The improved flow diverter for first flush management

Perfectionnement d'un séparateur de débit pour la gestion du premier flot d'orage

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RESUME

La construction d'un réseau d'assainissement semi-séparatif peut être une alternative intéressante aux solutions conventionnelles pour gérer le premier flot d'orage. Cet exposé présente un séparateur de débit de conception innovante permettant de créer un réseau semi-séparatif avec réduction de la surcharge hydraulique de la station d'épuration par temps de pluie. Ce séparateur Septurn fonctionne de manière fiable sans alimentation énergétique extérieure ni organes de commande sophistiqués et ne requiert qu'une maintenance minimum. Des études pratiquées en laboratoire ont confirmé la précision élevée du modèle mathématique sur la base duquel le séparateur fonctionne. Des simulations hydrodynamiques utilisant le SWMM5 (ondes dynamiques) et réalisées pour des d'événements pluvieux unitaires montrent une réduction du débit des eaux pluviales envoyé vers la station d'épuration pouvant aller jusqu'à 60% tout en maintenant une proportion semblable de la charge totale dirigée vers la station d'épuration.

ABSTRACT

A conception of the semi-separate sewer system can be an interesting alternative to conventional solutions in the field first flush management. Presented in this paper innovative construction of the flow diverter allows to create the semi-separate system with minimization of a wastewater treatment plant hydraulic overburden during wet weather. Septurn diverter operates reliably without any external power, requires minimal maintenance and no complicated controls. Research conducted at laboratory scale confirmed the high accuracy of the developed mathematical model of the Septurn diverter. Hydrodynamics simulations using the SWMM5 (dynamic wave route) made for single rainfall events shows the split reduction of stormwater discharge to WWTP can be reduced even to 60% maintaining similar ratio of the total load directed to WWTP.

KEYWORDS:

First flush, flow diverter, stormwater.

1 INTRODUCTION

The stormwater management in Polish cities are still realized by the conventional practice – to concentrate runoff and carrying it off a site as quickly as possible through storm sewers to the receivers. The majority of the pollutant load is contained in the first portion of the event - this phenomenon of a disproportionate delivery of pollutants during the initial portion of a storm event is termed a “first flush” (Larson et al 1998). Saget et al. have defined an event as having a first flush when 80% of the pollutant mass is transported in 30% of the total runoff volume (Saget et al. 1995). This was also the definition primarily utilized in work by (Bertrand-Krajewski et al. 1998). Research by (Saget et al. 1995) investigated events from 17 different catchment areas in France and concluded that the first flush phenomenon rarely occurred to any significant degree. This study revealed that 20% of the flow contained only 20 to 38% of the suspended solids load. In order to contain 80% of the total suspended solids loading, 60 to 150 m^3/ha active ha of impervious surface would need to be collected. Stormwater discharges to receivers can be treated locally (oil/grit separators in each outfall) or central when the first flush is transported to WWTP making a semi-separate system (Fidala-Szope 1997, Zaizen and Matsumoto 2005). This conception has not been applied on a wide scale in Poland but in some cases may be more effective than treatment devices on each outfall (maintenance costs!). The diversion of first flush is crucial issues in semi-separate system. The ideal conception is to intercept the most of contaminants and to minimize the sewage quantity transported to WWTP in order to keep an optimal treatment performance.

