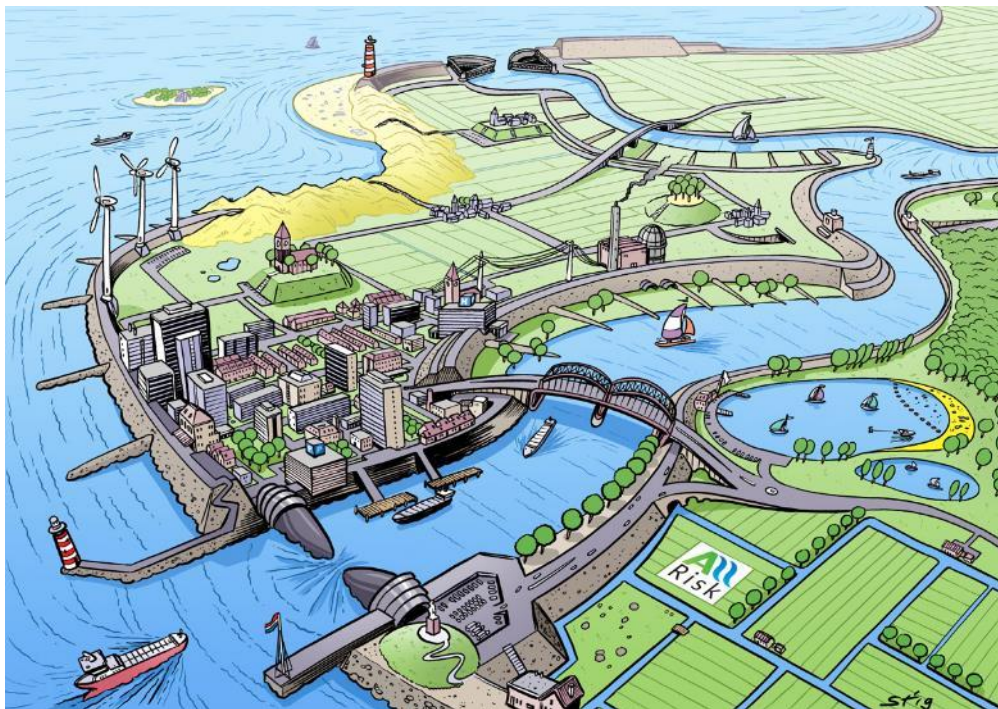


Two years All-Risk: working with the new flood risk approach



September 2019



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Foreword – All-Risk is halfway on steam!

All-Risk investigates flood risk and how measures such as flood defences can reduce this risk. In the Netherlands flood defences are by far the most adequate and efficient measure to reduce flood risks. In 2017 the Dutch government adopted a new approach, with standards for the flood defences expressed by means of tolerable flooding probabilities in the range of 1/100 – 1/100.000 per year.

In September 2019 the All-Risk program is halfway. In this document an overview is given of the results in the first 2 years of the program and the plans in the coming 2 years. Each of the 19 researchers have described their progress, and I am very proud of the ambitions and the results obtained. And there are still 2 years to come!

The ambition of the All-Risk program is to work intensively with the ‘dijkwerkers’ in the HWBP, the Flood Protection Program. There have been already a lot of cooperation, but there is room for further cooperation.

I hope and expect that all ‘dijkwerkers’ will enjoy this document, and if there are opportunities to work together, please contact us!! And we are open to receive comments and suggestions to improve the results.

Prof.dr. Matthijs Kok

Program leader All-Risk
Professor Flood Risk, TU Delft



Managing life-cycle reliability of flood defences

Wouter Jan Klerk

Practical information

University	TU Delft
Supervisors	prof. dr. ir. Matthijs Kok, prof. dr. ir. Rogier Wolfert & dr.ir. Wim Kanning
AllRisk project	A
Duration	From 9-2017 to 9-2021

Introduction

In the asset management of flood defences we have many different measures available to ensure and verify the reliability of our flood defences in time. Examples are different techniques for reinforcement, renovation, inspection and maintenance. However, within the framework of the new risk-based safety standards, it is not always clear what measures are to be preferred when and how to determine this. In this research we use optimization techniques and Bayesian decision models as a means of quantifying the benefits of different types of investment strategies for both short and long term investments in flood defence reliability. The main aim is to develop a generic framework to aid decision makers in making rational strategic, tactical and operational decisions on dike investments, based on optimal total cost (balancing reliability and cost), amongst other requirements.

Research approach and method

This research covers in principle three main areas of application. The first is risk-based dike reinforcement, for which a case study on optimization of dike reinforcements has been carried out, namely the determination of a scope for the dike reinforcement Streefkerk-Ameide-Fort Everdingen (SAFE). In this case study a heuristic (local) optimization method is used to derive a) the most effective sections for reinforcement and b) the principal directions for reinforcement solutions. It is also considered whether investments should be done now, or whether they can be postponed for some years. The next step is to validate the heuristic optimization method in comparison with other optimization techniques (e.g., Multi Integer Programming) and using Pareto fronts. The project has resulted in a preliminary set of reinforcement measures (a combination of geotextiles to solve piping, soil for heightening and soil and sheet piles to solve stability issues) that are optimally distributed over 2 moments in time.

The second area of application deals with risk-based inspection and maintenance of revetments. The first step is to develop a model for optimizing inspections of asphalt revetments and to derive the most critical factors for efficient inspection using a global sensitivity analysis (Sobol). Based on the outcomes some of those factors will be explored more thoroughly. This could be e.g. the reliability of inspection methods, the strength of damaged revetments or the use of existing inspection records to derive deterioration curves. Depending on the outcomes, additional topics towards the end of the PhD might include prioritization of dike reinforcement projects or the influence of large uncertainties on future dike reinforcement (e.g., sea level rise).

The third part deals with using structural health monitoring (SHM) for flood defences, and mainly in the context of long-term asset management decisions. For this a Bayesian decision model was developed with which, using the Value of Information concept, various strategies for SHM can be compared. See also publication 4.

Results up to now

Up to now the first case study (SAFE) has been finished and work is now being done on validating the method. The results from the prioritization of sections and reinforcement measures has been used by Waterschap Rivierenland to set the scope of the preparation phase for their dike reinforcement. This scope has been derived based on the curves shown in the figure below. Here TC (Total Cost) denotes the developed method in blue, whereas OI in red is a method that is a basic representation of the commonly used approach. The costs for the developed TC approach show that the developed approach (resulting in other measures and partially delayed reinforcements) results in lower cost for the same reliability level β (dotted line).

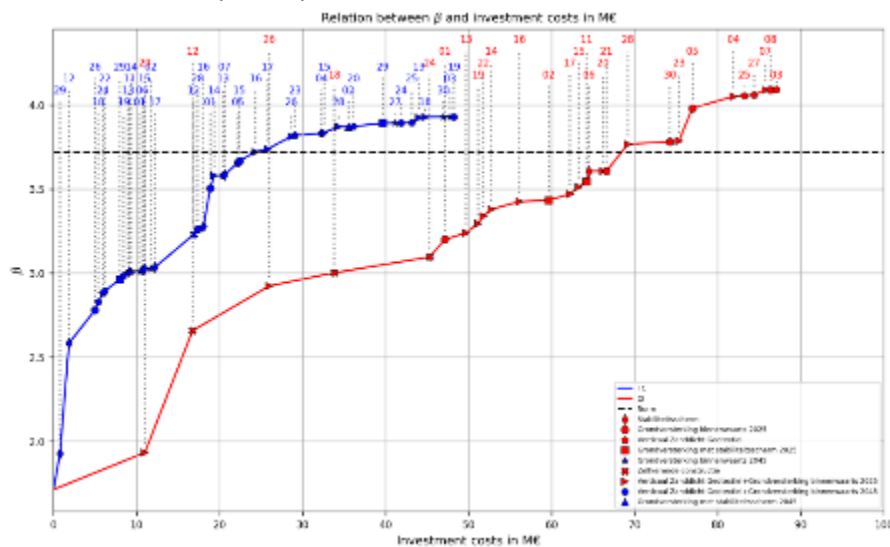


Figure: relation between reliability (β) in 2025 of dike segment 16-4 and the total life-cycle investment costs. In red the common approach (OI), in blue the developed approach (TC). Different markers indicate different types of measures.

In a paper on the Value of Information of Structural Health Monitoring (SHM), we have evaluated the benefits of SHM, also for a wide range of future climate conditions. Here we found that for more extreme conditions the Value of Information will increase, although the relative cost saving is approximately similar (due to higher overall costs).

