Dry rock avalanche propagation: unconstrained flow experiments with granular materials and small bricks

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Rock avalanches: experimental study

- Framework
- Testing and measuring devices
- Parametrical study
  - Material
  - Number of releases
  - Volume
  - Fall height
  - Basal friction
  - Panel inclination
- Complementary tests
  - Structured mass
  - Curved transition
- Quantitative analysis
- Conclusions
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Lack of case histories: need for laboratory tests

Experimental approach

- Ring shear tests
- Flume tests (Drake)
- Three-dimensional granular flows
  1. Hutter and his co-workers
  2. Denlinger and Iverson
  3. McDougall and Hungr
  4. Okura et al
  5. Davies and McSaveney

Davies and McSaveney (1999)
No theory universally accepted
Phenomena still poorly understood

Understand mechanisms and assess the main parameters of influence by means of an extensive experimental campaign

- Provide experimental evidences to considered theories and confirm influence and importance of certain parameters: volume, fall height, friction at the base, ...
- Study new parameters: consecutive releases, bricks
- Systematic analysis of each parameter (qualitative and quantitative approach)
- Observe phenomena at small scale where things can be controlled and measured with accuracy
- Improve measuring techniques using new method with instruments available at the laboratory

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How is the set-up?

- Two panels (3 m X 4 m) with a jointed side
- A wood box of 40x20x65 cm
- Instantaneous release of granular material generating an unconstrained flow

Which parameters are changed?

- Volume: 10, 20, 30, 40 litres
- Fall height: 1, 1.5, 2 metres
- Number of releases: 1, 2, 4 times
- Material: Gravel (Gr2) (and at the beginning Hostun sand)
- Panel covering: wood $\phi_b=32^\circ$; forex $\phi_b=28^\circ$
- Slope angle: 37.5° and 45°
What is measured and how?

- Runout: travel distance on the horizontal panel
- Deposit length
- Deposit width
- Front mass velocity by means of films analysis
- Deposit morphology by means of the fringe projection method
Fringe projection method

- Creation of the fringes and projection
- Registration of the object optical print (phase map)

\[ \varphi = \arctan \left( \sqrt{3} \cdot \frac{I_2 - I_3}{2I_1 - I_2 - I_3} \right) \]

- Phase unwrapping and calibration

\[ \Delta z = F \cdot \Delta \varphi = \frac{\Delta z_{\text{max}}}{\Delta \varphi_{\text{max}}} \cdot (\varphi_{\text{obj}} - \varphi_{\text{ref}}) \]

Tilting test
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Hostun sand and Gravel: differences in morphology

<table>
<thead>
<tr>
<th>Material</th>
<th>Diameter (mm)</th>
<th>Basal Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hs</td>
<td>D=0.318-0.8</td>
<td>$\phi_{int}=\sim 34^\circ$; $\phi_b=\sim 34^\circ$-40$^\circ$</td>
</tr>
<tr>
<td>Gr2</td>
<td>D=0.5-3</td>
<td>$\phi_{int}=\sim 34^\circ$; $\phi_b=\sim 32^\circ$</td>
</tr>
</tbody>
</table>

Electrostatic effects?
**Hostun sand** and **Gravel**: differences in morphology

Six des Eaux Froides  
Switzerland

Gravel better reproduces behaviour -> used for most tests

Rather flat in the centre, steep front and rear

**Benchmark test:**  
40 litres, gravel, 1 m, 1 release, 45°, forex
When released at once the mass reaches longer runout.

The first volume released determines the final runout.
The first volume released determines the final runout
Morphology doesn’t vary with volume
When the fall height increases the whole mass translates

- No changes in the centre of mass position
- The exceeding travel distance caused by spreading

- Centre of mass and distal end translate of the same distance
- The length does not vary significantly

Initial uniformly decelerated motion
Sudden attenuation of the deceleration

- Front and rear parts interact through momentum transfer inducing a propulsion of the front particles and a deceleration of the rear ones
- Volume influences mainly accumulation part of the process
Longer runout is induced by lower base coefficient of friction, higher slope angle.

- Travel angle decreases (40° -> 35°) when slope decreases.
- Energy dissipation not constant, greater on steep slopes where high velocity -> straight energy line no adequate.

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Which parameters are changed?

- Volume: 20, 40 litres
- Fall height: 1, 1.5 metres
- Number of releases: 1, 2 times
- Material: Gravel (Gr2) and Bricks
- Panel covering: wood \( \phi_b = 32^\circ \); forex \( \phi_b = 28^\circ \)
- Slope angle: 37.5° and 45°

What is measured and how?