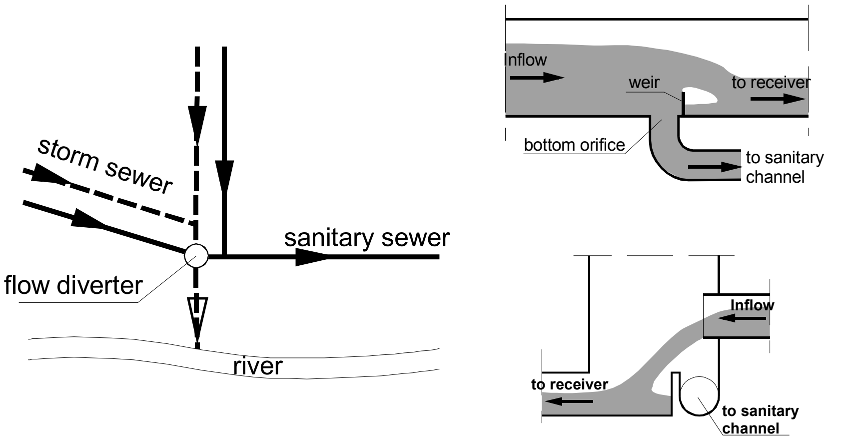


Fig.1. Scheme of the semi-separate sewage system and sample flow diverters: a) diverter with weir and bottom orifice (WO), b) cascade diverter

Application of the semi-separate sewer system is restricted in some cases:

- when a sanitary and a storm channel cannot be connected due to their elevation difference (but usually the foul channels are situated deeper than storm ones)
- existing WWTP has no enough capacity to treat additional volume of stormwater discharged to the sanitary sewers during wet weather - this problem can be resolved by a storage tank application.

Standard flow diverters (fig. 1a,b) have many disadvantages, the main are :

- cascade diverters operate temporary and not reduce a pollution load when the flow rate is bigger than “first flush“ flow rate (Q_0);

- diverters with transverse weir and sluice orifice (WO) operate continuously but cause a hydraulic overload of WWTP during long-lasting rainfalls.

2 SEPTURN DIVERTER

Due to abovementioned disadvantages an improved construction of flow diverter (fig.2) have been proposed with some initial assumptions:

- device require no external power (low operational costs),
- can be constructed in a channel or in a manhole,
- the flow-rate to the sewer channel (Q_0) can be adjusted to required value,
- the volume of stormwater discharged should be proportional to total impervious areas rather than to total inflow volume,
- total pollutant loads discharged to receiver are comparable to the WO diverter.
- high concentration of organic solids have been observed in a layer moving just above the bed (near-bed solids).

In proposed construction an outflow to the sanitary channel (2) is realized by the bottom orifice. Crucial part of the diverter is the quater turn flap valve that controls the flow balance – it has an upper (5) and lower part (4) moved along commonly shared axis of rotation. The axis is mounted on casing (3), which is also the transverse weir of height h_P over the channel bed. The neutral position of the valve close the outflow channel to a receiver, so the stormwater is directed to a sanitary sewer.

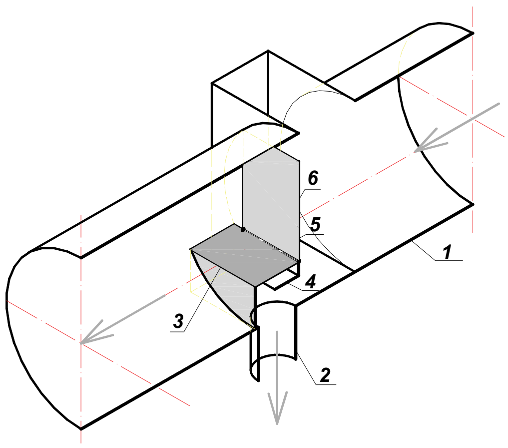


Fig.2. An isometric view of the Septurn diverter installed in drainage system – all remarks are described in the text.

During initial phase of a rainfall, the inlet channel operate as the storage tank with the bottom orifice as flow regulator (fig. 3a) – the outflow-rate through the orifice can be calculated using the standard formula. During this phase the heavier solids settle to the bottom of the channel. When the depth at the inlet channel achieve the upper crest (fig. 3b) of the valve, torque shifts causing a rotation of the flap valve. In effect the bottom orifice is closed and the wave of accumulated stormwater flows through the weir to a receiver (fig. 3c). When flows in the system have subsided after the storm, the valve returns to neutral position. Then the polluted stormwater retained in the inlet channel below h_P can be passed onward to WWTP (fig. 3d).

