Dynamics of Turbulent Sediment Transport: Experiments and Modeling

E. Lajeunesse, L. Malverti and F. Charru

1. Laboratoire de Dynamique des Fluides Geologiques, Institut de Physique du Globe de Paris, France
2. Institut de Mechanique des Fluides de Toulouse, UMR 5502, Toulouse, France

Abstract
Almost all bedload transport laws proposed in the literature consider implicitly that the sediment flux is a local function of the shear stress [Garcia, 2006 and references therein]. They consequently ignore any relaxation effect, although the latter is recognized to control the development of bedforms. To account for this relaxation effect, Charru [2006] proposed a theoretical erosion-deposition model of bedload transport. In this paper we report the results of an experimental investigation aimed at testing the prediction of this model. We study the motion of bedload particles in the case of a steady and uniform turbulent flow above a flat bed sediment bed of uniform grain size. Using a high-speed video imaging system, we visualize the trajectories of the entrained grains and measure the particles velocities, the length and duration of their flights and the density of moving particles. As far as we know, this study is the first one to present measurements of all these quantities in the same experimental conditions.

Our observations show that the particles entrained by the flow exhibit intermittent trajectories composed of the succession of periods of motion, hereafter called "flights," and periods of rest. During the same flight, a particle may go through phases of rolling, during which it moves in nearly perpendicular contact with the rough bed, and phases of saltation, during which it travels sufficiently high above the bed to reach high velocities. The experimental results support the erosion-deposition model of Charru [2006] and allow us to calibrate the values of the different coefficients of the model. The results presented in this paper provide a valuable physical framework to describe bedforms development in turbulent flows.

* An erosion-deposition model for bedload transport

- The sediment flux reads:
  - The sediment flux reads:
  - The number of moving particles per unit bed area is related to exchanges with the fixed bed, through the erosion rate \( \dot{\rho}_e \) and the deposition rate \( \dot{\rho}_d \), and to the divergence of the bedload flux.
  - Bedforms develop on timescales much larger than the characteristic scale of sediment transport so that this latter is commonly assumed to adapt instantaneously to the bed topology. In this case of steady sediment transport over a varying topography, mass conservation reduces to

\[
\dot{\ell}_d \frac{\partial \rho_{sat}}{\partial x_d} = \dot{\rho}_{sat} + \dot{\rho}_d
\]

- Physical and dimensional resoning leads to:
  - The saturated sediment flux above a flat topography:

\[
\dot{\rho}_{sat} = \frac{\dot{\rho}_e \sigma V}{1 + \frac{\dot{\rho}_e \sigma V}{\dot{\rho}_d}} \quad \text{with} \quad \frac{\dot{\rho}_e \sigma V}{\dot{\rho}_d}
\]

- As predicted by dimensional analysis, the average flight duration scales as the time necessary to settle from a height of the order of a few grains:

\[
\tau = \frac{\sigma V}{\dot{\rho}_e \sigma V} = \frac{\sigma V}{1 + \frac{\dot{\rho}_e \sigma V}{\dot{\rho}_d}}
\]

**Conclusion**
- Our experiments provide a unique set of consistent data (surface density of entrained particles, flight length and duration, velocity distributions, sediment flux...) that can be used by the community to test bedload transport models.
- They allow us to validate and calibrate an erosion-deposition model which naturally accounts for the relaxation effect which controls the development of bedforms.
- The next steps are:
  - 1. to test experimentally the model predictions against bedforms development in turbulent flows,
  - 2. to incorporate the effect of a more complex granulometric composition of the bed in the erosion-deposition model.

**References**
- Charru, F., Collection of the ripple length on a granular bed sheared by a liquid flow. Phys. Fluids, 18, 121, 2006