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COMPARISON OF SUSPENDED SOLID SEPARATION IN ADVANCED STORM OVERFLOW STRUCTURES

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ABSTRACT: This paper describes a laboratory investigation of the separation of suspended solids in a circular weir overflow and a vortex separator. The basic idea is to evaluate the efficiency of a vortical flow in the overflow chamber, and to compare these results with other overflow structures.

KEYWORDS: Hydraulic Scale Model, Solid Separation, Storm Sewage Overflows, Use of Vortical Flow.

1. INTRODUCTION

In Denmark Storm Sewage Overflows (SSOs) has for decades been designed to avoid floodings in sewer systems rather than to avoid undesired impacts on receiving waters. In 1987 the Danish Parliament passed the Water Enviromental Act. The overall aim of the act is to improve water quality in Danish coastal waters. This means that requirements to the function of and discharges from SSOs will be made more rigorous in the years to come.

A SSO, which is found to be a considerable source of pollution for a river, stream or lake, is very often being provided with additional storages volumens. This reduces the overflow frequency and thereby retains a certain amount of pollutants. But it also increases the attention to maintenance for these storm tanks and the duration of maximal inflow on the treatment plant. In view of avoiding this, advanced storm overflow structures with separation of suspended solids are an alternative (see figure 1).

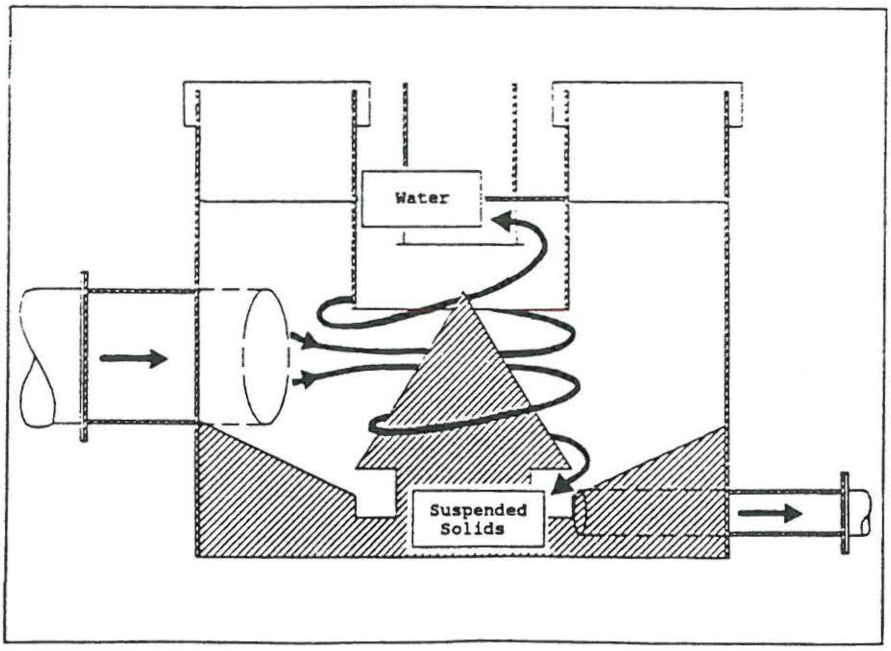

Figure 1. Principle of suspended solid separation.

Especially in England (Halliwell & Saul, 1980), (Saul & Delo,1982), (Balmforth, 1986), projects have been running in order to assess SSOs performance, hydraulically and qualitatively. In these studies the high side weir overflow and the vortex overflow have been prefered. A design guide for storm overflow structures (Balmforth & Henderson, 1988) has recently been published, using results from the abovementioned studies. These results indicate, that the use of a vortical flow in the overflow chamber has a better separating effect on suspended solids than conventional overflows.

The work outlined in this paper presents results of suspended solid separation in two SSOs, which have not earlier been systematically examined, namely the circular weir overflow and the vortex separator. A comparison between the results has been made to examine the efficiency of the vortical flow qualitatively under identical conditions. Furthermore, a comparison with the results from the abovementioned English investigations has been made, to see whether these two overflow structures appears to exert a good solid separating effect.

2. DESCRIPTION OF THE OVERFLOW MODELS

The circular weir overflow has a circular chamber and exerts good hydraulic control, due to the length of the weir. The circular weir overflow causes surcharging of the upstream sewer, which may make it inapplicable under certain circumstance. The scumboard is placed centrally and has its bottom placed under the weir level. In order to obtain optimal efficiency concerning retaining of floating solids, the inlet is extended into the scumboard. A screen is placed horizontally between the scumboard and the weir, slightly under the weir level.

