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EXPERIMENTAL MEASUREMENTS OF SOLUTE TRANSPORT AND FLOW VELOCITY IN A LABORATORY CHANNEL

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ABSTRACT

A set of experiments intended to measure velocity and concentration of a passive tracer (fluorescein) by means of optical techniques in a straight laboratory channel are reported. The objective was to obtain experimental data to calibrate solute transport in free surface simulation models.

As the numerical simulation to be calibrated is based on the 2D shallow-water equations, the experimental set up was accordingly prepared so that the fluorescein solution is released in the flow in a vertical-homogeneous way. Two types of experiments have been developed. One of them is the situation of a lateral dam-break in the channel. The flow in the main channel is uniform until the gate is opened and the solution is released into the stream. The other type of experiment consists of using a vertical cylinder, provided with two opposite vertical slots, located in the centre of the channel and full of solution that can be suddenly released into the stream by means of a quick rotation in the cylinder.

Velocity measurements have been carried out with a standard PIV (Particle Image Velocimetry) technique and the solute-concentration has been characterised by PLIF (Planar Laser Induced Fluorescence), measuring the fluorescence of solute when exposed to blue light.

Measurements and results are presented and discussed in this paper.

Keywords: Laboratory Channel. Lateral Dam Break. PLIF. PIV. Shallow Water. Numerical Calibration.

1. INTRODUCTION

The objective of the experiments was to obtain experimental data to calibrate the dispersion source term ($\vec{\nabla}\cdot\left(h\mathbf{K}\vec{\nabla}\phi\right)$) of the solute transport equation in free surface simulation models based in the shallow water equations.

$$\partial_t \mathbf{U} + \partial_x \mathbf{F(U)} + \partial_y \mathbf{G(U)} = \mathbf{S}(x, y, \mathbf{U}) \qquad (1)$$

where,

$$\mathbf{U}=\begin{pmatrix} h \\ q_x \\ q_y \\ h\phi \end{pmatrix},\qquad \mathbf{F}=\begin{pmatrix} q_x \\ \frac{q_x^2}{h}+\frac{gh^2}{2} \\ \frac{q_x q_y}{h} \\ q_x\phi \end{pmatrix},\qquad \mathbf{G}=\begin{pmatrix} q_y \\ \frac{q_x q_y}{h} \\ \frac{q_y^2}{h}+\frac{gh^2}{2} \\ q_y\phi \end{pmatrix},\qquad \mathbf{S}=\begin{pmatrix} 0 \\ gh\left(S_{ox}-S_{fx}\right) \\ gh\left(S_{oy}-S_{fy}\right) \\ \vec{\nabla}\cdot\left(h\mathbf{K}\vec{\nabla}\phi\right) \end{pmatrix}$$

h represents the water depth, $\boldsymbol{q} = \left(q_x, q_y\right) = h(u,v)$ is the unitary discharge vector, ϕ the averaged solute concentration and g is the gravity acceleration. The source term vector is formed by the slope terms, the friction losses, (in our model expressed in terms of the Manning coefficient, and the diffusion source term, where $\mathbf{K}$ is an experimental matrix that takes into account the diffusion due to averaged convection and the turbulent diffusion (Rowinsky and Kalinowska 2006).

For this purpose we took some measurements in a laboratory channel. Those measurements included detailed solute concentration and velocity ones as to some punctual measurements of the module of velocity and water depth. The first ones were taken to calibrate the numerical model in terms of the velocity and water depth predictions for this special case. As the numerical model has been calibrated during the last years in a wide range of real and academic cases giving an efficient result, the simulations carried out in comparison with the experimental water depth and module of velocity data were as good as they were expected.

The numerical scheme is based in the 2D transient shallow water equations on unstructured meshes solved with an explicit finite differences upwind scheme able to solve the advance over dry bed (Murillo et al 2006).

As the numerical simulation to be calibrated is based on the shallow-water equations, the experimental set up was accordingly prepared so that the solute is released in the flow in a vertical-homogeneous way. Two types of experiments have been developed. One of them is the location of a lateral dam-break in the channel. The flow in the main channel is uniform until the gate is opened and the solute is released into the stream. The other type of experiment consists of using a vertical cylinder, provided with two opposite vertical slots, located in the centre of the channel and full of solute that can be suddenly released into the stream by means of a quick rotation in the cylinder.

