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Experimental Study on the Hydraulic Impact of Discrete Top Blockages in Gravity Sewers †

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Abstract: The current study presents experimental results on how discrete top blockages alter the upstream flow depth in a gravity sewer. A full-scale experimental circular open-channel system (DN150, 30 m length) was constructed to simulate a gravity sewer. Discrete top blockages with various heights (80, 90, 100 mm) were tested with various flow rates and channel slopes. For various scenarios, the flow depths just upstream of the blockage were measured and analysed to reveal the impact of the blockages. The measured flow depths consistently exceeded those predicted by a reference formula from the literature, underscoring the difficulty in developing generalisable models.

Keywords: circular open channel; sewer blockage; sewer spill; smart sewer

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1. Introduction

A discrete top blockage acts similarly to the classical open-channel sluice gate example by forcing the flow to constrict underneath the obstruction. Sluice gates have been studied extensively for rectangular open channels. However, studies of sluice gates, also known as "slide gates", in circular channels are very limited.

Slide gates have mainly been used for flow control and metering in irrigation channels [1,2]. Hoseini and Vatankhah [3] noted that slide gates for irrigation flow control and metering purposes, the focus of most previous studies, behave differently from inline slide gates installed in circular open channels (partially full pipes). Because both the upstream and downstream flow depths are generally less than the channel diameter in circular pipes, the inline slide gate is comparable to the discrete top blockage in sewer pipes commonly caused by root intrusion, having practical implications for practitioners managing sewerage networks.

The current research focuses on experimental studies on the hydraulic impact of discrete top blockages in circular open channels. Three discrete top blockages were constructed and tested in an experimental circular open-channel system. The experimental results were visualised, discussed, and compared with results derived from one of the empirical formulas presented by [3].

2. Materials and Methods

The laboratory experimental system used was adapted from the one previously used for the investigation of bottom blockages [4]. A schematic drawing of the system is given in Figure 1. An upstream reservoir supplied a constant discharge through a 30 m long, 153 mm internal diameter clear PVC pipe. The discharge was controlled by adjusting a flow regulation valve in the recirculation line. The flow rate Q was recorded using an ultrasonic flow meter in the recirculation line. The slope of the clear PVC pipe could be configured by adjusting the height of the supporting jacks.

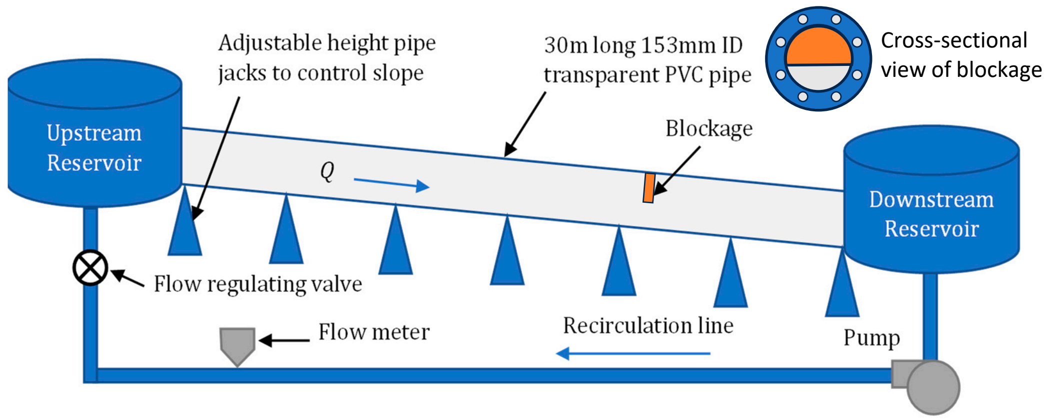

Figure 1. Schematic of the experimental system for simulating a gravity sewer.

Three discrete top blockages (orifice plate style) were designed and fabricated. A discrete blockage was created as a timber orifice plate bolted between two flanges that connected two pipe sections (see the cross-sectional view of blockage in Figure 1). The thickness of the timber orifice plate was 12 mm, and the height values of the three blockages were 80, 90, and 100 mm. Note that the edges were a straight cut of the plate.

Trials were performed by varying the height of the blockage, the slope of the channel, and the flow rate *Q*. For each blockage, two different channel slopes were tested, and they were 0% (horizontal) and 0.7%. For each system configuration, several flow rates were tested within the range from 1 to 10 L/s. The flow was increased from low to high for all cases to establish the choked flow condition (i.e., the flow in contact with the top blockage) from a free flow condition (i.e., the flow not in contact with the top blockage). For each trial, after recording the discharge at the flow meter, the water depth in the clear PVC pipe was measured 150 mm upstream of the blockage by using measuring bands wrapped around the circumference of the pipe (more details can be found in [4]).

3. Results

The measured depth values upstream of the top discrete blockage are summarised in Figure 2a for the 0% slope (horizontal) and in Figure 2b for the 0.7% slope.