The vortex separator is developed by Hydro Research & Development (HRD) in 1983, and is a further development of the vortex overflow. The water enters the chamber tangentially in a vortex separator. This leads to a spin in the water and a vortex is formed. The secondary currents in this vortex are employed for dynamically separation of the solids, leading these to the middle of the chamber, where the outlet is placed. In the middle of the chamber a cone is placed. This secures, that the cross section decreases to keep the velocity high. Hereby a greather volumen in the active zone of separation is used. The HRD-separator is known for having a fine separation performance. The separator used in this investigation was not a copy of the HRD-separator. Our separator had significant larger inlet pipe and higher hydraulic load than recommended by HRD.

To determine the efficiency of these SSOs, it is necessary to measure the discharges under a large variety of different natural conditions. Due to the fact, that this is timeconsuming as well as rather inconvenient, it has been necessary to develop and test the SSOs in a laboratory, where reproducible test conditions are ensured.

The two overflow structures were established with identical chamber volumens and physical conditions and was investigated under uniform flow conditions. Both overflow structures were made in model in Perspex (60 cm in diameter).

3. METHOD OF DATA COLLECTION AND ANALYSIS

The tests were performed under steady flow conditions. It was hereby possible to eliminate the scale effects due to time. This made it possible to simulate the suspended solids by single plastic beads with different terminal velocity. Instead of introducing a large number of identical particles into the inlet pipe at one time, one particle could be introduced several times showing uniform results. During the tests the terminal velocity of each particle was determined frequently in a high Perspex tube. If it changed, the results for this particle were discarded.

The maximum size of the beads allowed without getting scale effects is 0.07·D, where D is the diameter of the inlet pipe (Halliwell & Saul, 1980). In these tests the maximum was 10.08 mm, so to make it clearly visible, beads with a diameter of 10 mm were used. For the test 10 particles were chosen with terminal velocities in the range of -0.16 m/s to 0.16 m/s. The particles was introduced in the inlet pipe more than 10·D upstream the chamber in order to get the right distibution as the particles enters the chamber (Halliwell & Saul, 1980).

Two particles with the same terminal velocity were tested to check the steady conditions. There were no significant differences in the test results of these two particles. The conclusions hereof was that a definite efficiency exists for each single particle introduced into the system. The necessary number of introductions of each particle in each test series were examined by using t-test on a large number of introductions. It was hereby found that the minimum number for each particle was 60 introductions (95 % confidense interval). 22.200 introductions of particles on the two models were carried out during this study.

4. RESULTS

In literature the ability of retaining suspended solids in the chamber is called the efficiency of the SSO. The definition of efficiency is the ratio between suspended solids in the outlet and suspended solids in the inlet. The efficiency can be described as the ratio between outflow and inflow, if the particles has no terminal velocity. It is hereby obvious that the efficiency depends on the inflow as well as the outflow.

To examine whether the vortical flow gives a better efficiency the two models were investigated for retainment of each particle under a number of identical steady flow conditions. In figure 2 the efficiency for particles with an average terminal velocity of 2.72 cm/s is illustrated. With low ratio of outflow versus inflow, responding to low retainment, the efficiency for the vortex separator appears to be better than for the circular weir overflow. The difference is not significant, and on basis of these results it is subject to uncertainty to deside whether the vortical flow has a positive efficiency or not.

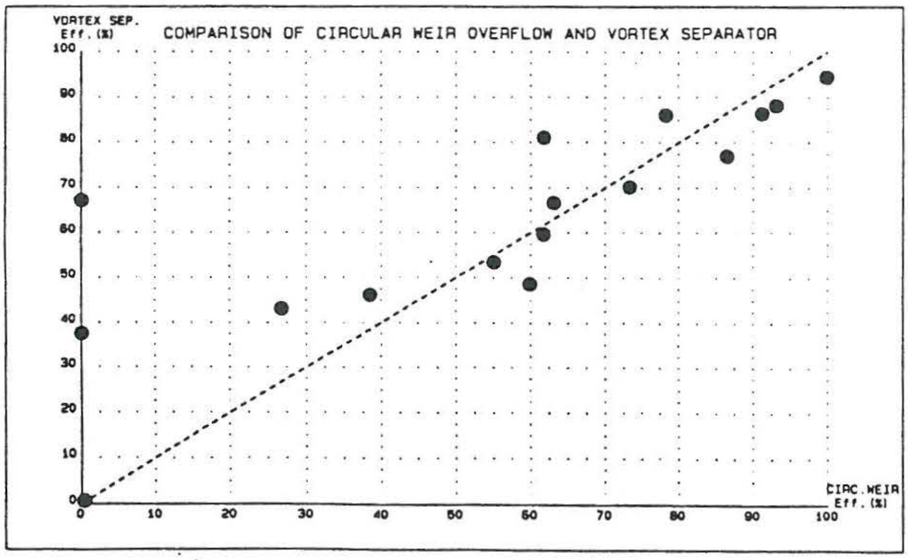

Figure 2. Comparison of efficiency of the circular weir overflow and the vortex separator for particles with a terminal velocity of 2.72 cm/s.

