Combined Effect of CSO Screen and Water Surface Control Device on Floatables Removal

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Abstract
A water surface control device (WSCD) consists of two baffles and removes floatables in CSO. We considered that combining WSCD with a CSO screen would greatly reduce the volume of floatables passing through the screen, thereby improving the screen maintenance performance. To test this idea, we installed a new WSCD in a CSO chamber already installed with a screen, and confirmed the expected outcome in an on-site demonstration experiment.

Keywords
Combined sewer overflow, floatables, screen, vortex, water surface control, video camera system

INTRODUCTION

Many combined sewer overflow (CSO) chambers are installed with screens that remove floatables from the CSO, thus helping to conserve the water environment. There are various types of screens, many with a mechanical cleaning function that prevents the floatables from clogging the screen. If the screen becomes over-clogged, an excessive torque is generated in the moving part, causing a malfunction. Therefore, these devices require periodic inspection and maintenance.

We have developed a water surface control device (WSCD) with no moving parts and a power-free operation. In Japan, at least 1700 WSCDs have been installed by many sewer authorities. The WSCD has also been introduced in the EU and cases are installed in Germany, France and Belgium. The WCSD is composed of two baffles, a horizontal baffle that guides the incoming floatables in the direction of the interceptor, and a vertical baffle that generates a vortex flow, drawing the floatables into the interceptor.

We considered that combining WSCD with a CSO screen would greatly reduce the volume of floatables passing through the screen, thereby improving the screen maintenance performance.
To test this idea, we installed a new WSCD in a CSO chamber already installed with a screen, and confirmed the expected outcome in an on-site demonstration experiment.

OUTLINE OF WSCD

Overview of WSCD

The WSCD device is installed within the CSO chambers of a combined sewer system. During rainfall, floatables in the CSO chamber run off into public water bodies with the overflow. The WSCD prevents debris from flowing into the outfall sewer and diverts it to the interceptor sewer (see Fig. 1).

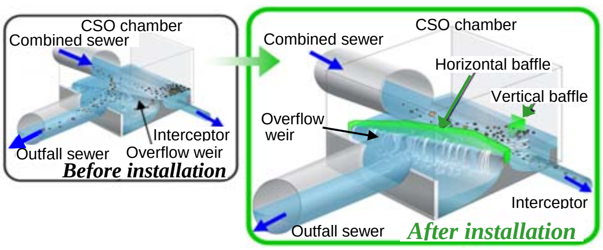


Figure 1. Floatables' movements before and after installing the WSCD.

Vertical baffle
The vertical baffle induces a vortex flow in front of the opening of the interceptor sewer in the CSO chamber (left panel of Fig. 2). This baffle drives the floatables into the interceptor sewer.

Horizontal baffle
The horizontal baffle is installed at the foreside of the overflow weir (right panel of Fig. 2). This baffle prevents the floatables from flowing over the weir into the outfall sewer.

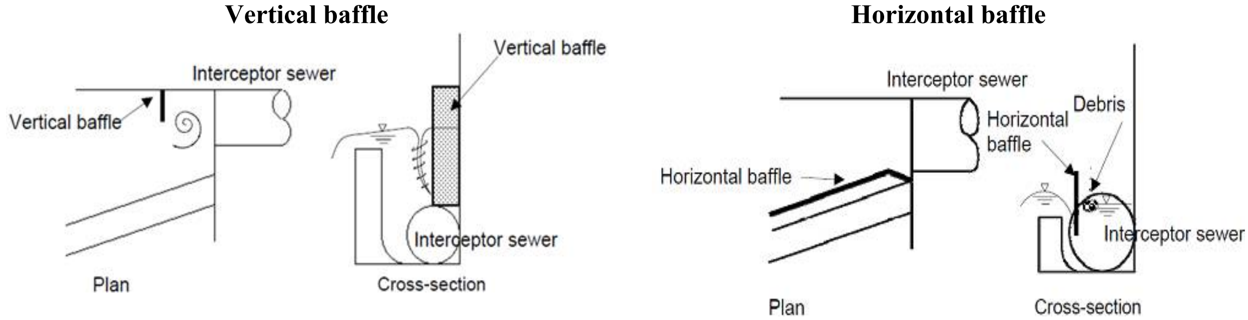


Figure 2. Schematics of the vertical (left) and horizontal (right) baffles.

