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SEWER SEDIMENT

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.

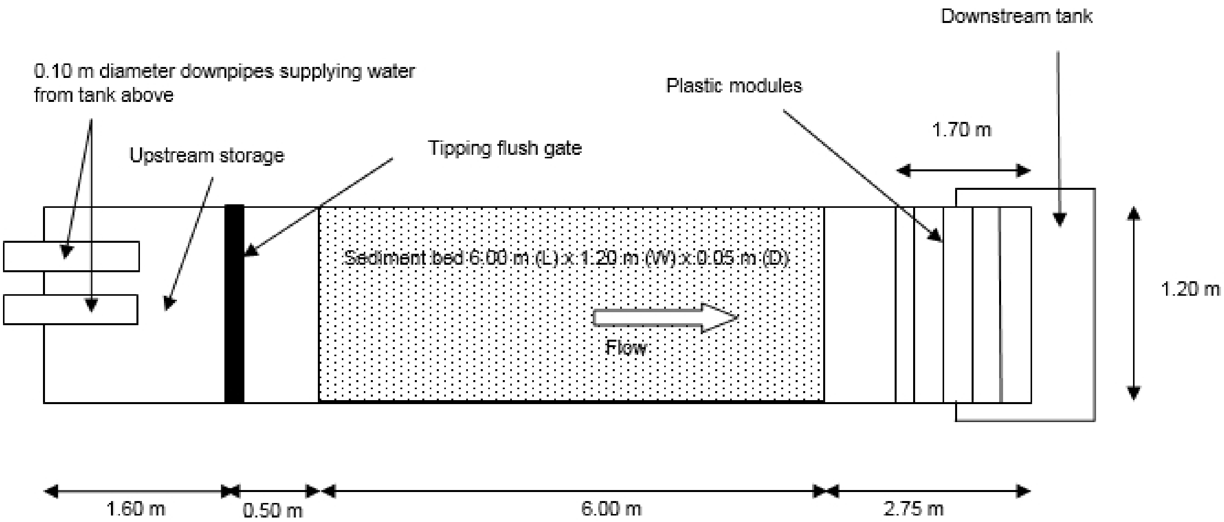


Figure 2. Schematic diagram for the flushing experiment (not to scale).

(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.

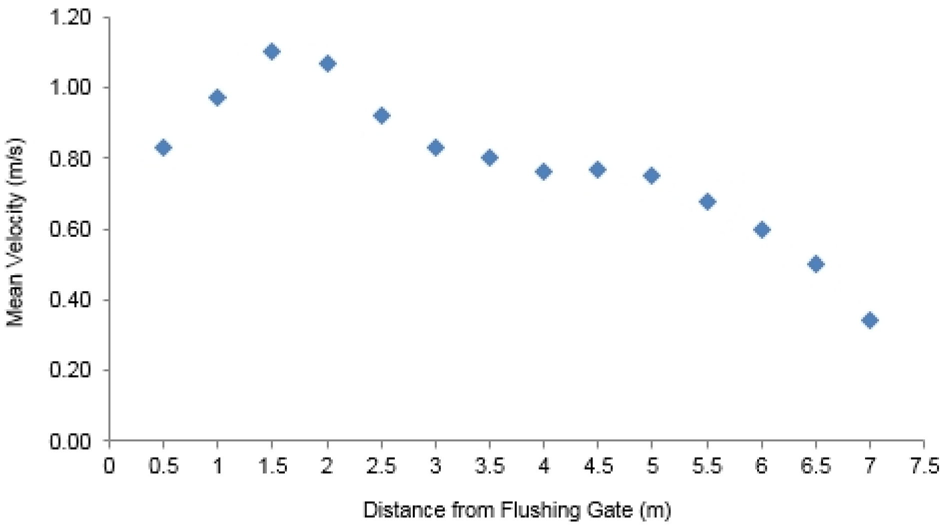


Figure 6. Variation of mean velocity of flush wave along the flume.