Output

1. Klerk, W.J.; Kanning, W.; Kok, M. Time-dependent reliability in flood protection decision making in the Netherlands. In *Safety and Reliability – Safe Societies in a Changing World: Proceedings of ESREL 2018*; CRC Press / Balkema - Taylor & Francis Group, 2018; pp. 3167–3174.
2. Klerk, W.J.; Roscoe, K.L.; Tijssen, A.; Nicolai, R.P.; Sap, J.; Schins, F. Risk based inspection of flood defence dams : an application to grass revetments. In *IALCCE2018 (submitted)*; 2018.
3. Klerk, W.J.; Kanning, W.; van Veen, N.-J.; Kok, M. Influence of monitoring on investment planning of flood defence systems. In *ISGSR2019*; 2019.
4. Klerk, W.J.; Schweckendiek, T.; Heijer, F. Den; Kok, M. Value of Information of Structural Health Monitoring in asset management of flood defences. *Infrastructures (submitted) 2019*, 1–17.

Interactions

In the first case study there is ample interaction with Waterschap Rivierenland. On the second topic we are still looking for water authorities that are interested in improving inspection & maintenance practice for revetments, but work is being discussed with Waterschap Noorderzijvest & Waterschap Rivierenland. Also the work being done is related to research by Rijkswaterstaat & STOWA into revetment inspection & maintenance.

Shared use of flood defences

Richard Marijnissen

Practical information

University	Wageningen University and Research
Supervisors	Jantsje van Loon-Steensma Carolien Kroeze Mathijs Kok
AllRisk project	A
Duration	From 21-09-2017 to 21-09-2021

Introduction

Flood defences have the potential to be integrated with many other function (e.g. nature, recreation, transport, housing etc.). A shared-use of the flood defence often implies a robust design to guarantee safety. Some functions impose new restrictions on the flood defence, some elements like natural foreshores can contribute to reducing flood risk by damping wave energy, while other functions like the grazing of sheep might hardly affect the functioning of the defence at all. The objective of this research is to gain more insight in the effects of the multifunctional use of flood defences on flood risk using the new probabilistic risk approach recently adopted in the Netherlands. With this research the effects of adapting dikes for new functions on flooding probabilities are quantified.

Research approach and method

The first step will be to decompose the different multifunctional dike concepts found into their (multi)functional elements. The common elements that facilitate the additional functions in the dike can be regarded as the building blocks for multifunctional dike design.

The probability of failure of a dike (section) can be understood as the probability that the loads acting on a dike exceed the capability of the dike to resist. The influence of multifunctional dike elements on the probability distribution of failure of the dike is calculated with a framework showing how these elements contribute to the overall probability of dike failure within the new Dutch risk approach. The models and methods from the new Dutch Legal Assessment Instruments (in Dutch “Wettelijk Beoordelingsinstrumentarium”, abbreviated to WBI 2017) form the starting point of these calculations and will be adapted for the purposes of this research. The WBI models are complemented by other tools common in dike safety assessments (e.g. Hydra-NL for determining storm exceedance probabilities, the SWAN wave model for foreshore effects, D-GEO for dike stability etc.).

It may turn out that the additional requirements from other functions are governing for the design of the multifunctional dike. In other instances the dike may receive benefits in safety not directly captured through the approach outlined in the WBI. The parallel dike in Delfzijl and the wide green dike along the Dollard will serve as case studies to verify the developed framework, and add to it when needed. Both cases involve challenges incorporating novel uses of the flood protection zone in dike assessment procedures (e.g. the use of salt marsh sediment for dike construction within the Dollard, and the use of saline agriculture in Delfzijl).

Looking back on the case studies of the parallel dike in Delfzijl and the wide green dike along the Dollard the approach is outlined and validated with other cases. From the developed framework and the practical cases generalised insights to implement specific functions will be established.

Research activities

- Develop a framework for the inclusion of multifunctional dike elements in dike assessments
- Apply the framework to the wide green dike case-study
- Apply the framework to the parallel dike case-study
- Synthesize a generalized approach for including multifunctional uses in dike assessment

Results up to now

- A review of the current approach to multifunctional dike design and assessment in relation to the new risk standard. Presented as part of the first paper (published)
- Assessment framework for the reliability of multifunctional dikes. Part of the first paper (published)
- Projecting the sustainability of sediment extraction out of the marsh as a resource for meeting future dike reinforcements under sea-level rise (case-study of the wide green dike). To be published in the second paper

Output

- Presentation at the conference “Water science for Impact” (16 – 18 October 2018, Wageningen): R.J.C. Marijnissen, M. Kok, C. Kroeze, J.M. van Loon-Steensma, Multifunctional flood defences as climate adaption measures for the Netherlands: Putting potential into practise
- First paper published: Marijnissen, R., Kok, M., Kroeze, C., and van Loon-Steensma, J.: Re-evaluating safety risks of multifunctional dikes with a probabilistic risk framework, Nat. Hazards Earth Syst. Sci., 19, 737-756, <https://doi.org/10.5194/nhess-19-737-2019>, 2019.
- Poster presentation at the EGU (05-12 April 2019, Vienna, Austria): A sustainable cyclical sea-level rise adaptation scheme for a wide green dike system

Interactions

- Discussions on multifunctional elements of the Grebbedijk project (Wageningen)
- Participation in the sea-level rise hackathon at Deltares
- Discussions and cooperation with the Wide Green Dike project

Room for the Delta

Yuka Yoshida

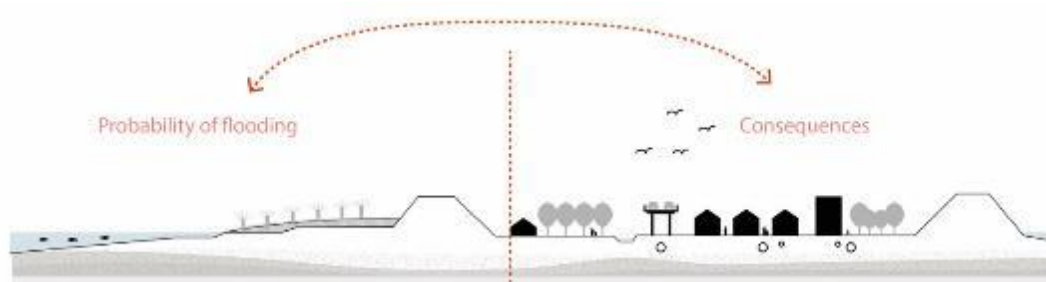
Practical information

University	TU Delft
Supervisors	Prof.Wil Zonneveld, Prof.Matthijs Kok, Fransje Hooimeijer
AllRisk project	A
Duration	From November 2017 to March 2022

Introduction

The design of flood defences has a large impact on the surrounding environment, including highly valued natural and cultural landscape features and lives of people (Van Loon-Steensma & Kok, 2016). A dike is an interest of a broader area including its environmental and spatial goals. The new safety standard which has been adopted in the Water Act (Rijksoverheid, 2017), defines 'risk' as the multiple of the 'probability' of flooding and the 'consequence' of an event in the protected area (hinterland). This implies that spatial development becomes part of the risk approach and engineering approach become part of a spatial design. However, the protected area is currently not explicitly integrated in the approach to flood defence. This is due to the focus on the measures to reduce the probability of flooding in the Netherlands. Consequently, the knowledge in the relationship between design of the protected area and the overall risk reduction by flood defences is still rather limited (Nillesen & Kok, 2015). This research seeks to deliver a strategic approach and integration of knowledge on the spatial design and flood protection system, by thinking in terms of an **area of flood protection including the foreshore and protected areas** instead of a line of defence.

The research will be conducted with the use of fundamental explorations into spatial morphology and flood risk management, research by design. As the impact of climate change may demand more room for water and the challenges continue to rise in addressing the sufficiency of the existing capacity to adapt future conditions, broadening the scope and including protected areas as part of flood defences needs to be further investigated. The expected outcome of this research is a design and theoretical framework with a set of design principles in which spatial design becomes an essential part of the planning of flood defences.

