Sediment Flushing using Tipping Flush Gate in an Open Storm Concrete Drain – A Case Study in Nibong Tebal, Penang, Malaysia

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ABSTRACT: This paper presents a case study of using a tipping flush gate for sediment flushing in an open concrete storm drain. The study was conducted in an open concrete storm drain located in Taman Pekaka, Nibong Tebal, Penang, Malaysia with the objectives to study the scouring effect of flushing on sediment in the drain and also the feasibility to use tipping flush gate in an open drain system. The monitoring period was from 14 November 2012 to 15 March 2013. Sediment profile was measured after each operation of the gate or rainfall event using a simple stick. Results from the study shows that the flush gate is efficient in sediment removal with longer flushing operation time than the study on Hydrass gate in closed sewer system. However, problems such as debris caught at the gate, accumulation of debris behind the gate and water ponding causing mosquito breeding need to be address before the gate could be implemented for an open drain system.
KEY WORDS: Flush gate, Open drain system, Sediment flushing, Storm drain, Sewer system.

1 INTRODUCTION

Sedimentation in sewer systems and open concrete drains had caused problems such as reduction of hydraulic capacity, odours due to anaerobic processes and source of pollutants during storm events (Bertrand-Krajewski *et al.*, 2003). Sediments originate from rooftops, streets and highways, construction sites, commercial and industrial parking lots and runoff (Fan *et al.*, 2003). Sediments in storm sewers are mainly inorganic and non-cohesive (Butler *et al.*, 2003). Study on the samples of sediment collected from open storm drains in Malaysia has generally shown it were predominantly sand and tend to cause blockage between 0.10% to 38.19% of the flow area of the drain (Ab. Ghani *et al.*, 2000;Bong *et al.*, inpress)

Various techniques have been developed especially in European countries to clean sediments in sewers. Of the various techiques; the one based on hydraulic effects mainly consists of creating a flushing effect by discharging a volume of water during a short period of time. The flushing effect could be created by storing water in upstream chambers and discharged through a gate, tipping bucket located above water level or mobile tipping plates like Hydrass gate (Chebbo *et al.*, 1996;Lorenzen *et al.*, 1996). These devices produce flushing waves to scour and transport sediments and represent an automated cost-effective solution for sewer cleansing. A study on flushing in a man-entry sewer in Lyon, France has shown that the Hydrass flushing gate is efficient and the mass of sediments appears to move downstream linearly with number of flushes (Bertrand-Krajewski *et al.*, 2006). However, for developing countries like Malaysia which use open storm drains system (Bong *et al.*, 2013) instead of closed combined sewer system; removal of sediments often involves manual handling which is labor intensive and costly.

This paper highlights a case study of using a tipping flush gate for sediment flushing in an open concrete storm drain. The study deals with two objectives: i) on site experiments on sediment scouring by means of a tipping flush gate; ii) the feasibility and problem faced in using tipping flush gate in an open drain system. Since the condition of flow in open storm drain could be quite different with closed sewer system; it is hope that this paper will fill the gap in the literature on the usage of flushing devices in open storm drain system which is lacking.

2 STUDY METHODS

2.1 Site Description

The experimental site is an open concrete storm drain of dimensions 0.8m (depth) x 1.2m (width) located in Taman Pekaka, Nibong Tebal, Penang, Malaysia (see Figure 1) which is an urbanised area consisting of commercial and residential areas. The drainage area for the chosen drain is about 0.11 km^2 with roughly 90% impervious area. Only 40 m of the drain stretch were chosen for monitoring purpose. The mean invert slope is very flat (0.00021m/m). For reference purposes, rainfall data was obtained from an automatic raingage installed in Universiti Sains Malaysia which is less than 1 km from the site which records continuous data at 5 minutes interval.

Figure 1 Site map of study area in Taman Pekaka, Nibong Tebal, Penang, Malaysia with the insert photo showing the drain stretch chosen for this study.

2.2 Site Installation

For the purpose of monitoring the site, two CCTVs had been installed on top of a tree about 40 m downstream from the flushing gate. One CCTV was installed for the purpose of capturing the footage of the gate operation while another CCTV was to monitor the water level at 40 m downstream of the gate. Stick gages were also installed at 10 m interval along the chosen drain stretch. Figure 2 shows the installation on site.

Figure 2 Site installation: CCTVs (left); stick gage (middle) and tipping flushing gate (right).

2.3 Measurement of Sediment Profiles

Since the initial drain cleaning carried out on 1 August 2012, sediment was let to accumulate until 14 November 2012 when the tipping flush gate was installed. Some sediment samples from the drain was also collected randomly just outside the monitoring stretch for sieve analysis (BS1377: Part 2: 1990) and determination of density (ASTM D854-10). After the installation of the tipping flush gate, sediment profile was measured after each operation of the gate or after a rainfall event. The sediment profile was measured manually using simple stick attached with a ruler with an uncertainty of about 0.5 mm. The sediment profile was measured with a space step of 2 m along the 40 m monitoring stretch and at every 0.15 m for each cross-section. The mean height at each cross-section was calculated. To further study the scouring effect of the tipping flush gate, sand of size d_{50} = 1.11 mm with specific gravity of 2.55 was added into the drain on 26 December 2012 starting from 2 m downstream of the gate with the sand bed extended for 4 m in length. The monitoring period was 4 months from 14 November 2012 to 15 March 2013 covering the beginning and ending of the wet season.

