Rheology and local study of a transparent model cohesive sediment

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A transparent model sediment with the same rheological properties than a natural one is used to study erosion in a narrow channel or a flume. Optical measurements allow accessing to local velocity fields within water and transparent sediment simultaneously.

Introduction
A cohesive sediment is a complex material of inorganic mineral, organic material and biological functions lead to viscoplastic and thixotropic characteristics (Toorman, 1997). To characterize their erosion two parameters are to be identified: bed shear stress from hydrodynamic forces and erosion rate from suspended sediment concentration. In a macroscopic framework, previous experimental studies on erosion have already defined different thresholds sediment behaviour (Van Rijn, 1993; Jacobs *et al.*, 2011). This study is based on the development of transparent model cohesive sediment to allow optical measurements and lead to local kinematic information during erosion tests. First, the transparent cohesive sediment is elaborated with similar rheological properties than a natural one (Pouv *et al.*, 2014). Secondly, erosion tests are carried out of the flume using particle image velocimetry (PIV) both to lead to, in the same time, the water velocity field and the displacements of the transparent sediment.

Material development
The transparent model cohesive sediment is prepared with classical modifier agent of viscosity: synthetic clay, laponite RD (Rockwood), and polymer, carboxymethylcellulose (Prolabo). Laponite leads to thixotropic properties and carboxymethylcellulose (CMC) enhances viscoplastic effects of the mixture.

CMC solution is prepared first with powder sprinkle in deionized water in 0.5% mass concentration. The solution is stirred at 600rpm with a magnetic agitator for 1 hour. In the same time, Laponite suspension with 1% mass concentration is prepared sprinkling laponite powder in deionized water. The suspension is then mixed during 15 minutes at 11000rpm with a homogenizer Ultraturax T25 (IKA). Finally the laponite suspension is added to the CMC solution for 1 hour mixing at 1100rpm with the magnetic agitator. The transparent sediment has a density close to $1kg.m^{-3}$.

Rheological measurements
The rheological characterisation of the transparent sediment is carried out with a HR-2 rheometer (TA Instruments) using plate-plate geometry of 4cm diameter. Both surfaces are covered with sand paper with a mean roughness of 58.5µm to prevent slippage effects. Each measurement is realised for a 300µm gap. Before flow curve measurements and to ensure a reproducible proceeding a pre-shear is applied with a shear rate of $10s^{-1}$ during 120s following by a 600s rest period. Then shear rate steps ranging from 10^{-3} to $10^{3}s^{-1}$ are applied in a logarithmic repartition to obtain up and down curves. Each curve is corrected using Rabinowicz formula to minimize existing error on the estimation of shear rate by using plate-plate geometry.

Rheological properties of the transparent sediment evolve with time but reach to a stable state after 20 days. It has been confirmed by following rheological properties of the sediment throughout 35 days.

To study the relation between rheological properties and concentration, a range up from 20% to 70% (mass concentration) was done from the transparent sediment which has a solid fraction of 10g/l. Hereafter solid part is representing by CMC and laponite particles.

The down curves of each obtained rheogram follow a Herschel-Bulkley model:

$$\begin{cases} \tau = \tau_s + k\dot{\gamma}^n & \text{for } \tau \geq \tau_s \\ \dot{\gamma} = 0 & \text{for } \tau < \tau_s \end{cases} \quad (1)$$

Where τ is the shear stress, $\dot{\gamma}$ the shear rate, τ_s the yield stress, k the consistency and n the viscosity index.

Flow curves are well classified as a function of the concentration (Fig. 1a): lowest concentration leads to a small yield stress, weak consistency and viscosity index tending to 1. Evolution of the yield stress as a function of solid fraction can be fitted with a power law model (Migniot, 1989; Berlamont *et al.*, 1993) (Fig. 1b).

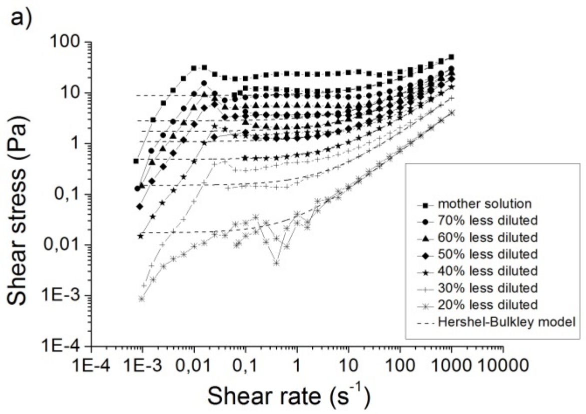

Fig. 1a. Rheogram of transparent sediment and their diluted concentrations fitted with Herschel-Bulkley model.

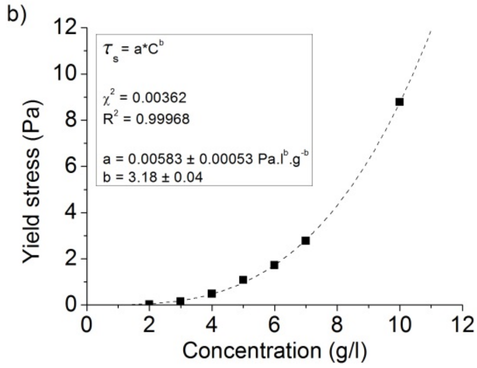

Fig. 1b. Yield stress from Hershel-Bulkley model as a function of concentration.

Flume measurements

Experiments are realised in a transparent PMMA flume with a square section (160mmx160mm). The channel is close to obtain bounded flow which is easier to control and prevent from the gravity effect. Hydraulic pumps allow to apply an average velocity up to 5cm.s^{-1}. Particle image velocimetry (PIV) measurements are obtained from a Yag laser and CCD cameras devices. Two different lighting seeds are used in order to distinguish water velocity fields (standard seeds) and transparent sediment (fluorescent seeds).

First, channel measurements are realised only with water to obtain hydrodynamic conditions in the reference simplest case (no sediment). Then, the visualized channel background is replaced with the transparent sediment which has almost the same refractive index than the water. Comparisons between flow fields obtained with these two configurations can be conducted.

Conclusion

A transparent model sediment with the same rheological properties as a natural one is used to study erosion in a flume. Optical measurements allow to access to local velocity fields within water and transparent sediment simultaneously. The kinematic evolutions of the two fluids are distinguished using two different lighting seeds. This work is the first step of a kinematic and dynamic study to understand local phenomena operating during erosion processes. A next step will be to add concentration measurements in the same time as PIV. Combined with the rheological data, the final goal of this new study is to rebuild the local shear stress field during erosion experiments.

References

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