Data artefact: Bathymetry reconstruction from experimental data with PDE-constrained optimisation

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1 Introduction.

This artefact provides data and a detailled description of the wave flume experiment analysed in the accompanying paper.[1] The paper reports on the reconstruction of a bathemetry (bottom topography) from measurements of the water height over time at four isolated points. This data set includes

- the data from the measurements stored in file called `Data_Sensors.zip`,
- a video `wave_flume_video.mp4` showing the waves in the flume and the setup of the experiment,
- this description which also includes pictures of the experimental setup.

2 Experimental setup.

This section describes the experimental setup. This includes descriptions of the geometry of the wave flume, of the water sensors and of the tank bottom topology (bathymetry).

Wave flume. The facility used to run the experiments is the wave flume of the Institute of Mechanics and Ocean Engineering at Hamburg University of Technology. A sketch of the wave flume is shown in Fig. 1. The flume has a length of 12 m, a width of 1.44 m and a depth of 1.5 m. Water waves are generated by a back-and-forth motion of a hydraulically actuated wave flap with flap angle γ_{wf}. In all experiments, the flap operated with a frequency of $0.35\,\text{Hz} = 2.2\,\text{rad/s}$. A beach is installed at the end of the wave flume to reduce the reflection of water waves. For all experiments reported here, a water depth of $h = 0.3\,\text{m}$ has been used. The video provided as part of this artefact should give a good visual impression of the general setup.

Sensors. Four resistive sensors of type GHM, manufactured by the Delft Hydraulics Laboratory, have been used to measure the water surface displacement at four positions in the wave flume. The positions of the sensors are given in Tab. 1 with numbers indicating the distance from the wave flap. Figure 1 also shows the four sensors and their positions.

The sensors measure the water surface displacement with a sampling rate of 100 kHz. The measured data are filtered using a low-pass Butterworth filter with a cutoff frequency of 20 Hz. After filtering, every 1000th value is saved. The data files provided in this artefact contain the filtered values.

[1] Angel; Behrens; Götschel; Hollm & Ruprecht. *Bathymetry reconstruction from experimental data with PDE-constrained optimisation* 2024.

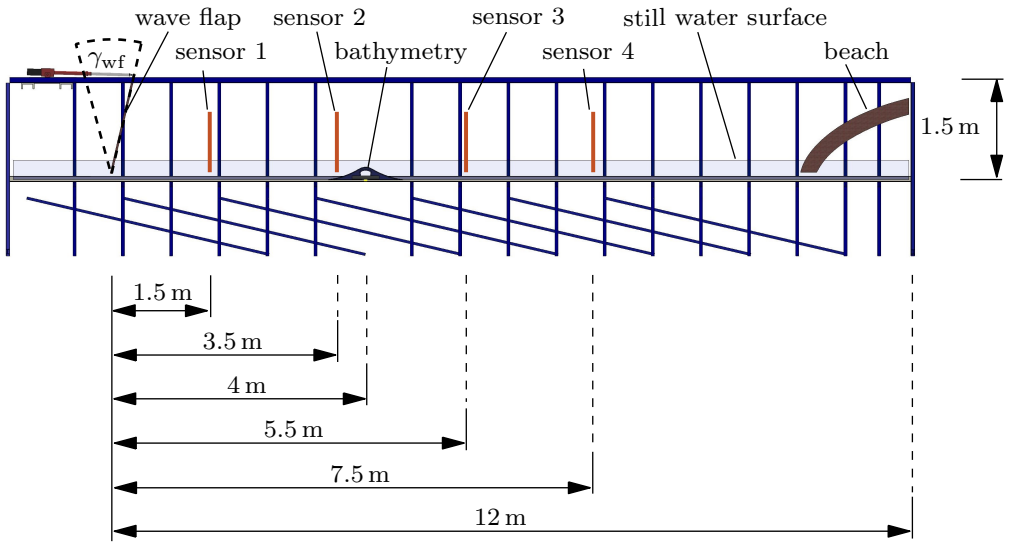

Figure 1: *Sketch of wave flume at the Institute of Mechanics and Ocean Engineering at Hamburg University of Technology.*

