Benchmark tests on medium-scale dam breaching due to overtopping

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1. Introduction

This document presents two benchmark tests based on two distinct experimental studies of breach formation in embankment dams due to overtopping flow. Both experimental setups are closer to prototype conditions than conventional small-scale laboratory tests, enabling a more realistic investigation of breach initiation and breach formation processes. The two experiments were conducted at medium scales, using either homogeneous or heterogeneous materials:

- Test 1: a 1 m high dam composed of non-cohesive homogeneous sand;
- Test 2: a 2.37 m high dam composed of a gravel–sand mixture.

The collected experimental data can serve multiple purposes, including (i) supporting the validation and calibration of existing dike breaching models, (ii) enhancing the understanding of physical breach mechanisms, (iii) identifying limitations in current modeling approaches, and (iv) providing guidance for future model development and refinement.

The following sections describe the two experimental setups, test conditions, boundary conditions, and the requested model outputs for participants engaging with the benchmark tests.

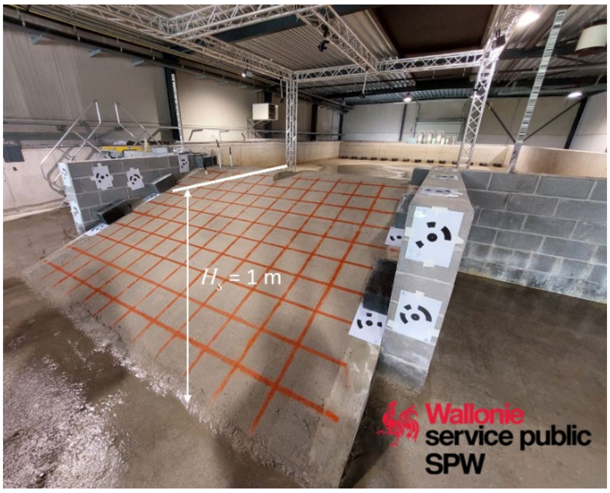
2. Test 1: homogeneous sand dike breaching at SPW-MI Dike Flume

This experiment was conducted in collaboration with the Hydraulics Research Laboratory of the Service Public de Wallonie Mobilité & Infrastructures (SPW MI) in Châtelet, Belgium. The setup is illustrated in Fig. 1. It consists of a 1 m high dike made of homogeneous non-cohesive material subjected to overtopping flow conditions.

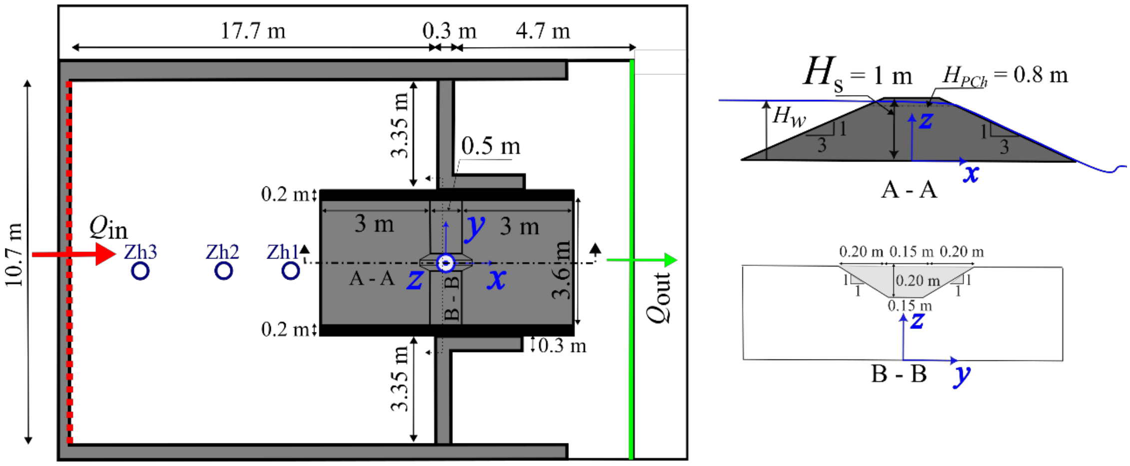
The sand used had the following properties: median grain diameter $d_{50} = 0.61$ mm, specific density $s = 2.65$, porosity $\varepsilon_0 = 0.42$, and an estimated internal friction angle $\varphi = 36.5°$. The dike was constructed in a wide flume made of concrete (Manning friction coefficient estimated to 0.014 $sm^{-1/3}$). The area upstream of the dike served as a reservoir, while the downstream part conveyed the water to the outflow area, where it dropped into a lower reservoir. Consequently, the downstream boundary condition had no influence on the flow.