Velocity measurements have been carried out with a standard PIV (Particle Image Velocimetry) technique and the solute-concentration has been characterised by PLIF (Planar Laser Induced Fluorescence), measuring the fluorescence of solute when exposed to Ar^+.

2. EXPERIMENT SET UP

The experimental channel is 6 m long and 24 cm wide and the discharge at the entrance is regulated by means of a centrifugal bomb and an electro-magnetic flow meter.

An Ar^+ laser and a PIVCAM 10/30 are used for both measurement systems which have been synchronised through a PIC 18F2550 microcontroller - based electrical assembly. In the case of velocity measurements, a Bragg cell is used as beam modulator, necessary to control the illumination intervals, and Polyamide spherical particles (60 μm of diameter and a relative density of 1.03) are used as tracers.

The two injection systems are based in their fast opening devices. In the case of the Lateral Dam Break system it has been used a pneumatic cylinder to lift the gate and the movement velocity of the system has been obtained by means of a CMOS *Redlake Motion*

Pro SI-4 fast camera reaching the conclusion that the gate was totally open in 12 ms. In the case of the cylindrical dam break the sudden opening was provided by means of a long stick levered by human force but as the slots are small (Fig. 1.) the opening time was less than 10 ms and the reproducibility of the movement was considered high enough. In both cases when the gates are opened there was an electrical signal to communicate it to the microcontroller.

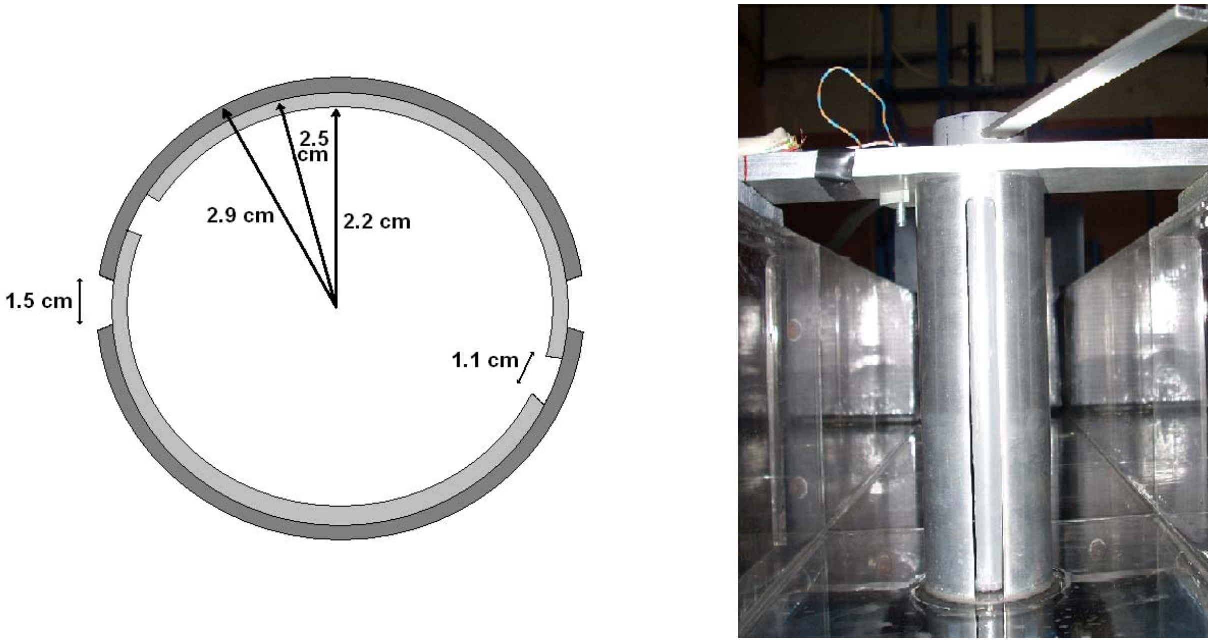

Figure 1: Left: Injection cylinder horizontal cut scheme. Right: Injection Cilynder.

