DURATION OF HYDRAULIC FLUSHING AND ITS EFFECT ON SEDIMENT BED MOVEMENT

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ABSTRACT

Hydraulic flushing is the most widely used method for sediment removal in sewer. However, open storm sewer tend to have longer flushing duration as compared to closed conduit sewer. This is due to storm water could enter more directly and rapidly into open storm sewer especially during rain events. The current study aims to determine the effect of flushing duration on the efficiency of sediment removal which is lacking in the literature. Flushing experiment was conducted in a rectangular flume for varying flushing durations namely approximately 3 seconds, 30 minutes and 60 minutes. Changes of the sediment bed profile were observed after each flush. Findings from the experiment has shown that short duration flushing is more efficient in terms of more sediment volume being removed as compared to long flushing duration. In terms of mean sediment bed front advancement, long flushing duration will moved the sediment bed front further than short duration flushing. The knowledge from the current study can be used to design a more efficient flushing devices for the management and active control of sediment in sewer system.

Keywords: Flushing devices; flushing duration; flush efficiency; hydraulic flushing; sedimentation.

1 INTRODUCTION

The control and cleaning of sediment deposited in sewer system has been a crucial aspect of sewer maintenance and operation (Bertrand-Krajewski et al., 2005). Of the various methods developed to clean sediments, hydraulic flushing is the oldest and most widely applied method in sediment removal (Bertrand-Krajewski, 2008). Flushing device such as the Hydrass gate used in Lyon, France (Bertrand-Krajewski et al., 2006; Bertrand-Krajewski et al., 2003) has proven to be successful in sediment removal for closed conduit sewer. An on-site observation at Nibong Tebal, Penang, Malaysia has shown that a tipping flush gate has the potential to be used for sedimentation management of open storm water sewer (Bong et al., 2016).

From available literature, the factors that have effect on flush cleaning efficiency are: i) height of water stored upstream of flushing device prior to flushing (Shafai-Bejestan et al., 2012; Guo et al., 2004); ii) partial exposure of deposit downstream or initial water depth downstream (Guo et al., 2004; Gendreau et al., 1993); iii) number or frequency of flushes (Ristenpart, 1998; Gendreau et al., 1993); distance of sediment deposit from flushing device (Guo et al., 2004; Ristenpart, 1998); v) sediment cohesiveness and void ratio (Shafai-Bejestan et al., 2012; Campisano et al., 2008) and vi) sediment deposits thickness (Bong et al., 2013). Another factor that might have effect on the flushing efficiency is the flushing duration but it is lacking in the literature. Flushing duration can be defined as the time between the opening of the flushing device to discharge a volume of water and the closing of the device. Flushing duration is dependent on the volume of water or water level needed for the operation (opening and closing) of the flushing device.

The flush duration for the Hydrass gate installed in a closed conduit sewer in Lyon, France under wet weather conditions was observed to be approximately equal to 3.5 minutes (Bertrand-Krajewski et al., 2003). As for the open storm water sewer in Nibong Tebal, Penang, Malaysia, the flushing duration could range between 22.8 minutes to 179.5 minutes and were dependent on the rainfall duration and intensity (Bong et al., 2016). Since surface runoff could enter open storm water sewer system more directly and rapidly during rainfall event as compared to closed conduit sewer system, the volume of water upstream of the device installed in open storm water sewer system could be maintained longer leading to longer flush duration.

The current study aims to determine the effect of flushing duration on the efficiency of sediment removal. Flushing experiment was conducted by varying the duration of flushing. Changes of the sediment bed profile were observed after each flush. The results from this study could be used in designing a more effective flushing device as well as filling the gap in the literature on flushing duration.