The upstream boundary condition consisted of a constant inflow discharge Q_{in} = 224 l/s, maintained throughout the test, i.e. both the initial reservoir filling phase and the entire duration of the overtopping event. Since dissipative devices are placed next to the pumps, it can be considered that the flow was uniformly distributed along the upstream wall. To initiate overtopping in a controlled manner, a pilot channel of trapezoidal cross-section was pre-cut at the center of the dike crest (Fig. 1b).

The reservoir inflow discharge Q_{in} and the breach outflow hydrograph Q_{out} were recorded. Three gauges located in the upstream reservoir measured the water level evolution in time. Their locations relative to the system of coordinates (Fig. 1), with the origin of the x- and y-axes at the center of the dike crest and the elevation z referenced to the reservoir bed elevation, are provided in Table 1. The dike geometry evolution during the breaching phase was recorded and monitored using close-range photogrammetry offering the possibility to reconstruct the 3D model of the dike.



(a)



(b)

Figure 1. (a) Experimental setup at the hydraulics laboratory of SPW MI, (b) setup dimensions. H_s: dike crest elevation, H_w: initial water elevation, H_{PCh}: elevation of the pilot channel bed

Table 1. Locations of water level gauges in the upstream reservoir

Water level sensors	*x* (m)	*y* (m)
Zh1	-6.1	0
Zh2	-11.1	0
Zh3	-16.1	0

Time t = 0 is considered when the water level at Zh1 reaches 0.75 m, i.e. 0.05 m below the pilot channel bed. Therefore, numerical simulations can be initiated in two different ways, to reproduce the initial conditions:

- Start with an empty reservoir, like in the experiment, with a 224 l/s inflow discharge to establish the flow conditions at t = 0 when the water level at Zh1 reaches 0.75 m;
- Start with a reservoir filled with 0.75 m water and imposing the prescribed inflow discharge: in this way, it can be considered that the waves generated by the inflow discharge have been dissipated enough when the water level will reach the bed of the pilot channel.

3. Test 2: Medium-scale gravel-sand dike breaching at the hydraulic laboratory of CESAME, CNR

The experiment was conducted at the hydraulic laboratory of CESAME, Compagnie Nationale du Rhône (CNR), France (Figs. 2-3). The dam embankment, built in a concrete flume, was 2.37 m high and 8.5 m long, with upstream and downstream slopes of 2:1. The dam crest was 4 m wide and 0.8 m long. On the upstream face, the dam was topped with a small wall 0.85 m high (Fig. 3b). A trapezoidal pilot channel, 0.14 m deep, 2 m wide at the bottom, and 1.4 m long, was pre-cut at the center of the crest to guide the overtopping flow. The side slopes of the notch were 1:1.

