Project Summary A3 - Dike reliability analysis
Better methods for the assessment and design of dike systems

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Project Summary

A3 - Dike reliability analysis

Better methods for the assessment and design of dike systems

By Wim Kanning
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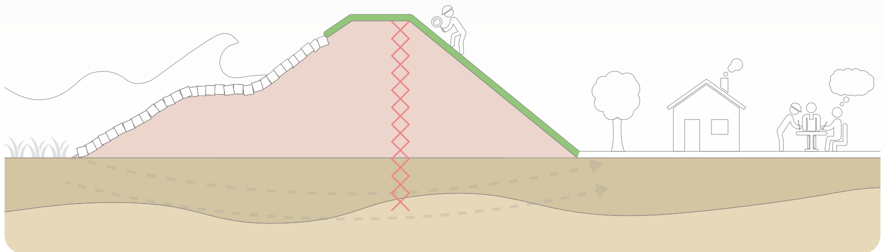
Project start: 09/2017 (Part-time)
Project end: 09/2021



Outcome

This project developed better methods to assess the strength and performance of dikes using data from past events and experiments for optimising the design of flood defences. With the improved methods from MSc and PhD research, we focus more on what is in the subsoil and how this affects dike performance. Dikes will not necessarily fail if budgets for the different failure mechanisms are not allocated perfectly but may fail if subsoil properties investigation, inspection and maintenance are not carried out properly. Overall, we concluded that it is important to look beyond models and get a wider view of what makes the dike perform better.

Figure 1: Dike failure in Breitenhagen, Germany. Photo by Weichel (2013).

Motivation and practical challenge

Seeing the aftermath of the New Orleans flood in 2005 motivated me to work on dike reliability modelling (**Figure 2, bottom-right photo**). The flood consequences were grave and very impressive (**Figure 2, top and bottom-left photo**). That event made me realise the difficulties in predicting dike reliability first-hand and the need to reduce modelling uncertainties abroad and in the Netherlands.

On the one hand, it showed me failure mechanisms that are rarely observed in the Netherlands outside books and laboratories. On the other hand, it showed that modelling these failures involves much more than applying well-known calculation rules. Very uncertain subsoil conditions determine the strength of the dike. For example, very small weak zones in the soil proved critical for slope stability. Hence, modellers and designers of dikes should better account for the uncertain factors influencing the dike strength as much as possible.

Research challenge

To improve the modelling of failure mechanisms of flood defences, I explore together with MSc and PhD students from All-Risk and SAFELevee projects how uncertainties in dike performance can be accounted for and best mitigated.

Innovative components

Our research helps in better understanding failure mechanisms for optimising the design of flood defences to better comply with the new flood protection standard. Some of the unique topics that I'm working on as a daily supervisor of the following PhD researchers are (related projects):

Figure 2: **Top and bottom-left:** Floodwall failure on 17th Street Canal from Hurricane Katrina in New Orleans (photos by U.S. Army Corps of Engineers and IPET, 2005). **Bottom-right**: Rebuilt New Orleans floodwall in 2013 (Photo by Bianca Hardeman).

- **The temporal development of failure mechanisms.** Together with Joost Pol (Project D3), we look at the progression rate of piping using full scale and small-scale experiments. This temporal development shows how long piping needs to occur to result in flooding along the coast and on riverine areas.
- **Method to derive the most likely causes of failure of past breach events.** Together with Job Kool (part of the SAFELevee project), we improve the