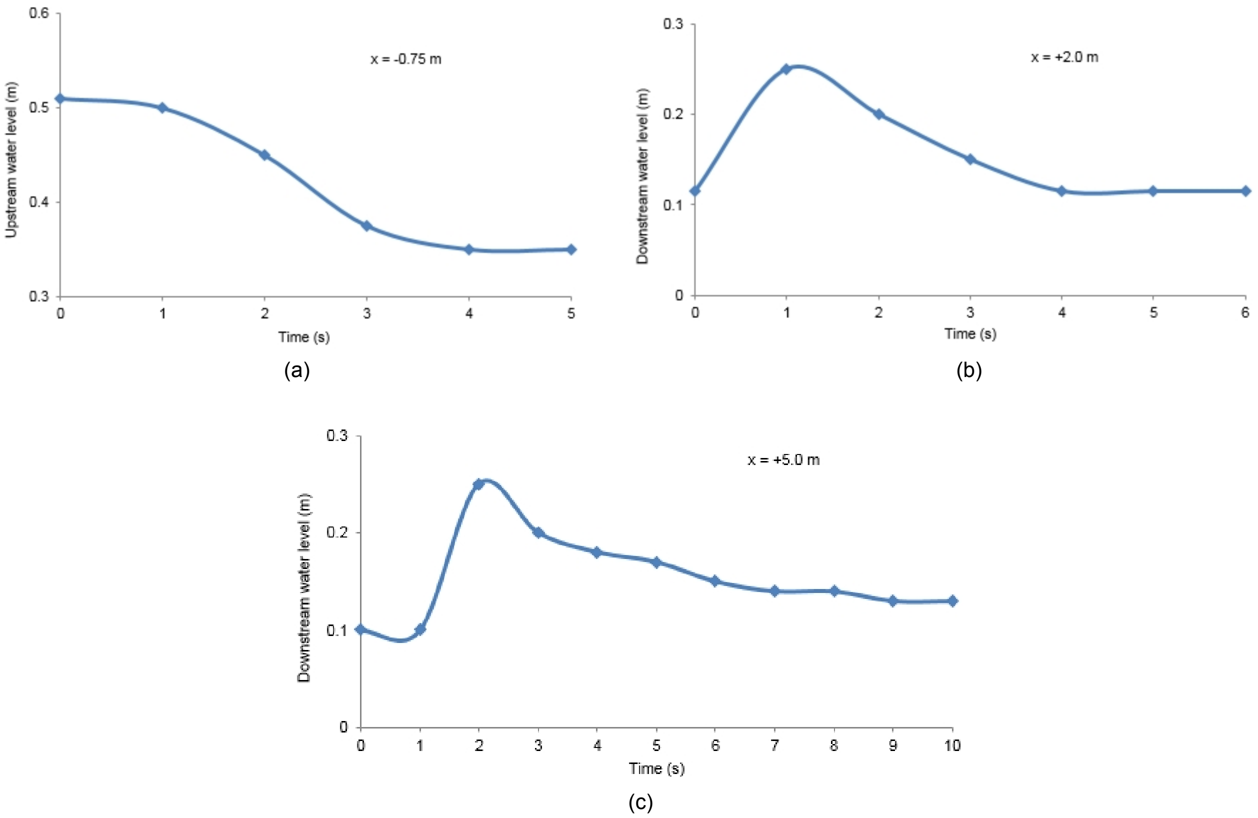


Figure 7. Water level variation at: (a) 0.75 m upstream of gate; (b) 2 .0 m downstream of gate; and (c) 5.0 m downstream of gate.

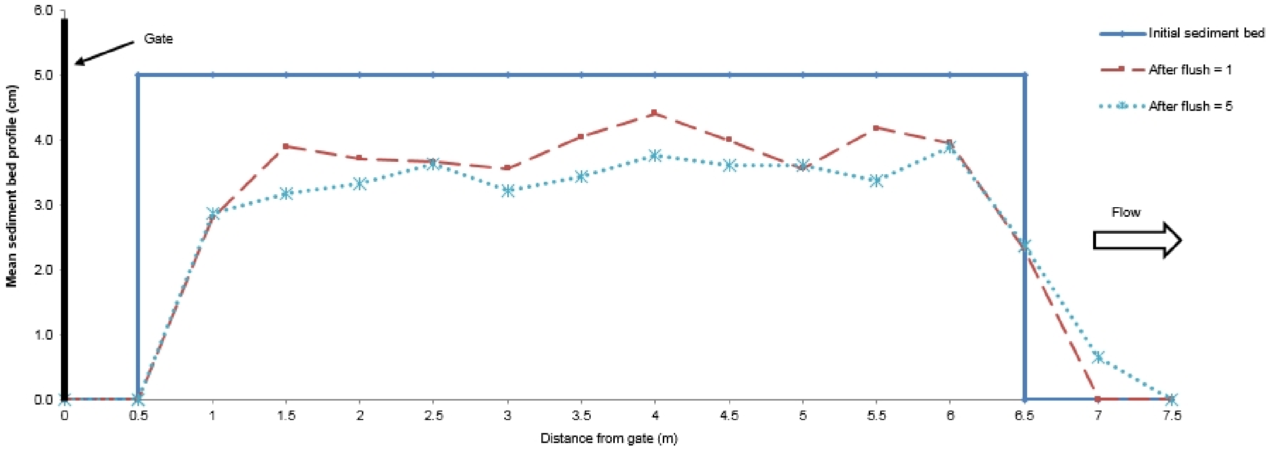
3.2 Effect of flush duration on sediment bed profile

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.

