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Project Summary D3 - Time-dependent piping and interactions

A framework for safety assessment with time-dependent failure processes

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Publication date
2022

Document Version
Final published version

Published in
Towards Improved Flood Defences

Citation (APA)
Pol, J. C. (2022). Project Summary D3 - Time-dependent piping and interactions: A framework for safety assessment with time-dependent failure processes. In M. Kok, J. Cortes Arevalo, & M. Vos (Eds.), *Towards Improved Flood Defences: Five Years of All-Risk Research into the New Safety Standards* (pp. 137-140). TU Delft OPEN Publishing.

Important note
To cite this publication, please use the final published version (if applicable).
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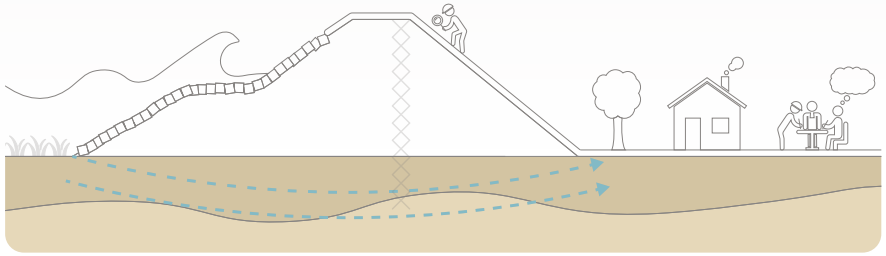
Project Summary

D3 - Time-dependent piping and interactions

A framework for safety assessment with time-dependent failure processes



By Joost Pol

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Project start: 09/2017

Project end: 03/2022

Promotors

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Outcome

The project focuses on two aspects of the new definition of safety standards as flooding probability. The first aspect is related to piping and accounts for most of the results, which show how time-dependent pipe development affects dike reliability. To this extent, we performed lab experiments, developed a pipe progression model, and integrated this knowledge into a time-dependent piping reliability analysis. Our analysis shows that dike reliability increases significantly in relatively short high-water durations or effective flood fighting. The second aspect explored the potential impact of interactions between failure mechanisms.

Figure 1: The Waal river dike at Beuningen during the 1993 flood. Photo by Rijkswaterstaat, beeldbank.rws.nl / Bart van Eyck.

Motivation and practical challenge

It is of great societal importance to improve safety estimates to optimise investments. Current safety assessments result in unexpected high failure probabilities for some failure mechanisms, such as piping. These conservative estimates for the probability of failure may result in high costs for dike reinforcement projects in the Netherlands. In the case of high water levels (**Figure 1**), including the flood duration in the analyses is one of the aspects that can contribute to lower assessed failure probabilities and more efficient reinforcements.

Related to piping, the dike failure starts when water flowing through a sandy dike foundation erodes so much sand that it forms a small (mm size) channel or 'pipe' (**Figure 3**). Therefore, an important challenge is the interpretation of field observations during floods. For example, sand boils are the only visual manifestation of piping, but most do not result in a dike breach. A better understanding of the erosion process in the laboratory and the field (**Figure 2**) is important to estimate the likelihood of a dike breach during a flood to plan emergency responses.

Research challenge

The research aims to show how to quantify failure probabilities, including (uncertain) flood durations and time-dependent failure processes. The assessment framework is elaborated for piping, for which a model shows the development over time.

Innovative components

Including time-dependent information in dike safety assessments requires understanding the development of failure mechanisms such as piping at different levels over several flood events. To do so, I use the following innovative components:

Figure 2: Piping in the laboratory. Photo left by Toan Nguyen and photo right by Joost Pol.

1. A better understanding of the development of the piping erosion process over time, using small-scale and large-scale experiments.
2. Modelling of the piping erosion process for deriving a simplified model that complements the current practice (Sellmeijer model).
3. Exploring when interactions (causal dependencies) between failure mechanisms are relevant.

Based on this improved understanding, I am developing a probabilistic framework to integrate uncertainties and time aspects in hydraulic loads, dike properties and failure processes, both over single and several flood events. The framework quantifies the effect of time dependence in several types of water systems such as rivers, coasts, and lakes. The project focuses on piping failure, but similar probabilistic methods can be used for other failure mechanisms.

Relevant for whom and where?

Technical managers of flood defences, especially in areas with short flood durations. They can use the research to improve reliability estimates in

assessment, design and operational phases. The research can also help in the planning of emergency measures.

Progress and practical application

At the moment of writing (December 2021), the analysis of the experiments is finished. In the following months, the pipe erosion modelling and reliability analysis will be fine-tuned and applied to field-scale examples. The results so far indicate that a time-dependent analysis can considerably reduce calculated piping failure probabilities. The time-dependent analysis can decrease the probability of piping failure with several orders of magnitude in areas with short, storm-dominated floods. This effect is smaller in prolonged river floods but still significant if combined with timely flood-fighting interventions. Results also show that a breach often occurs after the flood peak. Reaching this peak can take several days in riverine areas, which is a significant delay for allowing operational flood management. The results can be applied in tailored dike reliability analysis and used to derive simplified rules for assessing time-dependent pipe development.

