Numerical simulation of viscoplastic avalanches

A general overview

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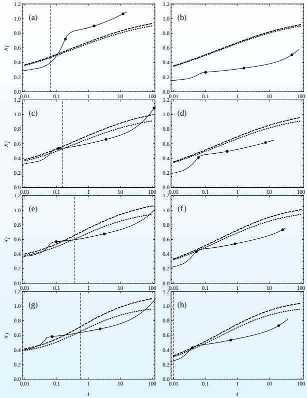
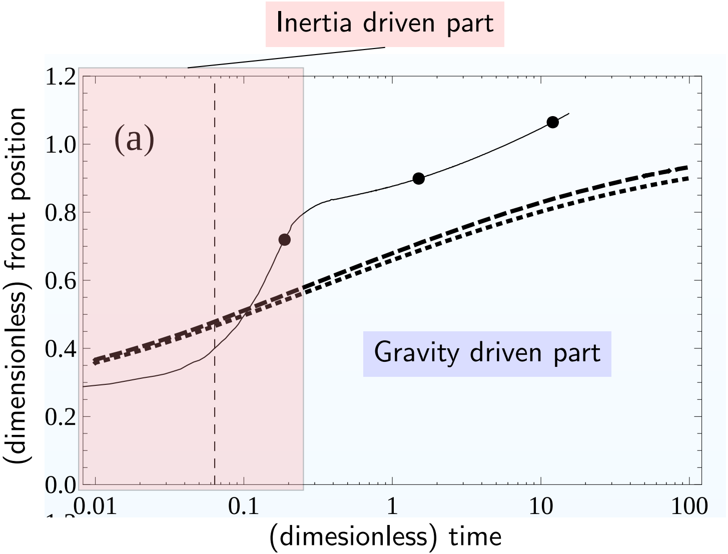
Application to viscoplastic avalanches (continued)



Variation in the front position with time for $\theta = 12^\circ$. Experiments done with Carbopol at various concentrations. Dashed curves: theoretical prediction given by a zero-order nonlinear convection equation (modeling the behavior of an avalanching mass of Herschel-Bulkley fluid).

Problem statement


Inertia driven part

Gravity driven part

Problem statement

Figure: Experiment: Dambreak of viscoplastic material on an inclined plane (more details in the talk of Steve Cochard)

Governing equations

Incompressibility

$$\nabla \cdot \vec{u} = 0 \tag{1}$$

Conservation of Momentum

$$\frac{\partial \vec{u}}{\partial t} = -\vec{u} \cdot \nabla \vec{u} - \frac{1}{\rho} \nabla p + \frac{1}{\rho} \nabla \tau \tag{2}$$

Newton's law

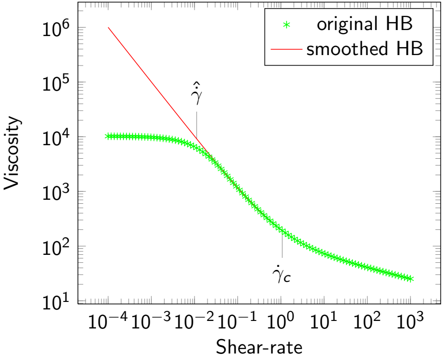
$$\tau = \mu \underbrace{\left(\nabla \vec{u} + (\nabla \vec{u})^T \right)}_{\dot{\gamma}} \tag{3}$$

with viscosity $\mu(\vec{r}, \dot{\gamma})$, density $\rho(\vec{r})$, velocity $\vec{u}(\vec{r})$ and pressure p.

Rheological model

Herschel-Bulkley model

$$\mu(\vec{r},\dot{\gamma}) = \frac{\tau_0}{|\dot{\gamma}|}\left(1+\left(\frac{|\dot{\gamma}|}{\dot{\gamma}_C}\right)^n\right) \qquad \forall \vec{r} \in \Omega_{liquid} \subset \mathbb{R}^3 \qquad (4)$$



The Solver

- Chorin's Projection scheme
  BICG to solve the pressure equation
- Semi-implicit,
  the parabolic (stress) term is treated implicitly
- Two phases: Gas./.Liquid
- Level-Set and Volume of Fluid to represent the free-surface
- Parallel by domain decomposition (mpi)
- Various rheologies:
  Bingham, Herschel-Bulkley, Coulomb ...

