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Small-scale study of Debris-Flow Interactions with a Lateral Debris Basin and Crossings: The Manival Torrent case study

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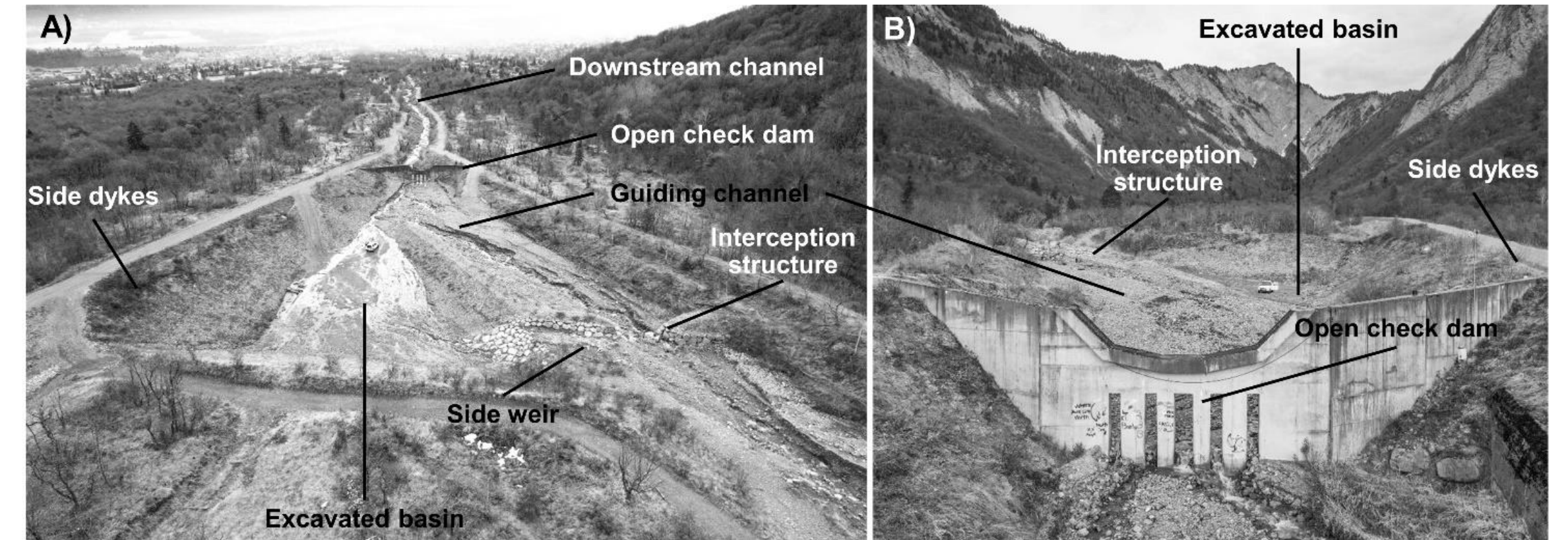
Small-scale study of Debris-Flow Interactions with a Lateral Debris Basin and Crossings: The Manival Torrent case study

Introduction

Retention basins are common mitigation measures against debris-flow hazards. Even if thousands of such structures exist in mountain areas, notably in Europe and Asia, the interactions between those structures and debris flows and floods are insufficiently known and many open questions remain. In addition to numerical models, small-scale models are interesting options to study sites with complex topography and interactions with structures. Small-scale modelling of debris flows remains difficult because of the complex rheology and scaling challenges posed by such natural materials.

Context

- The Manival is a steep mountain stream located in the Chartreuse mountain range in the Northern French Prealps. Its catchment has a drainage area of 3.6 km² at the inlet of the modelled area. The Manival experiences bedload transport, debris floods and debris flows with one major event every three years, on average.
- To mitigate the risk, torrent control works have been implemented since the 1890s. Nowadays, the torrent is equipped with more than 160 check dams, dikes and a 100 m long debris basin closed by an open check dam.
- The debris basin has a derivation configuration, with: 1/ a guiding channel equipped with an interception structure at its upstream end, and 2/ a lateral weir guiding high flows toward the deposition basin which is located on the left bank and excavated deeply below the guiding channel level.



Objectives

Main objective is to build up a tool that could help optimizing the design of the debris basin and channel downstream with respect to:

- Retention capacity of debris flows by the debris basin
- Reducing the sediment trapping related to small debris floods (not presented here), thus leading to better sediment continuity and reduction of the often observed scouring of downstream channel
- Reducing the risk of avulsion in the downstream channel (fords, bridges, small height of the banks...), notably if the debris basin retention capacity (around 10,000 to 17,000 m³) is exceeded (100 years return period debris flow around 30,000 m³)

Mixture calibration in small flume

Mixture calibration was carried out in a 3 m-long, 0.18 m-wide trapezoidal-shape flume with a 0.13 m/m slope gradient corresponding to the actual upstream channel slope. Tests were performed releasing 300 kg of mixture varying the contents of water, clay and sand. We adopted a Herschel-Bulkley rheology, which is assumed suitable for the muddy debris flows occurring in the Manival torrent. Similarity criteria are selected accordingly as well as a 1:25 scale.