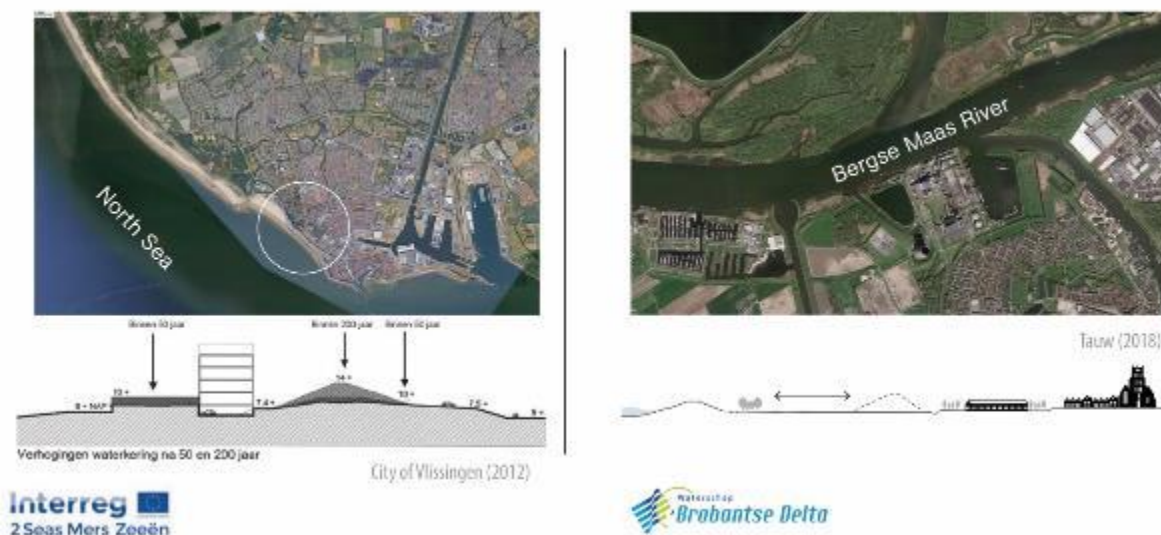


Area of Study, by author

Research Approach and Method

To define the comprehensive design approach strategy, the perspective from engineers and spatial designers in relation to designing flood defenses are studied and the potentials for integration and synergy are defined. Within the hydraulic engineering perspective, the main goal is to make a defence line safe and reduce uncertainties (van den Hoek, Brugnach, & Hoekstra, 2012). Whereas in the landscape design approach, safety includes other aims such as, but not limited to, ecological and cultural values. These latter aims are translated into characteristics of the spatial order such as spatial quality, environmental quality and functionality (Dammers, Bregt, Edelenbos, Meyer, & Pel, 2014) for a specific project and/or a site. Through an interdisciplinary design as a research method, these two perspectives are investigated to find a strategy to adapt to future conditions the Dutch flood management will be facing.

Cases



The cases studies that will implement these frameworks are the areas of Vlissingen and Geertruidenberg. Both of the project teams have ambition and need to consider spatial development in the hinterland as a part of the flood defence system because, in the case of Vlissingen, the existing engineering solution would have a negative impact on the surrounding areas. And in the case of Geertruidenberg, a decision to implement a gate to meet the new safety standard has a consequence on the water management system of the regional scale.

The Vlissingen case study is a part of the “Interreg” project, which also has international partners involved in its development. Geertruidenberg is a pilot project of the Water authority the Brabantse Delta. Both case studies involve the perspectives of hydraulic engineers, municipal workers, water authorities, and landscape architects.

Interactions

Water Authority Brabantse Delta, Rijkswaterstaat, City of Vlissingen

AllRisk Dikes: Risk Framework

Wim Kanning

Practical information

University	TU Delft
Supervisors	Prof. Matthijs Kok
AllRisk project	A
Duration	From 15-09-2017 to 15-09-2021

Introduction

For the All-Risk program, I work as a part-time researcher. My main expertise lies in probabilistic analysis of dikes and failure mechanism modeling. My main AllRisk tasks are the supervision of AllRisk PhD candidates, general AllRisk activities, supervision of MSc students and my own research.

Research activities

1. Supervision PhD candidates

I work closely with the following PhD students:

- Wouter Jan Klerk from All-Risk project A who works on risk based optimization for flood defence reinforcements and inspections.
- Joost Pol from All-Risk project D who mostly works on time-dependent effects in the piping failure mechanism. After data collection and analysis, he recently carried out a full-scale test at Flood Proof Holland.
- Job Kook from SAFElevee at TU Delft who is working on the hindcasting of levees, most notably the slope instability failure at Breitenhagen (Germany).
- Carolyne Bocovich from the Colorado School of Mines who just defended her PhD thesis on inverse modeling of piping progression based on pore water pressure measurements

2. General All-Risk activities

This comprises various activities for All-Risk in general and for specifically for projects A and D, amongst which:

- Organization of and progress reports for the user meetings of project A and D
- White paper on definitions of failure, discussing the difference between ultimate limit state and serviceability limit state requirements.
- Workshops at the annual "Dijkwerkersdag"
- Organization of All-Risk field trips. The 2018 field trip was to the Rhine river area, the 2019 field trip to the Wadden Sea area.

3. Supervision of MSc students

Supervision of MSc students, most recently:

- David Knops: "Effects of the foreshore and heterogeneities of the subsoil on the safety analysis of piping" defended December 2018
- Nick van den Berg: "Spatial integration of dike reinforcements - Development of a method that compares the spatial influence of design alternatives". defended December 2018
- Laura van der Doef: "Interaction of the failure mechanisms backward erosion piping and slope stability". Defended August 2019
- Pauline van Leeuwen "An analysis of the influence of the flood duration on slope stability". Defended August 2019

4. Research

Own research is limited by the other activities, but mainly focusing on:

- Writing a paper on length-effects in flood risk assessment
- Analyzing past piping failures
- Organizing a special session on Earth Levees and Dams during ISGSR2019.
- White paper on heterogeneity in dikes

Results up to now

Among the many interesting results, the analysis of the Breitenhagen levee failure in Germany in 2013 is highlighted. This slope instability is described by Kool et al (2019); a time lapse is shown below. One of the main findings of the Kool et al paper is that the slope instability most likely occurred as the result of an old breach. This old breach likely eroded the blanket layer, creating a direct connection between river and aquifer below the reconstructed dike, thereby increasing pore water pressures. For more information, refer to Kool et al (2019).



Time-lapse of the Breitenhagen levee failure along the River Saale in Germany, 2013. (from Grubert, 2013; see Kool et al, 2019).

Output

Recent accepted/published papers include:

- Jongejan, R.B., F. Diermanse, W. Kanning, M. Bottema (2020). Reliability-based partial factors for flood defenses. Reliability Engineering & System Safety Volume 193, January 2020.
- Kool, J.J., W. Kanning, T. Heyer, C. Jommi, S.N. Jonkman (2019). Forensic analysis of levee failures: the Breitenhagen case. Accepted for International Journal of Geoengineering Case Histories.
- Kanning, W. and T. Schweckendiek (2019). Bayesian inference of piping model uncertainties based on field observations. Accepted for ISGSR2019.

Interactions

Interactions with users are mainly through the PhD students and annual AllRisk excursion.

How to manage and design foreshore ecosystems to gain both coastal protection and ecological value?

Beatriz Marin Diaz

Practical information

University	NIOZ & University of Groningen
Supervisors	Tjeerd J. Bouma (NIOZ), Han Olf (RUG), Laura Govers (RUG), Daphne van der Wal (NIOZ)
AllRisk project	B
Duration	From 01/09/2017 to 31/08/2021

Introduction

In the Wadden Sea we can find foreshore ecosystems like saltmarshes and tidal flats in front of the dikes. Saltmarshes are formed by plants that tolerate the seawater coming from the high tides. These plants can reduce the waves in front of the dikes by trapping sediment and making the foreshore higher, and also by reducing the waves and currents when the water goes through the vegetation stems. Tidal flats are the areas of soil without saltmarsh plants covered by seawater during the high tides. Therefore, a dike with a saltmarsh in front may be more protected than a dike next to a bare tidal flat. In face of climate change and sea level rise, adequate management of these foreshores along the Wadden Sea dikes may convert the safety status of > 100 km dikes from insufficient to safe. Nevertheless, the implementation of such foreshore management measures is hampered by uncertainties about i) the impacts on natural values (protected species & habitats) and ii) the ecosystem-based safety during sequential storms. The aim of this project is to reduce these uncertainties by providing thorough understanding of the functioning of these ecosystems and the effect of the management on their safety value.

Research approach and method

Within this project, four main questions are being addressed:

Question 1: *Does the saltmarsh vegetation stabilize the soil in front of the dikes across The Netherlands compared to the bare tidal flats? In case of a dike failure, can the presence of a saltmarsh limit the dike breach dimensions?*

Sediment stability of tidal flats and saltmarshes across the Netherlands was tested. For this, soil blocks were collected in the different locations, transported to the NIOZ and exposed to fast water flow in controlled conditions.

Question 2: *How does grazing management affect the safety and long term saltmarsh soil stability? Does the saltmarsh elevation and age also have an effect in the soil stability?*

Saltmarshes can erode laterally (cliff formation) due to sea level rise or pond formations. In this case, we studied the lateral-soil stability of grazed and non grazed saltmarshes, in low and high soil elevations and different marsh ages. For this, soil blocks were collected in the field and exposed laterally to waves in controlled conditions in the NIOZ.

Question 3: *What is the impact of sequences of storms on safety provided by saltmarshes?*

Wave run-up on the dike can be reduced by the presence of a saltmarsh in front of the dike. But, does the effect remain the same after sequences of storms during winter, when the vegetation breaks or with different dike exposures? To study this, we are monitoring the wave attenuation over marshes vs. tidal flats and the wave run up on the dike after storms to later relate to the state of the vegetation and foreshore exposure.

Question 4: Can we develop nature-based management on the tidal flats to promote expansion of the saltmarsh and enhance the ecological value of the system?

In this case, we are studying the effect of installing artificial mussel beds on tidal flats to promote soil stabilization in front of the saltmarsh, which could enhance the saltmarsh expansion in the future. This is monitored with wave sensors and by measuring soil elevations periodically. In addition, a study of the development of the saltmarshes in the Wadden Sea over the past years will be carried out with satellite images and maps to find which factors may promote saltmarsh expansion.