2.1 Concentration measurements set up

In the case of fluorescence, where the photographs of the cross sections have been taken with the optical axis not normal to the illuminated plane (Fig. 2.), the images have been post-processed pixel by pixel to correct the perspective effects, a rectangular mesh placed at the illuminated plane is used as reference, so the own method do not need knowledge of distances and angles between object and image planes. As it has been tested the linearity of the relation between concentration and fluorescence in the limits of detection and the vertical absorption has been demonstrated to be neglectful for the used concentrations, the conversion light detected – concentration its carried out pixel by pixel by adjustment to a linear calibration taken out from the measurement of two dilutions with known concentration placed in the same section and with the same conditions as the rest of the experiments.

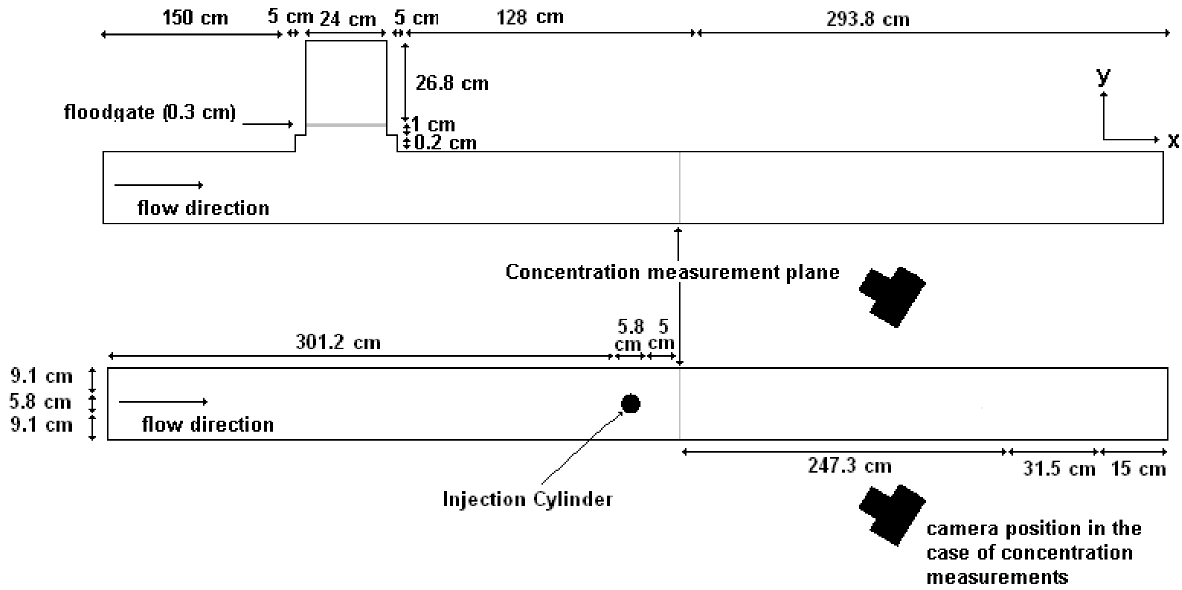

Figure 2: Up: Lateral dam-break concentration measurements set up scheme. Down: Cylindrical dam-break concentration measurements set up scheme.

2.2 Velocity measurements set up

In the case of velocity measurements the camera was located downside the channel and the laser plane was parallel to the channel floor. In these conditions and with our system we were not able to focus the entire plane but a 14x14 cm zone in the middle of the channel cross section at 12 mm over the channel bed.

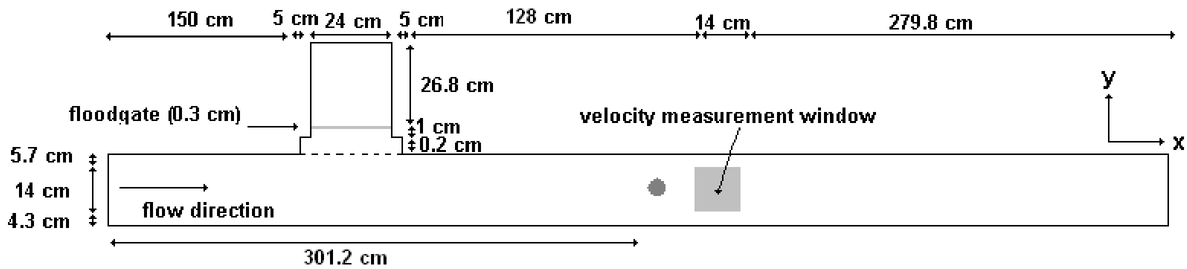

Figure 3: Velocity measurements set up scheme.

