How can computational fluid dynamics improve measuring in real sewers?

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Flow-rate is an important parameter for the management of sewer networks. One of the most common methods for the evaluation of the discharge consists in measuring the water depth together with the mean velocity in the cross section. The challenge is to obtain an accurate estimation of the mean velocity with available sensors that sample only a limited volume. Computational fluid dynamics (CFD) can be a useful tool for improving the representativeness of measurement: it enables to optimize the position of the sensor in the collector and to determine the processing of the gathered data. This paper presents an application of CFD to calculate the corrective coefficient which must be applied to the measured value of velocity to get the mean velocity for different acoustic Doppler sensors, thus making it possible to improve the accuracy of the calculation of the discharge. The baseline idea is to obtain a good adequacy between an instrument and a measurement section in order to improve the reliability and the accuracy of the measured values.oherent structures in the near field of a free jet have been studied. Experiments are carried out for the free jets issuing from circular and square nozzles using a water channel. Instantaneous velocity profiles are obtained in the radial directions by using an ultrasonic velocity profiler (UVP). Coherent structures in the radial direction are investigated in terms of the proper orthogonal decomposition (POD). The radial oscillation of the mixing layer is captured by the only first POD mode with about half a total energy. These velocity fields are reconstructed by the only lower-order POD modes and the reconstructed velocity fields by the lower-order and higher-order POD modes demonstrate large-scale and smaller-scale coherent structures, respectively. In the case of circular jet, there is a peak of power spectrum of the random coefficient at the first POD mode.

Keywords: Computational Fluid Dynamics, flow-rate measurement, flow velocity, spatial sampling.

1 INTRODUCTION

Like any industrial process, wastewater collection networks need measuring means for real–time control of flows, as well as for performance evaluation, and this need is supported by European and French regulations. The choice of a measuring section may be difficult as it is necessary to take into account both hydraulic conditions and practical criteria, which are not directly linked to “metrology” such as accessibility, security of staff and equipment, connection to electric and communication networks etc. These parameters determine which measuring sites are possible candidates, provided a suitable measuring method is designed.

From a metrological point of view, it is important to be able to guarantee certain accuracy for the measurement, that means evaluating and limiting uncertainties in a reliable manner, according to the objectives. However, flow-rate measurement is always obtained through an indirect method. Thus some kind of modelling is embedded in every flow-meter in order to transform the measured parameters (water height, sampled velocity in its volume of measurement) into flow-rate. So the inherent uncertainty of in situ measurement combines two uncertainties: (1) the measured parameters and (2) the validity of the applied transformation (or representativeness of measurement). The former is much related to the apparatus and the latter depends primarily on the site of measurement. Methods relying on a simultaneous measurement of depth and velocity are quite flexible widely used. But it is important to notice that the measured local velocity (either mean velocity $U_{meancone}$ or maximum velocity $U_{maxcone}$ according to the type of sensor) is usually different from the area-averaged mean velocity on the cross section (Hughes *et al.* 1996, [2]). Then special attention has to be paid to the representativeness of the measurement of velocity. In order to get a good evaluation of the mean velocity, a corrective coefficient is needed, and can be defined by considering the measured velocity in the volume explored by the sensor as follows:

$$K_U^{mean} = \frac{U_{mean}}{U_{meancone}} \quad (1)$$

$$K_U^{max} = \frac{U_{mean}}{U_{maxcone}} \quad (2)$$

where U_{mean} is the mean velocity in the whole cross section. The coefficient can be dependent on 4 parameters: (1) geometry of the collector, (2) position of the sensor, (3) type of sensor and (4) hydraulic condition. It is difficult to determine precisely for a particular real case, especially because it may change as condition (4) is variable.

The aim of this study is to show the possible application of the computational fluid dynamics (CFD) for the calculation of corrective coefficients by considering the 4 parameters quoted above. The measurements obtained by various sensors according to their positions and hydraulic conditions (height of water) have been simulated, and made it possible to propose solutions for instrumentation, combining a choice of sensor and its positions in a cross section.

