Hydraulics and deposit evolution in sewers

Nicolas Hemmerle[1], Jean-Jacques Randrianarimanana[1,2], Claude Joannis[1] and Frédérique Larrarte[1]
1) LUNAM, IFSTTAR, department GERS, Laboratoire Eau et Environnement, Route de Bouaye CS4, 44344 Bouguenais Cedex, France, frederique.larrarte@ifsttar.fr
2) GEMCEA, 149 rue Gabriel Péri, F-54500 Vandoeuvre-les-Nancy, France

Sewer deposit is a complex mix of mineral and organic materials whose dynamics remain poorly understood to such a point that the transport formulas, mainly developed for rivers sediment, are still missing accuracy. IFSTTAR researches aims at helping networks managers by investigating hydraulics and solid transport occurring in urban sewer networks. The current paper presents an experimental study of the influence of the hydraulic parameters on the deposit bathymetry. Various ultrasonic devices are used in the study to measure the transversal variation of the deposit and the velocity profiles sewer. The results show the relation between the deposit height and the bottom shear stress and will be presented and discussed in paper. In similar cases studies (hydraulics conditions), results of bottom shear stress profiles are different.

Keywords: Sonar, velocity profiler, shear velocity, solid transport, sewer network,

1 INTRODUCTION

For several years, it has been recognized that untreated wastewater discharged into receiving waters during rain events contributes significantly to the degradation of the quality of the aquatic environment. Furthermore, sewer deposit is a complex mix of mineral and organic materials whose dynamics remain poorly understood to such a point that the transport formulas, mainly developed for rivers sediment, are still missing accuracy. [1] as well as [2] argued that one way to improve the knowledge on sewer process is to obtained detailed and long term measurements but that appropriate techniques are missing.

IFSTTAR researches aims at helping networks managers by investigating hydraulics and solid transport occurring in urban sewer networks. The current paper presents an experimental study of the influence of the hydraulic parameters temporal evolution on the deposit bathymetry and its evolution.

One key point of the current project, comparatively to previous investigations, is related to newly developed ultrasonic devices that allows non intrusive and faster screening of both the velocity profile and the deposit evolution. Those sensors as well as the experimental site will be described. Then the results will be presented and discussed in relation to literature data.

2 EXPERIMENTAL STUDY

For this project, we focused on combined sewer which may be involved in pouring untreated waters to receiving bodies.

2.1 Experimental site

The experimental site is located in the downtown part of the Nantes metropolitan network (North-western France), along the former bed of the Erdre river. The catchment area is 1.8 km² for 100 000 equivalent inhabitants. The invert slope is equal to 0.01%. The sewer has a 2.3 m high egg shaped section with a bank (Figure 1). A 20° bend is located about 10 m upstream the measurement point. This site presents a relatively thick deposit (about 0.30 to 0.45 m) and a relatively slow velocity (about 0.10 to 0.25 m.s^{-1}).

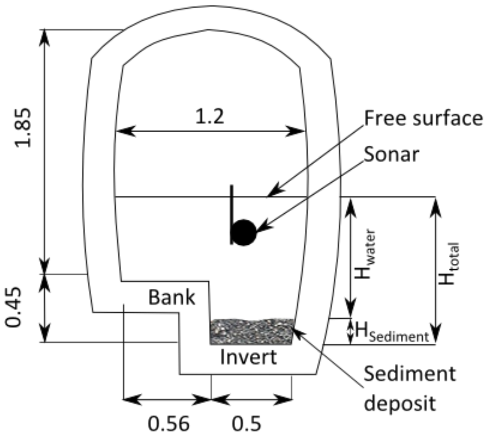

Figure 1: Collector geometry

The water level and velocity have been continuously recorded with an acoustic Doppler flowmeter Isco 2150 for 42 months. Thus statistics can be made to identify the typical dry weather hydraulic context. Figure 2 shows the water height and velocity evolution for a common working day in autumn. The water height decreases between 0:00 and 6:00, increases between 5:30 and 7:00 and then remains quasi-constant up to next midnight. The velocity increases between 0:00 and 7:00, decreases between 7:00 and 8:00 and then remains quasi-constant for the last of the day.