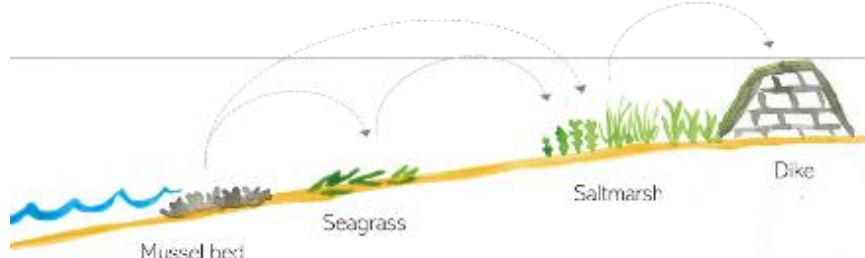


Fig 1. Interconnection between foreshore ecosystems: mussel beds and seagrass may change the tidal flat morphology, which in return may promote saltmarsh expansion (Question 4); and the presence of a wide saltmarsh may protect the dike (Question 1, 2 and 3).

Results up to now

Question 1: Mainland saltmarshes soils range from coarse sand to compact clay, while in Schiermonnikoog (barrier island) we could distinguish a clay/peat layer accreted on the top of coarse sand. Preliminary results show a much more stable top soil of the saltmarshes with clay compared to the tidal flats or sandy soils, even if the clay layer is thin (1 cm). Grazing did not clearly affect the top soil stability, compared to non-grazed saltmarshes.

Question 2: Preliminary results show that young saltmarshes may be more vulnerable to lateral erosion due to the shorter clay layer depth, as well as marshes in high elevations (Fig. 2). Grazing by cows reduced lateral erosion by compacting the soil. Grazing by small herbivores slightly reduced the lateral erosion in the low marsh. This seems to be due to a change in the vegetation type.

Question 3: Preliminary results show that the wave reduction over the saltmarshes and wave run up on the dike seems to depend on the soil elevation and saltmarsh width rather than the vegetation state.

Question 4: Preliminary results show that the artificial mussel beds not always reduce the waves and trap sediment, and it seems to depend on the water flow direction of the different storms.

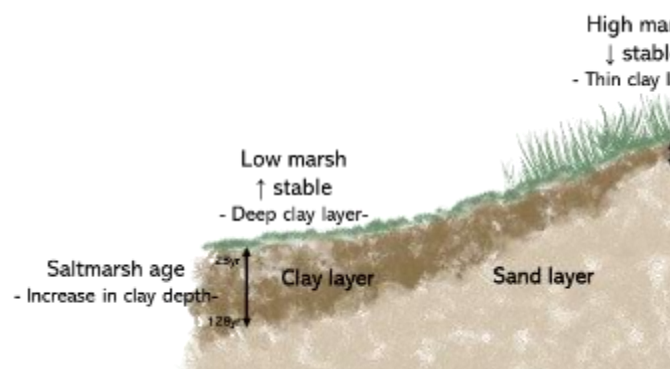


Fig. 2. Diagram of a saltmarsh profile in a barrier island.

Output

-

Interactions

-

Impact of Shallow Foreshores on Wave Transformation and the Crest-level Design of Dikes

Christopher Harold Lashley

Practical information

University	Delft University of Technology
Supervisors	Jentsje van der Meer, Bas Jonkman, Jeremy Bricker
AllRisk project	B
Duration	From September 2017 to September 2021

Introduction

In line with the new probabilistic risk-based approach to flood management adopted by the *Hoogwaterbeschermingsprogramma*, this research focuses on how the failure probability of coastal dikes may be affected by processes occurring in the area in front of the structure: the foreshore. Foreshores may be classified as deep, shallow, very shallow or extremely shallow depending on the extent to which they interact with the incoming waves. Shallow foreshores are considered potential nature-based solutions to coastal flood protection as they have been proven to attenuate waves by initiating wave breaking. However, several studies have also shown that as conditions become shallower, wave energy is not only dissipated by depth-induced breaking but is also transferred from higher frequencies (that of typical wind sea and swell waves) to much lower frequencies, producing so-called infragravity waves.

In the design of sea dikes, nearshore wave heights, water levels and the resulting wave overtopping constitute the main hydraulic loads. While several numerical (e.g. SWAN) and empirical (e.g. EurOtop) models to predict these parameters exist, they do not (directly) consider the generation and propagation of IG waves. This results in significant uncertainty when they are applied to areas where IG waves tend to dominate. Therefore, this research aims to reduce this uncertainty by: i) enhancing our understanding of the generation, propagation and overall impact of nearshore IG waves under varied hydro-morphodynamic and vegetated conditions; and ii) validating and improving the existing models and methods.

Research approach and method

The research is guided by the following questions:

1. Under what conditions do IG-wave phenomena play a role in the description of wave conditions at the dike toe?
2. Given wave conditions at the dike toe with some or only IG-wave energy, what will be the effect on wave overtopping?

The research has been broken down into 4 key activities which address both the physics of the dike-foreshore system and the application of this knowledge to dike design and assessment:

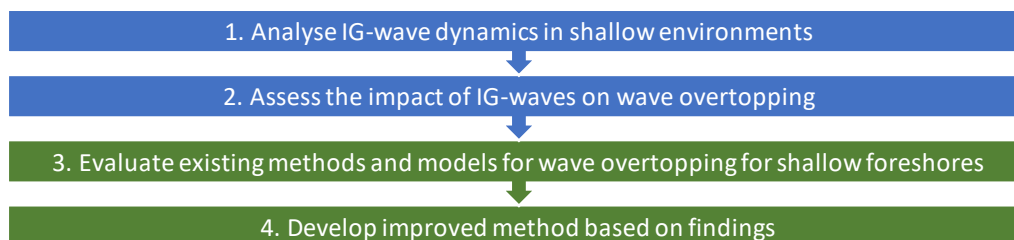


Figure 1 Research approach highlighting both physics (blue)- and application (green)-related activities.

The above activities will make use of **physical modelling** (carried out in Belgium), **numerical modelling** (such as: XBeach, SWAN, SWASH and OpenFOAM) and **field investigations** (carried out in: the Netherlands, France and USA) in order to provide a comprehensive analysis.

Research activities

1. **Analyse IG-wave dynamics in shallow environments:** here the influence of various offshore, foreshore and dike slope conditions on the magnitude of IG waves at the dike toe will be assessed, with a particular focus on areas with shallow foreshores.
2. **Assess the impact of IG-waves on wave overtopping:** this activity examines the effect of having some (or only) IG-wave energy, at the dike toe, on wave overtopping.
3. **Evaluate existing methods and models for wave overtopping in shallow environments:** in this activity, the existing numerical and empirical models used in the design and assessment of coastal dikes will be evaluated for shallow foreshores, where IG waves are significant.
4. **Develop improved method based on findings:** here, an improved approach to estimating wave overtopping under shallow foreshore conditions is developed.

Results up to now

To answer the first research question, the influence of several environmental parameters on the magnitude of IG waves at the dike toe was assessed, including: deep-water wave height ($H_{m0,deep}$), peak period (T_p), directional spreading (σ), water depth (h_{toe}), foreshore slope (α_{fore}), vegetated cover (W_{veg}), bottom friction (n) and dike slope (α_{dike}), see Figure 2.

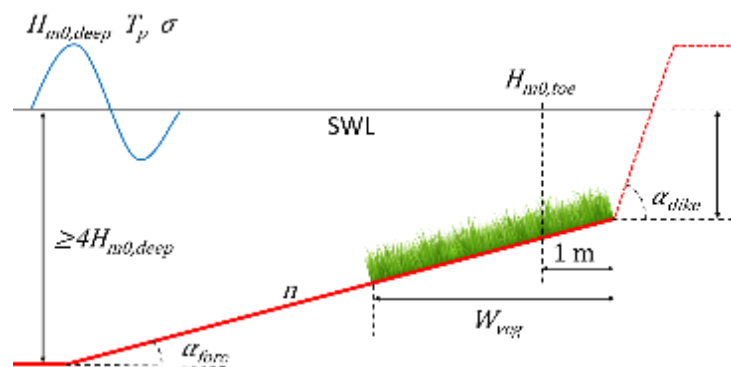


Figure 2 Schematic representation of dike-foreshore system indicating the relevant environmental parameters.

Findings show that higher, directionally narrow-banded incident waves; shallower water depths; milder foreshore slopes; reduced vegetated cover; and milder dike slopes promote the dominance of IG waves (over typical sea and swell waves) at the dike toe; while the effects of incident wave period and bottom friction were found to be minor.

