An improved method of screening sewer solids during CSO events

Une méthode améliorée pour le piégeage de matières solides pendant les déversements de réseaux unitaires

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RÉSUMÉ
Des déversements d'un réseau d'assainissement unitaire peuvent avoir un impact considérable sur l'environnement, à la fois sur le plan esthétique et sanitaire. Les auteurs de cette communication ont conçu un dispositif appelé Mischwasser Siebsystem (MWSS - système de tamis pour réseau unitaire) pour le compte de l'Emshergenossenschaft, afin de traiter les débordements d'une chambre de déversoir dans le Vorthbach, un cours d'eau proche d'Essen, en Allemagne. Le MWSS retient les éléments solides et les réachemine ensuite au réseau unitaire au moyen d'une vanne unidirectionnelle. Le dispositif fonctionne depuis quatre ans mais, contrairement à ce qui était prévu, nécessite plusieurs opérations de maintenance par an en raison de problèmes de colmatage du tamis durant les déversements de réseau unitaire.
Cette communication propose une solution à ce problème : envoyer l'eau sur une crête à angles vifs avec un flux ayant une lamelle de flux d'eau libre même pendant les petites déversements. La lamelle d'eau est "peignée" au moyen de fils métalliques qui retiennent les éléments solides et permettent à l'eau de se déverser directement dans les eaux réceptrices. Les solides ainsi interceptés sont amenés vers la chambre de stockage et seront restitués au réseau d'assainissement à la fin de l'événement.

ABSTRACT
Combined sewer overflows can pose serious environmental, aesthetic and public health concerns when present in receiving waters. Past papers by the above authors reported on a device commissioned by the Emschergenosschaft known as the Mischwasser Siebystem (MWSS) that was designed to manage overflows from a CSO chamber discharging to the Vorthbach, a watercourse near Essen in Germany. The MWSS screens out sewer solids during CSO events and later returns them to the sewer via a one-way valve. It has now been monitored for four years but despite modifications continues to exceed the once annual maintenance target due to blinding of the perforated screen during CSO events. This paper reports a novel approach to this problem wherein overflow occurs over a sharp-crested weir as a free nappe even at quite low overflows. The nappe is combed as it passes through arrays of vertically inclined wires hanging down into the holding chamber. These intercept the entrained solids while allowing the screened nappe to discharge to the receiving water. The intercepted solids wash down the wires into the holding chamber. The wash water then passes through a further retaining screen at non-blinding velocities to the outlet. Following the CSO event the valve opens and the sewer solids are flushed back to the sewer by a reserve of filtered water.

KEYWORDS
CSO chambers, screening, sewer solids, wire comb arrays
1 INTRODUCTION

Combined sewer overflows can pose serious environmental, aesthetic and public health concerns when released to urban water bodies. CSO events occur when the combined sewage and storm water flow exceeds the capacity of the sewer system.

Present measures to mitigate the impact of these events include temporary holding tanks at sewerage treatment plants, enlarged upstream sewers to provide transient storage, real time control of sewer systems, separation of storm and sewage flows and various screening devices in CSO chambers.

In many situations screening is the only economically viable method but experience has shown that blinding of screen perforations or bar slots by sewer solids is a major problem. Mechanical brushing or water jetting is often used where external power sources are available.

Previous papers by the authors (Simon & Phillips 2008) (Phillips & Simon, 2007), reported on an ongoing trial by the Emschergenossenschaft of a screening device known as the Mischwasser Siebsystem in a CSO outlet on the Vorthbach, a watercourse near the city of Essen, Germany (Simon 2003, 2006). The device relied on the energy of the falling water to clean the screen but blinding, despite modifications, has been a major problem with the annual maintenance target being regularly exceeded.

This paper reports on an improved patented method of sewer solids screening for use in the MWSS that should meet or better the maintenance target. Laboratory trials on a near full-scale model are expected to show improved performance leading to a more economical and compact MWSS that readily fits into CSO chambers.

This paper covers the hydraulic theory and the design of a solution based on the Vorthbach MWSS spatial and hydraulic data. This includes the positioning of the comb arrays to screen the design overflows and alternative comb configurations.