For both experimental campaigns, the measurements are carried out between 7:00 and 10:00 am, when the velocity is statistically almost constant but, unfortunately the Doppler flowmeter was not in use during those two campaigns.

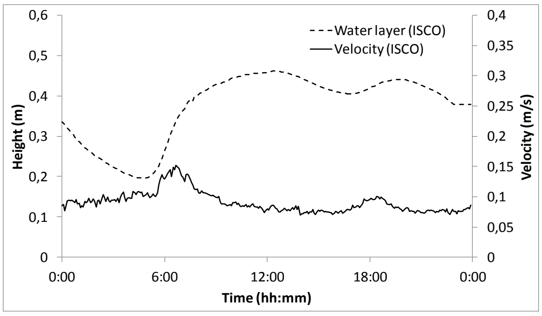

Figure 2: Typical evolution of water height and velocity for characteristic working day in autumn.

2.2 Ultrasonic sensors

The bathymetry is measured with a Marine Electronics 1512 sonar which emission frequency is 2MHz. A sound wave is emitted by the sensor and reflected by interfaces like sewer walls or sediment. Each measurement is constituted by several emissions with an angular resolution of 0.9° on 360° to completely scan the section [3], excepted in the 20 cm dead zone. The interfaces locations are obtained after a signal processing that suppresses the echoes due to noise and suspended solids, [3]. For solid interfaces (walls, consolidate sediment) the reflectivity is strong when, for muddy deposit, the reflectivity is more ambiguous, because muddy deposit isn't totally permeable of sound.

In order to measure the deposit height, the sonar is put in the middle of the main channel (Figure 1) for all the measurements. Those ones are focusing on the temporal evolution of the deposit during the velocity measurement.

The Ub-flow (F156 by Ubertone) is a velocity profiler made to simultaneously measures the streamwise and vertical velocities [4]. This profiler has been chosen because it can be implemented at the free surface as the set-up proposed by [5] proved impossible to implement in a real network. This sensor is constituted by two transducers: the first one (Tr 1) has an inclination angle of 65° (β_1) with regard to the Ub-flow base (Figure 3) and an emission frequency centered on 1.5 MHz. The second transducer (Tr 2) has an inclination angle of 97° (β_2) with an emission frequency centered on 3 MHz. This sensor configuration allows to make a velocity profile with a spatial discretisation of 5 mm below the dead zone that is 5 cm long, and a transversal resolution of 10 cm. Data recording time is chosen to 3 min for each vertical profile, and cross section scan times vary from 25 to 35 min. On each cell, the V_1 and V_2 velocities are measured along the beam axis, respectively the Tr1 profile and the Tr2 profile [4], so the streamwise and vertical velocities can be calculated by equations (1) and (2):

$$u_x = 1.873 * V_1 - 1.873 * V_2 \tag{1}$$

$$u_z = -0.230 * V_1 - 0.798 * V_2 \tag{2}$$

Moreover, the implementation at the free surface minimizes the interactions with the deposit and the backscattered intensity of the ultrasonic beams can be analyzed and used to locate the deposit interface. It has to be pointed that this sensor does not allow to measure the 3 components of the velocity as an Acoustic Doppler Velocimeter that is only giving a one point measurement or as an Acoustic Doppler profiler but there is no device adapted for the narrow context of sewers [6].

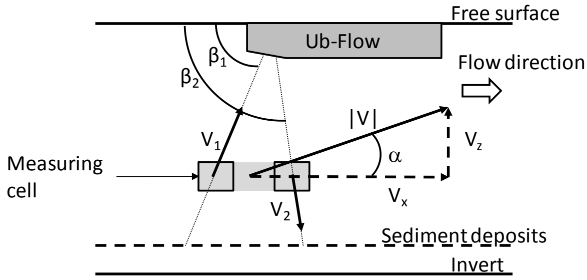

Figure 3: Schema of measurement cell and Ub-flow position at free surface

2.3 Data processing

At each time, the mean velocity in the cross section is calculated with the area method described in [7] and confirmed in [8].