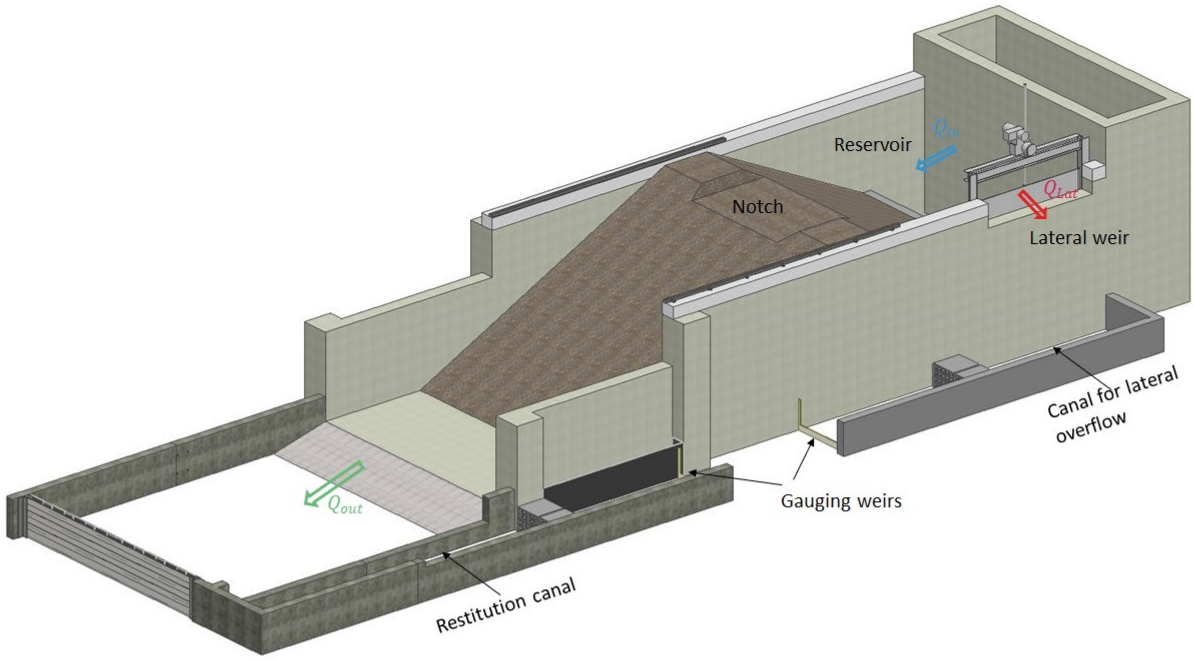


Figure 2. View of the laboratory setup at CESAME, CNR

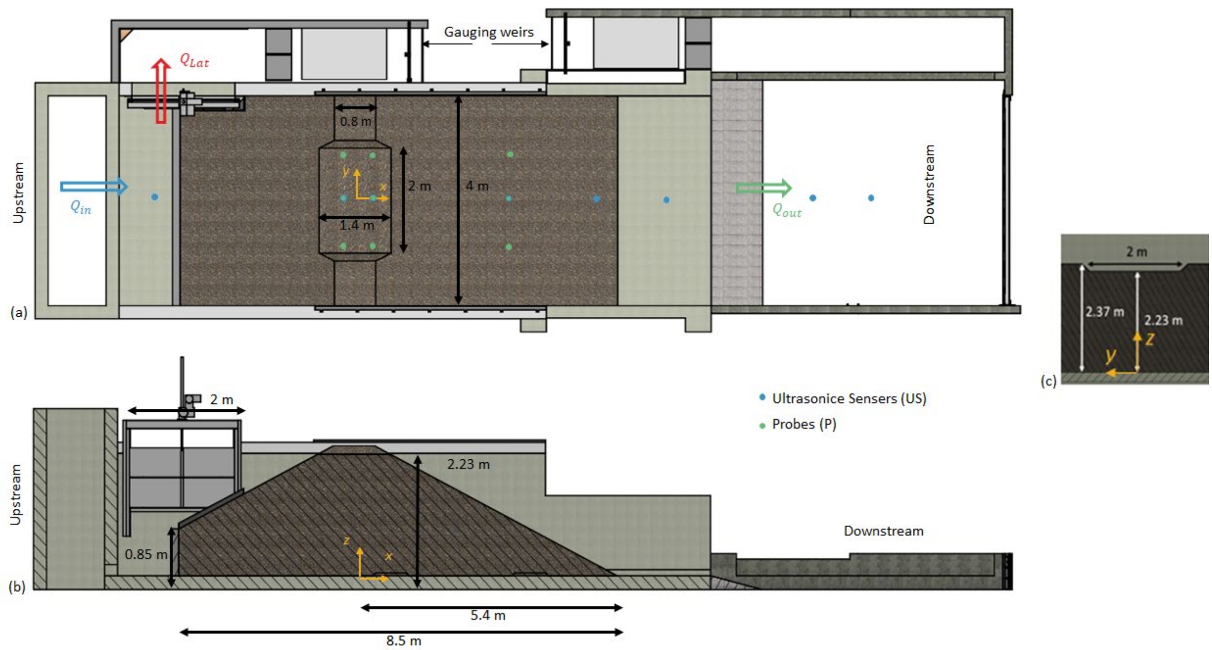


Figure 3. Embankment geometry of the CNR Test: (a) top view with locations of ultrasonic sensors and probes, (b) side view, and (c) cross section for the embankment

The dike material consisted of a mixture of gravel (67%), sand (29%), and silt (4%) (Fig. 4) taken from a Rhône River levee. The material was placed in successive 30 cm-thick layers using a mechanical shovel, with each layer compacted twice with a vibrating plate.

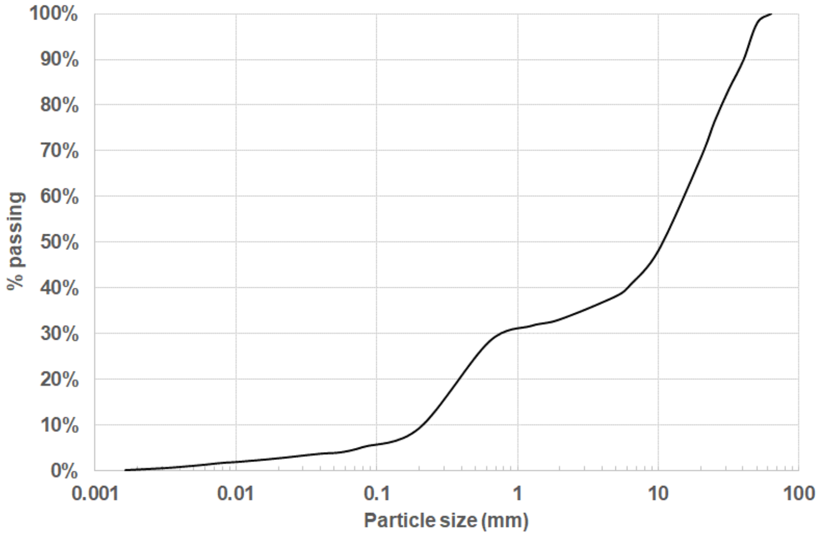


Figure 4. Soil grading curve

Water content and density were measured using a gamma densimeter after the construction and compaction of the 1st, 4th, and 8th (final) layers. The overall compaction rate achieved was approximately 92%, with a water content of about 7%. The average dry and wet densities of the soil were approximately 2150 kg/m³ and 2000 kg/m³, respectively. The porosity was estimated at $\varepsilon_0 = 0.25$ and the internal friction angle at $\varphi = 40°$.

The upstream section of the dike functioned as a storage reservoir, while the downstream restitution channel ensured discharge conveyance (Fig. 2). To limit seepage through the embankment, the upstream face was sealed with a kaolinite layer that provided watertightness without adding cohesion to the soil.

During the test, overtopping at the notch was intentionally initiated, with the objective of maintaining, for as long as possible, a water depth of 5 cm above the notch bed elevation. To this end, a lateral overflow weir was installed upstream to evacuate surplus inflow and regulate the reservoir level. The test procedure was conducted as follows:

- Initially, the reservoir was filled progressively using an inflow rate between 20 and 40 l/s to avoid disturbing the kaolinite sealing layer. The inflow discharge Q_{in} was then gradually increased up to the target discharge of approximately 240 l/s. During this phase, the inflow was entirely diverted through the lateral weir, allowing the reservoir water level to be maintained at the notch bed elevation (2.23 m), thereby preventing overtopping.
- Subsequently, the lateral weir was adjusted to initiate overtopping at the notch and erosion of the downstream side of the dike, while maintaining a controlled water level 5 cm above the notch bed. Under these conditions, the water level remained quasi-stationary for approximately 8 minutes.
- Upon initiation of the breaching process at the notch, the reservoir water level started to drop rapidly.

