Project Summary A1 - Life-Cycle Performance
Methods to align dike inspection, maintenance and reinforcement

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Project Summary

A1 - Life-Cycle Performance

Methods to align dike inspection, maintenance and reinforcement

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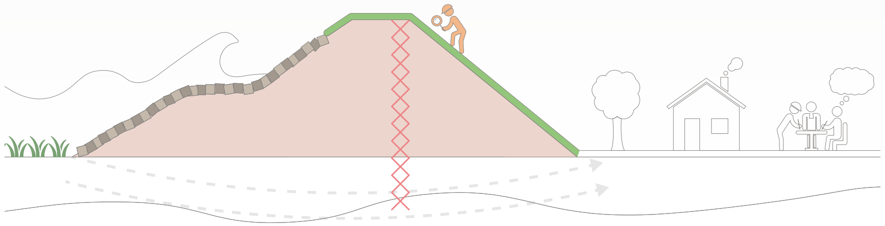
Project start: 09/2017
Project end: 09/2021



Promotors

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Outcome

This project developed novel methods for decisions on the life-cycle reliability of flood defence systems. By optimising flood defence reinforcements at a system level, the cost of reinforcement projects can be reduced significantly. Uncertainty reduction through monitoring and proof load testing lead to lower reinforcement and risk costs, both in short and long term. It has also been demonstrated that imperfect inspections and maintenance of flood defences lead to a failure probability increase. This contribution demonstrates the importance of including inspection and maintenance in flood risk assessments.

Figure 1: Experiment to determine the accuracy of visual dike inspection near Tiel. Photo by Wouter Jan Klerk.

Figure 2: Example of the activities to ensure life-cycle performance: photo 1 and 4 reinforcement, 2 and 3 inspection. Photos by HWBP (2018, p.103) / Pascal Ogink, Wouter Jan Klerk, Mark van der Krogt and the Flood Protection Programme, respectively.

Motivation and practical challenge

The asset management of flood defences in the Netherlands (**see Figure 2**) has been built upon centuries of experience. We have taken great leaps in quantifying the performance of these structures based on failure probabilities and increased our understanding of many potential failure modes. However, as a researcher and as an advisor on flood risk asset management, I saw some missing links in the translation of this knowledge to decisions. In this project, I considered three key topics that I'm convinced would help us to take the next step in flood defence asset management. Optimising flood defence reinforcement design at a system level can lead to more effective and efficient reinforcement projects. Countering large reducible uncertainties in dike strength and pore pressures by monitoring and proof load testing can lead to a more cost-effective dike design. And, quantifying the accuracy of inspections, and accounting for this in flood defence reliability estimates will greatly improve reliability estimates based on them.

Research challenge

Therefore, the challenge is to develop methods for addressing the missing connections between dike reinforcement, maintenance, monitoring, and inspection at different spatial and temporal scales. By doing so, how does, for example the reinforcement of a diaphragm wall at one spot (**Figure 2, bottom-left photo**) help the safety targets for a larger dike section in the coming decades? How does inspection help in maintaining sufficient reliability?

Innovative components

This research uses smart optimisation techniques to relate measures at different spatial scales. For instance, such a technique was applied to a dike reinforcement project to derive optimal planning of different measures (**Figure 3.1 and 3.2**). By using this technique, the system reliability requirement, incorporating all possible strengthening measures, was met optimally when looking at costs.

I use decision trees and Bayesian decision analysis (**Figure 3.3**) to translate monitoring outcomes into uncertainty reduction in dike reliability estimates. However, the accuracy of the inspections (i.e. the probability of detection) is unclear and to determine it, a field experiment was conducted (**Figure 3.4**).