In the inner region, the experimental velocity profiles are fitted with a logarithm law (Figure 4) to calculate the shear velocity:

$$\frac{u_x(z)}{u_*} = \frac{1}{k}\ln\left(\frac{z}{k_s}\right) + B_s \tag{3}$$

where $u_x(z)$ is the streamwise velocity at z above the invert, u_* the shear velocity, k the Von-Karman constant (0.41), k_s the equivalent sand grain roughness and B_s the integration coefficient (8.5 for rough turbulent flow) [9]. The bottom shear stress is calculated with equation 4:

$$\tau_0 = \rho u_*^2 \tag{4}$$

where ρ is the water density

3 RESULTS

3.1 Comparison of sensors interfaces detection

The profiler and the sonar are used together to investigate the influence of hydraulic parameters on the sediment evolution so it is interesting to compare what part of the water column they are investigating. Figure 5 shows the amplitude of the backscattering signals as a function of the depth below the sensors that are implemented close to the free surface. On October, a thin pick can be seen at 0.2 for both sensors, this is similar to the situations observed by [3] for sandy deposit. On November, a larger pick can be observed from 0.22 to 0.28 for both sensors, this is similar to the muddy situations presented by [3]. Moreover, some samplings made on that day have certified that a muddy layer was present in the main channel. It can also be noticed that the backscattered signal received by the sonar is greatly affected by the nature of the deposit as it decreases from 0.0023 to 0.0012.

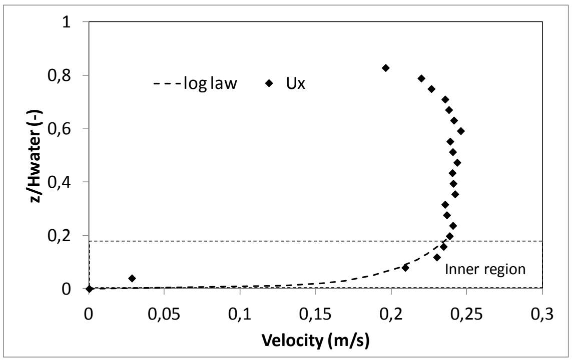

Figure 4: Longitudinal velocity profile and log law regression

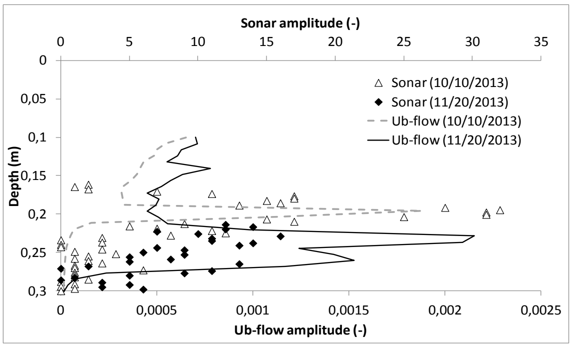

Figure 5: Signal amplitude measured by sonar and Ub-flow sensor

3.2 Sediment height evolution

Figure 6 shows the temporal evolution of the deposit height obtained for 2 dry weather days. On October 2013 the 10th, the water height above the bank is equal to 0.15 m and in the main channel it is equal to 0.20 m for a total height of 0.6 m from the invert. The mean velocity calculated with equation (5) is equal to 0.18 m/s. The sediment height is underneath the bank level. The channel aspect ratio (ratio of the free surface width to the maximum water level in the cross section) is equal to 5. From 8:44 to 9:45, the deposit height does not change. Its level is equal to 0.40 m in the main channel center but it increases by 5 cm from the vertical wall of he bank to the opposite wall (Figure 6 a). On November 2013 the 20th, the mean velocity is also equal to 0.18 m/s but the water height above the bank is equal to 0.30 m and in the main channel it is equal to 0.20 m for a total height of 0.75 m from the invert. The sediment is higher than the bank so the concrete main channel is full and the cross section is now like having a trapezoidal lower part and the aspect ratio is equal to 4. The sediment height in the main channel is equal to 0.55 with a transverse variation of 5 cm and there is no deposit over the bank. From 7:40 to 8:20, the deposit height does not change. Those results show that neither the mean velocity in the cross section nor the water heights are able, by its elves, to explain the complexity of the velocity distribution and of the deposit patterns.