3. RESULTS

In these conditions there have been taken several measurements of velocity and concentration in the case of the dam-break experiment with different concentrations and water depths contained in the lateral tank and the same has been done in the case of the sudden opening of the cylinder slots.

The calibration solutions used for both the cylindrical and the lateral dam break cases were 0.2 mg/l and 0.3 mg/l of fluorescein in water. They were placed in the control section by placing two locks after and before the cross section and then they were photographed in the same conditions as the measurements were taken. Then, as it has been tested a linear response of the fluorescence to the concentration in the limits of measurement we can make a pixel by pixel calibration of the light detected in function of the concentration in that point. The laser light power was set at 1W but for the modulated beam was 600 mW. In this conditions there were taken 10 photos /second in both velocity and concentration cases.

As an example there are presented the velocity measurements corresponding to a lateral dam break containing 5.18 dm^3 (water depth inside the lateral reservoir before the opening = 9 cm) when there were 8.6 m^3/hr circulating along the channel (Fig. 4.), and the velocity measurements corresponding to a cylindrical dam break containing 5.18 dm^3 (water depth inside the lateral reservoir before the opening = 9 cm) when there were 8.6 m^3/hr circulating along the channel (Fig. 4.)

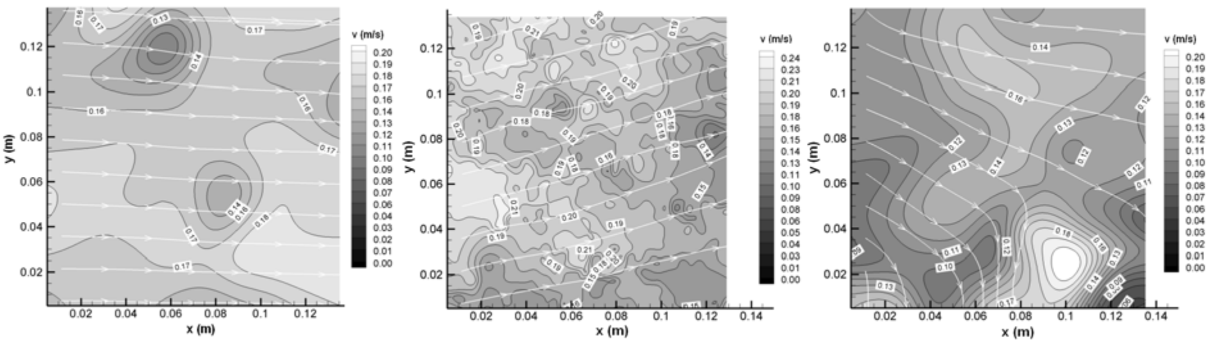

Figure 4: Lateral dam-break flow velocity measurement example (module of the velocity (m/s) and flow lines). Left, steady state before the opening. Center, 1.8 seconds after the opening. Right, 4.5 seconds after the opening.

In figure 4 can be seen the evolution of velocity with time. In the left figure flow lines are parallel as the flood has not reached the measurement window yet. In the right and middle figures it is shown how the velocity changes from right to left as the dam break effect affect the measurement window. After one minute from the opening the system has recovered it's stationary state and no fluctuations in the velocity are detected.

As an example of concentration measurements we present two results. The first example corresponds to a lateral dam break containing 1.785 dm^3 of a solution with concentration 6.66 mg/l (solution depth inside the lateral reservoir before the opening = 3.1 cm) when there were 8.6 m^3/hr circulating along the channel (Fig. 5.)