WSCD Performance
The floatable debris-outflow control capacities were evaluated by the screening retention value (SRV), which quantifies the improvement rate of the debris control after the WSCD installation, the $TSRE_{with}$ value, denoting the capture ratio of the debris intercepted from the CSO chamber and diverted to the interceptor after the WSCD installation, and the $TSRE_{without}$ value, denoting the same capture ratio as $TSRE_{with}$, but with only the overflow weir. These three indices are respectively calculated as follows:

$$SRV(\%) = \frac{TSRE_{with} - TSRE_{without}}{1 - TSRE_{without}} \times 100 \qquad (1)$$

$$TSRE_{with} = \frac{Intercepte\,dDebris_{with} + CapturedDe\,bris}{Intercepte\,dDebris_{with} + OverflowDe\,bris_{with} + CapturedDe\,bris} \qquad (2)$$

$$TSRE_{without} = \frac{InterceptedDebris_{without}}{InterceptedDebris_{without} + OverflowDe\,bris_{without}} \qquad (3)$$

In these expressions, Intercepted $Debris_{with}$ and Intercepted $Debris_{without}$ denote the intercepted debris (dry weight) with and without the WSCD installation, respectively, Overflow $Debris_{with}$ and Overflow $Debris_{without}$ are the overflow debris (dry weight) with and without the WSCD installation, respectively, and Captured Debris is the dry-weight increase in debris after the WSCD installation.

In an investigation conducted from 2005 to 2009, the SRVs after the WSCD installation were 86.1–99.3%, satisfying the target performance of 30%. The debris target in the SRV evaluation exceeded 4 mm.[1)2)] The performance results of the WSCD installation are shown in Fig. 3.

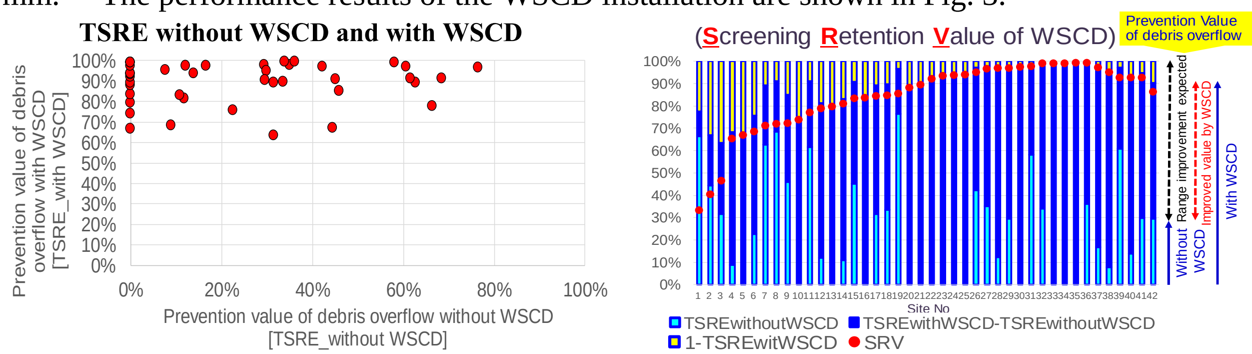


Figure 3. Performance of WSCD (42 sites in Japan).

METHODS

To verify the effect of the combined WSCD and CSO screen, we newly installed the WSCD in an existing CSO chamber (already installed with a CSO screen), and measured the following variables:
1) The floatables' movements in the CSO chamber,
2) The amount of floatables clogging the CSO screen.

The experimental site was the CSO chamber of the Tokyo Metropolitan Sewerage Bureau, where the screen was installed on top of the overflow weir 17 years ago. The CSO screen is equipped with a screen grate with a bar interval of 4 mm and a reciprocating rake that de-clogs the floatables from the screen. The experimental setup and photographs of the installation are shown in Fig. 4.
Our first and second measurements were performed before and after the WSCD installation, respectively. The two sets of measurements were compared to assess the effect of the WSCD.