Several types of data were acquired during the test, including discharge rates, water levels, local bed elevations, the time evolution of dam geometry using photogrammetry, free-surface flow velocities measured with the LSPIV, final dike geometry using a 3D scanner, and the grain size distribution at the free surface at the end of the experiment. Table 2 lists the locations of the eight ultrasonic sensors used to measure water levels and the nine probes used to monitor bed levels.

Table 2. Locations of ultrasonic sensors (US), float level (F) sensors and elevation probes (P)

Sensor/Probe	*x* (m)	*y* (m)	Comments
US1	-3.40	0	Water level in the reservoir
US2	-0.30	0	Water levels at the notch zone
US3	0.30	0	
US4	2.85	0	Water levels along the downstream side of the dike
US5	4.90	0	
US6	6.50	0	Water levels downstream of the dike
US7	8.70	0	
US8	10.70	0	
P1	-0.30	0.85	Bed elevations at the notch zone
P2	0.30	0.85	
P3	-0.30	0	
P4	0.30	0	
P5	-0.30	-0.85	
P6	0.30	0.85	
P7	2.85	-0.85	Bed elevations along the downstream side of the dike
P8	2.85	0	
P9	2.85	0.85	

Time $t = 0$ is defined as the moment when the water level in the reservoir is slightly below the notch bed elevation (i.e., 2.23 m). For the **upstream boundary condition**, numerical simulations can be performed by imposing the water level recorded at US1 in the reservoir. The digital elevation model (DEM) of the laboratory setup, including the restitution canal, as well as the soil grain size distribution are provided. **Modelers should note that the outflow discharge Q_{out} was measured using a gauging weir located at the end of the restitution canal (Fig. 2).**

The data files needed to run Test 2 will be sent by email upon request (water level at US1, grain-size distribution and DEM of the initial situation).

4. Expected results

The modelers are invited to simulate the two experiments and to submit their results with a brief report describing their simulations, as explained below, depending on whether a detailed or a simplified modelling tool is used. **Modelers' attention is drawn to the importance of using the same coordinate systems as shown in Fig. 1 (Test 1) and Fig. 3 (Test 2)**.

When submitting the results, all files should be included in a single zip file indicating whether Test 1 or Test 2 is considered, and the name of the modeler.

4.1. For detailed models (2D or 3D)

Report containing the following information:

- Model description
  - Governing equations;
  - Sediment transport formulation and breach widening treatment, if any;
  - Numerical resolution methods;
  - Mesh/grid type (structured/unstructured) and typical spatial resolution.
- Model parameters
  - Hydraulic roughness, turbulence parameters if any;
  - Sediment properties and parameters influencing erosion and transport especially when it results from a modelling choice;
  - Any other calibration parameters or assumptions applied in the simulations.
- Some examples of key results (among the requested results – see below)
  - Longitudinal profiles of bed and water elevation at some selected key times;
  - Breach cross-section at some selected key times;

Computed results, submitted as *.*csv* or text files:

- **Computed results at each computational point** (node or cell, described by the x and y coordinates as indicated below, with z_b the sediment bed elevation, z_w the water level, q_x and q_y the unit discharges in the x- and y- directions, and q_{sx} and q_{sy} the unit sediment discharges in the x- and y-directions (if these quantities are computed). The files should be named as follows: *Name_of_modeller_tXXX.ext* (*ext* standing for *extension*, being txt or csv).

x (m)	y (m)	z_b (m)	z_w (m)	q_x (m²/s)	q_y (m²/s)	q_{sx} (m²/s)	q_{sy} m²/s)
…							
…							
…							

  - **For Test 1**: results should be submitted at 10 s intervals, starting from $t = 0$ s (defined as the time when the water level in the reservoir reaches 0.85 m) until $t = 400$ s, with separate files for each considered time.
  - **For Test 2**: results should be submitted at 10 s intervals, starting from $t = 0$ s (defined as the time when the water level in the reservoir reaches the notch bed level 2.23 m) until $t = 900$ s, with separate files for each considered time.

