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# Experimental study of the variability of sediment transport processes under outburst flood conditions in mountain streams

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## Introduction

Outburst floods in mountain areas result, for instance, from the breaching of morainic or ice dams when a periglacial lake has formed under the effect of climate change. They also result from the breaching of a natural dam, often following the clogging of a valley by a lateral landslide. They may also result from the collapse of man-made dams. Outburst floods are very unsteady flows generally propagating as a wave of water and sediment. In Alpine environment, outburst floods can lead to very intense erosion and sediment transport processes, even catastrophic debris flows (e.g. Schuster, 2000 ; Laigle & Bardou, 2022).

To date, little is known on the features of sediment transport processes outburst floods can actually trigger for given field conditions. For authorities in charge of hazard assessment and risk mitigation, such lack of knowledge leads to uncertainty on the kind of phenomena to be dealt with. Thanks to flume experiments, we aim at establishing a typology of flow features, as well as evidencing the role played by parameters such as the slope gradient or the volume of water released.

## Methods

To our knowledge, Spinewine & Zeck (2007), among other publications from this research team, have presented the most advanced experimental and modelling work on the propagation of dam-break waves on an erodible stream bed. However, their flume experiments were carried out only in flat or very gentle slope gradient flumes. We made the choice to adopt the same principle, but to investigate a large range of slope gradients.

Experimental equipment (Figure 1):

- 5.0 m-long, and 0.2 m-wide flume with lateral glass walls and adjustable gradient from 0.0 % to 51.8 %
- A tank with a capacity up to 0.35 $m^3$ with a sluice gate that can be quickly opened
- A 0.08 m-thick layer of sand (grain size from 0.5 to 2 mm) deposited uniformly on the flume bottom over a 0.03 m-thick plastic grating to avoid sliding once the flume is inclined
- A tank located downstream collects water and sediment exiting the flume
- The set of devices used to characterize the flows is composed of:
    - 5 ultrasonic distancemeters
    - 3 video cameras located laterally, which take pictures through the lateral glass walls
    - 1 video camera located above the axis of the flume pointing downwards