Comparison in 2D

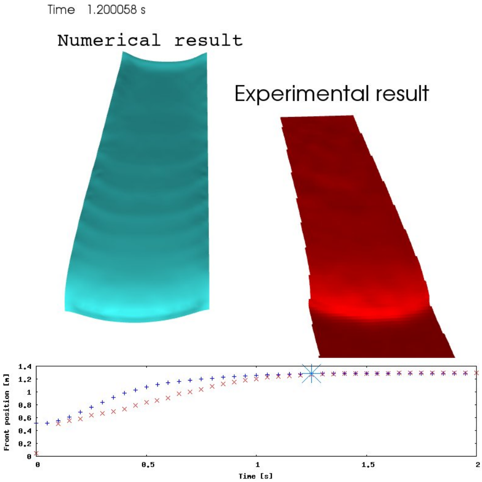


Figure: Comparison of the Numerical Result with S. Cochards experiments. Quasi 2D in a channel.

Comparison in 3D

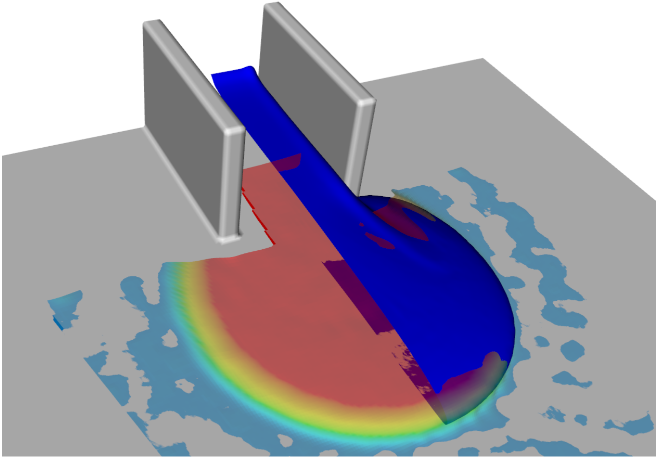


Figure: Comparison of the Numerical Result with S. Cochards experiments. 3 dimensional flow.

Pseudo-plug region

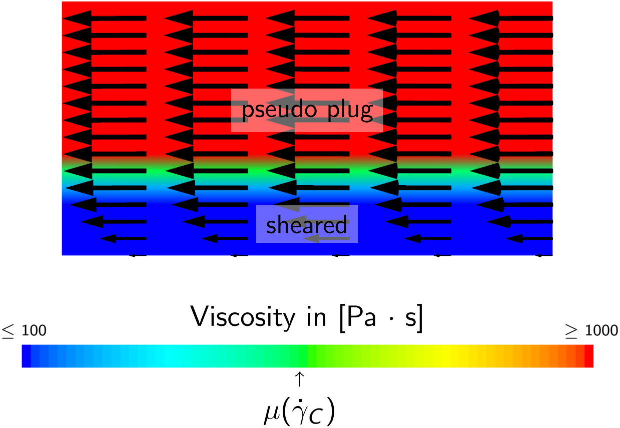


Figure: Permanent uniform flow of a HB-fluid down an inclined channel. $\dot{\gamma}_C$ defines the critical viscosity to identify *pseudo plug* regions.

Pseudo-plug regions

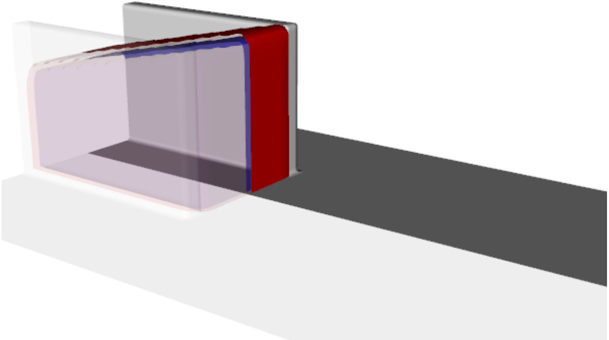


Figure: *Pseudo yield surface*: The blue transparent suface represents the free surface, the red the yield surface.[2]

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[1] Inclination 12^o, Concentration 0.25%

[2] Inclination 12^o, Concentration 0.25%

Collaps of a sandpile

Figure: Collaps of a column of sand with different layers of sand to visualize the deformation.

Comparison to experimental results

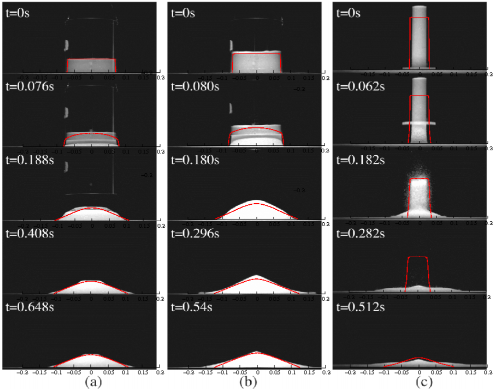

Figure: Comparison of the free-surface with laboratory experiments[3].

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[3] Lajeunesse, E., Mangeney-Castelnau, A., and Vilotte, J.P., 2004. Spreading of a granular mass on an horizontal plane, Phys. Fluids, 16(7), 2371-2381.