Exploratory study of Flow-Particle interaction using Particle Image Velocimetry (PIV)

Françoise Bigillon[1] and Marcelo Garcia[1]

[1]Ven.Te Chow Hydrosystems Laboratory, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign,
205 N. Mathews Avenue, IL 61801; emails: bigillon@uiuc.edu and mhgarcia@uiuc.edu

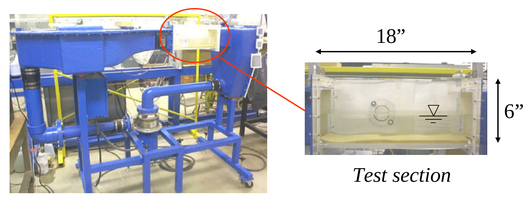
Abstract

An exploratory study of flow-particle interaction in a small water tunnel has been performed using flow visualization. Images are recorded following the Particle Image Velocimetry technique. The frames are analyzed in order to get information on flow turbulence and particles carried by the flow. The turbulence of the flow is considered in terms of the coherent structures that develop essentially in the wall region. The methods investigated allow the detection and quantitative description of these structures. Concerning the solid phase, two kinds of methods were considered: one to locate particles on the frames, and the other to track the particles. The methods are tested with simple experiments performed in a small water tunnel. Results concerning the fluid and solid phases are analyzed together. They show two kinds of particle behavior: particles that travel following coherent structures and particles that do not follow any particular turbulent structure.

Experimental facilities

The small water tunnel

Experiments were conducted in a small recirculating water tunnel. The dimension of the test section are 6" wide by 6" high and 18" long. The test section was operating with a free surface.

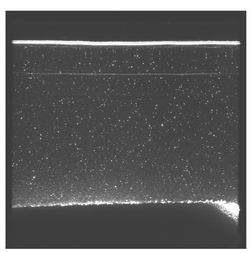


Small water tunnel

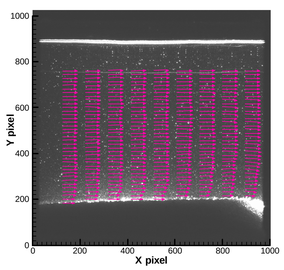
Test section

PIV technique

In PIV experiments, particles are illuminated by a laser sheet. A camera records the positions of these particles at different times. Then, by measuring the particle displacements, the motion of the fluid (i.e. velocity field) can be ascertained. Also, from the same frames the solid-phase can be characterized. The PIV system used in these experiments is: a YAG laser, a 10-30 cross correlation camera manufactured by TSI. The rate of the camera is 15 pairs of frames per second.



Frame 129a



Frame 129b

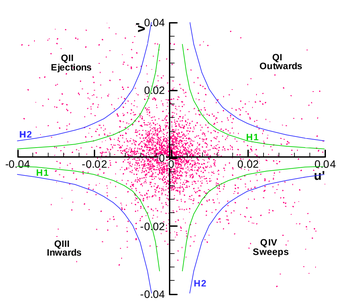
Image analysis

A velocity field is deduced from each pair of frames using a 2D cross correlation algorithm provided by the Insight TSI software. Turbulence characteristics are then deduced from the flow field. Particle characterization is performed by using the first frame of every pair with the help of WIMA software (ST Etienne, France).

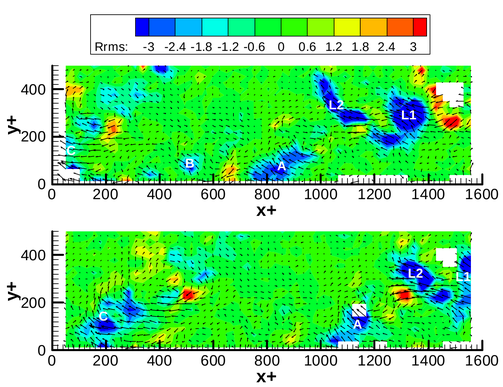
Detection of coherent structures

Events are detecting and sorting using the quadrant method with a threshold H and a detection function S_Q. A sequence of R_{rms} contour plots superimposed on the fluctuation velocity vector fields are generated and analyzed. For an ejection, the detection function takes the form:

$$S_Q(H) = \begin{cases} 1 \text{ if } \; u' < 0, v' > 0 \text{ and } |R_{rms}| > H \\ 0 \text{ otherwise} \end{cases} \quad \text{with } R_{rms} = \frac{u'v'}{u_{rms} v_{rms}}$$



