Monodisperse granular flows in viscous dispersions in a centrifugal acceleration field

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Motivation

In mountain areas after intense periods of rain or ice melting seasons, the saturation of slopes leads to mass flows involving large volumes of soil, water, and vegetation. These mass movements form a complex network of interactions between the fluid and particle phase and are often referenced as debris flows, mud flows, debris floods among others (Hungr et al., 2013).

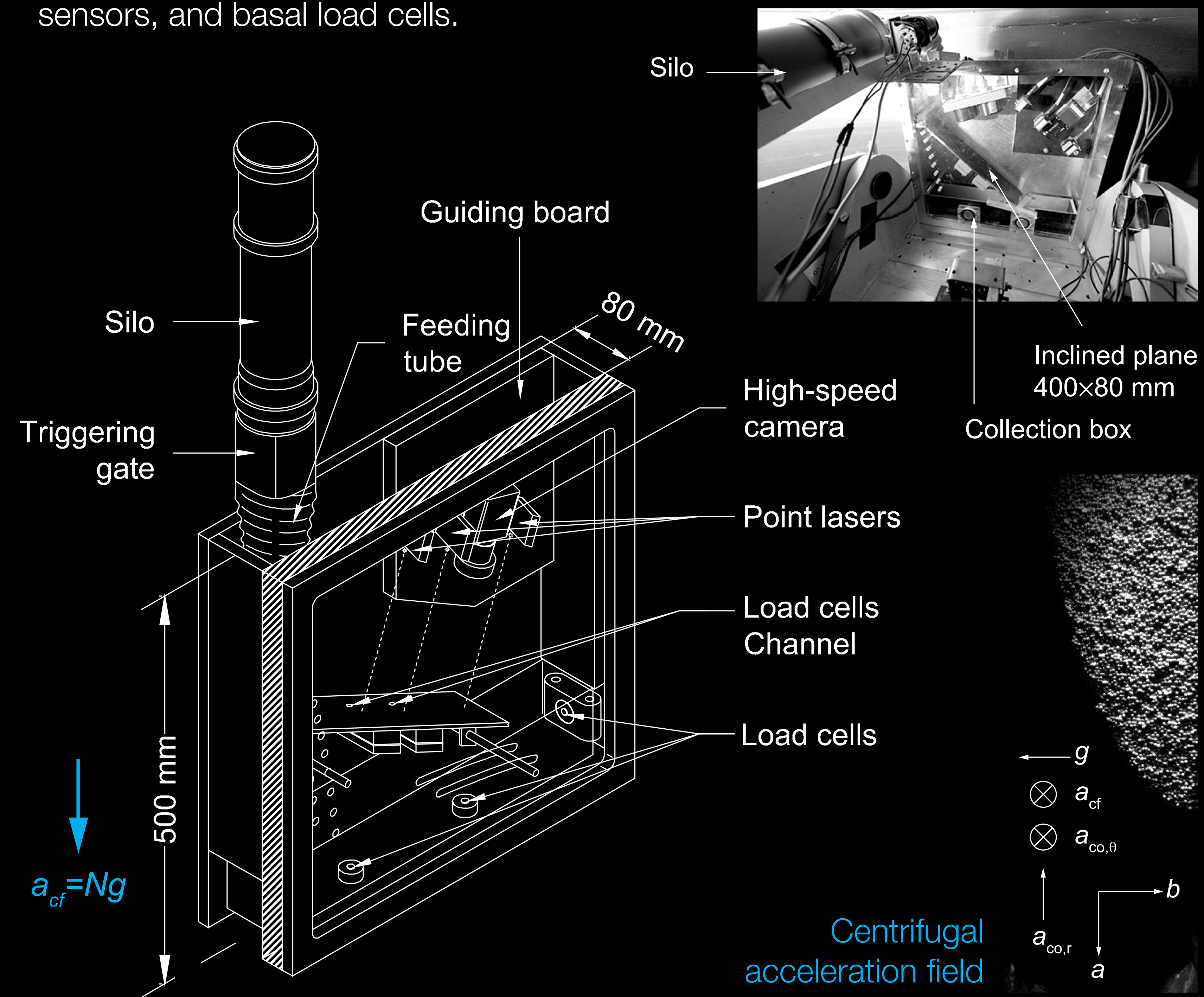
We study the scaling principles of the fluid viscosity and its effects on a granular suspension by varying the effective driving acceleration in the model by means of a centrifugal acceleration field.

