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Accumulation of floating particles at hydraulic structures

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Introduction

Plastic pollution is a threat for all ecosystems due to its effects on people, animals, and environment (*Mai et al.*, 2020). Rivers are estimated to transport around 0.5 millions tons of plastic per year (*Strokal et al.*, 2023). When plastic enters a river system, it is transported downstream towards the sea but it is also likely to accumulate at specific cross sections and locations, including hydraulic structures (*Al-Zawaidah et al.*, 2021), eventually increasing the risk of floods.
Gates, locks, weirs, and bridges are commonly present in rivers and canals and have several functions, including water level regulation, flood safety, and inland water shipping. These can also be found in water treatment plants, hydropower stations as well as debris/plastic collection systems (*Honingh et al.*, 2020). Riverine plastic accumulation is also known to cause geomorphic changes (*Al-Zawaidah et al.*, 2021).
In-depth knowledge on how plastic particles accumulate upstream of hydraulic structures is therefore crucial to understand the processes that affect plastic transport, its influence on the safety and functionality of hydraulic structures and their effects on the hydro- and morphodynamic conditions of the flow (*Yan Toe et al.*, 2022).
In this research experiments were performed using simplified plastic particles to analyse the processes that lead to the instability of accumulated particles upstream of a simple gate.

Rise Velocity

As we are dealing with floating particles, their characteristics are reflected in the rise velocity and need to be determined first. Initial experiment determined the rise velocity of single plastic particles in a 2 m tall water column. The particle with diameter $d_p = 6$ mm and density $\rho = 904$ kg/m^3 was released from the bottom of the column with almost no initial velocity ($u_{s,0} \simeq 0$ m/s).

The rise velocity was computed as

$$u_s = \frac{l}{\Delta t} \tag{1}$$

where l is the distance between two marks on the water column and Δt is the time interval in which the particle passed between the two marks (Fig. 1). This time interval was extracted from videos recorded with a frame rate of 25 frames/second.

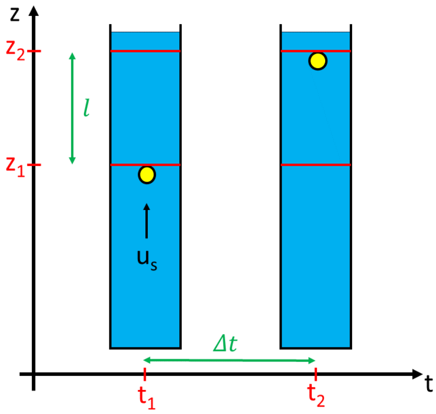

Figure 1: Sketch of setup used during the rise velocity experiment. The image is not to scale.

The experiment was repeated nineteen times. Fig. 2 shows the experimental data, which compares well with a CDF assuming a normal distribution for the rise velocity.

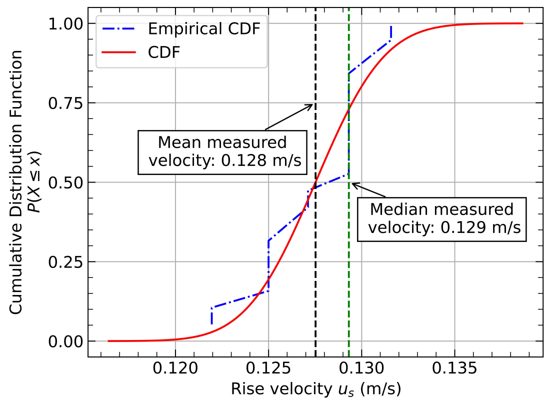

Figure 2: CDF of the measured rise velocity. The black and green lines represent the mean and median velocity.

At the end of the tests, the mean measured rising velocity was $\overline{u}_s = 0.128$ m/s, the median

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was $u_{s,median} = 0.129$ m/s and the standard deviation was $\sigma_{u_s} = 0.003$ m/s. From rise velocity and drag coefficient formulas included in *Yang et al.* (2015) and *Kuizenga et al.* (2022), the expected rising velocity was slightly larger than the measured ones, between 0.131 and 0.144 m/s, with a median value of 0.134 m/s.

Carpet instabilities

This experiment determined the flow velocity for which the particles were no longer stable in the carpet. For that, a carpet of the same particles (Fig. 3) was placed upstream of a 0.06 m deep gate, allowing for a 0.10 m clearance, installed in a 14 m long and 0.40 m wide flume. The discharge was increased by steps until instabilities were observed.
The following regimes were identified:

- **Stability Region**: This is defined by a set of hydraulic conditions ($\overline{U}$, d_w), carpet length (λ), and particles characteristics (u_s, d_p), ensuring stability for the particles.
- **Squeezing**: This phenomenon occurred when a particle within the carpet, positioned at a minimum distance of 5 cm upstream of the gate, was pushed down by neighboring particles and completely submerged.
- **Erosion**: This took place when a particle on the upstream section of the carpet underwent a horizontal downstream displacement, causing it to be located in a second carpet layer below the initial one.

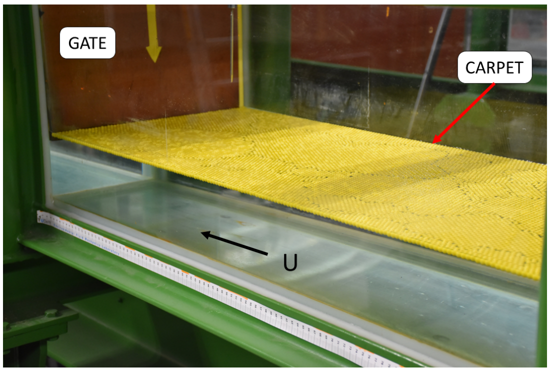

Figure 3: Configuration of the particle carpet setup.

Experiments were performed two times for multiple carpet lengths $\lambda = 0.30, 0.45, 0.60, 0.67, 0.75$ and 0.90 m. Despite some scatter, a linear relation seems to exist between carpet length and velocity at which both processes occur. The resulting coefficients of determination R^2 seem to confirm this relation. Erosion is always observed to occur for larger velocities than squeezing (Fig. 4). For $\lambda/d_p \leq 40$, where the two regression lines seem to meet, the carpet is too short to distinguish erosion from squeezing.

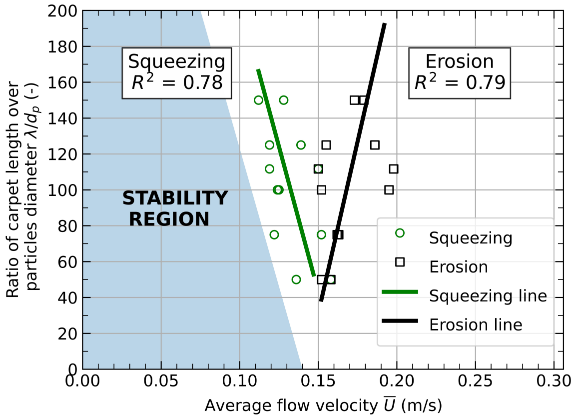

Figure 4: Stability region (blue light area on the left). Circles and squares are the observed values, while lines are the regressions of the observations.

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