2.4 Tipping Flush Gate

Figure 3 shows the front and isometric view of the tipping flush gate used in this study. The gate was made from plasboard (density = 1092 kg/m^3). The gate was designed to open up to 30° from the horizontal. During operation of the gate, water transported in the drain is stored behind the gate (storage phase) until water level reaches 0.51 m from the drain bed at which the gate will tip and open. This rotation is due to the change of momentum due to the force of water level upstream of the gate. When the gate opened, the stored volume is rapidly discharge and creates a flush (flushing phase). The force from the receding water level will push the gate to close. The gate will close when the water level recedes to about 0.35 m from the bed.

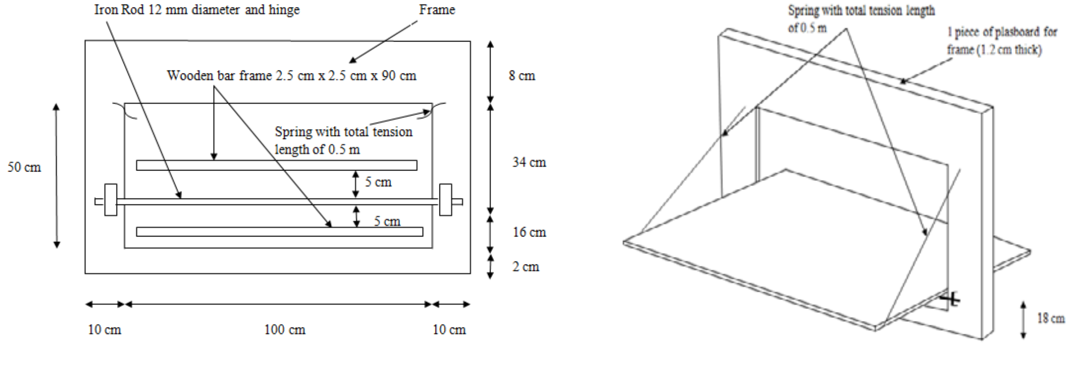

Figure 3 Front view (left) and isometric view (right) of tipping flush gate used in this study.

3 RESULTS AN DISCUSSION

3.1 Sediment Characteristics

From the sieve analysis of the natural sediment samples randomly collected from the drain, it was found that the d_{50} = 1.06 mm with a specific gravity of 2.52. These values correspond to usual literature values (Ab. Ghani *et al.*, 2000;Bong *et al.*, inpress). The sediment sample was mainly inorganic and non cohesive with predominantly sand by 68.4%, gravel at 30.1% while silt and clay at 1.5%.

3.2 Tipping Flush Gate Operation

Between 14 November 2012 (gate installation date) to 13 February 2013 (the last time the gate operate during the monitoring period), there were a total of 39 rainfall events recorded by the rain gage in Universiti Sains Malaysia with a duration of more than 30 minutes with intensity between 3 mm/hr to 67.7 mm/hr. The tipping flush gate was observed to only operate during or just after the rainfall event. The tipping gate operated 18 times during this period with the duration of flushing ranging from 22.8 minutes to 176.5 minutes before the gate automatically closed. The flushing duration was longer compared to the flushing duration for Hydrass gate in a sewer system such as the study in Lyon, France where the flushing duration was about 30 seconds (Bertrand-Krajewski et al., 2006) to 3.5 minutes (Bertrand-Krajewski et al., 2003). This could be due to water could move into open drain system more directly during rain as compare to sewer system, thus maintaining the water level during flushing longer. Table 1 shows the gate operation time together with the corresponding rainfall duration and intensity. Figure 4 shows the photos as captured by the CCTVs during the operation.

Table 1 Gate operation time with the corresponding rainfall duration and intensity

Date	Gate opening time	Rainfall duration (min)	Rainfall intensity (mm/hour)
19/11/2012	1:31 pm	90	43
2/12/2012	7:19 pm	n/a	n/a
10/12/2012	4:17 pm	160	22
12/12/2012	8:30 pm	n/a	n/a
13/12/2012	3:14 am	n/a	n/a
14/12/2012	3:37 am	145	28.5
15/12/2012	4:19 am	n/a	n/a
15/12/2012	6:39 pm	250	16.1
17/12/2012	5:22 am	125	9.6
20/12/2012	6:11 pm	n/a	n/a
22/12/2012	5:19 pm	n/a	n/a
27/12/2012	5:59 pm	140	33
2/1/2013	4:48 pm	135	8.6
25/1/2013	3:23 am	190	18.1
31/1/2013	7:59 pm	n/a	n/a
9/2/2013	5:17 pm	40	67.7
12/2/2013	2:31 pm	65	63
13/2/2013	7:58 pm	55	57.5

Figure 4 Tipping flush gate in operation: the flush wave created moment after the gate open (left); the flush wave reaching the end of the monitoring stretch 40 m from the gate about 20 second after the gate open (right).