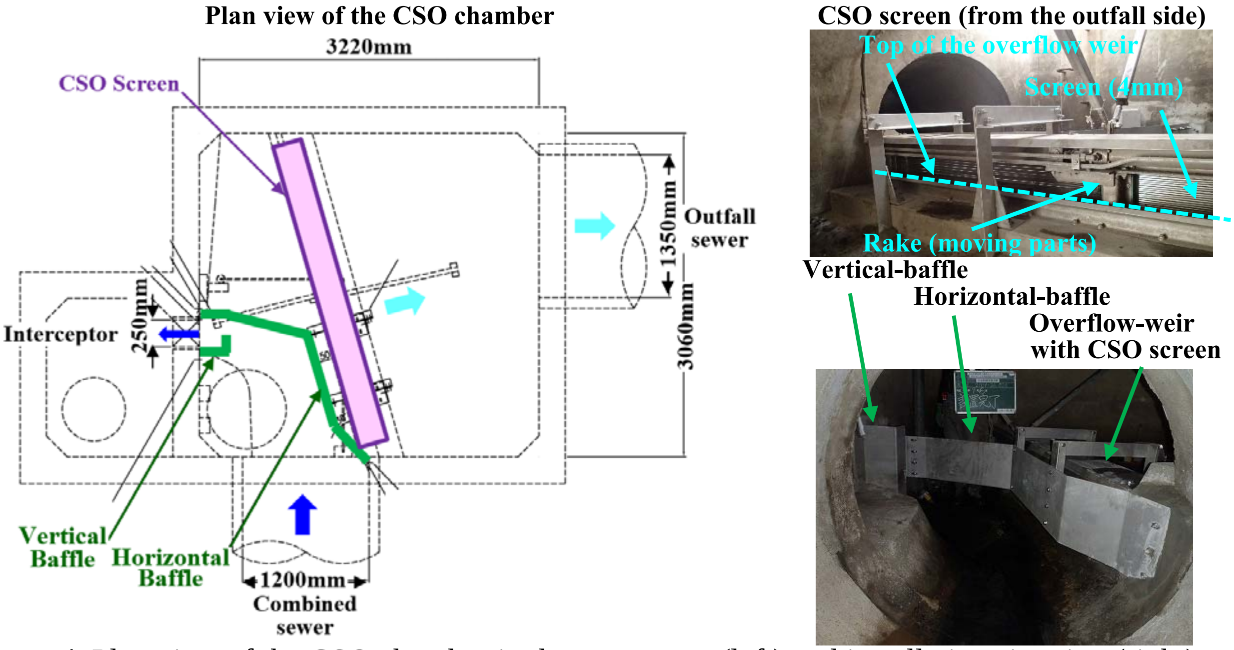


Figure 4. Plan view of the CSO chamber in the experment (left) and installation situation (right).

Measurement of floatables movements in the CSO chamber

Moving images of the flowing floatables during wet weather were captured by a video camera system set in the CSO chamber installed with the CSO screen (Fig. 5). The flow situations of the floatables in the CSO chamber before and after installing the WSCD were then compared. The video camera system consisted of a charge-coupled device camera, a data logger and LED light. When the water level in the chamber rose towards the overflow weir (specifically, to 5 cm below the top of the overflow weir), the water level switch operated, and the video recording started. When the water level dropped below the overflow weir, the level switch was turned off and the video recording stopped.

Figure 5. Installation situation of the video camera system.

Measurement of the amount of floatables clogging the CSO screen

In dry weather, we manually removed any floatables clogging the screen, and left the screen over a certain period of intermittent rainfall. After the experimental period, all floatables clogged on the screen were again manually removed, and classified by type (vegetation, fatty matter, paper, plastic, hair, metals, fecal matter, garbage, or others). The dry weights of the collected floatables were measured for each type. The collection methods and floatables classification are shown in Fig. 6.

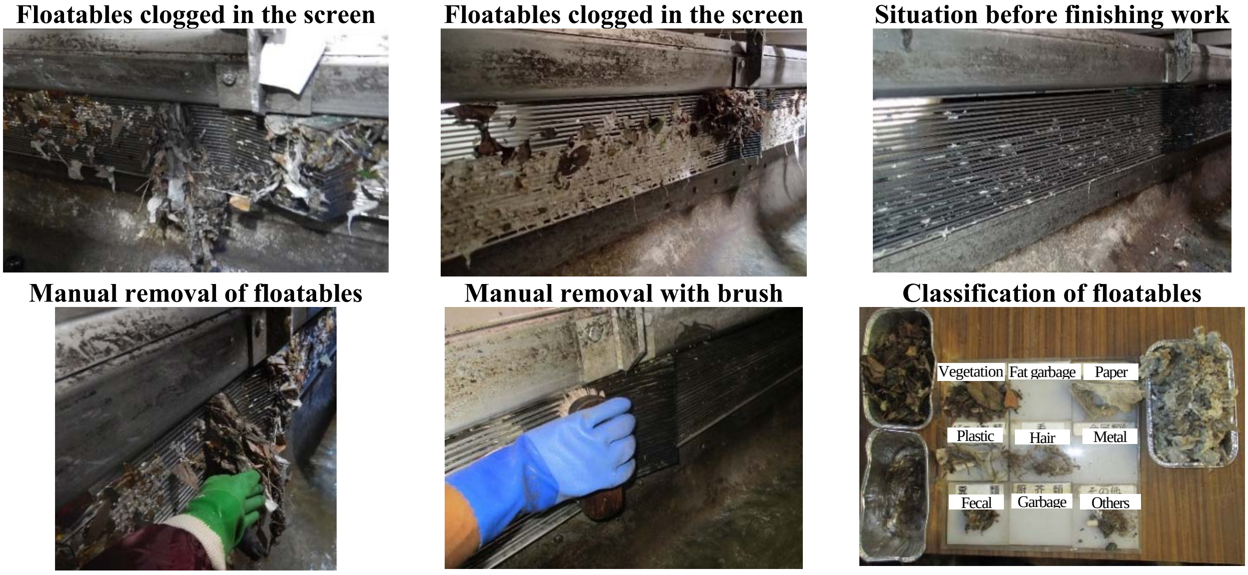


Figure 6. Collection methods and classification of floatables.

In addition, we continuously measured the water level in the CSO chamber using a pressure-type water level gauge, which recorded the presence or absence of overflow and overflow discharge during the experimental period. After determining the overflow depth from the measured water level, the overflow was calculated as

$$Q = CLH,^{1.5} \qquad (4)$$

where Q is the overflow discharge (m^3/s), C is the flow coefficient (1.8), L is the Weir length (2.838 m), and H is the overflow depth (m).