2 METHODOLOGY

The flushing experiment was conducted in a rectangular flume with dimensions 11.0 m (L) x 1.2 m (W) x 0.8 m (D). The tipping flush gate (see Figure 1) has an opening width of 1.0 m and opening height of 0.5 m, similar in design and dimensions to the gate used on-site for the study by Bong et al. (2016). The tipping flush gate was installed at 1.6 m from the beginning of the flume (see Figure 2), thus providing an area for water to store upstream of the gate before flushing. The tipping flush gate was observed to open when the upstream water level was 0.51 m from the bottom of the flume and close when the upstream water level was 0.35 m from the bottom of the flume. The flume was supplied with water through two 0.10 m diameter downpipes from tanks installed above the flume which have a self-circulation system, drawing water from a sump. Some plastic modules were installed at the end of the flume, starting from 7.55 m from the tipping flushing gate and extended for about 1.7 m. These plastic modules were used to dampen the force of the flush waves, reducing the effect of the waves reflected back into the flume after hitting the downstream end of the flume. At the end of the flume was a downstream tank that collects water before diverting it into a sump. The flume has an average slope of 0.0016. Wooden stick gages were installed along the flume at an interval of 0.5 m to facilitate the reading of water level and sediment profile during experiment.

Sediment bed was laid starting from 0.5 m from the flush gate and extended for 6.0 m with the thickness of 0.05 m. Hence, the total volume of sediment bed inside the flume prior to flushing was 0.36 m^3. The sand used for the sediment bed was of size d_{50} = 1.11 mm and specific gravity of 2.55. Velocity of the flush wave during experiment was measured using MARSH McBIRNEY FLO-MATE electromagnetic flowmeter installed at the centreline of 2.0 m and 5.0 m from the gate and about 0.05 m above the sediment bed (see Figure 3(a) for the general view of the experimental set up). The flow meter has an accuracy of ± 2% of the true velocity value. Using the Fixed Point Average (FPA) option in the flow meter, the velocity reading was continuously taken during flushing and the average velocity was updated every 2 seconds. The highest velocity during the flushing period was recorded. Digital cameras were also installed at the distances of 2.0 m and 5.0 m from the gate to capture the variations of water level during flushing at these two sections. To understand the characteristics of the flush wave, a preliminary flush experiment was conducted where the velocity at the centerline along the flume at an interval of 0.5 m was recorded.

For the flushing experiment in the current study, the gate opening angle was set to 30° from the horizontal axis. During the trial run of the experiment, the gate was observed to open when the water level in the storage area upstream of the gate reached 0.51 m and close when the water level subsided to 0.35 m, discharging 0.31 m^3 of water. The duration taken for the gate operation (open and close) was approximately 3 seconds. To achieve longer flushing duration, once the gate tip opened, a wooden stick was placed between the gate leaf and the frame to prevent it from closing (see Figure 3(b)) while water supply was maintained to flow from the two downpipes through the gate. The flushing duration used for the current study was decided to be of short duration of approximately 3 seconds and long durations of 30 minutes and 60 minutes.

During the experiment, pumps that supply water from the sump and the downpipes valves were turned on to the maximum and water was let to fill the storage area behind the gate up until the gate tip and the gate was opened. Once the gate opened and flush wave was created, the gate was either let to automatically close (for short duration experiment) or left to open (using wooden stick) and water was allowed to flow through the gate until the end of the 30 minutes or 60 minutes duration. Since there was no adjustment to the pumps and valves during the duration of the experiment, the flow in the flume became uniform and velocity became constant after some time for the long durations experiment. Once the required duration was achieved, the pumps and downpipes valves were turned off and water level was allowed to recede in the flume before the sediment profile was measured.

Once the water level had receded and the sediment bed was visible, reading of the sediment profile was taken for every 0.5 m along the flume and for every 0.3 m across each cross-section with a steel ruler and measuring tape with accuracy of 0.5 mm (see Figure 4). Beside the sediment profile, the advancement of the sediment bed front from the initial position was also measured on the left, center and right side (looking downstream) of the flume and the mean distance was calculated (see Figure 5). The measurement of the sediment bed profile and sediment bed front movement were done after each flush. The flushing procedures as mentioned previously were repeated for five times for each of the different flush durations.

