Water Research 118 (2017) 59–69

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

A field experiment to evaluate the cleaning performance of sewer flushing on non-uniform sediment deposits

Gashin Shahsavari [a, *, 1], Gilles Arnaud-Fassetta [a, 1], Alberto Campisano [b, 1]

[a] PRODIG Laboratory (UMR CNRS 8586), Paris Diderot University, Rue Albert Einstein, 75013 Paris, France
[b] Department of Civil Engineering and Architecture, University of Catania, Viale A. Doria, 6, 95125 Catania, Italy

ARTICLE INFO

Article history:
Received 5 November 2016
Received in revised form
5 April 2017
Accepted 9 April 2017
Available online 10 April 2017

Keywords:
Flushing
Sewer cleaning
Sediment deposits
Non-uniform sediment mixtures
Erosion

ABSTRACT

The results of a field experiment to evaluate the scouring effect of a single flush operation in a compound-section sewer channel in Paris, France, are presented in this paper. Full monitoring of the experiment allowed identifying flush-related transport/deposition key processes playing a role on the evolution of the deposited sediments. Overall, the flush was able to scour sediments accumulated over the channel invert up to a significant distance from the gate. The analysis of the results revealed that the flush had a different impact on the various sediments present in the bed mixtures, with most of the eroded volume including sediment particles smaller than the median grain size.

1. Introduction

Sediment settling and accumulation are the cause of worrisome hydraulic and environmental problems in combined sewer systems. Negative impacts range from the reduction of sewer flow transport capacity to the increase of pollution associated with the discharge through overflow devices of sediments re-suspended from the channel invert during storm flow events.

During the last decades, flushing has been recognized as a cost-effective technique for the removal of sediments deposited in sewer channels. Such a technique consists of generating artificial flushing waves able to scour sediments accumulated over the channel invert and to transport them downstream through sections that endow sufficient self-cleaning conditions. Recently, experimental and numerical researches have been carried out to investigate the cleaning performance of different flushing devices for both storm water and combined sewer channels (Bertrand-Krajewski et al., 2003; Guo et al., 2004; Bong et al., 2015).

Results from field experiments have shown different impact of flushing depending on the geometry of the sewer (e.g. type of cross-section and longitudinal slope of the invert), on the hydraulic characteristics of flushing devices (e.g. initial water head and stored volume available for the flush), and on the properties of accumulated deposits (e.g. type and size of sediments, organic matter content, degree of consolidation, etc.). Based on the results of an early analysis carried out in a combined circular sewer with relatively flat invert, Ristenpart (1998) has shown that flushes generated by a valve gate holding an initial water head of 0.8 m were able to provide erosional effects up to about 90 m in the downstream channel. Lorenzen et al. (1996) explored the impact of flushes characterized by high initial water head in a large compound sewer in Hannover (Germany). They reported significant erosional effects on the deposits (prevalently composed by fine sandy sediments) over a distance of about 600 m downstream of the gate. Experiments involving larger sediments were carried out by Dettmar and Staufer (2005) in a circular combined sewer channel with trunks of variable diameter and slope. Results of the experiments revealed that the shear stresses generated by the flushes were able to erode sediments up to a distance of nearly 300 m downstream of the gate. In addition, the effects of flushes on coarse sands deposited on the bottom of a circular sewer were observed by Dettmar et al. (2002) who highlighted the occurrence of erosion also in sewer sections upstream of the gate. More recently, Creaco and Bertrand-Krajewski (2007, 2009) evaluated the cleaning performance (in

* Corresponding author.
E-mail addresses: gashin.shahsavari@gmail.com (G. Shahsavari), gilles.arnaud-fassetta@univ-paris-diderot.fr (G. Arnaud-Fassetta), acampisa@dica.unict.it (A. Campisano).
[1] The authors have contributed equally to this paper.

http://dx.doi.org/10.1016/j.watres.2017.04.026
0043-1354/

terms of removed volume of sediments) of thousands consecutive flushes on relatively fine sediments accumulated in a large oval-shaped sewer channel in Lyon (France). Results of the experiments highlighted that nearby 200 m channel length downstream of the gate was subject to erosion. It was also highlighted that invert irregularities played a key role in affecting transport and re-deposition processes during the flushes.

Side to field experiments, laboratory tests using scaled physical models of flushing devices were also carried out by Guo et al. (2004) and by Campisano et al. (2004) in order to investigate the scouring effects determined by flushes of variable water head on deposits of prefixed thickness and uniform sediment size. Other laboratory tests (Campisano et al., 2008; Todeschini et al., 2008) have further explored the flushing erosional effect on sediment mixtures with cohesive behaviour.

Moreover, data from both field and laboratory flushing experiments have been compared with numerical models proposed by various researchers. Early works have focussed on the hydraulics of the flushing process with the main aim to identify relationships between induced shear stress and sediment scouring capacity of the flush (e.g. Staufer et al., 2007). More recent studies include coupling 1-D unsteady flow modelling with sediment transport equations for a detailed simulation of erosion and transport phenomena associated with flushing (Creaco and Bertrand-Krajewski, 2009; Shirazi et al., 2014). Also, results of model simulations have been used to develop compact charts/relationships for flush design in combined/stormwater sewers based on hydraulic and sediment-related parameters (Campisano et al., 2007).