2 EXPERIMENTAL SITE

An experimental site in Nantes (North West of France) has been considered in this study. For this site, the channel is narrow with a channel aspect ratio (width y/ height z) between 1.4 and 2.6. As expected in such narrow channels, the maximum velocity is clearly located below the free surface (Larrarte, 2006, [5]) and this phenomenon is called dip phenomenon (Nezu and Nakagawa, 1993, [6]), as shown in Fig. 1a).

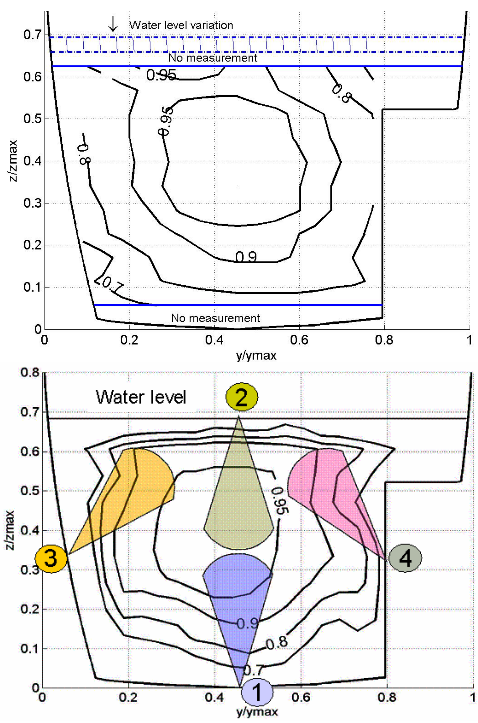


Figure 1: Comparison of experimental velocity measurement and numerical simulation for high water level conditions, a) experimental results b) numerical results with CFX.

3 NUMERICAL STUDY

The numerical procedure uses CFX software package for solving 3D Navier-Stokes equations, and predict distributions of velocity over a cross-section. This study is based on a biphasic modelling (water+air). The numerical simulation gives a good representation of the experimental results as shown in figure 1-b (Bonakdari et al., 2006, [1]).

4 EVALUATION OF THE MEASUREMENTS CARRIED OUT BY SENSORS

Three types of sensors referred as A, C, D were used after being tested by Larrarte *et al.* (2006), [4]. These sensors commonly used in sewers, primarily measure either a maximum or a mean velocity in the sampled volume. These sensors are also different in terms of emission angle, range and beam width as indicated in Table 1.

Table 1: Characteristics of three types of sensors according to Larrarte et al. (2006)ean flow velocities

Emission angle (°)	Range (m)	Beam width (°)
15	3.5	17
31	0.8	10
14	1.3	24

With a velocity field calculated by means of a numerical code, it is possible to determine the theoretical measurement carried out by a sensor by considering its position in the collector, and its own characteristics. According to the type of sensor, we determine either the maximum value or the average value in the scanned volume. This conic volume is deduced from the characteristics of the sensor, by knowing the emission angle, the range and the beam width. It is supposed that the opacity of waste water does not reduce scanned volume. The maximum value ($U_{maxcone}$) is searched among the velocities calculated numerically at the points of the mesh in the cone of measurements. The mean velocity delivered by the sensor is estimated from the weighted average of the velocities, as follows:

$$U_{meancone} = \frac{\sum_{i=1}^{n} U_{elementi} \times \forall_{elementi}}{\sum_{i=1}^{n} \forall_{elementi}} \qquad (3)$$

where $U_{meancone}$ is the mean velocity in the cone of the sensor, $U_{elementi}$ local velocity on the center of the element i, $\forall_{elementi}$ the volume of the element i and $\sum_{i=1}^{n} \forall_{elementi}$ the sum of n volumes of elements, that means the volume explored by the ultrasonic cone. Four positions for each sensor was studied in the vertical section of the collector, see figure 1b : position 1 is the usual position at the bottom of the channel, position 2 has been proposed by (Laplace et Deshons, 1998, [3]), position 3 and 4 have been observed in real sewers.