Figure 1. Front view of the tipping flush gate.

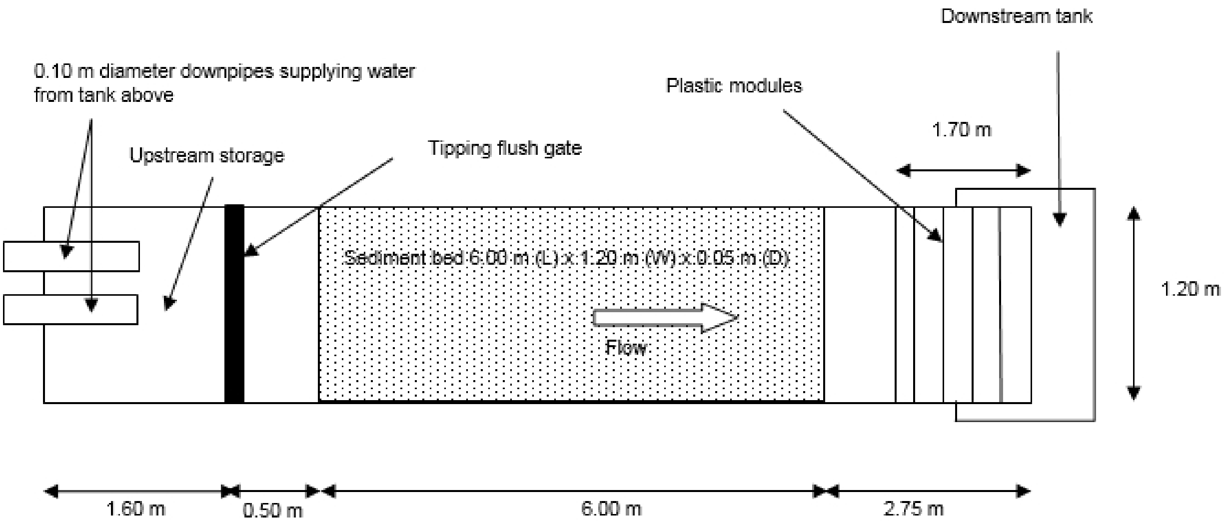


Figure 2. Schematic diagram for the flushing experiment (not to scale).

(a) (b)

Figure 3. Experimental set up: (a) general view and installation set up for the flushing experiment; and (b) wooden stick to prevent the gate from closing after flushing for the 30 minutes and 60 minutes duration experiments.

Figure 4. Measuring sediment profile using steel ruler and measuring tape after each flush.

(a) (b)

Figure 5. Advancement of sediment bed front: (a) before flushing; and (b) after the fifth flush.

3 RESULTS AND DISCUSSION

3.1 Flush characteristics

Figure 6 shows the flush wave characteristic in terms of velocity generated by the tipping flush gate along the flume. From Figure 6, the mean velocity was the highest at 1.5 m from the gate with a velocity of 1.10 m/s. Figure 7 shows the variation of water level at 0.75 m upstream of the gate as well as at 2.0 m and 5.0 downstream from the gate. From the observation during the experiment, the flush wave took about 1.21 seconds and 2.48 seconds to reach the distances of 2.0 m and 5.0 m from the gate respectively. For the short duration flush of approximately 3 seconds, the variation of velocity and water level were similar with both in Figures 6 and 7. For the long duration flush of 30 minutes and 60 minutes, the variation of velocity and water level were similar during the initial few seconds, however, as the gate remained open and water flow through the gate slowly became uniform; the water level remained steady at 0.25 m with the velocity around 0.2 m/s throughout the duration of the experiment.

