PARTICLES
BREAKING OUT OF DEBRIS FLOWS

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Debris flows

- Fast moving, subaerial gravitational flows of water, sediments and coarse material (rocks, trees boulders)
- A general term encompassing lahars, landslides, jökulhlaups.
e.g. Vargas, Venezuela 1999
With our debris flow experiments we want to

- Understand the effect of various flow variables, e.g. surface roughness, particle size
- Use large particle sizes to (try and) achieve Froude and particle Reynolds number similarity
- Simultaneously measure velocity profiles, pore pressure and basal shear and normal stress
**Design Criterion - Similarity**

- Always difficult in particle laden flows!

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
<th>Force Balance</th>
<th>Notts Chute</th>
<th>USGS Chute</th>
<th>1982 Oddstad</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{Bag}$</td>
<td>Bagnold number</td>
<td>Inertial grain stress to viscous shear stress</td>
<td>2</td>
<td>400</td>
<td>4</td>
</tr>
<tr>
<td>$N_{Sav}$</td>
<td>Savage number</td>
<td>Inertial grain stress to friction</td>
<td>0.2</td>
<td>0.2</td>
<td>$2 \times 10^{-4}$</td>
</tr>
<tr>
<td>$N_{fric}$</td>
<td></td>
<td>Friction to viscous shear stress</td>
<td>9</td>
<td>$2 \times 10^3$</td>
<td>$2 \times 10^4$</td>
</tr>
<tr>
<td>$N_{mass}$</td>
<td>Mass number</td>
<td>Solid to fluid inertia</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$N_{Rey}$</td>
<td>c.f. Reynolds number</td>
<td>Fluid inertial stress to viscous shear stress</td>
<td>2.5</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>$Fr$</td>
<td>Froude number</td>
<td>Inertial to gravitational</td>
<td>0.6</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

Data from
## Experiment Design

### 2D CHUTE

Lock release

<table>
<thead>
<tr>
<th>Variable</th>
<th>Notation</th>
<th>Values</th>
<th>(units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids volume fraction</td>
<td>$\phi_s$</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Volume of solids</td>
<td>$\phi_s V$</td>
<td>1</td>
<td>litre</td>
</tr>
<tr>
<td>Roughness length</td>
<td>$[d_{r1}, d_{r2}, d_{r3}]$</td>
<td>[2, 4, 8]</td>
<td>$\times 10^{-3}$ m</td>
</tr>
<tr>
<td>Angle of inclination</td>
<td>$\theta$</td>
<td>27°</td>
<td></td>
</tr>
<tr>
<td><strong>Solids: glass beads</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>$\rho_s$</td>
<td>2600</td>
<td>kg m$^{-3}$</td>
</tr>
<tr>
<td>Diameter</td>
<td>$[d_1, d_2, d_3]$</td>
<td>[2, 4, 8]</td>
<td>$\times 10^{-3}$ m</td>
</tr>
<tr>
<td><strong>Fluids: water, glycerol</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>$[\rho_{f1}, \rho_{f2}]$</td>
<td>[1000, 1260]</td>
<td>kg m$^{-3}$</td>
</tr>
<tr>
<td>Viscosity</td>
<td>$[\mu_1, \mu_2]$</td>
<td>[1.41, 0.8]</td>
<td>Pa s</td>
</tr>
</tbody>
</table>
Experiment
What happens?

- Snout formation
- Longitudinal and vertical particle size and volume fraction variation
- Distinct collisional and continuum regions
Flow regimes

Quivers scaled by 0.1
SD > 150 mm s\(^{-1}\)
Granular region, dark grey
Low SD, viscoplastic, pale grey
14 frame (0.2 s) averages
Velocities 600--1000 mm s\(^{-1}\)
Power law profiles

By particle size

Roughness increases in the order circles, triangles, squares

![Graphs showing power law profiles for different particle sizes.](image-url)
Power law profiles

By roughness length
Particle size increases with black, red, blue. Green is a mixture

\[ v(z) = v_h + (v_0 - v_h) \left(1 - \frac{z}{h}\right)^\alpha \]
Pressures

- 4mm particles
- 8mm roughness

Graph showing:
- Pore pressure, $P$
- Shear stress, $\tau$
- Normal stress, $\sigma$
This is a method for systematically determining the extent of continuum versus intermittent/collisional behaviour within a laboratory debris flow.