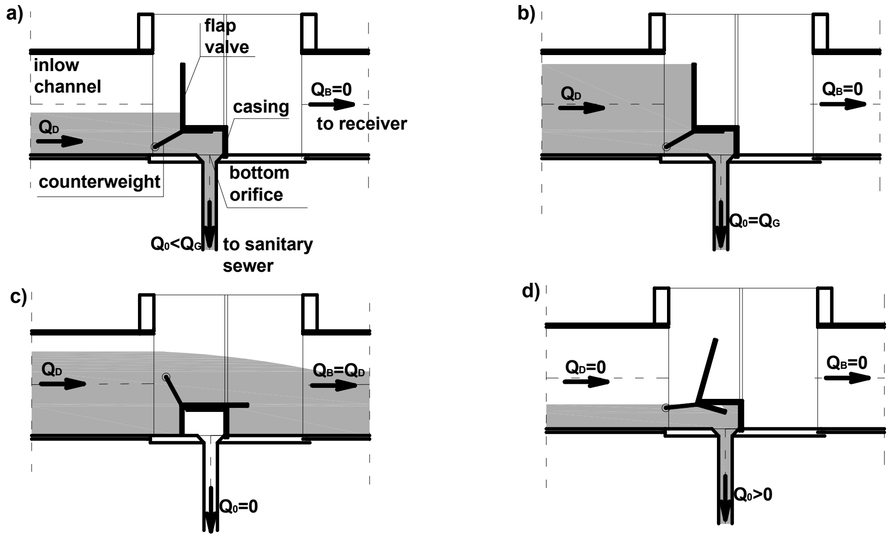


Fig.3. Main operational phases of the Septurn diverter during wet-weather flow.

3 MATHEMATICAL MODEL OF THE SEPTURN DIVERTER

Mathematical model of the Septurn diverter have been developed based on the equilibrium of turning moments from hydrostatic pressures and specific weights of the valve. The rotation of the valve for initial angle α (fig.4) is possible when the following inequality is satisfied:

$$r_{PG} \cdot P_G + r_{KD} \cdot G_D + r_{KG} \cdot G_G > r_{PD} \cdot P_D \cdot + r_0 \cdot G_0$$

where:

G_D , G_G - weight of the upper and lower part of the valve, [N],

G_0 - counterweight (include buoyancy), [N],

P_D , P_G - hydrostatic forces on upper and lower part of the valve, [N],

r_{PD} , r_{PG} - arm of hydrostatic forces on upper and lower part of the valve, [m],

r_{KD} , r_{KG} - arm of the weights (upper and lower part of the valve), [m],

r_0 - arm of the counterweight, [m],

β - angle between the counterweight and horizontal axis, [°],

The hydrostatic forces on the upper part of valve is proportional to depth at the inlet channel. Because the total area of the upper part is larger than for lower one it's possible to precisely define depth h_R that causing rotation.

Counterweight is the crucial part of the device:

- it is the regulation element allows to adjust the depth corresponding to actuating torque,
- makes possible to return of the valve to neutral position when the water level drops to h_P.

Return to the neutral position acts under following condition:

$$r_{KD} \cdot G_D + r_{KG} \cdot G_G < r_{PD} \cdot P_D \cdot + r_0 \cdot G_0$$

where G_0 - counterweight (unsubmerged, without buoyancy), [N],

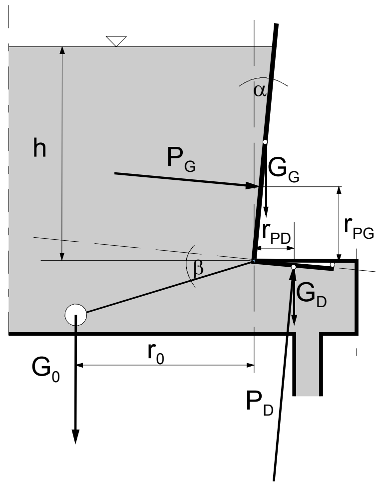
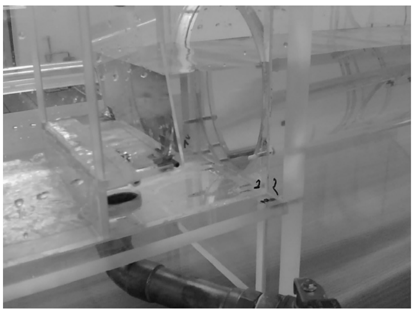


Fig.4. An scheme for mathematical model of the Septurn diverter.