- **Computed outflow hydrograph**: a two-column text file with the time t (s) in the first column and the discharge *Q_out* (m³/s) in the second column, named as *Name_of_modeller_OutflowHydrograph.ext* (*ext* standing for *extension*, being txt or csv).

- Time series results
  - **For Test 1**: **computed time series of water level** at the three gauges: a four-column text file with the time *t* (s) in the first column and the water levels (m) at Zh1, Zh2, Zh3 in the three other columns, named as *Name_of_modeller_WaterLevel.ext* (*ext* standing for *extension*, being txt or csv).
  - **For Test 2**:
    - **Computed time series of water level** at four gauges: a five-column text file with the time *t* (s) in the first column and the water levels (m) at US2, US3, US4 and US5 in the four other columns, named as *Name_of_modeller_WaterLevel.ext* (*ext* standing for *extension*, being txt or csv).
    - **Computed time series of bed level** at nine positions: a ten-column text file with the time *t* (s) in the first column and the bed levels (m) at P1, P2, P3, P4, P5, P6, P7, P8, P9 in the nine other columns, named as *Name_of_modeller_BedLevel.ext* (*ext* standing for *extension*, being txt or csv).
    - **Computed time series of three longitudinal profiles** LP1 (y = 0.85 m), LP2 (y = 0 m) and LP3 (y = -0.85 m) at 10 s intervals, starting from *t* = 0 s (defined as the time when the water level in the reservoir reaches 2.23 m (notch bed level) until *t* = 900 s, with separate files for each considered time. The profiles should be written in separate files, named as *Name_of_modeller_LPX_tXXX.ext* (*ext* standing for *extension*, being txt or csv).
    - Computed time series of four cross-sections CS1 (x = -0.30 m), CS2 (x = 0 m), CS3 (x = 0.30 m) and CS4 (x = 2.85 m) at 10 s intervals, starting from *t* = 0 s (defined as the time when the water level in the reservoir reaches 2.23 m (notch bed level) until *t* = 900 s, with separate files for each considered time. The profiles should be written in separate files, named as *Name_of_modeller_CSX_tXXX.ext* (*ext* standing for *extension*, being txt or csv).

4.2. For simplified models

Report containing the following information:

- Model description
  - Governing equations and required parameters;
  - Sediment transport formulation and breach widening and deepening treatment, if any;
  - Numerical resolution method.
- Model parameters
  - Sediment properties and parameters influencing erosion and transport especially when it results from a modelling choice;
  - Values of the parameter of the model applied in the simulations.
- Some examples of key results (among the requested results – see below)
  - Breach outflow hydrograph;
  - Longitudinal profiles of bed and water elevation at some selected key times;
  - Breach cross-section at some selected key times;
  - Any other useful illustration of the model performances.

Results, submitted as *.*csv* or text files:

- Computed outflow hydrograph: a two-column text file with the time *t* (s) in the first column and the discharge *Q_out* (m^3/s) in the second column, named as *Name_of_modeller_OutflowHydrograph.ext* (*ext* standing for *extension*, being txt or csv).
- Computed breach evolution at 10 s intervals, starting from *t* = 0 s, defined as the time when the water level in the reservoir reaches 0.85 m (Test 1) or 2.23 m (Test 2), until *t* = 200 s (Test 1) / 900s (Test 2). The breach geometries should be written in separate files, named as *Name_of_modeller_BreachProfile_tXXX.ext* (*ext* standing for *extension*, being txt or csv).

5. Contacts

For further enquiries and questions please contact:

- Test1: sandra.soares-frazao@uclouvain.be or masoumeh.ebrahimi@uclouvain.be
- Test 2: k.elkadiabderrezzak@cnr.tm.fr