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Measuring flap gates flow

Mesure de débit des clapets anti-retour

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ABSTRACT

Monitoring wastewater flow is critical to manage sewer system. Locations equipped with flap gates to prevent backflows are a good opportunity to measure flow. Theoretical studies that necessitate simplifications and field results are not very accurate (error >20%). Field tests can provide accurate discharge relation but are costly and not always doable on actual sewers. Faster software and hardware have recently made possible to numerically study flap gates with Computational Fluid Dynamics (CFD). The main objective of this article was to validate Smoothed Particle Hydrodynamics (SPH) to simulate flap gates. Five flap gates configurations (different resistive torque and downstream conditions) were studied with an experimental setup and then successfully simulated (mean absolute error from 4 to 12 L.s⁻¹. and mean relative error from 2 to 14 %). More configurations were numerically studied. All results showed that gate properties and upstream and downstream conditions are very influential on the gate behavior. Thus, specific study with accurate representation of the gate is needed to establish the discharge relation of a specific flap gate.

RÉSUMÉ

La mesure des débits d'eaux usées est cruciale pour la gestion des réseaux d'assainissements. Les clapets anti-retours offrent une solution de mesure économique et pratique. Les études théoriques nécessitant des simplifications et des résultats de terrain sont peu précises (erreur >20%). Les études de terrain sont précises mais coûteuses et pas toujours possible *in situ*. Des programmes et des ordinateurs plus rapides permettent aujourd'hui d'étudier numériquement les clapets anti-retours à l'aide de la Mécanique des Fluides Numérique. L'objectif principal de cet article est de valider l'utilisation de « Smoothed Particle Hydrodynamics » (Hydrodynamique des Particules Lissées) pour modéliser les clapets anti-retours. Cinq configurations de clapets (couple résistif et conditions aval différentes) ont été étudiées sur un banc d'essai puis simulées avec succès (erreur absolue moyenne entre 4 et 12 L.s⁻¹. et erreur relative moyenne entre 2 et 14 %). Des configurations additionnelles ont été simulées. Tous les résultats montrent que les propriétés des clapets anti-retours ainsi que les conditions amont et aval ont une grande influence sur le comportement des clapets. Ainsi, des études spécifiques avec représentation fine du clapet sont nécessaires pour proposer des lois de fonctionnement propre à chaque ouvrage.

KEYWORDS

Combined sewer overflow (CSO), Computational fluid dynamics (CFD), Inclination sensor, Smoothed Particle Hydrodynamics (SPH), Sewer monitoring

CONTEXT AND OBJECTIVES

Monitoring wastewater flow is critical to manage sewer system. Especially concerning overflow to the environment that are subjects to regulation and are an important pollution source. However, measuring wastewater flow can be difficult and costly (Campisano *et al.*, 2013). Lots of monitoring locations have a unique design, preventing the use of standard laws and requiring complex studies.

A lot of overflow infrastructures are equipped with flap gates as a simple and effective way to prevent backflows (Lewin, 1995). While most of the studies investigate the induced head losses in the system, a few studies have identified them as a cost-efficient opportunity to monitor flow (Burrows, 1986, Charron *et al.*, 2012), regardless of the gate properties (shape and weight) and upstream and downstream conditions. The idea is to link the flow to either the gate rotation or the water level on both sides of the gate. Two methodologies have been explored.

The first is a theoretical mechanical description of the problem, by applying the principle of conservation of angular momentum to a control volume of the flow (Burrows *et al.*, 1997, Mahmoudi and Farhoudi, 2019). Many assumptions are made and experimental data are necessary (flow velocity profile, flow constriction coefficient for the gate). The prediction accuracy is around $\pm 20\%$.

The second consists of calibrating specific discharge laws for specific flap gates in specific conditions (Panasiuk *et al.*, 2019, Vatankhah and Ghaderinia, 2018). This produces very accurate laws. While this could be useful to systems where flap gates and their environment are normalized, for the wide range of situation that are encountered in sewers, it could be impossible or more costly to retrofit existing gates to the ones studied. More broadly, it has been demonstrated that gates with different properties and upstream and downstream conditions follow discharge laws of different form (Moghtaderi *et al.*, 2021).

In the recent years, computation capabilities have greatly increased (Shalf, 2020). As a results, new computational fluid dynamics (CFD) techniques are now mature enough. A particularly efficient CFD method is Smoothed Particle Hydrodynamics (SPH). It is capable to model dynamic flows in complex geometries with two-way fluid-solid interactions (Domínguez *et al.*, 2022). SPH was successfully used to study overflow problems in sewers. It proved to be more efficient than traditional CFD methods such as Reynold Average Navier Stokes (RANS) (Pouzol *et al.*, 2019).

In this context, the first objective of this article is to validate the use of SPH to model flap gates using field experiments. Then, various flap gate properties and upstream and downstream flow conditions will be numerically studied to identify which configurations are offering the best monitoring solutions. This will help sewer system managers choose which flap gates to investigate further, to cut cost for their monitoring solution.