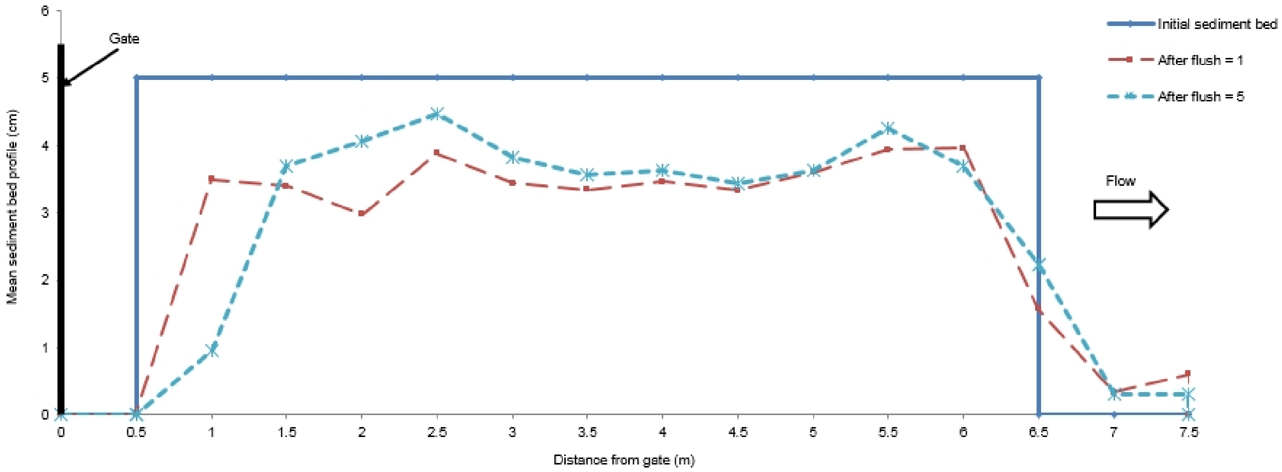
At 2.5 m and 5.5 m or 6.0 m from the gate, the reduction of the velocity were more sudden as shown in the previous Figure 5 where the graph has steeper slopes at these points. Sudden reduction in velocity caused the sediment carried in the flush flow to have the tendency to settle at these points. For 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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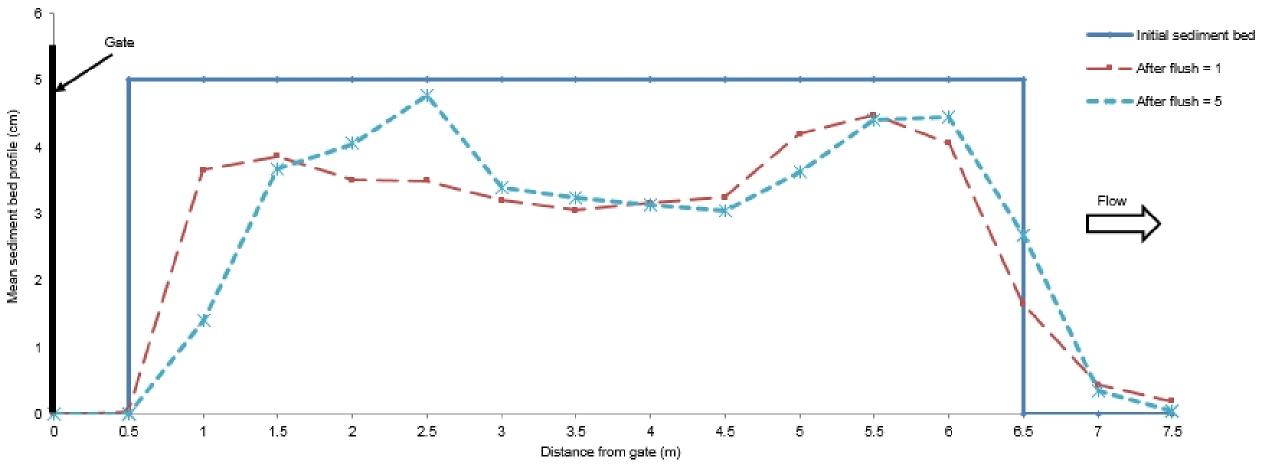
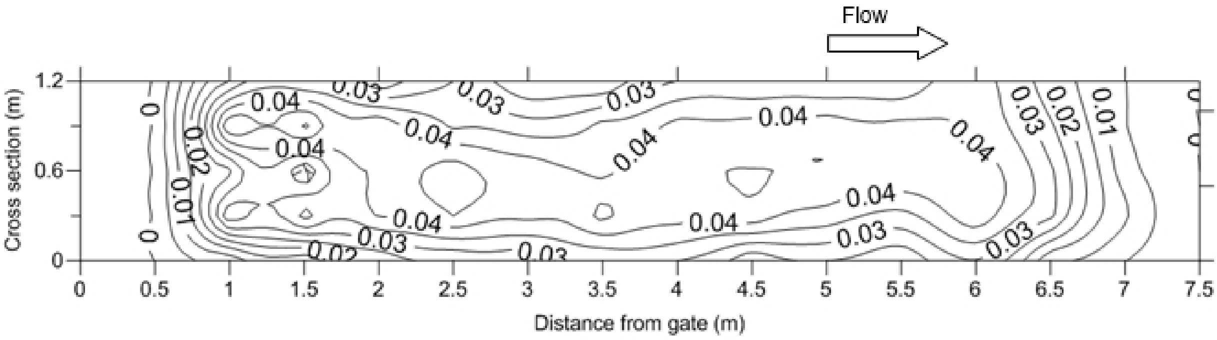
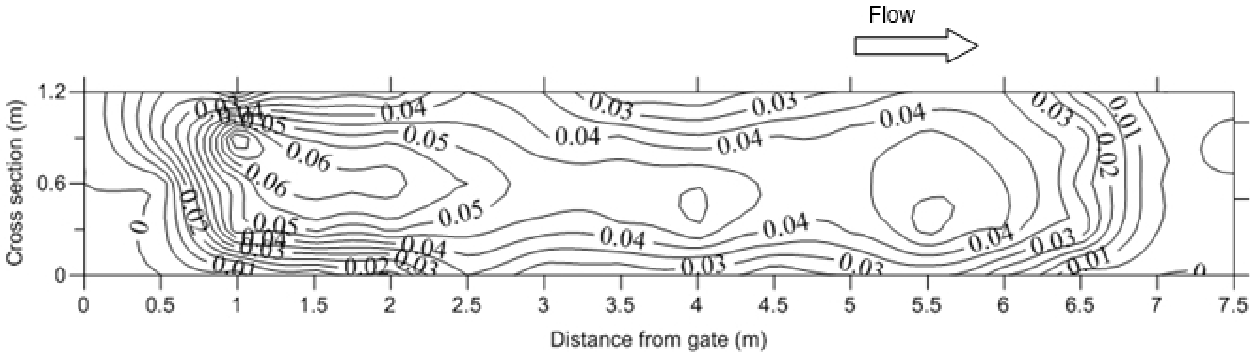


(c)

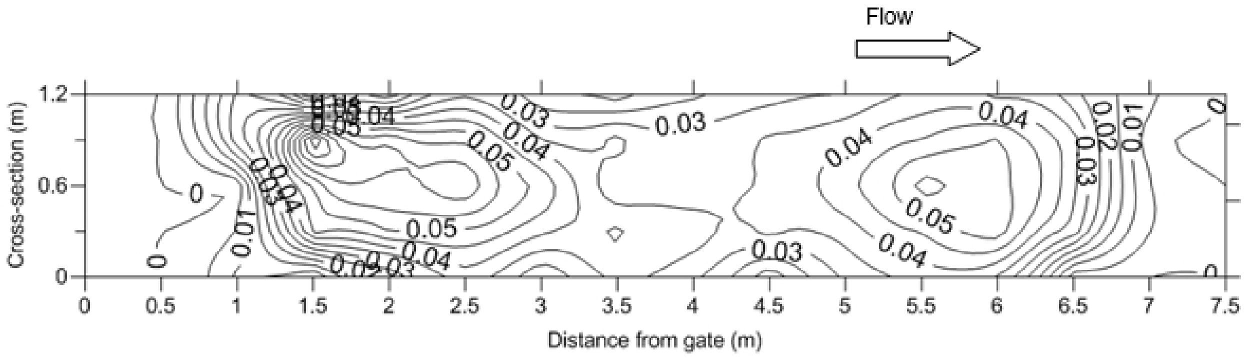
Figure 8. Changes of mean sediment bed profile for flush duration of: (a) 3 seconds; (b) 30 minutes; and (c) 60 minutes.