3.3 Sediment Flushing

The sediment flushing experiment was initially conducted for the sediment that was naturally existed in the chosen stretch when the tipping flush gate was installed on 14 November 2012. Figure 5 shows the changes of the mean sediment profile for the period 14 November 2012 to 26 December 2012. There were 11 flushes operation by the gate during this period. The flushing gate is efficient and it was observed that after 11 flushes, the sediment level in the monitored stretch was not significant.

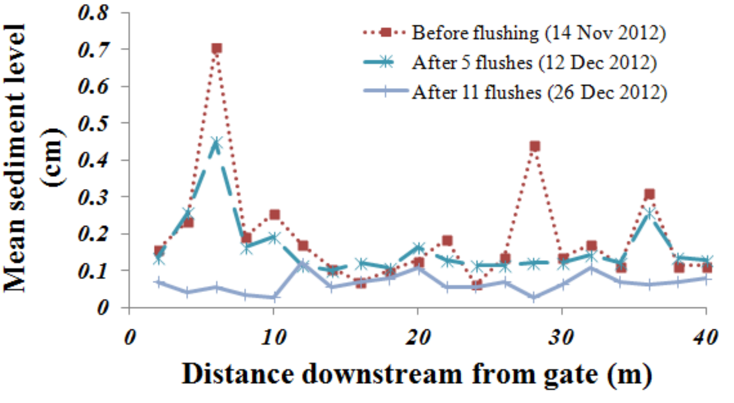

Figure 5 Changes of mean sediment profile with number of flushes for the period 14 November 2012 to 26 December 2012.

On 26 December 2012, about 1000 kg of sand was added into the monitored stretch starting from 2 m in front of the gate and the sediment bed extended for 4 m. For the period 26 December 2012 to 13 February 2013; the gate operated seven times and the movement of the sediment profile is as shown in Figure 6. The scouring effect from the flushes seems to produce lowering and lengthening of the initial bed deposit.

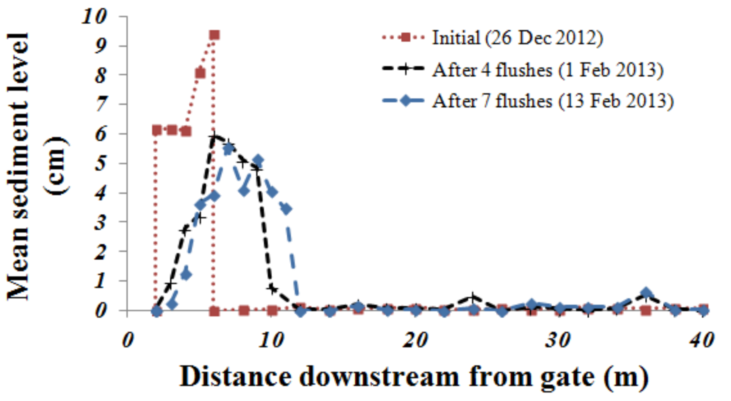

Figure 6 Changes of mean sediment profile with number of flushes for the period 26 December 2012 to 13 February 2013 after sand was added into the drain.

3.4 Feasibility to use Tipping Flush Gate Onsite

Though the tipping flush gate is efficient in sediment removal, some problems were observed in the usage of the gate onsite. For open storm drain system, debris such as dry leaves, plastic bottles, plastic bags, etc tend to get into the drain system more easily as compare to closed sewer system. These debris sometimes tend to caught at the gate thus preventing the gate from closing properly (see Figure 7). Debris also tends to accumulate behind the gate during in between period of the gate operation. A proper debris/litter management is needed if this tipping flush gate is to be installed in an open storm drain system such as installation of trash rack and also to educate the community so as not to throw litters into the drain system. Another concern is the ponding of water behind the gate between the period of gate operation could breed mosquito.

Figure 7 Litter caught at the gate preventing the gate to close properly (left); accumulation of debris behind the gate during in between period of gate operation (right).

4 CONCLUSIONS

The study in Taman Pekaka, Nibong Tebal, Penang, Malaysia from 14 November 2012 to 15 March 2013 has proven that tipping flushing gate is efficient in removing sediment for an open storm concrete drain system. The gate has longer flushing duration if compared to the flushing duration of Hydrass gate in closed sewer system. However, problems such as debris caught at the gate, accumulation of debris behind the gate and mosquito breeding need to be address before the gate could be implemented for an open drain system.

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