Table 1: *Positions of resistive sensors and peak of bathymetry.*

Sensor 1	Sensor 2	Sensor 3	Sensor 4	Bathymetry peak
1.5 m	3.5 m	5.5 m	7.5 m	4 m

Bathymetry. The bathymetry has a roughly Gaussian shape as shown in Fig. 2. It was manufactured out of three skate board ramps, each with length 117.5 cm, width 39.5 cm and a height of about 20 cm. The ramps were covered with a PVC plastic plate, which had a thickness of 2 mm and a width of 143 cm, fitting into the 144 cm wide flume. The three skate board ramps has been placed equidistantly below the PVC plastic plate. To prevent the bathymetry from floating, weights were mounted below the PVC plastic plate. Its final total mass is about 30 kg.

The peak of the resulting bathymetry is 20 cm high and was placed at 4 m in the flume, see Tab. 1 and Fig. 1. The bathymetry has a length of 117.5 cm and is constant along the width of the wave flume. The profile of the bathymetry was measured and the corresponding geometry data are shown in Fig. 2 with numbers indicating lengths in mm. Figure 4 shows photographs of the bathymetry in the wave flume from two different perspectives. Sensor 2 is visible located slightly before the peak. As reference, we also ran experiments without the bathymetry where the flume bottom is simply flat. In this case, the bathymetry in Fig. 4 was removed. Everything else, including the positions of the sensors, was not changed.

The representation of the bathymetry in the Python code was done by interpolating the geometry data read off manually at the vertical lines in Fig. 2 with the `PchipInterpolator` function that is included in the SciPy package.[2]

3 Measurements

In total, we ran 20 measurements without bathymetry and 20 measurements with bathymetry, all with identical parameters. Every experiment recorded water heights over a time span of 100 s. We waited 5 min between experiments to give the generated waves time to decay and the water in the tank to settle. In each experiment, the first 30 s have been measured without waves being generated. These data allow us to get an idea of the magnitude of noise that affects our readings.

[2]https://docs.scipy.org/doc/scipy/reference/generated/scipy.interpolate.PchipInterpolator.html

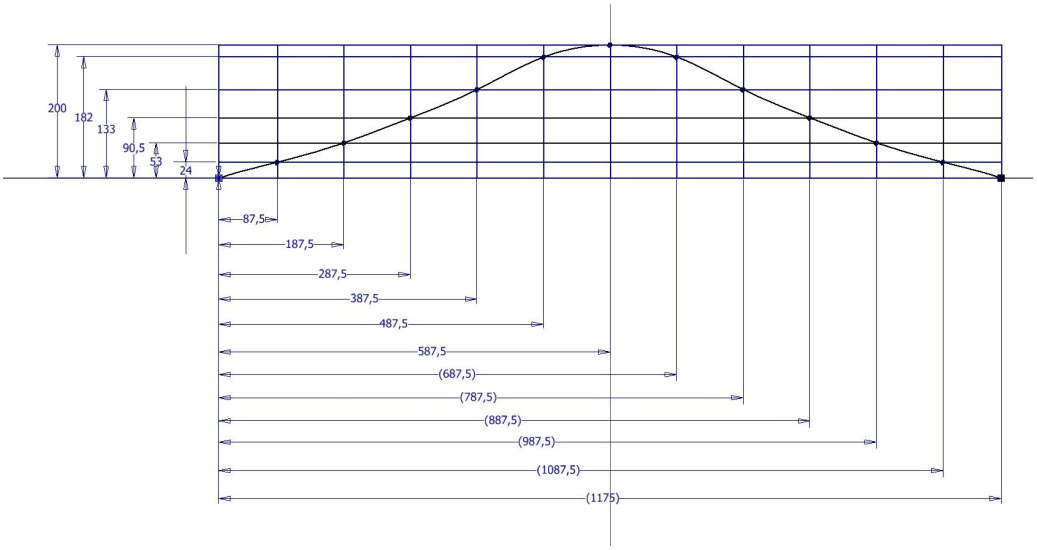

Figure 2: *Geometry data of the profile of the used bathymetry. All presented data are given in millimeters.*

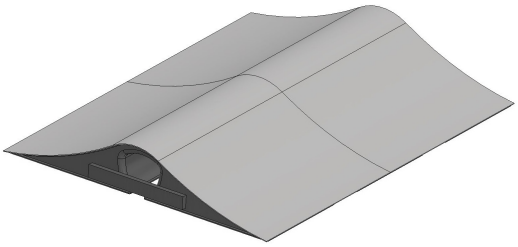

Figure 3: *Sketch of the used bathymetry.*

At 30 s, the wave flap starts to move and water waves are generated. A few seconds later, the generated water waves start reaching the positions of the four sensors and are being recorded. Figure 5 shows an example of the resulting time series of measured water waves.