(a)



(b)



(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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PHYSICAL TEST METHOD RESEARCH ON COUNTERMEASURES FOR SEDIMENT DEPOSITION IN INTERCEPTING DRAINAGE CULVERT SYSTEM

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ABSTRACT

As a necessary choice for China's urban drainage system in a fairly long period, combined drainage system is an effective solution to solve the problem such as mixed underground pipe network and non-point source pollution due to dry season and light rain. Accompanied by waste water in dry season and light rain, muddy sediment and garbage can enter the sewage interception box culvert drainage system easily to produce unfavorable siltation. Based on a combined technical means including prototype data analysis, sedimentation sampling detection and reasonable simulation schemes for boundary conditions of sewage interception drainage system, a physical model was set up to study the causes and countermeasures for sediment deposition, Moreover, the feasibility of hydrodynamic and scouring sediment deposition in intercepting drainage system by dry season sewage and rainy season floods was studied with the aid of physical model experiments. Under different rainfall and flow conditions, optimal scheduling strategy of interception box culvert ware proposed for reducing sedimentation and dredging scheme. Results show that the physical model test method in this paper can be applied to sedimentation countermeasures research on similar sewage interception culvert drainage system.

Keywords: Combined drainage system; sewage interception box culvert; sedimentation deposition; physical model; dredging countermeasures.

1 INTRODUCTION

Combined drainage system and complete diversion system are widely applied in urban sewage drainage system. With the increasing urbanization, the urban wastewater discharge has exceeded the design capacity of the drainage system ubiquitously. Following the absent of drainage pipe network construction, operation, maintenance and residents' awareness of water environment protection, the pipe networks of rain and the sewage often appear to be mixed complicatedly. As a result, the sewage flow into rain pipeline, rivers and lakes in urban area (Zhao et al., 2008). The practice of combined drainage system has proved that the urban sewage (domestic sewage and industrial waste water) and non-point source sewage (pollution from initial and light rain) can be completely intercepted, then the sewage will be purified in sewage treatment plant to satisfy discharging standard in China, which is an effective solution to solve the problem originated from mixed underground pipe network and non-point source pollution originated from initial and light rain (Yan et al., 2010; Chen et al., 2012). In dry season, initial and light rain day, carrying sand, very fine sand, muddy sediment and domestic garbage from sewage can flow into the intercepting drainage culvert system easily. Moreover, the complex component sediment will become compact and hardened in the enclosed space which is difficult to be scoured by natural flow or artificial dredging. So, the operation and function of sewage box culvert system and water intake facilities for sewage treatment plant will be restricted negatively.

The research on sewage box culvert system usually focuses on drainage system (Wang et al., 2007), the pipe network transformation plan, and the optimized dispatch (Lamprea and Ruban, 2011; Yu et al., 2013; Schroeder et al., 2011). However, the model test on dynamic characteristics and countermeasures for sediment dredging are rarely reported. Based on the experiment of sediment component in sewage interception drainage system, a reasonable simulation material for the prototype sediment was selected through empirical formula calculation and scouring test in flume. A physical model was built up to research the countermeasures for sediment deposition in drainage culvert system by means of fixed bed and moving bed model tests under different flow conditions in dry season and flood season.

2 ANALYSIS OF URBAN DRAINAGE SYSTEM

2.1 Classification characteristics of urban drainage system

The urban drainage system has three representative classifications such as complete separation system, combination system and mixed system. Domestic sewage, industrial waste water and rainwater use the same drainage system known as the combined system. The mixed system includes both the combination system and the separation system (Zhou et al., 2015). There are six characteristics in intercepting drainage system (Wang et al., 2015): (1) all of the non-point source pollution originated from dry season and light rain will be intercepted for sewage treatment, however, the water for moderate and heavy rain will not be purified in sewage treatment plants; (2) manufacturing cost of intercepting drainage system is less by using currently available combination system; (3) the water from domestic sewage and light rain can be used for scouring the sediments in intercepting drainage culverts; (4) sewage treatment plant is required to be constructed to meet the sewage amount from the intercepting drainage culvert; (5) the water quality change much after flowing into intercepting drainage culvert, storage tank and sewage treatment plant step by step; (6) since the flow and velocity in culvert are small in dry season, sewage culvert dredging project is necessary. Intercepting drainage culvert system is shown in Fig.1. Sewage interception project in Baihua River is shown in Fig.2.

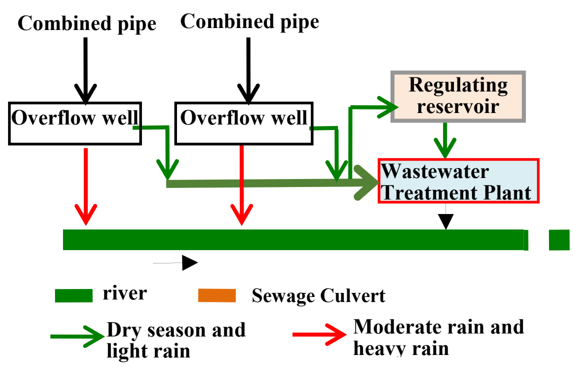

Figure 1. Interceptive combined drainage system.

