A simple technique to measuring surface flow velocity to analyze the behavior of fields velocities in hydraulics engineer applications.

Jackson Tellez (1), Manuel Gómez (1), Beniamino Russo (2), José Manuel Redondo (3).

(1) FLUMEN Research Institute, Hydraulic, Maritime and Environmental Engineering Dept., UPC Barcelona Tech., 1-3 Jordi Girona St., Barcelona 08034 Spain.
(2) Civil Engineering Dept., Technical College of La Almunia (University of Zaragoza), Mayor St., La Almunia de Doña Godina 50100, Zaragoza, Spain.
(3) Applied Physics Dept., UPC Barcelona Tech. 1-3 Jordi Girona St., Barcelona 08034, Spain.

Abstract

An important achievement is the invention and development of techniques for measurement of velocities in hydraulic engineering applications. Knowledge of the technological advances in digital cameras with high resolution and high speed are extremely useful to measure relevant predictive parameters in the environment. Here we present some advances in image processing techniques, these can be used in hydraulic hazard predictions therefore, providing a tremendous potential to measure the behavior of the water surface flow.

This technique was performed at the Laboratory of Hydraulics Department of Hydraulic, Maritime and Environmental Universidad Polytechnic de Catalonia, (UPC Barcelona Tech) where we used a water flow platform with dimensions of 5.5 m long and 4 m wide allowing a zone of useful measurements of 5.5m x 3m, where the width is similar of a typical urban road. The platform allows to modify the slopes longitudinal at angles between 0% and 10% and transversal slopes of between 0% and 4%. And there is also the possibility of a range of flows. In the experiments discussed here we used flow rates up to 200 l/s [1].

In addition, a camera high resolution 1280 x 1024 pixels with maximum speed of 488 frames per second. A novel technique using particle image velocimetry to measure surface flow velocities has been developed and validated with the experiments assays with the grate inlets. In this case, the Methodology carried out can become a useful tools to understand the hydraulics behavior of the flow approaching the inlet where the traditional measuring equipment have serious problems and limitations.
Introduction

An important achievement in hydraulic engineering is the proposal and development of new techniques for the measurement of field velocities in hydraulic problems. The technological advances in digital cameras with high resolution and high speed found in the market, and the advances in digital image processing techniques, now have an enormous potential to measure and study the behavior of the water surface flows.[1,4]

Methodology to estimate the velocity field in 2D

This technique was applied at the Laboratory of Hydraulics of the Technical University of Catalonia – Barcelona Tech to study the 2D velocity fields in the neighborhood of a grate inlet. The experimental campaign to test grated inlets capacity was carried out on a platform simulating a road lane with dimensions of 5.5 m long and 3 m wide. The platform allows to modify the longitudinal slope from 0% to 10% and transversal slope from 0% to 4%. Flow rates can reach the maximum value of 200 l/s. In addition a high resolution camera with 1280 x 1024 pixels and maximum speed of 488 frames per second was used (Figure1).

![Figure1: UPC Flow Platform.](image)

The prototype Barcelona1 (Figure2) was the grate tested in the mentioned platform. This grate is the most common in the city of Barcelona. The test protocol considered different circulating flows, varying both the longitudinal and transversal slope for each circulating flow. [2,3]
For each geometric configuration and each circulating flow, the flow captured by the grate was calculated using the advanced surface PIV method. Moreover, flow depth was measured in each condition estimating momentum and mass fluxes near the grate. Digital processing of images taken with a high resolution camera was used for determining the velocity field of the flow approaching a grated inlet. The images for each assay were treated with a correlation procedure through the software DigiFlow and the results were compiled in MatLab.

Processing of the obtained images allows to know velocity field of the flow patterns around the grate inlet and therefore to estimate the frontal and lateral flows approaching the grate. The results and the methodology carried out demonstrate that it is possible to determine a detailed field velocity for a shallow flow using a commercial software. In order to estimate accurately the mass and momentum fluxes it is necessary to have information on the shape of the velocity profiles near the grate openings because presently only plan velocity measurements are available, below we will use turbulent logarithmic profiles as a possible hypothesis.

**Simulation results: Digiflow**

DigiFlow is a software developed by the University of Cambridge, and specifically by the Department of Applied Mathematics and Theoretical Physics (DAMTP) [2], [3].

