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Vertical size sorting in bedload transport on steep slopes : Investigation at the grain scale

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Bedload, the coarser material transported in contact with the bed by turbulent flow in stream channels, has major consequences for public safety, water resources, and environmental sustainability. In mountains, steep slopes drive intense transport of a wide range of grain sizes, suggesting that size sorting or segregation is largely responsible for our limited ability to predict sediment flux and river morphology in this context.
Most studies have focused upon the spontaneous percolation of fine grains into immobile gravels. However when the substrate is moving, the segregation process is different as dynamically available void openings permit downward percolation of larger particles, a process known as 'kinetic sieving'. Since spontaneous percolation and kinetic sieving both occur in natural streams, specific experiments [1] to study both processes simultaneously were carried out in a tilted, narrow, glass-sided channel, at Irstea in Grenoble, France [2]. The flume slope and width were 10.1 % and 10.3 mm, respectively.
All of the experiments were undertaken with a constant supercritical flow rate in two stages. In the first stage, coarse beads of diameter 5 mm were introduced at a constant feed rate to obtain a sediment bed in one-size-equilibrium (sediment influx = sediment outflux). In the second stage, beads of different diameters (0.7 mm, 0.9 mm, 1.5 mm, 2mm) were introduced at different feed rates, during which the coarse feed rate remained constant at the rate in the first stage. The objective was to study the influence of (1) the grain size ratio and (2) the percentage of the fine feed rate in the total feed. Depending on these parameters, the slope of the bed evolved eventually reaching a new two-size equilibrium value either larger (aggradation) or smaller (degradation) than the one-size slope. A layer of fine grains on top of which coarse grains moved, which varied in thickness, was observed.
Each experiment was recorded using a high-speed camera. Image processing algorithms applied to a sequence of images permit us to detect the water free surface, the bed elevation and the coarse beads, and to calculate their trajectories. In this contribution, we will analyse the depth profiles of particle streamwise velocity and concentration, and the sediment transport rate of the coarse beads once the two-size equilibrium is reached. Depending on the grain size ratio and the percentage of the finer feed rate in the total feed, coarse grains moved either in concentrated low velocity clusters or individually at higher velocity. Better understanding of bedload size sorting at the grain scale should permit upscaling and improvement of sediment transport and river morphology modelling.

[1] Dudill A, Frey P, Church M. 2017. Infiltration of fine sediment into a coarse mobile bed: A phenomenological study. Earth Surface Processes and Landforms 42(8): 1171-1185.
[2] Frey P. 2014. Particle velocity and concentration profiles in bedload experiments on a steep slope. Earth Surface Processes and Landforms 39(5): 646-655.