Figure 2. Sewage interception project for Baihua River in Shenzhen.

2.2 Intercepting drainage culvert system

Under the premise of ensuring the flood discharge capacity, intercepting drainage culvert system is usually established at the corner of the river channel. Operating conditions include: (1) dry season mode, all the sewages in the dry season are intercepted and send to the sewage treatment plants until they meet the discharge standard; (2) light rain mode (≦7mm/hr, initial rain within 1.5hr), the mixing sewage is intercepted by the intercepting drainage culvert and sent to storage tank, then the sewage will be sent to sewage treatment plants after rain; (3) Heavy rain mode(＞7mm/hr, rain more than1.5hr), when the rainfall exceeds the total capacity of culverts and storage tanks, the sewage water inlet in the branch is closed, because the sewage water has been diluted by the heavy rain which is unnecessary to be purified in sewage treatment plants. In fact, the condition where intercepting drainage culvert system accounts for all the drainage pipe network is more than 70% ~ 90% in Germany, Britain, France, Japan and other countries.

3 CAUSE ANALYSIS ON THE SEDIMENT DEPOSITION IN DRAINAGE CULVERT SYSTEM

3.1 Characteristics of sediment distribution in intercepting drainage culvert

Intercepting drainage culvert engineering of Shenzhen Guanlan River was put into trial operation in April 2009, including the interception, storage, treatment and water supply engineering. Sediment concentration is high in main stream (at the junction of Baihua River, the suspended solid is 34mg/L in dry season and 41.8mg/L in flood season, while the sediment concentration is 0.07kg/m^3 in dry season and 0.09kg/m^3 in flood season). Characteristics of sediment distribution includes: (1) the deposition thickness was 1.08m~1.80m in

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the section from the bridge in Guihua road to the control gate in the end, and sedimentation had accounted for 30%~45% of the culvert flow section; (2) damming gate in emergency sewage treatment plant and stack weir in inlet pipe of Guanlan sewage treatment plant have effects on damming and resisting sediment, that is why the sediment deposition in the culvert is so serious at the upstream. (3) Deposition thickness, sedimentation volume at downstream increases significantly for the gradient decrease, sediment increase and velocity decrease; (4) the deposition thickness and amount increase gradually, and sediments deposit quickly after dredging engineering. Guanlan River Basin sewage culvert section deposition is shown in Figure 3, the main sewage culvert sediment measurement results are shown in Table 1.

(a) The position of sewage interception in Guanlan RIVE (b) the position of terminal control sluice

Figure 3. The situation of sediment deposition in sewage interception culvert system in Guanlan River.

3.2 Analysis of the composition of sediment in the culvert

Sediment sampling photos and gradation curves of the culvert in Guanlan River in April 2015 are shown in Fig.4~Fig.5. Component test result shows that: (1) the main sediment component in the section from the bridge in Guihua road to the control gate in the end is coarse sand, and the rest are fine sand and silt; (2) the particle size range is 0.005mm~8mm, and the sediment accounted for 65% of the total sample quality; (3) the particle sizes from the upstream to the downstream are as follows: 1.754mm, 1.148 mm and 0.051mm, and the non-uniform coefficients of sediment are 2.09, 2.17 and 4.12. The composition of the sediment is complex which includes life waste, construction waste and debris (plastic bags, steel wire, branches, etc.); (4) most of the black silt comes from dry season ,because in the dry season, domestic sewage bring rubbish and wash load into the culvert (5) under the rainy season and flood, if the main branch of the river is not closed in time, the flood would carry sand and garbage from branch and sewage outfall into the main interception culvert, so most of the coarse sand comes from the rainy season or flood season.

（a）Pile No.CR4+465 （b）Pile No.Z0+300 （c）storage tank of Guanlan RIVER

Figure 4. The photos of sediment samples in sewage interception culvert in Guanlan River.

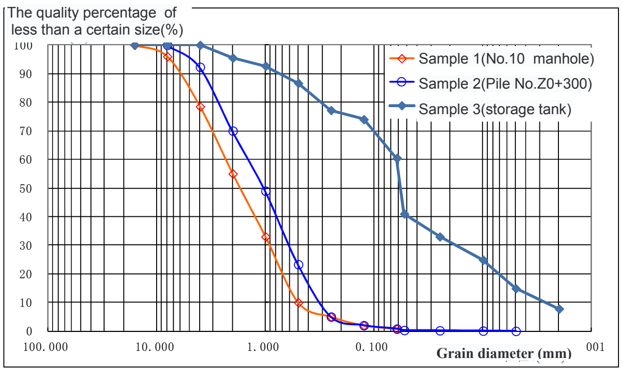

Figure 5. Sediment grading curve of the sediment in sewage interception culvert.

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3.3 Analysis on the cause of sedimentation of interception drainage culvert

The upstream of the Guanlan River Basin cannot control the soil erosion effectively, so the light rain carry sediment into the culvert system continuously; (2) the main sewage interception entrance of the tributaries failed to build an effective sediment retaining and sedimentation facilities, and the suspended sediment pool failed to implement the regular dredging system. In the rainy season, the gates of intercepting culverts and rubber dams are not managed according to the rainy season conditions; (3) due to the partial blockage of channel, the flow velocity in culvert (0~0.9m/s) is much smaller than the designed flow velocity (1.6~1.9m / s). Since the composition of the sediment is complex and the gradation is good, in the siltation of dry and wet alternated in dry season and rainy season, the sediment is easy to become hardened which has larger scour resistance; (4) intercepted box culvert is a relatively closed channel, and it does not set a reasonable export for deposition, so the confined space is not conducive to the implementation of mechanical and artificial dredging; (5) the water blocking effect from sluice gate, stack weir and the gate of terminal aggravates the siltation in the culvert.