Quadrant analysis using a threshold H



Exp rough03r - Frame 65 and 66

Detection of sediment particles

Frames, where only the sediment particles appear, are examined to provide the position and the size of each particle for each frame.

The tracking of the particle is difficult due to the limitation of the time resolution of the camera. The displacement of a particle is too large to be able to follow it from one frame to another.

Application of the methods to correlate turbulent events and particle behavior

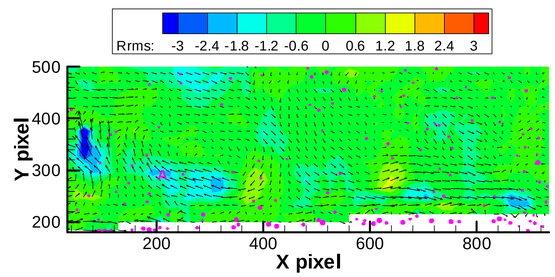
Experimental conditions

Experiments were performed in a small water tunnel using 0.5-mm diameter sand and 50-µm diameter seeding particle. A 1-cm layer of sand covered the bottom. On each frame, sediment particles were differentiated from seeding particle using WIMA by filtering objects with perimeter less that 10 pixels.

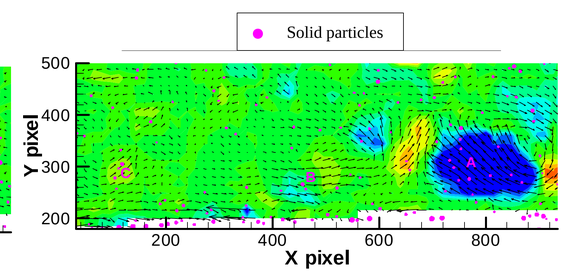
Preliminary results

Results were obtained by analyzing R_{rms} contour plots superimposed on the fluctuation velocity vectors and particle position to observe potential correlations.

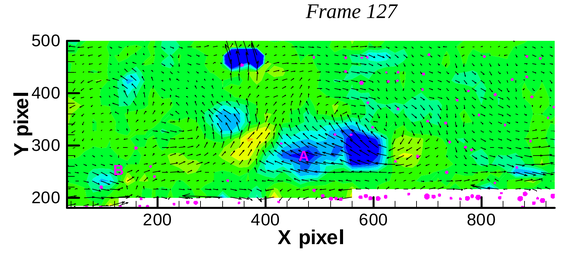
Some groups of particles seem to be correlated with structures. For instance, the group of particles labeled A is clearly associated with an ejection. Other particles can not be related to any particular structures.



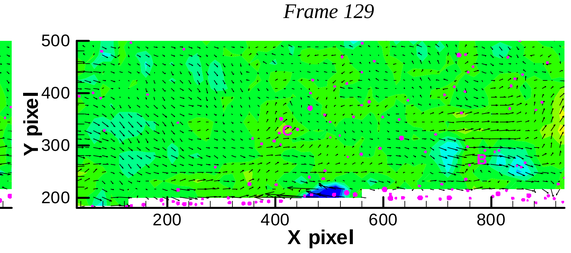
Frame 127



Frame 129



Frame 128



Frame 130

Conclusions

Interaction between coherent structures and sediment particles has been investigated using PIV. Tools to detect and characterize turbulent events, and to provide position and size of sand particles were tested during this exploratory study. More research is necessary to understand how a given particle responds to organized turbulent events. This is part of an ongoing research effort to characterize fluid-sediment interaction in unidirectional and oscillatory flows.

Acknowledgment

This research was supported by the Marine Geophysics Program of the US. Office of Naval Research.