# Acoustic monitoring of a failing dike

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## Introduction

The 'IJkdijk' in Groningen, The Netherlands, is an international fieldlab for new inspection and monitoring techniques for water barriers [1]. The goal is to learn more of their behaviour and to increase confidence in dikes. The dike of the future is filled with many sensors which are used for monitoring and to predict failure of the dike. During the initial experiments a lot of parameters are measured, with all kind of sensors. The current paper deals with the acoustic experiments in the dike during the macro-stability experiment in September 2008 while a complete collapse of the dike was forced.

## Experiments

### Macro-stability experiment

A special water barrier was built for the macro-stability experiment. The dike was 100 meters long and 6 meters high and equipped with all kind of sensors. An impression of the dike is given in Figure 1.

**Figure 1**: Impression of the 'IJkdijk' in Groningen, The Netherlands.

During the experiments, which took several days, the stability of the dike was gradually decreased till the moment of complete collapse of the dike. The goal of the experiment was to find out which sensor types were able to monitor the process of dike failure and how different sensor systems can be built in the dike.

### Acoustic experiments

This paper deals with the acoustic measurements in the dike. In the dike two tubes were placed in axial direction of the dike, see Figure 2. The upper tube was filled with air and the lower tube with water. Three types of experiments were carried out, which are explained below.

**Passive experiments:** Two microphones were placed at both ends of the air filled tube and two hydrophones at both ends of the water filled tube. Furthermore, a couple of microphones were placed outside the dike. During the experiments the sensors listened to all events in and around the dike. All signals were recorded at 16.4 kHz and are available for analysis afterwards.

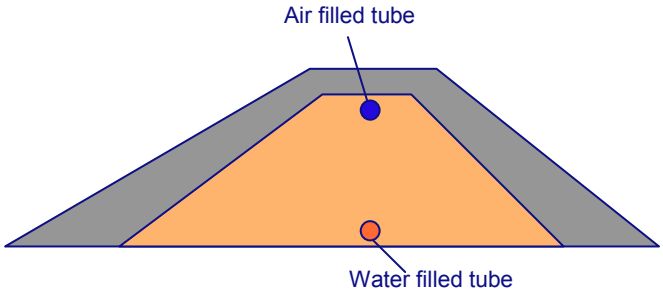


**Figure 2**: Cross-section of the dike with the two tubes.

**Active experiments:** An array of hydrophones was placed in the water filled tube. This array was listening to an array of special loudspeakers which were put in axial direction on top of the dike. Sequentially each actuator emitted a sweep signal generating waves travelling through the dike to the hydrophone array, see Figure 3.

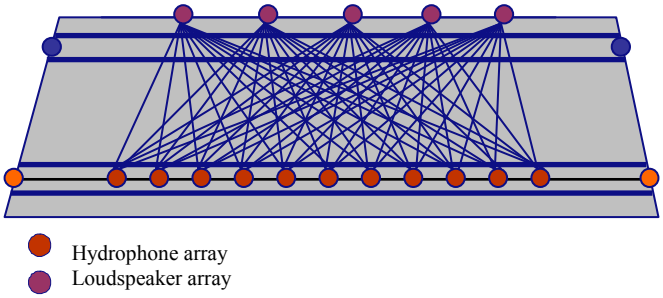


**Figure 3**: Layout of the active experiments.

The goal of this experiment was to obtain information of the inner properties of the dike, such as water distribution, by acoustic imaging. Each hour a complete measurement was carried out.

**Fibre optic sensors:** Furthermore, fibre optic sensors were developed and applied as a prototype hydrophone for future applications. Two sensors were specially made for this purpose. They were placed at the same positions as the passive hydrophones at both ends of the water filled tube in the dike. Beside the acoustic pressures, the fibre optic hydrophones measured also the static pressure in the dike during the complete experiment.

The three experiments generated a lot of data which was partly analysed afterwards. Some preliminary results will be given in the next section.

## Preliminary results

**Passive experiments:** The microphones and hydrophones in the dike recorded all events. Spectrograms of some signals during collapse are shown in Figure 4.

