Debris-flow generated tsunami waves

Physical experiments of debris-flow generated impulse waves and their dependence on debris-flow properties

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1. Introduction

Debris-flow generated impulse waves can be extremely dangerous for lakeside settlements, and prediction of their characteristics is of major importance for hazard mitigation and management. However, the effects of debris-flow composition on wave generation and evolution are poorly understood.

2. Objectives

We investigate the influence of multi-phase debris-flow volume, composition (gravel, sand, clay, water) and subaerial outflow slope on wave celerity and amplitude, in a small-scale 3D physical laboratory model. We focus on wave amplitude and celerity, being the two most important factors for hazard management.

3. Methods

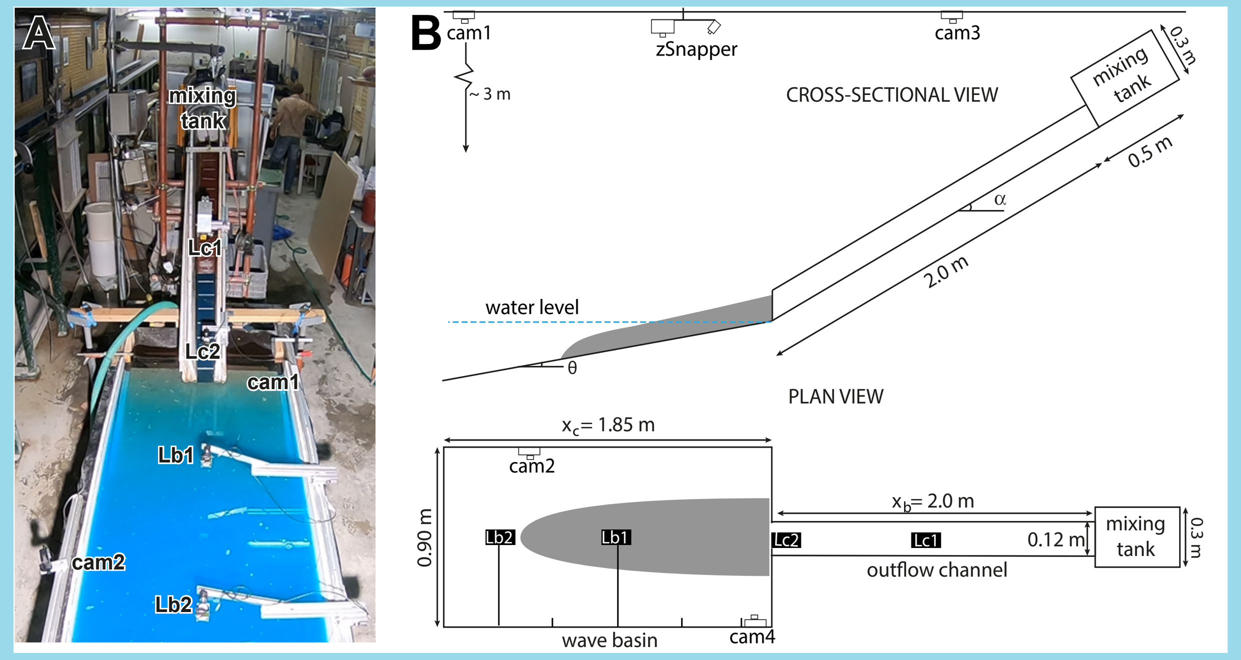

Fig. 1. Experimental flume setup. A: the mixing tank, outflow slope and wave basin with various instruments (cam: camera. Lb/Lc: laser scanner). B: Planview and topview of the setup.