Experimental period and rainfall situation

The screen-only experiment (without the WSCD) was started on July 10 of 2018 and ran for approximately one month. The vertical baffle was then installed, and the observing continued for another month. Finally, the horizontal baffle was installed in September, and the WSCD experiment (CSO screen and WSCD) continued for approximately two further months. Thereafter, the screen-only experiment was repeated for approximately 5 months (until the end of March).

In addition, the amount of clogging floatables on the CSO screen was measured once in each experimental period, at a time of multiple rainfalls. The experimental timeframes are summarized in Table 1, and the precipitation, chamber water levels and sampling periods are shown in Fig. 7.

Table 1. Experimental periods and rainfall situations.

		Without WSCD (CSO screen only)	With WSCD (CSO screen and WSCD)
Experimental period		1 month + 5 months (10 Jul.– 6 Aug.+ 8 Nov.– 25 Mar.)	2 months (6 Sep.– 8 Nov.)
Measurement period of the amount of clogging floatables		12 days (25 Jul. – 6 Aug.)	11 days (20 Sep. – 1 Oct.)
	Rainfall *Major rain	3 rain, 69 mm *28 – 29 Jul.;54 mm (14 mm/hr)	9 rain, 139 mm *26 – 27 Sep.;46 mm (9 mm/hr)
	Overflow	4400 m^3	19600 m^3

If the water level in the chamber shown in Fig. 7 is higher than the top end of the overflow weir we can evaluate as CSO occurrence.

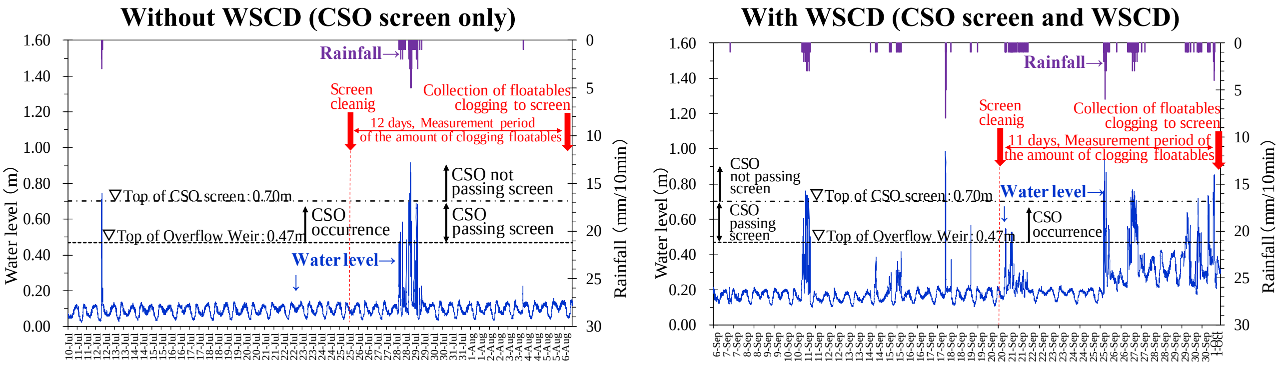


Figure 7. Water levels in the CSO chamber (left-side scale) and rainfall (right-side scale) during the experimental period. Right and left panels are the conditions of the screen-only and WSCD experiments, respectively.

RESULTS

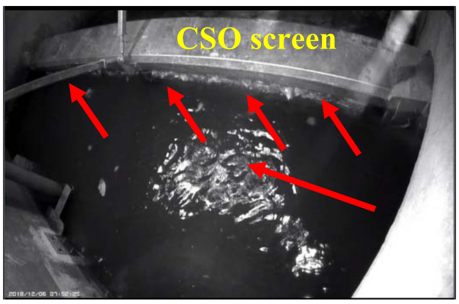
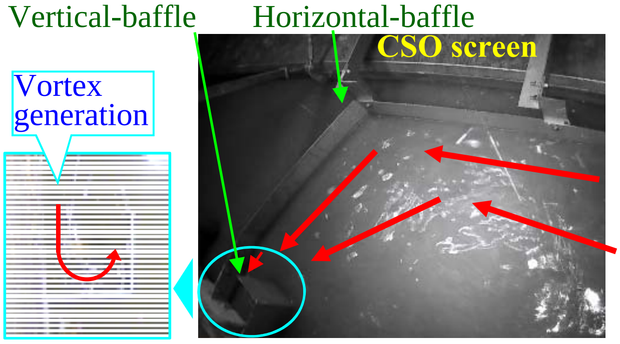
Floatables' movements in the CSO chamber

Table 2 shows the results of arranging the flow directions of the floatables in the CSO chamber, obtained from the captured video images. Without the WSCD installation (CSO screen only), the floatables flowing into the CSO chamber headed towards and adhered to the CSO screen. Although the attached floatables were removed by the reciprocating scraping blade, they repeatedly returned to the screen and remained on the water surface.