The major part of the previous works have analysed the sensitivity of the flush “cleaning” performance to the flush hydraulic parameters and to the sewer geometrical characteristics. However, so far very limited attention has been addressed to the impact that sediment characteristics may have on the flush removal process, i.e. the way type and size of the deposited sediments affect the transport processes associated with the flush. The laboratory flush tests have been usually developed under simplified conditions by using sediments of almost uniform characteristics, thus precluding the analysis of flush differential effects on sediments of non-uniform size. In contrast, a number of studies have pointed out that sewer sediment characteristics are highly variable (Crabtree, 1989; Ashley et al., 2004) and that solid transport in combined sewers may show patterns typical of sediment mixtures (Verbanck et al., 1994; Ashley and Verbanck, 1996; Ota et al., 1999).

Although the review of the scientific literature highlights that much work has been carried out in the past, sediment transport mechanisms/modalities associated with the rapidly varied flow conditions occurring during sewer flushing are still far from being fully clarified. Actually, an important gap concerns the lack of experimental observations of flush erosional effects on the modification of the sediment deposit texture and composition. Understanding selective erosional/depositional effects of the flush on non-uniform sediment beds may enable an improved evaluation of the flush removal efficiency in sewers.

In order to contribute to increase the comprehension of the described processes, a field campaign of experiments was recently launched in Paris within the framework of a larger project supported by the municipality and aiming at exploring the potential of implementation of flushing techniques in the parisian combined sewer network. A trunk of a large combined sewer prone to sediment deposition was selected as pilot channel for the experiments. An existing gate device already installed into the channel was re-arranged for flushing purposes. The channel was equipped with sets of measurement devices in order to monitor flow and sediment-related processes during a full-scale flush experiment. This paper reports in detail the results of the experiment with a focus on the evolution of the bed sediment deposits induced by the flush. The analysis allowed to identify erosional and depositional processes occurred in the channel, as well as to evaluate the flush removal effects on deposited sediments of different size. The results of the analysis may contribute to the improvement of knowledge for the assessment of the performance of flushing in sewer systems.

2. Materials and methods

2.1. Study site

Paris municipality (*Ville de Paris*) spends annually hundred thousands €/km to clean out combined sewers from accumulated sediments. The need to reduce costs as well as risks for health and safety of sewer operating personnel (by limiting direct entrance into the network) has motivated recently the municipality to explore the potentiality of flushing techniques in cleaning sewer channels (Alzabadi, 2010).

A large combined sewer (*Collecteur des Coteaux*) belonging to the sewer sub-network of the 11th arrondissement of Paris city was selected by the municipality to conduct the experimental campaign. The sewer conveys an average dry-weather flow of about 0.35 m^3/s. The scouring effects of a single flush have been investigated over a 1.1 km long channel trunk of the selected sewer. The sewer trunk is characterized by a compound cross-section with central cunette and side-walkways (see Fig. 1). The figure shows the elevation profile of the channel, highlighting a weighted average longitudinal invert slope of about 0.09%. The upstream portion of the channel trunk shows several invert irregularities with the presence of sections in counter-slope. The channel receives combined sewer flows from four minor tributary inlets located at sections S_{+170}, S_{+650}, S_{+850}, and S_{+920}, being the first one the most relevant in terms of expected inflow and contribution of sediments to the trunk. At the downstream end of the channel a diversion structure allows to convey the flow to a chamber for trapping transported sediments.

An electrically-driven sector gate with sharp crested weir (Fig. 2) is placed at S_0, about 50 m downstream of the beginning of the studied channel trunk. The gate, which has been originally conceived with the aim to control combined sewer overflows during storm events, allows for in-line storing conveyed flows in the upstream channel stretch (several hundred meters long stretch with average slope of about 0.15%) and in additional upstream branches with an estimated volume of store in the order of 8000 m^3. Due to its potential to produce high water-head flushes, the control gate was adopted for the purpose of this project and thus re-arranged accordingly to the experimental setup.

2.2. Experimental setup and data collection

Five sections of the analysed channel trunk were selected and equipped with a set of measuring devices to monitor both flow and sediment transport parameters during the experiment. Monitoring sections were located upstream (S_{-50}, S_{-5}) and downstream (S_{+5}, S_{+50}, S_{+100}) of the gate.

Flow rate was measured with an accuracy of ±1% by a beam-pulsed Doppler device (Sontek IQ Plus™) installed on the sewer invert at each of the five identified sections (see Fig. 3). The device is an area/velocity sampler, i.e. the flow rate is indirectly obtained by simultaneous measurement of water level and flow velocity. Each monitoring section was equipped with an ultrasound probe installed on the top of the channel. Such probes enabled redundancy in water level measurements and allowed improved analysis of the flush release process. The used type of ultrasound sensor has a sampling resolution of 4 mm at full-scale water level of 3 m.