4 Possible sources of errors in the data set.

We try to give an account of possible sources of error in the measured data. First of all, the used wave flume has a finite length of 12 m. Although a beach is installed at the end to reduce reflection, there is still a significant impact from waves travelling back into the flume. The effect is visible in the time series presented in Fig. 5. It can be seen that the water waves behave harmonically during the time interval $[35\,\mathrm{s}, 43\,\mathrm{s}]$. After 43 s, the reflected waves start reaching the sensors and begin to alter the temporal behavior of the waves. In order to exclude these reflections, the reconstructions performed in the paper use only 10 s of measurements, starting at 30 s when the flap starts operating and stopping at 40 s before significant reflections arrive at sensor 4. However, the time series saved in the ZIP file `Data_Sensors.zip` always contain the data over the whole span of 100 s.

Noise from inaccuracies and inertia in the sensors also affects the measured values of water surface displacement. However, the influence of these inaccuracies is very small compared to the amplitudes of the measured wave. This can be seen in Fig. 5 by comparing the oscillations whilst the flap is at rest with the wave motion setting in after 30 s. Note that the oscillations in the first 30 s of the time series are not only sensor noise but also caused by remaining waves generated during the last measurement 5 min earlier or waves generated by external disturbances of the flume.

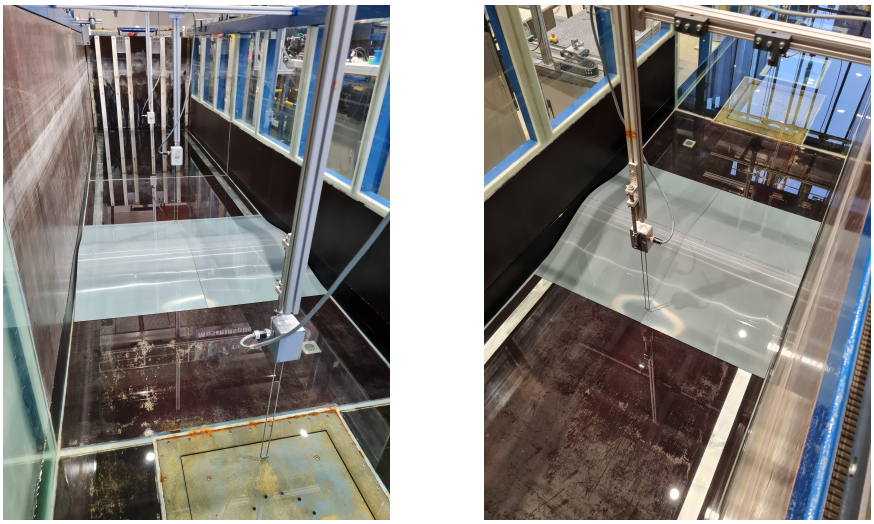

Figure 4: *Bathymetry in the wave flume. The bathymetry is shown from two different perspectives. The flap generating the waves can be seen at the end of the flume in the left figure. The sensor just at the start of the bathymetry is visible in the right.*