One of the reasons why the vortex separator was not functioning as expected, was that the model has a very little overflow orifice, which gives higher velocities in the chamber and thus more turbulence. The conclusion must be, that the expected positive efficiency from the vortical flow can easily be spoiled by a poor design of the overflow construction.

The efficiency of both models are found to depend on the inflow as well as the outflow. In figure 3 the efficiency for the circular weir overflow is given for two different outflows and a steady inflow (left), and for two different inflows and a steady outflow (right). The efficiency is more dependent on variation in the inflow than in the outflow.

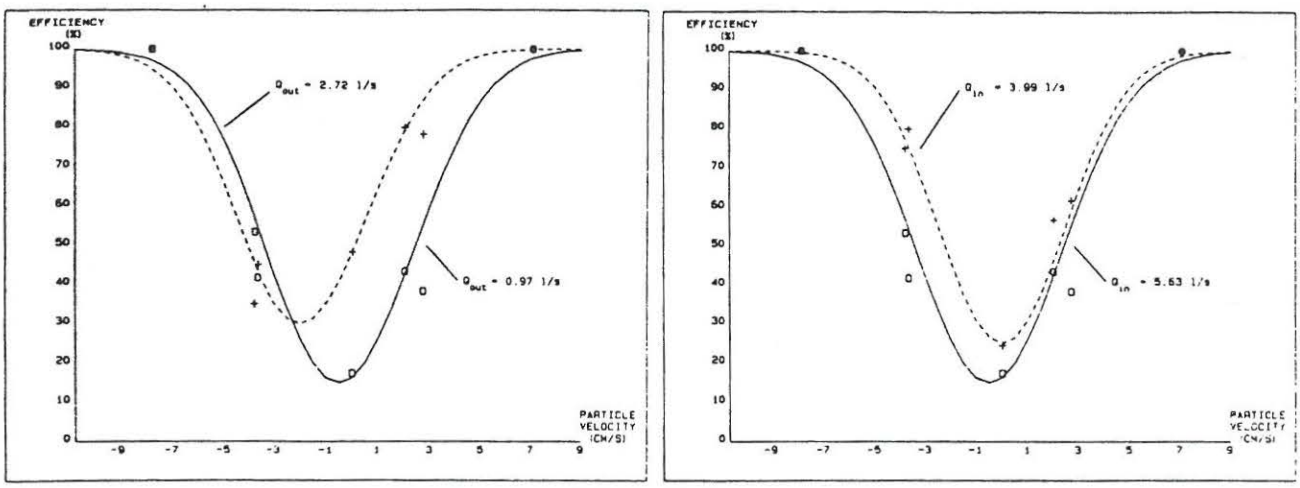

Figure 3. The efficiency of the circular weir overflow for constant inflow, Q_{in} = 5.63 l/s, (left) and for constant outflow, Q_{out} = 0.97 l/s, (right).

This means that a design criteria for these kinds of overflow structures, e.g. which physical condition they ought to have to retain an expected amount of suspended solids, must depend on the inflow as well as the outflow.

To upgrade the results from scale models to full scale constructions, the efficiency shall be described using a dimensionsless parameter W/V_o, where W is the particles terminal velocity and V_o is defined by

$$V_o = \frac{Q_{in} - Q_{out}}{F}$$

where Q_{in} is the inflow to the chamber
Q_{out} is the outflow from the chamber
F is the cross section area in the chamber

By plotting the efficiency, E(W), for each test against the dimensionsless parameter, W/V_o it is found, that all results can be described as an inverse normal distribution curve

$$E(W) = 1 - \frac{M}{\sqrt{2\pi\sigma}} \operatorname{Exp}\left(- \left(\frac{W - \mu}{\sqrt{2}\ \sigma}\right)^2 \right)$$

where μ, σ and M are normal distribution parameters.

For each of the tests appears one value for μ, σ and M. By using regression analysis on these values, one description of the three parameters appears valid for all the tests, depending only of the inflow and the outflow. Now the efficiency curve can be described for any flowconditions.

