

Laboratory experiments on silt infiltration into a gravel bed

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Introduction

Interaction between sediment fractions with a significantly different size is a common situation in mountain rivers. Deforestation or dam flushing operations are two examples of human activities that affect the sediment dynamics in a mountain catchment. Fine sediments travelling downstream can be deposited on the river bed or infiltrated within it. The infiltration alters dramatically the river habitat by reducing the permeability of the river bed and the oxygen and nutrient exchange at the flow-sediment interface, affecting specifically fish spawning and invertebrate species that inhabit the river bed (Wood and Armitage, 1997). Understanding the dynamics of fine sediment infiltration and the anthropogenic influence on it, is therefore important to minimize the impact of human activities on environment.

Previous studies highlight the influence on fine sediment infiltration of different variables such as fine sediment cohesion (Packman and MacKay, 2003), flow velocity (Cunningham *et al.*, 1987), bed shear stress (Diplas and Parker, 1992), suspended sediment concentration (Khullar *et al.*, 2013), interstitial hydraulic gradient (Schälchli, 1992), the presence of a biofilm (Arnon *et al.*, 2010), bed topography, i.e. occurrence and size of bed forms (Karwan and Saiers, 2012), and the size ratio between the coarse bed sediment and the incoming fine particles (Gibson *et al.*, 2009). Whereas many analyses describe the final equilibrium situation resulting from different flow and sediment conditions, less information is available about the time evolution of the process. Moreover, little work has been carried out concerning gravel and silt interaction, despite being a common situation found in mountain environments. The aim of the present study is to provide useful data to partially fill this gap.

Experimental setup

A series of experiments was performed in the tilting flume of the hydraulics laboratory at Irstea-Lyon (France). This new facility is 18m long and 1m wide and the slope can be varied from 0 to 5 percent. Before each test a 6cm-deep bed formed by clean gravel (5 to 12mm) was installed carefully in such a way that the bed slope coincided with that of the channel. Six cylinders made of a metallic grid with a hole size of 1mm were installed within the bed at three different longitudinal positions ($x = 6, 9$ and 12 m) in order to take samples of the bed and measure fine sediment content at different depths. The grid size was chosen so that it retains coarse particles and affects as less as possible the interstitial flow and the fine sediment particles in suspension. Three of the cylinders (one at each longitudinal position) were extracted after 8 hours of experiment whereas the other three were removed at the end of the test.

Water flow with a specified discharge was recirculated along the channel and through a 30m^3 reservoir. Silt size was added and mixed in this chamber to obtain a homogeneous suspended sediment concentration in the flow. As sediment-laden flow recirculates along the flume, part of the fine sediment infiltrates into the bed and suspended sediment concentration decreases. In order to keep an approximately constant concentration, bags of fine sediment were added at the reservoir at the required moment. This operation is based on suspended sediment concentration measurements carried out by two turbidimeters (Hach-Lange, Solitax 0–50 g/L) installed at the upstream and the downstream ends of the channel (Fig. 1). Water samples are taken periodically in order to further control sediment concentration and to calibrate the turbidimeters. Flow velocities are measured at $x = 8$ m and at the centre line of the channel using an ADV profiler (Nortek, Vectrino II). Water depth is registered at three different longitudinal positions ($x = 3$ m, $x = 8$ m and $x = 15$ m) by means of ultrasonic sensors. The sediment-laden flow is recirculated until the system reaches an equilibrium with no further fine sediment infiltration.

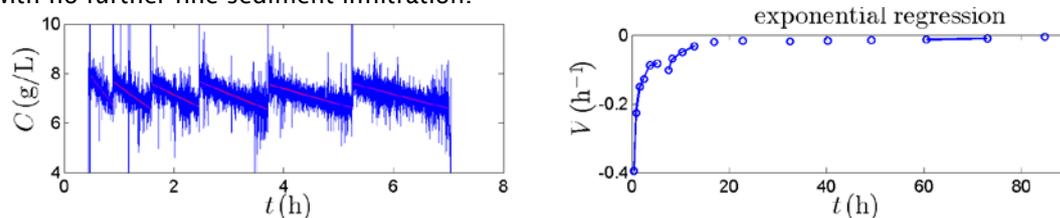


Fig. 2. Time evolution of sediment concentration (left). Infiltration rates are calculated from the time constant of an exponential fitting over each cycle and are plotted versus time (right).

Results

As soon as water and suspended sediment enter into the bed, fine particles start to deposit on the top of the gravel grains generating triangular deposits with a slope equal to the friction angle of the material. Simultaneously, fine sediment accumulates at the impermeable channel base and fills the bed from the bottom upwards. The concentration evolution in time allows evaluating the evolution of fine sediment infiltration rate by fitting each of the cycles separated by the addition of one sediment bag with an exponential curve. Fig. 1 shows how infiltration rate decreases during the experiment. It can be interpreted as the negative correlation of water mass exchange with bed depth (Grant *et al.*, 2012). As fine sediment accumulates at the channel base and develops an almost impermeable layer, the effective bed depth along which water mass exchange takes place decreases and so does the amount of fine sediment that access to and is retained within the bed. The bed evolves to a final state in which almost the whole depth is clogged with fine sediment.

Fig. 2 shows the depth profiles of fine sediment content after eight hours of experiment and at the end of it, for the different tests (Table I). The upwards filling trend can be observed in this comparison. On the other hand, there is a surface bed layer that remains free of sediment.

Fig. 3 shows the final state of tests 1 and 2 highlighting a difference in the thickness of this surface clean layer. The increase of the bed slope causes an augmentation of shear stress and turbulence transfer to the pore spaces close to the bed surface that prevent the deposition of fine particles.

Table I. Variable values for the two laboratory tests

Code	Concentration (g/l)	Slope	Discharge (l/s)
T1	4.0	1	30
T2	4.0	0.1	30



Fig. 4. Side view of the bed at the final state for Test 1 (top) and Test 2 (bottom).

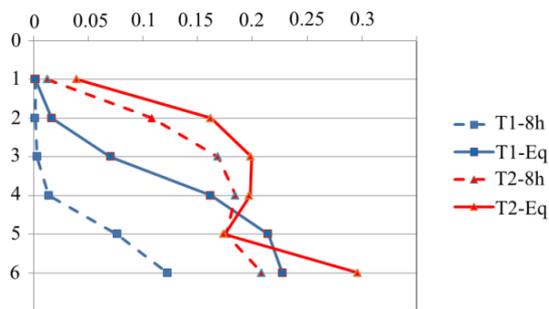


Fig. 3. Fine sediment content profiles after 8h of experiment (dashed lines) and at the equilibrium state (solid lines).

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