Project Summary D1 - Residual dike resistance
Insights in the process after a slope instability

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Project Summary

D1 - Residual dike resistance

Insights in the process after a slope instability

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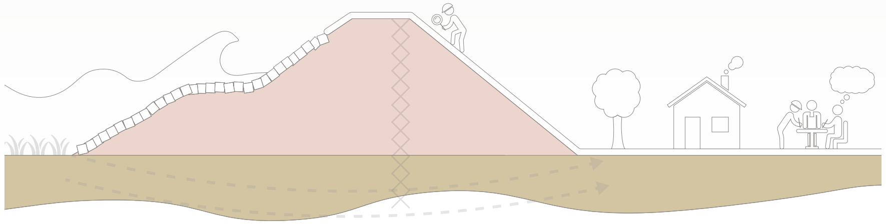
Project start:	09/2017
Project end:	09/2021



Promotors

Dr. P.J. Vardon	Prof. dr. M.A. Hicks
Delft University of Technology	*Delft University of Technology*

Outcome

The current assessment of dike slope instability is limited to predicting the likelihood of the initial instability, as conventional methods can not predict the failure process beyond. This project has further developed the Material Point Method (MPM), which can evaluate the processes after an initial instability. Analyses of simple dike geometries with MPM have shown that a significant reduction in the calculated probability of flooding can be achieved by assessing the complete failure process. Moreover, the results show that secondary failures are more likely when the first failure occurs in a weak layer than a more homogeneous material.

Figure 1: Macro-instability in Saxony-Anhalt (Germany) without flooding. Photo from Jüpner et al. (2015).

Motivation and practical challenge

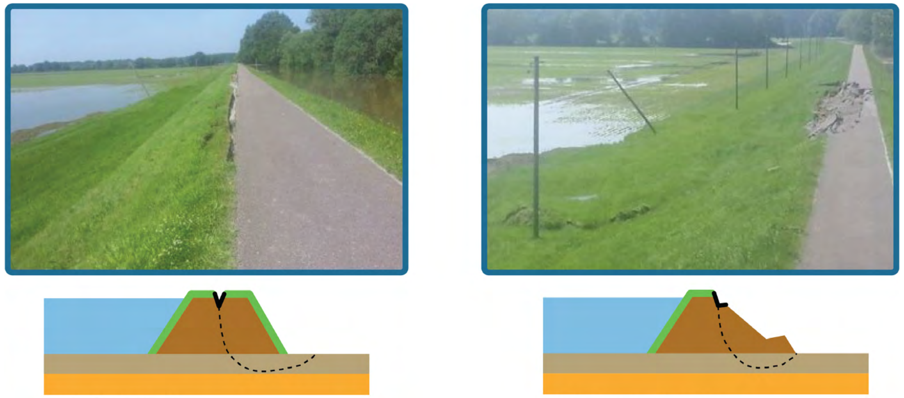
The challenge of this project is to predict for which dikes slope instability can(not) be allowed, i.e. depending on whether it causes flooding. The failure process of slope instability starts with a crack in the crest or inner slope (**Figure 2, photo 1**). After the crack has developed, deformations start as the slope slides (**Figure 2, photo 2**). For dikes with residual resistance, these deformations may stop before flooding occurs, while for others, large deformations occur (**Figure 2, photo 3**) potentially leading to secondary slides. Flooding is unlikely to occur for some dikes even after very large deformations. For others, the deformation will lead to flooding due to a dike breach (**Figure 1, photo 4**). Allowing an initial slope instability for dikes with residual dike resistance may be possible when flooding is unlikely to occur, i.e. a dike breach is unlikely. Considering this residual resistance can lead to more efficient designs, especially for dikes with a large width. Dike reinforcement can then take place where it is most necessary. Modelling and understanding the failure process helps predict in which cases the failure process stops before flooding due to a dike breach. Thereby, we can help engineering expertise evaluate and expand the existing guidelines for dike slope instabilities.

Research challenge

Implementing the new safety standards requires more realistic estimates of the probability of flooding. However, these realistic estimates are difficult as current assessment methods only predict failure initiation, not the failure process until flooding. Therefore, the challenge of this research was to design a method to predict the failure process and to use the method to determine the effect of residual dike resistance on the probability of flooding.

Innovative components

To predict if a dike may breach after the initial slope instability, I developed and used the (Random) Material Point Method (R)MPM. MPM is a new modelling approach similar to the widely used Finite Element Method that allows us to model the start of the initial failure and the dike deformations that may follow. Thereby, I determine the residual dike resistance, which is the difference between the probability of slope instability and a dike breach (**Figure 3**).



1) First crack

2) First instability

3) Second instability

4) Breach

Figure 2: Sequence of slope instabilities that lead to flooding. Photos by Grubert (2013) and schemes adapted from Calle & Knoeff (2002).