1 MATERIALS AND METHOD

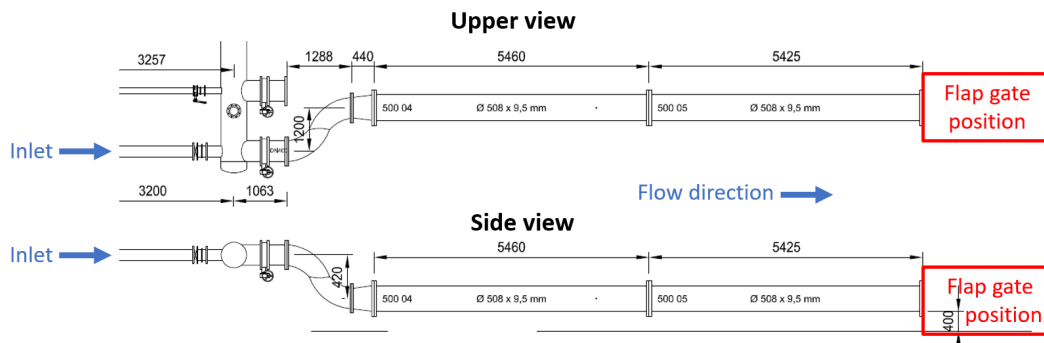


Figure 1: Test bench, upstream configuration.

The test bench was installed at “Société du canal de Provence et d’aménagement de la région Provençale” in France. It consisted of a series of circular pipes ending with a straight horizontal section ($\varnothing=0.5\text{m}$; $L=10.885\text{m}$) (see Figure 1). At the end of the pipe, five flap gate configurations were tested successively (see Figure 2). Each new configuration is built upon the previous one. The first configuration was a simple rectangular top hinged flap gate. Then a lever arm with counterweight linked to the flap gate with a connecting rod was added. This changed the relation between the gate opening angle and its resistive torque. Thirdly lateral flow constriction plates were added. Then side and bottom walls were added. And finally, a front wall was installed to flood the gate. Flows up to $0.2\text{ m}^3\cdot\text{s}^{-1}$ were imposed and measured with an electromagnetic flowmeter. The opening angles of the gate were monitored as well.

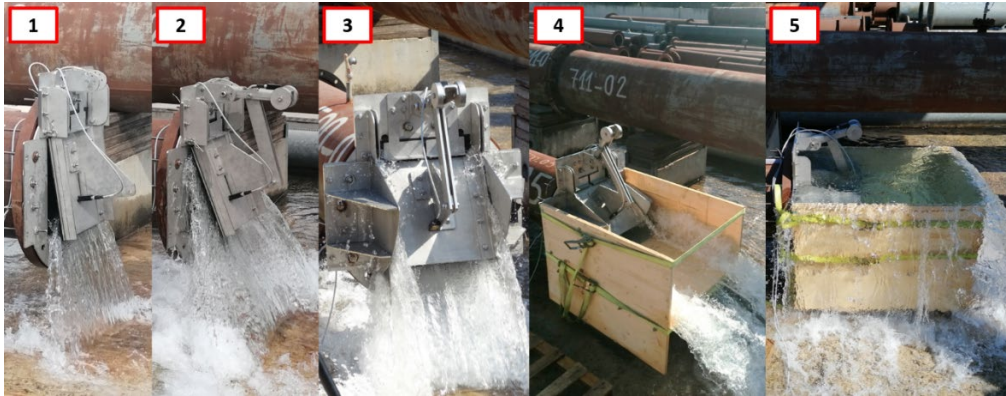


Figure 2: Flap gates tested. Each configuration is built upon the previous one, from left to right: 1) simple rectangular top hinged flap gate, 2) levered counterweight added, 3) lateral flow constriction plates added, 4) side and bottom walls added and 5) front wall added to flood the gate.

Numerical modelling was done using the CFD DualSPHysics software (Domínguez et al., 2022) based on the SPH method. Firstly, a numerical campaign reproduced the field experiment in order to validate the model. Then an exploratory campaign was designed to demonstrate the effect of different parameters on the flap gate behavior. It was designed around a simple rectangular top hinged flap gate with changeable resistive torque. Upstream conditions were either: 1) a rectangular channel with the flap gate dimension and slope and incidence changeable, 2) a sharp turn right before the flap gate imposing very dissymmetrical flow conditions, 3) a chamber with steady water flow. Downstream conditions were either a free fall or a rectangular channel with the flap gate dimension followed by a free fall at changeable distances.