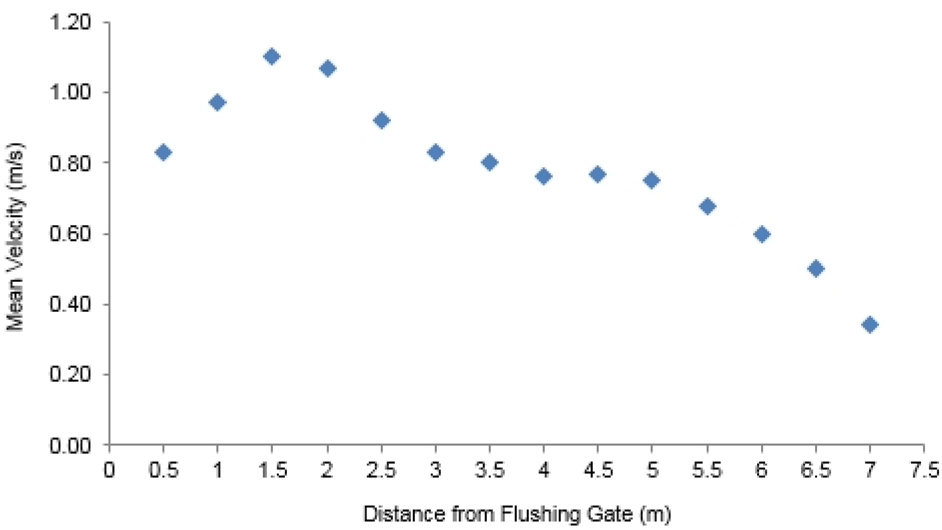


Figure 6. Variation of mean velocity of flush wave along the flume.