Circular Weir Overflow

$$K = -140.697 \cdot Q_{out}/Q_{in} + 133.86 \qquad (R = -0.969)$$
$$\mu = -2.308 \cdot Q_{in}/Q_o + 3.17 \qquad (R = -0.978)$$
$$\sigma = 1.617 \cdot Q_{in}/Q_o - 0.27 \qquad (R = 0.997)$$

Vortex Separator

$$K = -79.782 \cdot Q_{out}/Q_{in} + 133.54 \qquad (R = -0.882)$$
$$\mu = -5.015 \cdot Q_{in}/Q_o + 3.92 \qquad (R = -0.997)$$
$$\sigma = 2.659 \cdot Q_{in}/Q_o - 0.22 \qquad (R = 0.995)$$

where $K = M/(\sqrt{2\pi\sigma})$
$Q_o = Q_{in} - Q_{out}$

By using e.g. Simpsons rule and a well-known distribution of suspended solids in the sewage as a function of the terminal velocity, the expected total efficiency for the actual overflow structure can simply be calculated.

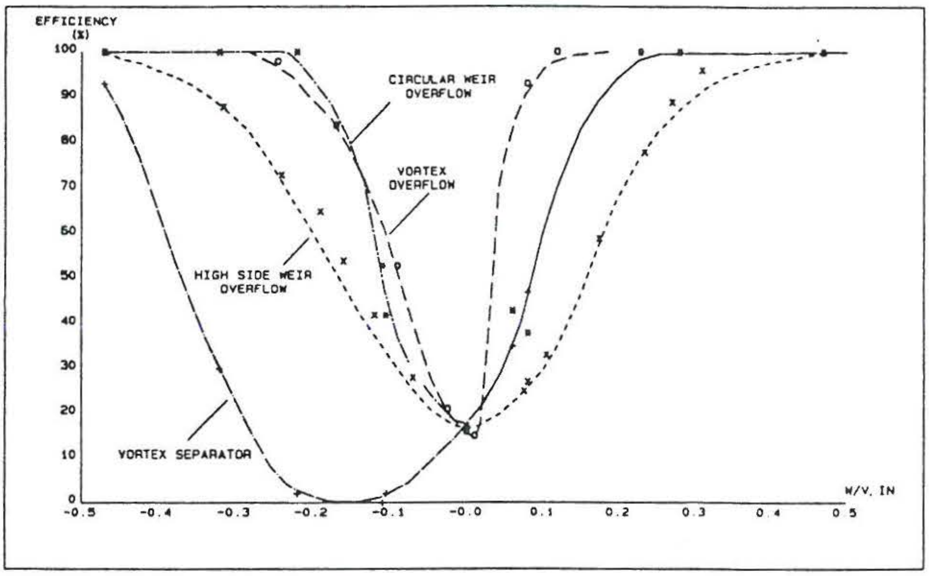

Figure 4. Comparison of the efficiency of the high side weir overflow (Saul & Delo, 1982), the vortex overflow (Balmforth, 1986) and the circular weir overflow and the vortex separator (this investigation) for identical flow conditions ($Q_{out}/Q_{in} = 0.16$).

To compare the results from these tests with results from well known successfully tests on other storm overflow structures, one has to plot the efficiency as a function of the dimensionsless parameter, W/V_i, where V_i is the average velocity in the inflow. This technique was first introduced by (Halliwell & Saul, 1980). In (Balmforth, 1986) there is a comparison of the vortex overflow and the high side weir overflow described for a ratio between outflow and inflow of 0.16. In figure 4 these results are compared to results of the circular weir overflow and the vortex separator, founded at the same flow ratio.

It is obvious that the vortex separator cannot retain floating particles as well as the other overflow structures. This is due to the poor design of the used model. There is no doubt, that the most efficient overflow structure in retaining suspended solids is the vortex overflow as described by (Balmforth, 1984). The circular weir overflow seems to give a better efficiency than the high side weir overflow, just like the vortex separator seems to do for falling particles.

In the future new tests must be required to decide whether the vortex separator can be advantageous used in Danish sewers. New tests on scale-models and perhaps a full-scale test are being planned at this moment of writing.

5. CONCLUSIONS

The result obtained in this study yields no indication of a vortical flow giving a better efficiency concerning retaining of suspended solids. This is tested by comparing a circular weir overflow and a vortex separator under identical physical conditions and flow conditions.

It is found that the efficiency of both models depends of the inflow as well as the outflow. The design criteria used for full-scale overflow structures has to involve both flows.

Compared to other modeltests, the circular weir overflow prove to be as good or even better than the high side weir overflow. Due to a poor design of the model, the efficiency of the vortex separator in this study is not as good as the other overflow structures. But the best efficiency is connected to the vortex overflow developed by (Balmforth, 1984).

It is obvious that advanced storm overflow structures are an alternative to storm tanks. One way of supporting this is by developing prototype structures and set up field monitoring programmes.

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