Roughness is only important in the when the roughness length is greater than or equal to the mean particle size.

But, we see that snout-body architecture formation does not require mixtures of particle sizes.
What about saturation?

- So if all that snout and body architecture needs is for the may-or-may-not be larger material at the top to be moving more quickly than the rest of the flow, then the level of saturation should be important.

- While rebuilding the chute to investigate this, I was wondering over what range a particle leaving a fluid surface remained ‘in touch’ with the surface.
To start with, consider one....

Pulley, to pull ball vertically

Winch to spindle on motor

Steel ball bearing on a needle, threaded to winch. Initially submerged in fluid
Experiments

- Particle diameters: 4, 6, 8, 10, 12 mm
- Winch speeds: 0.2, 0.3, 0.4, 0.5, 0.6, 0.7 m/s
- Fluids: Water, Kaolin solution (10% vol)
What happens?

Table 9: 12 mm, 12 V. If i) is at time zero, the subsequent snapshots are at ii) 38 ms, iii) 76 ms, iv) 133 ms, v) 193 ms and vi) 218 ms.

Table 10: 12 mm, 4 V. If i) is at time zero, the subsequent snapshots are at ii) 16 ms, iii) 32 ms, iv) 47 ms, v) 54 ms and vi) 63 ms.
Variation with winch speed, 12 mm

Table 5: 12 mm particle, [4 6 8 10 12 14] V to winch

Table 6: 12 mm particle, exiting 10% by volume kaolin suspension [4 6 8 10 12 14] V to winch

0.2 0.3 0.4 0.5 0.6 0.7 m/s
Variation with particle size (0.7 m/s)

Table 7: i–ii) 8 mm particle, 14 V to winch, repeated experiments. iii–iv) 6 mm particle, 10 V to winch repeated experiments - in this pair the winch went slack as the particle passed through the surface.

Table 8: i–v) [4 6 8 10 12] mm particles exiting water, with a 14 V to winch. vi) 12 mm particle, exiting 10% by volume kaolin suspension, with a 14 V to winch.
Ejection jet

- As the particle exits the surface, it leaves behind a little vortex ring.
- This continues to accelerate fluid through it after the particle has left.
- It may even accelerate the particle.
- A force balance allows to estimate a timescale, 
  \[ T_j = \frac{u}{g} \]
Draining flow

Stokes flow in a thin layer, invoke lubrication assumptions. Short time asymptotics...
Draining timescale

This draining flow has a layer Reynolds number that looks like

\[ \text{Re}_l = \frac{g(\varepsilon R)^3}{\nu^2} \]

and, without surface tension, that leads to a timescale

\[ T_d = \frac{\nu}{\varepsilon R g} \]

Clearly, this depends on the original layer thickness
Coating

- So how thick is the initial layer in this draining problem? i.e. $\varepsilon$
- 1. Inertial?
- 2. Capillary?
- If inertial, then I can imagine that the fluid that gets dragged with the particle is the added mass
- If capillary, ($Ca \ll 1$, ours are $\sim 10^{-2}$), the coat thickness varies with $Ca^{2/3}$
  
  \[ Ca = \frac{uv\rho}{\gamma} \]
  
  (Landau Levitch 1942)
Timescales

- Ejection jet
  \[ T_j = \frac{u}{g} \]

- Draining
  \[ T_d = \frac{\nu}{\varepsilon Rg} \]

- where \( \varepsilon = Ca^{2/3} \)
- or \( \varepsilon = 0.14 \)
Raw data
Ejection jet scaling

![Graph showing ejection jet scaling with varying nozzle diameters.](image-url)
Draining scaling, ‘inertial coating’
Draining timescale, ‘capillary coating’
The sustaining of the tendril scales more convincingly with time scales inferred from analysis of the draining flow.

But this itself depends on the way in which the particle became coated.

Include surface tension in the draining flow.

I would have done the experiments a bit differently if I had known this!
In reality?

- Rarely have real debris flows where a particle could eject in this way.
- But this might give a handle on the extent of the ‘intermittent’ zone.
- Or why particles stay in the flow.
- More significant for lab flows.