Validation of an unsteady flow numerical model for sediment transport induced by flushing operation in combined sewers

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Gashin Shahsavari[1], Alberto Campisano[2], Carlo Modica[2] and Gilles Arnaud-Fassetta[1]

[1]Paris-Diderot University, PRODIG Lab., Paris, France
[2]Dipartimento di Ingegneria Civile e Architettura, Università di Catania, Viale A. Doria 6, 95125, Catania, Italy

Abstract: An unsteady flow numerical model based on the solution of the 1-D De Saint Venant-Exner equations was developed and validated against the results of a field flushing experiment that was carried out in the year 2014 within a combined sewer trunk of the Paris sewer system. The comparison of numerical and experimental results showed that the model may reproduce in a proper way the erosional effects of the flush on the mobile bed of the sewer at the end of the experiment. Model results confirmed the potential erosive effect of the flush up to several hundreds meters downstream of the flushing device, with a significant reduction of the deposited sediments in the channel.

Keywords: Sewer flushing; Sediment transport modeling; Combined sewer

1. INTRODUCTION

The analysis of sediment transport induced by flushing operation in storm water/combined sewers has been the subject of several research studies in the recent years. Experiments have been carried out at both laboratory and field levels to explore the effects (*i.e.*, the cleaning performance) of a number of flushing devices on the sediments deposited on the invert of sewer pipes (Lorenzen, 1996; Ristenpart, 1998; Dettmar and Staufer, 2005; Campisano *et al*., 2006; Creaco and Bertrand-Krajewski, 2009).

At the same time, other studies have focused on modelling aspects of sewer flushing, including sediment erosion and transport processes (e.g. Campisano *et al*., 2006; Shirazi *et al*., 2014). However, much of the developed models have not been extensively validated against experimental observations obtained through field tests.

Very recently, Shahsavari *et al*. (2017) have shown the results of field experiments aimed at investigating the impact of a single flush on the sediment bed of a combined sewer trunk in the municipality of Paris. The objective of the present paper is to show the preliminary results of the validation of a 1-D unsteady flow numerical model for the analysis of the cleaning performance of the performed flush. The analysis includes the comparison of experimental and model results concerning the evolution of both hydraulic and sediment-related parameters during the flush experiment.

2. MATERIALS AND METHODS

2.1 Experimental data

The results of an experimental campaign carried out during the year 2014 in a large combined sewer (*Collecteur des Coteaux*) of Paris city were used for the validation of the model. The scouring effects of a single flush were explored over a 1.1 km long channel trunk of the selected sewer. The trunk is characterized by a compound cross-section with central cunette and side-walkways. The relatively low value of the average longitudinal slope of channel (~0.09%) determines relevant problems of sedimentation in the sewer. Mean d_{50} over the experimental channel is about 2.2 mm. A moveable gate was used to perform the flush through initial storage and successive release of combined sewer flows. The sewer trunk was fully equipped with a set of measuring devices to monitor both flow and sediment transport during the flush experiment. Flow parameters were measured in five cross-sections both upstream and downstream the flushing gate. Moreover, sediment depths throughout the channel were measured by radar/sonar scan systems before and after the flush for consistent evaluation of the flush cleaning performance (Shahsavari *et al*., 2017).

2.2 Description of the numerical model

The adopted numerical model is based on the solution of the 1-D De Saint Venant equations for the unsteady flow description, and on the Exner equation for the sediment continuity. For a prismatic channel without lateral inflows and outflows, the following conservative vector form can be used:

$$\frac{\partial U}{\partial t} + \frac{\partial F(U)}{\partial x} = D(U)$$

where U is the dependent variable vector, $F(U)$ is the flux vector, and $D(U)$ is the source term vector written as follows:

$$U = \begin{bmatrix} A \\ Q \\ A_s \end{bmatrix}, \qquad F(U) = \begin{bmatrix} Q \\ V \cdot Q + \dfrac{F_h}{\rho} \\ \dfrac{1}{1-p} \cdot Q_s \end{bmatrix} \quad \text{and} \quad D(U) = \begin{bmatrix} 0 \\ g \cdot A \cdot (i - J) \\ 0 \end{bmatrix}$$

being x [m] and t [s] the space and time independent variables; A [m^2] the water cross-section; Q [m^3/s] and V [m/s] the flow discharge and the flow velocity respectively; F_h [N] the hydrostatic force over the cross section; ρ [kg/m^3] the water density; g [m/s^2] the gravity acceleration; i the bed slope; J the friction slope; A_s [m^2] the sediment cross-section; Q_s [m^3/s] the volumetric sediment discharge; and p the sediment porosity.