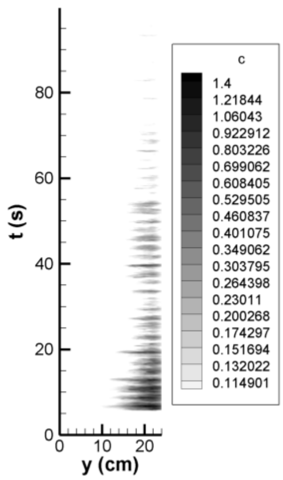

Figure 5: Lateral dam-break vertical-averaged solute concentration (mg/l) measured in the control section as a function of time.

The second example correspond to the concentration measurements in the case of the cylindrical dam break when the cylinder contained 150.0 cm^3 of a fluorescein solution of concentration 2.7 mg/l (Fig. 6.) and there were 4.26 m^3/hr circulating along the channel. There are not presented the velocity measurements taken from the cylindrical dam break experiment because the synchroniser system used only allow the possibility of taking autocorrelation measurements and, in the case of the cylinder there are vortex that make impossible to the autocorrelation algorithms to obtain the velocity vector from the taken images.

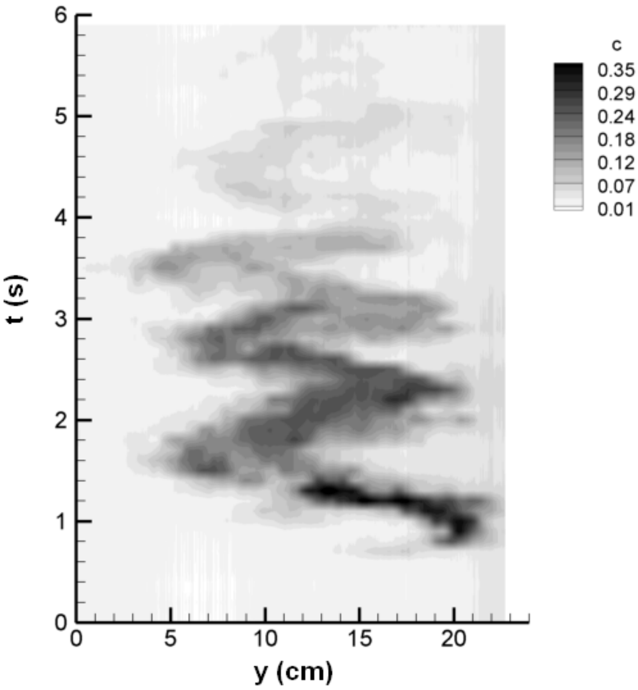

Figure 6: Sudden opening of the cylinder slots. Left: vertical-averaged solute concentration (mg/l) measured in the control section as a function of time. Right: Left: solute concentration (mg/l) measured in the control section y=15 cm coordinate as a function of time and z.

4. DISCUSSION

The cylindrical dam break concentration measurements taken are useful to check the model results obtained with the **K** values obtained from the lateral dam break analysis.

As a future work there should be improved the velocity measurements in the case of the cylindrical dam break in order to them to be useful in the calibration of the dispersion source term. For this purpose it is only necessary to change the synchroniser system or the laser source. But it is not necessary to do these changes to make the calibration with the measurements taken in the case of the lateral dam break as there are not vortexes that make difficult the autocorrelation treatment.

REFERENCES

Adrian RJ (1991) Particle-imaging techniques for experimental fluid mechanics. *Ann Rev Fluid Mech* 23: 261,304

T.F. Ayinde (2008) Experimental investigation of turbulent natural convection flow in a converging channel *Experimental Thermal and Fluid Science* 32 1204–1212

Murillo J., García-Navarro P., Burguete J., Brufau P. (2006) A conservative 2d model of inundation flow with solute transport over dry bed. *International Journal for Numerical*

Methods in Fluids. Published online in www.interscience.wiley.com.
P.M. Rowinsky and M.B. Kalinowska (2006) Admissible and inadmissible simplifications of pollution transport equations, in *River Flow 2006*, edited by Ferreia, Alves, Leal and Cardoso Eds.
C. Wagner, S. Kuhn, P. R. van Rohr (2006) Scalar transport from a point source in flows over wavy walls. *13th Int. Symp on Appl. Laser Techniques to Fluid Mechanics, Lisbon, Portugal, June 26 – 29, 2006*