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Figure 1. Failure of dike in North Holland, polder Beschoot (Photo courtesy Beeldbank Rijkswaterstaat beeldbank, Hein Versteeg).

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LEVEE SYSTEM RELIABILITY AND PERFORMANCE OBSERVATIONS

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Dissertation title:
'Bayesian networks for levee system reliability: Reliability updating and model verification.'

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Flood risk analysis is necessary to make smart, informed decisions about which risk reduction measures deserve priority. When levee systems play a key role in flood protection, these decisions often translate to which levee improvements should be carried out first. In flood risk analysis, the probability that a levee system fails is a critical component, but one that is wrought with uncertainty. Much research has focused on how to calculate the probability of system failure. However, for levees, what is typically seen in practice is an over-simplification of the system to make calculating the system failure probability easier.

In the Netherlands, over 30 years of research has led to a rigorous methodology for calculating the probability of levee system failure, which has been encoded into the software Hydra-Ring. Two key algorithms calculate

1. the segment failure probability, and
2. the system failure probability.

The first is referred to as the modified outcrossing (MO) method, and takes into account the spatial autocorrelations within a levee segment. The latter, referred to as the Equivalent Planes (EP) method, accounts for the correlation between levee segments. The methods are both approximate, and very efficient, but a thorough description of them, as well as a verification, was lacking in the literature. Furthermore, there has been a surge of interest recently in using survival observations - the survival of a levee during an observed (high) water level - to update levee reliability estimates. However, use of the MO and EP algorithms in combination with updating has not been explored.

The implementation and accuracy of these algorithms in combination with a survival observation are topics of current relevance. We explored the development and use of a Bayesian network (BN) for levee system reliability, to augment and verify the methods already in use in the Netherlands. BNs are a type of probabilistic graphical model, in which correlations between variables can be seen in the structure of network. The BN selected for use in this dissertation works with Monte-Carlo (MC) sampling, and correlates variables in the network using the Gaussian copula. In this sense, it can be considered a more explicit, less approximating method than the algorithms in Hydra-Ring.

The BN was used to test the MO algorithm, and MC directional sampling and exact solutions were used to test the EP algorithm. While both methods produce some error relative to more exact MC methods, the error is not substantial, even after incorporating a survival observation. The BN was applied to two case studies in the Netherlands, to calculate system failure probabilities due to the piping failure mechanism. In these cases survival observations were used to improve the system reliability estimate.

These applications show that not all survival observations have equal impact on the levee system reliability estimate. It was investigated under which conditions survival observations are useful. A BN was also developed specifically for the estimation of the model uncertainty in a geotechnical failure model. This uncertainty can dominate the failure probability estimate, and it is therefore important to estimate it as sharply as possible. The research shows that using a BN, high quality hindcasts (geotechnical model output for historic input data) can be used together with observed failure (or survival) to substantially improve the model uncertainty estimate, even with limited data.

The developed BN serves as a useful augmentation to the levee system reliability methods currently in use. A system reliability calculation with the BN is not prohibitively slow, but it can be substantially slower than the approximate algorithms within Hydra-Ring. Therefore, it should not be seen as a replacement for Hydra-Ring, but rather a yardstick which can be used to verify Hydra-Ring algorithms when results are questionable, or when survival observations are expected to be useful

This text is adapted from text in Bayesian networks for levee system reliability: Reliability updating and model verification' by Kathryn Roscoe (2017).