The paper concludes that the improved method of solids separation should result in a more efficient, cost-effective method of CSO management. Further laboratory testing and field studies will be conducted to confirm the veracity of the methodology.

2 DESIGN CRITERIA

The following criteria were established for the design of the MWSS:

- Installation within a CSO chamber
- No external power requirements
- Treatment of all overflows up to the once in five-year overflow event
- Interception and retention of sewer solids exceeding 10mm
- Return of the captured solids to the sewer at the end of the event
- To need only annual inspection and maintenance from above-ground
- Provision for fail-safe bypass

The Vorthbach MWSS met all these criteria with the exception of that of maintenance frequency. To address this deficiency this paper presents an improved method of screening sewer solids.

3 DESCRIPTION OF ARRANGEMENT

Figure 1 below shows the general arrangement of the device with a free nappe passing through the overlapping vertical wire combs. The combs intercept the entrained solids together with a small portion of the nappe, the latter washing the solids down to the holding chamber.

A screen in the chamber retains the solids and allows the wash water to pass through to the filtered water chamber. The wash water, together with the combed nappe, exits the MWSS via the exit weir.

When the level in the sewer chamber falls sufficiently, the ball valve opens and the retained solids are flushed back to the sewer chamber for conveyance to the sewerage treatment plant.
4 DESIGN THEORY

Figure 2. Ogee spillway cross-section

The profiles of the underside of the nappe can be calculated from formulae given in hydraulic textbooks, (e.g. Featherstone & Nalluri 1982) and are essential in order to correctly position the...
interception combs. The algebraic expressions shown in figure 2 above are for an ogee-shaped weir. As the overflow weir is sharp-crested, overflow takes place as a free nappe whose underside profile is given by the equations for an ogee weir. However the textbook expressions refer to an origin at the apogee, or high point, of the underside of the nappe and so must be transferred to an origin on the sharp-crested weir. The profiles will be calculated using the Vorthbach MWSS design overflow data.

The nappe profiles, or trajectories, to be determined are the \( Q_5 \), the once in five years maximum design overflow; the \( Q_1 \), the once a year overflow; the \( Q_{1/2} \), the twice a year overflow and the \( Q_{1/4} \), the four times a year overflow.

To determine the profile of the nappe for the \( Q_5 \) overflow of 0.333 m\(^3\)/s per metre of weir crest and head on the weir, \( H_d \) of 0.260 m, these values are substituted in the above expressions producing figure 3 and table 1 below.

\[
\begin{array}{c|c|c|c|c|c|c|c|c}
\hline
x(\text{m}) & y(\text{m}) & x(\text{m}) & y(\text{m}) \\
\hline
0.1 & 0.022 & 0.5 & 0.436 \\
0.2 & 0.080 & 0.6 & 0.610 \\
0.3 & 0.169 & 0.7 & 0.710 \\
0.4 & 0.288 & 0.8 & 1.040 \\
\hline
\end{array}
\]

Table 1 Coordinates for \( Q_5 \) with respect to apogee of underside of nappe

These substitutions can be repeated for the \( Q_1 \) overflow of 0.07 m\(^3\)/s with an \( H_d = 0.100 \) m, the \( Q_{1/2} \) overflow of 0.03 m\(^3\)/s with an \( H_d = 0.060 \) m and the \( Q_{1/4} \) overflow of 0.01 m\(^3\)/s with an \( H_d = 0.030 \) m.

The values of \( x \) and \( y \) shown in table 1 for the \( Q_5 \) together with those for the \( Q_1 \), \( Q_{1/2} \) and \( Q_{1/4} \) overflows are transferred to an origin on the sharp-crested weir by adding the term 0.282\( H_d \) shown in figure 2 to the \( x \) values and deducting the term 0.127\( H_d \) from the \( y \) values.