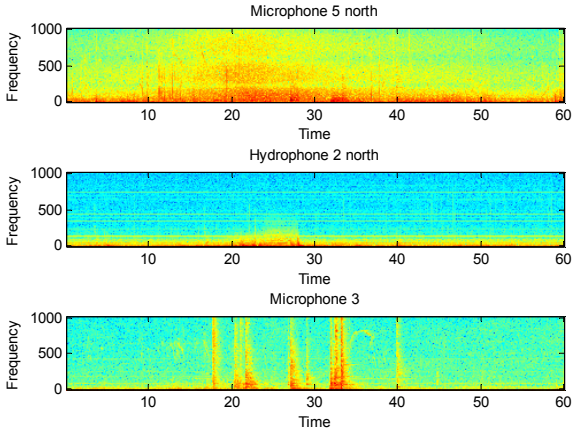


**Figure 4**: Spectrograms of microphone and hydrophone signals during collapse of the dike.

During the experiments there was a lot of activity around the dike. An effect of all these activities, such as running machines and talking people is visible in the recorded data. In the end, the goal is to find in all these data, the events which are related to failure of the dike, which is not straightforward.

**Active experiments:** The active experiment with the hydrophone array was not completely successful. There were some difficulties with getting the hydrophone array in the tube and the applied hydrophone array showed to be not very sensitive, so not all the actuator signals were recorded. However, the correlated time signals which could be measured show clearly changes in the dike related to filling of the dike with water, see Figure 5. It is clearly visible that after some time, the waves propagate faster with less attenuation, indicating an increased water level in the dike. The arrow indicates the time that the dike collapses.

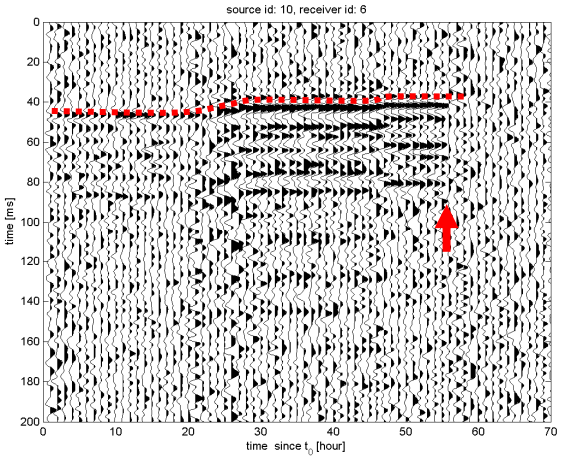


**Figure 5**: Correlated time signals of the hydrophone array.

**Fibre optic sensors:** A signal of one of the two fibre optic sensor is given in Figure 6. A can be seen, the sensor clearly monitors the dynamic pressure, but also static pressure signals are measured. Because the sensors were close to the hydrophone sensors in the dike, a comparison can be made between both outputs. This has still to be done. What we learned is that the sensors are able to monitor static and dynamic pressure in a real dike.

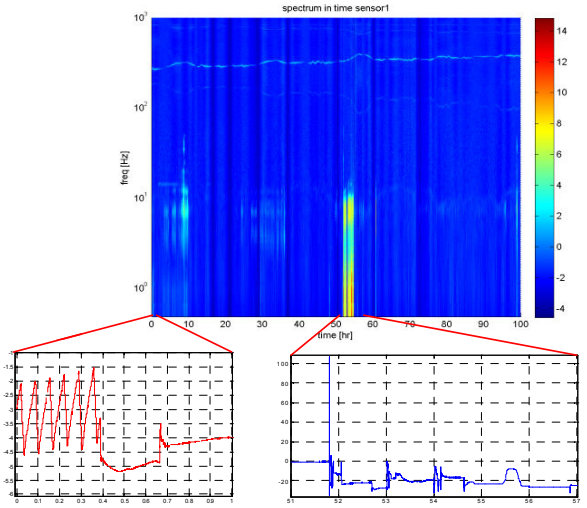


**Figure 6**: Upper: Spectrogram of fibre optic sensor signal. Lower: Time signals, showing the static pressure during the start-up of the experiment and during failure of the dike.

## Discussion and conclusions

The acoustic experiments generated much data which includes a lot of information about events in and around the dike. In the acoustic data we see some indications of changes, which can be attributed to mechanisms playing a role in failure of the dike. The analysis of the current data set is still going on. Next steps will be taken towards prediction of failure of the dike.

Furthermore, it is demonstrated that the optic sensors are able to measure acoustic pressures in the dike and as sensor system seem to be feasible for the current purpose. To our knowledge this is the first time the feasibility of acoustic optic sensors is demonstrated.

The ultimate goal is to develop an acoustic system which is able to act as an early warning system for dike failure, so that one can take measures in time. The activities in the macro-stability experiment were a first step to reach this goal.

The sensors and signal processing techniques will be further developed and tested in next experiments with alternative failure mechanisms. The next experiment where the so called piping mechanism will be studied as the failure mechanism is already planned.

## References

[1] Reference to the IJkdijk homepage.
URL: `http://www.ijkdijk.nl`