Output

- Baron-Hyppolite, C., **Lashley, C. H.**, Garzon, J., Miesse, T., Ferreira, C., and Bricker, J. D. (2018). "Comparison of Implicit and Explicit Vegetation Representations in SWAN Hindcasting Wave Dissipation by Coastal Wetlands in Chesapeake Bay." *Geosciences*, 9(1), 8.
- **Lashley, C. H.**, Bertin, X., Roelvink, D., and Arnaud, G. (2019). "Contribution of Infragravity Waves to Run-up and Overtop in the Pertuis Breton Embayment (France)." *Journal of Marine Science and Engineering*, 7(7), 205.
- **Lashley, C. H.**, Bricker, J. D., van der Meer, J., Altomare, C., and Suzuki, T. "Infragravity-wave Dominance at Sea-Dikes fronted by Very and Extremely Shallow Foreshores." *Proc., Twenty-ninth (2019) International Ocean and Polar Engineering Conference*, 3553-3559.

Interactions

One of the intended deliverables of the subproject is a *Practitioners' Guide* (integrative product), developed with user input, outlining the main findings of the research and the improved methods for the crest level design of dikes fronted by (very) shallow foreshores.

Large-scale uncertainties in river water levels

Matthijs Gensen

Practical information

University	University of Twente
Supervisors	Suzanne Hulscher, Jord Warmink
AllRisk project	B
Duration	From 2017 to 2021

Introduction

Water levels determine the main dynamic load on the 1430 km river dikes. The recently executed Room for the River project consisted of 34 large-scale river interventions, but their hydraulic effects were studied only locally and deterministically, in spite of inherent uncertainty. This uncertainty is dominated by the discharge distribution over the river branches at bifurcation points. The uncertainty of the discharge distribution is strongly affected by bedform-dominated main channel roughness, river interventions and regulation structures. We aim to quantify and possibly reduce the river water level uncertainties in a bifurcating river system that includes uncertain river dune dynamics, river engineering works and regulations structures, to support more accurate and robust dike designs and improved management strategies for the river system.

Research approach and method

Numerical modelling is applied to assess the effects of river dune dynamics, river engineering works and regulation structures in the bifurcating river Rhine system separately and in combination. As long as 2D processes are negligible, a 1D model is applied. 1D modelling has the advantage of being able to execute a large amount of simulations with different set-ups, without restrictions related to computational resources. The available 1D Sobek model schematization of the Rhine branches (Rijn-j16_5_v1) is used.

Results up to now

System effects in a bifurcating river through changes in discharge distribution proved to be an important self-regulating mechanism for system-wide water level uncertainties. Previous research (e.g. Warmink et al. 2013) has shown that uncertain river dune dynamics and the hydraulic roughness it creates, can lead to water level uncertainties of up to 0.5 meters. These water level uncertainties are significantly smaller, e.g. 0.2 meters in the Waal, in a bifurcating river system as changes in the discharge distribution partly compensate for the water level variations (Figure 1).

In the unequally sized river Rhine branches, the water levels respond differently to changes in roughness in the system. Variations in roughness in the larger Waal branch lead to large variations in water levels throughout the entire system. In contrast, variations in roughness in the smaller branch lead to little changes in water levels locally, as well as elsewhere in the system. These principles are generally valid and therefore it implies that in bifurcating river systems the largest downstream branch dominates the water levels in the entire system.

The research up to now has indicated that in a bifurcating river system, interactions of water levels and discharge distributions have a large influence on water levels throughout the system. The self-regulating mechanism against water level uncertainty, through a change in discharge distribution may indicate that water level uncertainties in a bifurcating river system are smaller than for one single stretch of river. Therefore, the river system needs to be regarded as one interconnected system

in the analysis of the water levels along the branches. This of importance for river maintenance, assessment of flood risks and future planning of river engineering works.

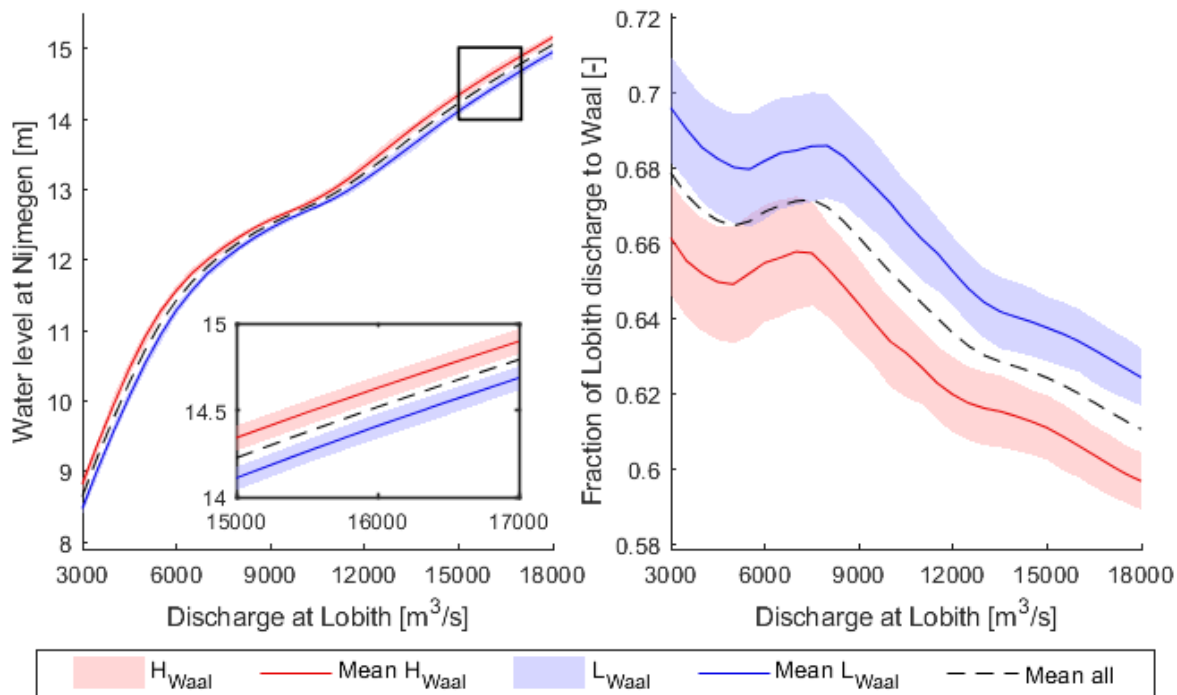


Figure 3: Left panel: water levels at Nijmegen as function of discharge at Lobith. Under high Waal roughness scenarios (red shaded area) compared to low Waal roughness scenarios (blue shaded area) water levels are on average 0.2 m higher. Right panel: fraction of Upper Rhine discharge diverted towards the Waal branch. The observed change in discharge distribution dampens the water level effect of increasing roughness.

References:

Warmink JJ, Booij MJ, Van der Klis H, Hulscher SJMH (2013) Quantification of uncertainty in design water levels due to uncertain bed form roughness in the Dutch river Waal. *Hydrological Processes* 27:1646-1663

Output

- **Gensen, M.R.A., Warmink, J.J. and Hulscher, S.J.M.H., 2018.** Large-scale uncertainties in river water levels. 122-123. Abstract from NCR Days 2018, Delft, Netherlands.
- **Gensen, M.R.A., Warmink, J.J. and Hulscher, S.J.M.H., 2019.** Propagating main channel roughness uncertainty in the bifurcating Dutch Rhine system. 28-29. Abstract from NCR Days 2019, Utrecht, Netherlands.
- **Gensen, M.R.A., Warmink, J.J. and Hulscher, S.J.M.H., 2019.** River dune based roughness uncertainty for the Dutch Rhine branches. 101-106. Abstract from MARID VI, Marine and River Dune Dynamics 2019, Bremen, Germany.
- **Gensen, M.R.A., Warmink, J.J., & Hulscher, S.J.M.H., 2019.** *Water level uncertainties due to uncertain bedform dynamics in the Dutch Rhine system.* Abstract from XXXVIII International School of Hydraulics 2019, Łąck, Poland.

Interactions

- The idea of a self-regulatory mechanism in the river Rhine system fits well within the framework of the 'Self supporting river system', which is currently a much discussed topic in Dutch river management.
- During the research knowledge is gained on how uncertainties influences and interacts with the effectiveness of river interventions. This knowledge is fuel for discussions and interactions with users
- A MSc student will work at HKV Lijn in Water on the topic of 'uncertainties in rating curves at bifurcation points'.

Improvement of dike failure probability estimates using knowledge of the subsurface

Bas Knaake

Practical information

University	Utrecht University
Supervisors	H. Middelkoop, E. Stouthamer, K.M. Cohen
AllRisk project	C
Duration	From 12-2017 to 12-2021

Introduction

The stability of dikes may be influenced by various failure mechanisms such as liquefaction and dike slope instability near deep channel scour. Liquefaction is the occurrence of flow slides in submerged slopes which can be divided into two different processes: static liquefaction and breachflow. Static liquefaction refers to a sudden loss of strength and collapse of a loosely packed body of sand. Breachflow is a backward erosion process which occurs in more densely packed sands. Channel scour is a form of bed erosion that imposes increased probability of river bank instability and hence of dike failure. Main causes for scour hole formation are hydrodynamic conditions, local channel morphology and subsurface buildup. Scour holes generally reflect where the subsurface was locally more erodible.