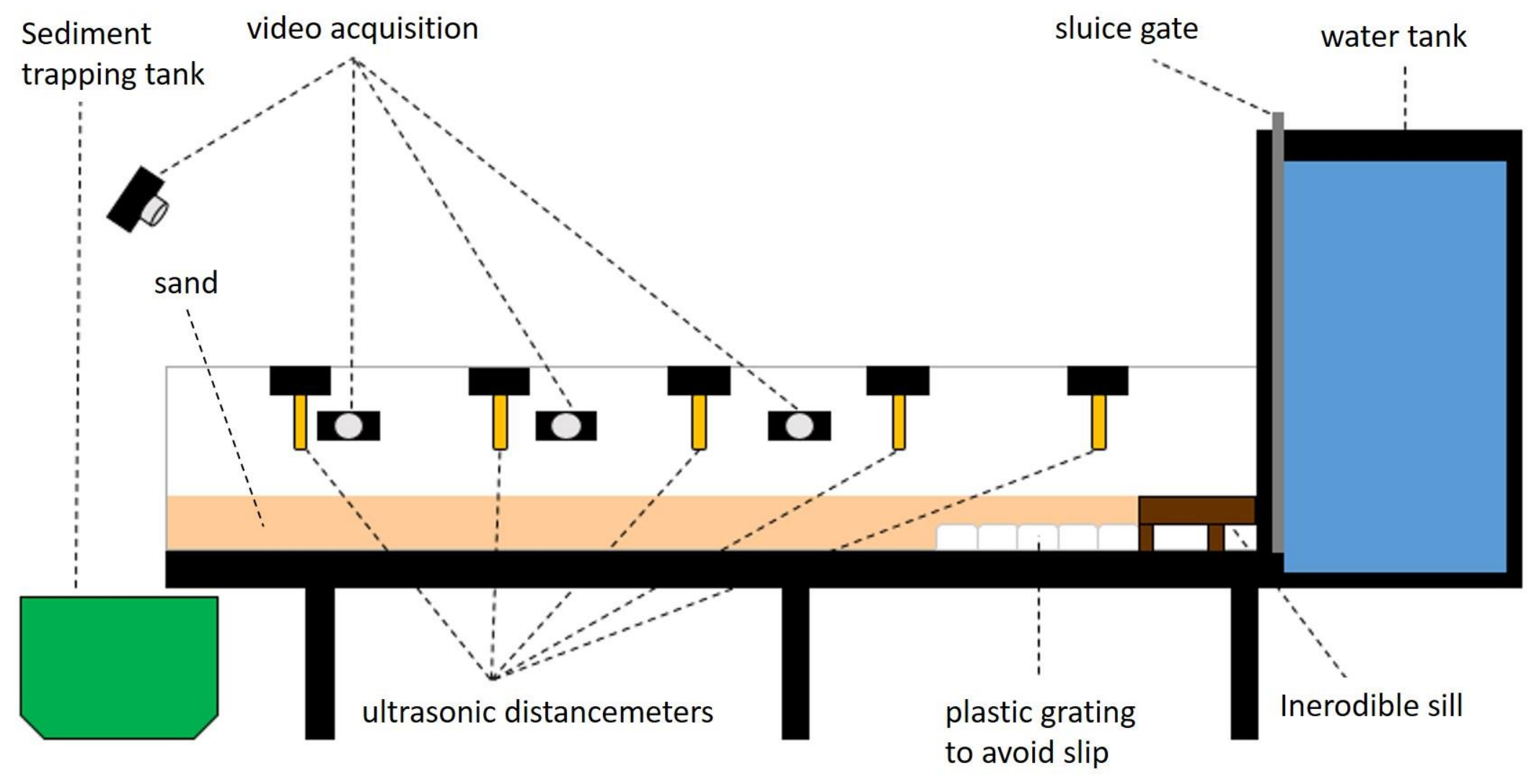

Figure 1: Sketch of the experimental flume. Considering a Froude similitude, these experiments can be interpreted in the field with a 1/25 geometric scale

## Results and discussion

94 experiments were carried out on 16 slope gradient values ranging roughly from 1.7 to 38.0 %, and volume of water released ranging from 12.0 to 58.0 liters. As the water is suddenly released from the upper tank, the propagation systematically exhibits a wave front. The features of this front strongly depend on the quantity of sediment entrained. 3 phases generally observed: erosion upstream, propagation, possibly deposition downstream.

Figure 2: Shape of the flow front with slope gradient and volume of water released respectively: A/ 5.12 % - 58. l, B/ 8.55 % - 58. l, C/ 20.88 % - 26. l.

On gentle slope (Figure 2-A, 5.12 %), only the water propagation (front velocity ≈ 0.75 $m.s^{-1}$) can be visually identified. The sediment transport remains limited in an active layer located below the water layer (Figure 4-A). Figure 2-B (8.55 %, front velocity ≈ 0.5 $m.s^{-1}$) shows similar features, except the presence of a cord of sediment, about 4 cm long and 2 cm thick, located at the wave tip. On Figure 2-C (20.88 %, front velocity ≈ 0.35 $m.s^{-1}$), a sediment front, about 3 to 4 cm thick, is present at the wave tip. Its volume remains limited (yellow arrow shows the length). This front is unstable in time and space showing fingers where the sediment is pushed by the flow for a few seconds and then stops.