For \( Q_5 \) the \( x \)-value is 0.073 m, for \( Q_1 \), 0.028 m, for \( Q_{1/2} \), 0.017 m and for \( Q_{1/4} \), 0.090 m while for \( Q_1 \) the \( y \)-value is 0.033 m, for \( Q_{1/2} \), 0.013 m, for \( Q_{1/4} \), 0.008 m and for \( Q_{1/4} \), 0.004 m. Hence the \( X \) and \( Y \) coordinates of the nappe profiles for the \( Q_5 \), \( Q_1 \), \( Q_{1/2} \) and \( Q_{1/4} \) overflows referred to the crest of the sharp-crested weir can now be calculated and are given in tables 2, 3, 4 and 5 respectively below.

### 5 LOCATION OF SCREEN ARRAYS

The tables below can now be used to position the interception combs so that the free nappe passes
through them before impacting on the lower water surface. From an inspection of the tables it will be seen that the trajectory of the $Q_{1/4}$ nappe in table 5 is the steepest and so will be examined first.

<table>
<thead>
<tr>
<th>X(m)</th>
<th>Y(m)</th>
<th>X(m)</th>
<th>Y(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.173</td>
<td>-0.011</td>
<td>0.573</td>
<td>0.403</td>
</tr>
<tr>
<td>0.273</td>
<td>0.047</td>
<td>0.673</td>
<td>0.577</td>
</tr>
<tr>
<td>0.373</td>
<td>0.136</td>
<td>0.773</td>
<td>0.677</td>
</tr>
<tr>
<td>0.473</td>
<td>0.255</td>
<td>0.873</td>
<td>1.007</td>
</tr>
</tbody>
</table>

Table 2. Nappe underside coordinates with respect to the sharp-crested weir for $Q_5$

<table>
<thead>
<tr>
<th>X(m)</th>
<th>Y(m)</th>
<th>X(m)</th>
<th>Y(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.173</td>
<td>0.087</td>
<td>0.375</td>
<td>0.487</td>
</tr>
<tr>
<td>0.239</td>
<td>0.187</td>
<td>0.411</td>
<td>0.587</td>
</tr>
<tr>
<td>0.291</td>
<td>0.287</td>
<td>0.444</td>
<td>0.687</td>
</tr>
<tr>
<td>0.335</td>
<td>0.387</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Nappe underside coordinates with respect to the sharp-crested weir for $Q_1$

<table>
<thead>
<tr>
<th>X(m)</th>
<th>Y(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.117</td>
<td>0.070</td>
</tr>
<tr>
<td>0.217</td>
<td>0.270</td>
</tr>
<tr>
<td>0.317</td>
<td>0.581</td>
</tr>
</tbody>
</table>

Table 4. Nappe underside coordinates with respect to the sharp-crested weir for $Q_{1/2}$

<table>
<thead>
<tr>
<th>X(m)</th>
<th>Y(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.109</td>
<td>0.136</td>
</tr>
<tr>
<td>0.159</td>
<td>0.296</td>
</tr>
<tr>
<td>0.209</td>
<td>0.496</td>
</tr>
</tbody>
</table>

Table 5. Nappe underside coordinates with respect to the sharp-crested weir for $Q_{1/4}$

Since the Vorthbach MWSS floor is 0.700m below the weir crest and the exit weir crest is 0.200m above the floor and as the depth on the exit weir for the $Q_{1/4}$ overflow is 0.030m, the fall from the weir crest to the lower water surface will be 0.470m. By plotting the coordinates of table 5 and interpolating for a fall 0.470m a horizontal projection of the nappe of 0.200m results.

Hence if the retention screen is placed 0.200m from the sharp-crested weir, the $Q_{1/4}$ nappe will just reach the retention screen before impacting on the lower water level.

Similarly this process can be repeated for the $Q_{1/2}$ nappe that has a depth on the exit weir of 0.060m and so an available fall of 0.440m. Interpolating table 4 gives a horizontal projection of 0.280m.

Again, this process can be repeated for the $Q_1$ nappe that has a depth on the exit weir of 0.100m and so an available fall of 0.400m. Interpolating table 3 gives a horizontal projection of 0.350m.