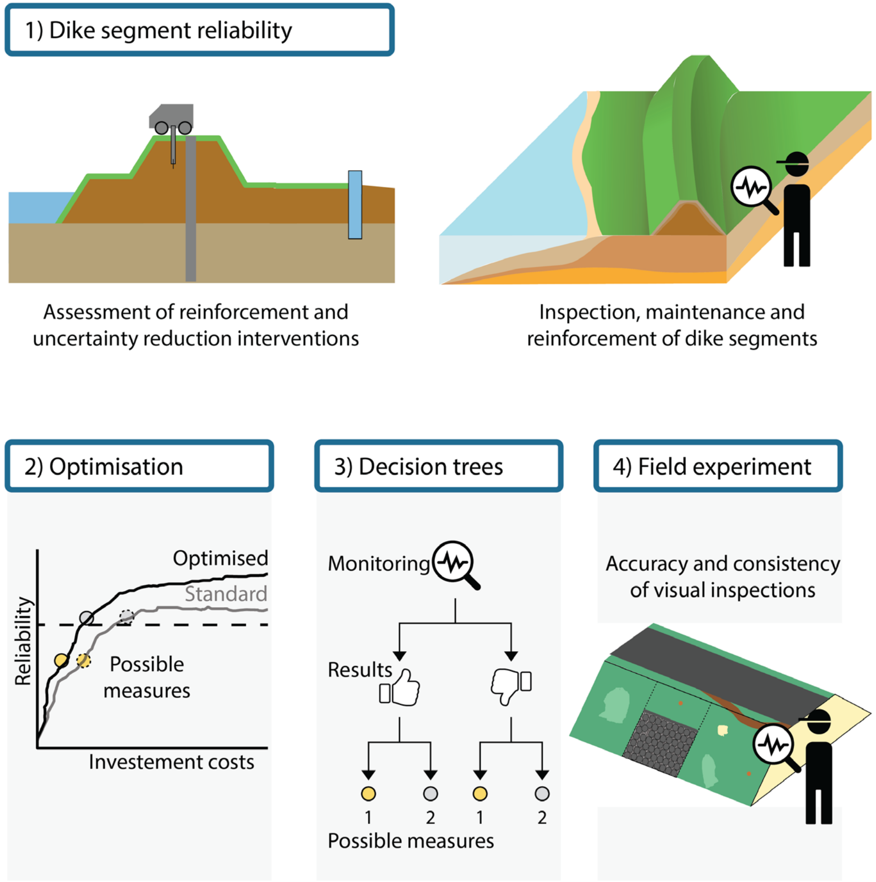

Figure 3: Components of the research relating decisions at a dike section to a whole segment. Figure 3.1 is based on schemes by Wouter Jan Klerk, dike segment scheme prepared by Richard Marijnissen.

The insights have been used to determine the impact of damage and imperfect inspections on failure probabilities. To achieve this, degradation rates were based on data analysis of past inspection reports, and a Dynamic Bayesian Network was used to determine the life-cycle cost of different inspection and maintenance strategies.

Relevant for whom and where?

Within the Netherlands, this research is of relevance to the regional water authorities, the Dutch Flood Protection Programme and the Ministry of Water and Infrastructure. In an international context, anyone with a keen interest in risk/performance-based asset management of flood defences can use it in defining projects and optimising inspections and maintenance.

Progress and practical application

It is demonstrated that optimisation of flood defence reinforcements at a system level can reduce reinforcement costs by about 40%. For studies on the effectiveness of proof loading and dike monitoring, cost savings were in the range of ~25% due to the achieved uncertainty reduction leading to more efficient designs.

However, not only investment costs but also risk costs can be avoided. For example, when accounting for damage to grass revetments, the estimated failure probabilities differ several orders of magnitude from the estimates from the safety assessment. By including this, effective investments in, for instance, more frequent inspections can be properly valued, leading to more effective and efficient asset management.
Further improvements can be achieved by improving the collection of inspection data to more accurately estimated degradation rates, and further investigating the impact of damage to for instance revetments on their failure probability.

Recommendations for practice

- Take a system perspective towards flood defence reinforcement projects to achieve more cost-efficient and transparent reinforcement decisions.
- Ensure that reduction of uncertainty is considered properly within and outside the context of dike reinforcements, and ensure that funding arrangements facilitate this.
- Consider uncertainty reduction an effective starting point for long-term adaptation strategies of flood defence systems.
- Improve the collection of inspection data to better understand the degradation behaviour of flood defences.
- Aim for continuous and targeted improvement of visual inspection of flood defences.

Key project outputs

Klerk, W.J.; Kanning, W.; Kok, M.; Wolfert, R. (2021). Optimal planning of flood defence system reinforcements using a greedy search algorithm. Doi: 10.1016/j.ress.2020.107344.

Klerk, W. J., Kanning, W., & Kok, M. (2018). Time-dependent reliability in flood protection decision making in The Netherlands. Doi: 10.1201/9781351174664

Klerk, W.J.; Kanning, W.; Kok, M.; Bronsveld, J.; Wolfert, A.R.M. Accuracy of visual inspection of flood defences. Doi: 10.1080/15732479.2021.2001543

The research includes key locations for the reinforcement of a dike section and the field experiment to assess the quality of inspections.

Photos by Waterschap Rivierenland.