- Runout: travel distance on the horizontal panel
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Different disposition of bricks before failure

- No significant difference between gravel and Random bricks
- Longer travel distance for Piled bricks

Different mechanisms of propagation

- Gravel and Random bricks (loose material): similar behaviour
- Piled bricks: spreading of a coherent mass, frictional mainly at the base on inclined board, then impact, shatter: collisional and frictional within the mass and at the base
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Which parameters are changed?
Slightly curved discontinuity

- Loss of energy at sharp toe causes much shorter runout
- Curve toe -> less energy dissipation when impact -> greater velocity

Shattering of a coherent mass due to the connection at the toe

- Decrease of energy loss
- Less shattering when curved toe -> maintained coherence
Shattering of a coherent mass due to the connection at the toe

- Erismann identified the stratigraphy coherence as a characteristic of rock avalanches
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Terms of interest

- $h^*$ = cubic root of the volume
- Excessive travel distance
  \[ L_e = L - \frac{H}{\tan 32^\circ} \] (Hsü)
- unconstrained

\[ \text{total fall height } H \]
\[ \phi_\text{ap} \text{ Fahrböschung} \]
\[ \phi_\text{CM travel angle} \]
\[ \text{energy line} \]
\[ \text{travel distance of the centre of mass } L_\text{CM} \]
\[ \text{deposit length } L^* \]
\[ \text{total travel distance } L \]
**L*/h*/=1-3 in Davies tests; in contrast with large rock avalanches (L*/h*/=5-10)**

- Laboratory tests agree with Davies data but for tests with piled bricks (L*/h*/=3.2-4.3)

- **Gravel**
  \[ L^* = 2 \div 2.7h^* \]

- **Random Bricks**
  \[ L^* = 2.2 \div 3.8h^* \]

- **Piled Bricks**
  \[ L^* = 3.2 \div 4.3h^* \]
$L^*/h^* = 1-3$ in Davies tests; in contrast with large rock avalanches ($L^*/h^* = 5-10$)

- Data in the range of real cases for piled bricks and smooth connection at the toe

- Gravel
- Random Bricks
- Piled Bricks

$L^* = 2.8 \div 3.3 h^*$

$L^* = 5.1 \div 5.6 h^*$

$R/h^*$ is not constant (R = runout on the horizontal panel)

$R = ah_v + bh^*$

$a$ and $b$ depend on:
- Material
- Coefficient of friction
- Slope angle
- Regularity of the path
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Conclusions and main contributions

- Fringe projection method adapted to be used in laboratory tests with very limited expenses

- Parameters of influence:
  - At small scale deposit characteristics and morphology dependent on material used: sand or gravel.
  - Number of releases has a significant influence on propagation. If the mass falls all at once it reaches longer runout than if at different times. Evidence of Randa. The first release determines the runout.
  - The excessive travel distance is determined by the spreading of the mass when only the volume varies.
  - The longitudinal extent of the final deposit does not depend on the fall height but on the topography
  - The more the mass is structured before failure and the more the pathway of the mass is regular the longer is the runout
Conclusions and main contributions

- Normalized length (spreading):
  - $L^*/h^*$ between 2 and 3.8 for tests with gravel and random bricks, curved and smooth at the toe, loose material far from real cases even on smooth connection. Greater energy dissipated form the beginning.
  - $L^*/h^*$ is higher (3.2-4.3) if bricks are piled orderly before failure (spreading of a coherent mass) and are in the range of real events (5.1-5.6) if curved toe. It is the combination of the structure of the mass and the regularity of the pathway which leads to longer runout.

- The runout of the deposit ($R$, travel distance) depends linearly on volume and fall height, according to friction, topography, material:
  \[ R = ah_v + bh^* \]

Conclusions and main contributions

- Experimental evidence of:
  - Excessive travel distance partly caused by transfer of momentum between the rear and the front parts (Heim). Volume influences only on the accumulation part.
  - Energy line depends on the slope (Legros) and on the regularity of the pathway (Heim).
  - Straight energy-line based on a simple frictional model is not adequate. Take into account a velocity dependent term.
  - Predominance of the frictional regime at the base when mass is structured, sparing of energy, longer runout. When it shatters preponderance of frictional and collisional regime.

- Even if difficult to perform tests with piled bricks, it represents well a structured mass able to shatter and helps understanding mechanisms likely to happen in reality.
Outlooks

SNF funded research in progress to extend the findings to date
PhD thesis of Claire Sauthier focusing on experiments with gravel

- Extend ranges of the parameters
  - Volume and height ($hv/h^*$)
  - Grain size distribution and shape of the grains
  - In deep investigation on topography of the path

- Further development of the fringe projection method to follow the centre of mass along the slope and consequently evaluate the energy loss, transfer of momentum and velocity

- Further numerical simulations of the tests, implement parameters in numerical codes