4. Experiments vs nature

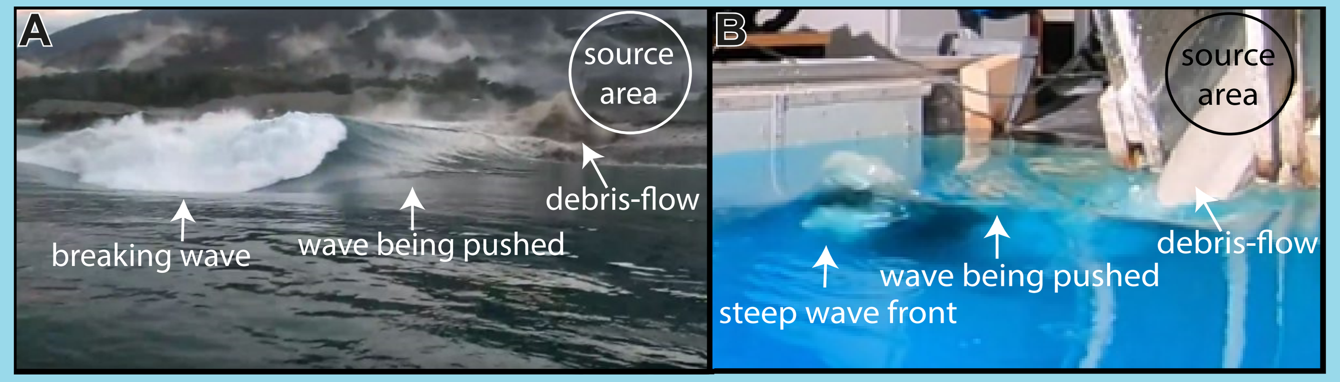

Fig. 2. Comparison between debris-flow generated tsunami in nature, Sulawesi 2018 (A) and in our setup (B).