4 PHYSICAL TEST OF INTERCEPTING DRAINAGE CULVERT

The Physical Model Task includes: (1) analysis and design of model similarity theory; (2) selecting a reasonable roughness scheme; (3) precise measurement and control system (software and hardware) on inflow boundary and; (4) modeling sand for starting velocity.

4.1 Model scale and roughness

The section of downstream of Guanlan River intercepting drainage culvert which deposition is significant was chosen to be the model research section. The upper boundary is located at the bridge of Guihua road and the lower boundary is located at culvert outlet in the downstream of Guanlan Rive, and the total length is 3.6km. Based on the gravitational similarity criterion and “*Water engineering (conventional) model test procedure*” in China, the plane scale selected for this normal model was 25. The roughness of prototype reinforced concrete is 0.014. Moreover, the roughness ratio is 1.71. So, the roughness value of model is 0.0082. The plexiglass can satisfy the similarity requirement of roughness. The model layout is shown in Fig.6.

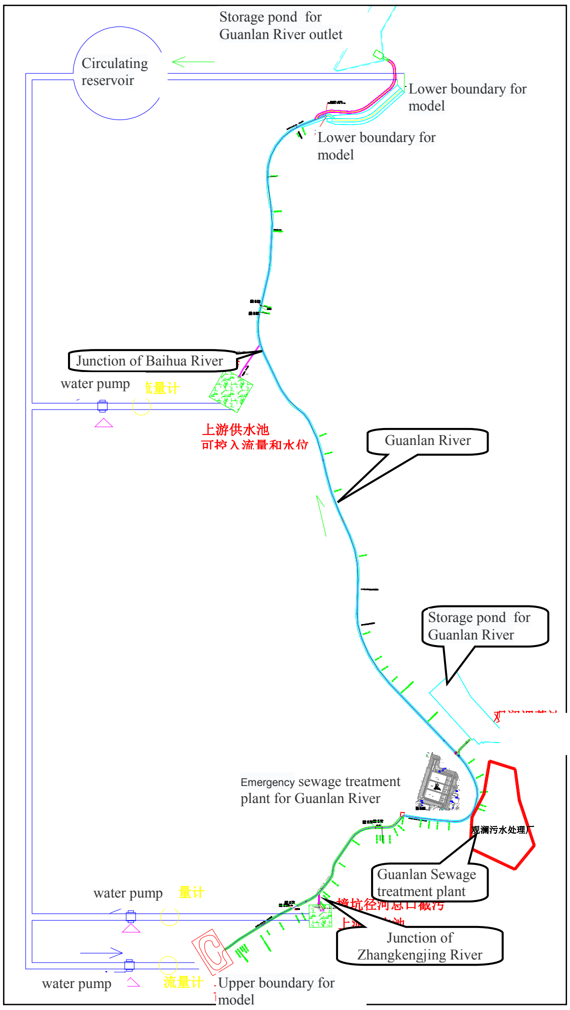


Figure 6. Floor plan of physical model.

4.2 Model boundary control

The water level and flow of upper boundary is controlled by submersible pump, float flowmeter, scale water level meter. According to the characteristics of the each branch of drainage culvert, the different generalization and simulation schemes were adopted.

(1) Considering the site size, the upper boundary of the model was modeled by the "multiple-fold-twisted channel" to simulate the hydraulic gradient, hydrodynamic characteristics and water storage capacity of the intercepting culvert above the upper boundary. The section of the twisted channel is as large as the intercepting culvert, and the upstream water supply pipe was set at the end of the twisted channel.

(2) The sewage flows into the main culvert through two circular culverts (D=1.2m) (in the pile CR4 +195) at the junction port, and two interception control gates whose sizes are 2.2 * 1.6m were set up at the imports, a overflow weir was set up at Zhangkeng River estuary. A reservoir with unilateral overflow weir simulated the hydraulic characteristics of Zhangkeng River Estuary and the Plexiglass tube was used to simulate the water delivery culvert. Flow control was applied for dry season and initial light rain while the overflow weir was applied for flood season.

(3) The sewage interception confluence of the branch named Baihua River access main interception box culvert through two rectangular culverts (3*2.5m)(at Pile number (Z1+888)). Grit chamber and interception control gate with two holes were set at the import and the inflatable rubber dam was set at the estuary. The model used "multiple Z- twist waterway" to simulate the river interception box culvert inlet, hydraulic gradient and the water quantity of hydraulic characteristics above the confluence of Baihua River.

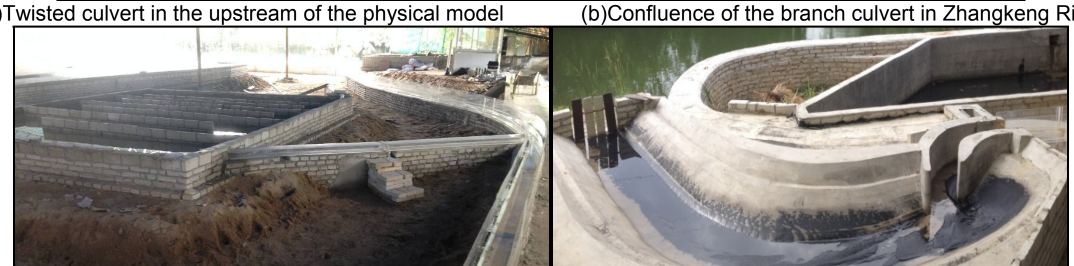
(4) Two rectangular control gate located at the end of sewage interception box culvert downstream were respectively used to control the storage tank of Guanlan Estuary and side outlet of the river. The boundary simulation photos of physical model for long distance sewage interception culvert are shown in Fig.7.