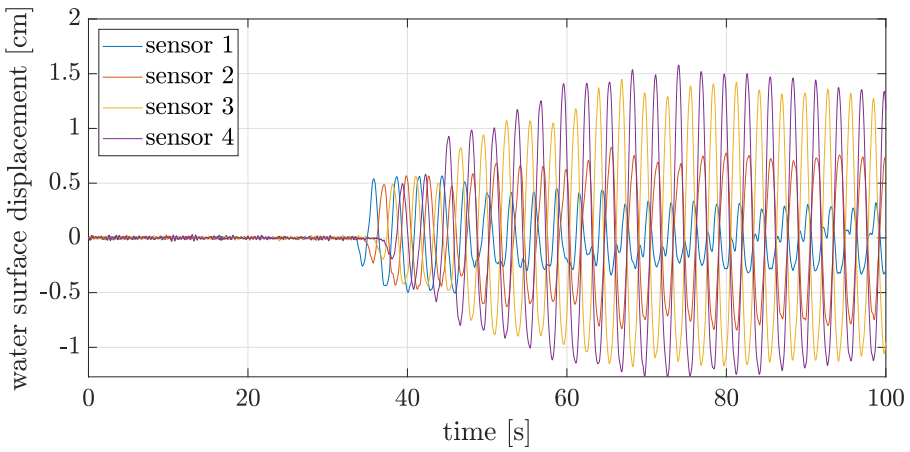

Figure 5: *Example for a time series of measured water height.*

Quantification of noise levels. Assuming a normal distribution of the experimental data of the oscillations prior to wave generation, we computed 95% confidence intervals [3] for the measurements of the water at rest. The noise in Fig. 6 is about $1\% - 3\%$ of the largest wave amplitude at the sensor.

5 Material provided in this artefact.

This documentation is accompanied by data files, pictures and a movie to give the reader a clear impression of the experiment.

File structure and file content of provided data. The ZIP file `Data_Sensors.zip` contains data from 20 experiments with bathymetry and 20 experiments without bathymetry. The file contains two folders called "With_Bathymetry" and "Without_Bathymetry", respectively. Each folder contains 20 `.txt` files numbered consecutively from `Heat1.txt` to `Heat20.txt`. Every experiment lasts 100 s including the 30 s quiet period before the wave flap starts operating. After filtering, sensors provide

[3] L. Dümbgen, Einführung in die Statistik, Birkhäuser (2016).

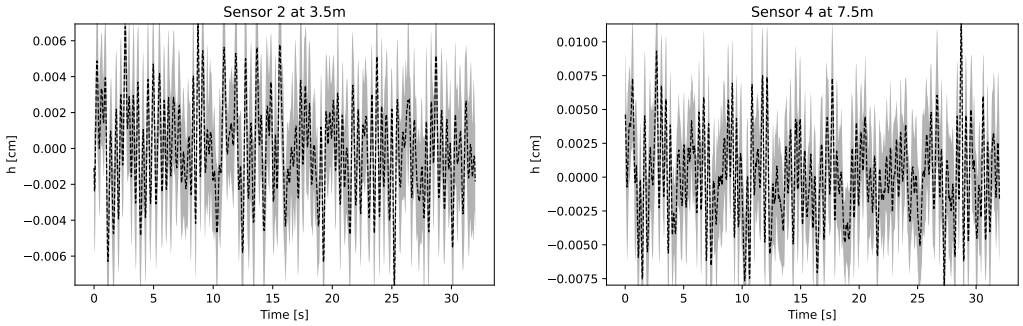

Figure 6: *Noise in the measured water elevation over the first* 30 s *period while the tank is at rest at sensors two and four. The gray area indicates the 95% confidence interval. The noise at sensors one and three looks very similar and is therefore not shown.*

measurements of the water surface displacement with a sampling rate of 100 Hz for a total of 10001 data points for every sensor over the course of each experiment. Every .txt file contains 5 columns and 10001 rows of numbers plus a header row for a total of 10002 rows. The header row identifies the content of the corresponding column. Columns one to four contain the measured water surface displacement in centimeters at sensors 1-4. The fifth column shows the corresponding time point of the measurement in seconds from the start of the experiment.

Additionally, every `txt` file has an accompanying `png` file that visualizes the corresponding data by showing the water surface displacement in centimeters over time for all four sensors so that each folder in `Data_Sensors.zip` contains a total of 40 files.

Accompanying movie. The artefact includes a movie `wave_flume_video.mp4` showing 21 s of an experiment with bathymetry. The movie was shot looking down the flume from the wave flap with the beach visible at the end. The four sensors (vertical metal rods pointing into the flume) and the bathymetry can also be seen.

6 Terms of use.

Acknowledgments.

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