

OVERTOPPING-INDUCED BREACHING IN SAND DIKES: EXPERIMENT AND MODELLING

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1. INTRODUCTION

Flood protection remains a major global challenge, especially for low-lying countries such as Belgium and the Netherlands. Designing safe riverine and coastal regions involves constructing and maintaining protective structures like dikes. Among various failure mechanisms or earthen dikes, overtopping accounts for most failures (Foster et al., 2000). Predicting the breaching process is therefore essential for flood risk mitigation. However, it remains difficult to fully capture its complex dynamics and incorporate them into reliable numerical models (ASCE/EWRI Task Committee on Dam/Levee Breaching, 2011). Laboratory-scale experiments have long been used to study breach initiation and development under controlled conditions. Small-scale physical models provide flexibility, repeatability, and high measurement resolution, making them suitable for generating datasets to support numerical model calibration and validation. However, accurately capturing the rapid morphological changes during breaching remains a challenge and requires advanced, non-intrusive monitoring techniques.

This study presents an integrated approach that combines small-scale flume experiments with two-dimensional morphodynamic modelling, including a bank failure operator. The experimental setup uses close-range photogrammetry to record breach topography with high spatial and temporal resolution. The resulting dataset is used to validate the numerical model and highlights the importance of accounting for bank erosion to accurately reproduce the breach widening process.

2. SMALL-SCALE EXPERIMENTS

The physical experiments were conducted at UCLouvain using a small-scale flume designed to study overtopping-induced breaching in non-cohesive sand dikes. The flume is 14 m long and 1.22 m wide. A trapezoidal sand dike was constructed across the channel with consistent dimensions for all tests: a height of 0.217 m, a base width of 1.30 m, and a crest width of 0.10 m. Both the upstream and downstream slopes were set at 1:3. A narrow pilot channel was cut at the dike crest to control the breach

initiation point and improve repeatability of the experiments. The pilot channel had a trapezoidal shape, with a 0.03 m base, 0.124 m top width, and 0.047 m height. The layout and dimensions of the flume and the dike with the pilot channel are shown in Figure 1.

Two types of uniform fine sands were used to assess the influence of grain size on breach development: a very fine sand ($d_{50} = 0.31$ mm) and a medium sand ($d_{50} = 0.61$ mm). Prior to the experiments, the sand was compacted at its optimum moisture content, determined through Proctor tests (14.5% and 15.5%, respectively) to ensure consistent material properties. The upstream inflow was maintained at a constant rate of 4 l/s throughout the entire test.

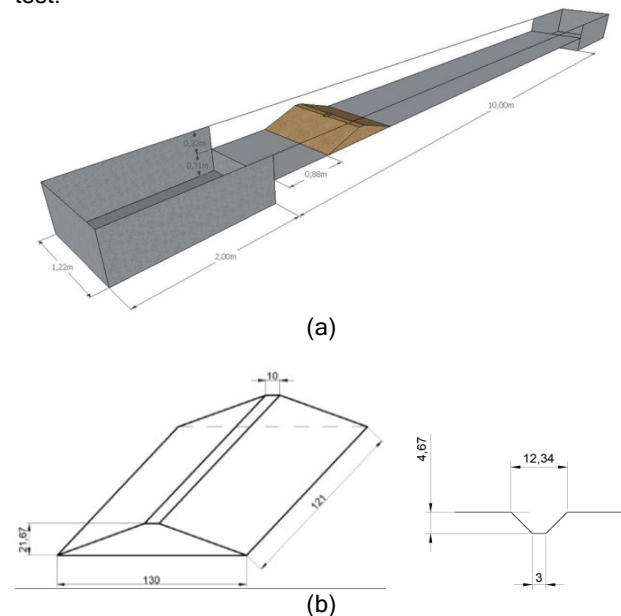


Figure 1 - Dimensions of (a) the flume (m) and (b) the dike with the initial pilot channel (cm) (Anspach et al., 2025). High-resolution topographic data of the evolving breach was obtained using close-range photogrammetry