4.3 Model verification

One-dimensional mathematical model of constant channel hydrodynamics was applied to the calculation of sewage interception box culvert. Design flow of dry season and initial light rain were used to carry out steady flow verification test, the result showed that the different depth of the box culvert between physical model test and calculated value was less than 5cm (model test is 2mm), the relative error of velocity was less than 10%, which can meet the requirements of the hydrodynamic similarity of model and prototype.

Starting velocity and scouring velocity test were started in glass tank after calculating the starting velocity of prototype sand and model sand by Zhang Ruijin and Samov's incipient velocity formula. Since the median size of the prototype bed sand was d_{50}=1.148mm, its starting velocity was 0.381～0.558m/s, which required the model starting velocity to be 7.6 ~11.2cm/s, so the pulverized coal whose particle size range is 0.05～2.00mm、and d_{50}=0.30mm was suitable for the model bed sand. The pulverized coal has the characteristics of stable, does not rot in the water in long-term, recyclable and others. Its dry bulk density, $\gamma_{Sm} = 0.72\,\mathrm{g/cm^3}$, and saturated bulk

(a)Twisted culvert in the upstream of the physical model (b)Confluence of the branch culvert in Zhangkeng River



(c)Confluence of the branch culvert in Baihua River (d) River downstream under the terminal sluice of main culvert

Figure 7. The boundary simulation photos of physical model for long distance sewage interception culvert.

density, $\gamma_s = 1.40\text{g/cm}^3$. When the water depth was 0.8 ~ 12.0cm, the model sand starting velocity was 8.4 ~ 12.7cm/s. The model sand was chosen according to the similarity criterion of sediment starting velocity and the parallel principle of the fractal curve.

4.4 The model test of scouring sediment in sewage culvert system

The main culvert is used to control the hammed water sluice (Z0+130) of Guanlan emergency sewage treatment plant, storage tank sluice (Z+430) of Guanlan, intake sluice (Z1+888) of the branch culvert of Baihua river and other sluices. The control principle "Staged storage, suddenly releasing, relay scouring" means that through the regular water storage in dry season, the water head can be used to flush the sediment in the interception box culvert into storage tank or the downstream river. The condition description is shown in Tab1.

Table 1. The instruction of test conditions for Physical model.

Condition No.	Control sluice	Target scouring section	Place for sediment
1	Hammed water sluice of Guanlan emergency sewage plant （Z0+130）	Hammed water sluice upstream (CR4+367）~Hammed water sluice downstream（Z0+130）~Guanlan control sluice（Z+430）	3#Guanlan storage tank
2	Control sluice of storage tank （Z+430）	Control sluice of Guanlan storage tank (Z+430）~Confluence of Baihua River branch culvert（Z1+888）	Downstream culvert, storage tank in estuary and downstream river
3	Inlet sluice of Baihua River branch culvert（Z1+888）	Confluence of Baihua River branch culvert（Z1+888）~Control sluice in the end of Granlan River（Z+430）	storage tank in estuary or downstream river

4.4.1 Initial condition of scouring

Considering the Baihua River culvert intake sluice (Z1+888) as an example, the sediment in culvert laid for a total length of 315m and its thickness was 0.75m, then the main sewage interception control sluice was closed to store the mixed sewage from dry season and initial light rain. When the water level increased over the top of culvert, the control sluice was opened to implement hydraulic erosion and deposition. The sediment resettlement area is the storage tank in Guanlan Estuary. Test initial conditions are shown in Figure 8 and Figure 9.

4.4.2 Analysis on the results of scouring

(1) Analysis on velocity and water depth. After the water scouring sluice was opened, the maximum velocity from the sluice to the main culvert control sluice was 2.0m/s~4.5m/s, the upstream velocity was slightly larger than downstream. With the gradual release of water of Baihua River, the water, velocity and water level in culvert showed a progressive decrease trend. The downstream velocity of Baihua River branch culvert at the confluence(Z1+888) was larger than 1.5m/s and lasted about 70 minutes, and 100 minutes later, the velocity tended to be stable that decreased to 1.4m/s~1.7m/s. In the process of opening scour culvert, upstream water level was slightly larger than the downstream water level, and the downstream water level in culvert followed two steps: the rapid increase and the slow decrease which gradually decreased from 1.20m~1.45m to 0.78m~0.83m.

Figure 8. Initial condition for water storage and scouring test.

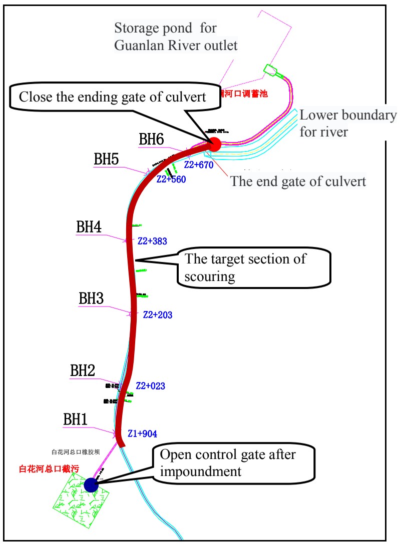


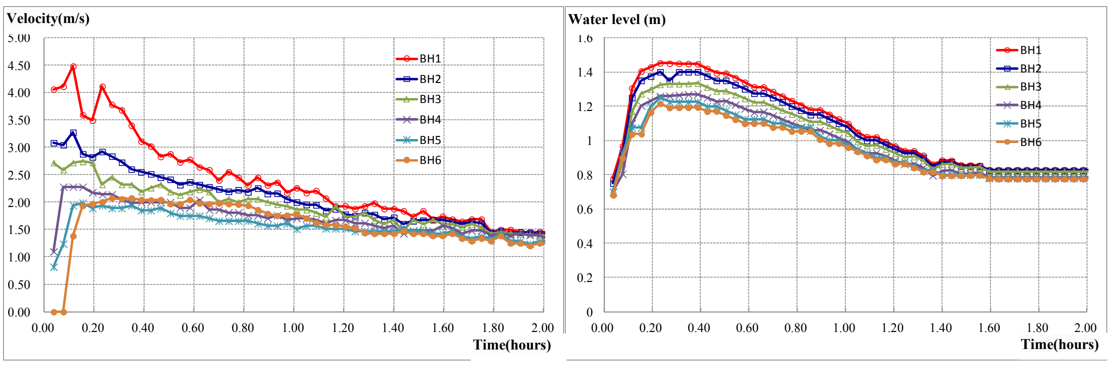
Figure 9. Summary of culvert scouring conditions for Baihua section open control gate after impoundment.