Local (geotechnical) properties of the subsurface play an important role in both liquefaction and channel scour. These properties are related specific architectural elements (e.g. older channel belt) in the subsurface and thus to the processes that formed the deposits in the past. Using genetic information of the subsurface can generate better understanding of the geologic boundary conditions for failure mechanisms. This helps in more detailed quantification of subsurface properties and their distribution as well as the possibility to identify potential weak areas for failure mechanisms.

Research approach and method

The aim is to determine the relevant geologic parameters and thereby gaining better understanding of the geologic boundary conditions for liquefaction and channel scour. In the Netherlands liquefaction occurs predominantly in Zeeland, Zuid-Holland and the Wadden Sea. Due to the availability of an extensive database of historical liquefactions in Zeeland this research focuses on the Eastern and Western Scheldt. Earlier inventories identified channel scour in the lower part Rhine-Meuse delta. This study will extend this inventory to the entire Rhine-Meuse delta. We look at the occurrence of liquefaction and scour holes and the relation to the local and large scale geological buildup of the study area.

Research activities

A time series of bathymetric data (Δt : 1 year) for the entire Rhine-Meuse delta is gathered and analyzed semi-automatically. Earlier research (Huisman et al., 2016) identified approximately 120 scour holes in the lower part of the delta. We revisit and extend this inventory to the central and upper delta. Scour holes are identified by visual inspection of bathymetry data and subsequent attributes are derived objectively. Based on several conditions (e.g. slope, local drainage) the boundaries of scour holes are determined and attributes of a scour hole (i.e. area, morphology) are derived. Geological data compiled consists of detailed mappings of older channel-belts (e.g. Cohen et al., 2012) and 3D subsurface models GeoTop and NL3D (DINO-TNO). We use this data to map the lithological and lithostratigraphical composition at the base of modern rivers. We compare the occurrence of scour holes and their attributes to regional and local buildup of the subsurface.

For liquefaction we combine subsurface data with an existing database of historical flow slides in the Western Scheldt (Van Dijk et al., 2018) with location, area, volume and slope. First, we compare the occurrence of flow slides to the large scale buildup of the study area to derive relevant geological units for flow slides. Next, we focus on characterization at the more local scale to derive (geotechnical) properties for identified units.

Results up to now

Occurrence of channel scour is much more common in the lower part of the study area compared to the central and upper parts. Large scale trends in the subsurface buildup suggest this is partly due to a more heterogeneous subsurface buildup in the lower part of the delta. In the lower part of the study area there is a higher spatial variability of alternating less resistant (e.g. sand) and more resistant (e.g. clay, peat) layers in the subsurface.

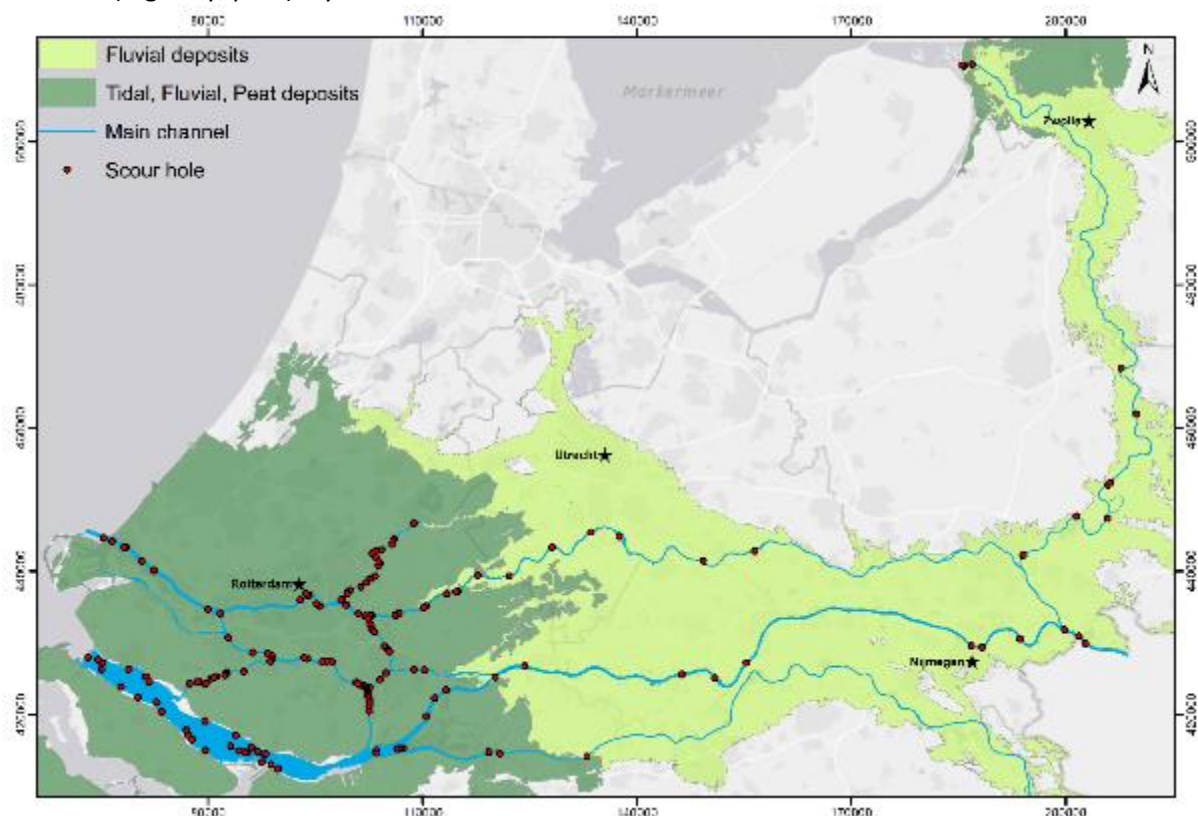


Figure 1. Locations of scour holes identified in the Rhine-Meuse delta in relation the large scale trends in the subsurface buildup. The western part of the study consists of alternating tidal, fluvial and peat deposits whereas the eastern part is mainly dominated by fluvial deposits.

Output

- S.M. Knaake, M.W. Straatsma, Y. Huismans, K.M. Cohen, E. Stouthamer, H. Middelkoop (2019). The influence of subsurface heterogeneity on scour hole development in the Rhine-Meuse delta, the Netherlands. Land of Rivers: NCR DAYS 2019 (Book of Abstracts) Proceedings. Netherlands Centre for River Studies publication 43-2019
- S.M. Knaake, M.W. Straatsma, Y. Huismans, K.M. Cohen, E. Stouthamer, H. Middelkoop (2019). The relation between scour holes and subsurface architecture in the Rhine-Meuse delta, the Netherlands. Abstract Nederlands Aardwetenschappelijk Congres 2019.

Interactions

Identifying geotechnical properties of subsurface architectural elements in the study area can help in better prediction of potential risk areas for a failure mechanism which leads to more efficient design of dikes.

De toevoeging van 3D ondergrondheterogeniteit aan dijkstabiliteitsbepalingen met hydrologische modellering

Teun van Woerkom

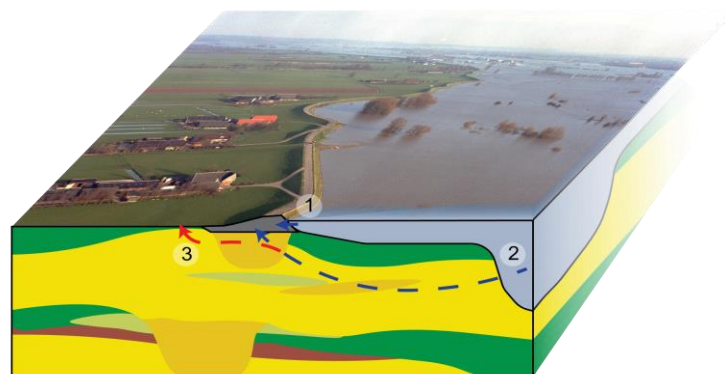
Practical information

Universiteit	Universiteit Utrecht
Promotors	Prof. dr. ir. Marc Bierkens, Prof. dr. Hans Middelkoop, Dr. Rens van Beek
AllRisk project	C
Duur	Van 1-9-2018 tot 1-9-2022

Introductie

Na de implementatie van de probabilistische dijktoets (HWBP, 2014) zijn er meer faalmechanismen toegevoegd aan de rekenmethode voor dijkveiligheid. Hiervan is een groot aantal gevoelig voor veranderingen van grondwaterstroming en poriedrukken, welke in grote mate worden bepaald door de heterogeniteit in de ondergrond. Heterogeniteit is een breed begrip, en kan gaan over grootteschalen van hectometers tot millimeters. Hiervoor zijn de grootschalige afzettingmilieus van belang, maar ook kleinschalige variatie in topografie of riviermorphologie. Door het creëren van preferente stroombanen voor het grondwater, kan ondergrondheterogeniteit leiden tot extreme poriedrukken onder het dijklichaam, mogelijk resulterende in piping of uplift. Deze poriedrukken kunnen echter ook de verzadiging van het dijklichaam beïnvloeden, resulterende in een kleinere macrostabiliteit (Figuur 1). De invloed van de ondergrond is in de huidige meetregels opgenomen in 2D doorsnedes dwars op de dijk,

maar negeert in grote mate de 3D variatie zoals die in de ondergrond aanwezig is. Het hoofddoel van mijn onderzoek is daarom om zowel de 2D als 3D invloed van ondergrondheterogeniteit op grondwater-gerelateerd dijkfalen te onderzoeken, om conclusies te kunnen trekken over het belang van detail in de ondergrondschematisatie gebruikt bij dijkstabiliteitsberekeningen.