On the other hand, when the WSCD was installed (CSO screen and WSCD), the floatables flowing into the CSO chamber were transported to the interceptor along the wall of the horizontal baffle. In addition, they were drawn into the vortex generated between the vertical baffle installed near the interceptor and the chamber wall face on the interceptor side.

By redirecting the floatables entering the CSO chamber, the WSCD markedly reduced the load on the CSO screen, and removed the floatables from the water surface.

Table 2. Flow direction of floatables in the CSO chamber without and with the WSCD.

	Without WSCD (CSO screen only)	With WSCD (CSO screen and WSCD)
Status of flow in the CSO chamber	 → Flow direction of floatables	 → Flow direction of floatables

Reduction effect of floatables overflow by WSCD

Figure 8 shows the situation before and after the overflow from the top of the screen in the CSO chamber without the WSCD. When the water level in the chamber was below the top of the screen, the floatables were trapped on the screen, but were periodically stripped off by the moving rake. Consequently, they remained on the water surface in the chamber. When the water level in the chamber rose, the floatables on the water surface overflowed into the outflow sewer.

In contrast, the WSCD drew the floatables on the water surface into the interceptor, reducing the amount of floatables in the overflow even when the water level rose above the horizontal baffle.

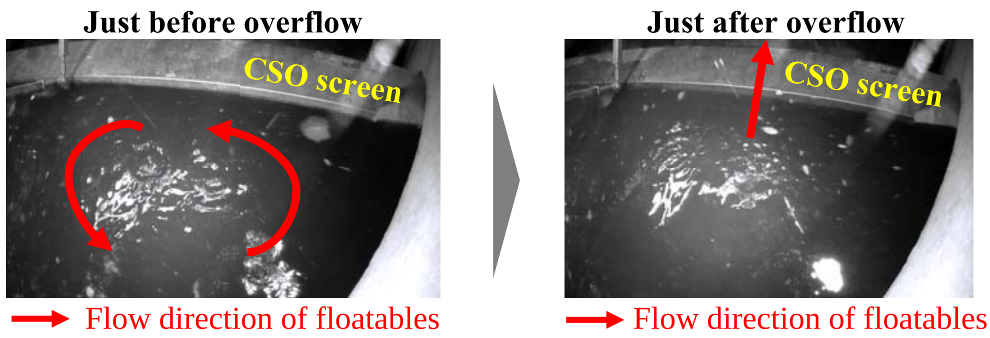


Figure 8. Flow situations of the floatables before/after overflow from the top of the screen in the CSO chamber without the WSCD.

Amount of floatables clogging the CSO screen

The dry weights of the floatables clogging the screen in the CSOs with and without the WSCD are shown in Table 3 and Figure 9. In both cases, the floatables clogging the screen had many papers and vegetations, and the total amount was different.

Without the WSCD, 136 g of material was removed from the CSO screen. The WSCD reduced the amount of clogged matter to 80 g (an approximate reduction of 41%).

Table 3. Amounts of clogging floatables.

	Without WSCD (CSO screen only) (g)		With WSCD (CSO screen and WSCD) (g)	
Paper	21.3	16%	30.9	38%
Plastic	3.3	2.4%	1.1	1.4%
Hair	0.4	0.3%	2.1	2.6%
Vegetation	95.1	70%	39.7	49%
Fecal	4.5	3.3%	1.9	2.4%
Others	11.8	8.7%	4.6	5.7%
Total	136.3	100%	80.4	100%
	100%		59%	

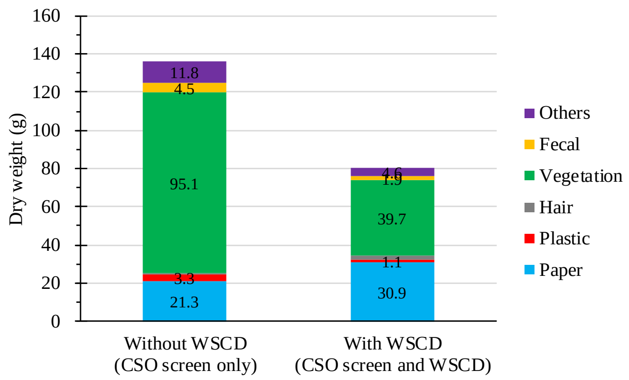


Figure 9. Comparison of floatables dry-weights accumulated on the screen.

During an overflow, the floatables that clog up the screen are repeatedly removed by the moving rake, but re-closed by the overflow passing through the screen. Therefore, a fixed amount of debris is trapped on the screen even when the water level drops after the rain. Although the screen is maintained by the regular rake operations even in dry weather, the floatables adhered to the screen cannot be completely removed.

During the next rainfall, most of the floatables clogging the screen were removed by the moving rake, but the amount of floatables trapped at unreachable places, such as the end of the rake's movable range, gradually increased. If these non-removable floatables grow by a certain amount, they will likely generate a torque in the movable mechanism, with consequent failure of the system.

Combining WSCD with the CSO screen reduced the floatable load passing through the screen, reducing the floatable contents in the CSO, and hence improving the maintenance and management of the screen.