The friction slope is evaluated using the Strickler roughness equation (Strickler, 1923):

$$J = \frac{Q^2}{k_{eq}^2 \cdot A^2 \cdot R^{4/3}} \quad \text{with} \quad k_{eq} = \left(\frac{P}{\sum \dfrac{P_i}{k_i^{3/2}}} \right)$$

being R [m] the hydraulic radius, k_{eq} [m$^{1/3}$/s] the composite roughness coefficient, P [m] the wetted perimeter, k_i [m$^{1/3}$/s] the roughness coefficient of the part P_i of the wetted perimeter. Coefficient k_i for the sediment bed was calculated based on the sediment characteristic size using the well-known Strickler formula. Coefficient k_i for the channel walls was calibrated based on water level and flow measurements under uniform flow conditions.
The system of equations is solved by using the “shock-capturing” TVD-McCormack scheme (Garcia-Navarro and Saviron, 1992). Meyer-Peter and Müller (1948) formula is used for the

estimation of the sediment discharge Q_s (bed load component) as a function of the flow and sediment characteristics. Moreover, the Velikanov approach (Velikanov, 1954) is used to evaluate the suspended load component.
Boundary conditions on the hydraulic variables (flow and water level) are prescribed at the upstream and downstream channel ends, as well as in correspondence of the gate as internal conditions. Additional boundary conditions for the sediment are also imposed at the two channel ends based on the information obtained by the experiments

3. RESULTS AND DISCUSSION

Simulations were extensively compared with the field data, including hydraulic parameters monitored during the experiment as well as sediment depths after the flush. Figure 1 shows examples of the comparison between simulated and experimental variables during the flush (i.e. flow discharge and water level) at sections -5 m and +50 m upstream and downstream of the gate, respectively. The graphs show that the model results are in relatively good agreement with the experiments, including the initial abrupt water level increase at section +50 m, subsequent to the transit of the flush wave front that propagates downstream. Results also show the water level at section -5 m to drop down due to the flow release process upstream of the gate. Also, the model correctly reproduces the declining trend of the flow discharge after the flush peak.

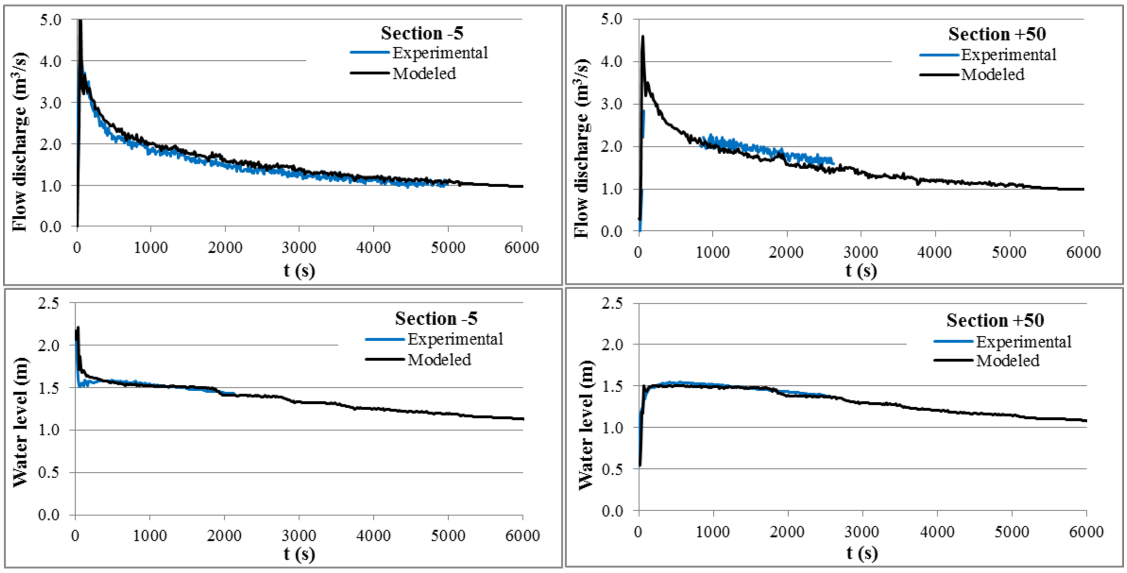

Figure 1 Comparison between experimental and numerical results at sections -5 m and +50 m from the gate.

Figure 2 shows the results in terms of bed erosion in the channel as induced by the flush. Due to the high energy of the flush, erosional effects were observed in the channel bed over a distance up to about 850 m downstream of the gate. Due to the relatively large size of d_{50}, the results of the used model for uniform sediments did reveal occurrence of bed load transport only. Although the comparison between observed and simulated values of the sediment depths at the end of the flush shows relatively large differences in some sections of the channel, a sufficiently small value of the RMSE (0.044 m) was obtained. Overall, a significant reduction of the sediments initially deposited on the trunk invert was obtained with the flush. The model results provided about 3.7 m^3 of sediments washed out from the channel as compared with the 5.4 m^3 measured through the experiments.