Herschel-Bulkley model

$$\tau = \tau_c + K \left(\frac{\partial u}{\partial z} \right)^n$$

3 non-dimensional numbers including the classical Froude number

$$Fr = \frac{U}{\sqrt{gh \cos \theta}} \quad G = \frac{\rho g h \sin \theta}{\tau_c} \quad Hb = \frac{\tau_c}{K} \left(\frac{h}{U} \right)^n$$

The objective was to define two suitable mixtures mimicking:

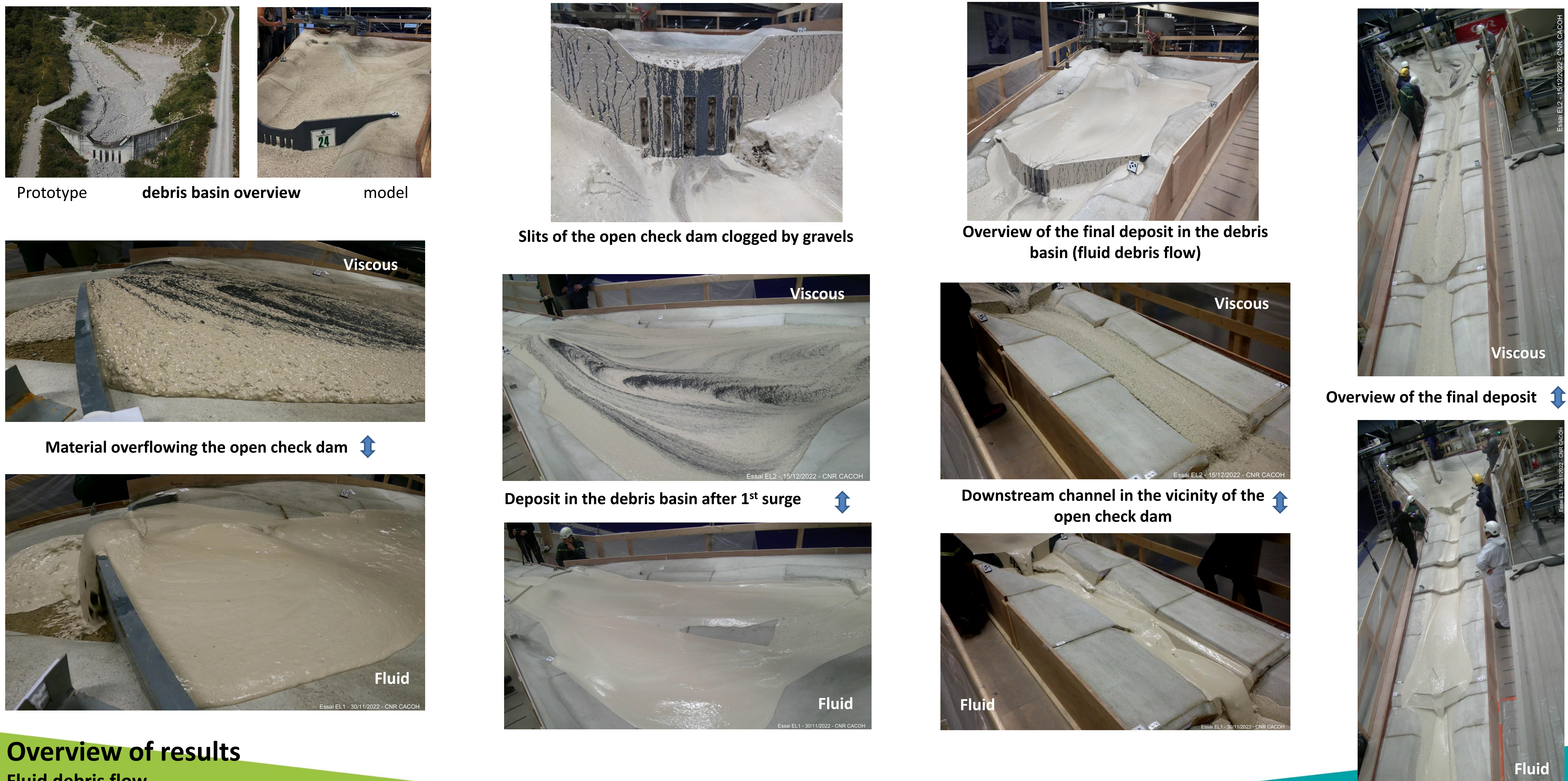
- A rather fluid debris flow (criterion: yield-stress leading to 0.4 m-thick deposit in nature with a 0.13 m/m slope, roughly 0.018 m on the model). This was achieved using: 31.2% of water, 18.8% of kaolin clay, 50% of 0-11 mm sand and gravel. Density is 1,825 kg/m³.
- A more viscous debris flow (criterion: yield-stress leading to 1.30 m-thick deposit in nature with a 0.13 m/m slope, roughly 0.06 m on the model). This was achieved using: 16% of water, 7.5% of kaolin clay, 76.5% of 0-11 mm sand and gravel. Density is 2,092 kg/m³.



Fluid propagation in small flume Viscous

Experiments on the platform

The small-scale model study is performed at CNR hydraulic flows and structures laboratory (Lyon, France). The model is 22.5 m-long (550 m at prototype scale), up to 6.3 m-wide, and includes the debris basin and part of the downstream channel, at scale 1:25. The bed is erodible, with medium grain size: 1.36 mm. The debris-flow material is released in two successive surges with a total volume of 1.6 m³ (25,000 m³ in nature) for fluid debris flows and 1.86 m³ (29,000 m³ in nature) for viscous debris flows. The platform is equipped with video-cameras, a weighing machine and an ultrasonic sensor.



Overview of results

Fluid debris flow

Equivalent in nature: 25,000 m³ released / 8,000 m³ deposited in retention basin / 6,000 m³ in downstream channel / 9,000 m³ passing through

Viscous debris flow

Equivalent in nature: 29,000 m³ released / 21,000 m³ deposited in retention basin / 8,000 m³ in downstream channel

Conclusions and outlooks

This work is still in progress.

This small-scale model study has proved very useful to better understand debris flow trajectories over protection structures with complex geometry. In the next phases, adaptations will be performed to optimize the debris flow spreading in the basin to maximize the trapping, and to adjust the ford and bridge geometries to minimize the probability of avulsion or bank overflowing.

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