2 RESULTS AND DISCUSSIONS

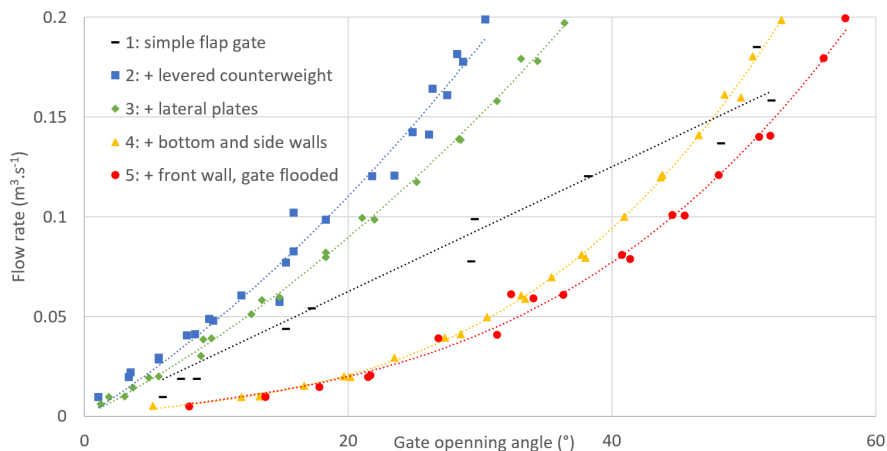


Figure 3: Field experiments results

Results of the field tests are shown in Figure 3. Very different behaviors were observed between test 1 (simple flap gate) and the other tests (with levered counterweight). Having a significant smaller resistive torque, gate 1 suffered from unstable opening angle for high flows (4° at $0.08 \text{ m}^3 \cdot \text{s}^{-1}$ and 15° at $0.2 \text{ m}^3 \cdot \text{s}^{-1}$). Gates 2 to 5 had stable behavior and the more the downstream flow was constricted the more open the gate was for the same flow. The addition of a bottom wall seemed to have the greater effect. More constricted flows gave discharge relation with less uncertainties (less steep relation).

Simulation results of the 5 field tests gave good results. Mean absolute error are, in order, 12 ± 10 , 4 ± 2 , 4 ± 7 , 9 ± 5 , $9 \pm 6 \text{ L} \cdot \text{s}^{-1}$. Mean relative error for flow greater than $0.02 \text{ m}^3 \cdot \text{s}^{-1}$ are, in order, 12 ± 6 , 8 ± 6 , 2 ± 2 , 13 ± 11 and $14 \pm 16 \%$. Results of gate 1 shows difficulties in both field measurements and flow modelling. The incoming flow was very torrential, unsteady and unsymmetrical with a hydraulic jump right before the gate (see Figure 4). Gate 2 shows that increasing the gate resistive torque (here with the levered counterweight) is beneficial for measurement since the hydraulic jump is pushed upstream and steady fluvial conditions are imposed in the upstream pipe. Gate 4 and 5 gave slightly worst results, this could be the results of the uncertain description of the wooden box used to add the different walls.

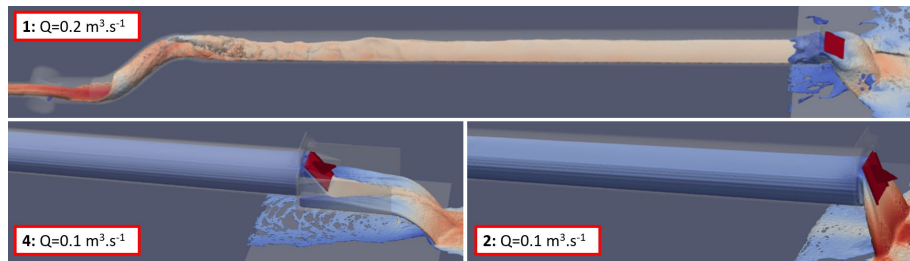


Figure 4: Simulation results for tests 1, 2 and 4. Levered counterweight parts are not shown.

The exploratory campaign demonstrated the great influence of every parameter (gate properties and upstream and downstream conditions).

For example, regarding light flap gates, results of gate 1 and the exploratory campaign shows that they can have unstable behavior (oscillation or jump on the water free surface). While this would simplify the modelling, discharge relations based on the assumption that flap gates sit tangentially to the free surface without any perturbation are underestimating the flow. In the context of pollution control this is problematic.

So, while flap gates are a good monitoring opportunity (low investment and maintenance costs), they require specific modelling in order to determine their discharge relation. Detrimental to measurement are: upstream conditions exposing the gate to violent unsteady flows, gates with low resistive torque and/or un-constricted downstream conditions. Increasing the resistive torque of the gate is an efficient way to mitigate bad upstream flow conditions.

3 CONCLUSIONS AND PERSPECTIVES

Five flap gates configurations were studied on the field and then successfully simulated using SPH. Secondly, an exploratory numerical campaign was conducted to test more configurations. All results gave the same insight for measuring flows with flap gates: 1) gate properties and upstream and downstream conditions are very influential on the gate behavior; 2) specific study with accurate representation of the gate is needed to establish the discharge relation of a specific gate; 3) gates with low resistive torque are sensitive to unsteady flow conditions; 4) gates with high resistive torque can potentially impose steady upstream flow conditions regardless of upstream conditions.

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