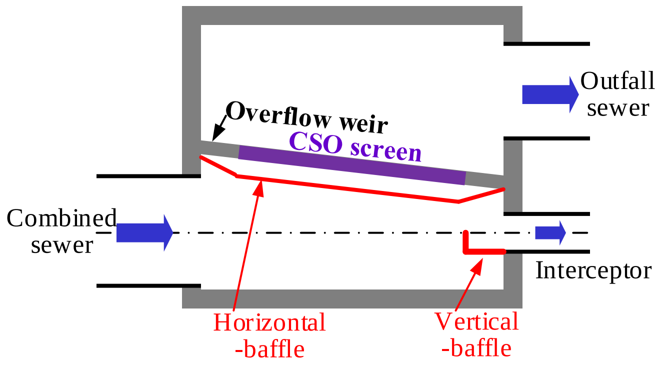
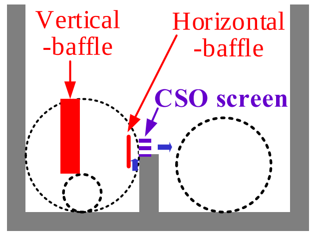
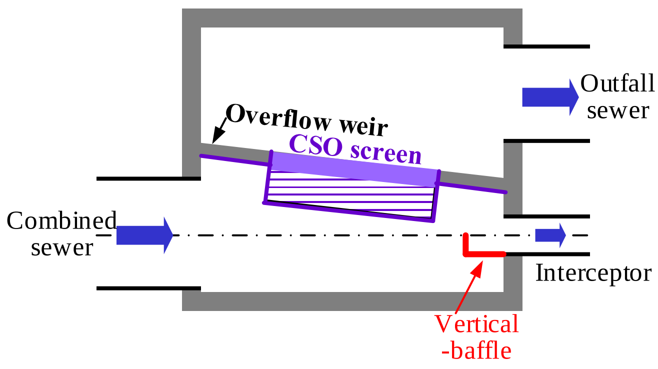
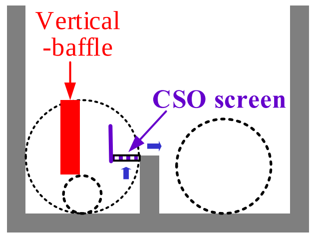
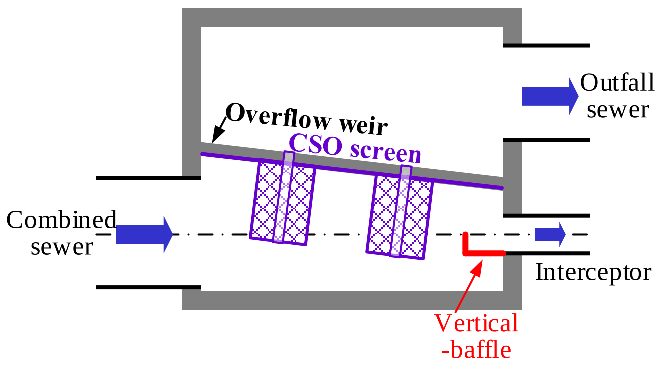
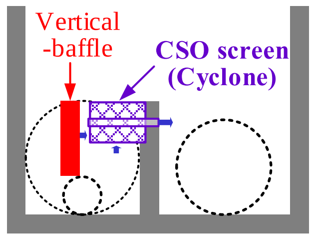
DISCUSSION

Application of WSCD to various types of CSO screens

In this experiment, we examined the applicability of WSCD to CSO screens installed vertically at the top of the side weir. However, considering the diversity of current CSO screens[3)], we also applied the WSCD to different types of CSO screens. The results are compared in Table 4.

In the target experimental configuration (the vertical-weir-mounted screen), the horizontal baffle operates as a scum board, while the vertical baffle guides the inflowing floatables to the interceptor side. However, in the cases of the horizontal installation-type screen and other configurations, the horizontal baffle appeared to be redundant (see Table 4).

Table 4. Application of WSCD to various types of CSO screens.

	Plan view	**Cross-section view**
Vertical weir mounted screen (Side flow screen)		
Horizontal screen incorporating a relief weir (Upward flow screen)		
Others (Cyclone screen)		

Verifying the applicability of WSCD to a horizontal screen

The applicability of WSCD to the horizontal screen was verified in hydraulic model experiments. As shown in Fig. 10, the implemented physical model replicates the CSO chamber, an inflow pipe, an interceptor, an outflow pipe, an overflow weir and a horizontally installed screen. The scale is 1:5, and only the vertical baffle was installed in the WSCD.