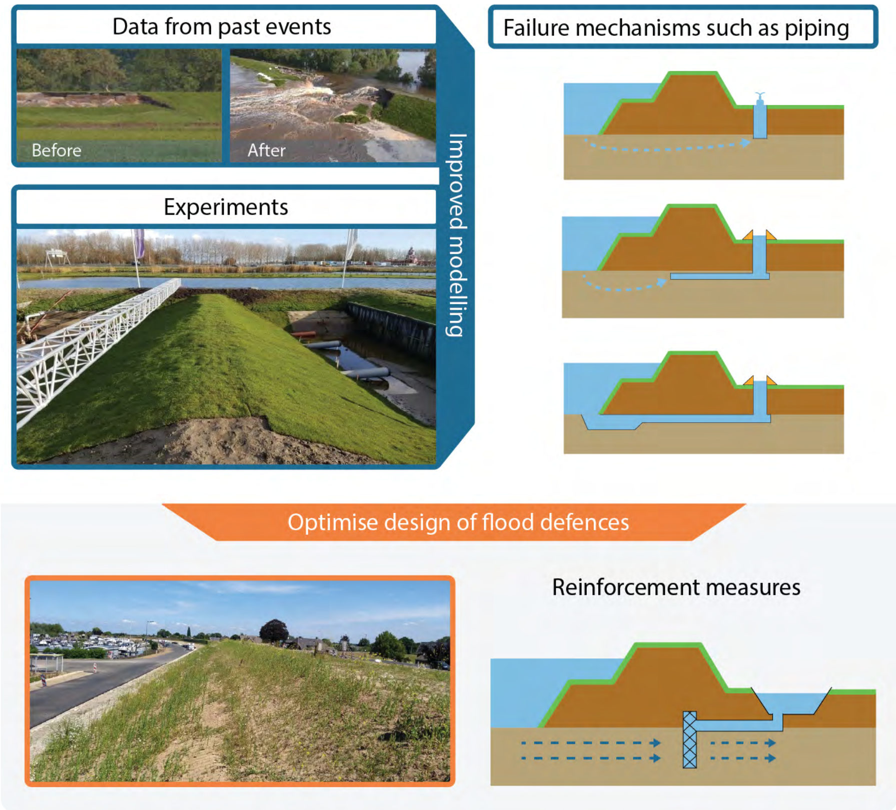


Figure 3: Components include data from **top:** the dike failure in Breitenhagen, Germany (source: Weichel, 2013); **middle:** the Flood Proof Holland backward erosion piping experiment (source: Pol, Kanning & Jonkman, 2021), and **bottom:** reconstructions around Kinderdijk in South Holland (source: TU Delft [SAFELevee], 2021). The piping and reinforcement schemes were adapted from van Beek (2015).

modelling of failure mechanisms via the structured deduction of failure scenarios from before and after data. We tested this approach to find the most likely cause of the failure of the Breitenhagen dike in Germany (Figure 1). The method is generically applicable to other locations.

- **Optimisation of dike reinforcements.** With Wouter Jan Klerk (Project A1), we look at various measures to, for example, reduce uncertainties on the soil parametres and implement reinforcement techniques.

Relevant for whom and where?

Other researchers interested in the probabilistic analysis and failure mechanisms modelling. Organisations planning the reinforcement of dikes and authorities setting the design requirements.

Progress and practical application

For a detailed description of each finding, please **see the key project outputs on the next page**. The analysis of the 2013 failure on the Breitenhagen dike in Germany shows that the slope instability most likely occurred as the result of an old breach. This old breach probably eroded the soil in front of the reconstructed dike, creating a direct connection between river and aquifer, thereby increasing pore water pressures.

By including temporal progression rates in the failure probability assessment due to piping, the improvements on the dike safety are small for riverine cases, which have long-lasting high water levels. However, the improvements are much larger for the coastal cases, which have short-lasting high water levels resulting in insufficient time for piping to develop fully. There is still a considerable delay of several days in the expected time of piping development in the riverine cases, which is beneficial for emergency interventions. Instead, piping is less likely to occur with floods of low duration for coastal cases.

Finally, our application example for five dike sections along the river Lek in the Netherlands shows that additional monitoring information is only valuable if the expected reinforcement decision is likely to be different.

Recommendations for practice

- Look beyond the models by considering more the dike subsoil history and other sources of information such as the analysis of past dike breaches to understand dike performance better.
- Old dike breaches and former river meanders are the most critical dike sections.
- Take inspections more seriously.
- Put more effort into understanding piping.
- Case studies should be more central in the development of dike assessment tools.

The research include key locations in the Netherlands and abroad to use data from past events and experiments in the optimisation of flood defences.

Photos by Waterschap Rivierenland.

Key project outputs

Kanning, W., Schweckendiek, T. (2019). Bayesian inference of piping model uncertainties based on field observations.
Doi: 10.3850/978-981-11-2725-0_IS4-9-cd

Jongejan, R.B., Diermanse, F., Kanning, W., Bottemad, M. (2020) Reliability-based partial factors for flood defenses.
Doi: 10.1016/j.ress.2019.106589

Kool, J.J., Kanning, W., Jommi, C., Jonkman S.N. (2020). A Bayesian hindcasting method of levee failures: The Breitenhagen case. Doi: 10.1080/17499518.2020.1815213