5.1 Wave generation

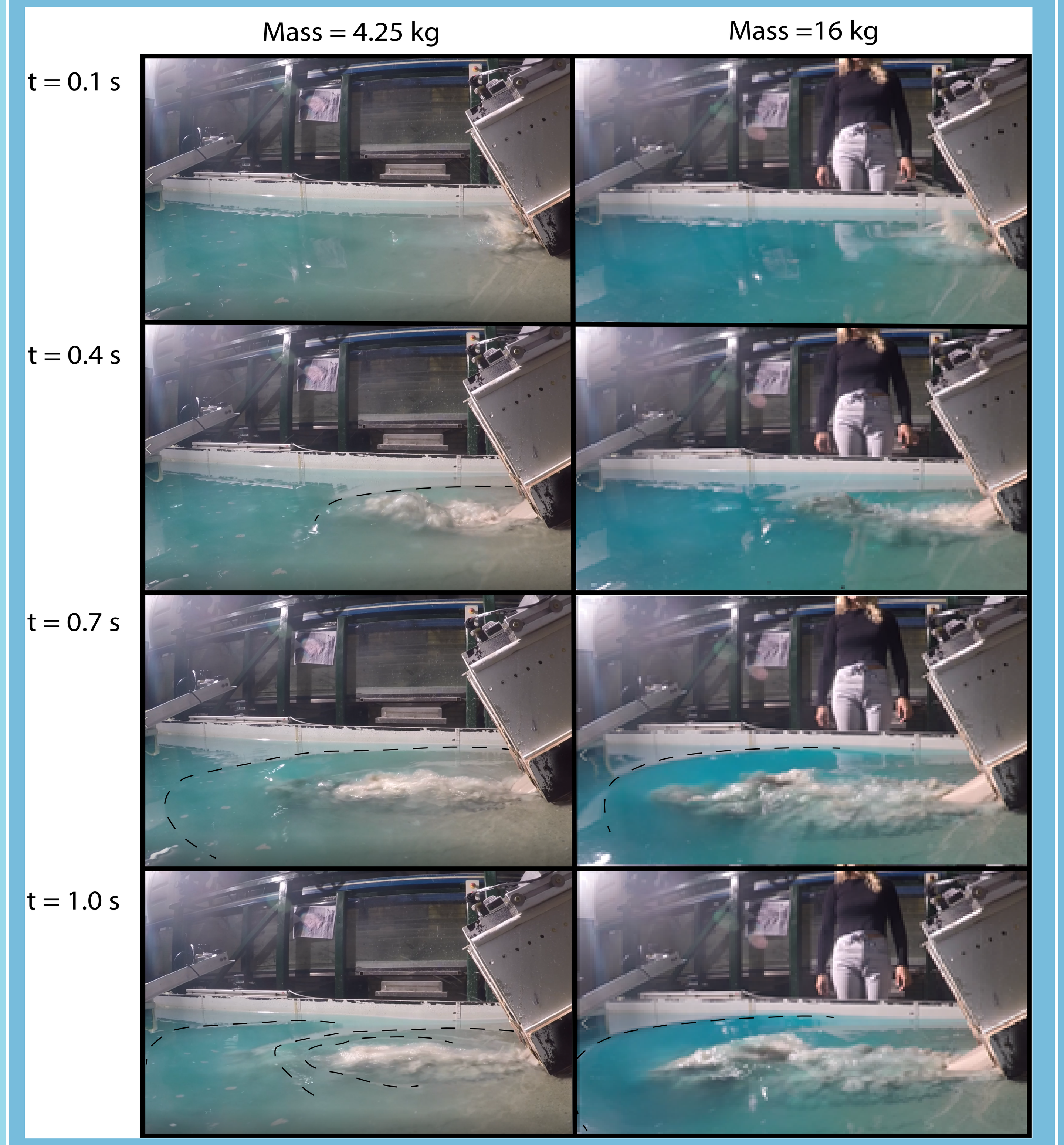

Fig. 3. Wave generation of two runs with varying debris-flow volume. When the debris-flow debouches into the water, it transfers a substantial portion of its energy (~15%) by pushing the water forward, until the wave celerity exceeds the subaqueous debris-flow velocity and the wave becomes 'detached' from the debris flow.

5.2 Wave evolution

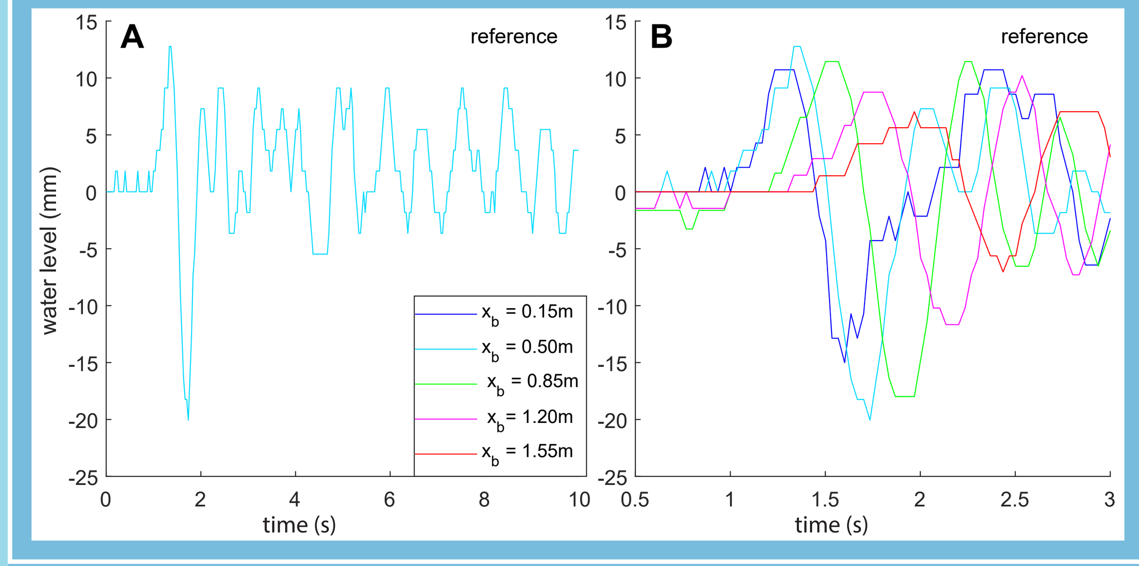

Fig. 4. Wave profile of the reference experiment (8 kg, 44 vol% water, 18 vol% gravel, 2 vol% clay, 30° outflow slope). A) Near-field wave profile over the first 10 seconds after debris flow release. B) Leading crest and trough at different longitudinal locations along the wave basin.