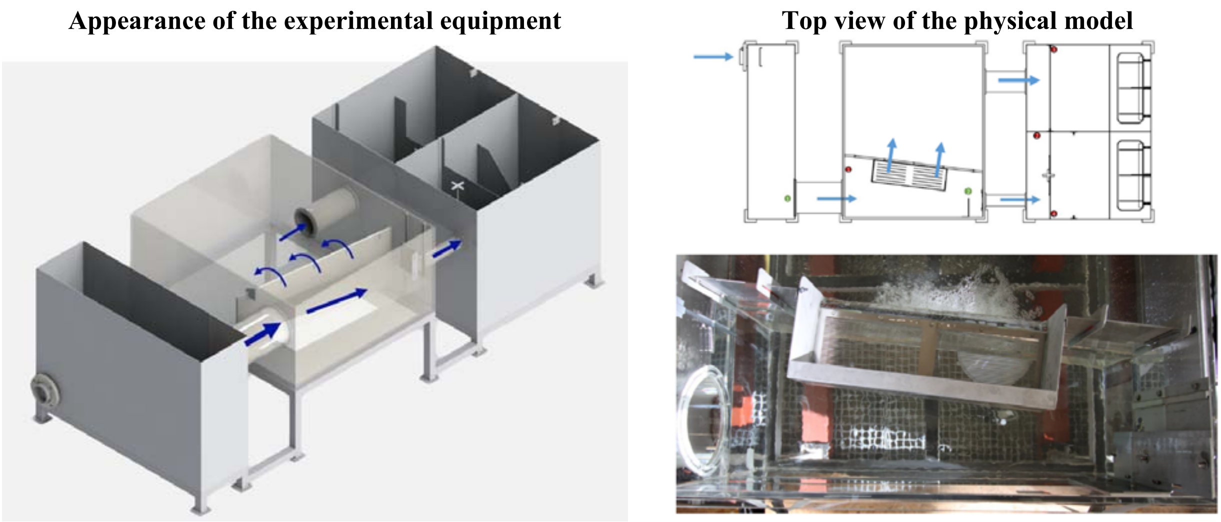
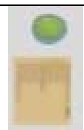


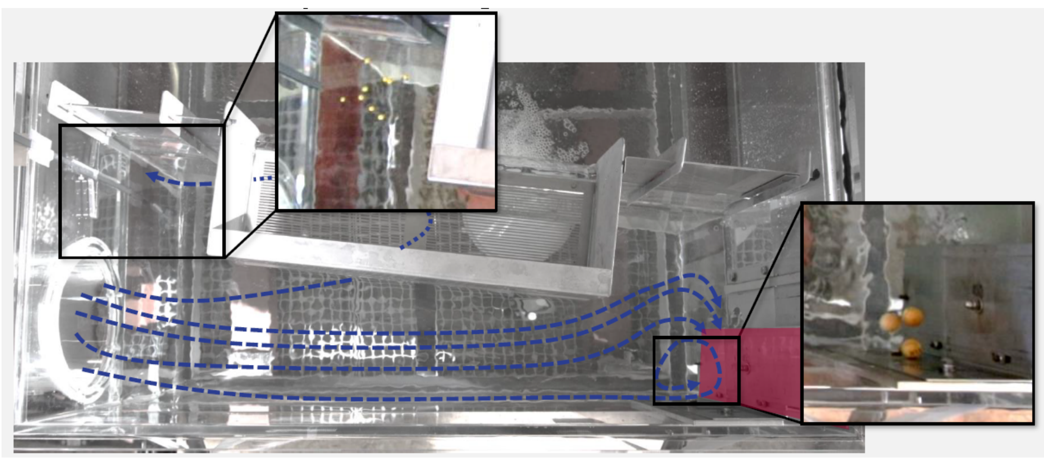
Figure 10. Outline of the physical model (scale 1:5).

Artificial floatables (22 floating solids; see Table 5) were simultaneously introduced to the inflow pipe, and their movements were captured from the top of the chamber by a video camera. The behaviours of the floating solids were then analysed from the video images.

Table 5. List of artificial floatables (floating solids) in the model experiment.

No	H20	H25	W25	P6
Diameter, Material	20 mm, wood	25 mm, wood	25 mm, cotton wool	6 mm, plastic
Number of samples	4	4	4	10
Appearance				

The flow in the experimental chamber is shown in Figure 11. Two recirculation zones were observed in the chamber, but most of the floating solids approached the vertical baffle and were drawn into the interceptor by the vortex. Some floating solids reached the vertical baffle after a delay.



Flow direction of floating solids in the chamber

Figure 11. Flow appearance in the model chamber.

The horizontal screen installation generated vortices of high transport capacity. To understand the cause of this phenomenon, we compared the horizontal screen and horizontal baffle cases.
Figure 12 shows the behaviours of the floating solids in the vertical baffle plus screen installation and the vertical and horizontal baffle installation. In the latter case, the water surface in the chamber flowed mainly along the direction of the baffle; the flow velocity in the vertical-baffle direction was low, and the transport capacity of the floatables by the vortex was also low. On the other hand, in the vertical baffle with screen installation, the screen reduced the channel width, so the water surface flowing into the chamber moved at fast velocity towards the vertical baffle. Consequently, the vortex transport capacity of the floatables was high. These results imply that the screen does not worsen, but instead marginally enhances, the vortex transport capability.