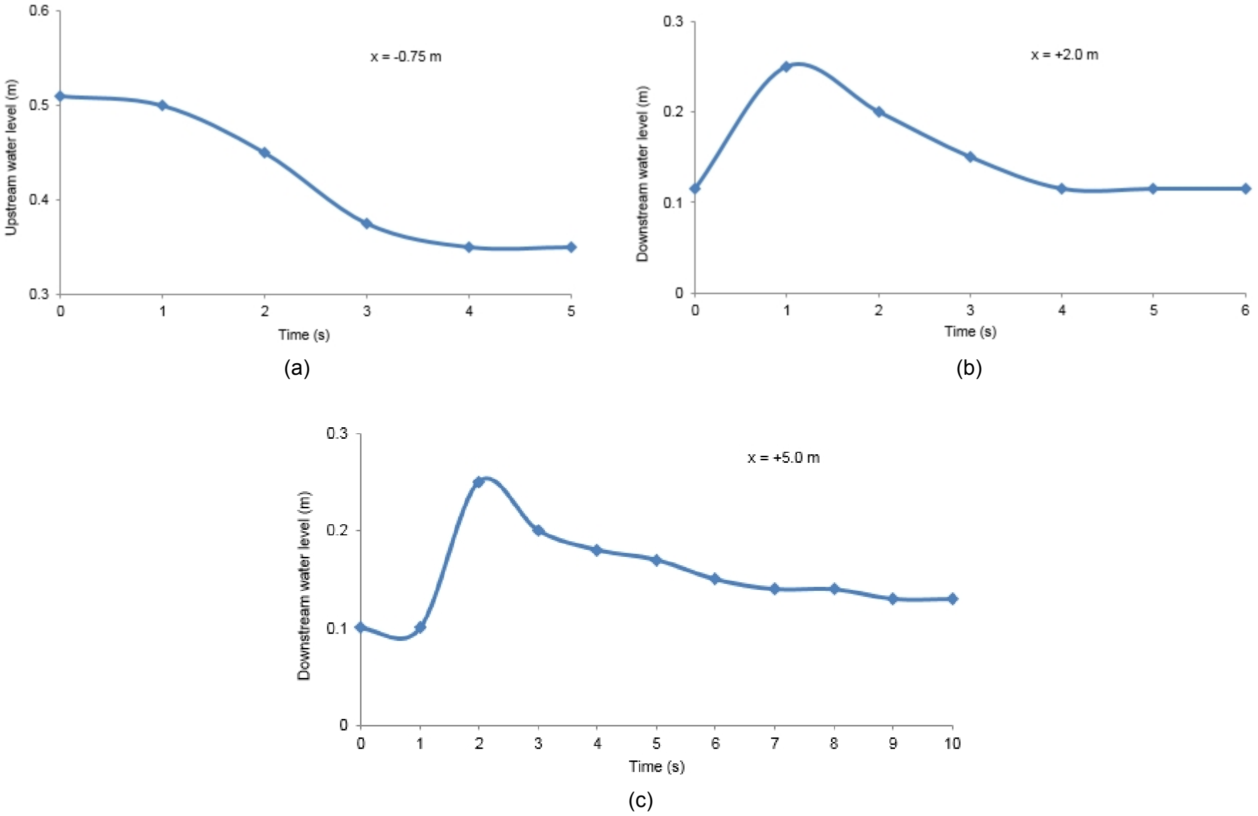


Figure 7. Water level variation at: (a) 0.75 m upstream of gate; (b) 2 .0 m downstream of gate; and (c) 5.0 m downstream of gate.

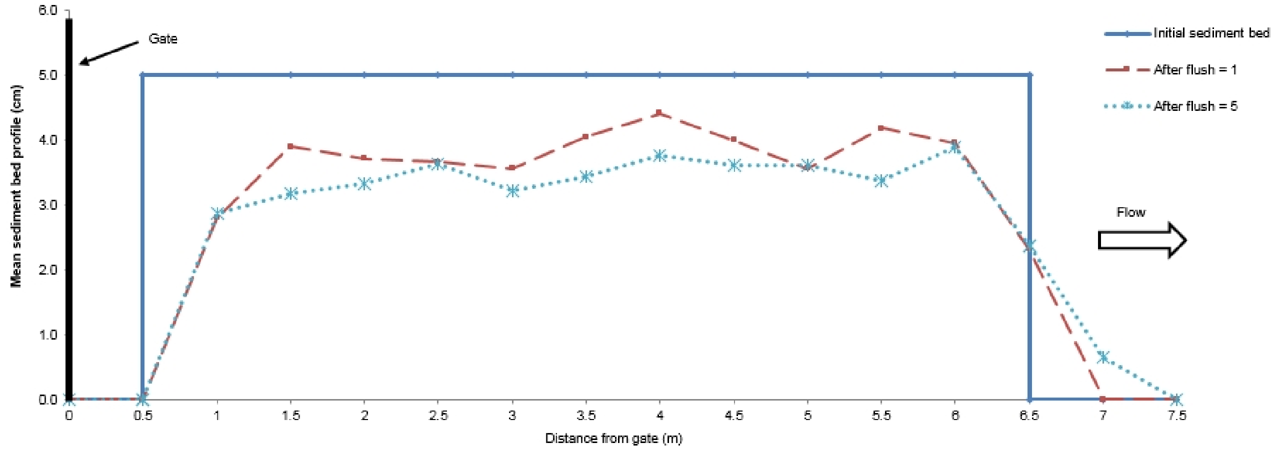
3.2 Effect of flush duration on sediment bed profile

Figure 8 shows the changes of the mean sediment bed profile for the different flushing duration respectively. Generally, the first flush caused the lowering and lengthening of the sediment bed profile for all the flushing durations. Short duration flushing of approximately 3 seconds tend to produce a more uniform mean sediment bed profile along the flume after five flushes (see Figure 8(a)). Longer flushing durations, namely 30 minutes and 60 minutes tend to have two peaks for the mean sediment profile at 2.5 m and 5.5 m or 6.0 m from the gate (see Figures 8(b) and 8(c)) after five flushes.