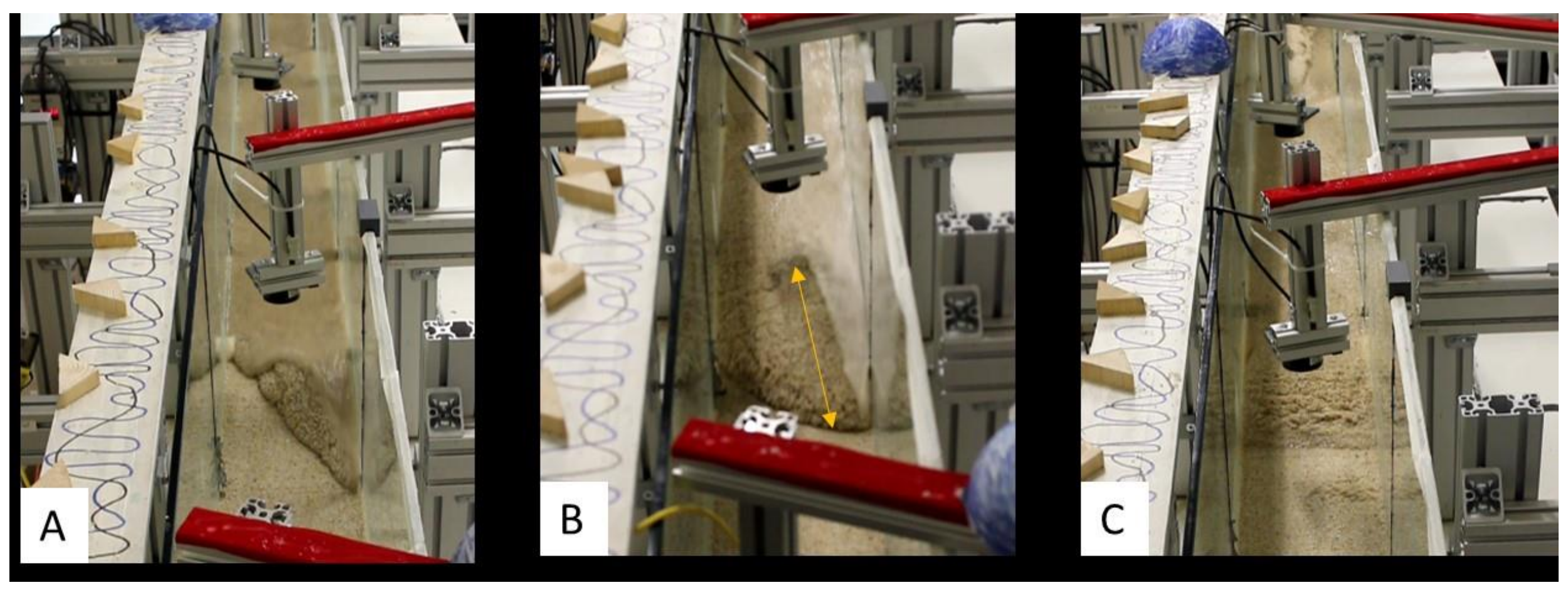

Figure 3: Shape of the flow front with slope gradient and volume released respectively: A/ 24.56 % - 27. l, B/ 36.24 % - 28. l, C/ 34. % - 12. l, dislocation of the front.

On Figure 3-A (24.56 %, front velocity ≈ 0.26 $m.s^{-1}$), processes are somewhat similar to those observed in Figure 2-C, except that the volume of the sediment front is larger, and its instability in time and space has slightly reduced, compared to the latter. Sometimes, the water may overflow the sediment front. On Figure 3-B (36.24 %, front velocity ≈ 0.26 $m.s^{-1}$), most of the sediment is mobilized in a mass flow, with a long front (yellow arrow shows the length), up to 8 cm thick, which occupies the whole flume width. The front tip is followed by some visually homogeneous mixture of water and sediment, sheared over the whole flow thickness (Figure 4-B), and is quite stable in time and space.

On Figure 3-C (34.0 %), the front velocity is less than 0.1 $m.s^{-1}$. Conditions are similar to Figure 3-B, except for the limited volume of water released. A large front has formed, stopped in the flume, and then slowly dislocated under the effect of the water still circulating inside the sediment mass.