Figuur 1; De relatie tussen ondergrondheterogeniteit en grondwaterstroming. Preferente stroombanen bevatten directe infiltratie in de dijk (1) en indringing in het voorland (2). Deze laatste kan zorgen voor hoge poriedrukken onder het dijklichaam (3).

Onderzoeksaanpak en methode

Door de relatieve onbereikbaarheid van de ondergrond, bestaat de hoofdmoot van dit onderzoek uit hydrologische modellering met behulp van Modflow 6 software. Relatief simpele hydrologische belasting kan in sommige gevallen worden toegepast, maar vaker zijn er terugkoppelingmechanismen actief. Dit vraagt om meer complexe modellen, die de mogelijkheid hebben poriedrukken met veranderende ondergrondparameters te kunnen simuleren. Voor beide mogelijkheden is uitgebreidere kennis van grondwaterstromingen en poriedrukveranderingen bij hoog water nodig. Om uiteindelijk toe te werken naar een model die een indicatie kan doen van de faalkans (op sub-dijkvak schaal) op basis van de hydrologische randvoorwaarden, moet er zeer precies, doch efficiënt, worden gerekend.

Onderzoeksverdeling

Het onderzoek is opgedeeld in een viertal secties:

Gevoeligheid van 2D dijk- en ondergrondgeometrie voor het bereiken van kritieke poriedrukken

In deze eerste analyse wordt op basis van mogelijke geometrie (helling, dijkhoogte, deklaagdikte) en materiaaleigenschappen (cohesie, doorlatendheid) een gevoeligheidsanalyse uitgevoerd. Het doel is om te ontdekken in hoeverre een samenspel van deze factoren effect heeft op de poriedrukken in en onder de dijk met behulp van hydrologische modellering. Dit wordt vervolgens gerelateerd aan de faalkansen van een dijk, betreffende laterale afschuiving en macrostabiliteit.

Verschillen in hydrologie en dijkstabiliteit tussen 2D en 3D schematisering

Voor verschillende hypothetische en werkelijke situaties zal met behulp van hydrologische modellen de verschillen in poriedrukken tussen 2D en 3D schematisering worden bepaald. Het doel is om de situaties te ontdekken waarin deze sterk afwijken. Een dergelijk onderzoek zal ook gedaan worden voor verschillende case-studies.

Het gebruik van hydrologische en geofysische methoden voor grondwaterrespons metingen

Tijdens de modellering is het belangrijk om deze modellen te verifiëren met gemeten data. Hiervoor is een hoogwatermeetplan opgesteld. In geval van hoogwater zal met conventionele (peilbuizen, drukmeters) en geofysische methoden de grondwaterrespons worden bepaald, en in een later stadium gemodelleerd.

Restabilisatie en hydro-mechanische feedback bij dijkstabiliteit

Door een hydrologische situatie (hoge poriedruk) kunnen de mechanische bodemparameters veranderen (opheffing). Dit heeft dan weer effect op de hydrologische situatie. Dergelijke terugkoppelingen kunnen ervoor zorgen dat een nieuw stabiel evenwicht ontstaat. Een gekoppeld hydrologisch-mechanisch model zal worden ontwikkeld dat hier rekening mee kan houden.

Voorlopige resultaten

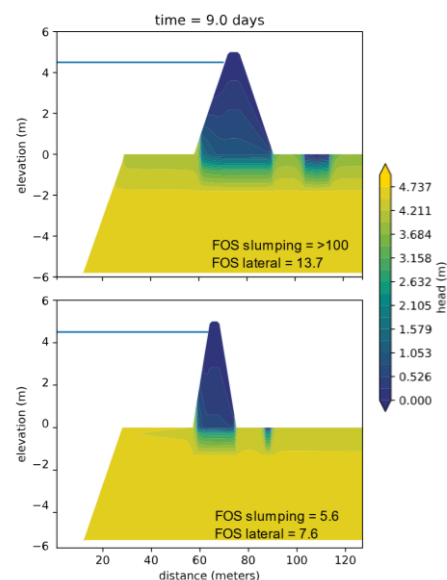
De voorlopige resultaten bestaan uit een gekoppeld grondwater en stabiliteitsmodel, die in staat is om efficiënte en nauwkeurige berekeningen uit te voeren voor een groot aantal dijk- en ondergrond geometrieën. Hiermee is de stabiliteit van een groot aantal variaties berekend (Figuur 2). Momenteel worden deze resultaten geanalyseerd, en wordt hieraan een tijdsafhankelijkheid toegevoegd. Daarnaast is een eerste versie van het 3D grondwatermodel in de testfase.

Output

-

Samenwerkingen

Betreffende de grondwaterrespons zijn samenwerkingsprojecten geïnitieerd met All-Risk onderzoeker Juan Chavez Olalla en het waterschap Rivierenland. Betreffende de 2D-3D verschillen is er contact met de waterschappen HDSR en Drents Overijsselse delta.



Figuur 2; Effect van dijkgeometrie en management (bemaling) op poriedrukken en dijkstabiliteit.

Heterogeneity in subsoil geophysical measurements of the subsurface

Juan Chavez Olalla

Practical information

University	Delft University of Technology
Supervisors	Prof. dr. T.J. Heimovaara; dr.ir. D.J.M. Ngan-Tillard & dr. R. Ghose
AllRisk project	C
Duration	From 15-09-2017 to 15-09-2021

Introduction

Several failure mechanisms of primary and secondary embankments and dikes are related to the structure and properties of the subsurface underlying the dike. Current predictive models rely on average subsurface properties and do not account fully for spatial heterogeneity, resulting in large uncertainties in safety estimates. The general objective of this project is to improve current estimates of dike safety, considering several key failure mechanisms and incorporating multi-method geophysical input regarding subsurface heterogeneity distribution underneath a dike. The scientific goals of this project are as follows:

- Demonstrate the added value of using low-cost geophysical techniques during dike inspections in order to detect potential problems;
- Show the potential of combining Electrical Resistivity Tomography (ERT), Ground Penetrating Radar (GPR) and seismic methods to detect and map suspected weak zones under a dike;
- Take advantage of the state-of-the-art shallow seismic and radar methods in order to map the architecture of the dikes and their foundation layers;
- Inventorize a set of geophysical methods which is likely to provide the necessary subsurface information and the spatial resolution up to a required depth of investigation, for a given geology and a mode of dike failure;
- Develop an approach to integrate (multi-method) geophysics into a probabilistic site investigation framework and translate it to geotechnical models.

Research approach and method

Numerical simulations of geophysical responses were carried out initially. Electric Resistance Tomography (ERT), Ground Penetrating Radar (GPR) and seismic wave propagation models were created in order to simulate data acquisition and test processing schemes. These simulations are the cornerstone of this research, for they allow to assess the sensitivity of geophysical methods to geological architecture in dikes. Moreover, these simulations provide a robust framework to interpret field data in terms of geological layering.

Research activities

Field investigation has been carried out at an old sand channel. Although this case study is not located in the vicinity of a dike, the underlying geology is similar to a large number of dikes prone to piping in the Netherlands. This case allows to test geophysical methods and validate data interpretation via cores and samples. At this test site, as opposed to an actual dike, a large disturbance of the soil is permitted. The geophysical investigation will be extended to an actual dike in the coming months.

Results up to now

Geophysical exploration was carried out at an old sand channel belt in Montfoort (Figure 1) in order to study piping susceptibility due to geological architecture.