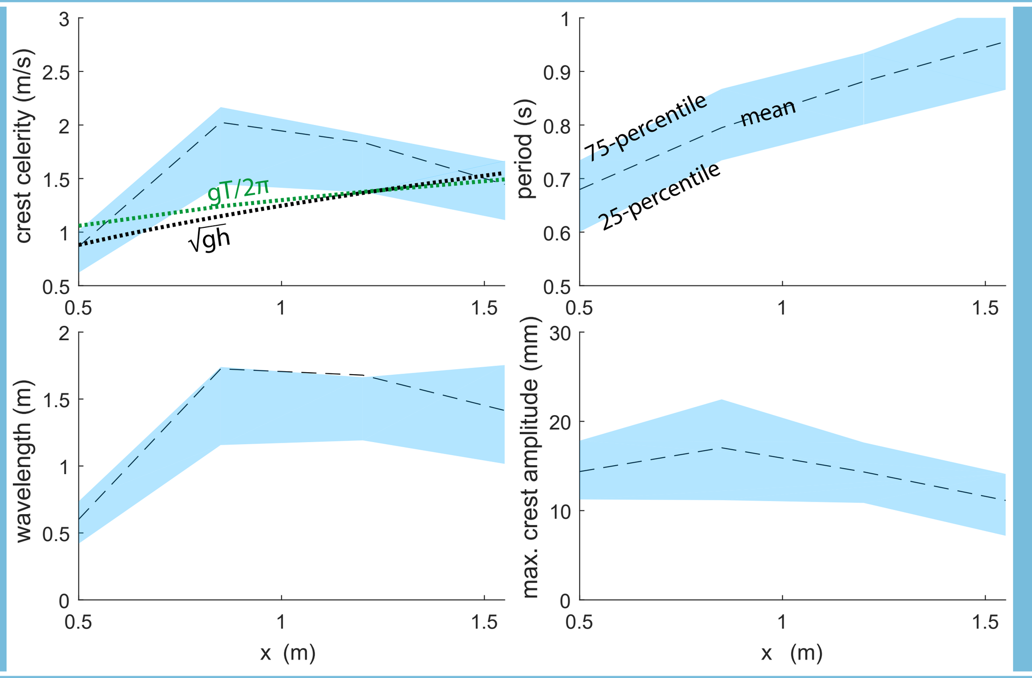

Fig. 5. Wave celerity, period, wavelength and amplitude over distance from impact area. The pushing of the debris-flow over steepens and accelerates the wave, which increases its non-lineairity but does not result in wave breaking. After detachment (x = 0.80 m), the wave energy becomes dissipated.

5.3 Debris-flow composition

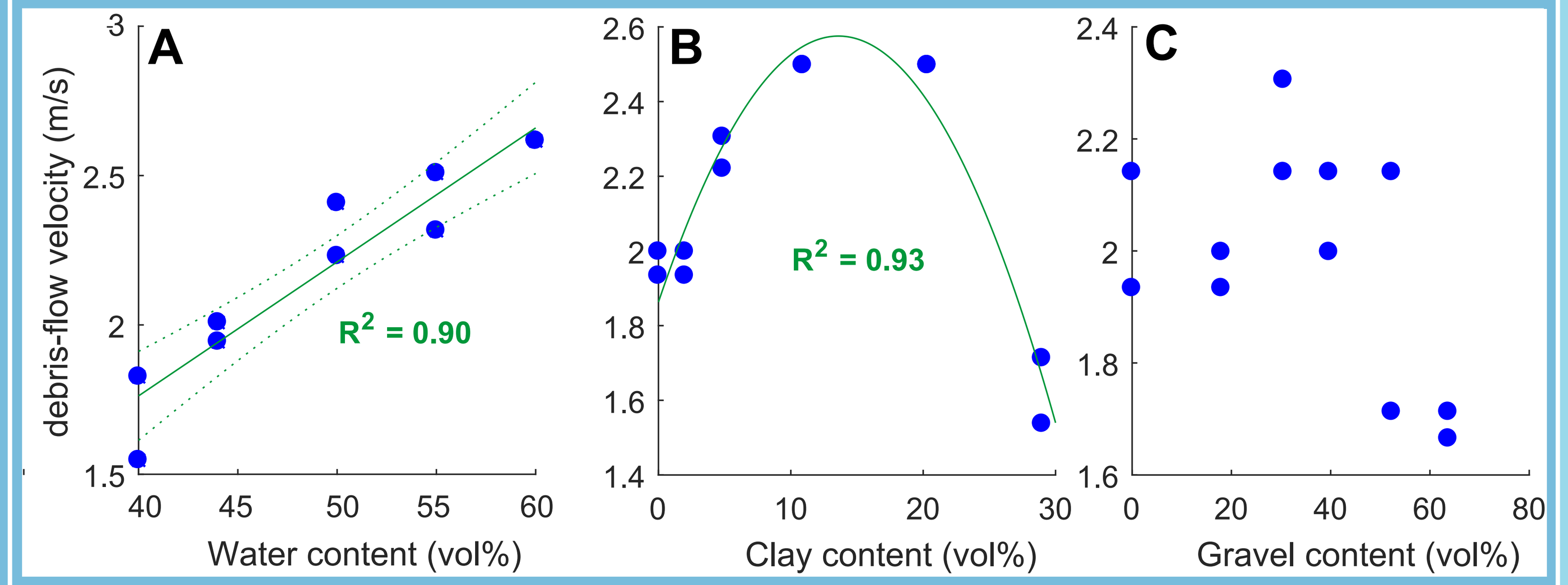

Fig. 6. Example of the influence of debris-flow composition (water, clay and gravel content) on debris-flow characteristics (velocity). Debris-flow velocity is enhanced with an increasing water and clay content (up to 22%) of the debris flow, which both have a lubricating effect. There is no significant relation with gravel content. Debris-flow thickness and thus effective mass, increase with increasing debris-flow volume (not shown).