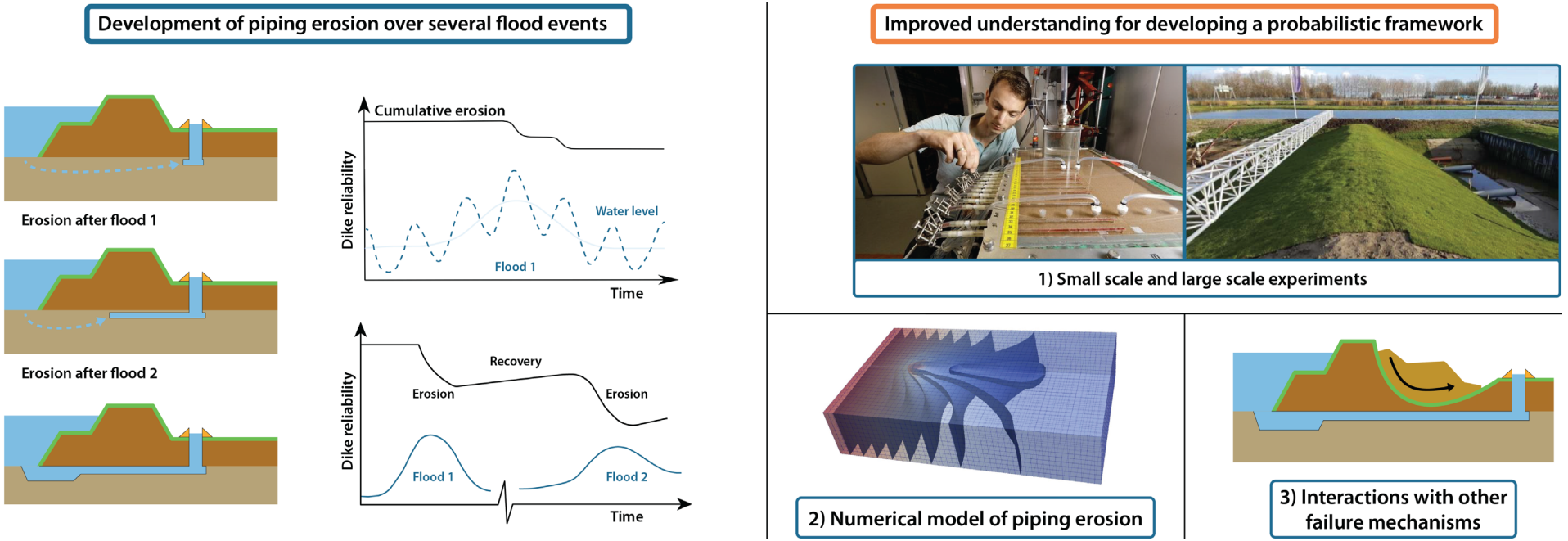

Figure 3: **Left:** Piping schemes adapted from van Beek (2015) and dike reliability graphs sketched by Joost Pol.
Right: Main components of the research. Left photo © Sam Rentmeester and right photo and schemes by Joost Pol.

Recommendations for practice

- Safety assessments and reinforcement projects should consider where they can benefit from the time required for piping development.
- Discuss including flood-fighting interventions in reliability analyses; this yields lower failure probabilities and more efficient designs combined with slow pipe development.
- Derive simplified rules for the assessment of time-dependent pipe development.
- Keep investing in experimental research to study the piping process.
- When using a failure path analysis to quantify residual strength, check for potential interactions between failure mechanisms, decreasing the reliability.

Findings of this research are developed in the laboratory and a field test site and will be applicable to dike reinforcement projects in the Netherlands.

Photo by Joost Pol.

Key project outputs

Pol, J.C., Kanning, W. & Jonkman, S.N. (2021). Temporal Development of Backward Erosion Piping in a Large-Scale Experiment. Doi: 10.1061/(ASCE)GT.1943-5606.0002415

Pol, J.C., van Klaveren, W., Kanning, W., van Beek, V.M., Robbins, B.A. & Jonkman, S.N. (2020). Progression Rate of Backward Erosion Piping: Small Scale Experiments. 10th International Conference on Scour and Erosion (ICSE-10) : Arlington, Virginia, USA. 18-21 October, 2021 (pp. 93-102).

Pol, J.C., van Beek, V.M., Kanning, W. & Jonkman, S.N. (2019). Progression rate of backward erosion piping in laboratory experiments and reliability analysis. Doi: 10.3850/978-981-11-2725-0_IS4-3-cd