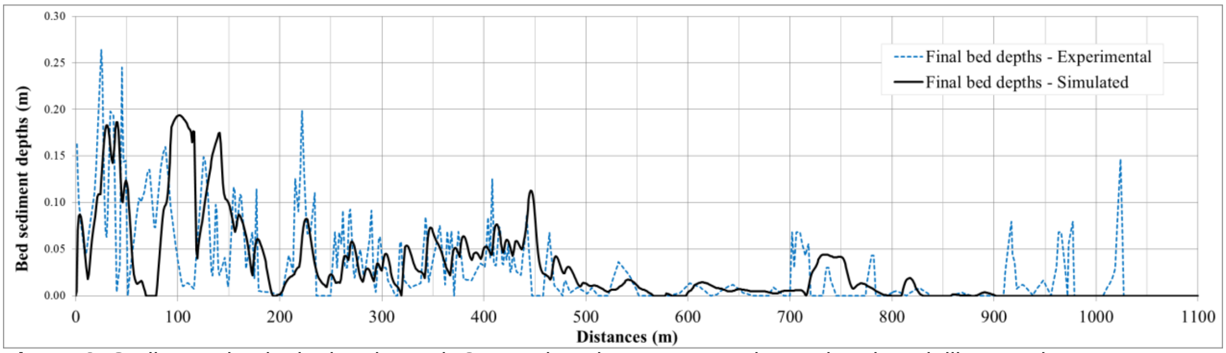

Figure 2. Sediment depths in the channel. Comparison between experimental and modelling results.

CONCLUSIONS

The results of the application of a numerical model for the evaluation of erosional effects of flushing in a combined sewer trunk of Paris sewer system were presented in the paper. The results were validated using the data derived from an antecedent field experimental analysis carried out in the same trunk. Overall, preliminary simulations showed a relatively good agreement between the model and experimental observations, including the ability of the model to correctly reproduce the main hydraulic processes. Globally, the uniform model showed appreciable erosional impact of the flush on the initial bed of sediments deposited over the channel invert. Improved modelling results are expected in the future with the use of a model for the transport of non-uniform sediments.

References

Bertrand-Krajewski, J.L., Campisano, A., Creaco, E. and Modica, C. (2005) Experimental analysis of the hydrass flushing gate and field validation of flush propagation modelling. *Water Sci. Technol*. **51**(2): 129−37.

Campisano, A., Creaco, E. and Modica, C. (2006) Experimental analysis of the hydrass flushing gate and laboratory validation of flush propagation modelling. *Water Sci. Technol*. **54**(6−7): 101−108.

Creaco, E. and Bertrand-Krajewski, J.L. (2009) Numerical simulation of flushing effect on sewer sediments and comparison of four sediment transport formulas. *Journal of Hydraulic Research* **47**(2): 195−202.

Dettmar, J. and Staufer, P. (2005) Modelling of flushing waves for optimising cleaning operations. *Water Sci. Technol.* **52**(5): 233−240.

García-Navarro, P. and Savirón, J.M. (1992) McCormack's method for the numerical simulation of one-dimensional discontinuous unsteady open channel flow. *Journal of Hydraulic Research* **30**(1): 95−104.

Meyer-Peter, E. and Müller, R. (1948) *Formulas for Bed-Load Transport*. IAHR-Meeting Stockholm, Zahlentabellen zu den Geschiebetriebsversuchen der Versuchsanstalt für Wasserbau und Erdbau an der ETH Zürich, unpublished supplement (in German).

Lorenzen, A., Ristenpart, E., Pfuhl, W. (1996) Flush cleaning of sewers. *Water Sci. Technol*. **33** (9): 221-228.

Ristenpart, E. (1998) Solids transport by flushing of combined sewers. *Water Sci. Technol*. **37**(1): 171−178.

Shahsavari, G., Arnaud-Fassetta, G. and Campisano, A. (2017) A field experiment to evaluate the cleaning performance of sewer flushing on non-uniform sediment deposits. *Water Research* **118**: 59−69.

Shirazi, R.H.S.M., Campisano, A., Modica, C. and Willems, P. (2014) Modelling the erosive effects of sewer flushing using different sediment transport formulae. *Water Sci. Technol.* **69**(6): 1198−1204.

Velikanov M.A. (1954) Principle of the gravitational theory of the movement of sediments. *Academy of Sciences Bulletin, Geophysical Series, Moscow, USSR* **4**, 349−359 (in Russian).

Strickler, A. (1923) *Beiträge zur Frage der Geschwindigkeitsformel und der Rauhligkeitszahlen für Ströme, Kanäle und geschlossene Leitungen*. Mitt. des Eidgenössischen Amtes für Wasserwirtschaft, **16**, Bern (in German).