5.4 Relation debris-flow & wave characteristics

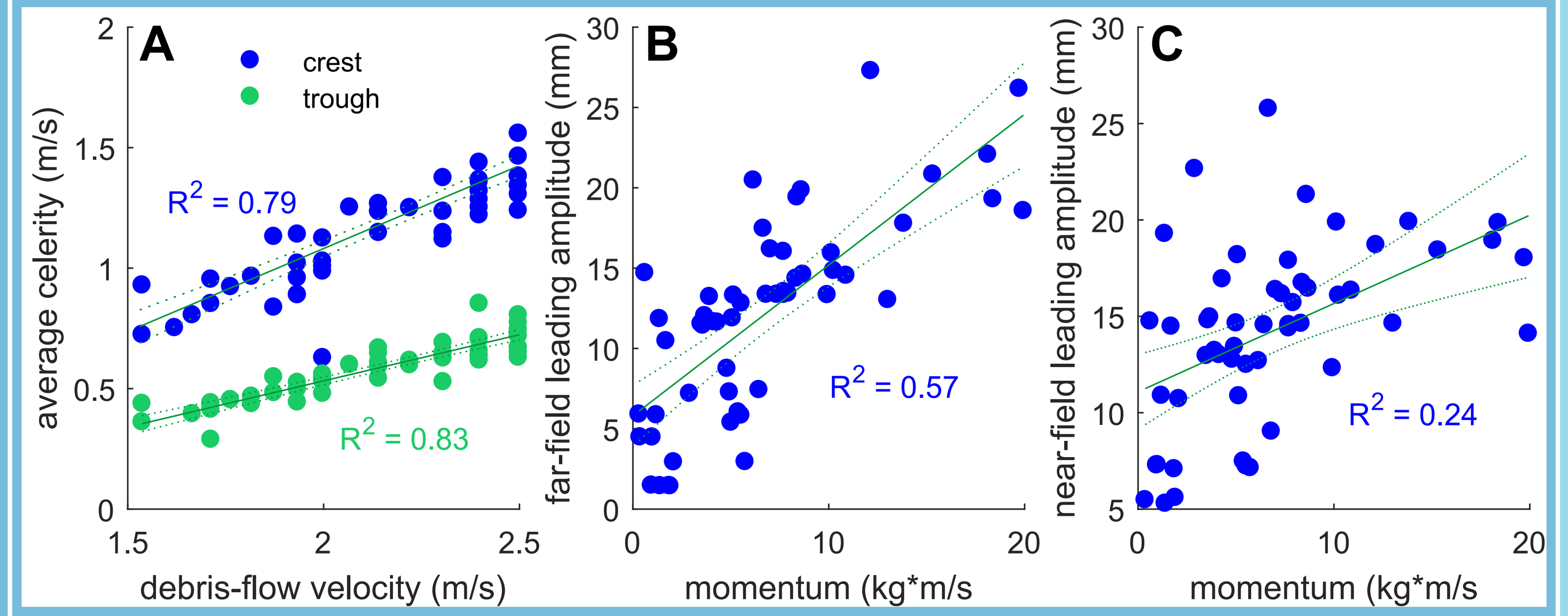

Fig. 7. Debris-flow velocity is the main driver for wave celerity (A) and wavelength (not shown). An increasing debris-flow velocity increases the momentum exerted on the water by the debris-flow, thereby increasing the wave celerity. It also increases duration of the pushing, thereby increasing the wave amplitude. The pushing is also increased by a thicker, higher volume, debris-flow. Debris-flow momentum is the main driver for far-field wave amplitude (B), but is poorly related to near-field wave amplitude (C).