(Ebrahimi et al., 2025). Nine GoPro cameras mounted on a fixed structure above the flume captured synchronized images at two frames per second. These images were processed in Agisoft Metashape to generate time series of 3D point clouds, from which digital elevation models (DEMs) were created (Anspach et al., 2025). Longitudinal and cross-sectional profiles were then extracted to analyze the erosion patterns. A sequence of top-view photographs and corresponding digital elevation models (DEMs) at different time steps – 0 s and 90 s– is shown in Figure 2. Time $t = 0$ s is considered as the time when the flow enters the pilot channel.

The water level was continuously measured in the upstream reservoir, using an ultrasonic sensor mounted on a bracket. From these measurements, the breach outflow discharge Q_{out} could be determined by applying the continuity equation to the upstream reservoir as shown below

$$Q_{out} = Q_{in} - A_{res} \frac{dz_w}{dt} \quad (1)$$

where Q_{in} is the inflow discharge, A_{res} the area of the upstream reservoir and z_w the measured water level in the reservoir.

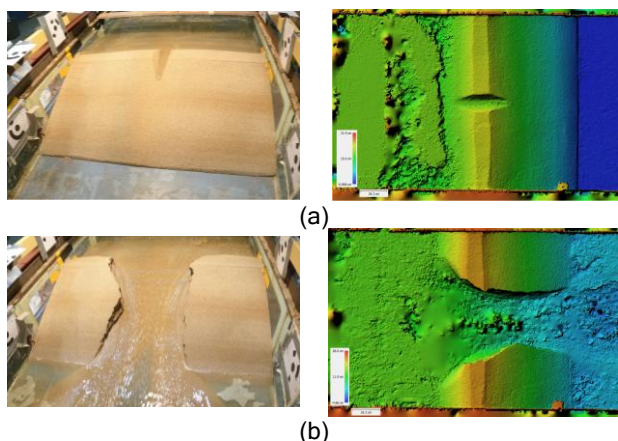


Figure 2 - Breach evolution for $d_{50} = 0.61$ mm, shown through photo and digital elevation models after (a) 0 s and (b) 90 s from the start of the breaching process (Anspach et al., 2025).

3. NUMERICAL MODEL

Numerical simulations were performed using a two-dimensional, depth-averaged morphodynamic model developed to simulate transient flows involving sediment transport. The model solves the shallow-water equations for flow dynamics, coupled with the Exner equation to represent sediment mass conservation and bed level changes. Sediment transport rates are calculated using the Meyer-Peter and Müller formula, as a closure equation for the Exner equation. To account for bank failures that govern the breach widening process, a dedicated module is used, based on the local angle of stability of the dike material (Swartenbroekx et al. 2010). The governing equations are discretized using an explicit finite-volume scheme, where flow and sediment variables are updated based on flux exchanges across cell

interfaces (Delpierre et al., 2024).

In this study, the numerical model was applied to reproduce the breach evolution and its sensitivity to sand size, as observed in the physical experiments. Simulations were conducted using the same inflow conditions and initial geometry as in the flume tests, allowing for a direct comparison between measured and modelled results. Special attention has been paid to the parametrization of the bank failure operator in order to properly calibrate the model according to the behavior of the sand dike constituted from different grain sizes.

4. CONCLUSIONS

This study combined small-scale laboratory experiments and two-dimensional morphodynamic modelling to investigate overtopping-induced breaching in non-cohesive sand dikes. High-resolution photogrammetry enabled detailed spatial and temporal monitoring of breach topography. The importance of accounting for specific bank erosion processes was highlighted through the comparisons with the numerical simulations. Future work will focus on improving bank failure mechanisms to better account for apparent cohesion effects. These developments aim to enhance the calibration and validation of numerical models, supporting more accurate predictions of breaching processes in real-world scenarios.

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