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The erosion behaviour of biologically active sewer sediment deposits: Observations from a laboratory study

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Abstract

The erosion behaviour of various fine-grained sediment deposits has been investigated in laboratory experiments. This work mainly focused on tests using sewer sediment in which strong biochemical reactions were observed during the deposit formation period. A small number of initial tests were conducted in which the deposits were made from mixtures of "clean" mineral and organic sediments. The erosion behaviour observed in these tests was compared with the erosion characteristics for sediments taken from deposits in a sewer. The impact of the biological processes on physical properties such as bulk density, water content, deposit structure and the erosive behaviour as a function of bed shear stress are quantified and discussed. Based on these observations it is believed that bio-processes weaken the strength of the in-pipe sediment deposits. A significantly weaker sediment surface layer was observed during deposition under quiescent oxygen-rich conditions. This resulted in a deposit with low shear strength which may be a cause of a first foul flush of suspended sediment when flow rates were increased. Comparison between tests with sewer sediments and the artificial representative surrogates suggested that the deposits of the later did not correctly simulate the depositional development and the resultant erosion patterns observed with the more bio-active sewer sediment.

Keywords: Sewer sediments; Surrogate sediments; Erosion; Deposition; Bed load; Microbiology

1. Introduction

In recent years demands for water quality improvement in natural watercourses has led to the mandatory assessment of the performance of sewer networks and where required the implementation of improvements especially with regard to the ecological impact of sewer overflows on recipient watercourses. Most of the sewer systems in the EU are combined, as they carry both domestic wastewater and rain water from urban areas to treatment plants. They can carry high loads of both organic and inorganic solid particles, often termed "in-sewer sediments".

Problems are associated with the presence of significant in-sewer sediment deposits. The presence of sediment deposits reduces the flow capacity due to the reduction of flow area and increased hydraulic resistance. This, as a consequence, can cause more frequent spill events and can therefore result in higher amounts of pollutants being released through combined sewer overflows into natural water courses during storm events.

Field studies have indicated that the re-suspension and transport of existing deposited in-pipe sediment can be the main source of pollution associated with storm events. Up to 80% of the pollutant loads discharged

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from overflows during storm events have been attributed to the erosion of deposited in-pipe sediments (Ahyerre, 1999; Ahyerre and Chebbo, 2002; Ashley et al., 1992a,b). These observations emphasise the desirability of having the ability to control in-sewer sedimentation processes as a method for reducing the subsequent pollutant releases from combined sewer systems. For this to be possible, proper design relationships, that can reliably predict sedimentation zones and subsequent erosion rates, need to be formulated. Existing numerical models simulate, with acceptable reliability, the time varying hydraulic performance of complex sewer networks. However, their performance in terms of sediment mobility and the related water quality parameters is much more limited. This poor performance may be due to the current assumptions made in the relationship used to simulate in-sewer sediment transport. Current methods (e.g. Ackers et al., 1996) assume that in-sewer sediments are granular and that particle characteristics are inorganic and uniform in nature. These models therefore neglect several important aspects in the in-sewer sediment cycle. In-sewer sediment follow a cycle of deposition in dry weather, followed by erosion and transport in storm events. Current modelling approaches ignore such physical processes such as consolidation, and do not consider any chemical and biological processes. The improvement of knowledge related to these processes will address key weaknesses of current sewer modelling and is essential for better management of sewer sediments (Ashley et al., 2000).

2. In-sewer sedimentation

Combined sewers experience a wide range of time varying flows during dry and wet weather conditions. In such sewers, a number of different types of sediment deposit have been identified and categorised either with reference to their source or their physical and chemical characteristics (e.g. Crabtree, 1989). Typically, in-sewer deposits are mixtures of inorganic and organic sediment fractions with the proportions depending on factors such as catchment characteristics, sewer type, sewer geometry, the prevailing domestic and industrial water use, and the sanitary habits of the contributing population. Field observations reported that sewer deposits have a wide range of physical characteristics and that they can possess a significant degree of cohesion and erosional strength. Fieldwork by Ristenpart and Uhl (1993) reported a range of entrainment thresholds for fine grained, cohesive-like deposits in combined sewers. During dry weather, they observed erosion beginning at bed shear stresses equal to $0.7\,N/m^2$, whilst after prolonged periods of dry weather flow the bed shear stress required to initiate motion increased to $3.3\,N/m^2$.

Exposed to such a variation of flow rates, the sedimentation or erosion processes normally do not reach a state of long-term equilibrium. Under dry weather conditions mixtures of solids are moving near the bed. During storm flows, a large proportion of the organic content of the near-bed material is re-entrained thus leaving predominantly larger inorganic sediments in the near-bed region (Arthur and Ashley, 1998). These denser, inorganic sediments usually form the major part of the sediment deposits found in the inverts of pipes (Crabtree, 1989).

Deposition in sewers generally occurs during periods of dry weather and during decelerating flows, when the generated storm flow is receding. At specific locations in the sewer network, settlement and deposition will occur depending upon the local shear stress and sewer geometry, the concentration and nature of solids in suspension near the bed (Laplace et al., 1992). Fine sediments in the water column, which have the ability to flocculate, can also deposit when bed shear stresses, as a result of changes in flow conditions or pipe topography, are reduced to a level below that which causes floc break-up. On top of the coarser, granular deposits a surficial fine-grained lamina can be formed and is frequently reported as a biofilm or organic layer (Ahyerre et al., 2001). This layer usually has lower erosion resistance and is believed to be continuously changing because of ongoing biological and sedimentation processes. It is also expected that the arrangement on the surface of both fine organic particles as well as the coarser inorganic ones will be influenced by the local near-bed flow, which arranges the surface particles to maximise their stability. Experimental work by Lau and Droppo (2000) indicated that fine-grained sediment beds, which are formed under shear flows, are often much more resistant to erosion than such beds deposited under quiescent conditions.

Storm events can input a wide range of sediment types and volumes into sewers and the resultant time varying flows can cause very different levels of disturbance to the in-pipe deposits. In-sewer deposits may therefore become layered or mixed due to these interacting processes and their structure can also be influenced by ongoing biochemical reactions. Hence the deposited beds in sewers are heterogeneous and can exhibit thixotropic characteristics (Ashley et al., 2000). Knowledge of the time-dependent flow variability, combined with knowledge of the sediment supplied is thus a key element for proper evaluation of in-sewer sedimentation processes.

3. Biological effects on the sediment bed

Sediments in sewer systems, once deposited and even when being transported, have the potential to be