Theoretical model have been verified on physical model at laboratory-scale – the main dimensions of the model: inlet channel diameter 0,15m, crest height 0,015÷0,045m, weir length 0,14m, max. orifice diameter 0,025m (adjustable). Small diameter of the pipe in the model preclude sedimentation processes modeling, therefore the verification tests was aimed to quantity aspects (to determine depth h_R). Some trial test shows a TTS load tends to be split between spill and orifice flow similarly as for WO diverter - the total efficiency factor is higher for the Septurn, but differences have not exceed 10%. The technical-scale pilot test have to be done in order to achieve a credible results.



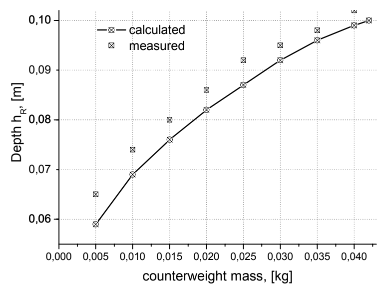


Fig.5. Laboratory investigations on Septurn diverter: a) model during detention phase b) results comparison between measured and calculated values of h_R for varying mass of counterweight.

The verification process was developed for variable geometric dimensions of the turn valve (width, mass of counterweight etc.). The depth h_R have been measured and compared to calculation results for 25 cases. Relative differences between the values have been on average about 3÷7%. The error is the result of the theoretical model assumptions - the mechanical losses on the axis and the velocity head (only hydrostatic forces was included) have not been taken into consideration. For the engineering purposes such error values can be considered as enough precise.

4 PERFORMANCE ASSESSMENT OF THE SEPTURN DIVERTER

The second stage of research was focused on a comparison of the Septurn and WO diverter efficiency. The hydrodynamic model (fig.6) of both diverters have been simulated in SWMM5 application for dynamic wave routing (solving the full Saint-Venant equation). The model main dimensions: inlet channel diameter 1200mm, slope 0,2%, crest height 0,3m, orifice diameter: 0,3m (WO) and 0,4m (Septurn). Five rainfall events measured on the urban watershed (Czestochowa city) had been selected to run the simulations – duration from 30 minutes to 4 hours. In order to simulate the Septurn operation phases a three control rules have been defined for the weir and the orifice (i.e. : Rule R1: if node 2 depth > 1.15 then weir 1 setting = 1 and orifice 1 setting = 0)

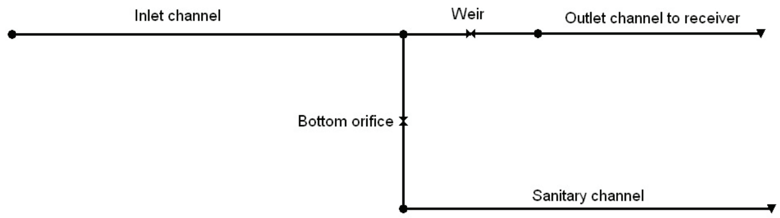


Fig.6. Scheme of the Septurn diverter in the SWMM5.

The operational performance of the diverters (both Septurn and WO) have been expressed using terms (Butler and Davies 2000):

- flow split factor K_F (storm volume directed to sanitary sewer / total storm inflow volume)
- total efficiency factor K_E (storm load directed to sanitary sewer/ total storm inflow load)
- treatment factor K_T (total efficiency / flow split)

Simulation results have been presented as outflow hydrographs to sanitary sewer and to receiver (fig. 7). On the base of these hydrographs, the total volume of stormwater flowing through the orifice/weir was determined. For WO diverter a relationship between split factor K_F and rainfall duration is linear (from 0,12 for t=30m to 0,22 for t=4h), whereas the Septurn diverter is characterized by quasi-constant value (about 4,2%). The differences between both devices were much higher considering absolute values, for 30min rainfall the total volume discharged to sanitary channel was equal to 91 m^3 (Septurn) and 254 m^3 (WO) while for 4-hour rainfall was 203 m^3 and 926m^3 respectively.