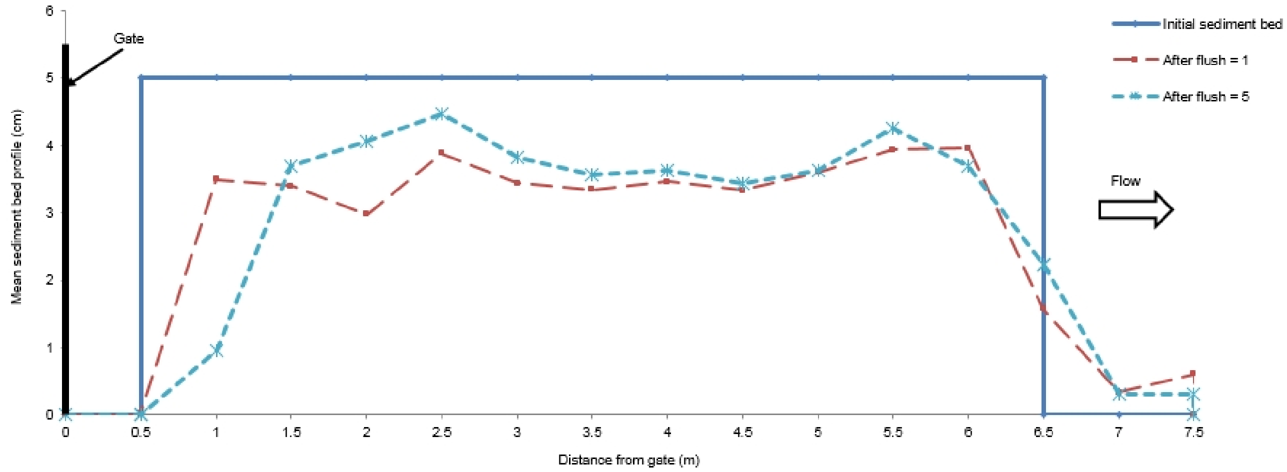
At 2.5 m and 5.5 m or 6.0 m from the gate, the reduction of the velocity were more sudden as shown in the previous Figure 5 where the graph has steeper slopes at these points. Sudden reduction in velocity caused the sediment carried in the flush flow to have the tendency to settle at these points. For short duration flush, the flush flow time was short and sudden, resulting in less time and less sediment particles to settle at these points; hence the more uniform sediment bed profile. Longer flush duration where the flow became uniform and the velocity became consistent (but lower than the velocity during flushing) after certain time allowed more time for the flow to carry and deposited sediment resulting in significant sediment accumulation at these points.

Figure 9 shows the bed profile contours after the fifth flush for short duration flush (3 seconds), 30 minutes and 60 minutes flush respectively. Generally, it was observed that short duration flush produced a more uniform sediment bed front as compared to 30 minutes and 60 minutes flush duration. More erosion was observed to happen at the centerline of the sediment bed front. This could be due to longer flushing duration which produced uniform flow after some time will have higher velocity at the centerline of the flume which caused sediment erosion as compared the lower velocity near the flume wall. This effect was not significant for short duration flush, hence resulted in a more uniform sediment bed front.

Table 1 shows the mean sediment bed front advancement L_s after the first and fifth flush and also the total sediment bed volume after the fifth flush for all the durations used in the current study. It was observed that longer flushing duration resulted in a further mean sediment bed front advancement. Longer flush duration allowed more time for sediment transport processes to happen, hence more sediment particles were carried further from the initial sediment bed position. In terms of sediment total sediment bed volume, short duration flush was observed to be more effective as compared to long duration flush. For short duration flush, the total volume left inside the flume after the fifth flush was 0.2644 m^3 as compared to 0.3040 m^3 and 0.2740 m^3 for 30 minutes and 60 minutes flushing duration respectively. Longer duration flush which allowed for uniform flow and sediment deposition at certain points along the flume, with bed forms formation may cause resistance to the sediment particles movement, hence less sediment being carried out from the flume as compared to short flush duration.