6. Natural variability

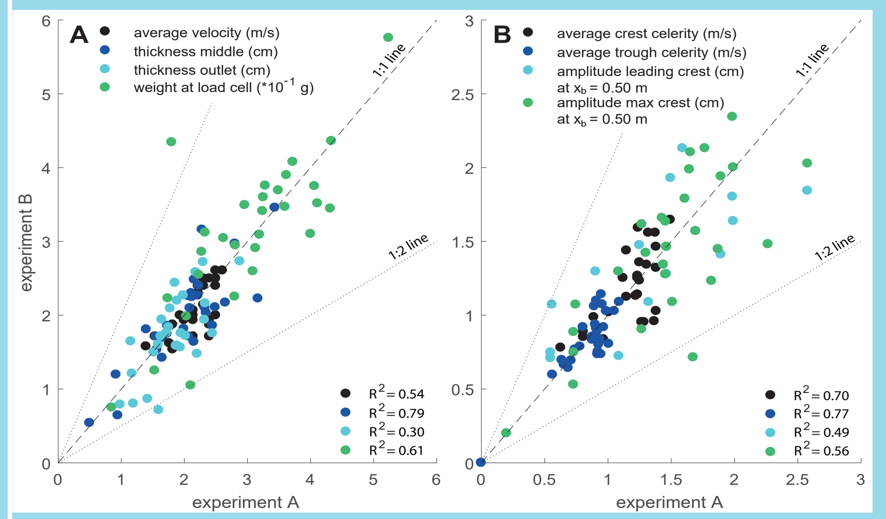

Fig. 8. Natural variability of debris flows (A) and the corresponding impulse waves (B). The numbers on the axis correspond with the actual value of the plotted variables. This graph gives an idication of the expected natural variability in the result section.

7. Predictor strength

Debris flow → Waves ↓	Velocity	Energy	Momentum
Crest amplitude (near field)	0.30	0.28	0.49
Crest amplitude (far field)	0.50	0.58	0.60
Crest celerity	0.79	0.65	0.60
Wave energy	0.53	0.68	0.64
Detachment time	0.30	0.40	0.47
Wavelength	0.64	0.50	0.45
Predictor strength	0.55	0.51	0.53

Fig. 9. R^2 values (indicating linear correlation) of debris-flow characteristics and the corresponding wave characteristics. The darker the green color, the stronger the correlation.

8. Conclusion

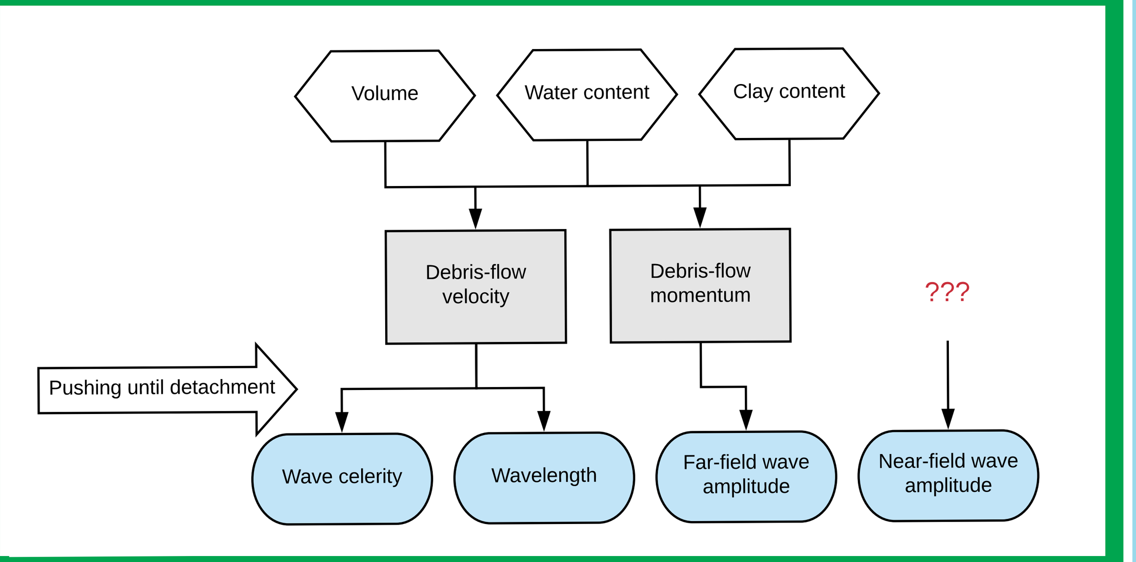

Fig. 10. Debris-flow volume, water content and clay content determine the debris-flow velocity and momentum. When the debris-flow debouches into the water, its momentum is transferred. The water mass is pushed away from the impact zone, until the wave celerity exceeds the debris flow velocity. The debris-flow velocity is the main driver for wave celerity and wavelength. Debris-flow momentum determines the far-field wave amplitude. The main driver of near-field wave amplitude is so far unknown and further research is warranted.