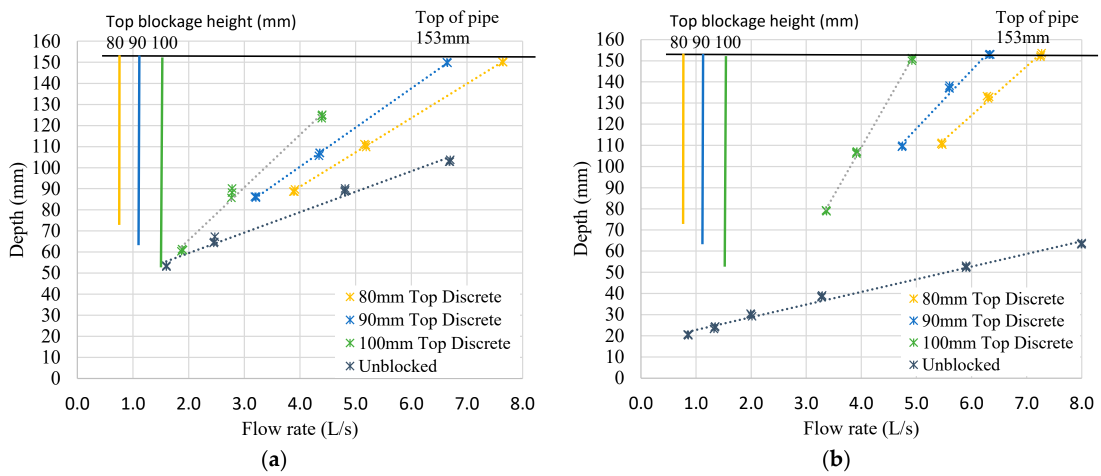

Figure 2. Flow depth upstream of discrete top blockages: (**a**) in a 0% slope channel and (**b**) in a 0.7% slope channel. Dotted lines are linear trend lines; solid vertical lines represent the height of the three top blockages relative to the results.

All three discrete top blockages could introduce an upstream flow depth much higher than that of the unblocked condition when the flow rate was high enough. With increasing flow, the surface of the flow reached the bottom edge of the blockage, introducing choking and turbulence upstream of the blockage and causing a rapid upstream depth increase. The channel with a 0.7% slope resulted in more rapid depth increases (as shown by the steeper gradient of the dash-dotted trendlines in Figure 2b) compared to the channel with a 0% slope.

4. Discussion

Hoseini and Vatankhah [3] studied the stage–discharge relationship for inline rectangular slide gates in two horizontal circular open channels (194 mm and 290 mm internal diameter). In their study, through experiments and dimensional analysis, the general relationship between the dimensionless flow rate and the dimensionless flow depth upstream of the gate (measured at 0.6 m upstream of the gate) was described by empirical formulas. The formula presented as Equation (25) in [3] is the most relevant for the current study and, therefore, used for further analysis. Note that the exact location of depth measurement (distance from the blockage) is not critical for horizontal channels.

Applying their empirical formula to the tested discrete top blockages, the upstream depth h can be estimated using the measured flow rate Q and other known information. The calculated results for the three discrete top blockages are compared with the experimentally measured upstream depth in Figure 3.

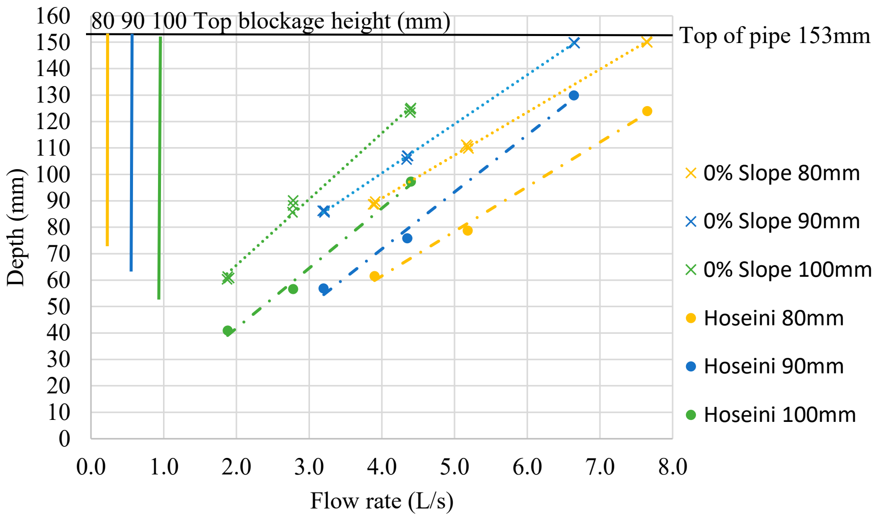

Figure 3. Comparison between the flow depth results upstream of discrete top blockages obtained from the current research and those obtained based on an empirical formula presented in Hoseini and Vatankhah [3]. Dotted and dash-dotted lines are linear trend lines.

Figure 3 shows that, for all three discrete top blockage sizes, the depth values measured from the experiments in this research are higher than those estimated using the empirical formula from Hoseini and Vatankhah [3], although the gradients of the trendlines are similar. This demonstrates that the energy losses experienced in the experimental system of this research were systematically higher than those in the system used by Hoseini and Vatankhah [3]. It also suggests that the empirical formula is not generally applicable to discrete blockages or even other rectangular slide gates in circular open channels. The discrepancy as well as the lack of generality of the empirical formula are understandable since it is reasonable to assume that the energy loss is system-specific. However, it highlights the difficulty in deriving a general numerical model or formula to predict the hydraulic impact of discrete top blockages in sewer pipes.

5. Conclusions

This research has provided insights into the change in water depth for partially filled circular open channels subject to discrete top blockages. With the flow increased from low to high, when the surface of the flow reached the bottom edge of the blockage, it introduced choking and turbulence upstream of the blockage, resulting in a rapid depth increase. The rate of increase in the channel with a 0.7% slope was higher than that in the channel with a 0% slope (horizontal).

The flow depth values measured upstream of the discrete top blockages in the current research were compared with the values estimated from an empirical formula presented by Hoseini and Vatankhah [3]. The experimentally measured depth values were higher than the calculated values for all the cases. This demonstrates that the energy losses caused by the top blockages in this research were higher than those embedded in the empirical formula. It highlights that the energy loss is system-specific, and a general model or formula to accurately predict the impact of top blockages would be difficult to obtain.

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