(a)



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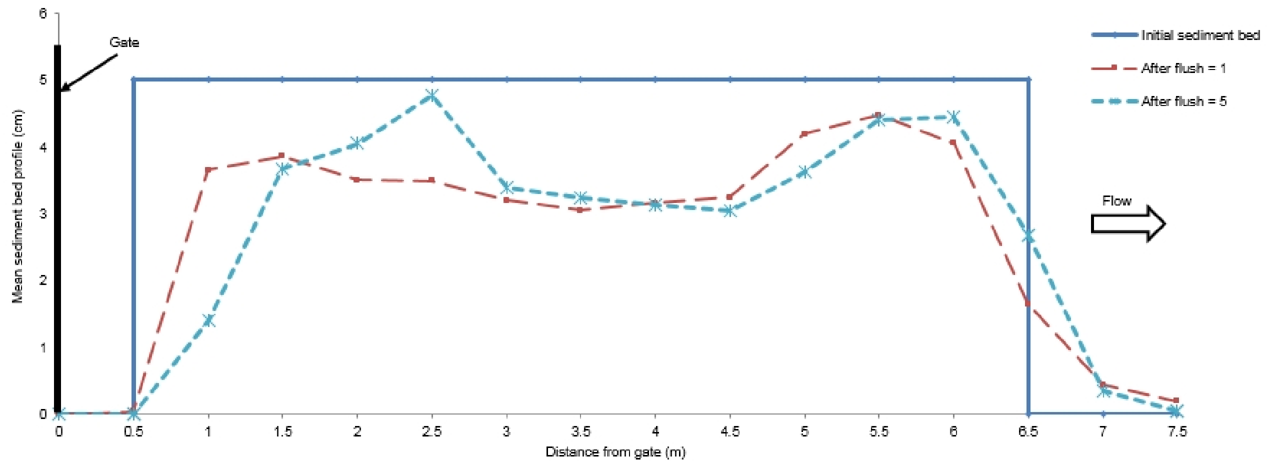
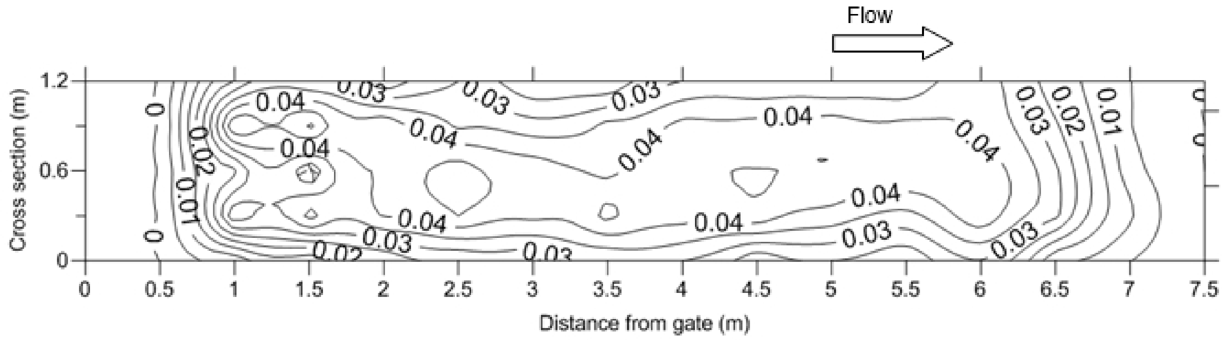
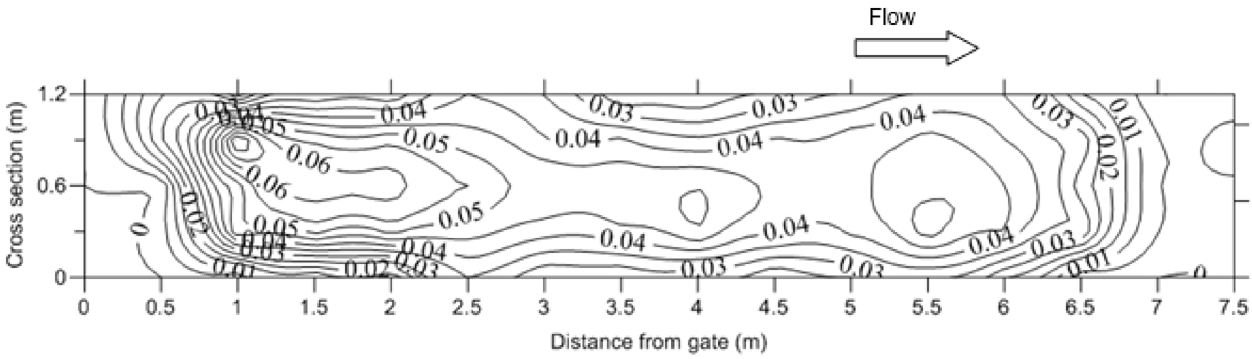


