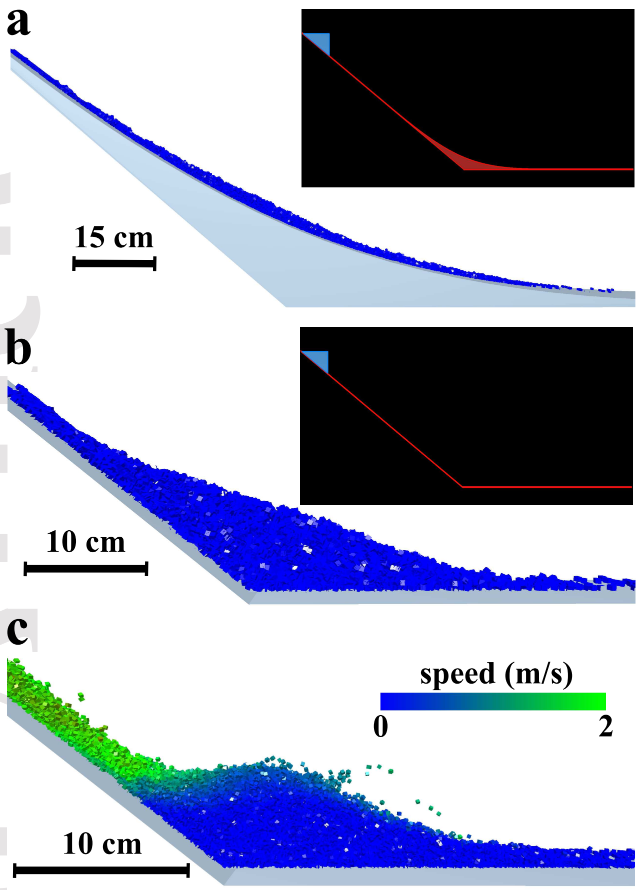
FIGURE CAPTION

Figure 1. Longitudinal cross-sections of: (a) deposit on the continuous subsurface (4 mm grain size), (b) talus cone on the slope-break (4 mm grains size) and (c) talus cone formation (2 mm

grain size). Insets show the two longitudinal subsurface profiles (the light blue triangles are the granular prisms before collapse).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