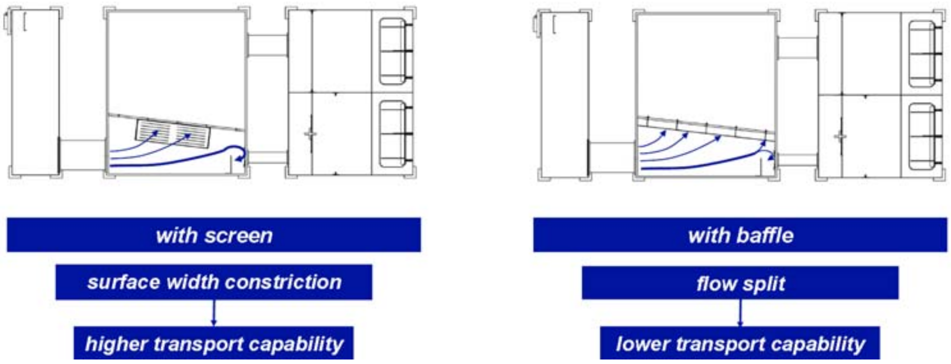


Figure 12. Comparison of water surface flow in two configurations: vertical baffle with screen (left) and vertical and horizontal baffles (right).

Application of WSCD to a cyclone screen

One of the various CSO screens is the cyclone screen. The screen is a cylindrical screen, captures debris in water flowing from the outside to the inside. The cylindrical interior has a self-cleaning mechanism that is rotated by the force of the flowing water. When the WSCD is simply applied to the cyclone screen, the floatables are drawn to the screen side because the screen is interfered by the surface flow towards the vertical baffle. As shown in Figure 13, if one of the two cyclone screens can be removed, the floatables flowing into the chamber move linearly towards the vertical baffle side.
Therefore, when applying the WSCD to a cyclone screen, one should first predict the behaviour of the floatables near the vertical baffle, and examine the presence or absence of screen interference.

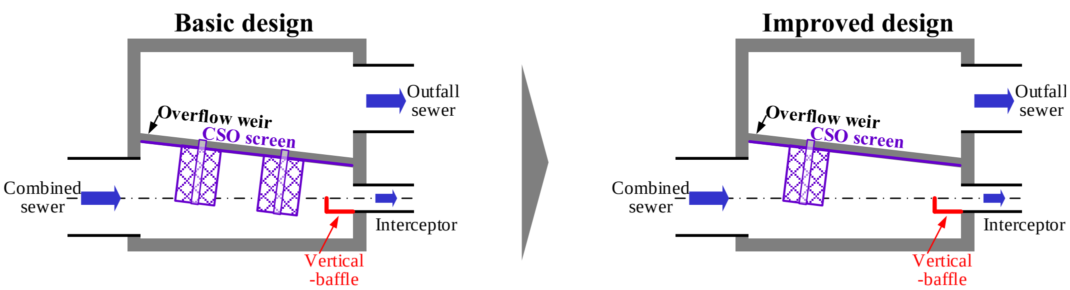


Figure 13. Proposed application of WSCD to Cyclone screen.

Currently, the WSCD is being installed in the CSO chamber of the UK's Wessex Water, which is installed with a cyclone screen (see Fig. 14). Demonstration experiments are now underway.

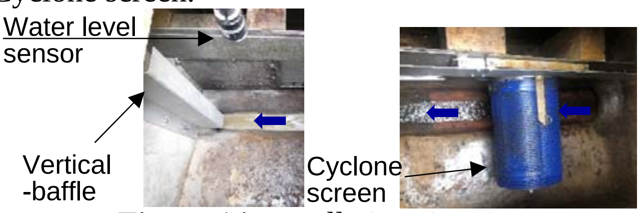


Figure 14. Installation situation.

CONCLUSIONS

We expected that combining the WSCD with a CSO screen would greatly reduce the amount of floatables passing through the screen, thereby improving the screen maintenance performance. To test this hypothesis, we installed a new WSCD in a CSO chamber with an already installed screen, and carried out an on-site demonstration experiment. The expected effect was confirmed in the results.

With the WSCD installed, the floatables entering the CSO chamber were conveyed to the interceptor without remaining on the water surface. In this way, the WSCD markedly reduced the load on the CSO screen. Moreover, because the floatables on the water surface were drawn into the interceptor, the floatables overflow was reduced (relative to the CSO with the screen only) even when the water level rose above the horizontal baffle.

Next, the applicability of WSCD to horizontal screens was validated in hydraulic model experiments. Two recirculation zones were observed in the chamber, but most of the floating solids headed towards the vertical baffle and were drawn into the interceptor by the vortex. Some of the floating test solids reached the vertical baffle after a delay. The screen was found to marginally improve the vortex transport capability.

When applying the WSCD to a cyclone screen, it is prudent to predict the behaviour of floatables near the vertical baffle, and to examine any interference between the screen and the vertical baffle.

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SUBMISSION TYPE

☐ 2-page extended abstract
☒ Full paper
☐ Poster