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

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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. 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. The experimental setup consists of a mixing tank to stir the sediment mixture, a 2.00 m long and 0.12 m wide subaerial outflow channel inclined at 20-40° and a 0.90 m wide and 1.85 m long wave basin inclined at 10°, with a maximum water depth of 0.33 m.

When the debris-flow debouches into the water, it transfers a substantial portion of its energy ($\sim$15%) by pushing the water forward, until the wave celerity exceeds the subaqueous debris-flow velocity and the wave becomes 'detached'. The pushing of the debris-flow over steepens and accelerates the wave, which increases its non-linearity but does not result in wave breaking.

We demonstrate that debris-flow velocity is the main driver for wave celerity and wavelength, while debris-flow momentum (velocity times effective mass) mostly determines (far-field) wave amplitude. 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, which relation is strengthened by a thicker debris-flow. 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. Debris-flow thickness and thus effective mass, increase with increasing debris-flow volume.

We further show that the existing laws of transfer of momentum of a subaerial debris-flow to the water body is applicable for predictions of wave characteristics generated by a multi-phase debris flows, but that formerly developed (semi-empirical) equations need to be adapted by including debris-flow composition and a sloping wave basin, to be able to make accurate predictions. Our results demonstrate the importance of debris-flow composition on impulse wave generation and evolution, and thus the necessity of including flow composition in predictive models.