(c)

Figure 8. Changes of mean sediment bed profile for flush duration of: (a) 3 seconds; (b) 30 minutes; and (c) 60 minutes.



(a)



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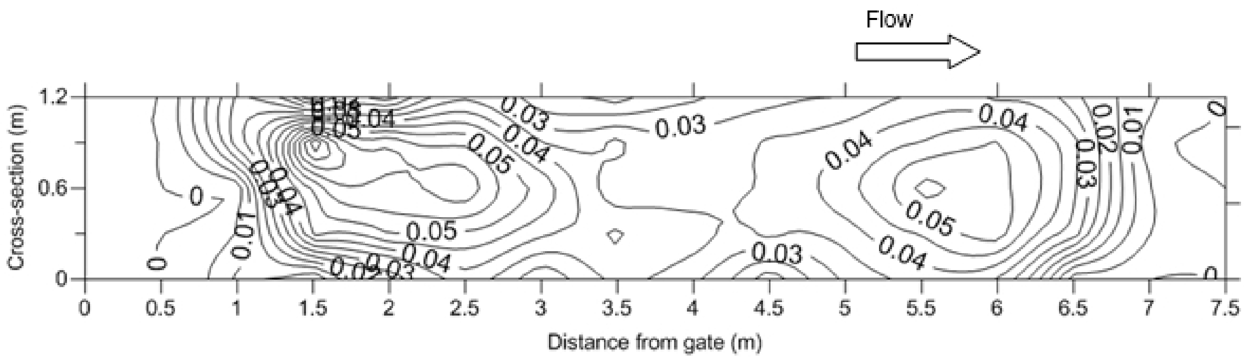

(c)

Figure 9. Contour profile of sediment bed for flushing duration of: (a) 3 seconds; (b) 30 minutes; and (c) 60 minutes.

Table 1. Mean sediment bed front advancement and total sediment bed volume after the fifth flush.

Gate opening duration	Mean sediment bed front advancement L_s (m)		Total sediment bed volume after 5th flush (m^3)
	After 1st flush	After 5th flush	
3 seconds	0.10	0.37	0.2644
30 minutes	0.12	0.45	0.3040
60 minutes	0.22	0.48	0.2740

4 CONCLUSIONS

From this study, it can be concluded that short flushing duration is more efficient in terms of the total volume of sediment being removed from the flume as compared to long flushing duration. However, in terms of mean sediment bed front advancement, longer flushing duration will moved the sediment bed front further as compared to short duration flush. With the knowledge from the current study, more efficient flushing devices can be designed to have a short flushing duration with higher flushing operation frequency. The results from this study needs to be confirmed by further experimental work and numerical modelling. Further study in terms other factors that might affect the flush efficiency such as length of initial sediment bed and opening size of the flushing devices can be conducted. With better understanding of flushing properties from this study, optimum design for flushing devices that promote efficient removal of sedimentation can be proposed.

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