The software was used jointly to provide digital processing and numerical treatment of the images, these were used to estimate the frontal and lateral flows approaching the inlet. In the Figure 3 some of the results representing velocity fields are shown. The achieved results were compared to the data obtained during the experimental campaign carried out in the hydraulic laboratory of the UPC.
In order to estimate how much of the water flow penetrates the grate under different combinations it is necessary to integrate along the side of the grate, let us assume it is straight of length $h$, with density $\rho$. And of profile in height at each position and at each direction $i = \{x, y, z\}$ so that $U_i(x, y, z)$ so the flow towards $x$ can be calculated as:

$$M_x = \int_{-h}^{+h} h(y) \cdot \rho \cdot U_x(o, y, z) \cdot dx \cdot dy$$

Table 1: Comparison between experimental and simulated captured flow.

<table>
<thead>
<tr>
<th>Type of combinations</th>
<th>Flow rate (l/s)</th>
<th>Transversal slope (%)</th>
<th>Longitudinal slope (%)</th>
<th>Experimental captured flow</th>
<th>Simulated captured flow</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combination 1</td>
<td>200</td>
<td>0</td>
<td>2</td>
<td>14.56</td>
<td>15.15</td>
<td>4.05</td>
</tr>
<tr>
<td>Combination 2</td>
<td>150</td>
<td>2</td>
<td>8</td>
<td>13.84</td>
<td>13.49</td>
<td>2.53</td>
</tr>
<tr>
<td>Combination 3</td>
<td>100</td>
<td>2</td>
<td>10</td>
<td>11.22</td>
<td>10.83</td>
<td>3.48</td>
</tr>
<tr>
<td>Combination 4</td>
<td>25</td>
<td>4</td>
<td>10</td>
<td>11.22</td>
<td>10.27</td>
<td>8.47</td>
</tr>
</tbody>
</table>

Evaluation of the mass, momentum, kinetic energy, and enstrophy (The square of vorticity) can become in themselves useful tools to understand the
hydraulics behavior of the flow approaching the inlet where the traditional measuring equipment have had serious problems and limitations.

In case of evaluating pollutant transport or concentration c. dye tracers may also be used with image analysis. Here considering both molecular and turbulent diffusivities we have the standard diffusion equation

$$\frac{dc}{dt} = D \frac{d^2c}{dx^2} + \frac{1}{k} \left( \frac{dc}{dx} \right)$$

In the case when a velocity Boundary Layer, such as in a cement or asphalt road modify the momentum profiles through horizontal shear. The same hypothesis used by Von Karman for the Atmospheric Boundary Layer may be used, defining a relevant scale of velocity, in large enough Reynolds number flow (Re = U h / ν), that associated to the turbulent sidewise and upward friction produced by the boundary as

$$\tau = \frac{u^*}{\rho}$$

then assuming that eddies proportional to the distance from the surface are most efficient we model the lateral and vertical shear in terms of the friction velocity, as above. We have that velocity shear is proportional to $u^*$ and inversely proportional to $k z = 0.42 z$ which would represent the maximum vertical transport eddies $L_z$. Other parametrizations are needed in case of horizontal shear or stratified environments, thus

$$dU/dz = u^* k z$$

being $\kappa$ the so called Von Karman constant with value for the atmosphere of 0.42. Integrating the differential equation we have a logarithmic current profile, typical of developed turbulence, such as

$$U(z) = u^* \ln(z/z_0) / \kappa$$

Here the parameter $Z_0$ is called the friction velocity and would vary with the type of material of the ground surrounding the grate.

The actual measurement of velocity profiles, which are affected by the strong suction at the grate holes will force the profiles to have a strong downwards component, it is also true that the maximum velocity is generally not at the free surface but at intermediate depth. Five different profile shapes have been suggested. The simplest one is a linear vertical uniform profile $U(z) = U_{max}$, then a linear one $U(z) = (z/Z_{max}) U_{max}$, The logarithmic profile as defined above, A $U(z) = U_{max} \tanh(z)$ and a double Boundary layer from the ground and the air interface. [5,6]
Conclusion

A novel technique using particle image velocimetry to measure surface flow velocities has been developed and validated with the experimental data from tests about grated inlets capacity. [2,5]

In this case, the proposed methodology can become a useful tool to understand the velocity fields of the flow approaching the inlet where the traditional measuring equipment have had serious limitations. The measurement of the velocity and momentum fluxes allow to compare the performance of different grates under varied realistic environments.

References