5 RESULTS AND DISCUSSION

3.1 Influence of sampled volume and positions of sensors measuring mean velocity

According to the characteristics of sensors, sampled volume allows a more or less representative estimation of the mean velocity in the cross section. This phenomenon induces the application of a corrective coefficient to the sampled mean velocity (K_U^{mean}) for the sensors performing this kind of measurement. Figure 2 gives the effects of water level variation and positions of sensors over K_U^{mean} in experimental site for the three studied sensors A, C and D.

For sensor A, it appears that above a height of 1.06 m, the coefficient K_U^{mean} remains constant. In lower part, only position 1 (at the bottom) provides an identical coefficient which corresponds to more important water heights. This sensor is characterized by a large range. When the height of water is sufficient compared to the range, scanned volume can be important. Thus, whatever the position, the measurement deduced from sampled volume remains constant. For the low water level, the sampled volume is smaller, thus the non-uniformity of the velocity field is reflected on the variation of measurement according to the position. For the sensor C, the coefficient K_U^{mean} varies according to the position, and for all the heights of water. It is advisable to pay attention to the positioning of this sensor. The results show that the coefficients K_U^{mean} are less dependent on the height of water for positions 1 (at the bottom) and 2 (free surface). Concerning sensor D, we note a large variation of the coefficient K_U^{mean} according to the water height. We note a lower variation of this coefficient for the positions 1 and 2, especially for the high water level.

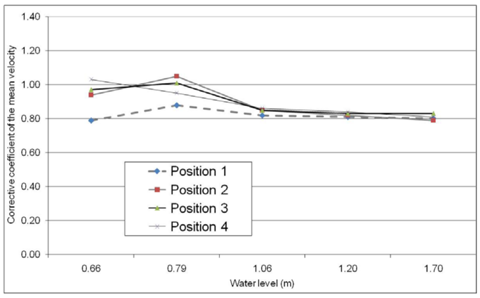
5.2 Influence of sampled volume and positions of sensors measuring maximum velocity

An increase in sampled volume increases the probability to capture maximum velocity in the cross section. But the relationship between the maximum velocity in the cross section and the average value of velocity is still needed. Figure 3 shows the effects of water level variation and positions of sensors over K_U^{max} in experimental site for the three studied sensors A, C and D. The variation of the coefficients K_U^{max} is low according to the height of water and position of sensors compared to the coefficients K_U^{mean} .

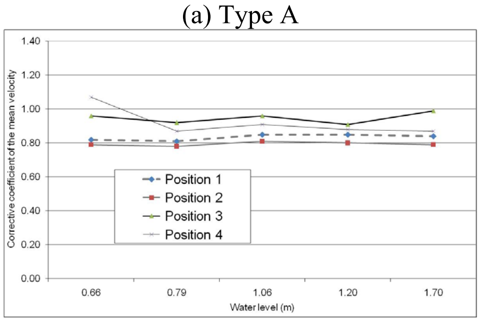
The measurement with sensor A is independent of the position for the high water level, and slightly dependent on the low water level. Other sensors show light variations according to the height of water and the position. As a whole, the maximum velocity measurement is definitely less sensitive than the mean velocity measurement.

5.3 Optimization of the position of sensors in a sewer

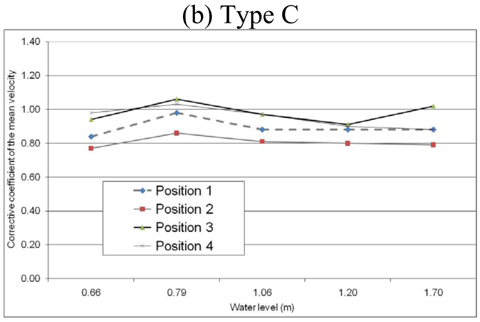
Concerning the optimization of instrumentation, the optimal solution should satisfy the two following criteria: (1) an estimation by the sensor close to mean velocity, which is equivalent to a correction factor near to 1 (2) an independence of the corrective coefficient against the hydraulic conditions (height of water).