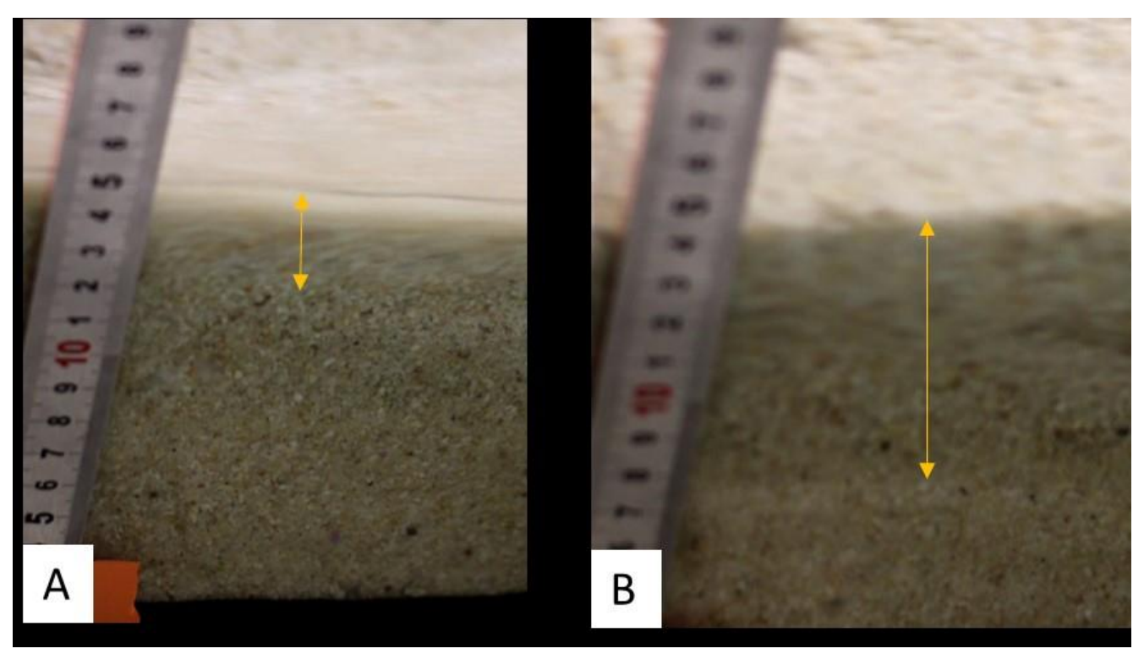

Figure 4: Thickness of the sheared zone with slope gradient and volume released : A/ 28.33 % - 20. l ; B/ 36.24 % – 28. l.

In reference to field phenomena, we suggest the tentative classification of the flows we investigated experimentally:

[1.70 % ; 20.88 %]: bedload transport / [20.88 % ; 28.32 %]: hyperconcentrated flow (e.g. Pierson, 2005) / [28.32 % ; 36.24 %]: debris flow (e.g. Takahashi, 2014, Laigle & Bardou, 2022).

With sub-domains showing slightly different features, apparently influenced by the volume of water released:

[8.55 % ; 20.88 %]: intense bedload transport / [30.26 % ; 36.24 %]: immature debris flow (e.g. Takahashi, 2014) / dislocation: over a large range of slope gradients.

## Conclusions and outlooks

The experiments have shown a large variability of flow features, ranging from rather diluted diphasic bedload transport to very concentrated, apparently monophasic, mass flows, and evidenced a series of intermediate phenomena where instability in time and space is very often present.

We have evidenced the role played by the slope gradient. However, it was not sufficient to establish a clear typology, and other parameters will require investigation.

We suggest a continuous evolution, and the existence of transitions between the rather well-known field phenomena – bedload, hyperconcentrated flows, debris flows.

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