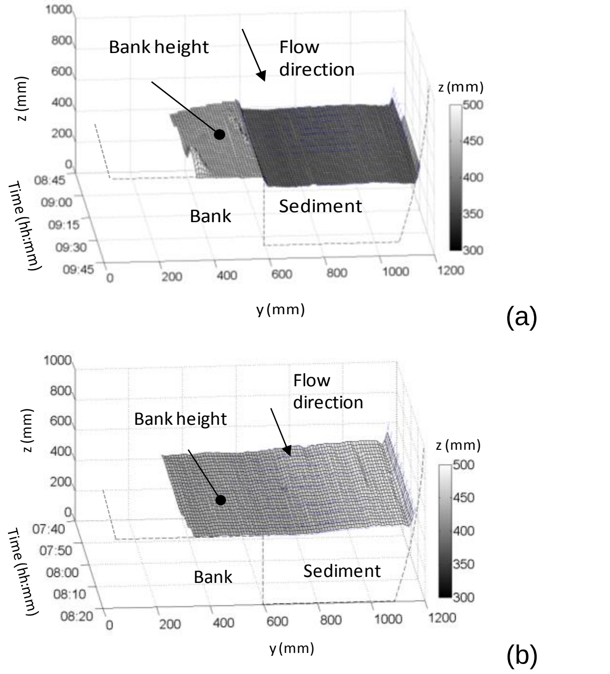

Figure 6: Temporal variation of sediment bathymetry, (a) 10/10/2013 and (b) 11/20/2013 measurements

3.3 Velocity field transverse variation

Figure 7 shows the velocity field in the cross section. On October the 10th, the maximum water velocity is located in the middle of the main channel and below the free surface (this is called a dip-phenomenon) that is relevant with the fact that this channel can be considered as narrow [9].

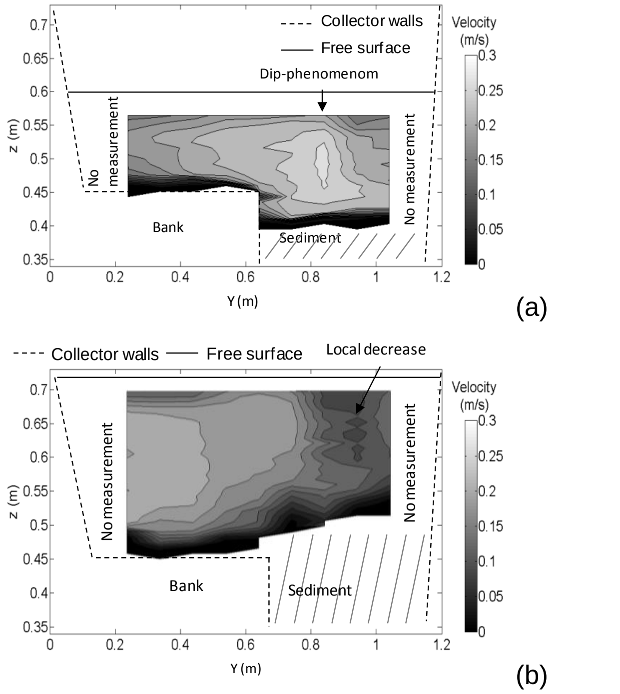

Figure 7: Transversal variation of longitudinal velocity, (a) 10/10/2013 measurements and (b) 11/20/2013 measurements

On November the 20th, the maximum water velocity is located above the bank that is now behaving as a main channel. This has also to be related to the upstream bend. Its influence is not noticeable on October with a main channel at the inner side of the bend but is strongly apparent on November with a "de facto" main channel in the outer side. This interesting point, that may be related to Prandtl secondary currents of 1st en 2nd kinds, would be further investigated. A minimum velocity can be observed on y equals to 1 m, this might be related to some blockage effects between the sonar and the deposit. This will be further investigated during new experimental campaigns.

3.4 Bottom shear stress transverse variation

Velocity profiles are used to calculate the bottom shear stress (equations 3 and 4). On October the 10th, in the main channel, the bottom shear stress profile is almost constant and equals to 4 N/m² (Figure 9) and decreases close to the bank corner, this has been observed by [9] in an single section. On November, the maximum bottom shear stress is located above the bank (Figure 9) that is related to the maximum velocity location. Above the main channel, the bottom shear stress is 66% smaller than on October has a consequence of the much more slower flow in this area and that may explain why the muddy layer is present on that day.