Materials:

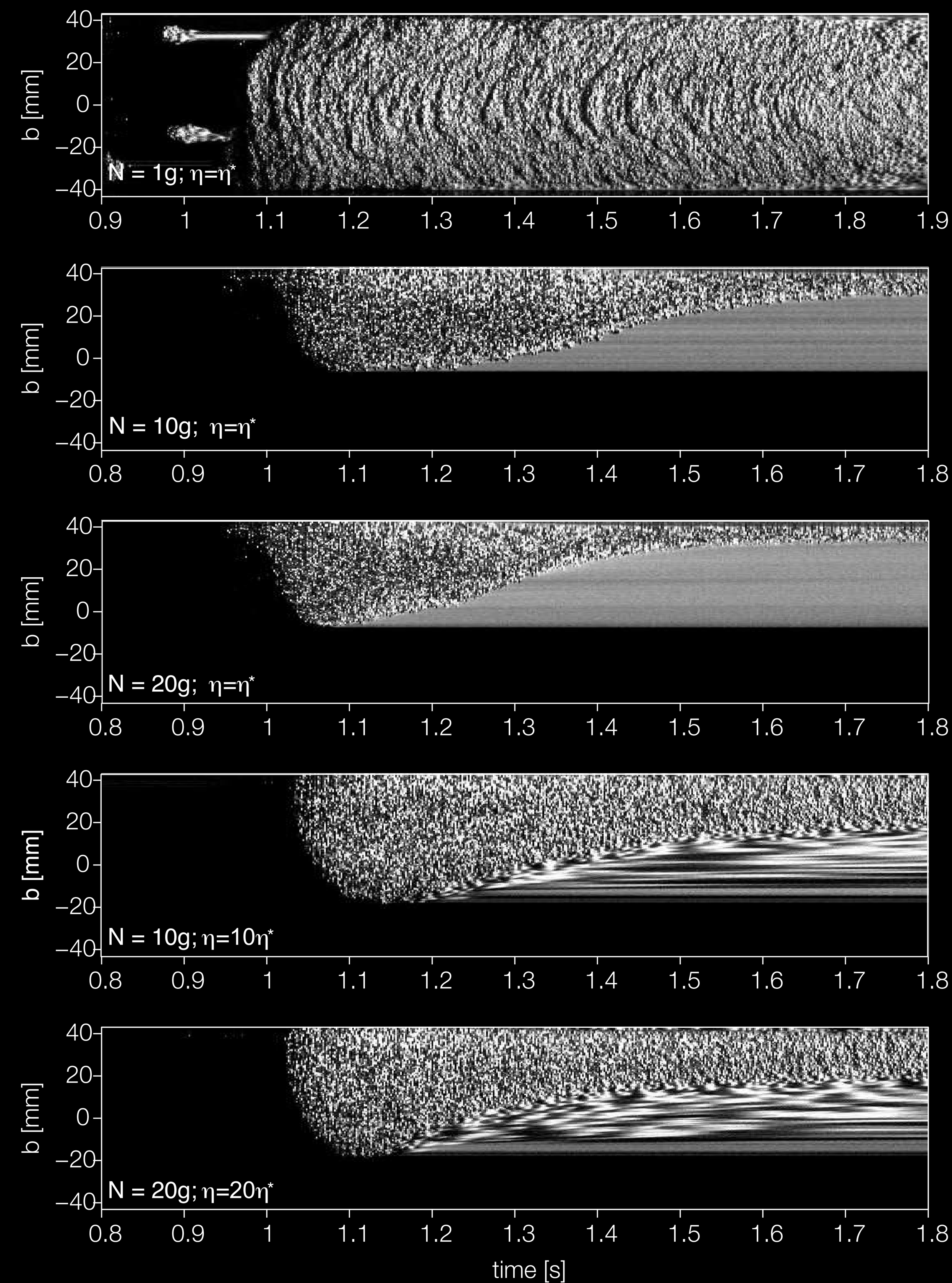
Kaolin-water	$\eta^* = 0.02$ Pa s
Glass beads	$d = 1.45$ mm
	$\varphi_0 = 22°$
	$\rho_p = 2750$ kg/m^3

Scale model

- The model is placed in a geotechnical centrifuge at an equivalent radius of 1.1 m and is tested at centrifugal accelerations up to 20 times Earth's gravity.
- In the scale model, a silo holds the testing material prior release and conducts it to an inclined plane through a feeding tube.
- The flow over the inclined plane is monitored by a high-speed camera, point laser sensors, and basal load cells.



