EXPERIMENTAL STUDY OF SEDIMENT TRANSPORT PROCESSES IN ENERGETIC SEDIMENT-LADEN OPEN-CHANNEL FLOWS

Étude expérimentale des processus de transport des sédiments dans les écoulements énergétiques chargés de sédiments

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Abstract

A process-based analysis of a new experimental dataset is carried out based on co-located 2C velocity, sediment concentration and sediment flux profile measurements obtained with an Acoustic Concentration and Velocity Profiler (Hurther et al. 2011). The experiments were carried out in energetic open-channel flows using the LEGI tilting flume, PMMA particles (ρ_p=1192 kg/m^3) of two diameters, dp=3mm and dp=1mm, covering a wide range of suspension numbers (given as the ratio between settling velocity w_s and friction velocity u_*) $0.4<w_s/u_*<1.3$ and Shields numbers $0.35<\theta<1.2$. Four sediment-load conditions are studied for a given hydraulic flow varying from clear water, 2 non-capacity to the full transport capacity conditions. Three hydraulic flow conditions are investigated for each particle diameter. All sediment-laden runs have one clear-water run as reference, acquired before each sediment-laden run. This allows the analysis of the particle effects on a wide variety of hydrodynamic quantities.

First, the ACVP measurement principles will be explained as well as the calibration methodology for the concentration inversion based on the controlled injected sediment loads. In addition, the techniques adopted to estimate different turbulence quantities will be presented. An overview of the measured hydrodynamic and solid-transport quantities will be presented.

Secondly, parametrizations for improved description of the solid-load as result of the product of velocity and concentration are discussed. The results indicate that at high sediment concentration, the velocity profile may not be strictly logarithmic, such that the adopted κ values represent a global trend, rather than the local flow feature. A parametrization of the depth-averaged ratio of sediment and momentum diffusivity, the β-factor (inverse of Schmidt number), based on the present experimental results is proposed, allowing to extend literature models to a wider range of suspension numbers ($0.4<w_s/u_*<1.5$). The bulk flow resistance, parametrized by the friction factor does not display discernible differences from the reference clear-water flows, indicating a negligible effect of sediment motion, in the upper plane bed regime. With the larger particle experiments (dp=3mm), it is shown that inside the bed-load layer, turbulent momentum mixing is highly reduced, compared to the corresponding clear-water flow. This change in flow structure should be taken into account in the turbulent mixing length model, affecting both the law of the wall and the Rouse formulation. As result, a modified analytical solution that includes the bed-load effects for the concentration profile was derived.

Further investigations show that the turbulent kinetic energy (TKE) balance is also heavily affected by the presence of a thick bed-load layer. A strong signature in these experiments is that the peak of turbulence production seems to occur around the edge of the bedload layer. This vertical upshift of the production region leads to an increased diffusion of TKE towards the bed. This may be the mechanism by which turbulent energy is transferred to the particles inside the bed-load layer. Regarding the parametrizations, it is shown that the closure coefficients of two-equations models such as $k-\varepsilon$ (or $k-\omega$) can be evaluated from the present TKE budget measurements. Furthermore, a potential parametrization of the solid flux based on the depth-integrated terms from the TKE budget is also briefly discussed.

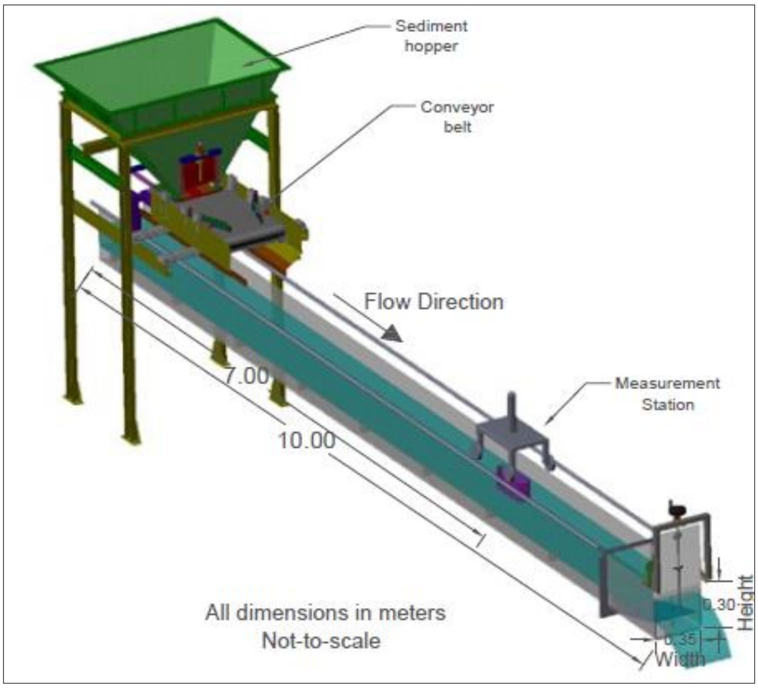

Figure 1. Sketch of experimental set up

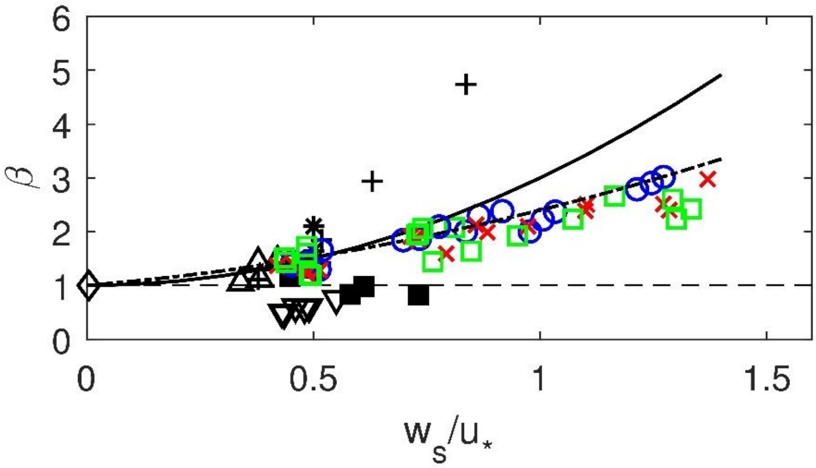

Figure 2. Values of depth averaged ratio of sediment and momentum diffusivity β as function of ws/u; For present results with different concentrations : (o) Full capacity, (x) Intermediate concentration and (□) Lower concentration; (-) Eq. from [2]; (-.-) Eq. from [1]; Other data from literature : (Δ) Barton and Li (1955), (+) Coleman (1970), (■) Lyn 1988, (▽) Graf and Cellino (2002), (◇) Nikora and Goring (2002), (*) Muste et al. (2005). Adapted from Lyn (2008).*

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