Project Summary D4 - Incorporating past performance
Improved methods for estimating dike failure probability

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Project Summary

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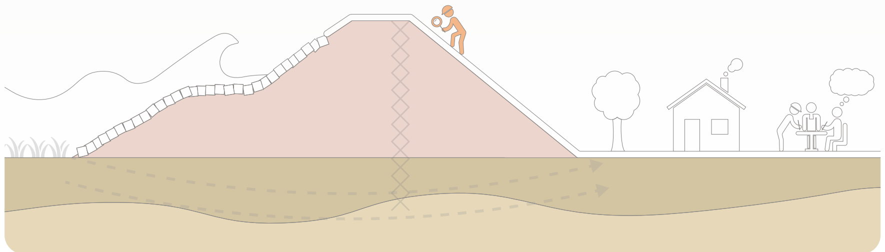

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Project start: 09/2017

Project end: 09/2021

Promotors

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Outcome

This project developed methods to improve the reliability estimates for dike slope stability by considering performance information. By incorporating the information of survived (proof) loads and monitoring during the construction of dikes, reliability estimates become more credible, safety assessments improve, and the design of dike reinforcements can be made more efficient. Even when it takes money or risk to obtain the performance information, a strategy with obtaining performance information can be cost-effective, improving the efficiency of flood risk management.

Figure 1: Construction of a dike. Source: HWBP (2018, p.103), photo taken by Pascal Ogink.

Motivation and practical challenge

Flood safety in the Netherlands is expressed in terms of the probability of typical failure mechanisms as of 2017. Dikes are assessed for safety by (semi-)probabilistic analyses methods. However, these failure probability estimates are dominated (among other factors) by the knowledge about the soil properties, which is often limited and uncertain. This limited knowledge is particularly the case for slope instability failures at the landward side, which may or may not lead to flooding due to a dike breach (**Figure 2**).

Measuring, monitoring and adding information about the past performance of dikes can reduce uncertainty and thus lead to better failure probability estimates. Some of this performance information is available when measuring the soil properties or monitoring existing dikes. Performance information is also gathered during dike reinforcement projects (**Figure 1**), such as pore water pressure monitoring and measurement of settlement during the dike construction. Unfortunately, not all information is used to assess the dikes' safety or improve estimates of the expected lifetime.

Research challenge

This research aims to develop updated methods to efficiently combine different performance information sources into safety assessments. I focus on dikes in the Netherlands with high reliability requirements, which are designed with a low probability of failure, due to the high potential flood damage a failure of these flood defences can cause.

Innovative components

I explore several ways to improve failure probability estimates by incorporating different types of past performance information:

Figure 2: Examples of slope instability on the landward side with and without flooding due to dike breach. Sources: Landesbetrieb für Hochwasserschutz und Wasserwirtschaft Sachsen-Anhalt (LHW) and Jüpner et al. (2015).

- Identification of how error sources combine into the total uncertainty in the spatial average of soil properties measured using cone penetration tests (CPTs in **Figure 3.1**).
- The value of information for proof loading (**Figure 3.2**) and pore pressure monitoring (**Figure 3.3**) by using a decision tree (joint component with related project A1).
- How loads during the construction stage (**Figure 3.4**), such as the weight of the soil used to reinforce dikes, can improve reliability estimates for a dike in flood conditions.
- Further reducing uncertainty by combining observations during the construction (**Figure 3.4**) such as survival, settlement measurement, and pore water pressure monitoring.
- Development of event trees to estimate the probability of flooding based on several (**Figure 3.5**) successive conditional instabilities.