Results at a slope angle of $\zeta = 30°$



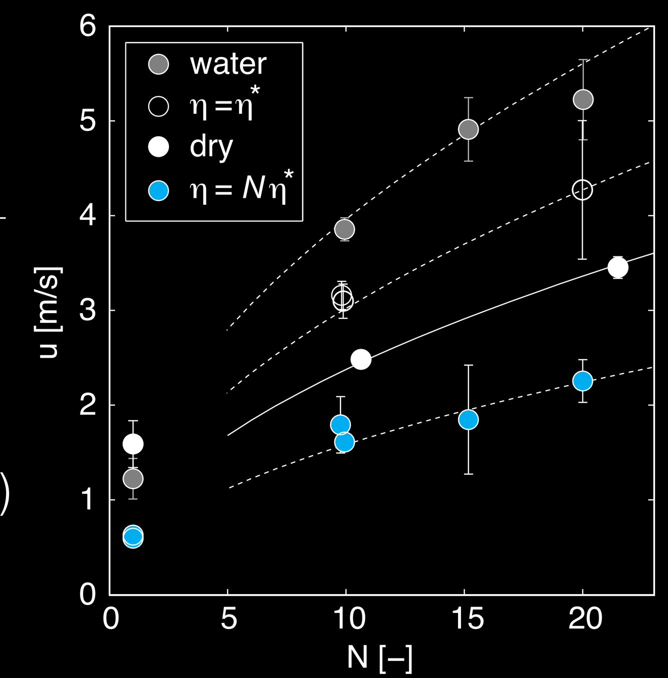
Space-time plot for the flows of glass beads mixed with a kaolin-water dispersion. On them a continous horizontal line refers to an static zone over the incline.

Increasing η^* proportional to Ng, results in particle deposition over the inclined plane.

Flow velocity

The down-slope median velocity of the particle-fluid mixtures follows a trend of:

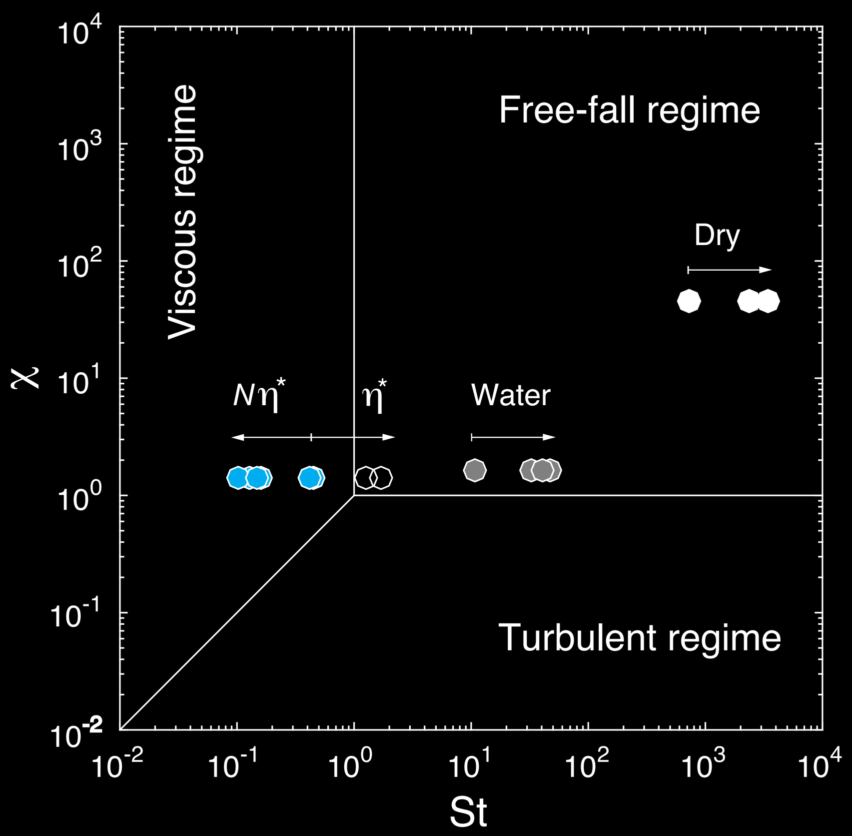
$$u = \alpha \sin\zeta \sqrt{Ng} \quad (1)$$



Particle-fluid flow regimes

The time scales describing the motion of a particle immersed in a fluid driven by gravity are the Stokes number St (Eq. 2) and the density ratio χ (Eq. 3). St and χ relate the characteristic time of a particle flow controlled by the fluid viscosity t_η, with the characteristic time of a particle in free-fall t_{ff} and the characteristic time of a particle driven by the turbulence of the fluid t_t, respectively.

$$\mathrm{St} = \frac{t_\eta}{t_{ff}} = \frac{1}{18\sqrt{2}} \frac{\sqrt{\rho_p d^3 \Delta\rho g \sin\zeta}}{\eta_f} \quad (2) \qquad \chi = \frac{t_t}{t_{ff}} = \sqrt{\frac{\rho_p}{\rho_f}} \quad (3)$$



In the Stχ-plane the arrows point the increase of Ng in the model.

Regime	Motion is controlled by
Free-fall	Driving acceleration
Viscous	Viscous drag and self-weight
Turbulent	Intertial effects of fluid phase

Increasing η^* proportional to Ng results in an augmented fluid drag over the particles, moving the flows towards a viscous regime.

Scaling principles

a) The viscosity of the fluid phase is increased by a factor of N equivalent to the acceleration of the model, reducing the relative drainage between both phases.

b) The fluid-phase matches the characteristics of the fluid-phase in the field, focusing on the stress-strain behaviour of the two-phase mixture at different acceleration levels.

References

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