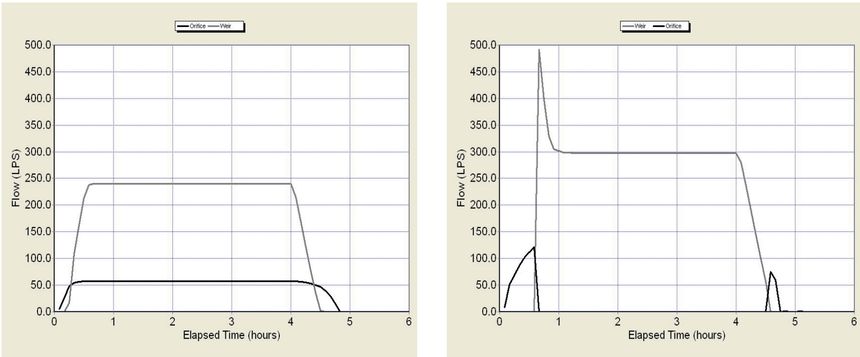


Fig.7. Hydrographs comparison for 4-hours rainfall: a) WO diverter , b) Septurn diverter

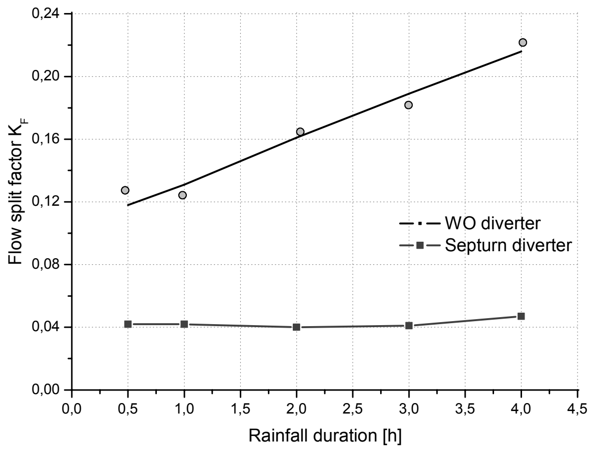


Fig.8. Relationship between flow split factor and rainfall duration.

Simulation results clearly show the split factor for the Septurn diverter has significantly lower values in comparison to WO separator for equivalent crest height. If the total efficiency factor has similar values for both devices (need to be confirmed at technical-scale) the treatment factor K_T is also expected to achieve significantly better values for the Septurn diverter. The final assesstment of a flow diverter should be based on long-term simulations rather than single event but the obtained results for five different rainfalls suggest that long-term simulations will show similar, positive trends for the Septurn diverter.

The main operational problem is the re-suspension of accumulated solids when the valve turns and create a wave of a high turbidity (peak flows) and cause a sediment resuspension. This disadvantage can be avoided when the valve is gradually opened.

5 CONCLUSIONS

Modern design of drainage systems have to concern with the quantity (i.e. flood prevent) as well as quality aspects (i.e. rivers an streams protection) of stormwater conveyance. Semi-separate sewage system allows to achieve both targets at relatively low investment costs. Presented construction of the flow diverter (Septurn) makes possible to reduce volume discharges to WWTPs during wet weather. Laboratory-scale tests positively verified the quantity mathematical model of the Septurn - the relative errors were not exceeded 7%. Due to model scale some flow conditions (i.e. flow regime, velocity values) in the inflow channel have not been taken into consideration, so a larger scale testing is needed in order to evaluate hydraulic performance and reliability (i.e. potential blockage problems) of the flow diverter. Quantity aspects (TTS load split) are going to be tested at technical-scale on a 1.0 meter diameter conduit in urban catchment of Czestochowa.

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