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What are the key elements that control the seismic signature of highly concentrated sediment flows?

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Flowing through the landscape, rivers generate high-frequency ground vibrations (> 1 Hz) by exerting force fluctuations on the bed. The well-established evidence that seismic sensors detect a wide variety of fluvial processes has motivated the use of seismology to indirectly measure sediment transport. In the last decade, numerous efforts have been dedicated to develop physically-based mechanistic models to investigate the link between the river-induced seismic signal and sediment transport properties such as the characteristic diameter of the transported sediments, bedload transport rate, debris flow thickness and velocity. However, most of the existing theories rely on simplistic descriptions of the transport dynamics that may not necessarily be sufficient to capture realistic behaviours. In particular, highly concentrated sediment flows are characterized by complex grain scale physical processes that could have a major impact on their seismic signature (Allstadt et al., 2020; Piantini et al., 2021).

Here, we carry out laboratory experiments to explore the seismic signature of highly concentrated sediment flows. Our scaled experimental setup allows the self-triggering and propagation of sediment pulses in a steep channel (slope of 18%), using a wide bimodal grain size distribution typical of mountain streams. We monitor physical parameters such as flow surface elevation, outlet solid discharge and the corresponding granulometric composition, together with seismically relevant quantities such as basal force fluctuations and flume vibrations using force and ultrasonic sensors, respectively. We observe transport conditions that range from the dilute transport of big grains (sediment pulse front) to dense sediment flows (sediment pulse body). Consistent with previous studies, the passage of the unsaturated front exerts the highest force fluctuations and seismic power. However, we also find that the body, despite having an amount of coarse particles similar to the front, becomes dramatically quieter when bulk density increases and the content of fine particles is maximum. We explain this latter behaviour by two main processes. First, flow stratification prevents a large part of the transported sediments from generating direct impacts to the fixed channel bed. Second, fines allow the formation of a conveyor belt that transport big particles with reduced collisions, as manifested by a considerable increase in their downstream velocity. These findings argue that internal stratification and the presence of a high content of fines may exert a major control on the seismic signature of highly concentrated sediment flows.

References

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