Similarly for the $Q_5$ overflow the depth on the exit weir would be 0.260m, so although the fall is only 0.240m, interpolating table 2 gives a horizontal projection of the combed nappe of 0.440m to the lower water level. As the MWSS is 0.450m in length the nappe would impact just before the exit weir.
Hence if the two interception combs are located 0.075m and 0.150m respectively from the sharp-crested weir, all the above overflows will be screened. However as overflow nappes less than the $Q_{\text{1/4}}$ overflow may not be screened, their velocities through the retention screen must be non-blinding.

If the retention screen wires were say, 3mm diameter and spaced 15mm centre to centre they would occupy 20 per cent of the screen area so that the $Q_{\text{1/4}}$ flow would have an average through-flow velocity of $V = Q/A = 0.01/0.80 \times (0.2 + 0.03) \times 1 = 0.054\text{m/s}$. Laboratory tests indicate that velocities less than 0.10m/s are non-blinding.

The retention screen is located 0.200m downstream from the weir and is 0.460m high so that it can retain captured solids in the holding chamber during the $Q_5$ overflow, ie $0.260 + 0.200 = 0.460\text{m}$.

The lowest nappe to clear the retention screen will be the $Q_{\text{1/2}}$ nappe as from table 4 it can be interpolated that when $X = 0.200$, $Y = 0.225\text{m}$. Hence $0.700 - Y = 0.465\text{m} > 0.460\text{m}$ so the $Q_{\text{1/2}}$ nappe will just clear the retention screen before impacting on the water surface of the filtered water chamber.

6 DISCUSSION OF DESIGN

From the foregoing, and as shown in figure 4 below, comb spacings of 0.075m and 0.150m respectively from the sharp-crested weir will be satisfactory. The front comb is terminated 0.600m above the chamber floor and the rear comb 0.400m to intercept all nappes down to the $Q_{\text{1/4}}$ overflow.

The short combs reduce the distance that intercepted solids must wash down the wires before free-falling into the holding chamber and so promotes the washing process. The two comb screens could be vertical 3mm stainless-steel wires spaced 30mm centre to centre although finer spring-steel combs
are possible. Overlapping the interception combs effectively reduces the clear gap to 12mm. Both combs are rigidly attached to the ceiling of the CSO chamber or to the baffle frame while the retention screen is rigidly attached to the chamber floor.

The tops of the retention screen bars are rounded to minimize solids adherence. This screen will be washed by the rising and recession limbs of overflow nappes that exceed the $\frac{Q}{1/4}$ event.

Aeration of the nappe is facilitated by the presence of naturally occurring air gaps to the rear of each interception comb wire.

There are other possible comb configurations that could improve solids washing that are to be tested in the laboratory. These include locating combs of increasing length in-line with one another so that only the lower section of a given comb intercepts a particular nappe.

Another variation of in-line combs is shown in figure 5 below where the combs are raked backwards at different angles so that a component of the nappe’s velocity facilitates the washing process.

![Figure 5. Raked in-line interception combs and corresponding nappes](image)

### 7 CONCLUSIONS

- Perforated screens for CSO sewer solids separation require cleaning by mechanical brushing or water jetting.

- Where external power sources are unavailable, combing the free overflow nappe using arrays of vertically inclined wires appears to offer a promising alternative.

- A sharp-crested weir at the inlet to the MWSS generates a free nappe that persists down to quite low overflows.

- The combed nappe passes directly to the outlet without further treatment.

- Overlapping of successive comb arrays improves sewer solids interception.
• Aeration of the nappe is facilitated by naturally occurring air gaps behind each comb wire.
• The nappe water intercepted by the comb arrays washes the intercepted sewer solids down into the holding chamber for retention and later return to the sewer.
• This wash-water passes through the retention screen at non-blinding velocities.
• Small overflow nappes, less than the once in three-monthly overflow, fall into the holding chamber without combing but pass through the retention screen at non-blinding velocities.
• After an overflow event, the water held in the filtered water chamber flushes the retained sewer solids back to the sewer via the one-way valve.
• Laboratory tests are to be conducted to determine the most effective comb configuration for screening solids from free nappes before field-testing its efficacy in a CSO chamber.

LIST OF REFERENCES