(a) Type A



(b) Type C



(c) Type D

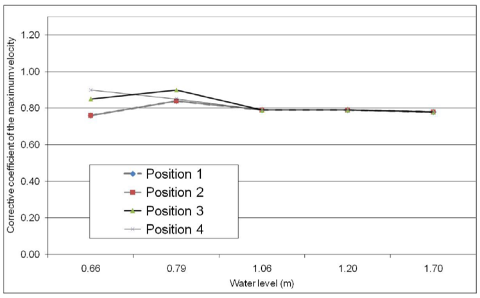
Figure 2: Influence of type and position of sensors on the coefficient K_U^{mean} for 5 water levels.

In the real case, as the first criterion can be difficult to obtain, we focus on the criterion (2) based on the variability of the measurement of a sensor according to the height of water. To evaluate the criterion (2), the coefficient of variation is defined as the ratio of the standard deviation σ to the mean μ :

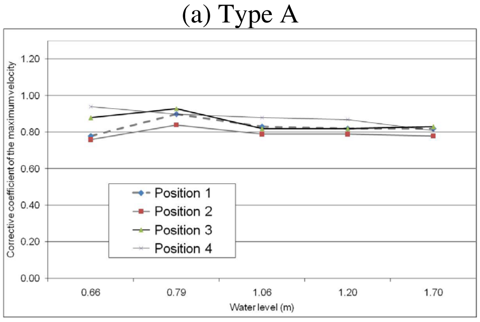
$$Cv=\frac{\sigma}{\mu} \qquad (4)$$

Table 2 shows all of the coefficients of variation for the various corrective coefficients, expressed in percentage.

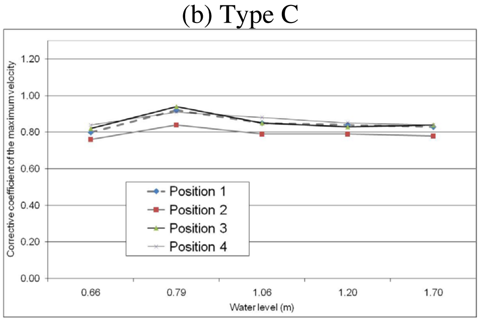
In a general way, for all of the sensors, positions (1) and (2), respectively at bottom and at the free surface, are interesting. In this case, the scanned volume relates to the slice in the central zone of the cross section. This configuration seems optimal to obtain a velocity close to that of the central zone non-disturbed by the walls.



(a) Type A



(b) Type C



(c) Type D

Figure 3: Influence of type and position of sensors on the coefficient K_U^{max} for 5 water levels.

Table 2: Coefficients of variation of K_U^{mean} and K_U^{max} for the sensors according to 4 positions.

	Cv (K_U^{mean})			Cv (K_U^{max})		
	A	C	D	A	C	D
Position 1	4,3%	2,2%	5,8%	3,7%	5,3%	5,2%
Position 2	11,9%	1,4%	4,2%	3,7%	3,7%	3,7%
Position 3	9,5%	3,5%	6,2%	6,3%	5,6%	5,6%
Position 4	10,1%	9,3%	6,4%	6,3%	6,4%	3,5%

The other positions which scan in diagonal the section can appear inadequate for sensors with a small range. Indeed, these sensors are not able to scan the central zone where maximum and mean velocities are located. If positions (1) and (2) allow an adequate measurement, they can induce practical problem. The position at the bottom can pose problems in term of sedimentation. The position at the free surface makes difficult the fixing of the sensor for installation. If the instrumentation can take place only by fixing the sensors at vertical walls, we can propose to determine the optimal angle allowing the sensor to scan the central zone.

In terms of choice of sensor, it appears that sensor A, which scans an important volume, is selected against the others. This kind of measurement appears less sensitive to the hydraulic conditions and positioning.

6 CONCLUSIONS

The modeling of flows in collectors, combined with a modeling of sampling with Doppler sensors, allow studying the principal parameters influencing measurement. Indeed, errors of measurement are dependent on: the sensor installation, the characteristics and the types of sensors, and the in situ hydraulic conditions. These errors can be corrected with a corrective coefficient of the mean velocity adapted to each case. If the first point depends on the efforts authorized by the building owner at the time of the studies of the project of instrumentation, the second depends on the information provided by the manufacturers of the measurement material. It can be the most difficult point to apprehend correctly today, because the sampling carried out by sensors is certainly not uniform inside the volume of measurement.

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