(2) Effect analysis of scouring and deposition. After five times of water storage and scouring, residual amount of initial sediment in the box culvert were 82.5%, 65.0%, 52.1%, 36.5% and 25.4%. Particles of sediment was first washed away, then the initial deposit within the culvert on the downstream was gradually scoured and attenuated. Some were washed into the storage tank in Guanlan Estuary, and the main body of silting in culvertgradually moved towards the downstream, and the thickness of it decreased gradually. All of these shows that the scouring effect is obvious. During water storage and scouring in dry season, the process of flow velocity and water depth is shown in Figure 10.The sedimentation thickness along the main culvert and eigenvalue statistics are shown in Table 2. The results of water storage and scouring test of hammed water sluice (Z+130) of emergency sewage treatment plant is shown in Fig.11.

The sewage interception culvert was controlled reasonably, the sluice of main culvert was loosened to store the flow from upstream in dry season and initial light rain until it is enough to scour the sediment. The planning scheme of "Staged sewage storage, suddenly releasing, relay scouring" implements once a month to wash the sediment from sewage interception box culvert to storage tank downstream. The results show that the effect of water erosion is significant.

Table 2. Result statistics of scouring test at Baihua River branch culvert (Z1+888).

Measurement condition	Maximum thickness of sediment(m)	Thickness range of Main sediment (m)	Transport distance of main sediment(m)	Sediment length (m)
Initial condition	0.75m	0.75m	0	315
First scouring	0.68	0.38~0.65	60	379
Second scouring	0.61	0.28~0.55	120	597
Third scouring	0.58	0.25~0.50	240	688
Fourth scouring	0.50	0.20~0.45	390	740
Fifth scouring	0.50	0.20~0.33	420	740



(a) Velocity change process (b) Water depth change process

Figure 10. The inlet sluice of the branch of Baihua River store the water for scouring.

(a) Initial condition; (b) First scouring; (c) Second scouring; (d) Third scouring

Figure 11. Terrain in sewage culvert after the third scouring test at Baihua River branch culvert (Z1+888).

5 COUNTERMEASURES FOR SEDIMENT DEPOSITION IN SEWAGE CULVERT SYSTEM

(1) Strictly controlling the sediment source of the sewage intercepting drainage culvert system. The implementation of the comprehensive treatment of watershed soil erosion is fundamental to reduce siltation of culvert and river. Renovation and new construction of sewage interception project at each branch like grit chamber and sand trap and implementation of grit chamber dredging system of regular and irregular combination can effectively stop the sediment from being collected into the main sewage culvert.

(2) The reform of water intake structure and sluice along the sewage interception box culvert. First of all, remove the bottom sill, then the sedimentation facilities must be set before the water intakes that has a backwater sluice. The fixed point and periodic mechanical dredging system should be formulated and implemented to ensure that the new sedimentation can be cleaned effectively in time.

(3) To conduct a thorough mechanical dredging along the culvert where sediments are deposited seriously. With the monitoring situation of culvert along the sediment, the scouring program is being implemented regularly to prevent the sediment from depositing and hardening.

(4) Planning a reasonable outlet for the sediment in sewage culvert system. We advice that the storage tank should be added with the function of collecting sewage during dry season and initial-light rain. The sewage interception culvert is divided into "scour" and "dredging" section, the "scour" section is to store water in dry season for preventing the culvert from depositing continually, then the sediment is washed into the storage tank, grit chamber, servicing silo and other "dredging" section to implement mechanical dredging.

6 CONCLUSION

(1) It has been proved by practice that the complete separation system is difficult to solve the pollution problem of urban sewage. The combination of intercepting combined drainage system and separated drainage system will be suitable for China's national urban drainage system in a long-time period in the future. All of the polluted water from dry season and origin-light rain will be intercepted for purification treatment for standards discharge which is the ultimate goal of urban sewage treatment. It is the focus of urban sewage and ecological management to improve collection-purification percentage and the comprehensive processing capacity for polluted water in dry season.

(2) Strictly controlling sediment source, sedimentation node modification, planning reasonable outlet for sediment are the main countermeasures for sediment depositing in interception culvert system. On the premise of strengthening monitoring sewage culvert sediment, the strategy including scouring in dry season and mechanical dredging to prevent sedimentation should be adopted actively.

(3) Combined with prototype dispatch testing for sediment scouring, a physical model made of plexiglass for long distance sewage interception culvert was built to study the cause and reducing countermeasure for sediment deposition. In order to control the similarity of physical model for the

sewage culvert system, the roughness for sidewall, hydrodynamic characteristics and the boundaries conditions should be simulated accurately according to the prototype of the actual situation.

(4) Controlling the key sluices to impound the mixed polluted water for segment scouring in dry season, the storage capacity of sewage interception culvert and rubber dams for branch river are used to implement the scheduling scheme for reducing sedimentation in sewage interception culvert system. By the means of measurement and control system for the physical model, result shows that engineering scheduling scheme for rational control of the sediment was proposed through model test. The research method for physical model in this paper can be extended to operation management for similar sewage culvert system.

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