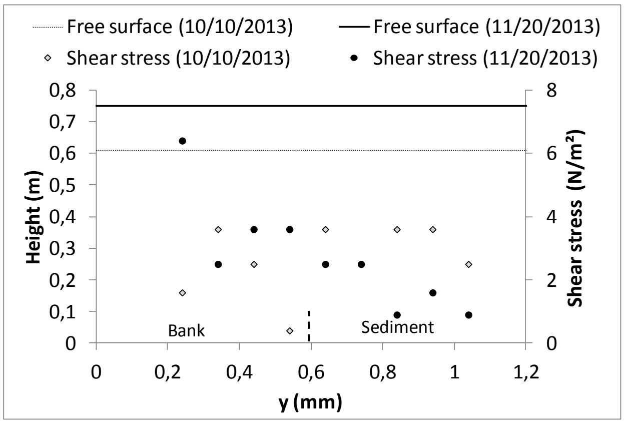

Figure 9: Transversal profile of bottom shear stress, 10/10/2013 and 20/11/2013 measurements

4 DISCUSSION

Transversal bottom shear stress profiles obtained in this study (with sediment) are in accordance with results of [2] and [9] with and without sediment respectively. However, bottom shear stress values in the main channel centre are higher than the values found by [2].These authors did syntheses of critical erosional shear stress ($\tau_{c,e}$) and found that, for organic sediments, the $\tau_{c,e}$ is lower than 2 N/m² when for mineral sediment it is higher than 6 N/m². In our study, the bottom shear stress varies between 1 and 4 N/m² for two measurements campaign whatever the sediment is.

5 CONCLUSION

Two ultrasonic devices have been used in a sewer network to study the deposit height in relation to the velocity field in a cross section. The transversal variation of the bottom shear stress is therefore determined. This study shows how different the transversal deposit height, the velocity field and the bottom shear stress can be at a given moment even if the mean velocity and water level remain the same. It is interesting to notice that the original main channel can be so full of deposit that part above the bank becomes like a new main channel. Further investigation should be made to assess the influence of the bank but also of the deposit characteristics. Moreover, it would be interesting to have longer investigations (at least all a day long) to investigate the influence of flow history on the deposit pattern at the moment of the observations.

6 ACKNOWLEDGEMENTS

The 2nd author fellowship is financially supported by the Agence Nationale de la Recherche (project ANR 11 ECOT 007 05). The authors would like to thank the technical staffs of both the Laboratoire Eau et Environnement, and the Direction de l'Assainissement de la Communauté Urbaine de Nantes (Nantes Metropolis Sewage Authority) for their valuable contributions to these experiments.

REFERENCES

[1] Delleur J.W. New results and research needs on sediment movement in urban drainage. *Journal Water Resource Manage*, 127, (2001), 186-193.

[2] Ashley R, Bertrand-Krajewski J, Hvitved-Jacobsen T and Verbanck M. *Solids in sewers: Characteristics, effects and control of sewer solids and associated pollutants.* IWA Publishing, Colchester: Scientific and technical Report N°14 (2004).

[3] Carnacina I, Larrarte F: Coupling acoustic devices for monitoring combined sewer network sediment deposits, accepted for *Water Science and Technology*, 69(8), (2014), 1653-1660.

[4] Fischer S. Evaluation of a high resolution acoustic profiler for hydraulic erosion studies. 6th Inter. conference on scour and erosion, Paris (Fr), (2012).

[5] Bares V., Jirak J., Pollert J. Spatial and temporal variation of turbulence characteristics in combined sewer flow. *Flow measurement and Instrumentation*, 19, (2008), 145-154

[6] Le Barbu E., Larrarte F. Acoustic profilers and urban pollutant fluxes. *European Journal of Environmental and Civil Engineering*, 14(5), (2010), 637-651

[7] Larrarte F. Velocity and suspended solids distributions in an oval-shaped channel with a side bank, *Urban Water Journal*, (2014), DOI: 10.1080/1573062X.2013.871043

[8] Larrarte F. Velocity fields within sewers: An experimental study. *Flow Measurement and Instrumentation*, 17, (2006), 282-290

[9] Bonakdari H, Larrarte F, and Joannis C. Study of shear stress in narrow channels application to sewers. *Urban Water Journal, 5* (1), (2008), 15-20.