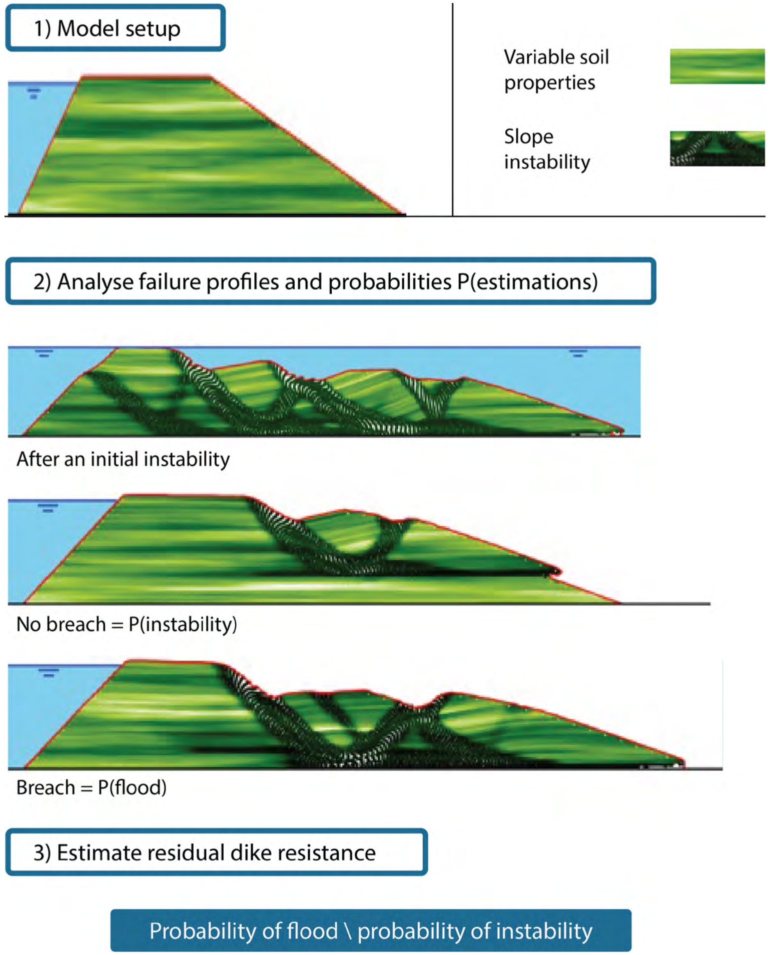


Figure 3: Main components of the modelling approach to estimate residual dike resistance. Based on Schemes from Guido Remmerswaal.

The model is set up for a given dike section and accounts for the variability in the dike and subsoil properties by generating several possible realisations of the material properties, each equally likely to occur yet different. Due to the variability, the failure process may also be highly variable, and MPM is therefore expanded into a fully probabilistic tool (Random MPM). Thereby, I extend the current probabilistic framework for dike design to include residual dike resistance. RMPM computes for each realisation if initial instability and flooding occur. The probability of initial instability and flooding can be estimated from all these failure processes. Thereby, the residual dike resistance is estimated. Finally, the results are compared to the existing guidelines to provide insight into their applicability.

Relevant for whom and where?

The research is relevant for anyone designing or assessing dikes who considers taking residual dike strength into account for dikes with a large width or dikes with a height above the water level.

Progress and practical application

Significant residual dike resistance was present in the examples tested, especially for wide dikes or lower water levels (compared to the dike height). In other words, MPM can reduce the calculated probability of flooding significantly compared to initial failure, reducing overconservative calculations.

The dikes tested in the examples were relatively weak compared to realistic dikes. This condition ensured a relatively high probability of initial failure and saved on computation costs. Consequently, these examples had a relatively ‘low’ residual dike resistance compared to realistic examples. The benefit of using MPM can therefore be expected to be higher for more realistic examples.

The analysis showed that the reduction is highly dependent on the geometry, material properties, soil variability and river/sea water level.

Current guidelines for residual dike resistance assume a 'safe' remaining dike geometry after the initial failure, which will never result in flooding. However, due to the large variation in outcomes after an initial failure, such a 'safe' geometry has not been found in the examples tested. In other words, the probability of flooding can be significantly reduced by residual dike resistance but will not become zero. For details about findings, **see the project outputs below**.

Recommendations for practice

- Evaluate failure processes up to flooding to reduce overconservatism.
- Be careful with quick estimations of the failure process.
- Provide detailed descriptions of dike slope failures for the development of MPM.
- Use MPM to model the failure process without replacing conventional methods for estimation of initial failure.
- Account for the effect of soil variability on slope instabilities as it leads to more efficient designs (with or without modelling the failure process).

Key project outputs

Remmerswaal, G., Vardon, P.J. & Hicks, M.A. (2021). Evaluating residual dyke resistance using the Random Material Point Method. Doi: 10.1016/j.compgeo.2021.104034

González Acosta, J.L., Remmerswaal, G., Vardon, P.J. & Hicks, M.A. (2019). An investigation of stress inaccuracies and proposed solution in the material point method. Doi: 10.1007/s00466-019-01783-3

So far the research components are developed for typical dike sections in the Netherlands without a specific case study or location in the map.