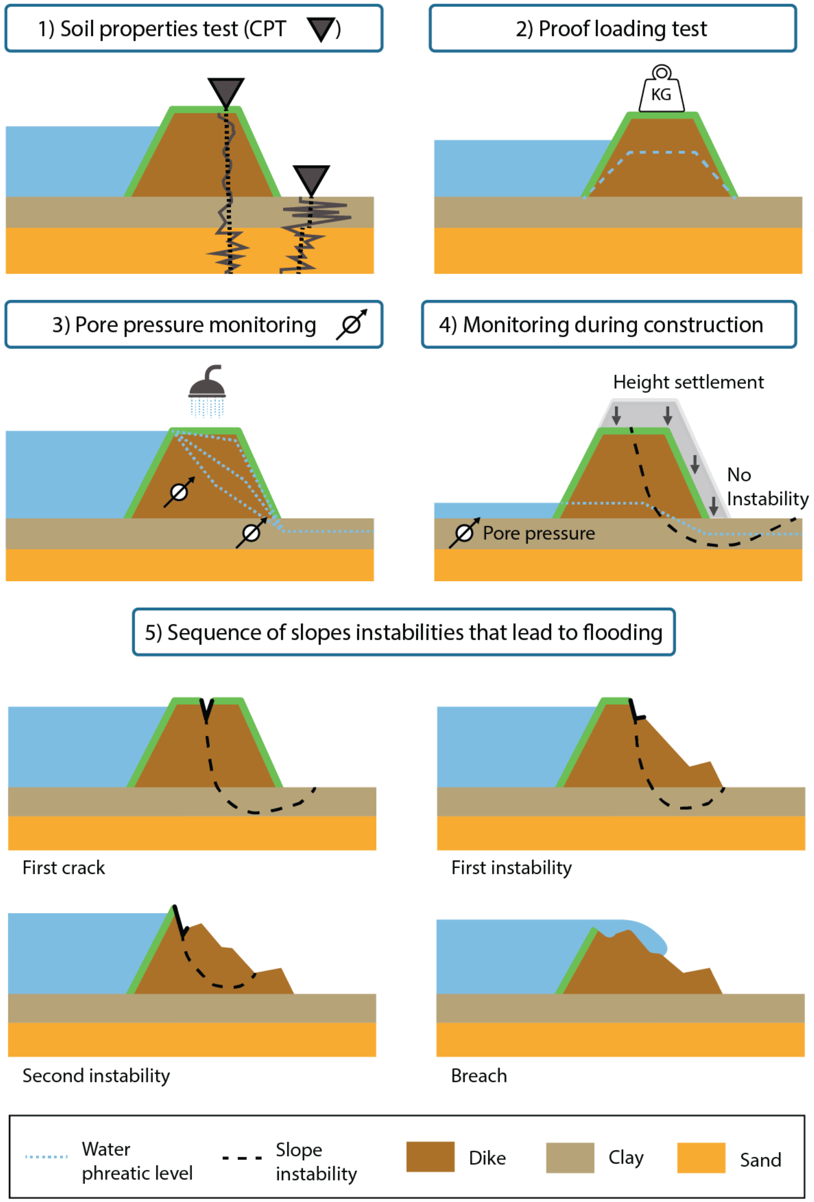

Figure 3: Schemes 1 to 5 with the type of performance information considered in this project. Based on schemes from Mark van der Krogt. 3.5 adapted from Calle & Knoeff (2002, Figure 4.1).

Relevant for whom and where?

Researchers interested in probabilistic analysis and organisations wanting more targeted and cost-effective flood protection.

Progress and practical application

The research demonstrated that characteristic values of soil properties determined with CPTs could be considerably higher if averaging of random errors is considered. Additionally, we can reduce uncertainty in site-specific transformation models by minimising the distance between boreholes and soil investigation tests (CPTs) and reducing bias in the measurements.

The construction of dikes is a large load on the soft subsoil. Using Bayesian updating, the information of construction survival can be incorporated in the dike reliability assessment. This reduces uncertainty and improves the estimates of the probability of failure. Depending on the situation, the probability of failure can reduce by more than a factor of 10. This reduction is especially significant when the load effects during construction are very similar to the future flood situation that is being assessed, such as for dikes on soft subsoils.

Uncertainty reduction measures such as proof loading and pore water pressure monitoring applied to typical dike sections in the Netherlands have a positive Value of Information, thus are often worth investing in. For a detailed description of each finding, **see the project outputs on the next page**.

Recommendations for practice

- Preferably use multiple boreholes sufficiently distanced rather than multiple measurements within one borehole to reduce uncertainty in site-specific transformation models for statistically homogeneous geological deposits (on a regional scale).
- Collect performance information during the construction of dike reinforcements (such as the survival of the construction phase and measurements of settlement after raising dikes) to reduce uncertainties, and use this information for optimising designs during the dike reinforcement.
- Consider performance information in future dike safety assessments, as it may extend the dike reinforcement lifetime, which is particularly interesting in light of accelerated climate change.
- Consider deliberately taking a small risk, for example, by adopting a more critical, staged loading scheme or proof loading, to potentially obtain a larger reliability update and thus a less costly design. This reliability update is especially important at locations where otherwise expensive (structural) solutions would be required.

Key project outputs

van der Krogt, M.G., Schweckendiek, T. & Kok, M. (2018). Uncertainty in spatial average undrained shear strength with a site-specific transformation model. Doi: 10.1080/17499518.2018.1554820

van der Krogt, M.G., Schweckendiek, T. & Kok, M. (2021). Improving dike reliability estimates by incorporating construction survival. Doi: 10.1016/j.enggeo.2020.105937

van der Krogt, M.G., Klerk, W.J., Kanning, W., Schweckendiek, T. & Kok, M. (2020). Value of information of combinations of proof loading and pore pressure monitoring for flood defences. Doi: 10.1080/15732479.2020.1857794

The components of this research are developed for a range of typical dike sections for the Dutch riverine area, and for a case study of a full-scale test embankment in Eemdijk and are applicable to dike reinforcement projects in the Netherlands.

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