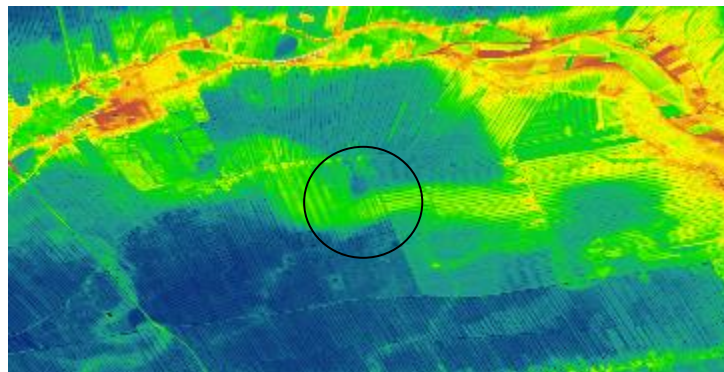


Figure 1. Old-river channel (lidar view)

The geophysical data shows good agreement with prior geological knowledge (geotop and boreholes). Moreover, geophysical data shows the extent of spatial variability with the added benefit of low disturbance of the ground. Electrical Resistivity Tomography, Ground Penetrating Radar, Seismic reflection, and Frequency Domain Electromagnetics were applied. Due to the geological architecture of shallow old river channels, ERT shows finer details of the geological setting (Figure 2) than other geophysical methods.

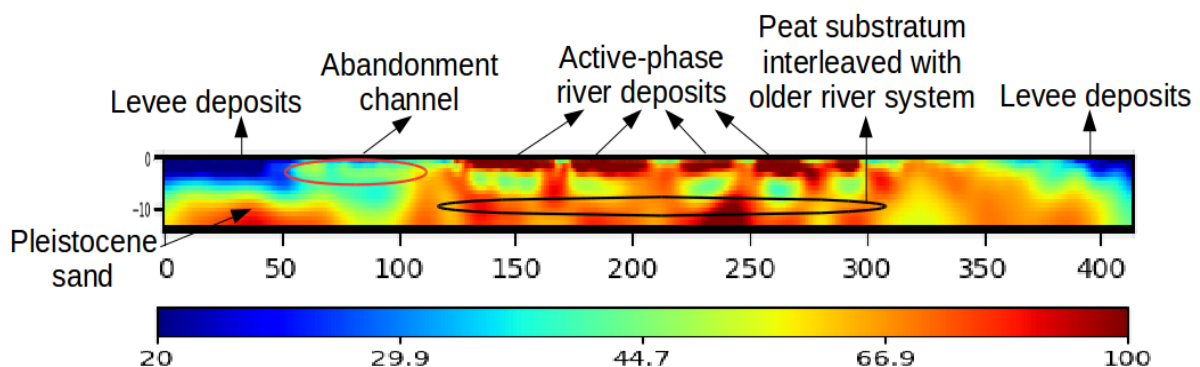


Figure 2. Electrical Resistivity Tomography

Geophysical data will be further validated via cores and grain size distribution. Moreover, synthetic the field data is to be compared to numerical simulations in order to assist interpretation.

Output

The results from the Montfoort case study will be presented in a journal paper.

Interactions

The Montfoort case study is carried out in collaboration with Utrecht University. At this moment, the project is in search of a case study in the vicinity of a dike.

Random Material Point Method for dykes

Guido Remmerswaal

Practical information

University	TU Delft
Supervisors	Prof. dr. Michael A. Hicks, Dr. Phil J. Vardon
AllRisk project	D
Duration	From 1-9-2017 to 1-9-2021

Introduction

With the new 'Waterwet' flooding, with serious consequences, is supposed to be considered as the new Ultimate Limit State (ULS) of a flood defense (or dyke). However, inner slope instability is often assumed to directly result in flooding, ignoring the potential residual dyke strength, 'reststerkte' in Dutch. This additional strength is often ignored, as it is difficult to 'guarantee' the presence of residual dyke strength, with the limited large deformation modelling capabilities currently available, especially within the (semi)-probabilistic framework. Taking into account the residual dyke strength can lead to more efficient designs (or assessments) and will allow dyke improvements to be focused on dykes with the highest probability of flooding, instead of the highest probability of inner slope instability. The goal of this research is to further develop the Material Point Method (MPM), a numerical model based on the Finite Element Method (FEM) which can deal with large deformations. MPM will be then used to estimate the residual dyke strength, based on the process between an inner slope instability and flooding (which can be modelled with MPM).

Research approach and method

The research approach is to further develop and use MPM, such that it is capable of estimating the residual dyke strength. As MPM is a relatively new method improvements are still necessary in order for the method to be applicable for dykes. Moreover, variability of the soil properties have a large impact on the expected failure surface with inner slope instability. Residual dyke strength is dependent on the shape of the failure surface, as a failure surface intersecting the crest is more likely to have a lower residual dyke strength compared to a failure surface through the inner slope. Also the process after inner slope instability is dependent on the variability of soil parameters. In order to include the effect of soil variability, Random MPM has been developed, which similar to Random FEM, can determine the effect of soil variability on failure processes. With Random MPM it will be possible to determine the probability of flooding given a probability of initial slope failure, i.e. it will determine the effect of residual dyke strength on the probability of flooding.

Research activities

To improve the applicability of MPM for dykes, several improvements must be made to MPM. MPM simulations tend to be influenced significantly by numerical oscillations, as errors are likely to occur when large deformation which are computed. Improvements are to be developed, together with other researches working on MPM at the TU Delft, to reduce these numerical errors. Moreover, special treatments must be further developed to deal with boundaries in MPM, as this is not trivial when compared to FEM. For example, a special treatment is necessary at the boundary between soil and water on the outer slope of the dyke. Furthermore, MPM will be extended from 2D to 3D, as it is currently uncertain how the process behaves after inner slope instability in three dimensions.

Random MPM will be used to compute the effect of residual dyke strength on the probability of flooding. The results from MPM and Random MPM in 2D and 3D will be compared to more conventional methods, for example Limit Equilibrium Method (LEM), FEM and Random FEM. In order to compute small failure probabilities, the efficiency of Random MPM must be improved. This

will definitely involve using the grid computing service provided by SURFsara, and potentially will involve subset-simulation or combining FEM with MPM to reduce computational costs. Finally, for proper 3D MPM simulations, parallel programming will be required, as the computational costs of 3D MPM with enough accuracy will be too high for a single processor.

Results up to now

Together with Leon Gonzalez Acosta, the accuracy of MPM has already been improved significantly by reducing most of the oscillations which occur at large deformations. With these improvements combined with a newly developed boundary condition, which is capable of applying an external water load to a dyke in MPM, the first dyke simulations have been performed using Random MPM. The extension of the program from 2D MPM to 3D MPM has also been started, but due to the large computation cost only low accuracy simulations have been performed with 3D MPM.

Two failures computed with 2D Random MPM are shown in Figure 1: A inner slope instability occurs in Figure 1a, but the dykes residual strength prevents retrogressive failure and thereby flooding; A similar inner slope failure occurs in Figure 1b, which due to a weak layer at the bottom of the dyke causes a horizontal sliding mechanism to occur, resulting in ULS failure of the dyke.

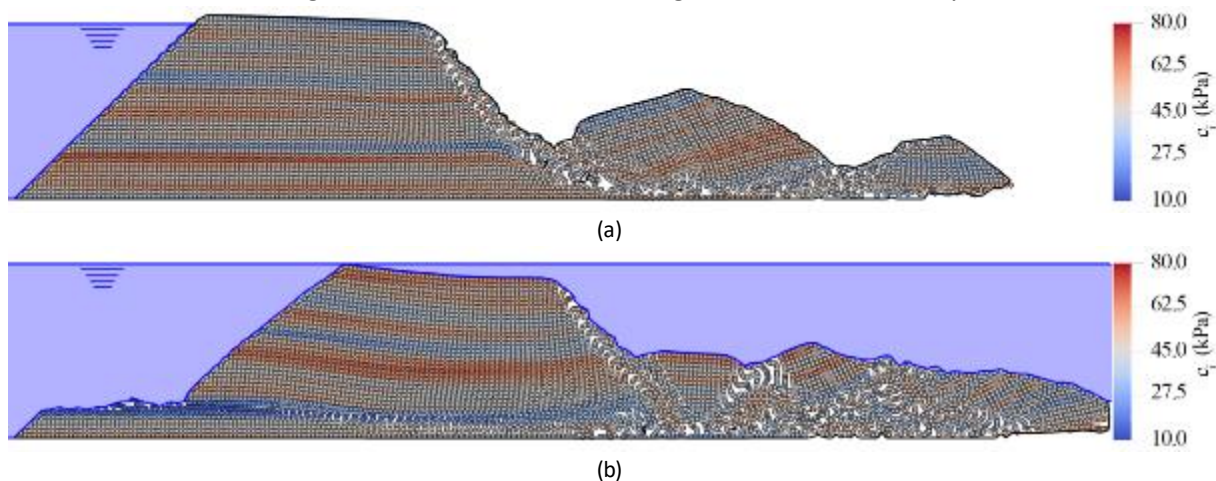


Figure 1: Two RMPM simulations a) no ULS failure; b) horizontal failure mechanism causing ULS failure.

This simulation, and especially the 3D simulations, have been performed at high probabilities of failure, to indicate the capabilities of this technique. In future analysis, by performing these analysis on a grid computing system, i.e. a system with much more computing power than a single computer, similar studies will be performed at lower probabilities of failure. These lower failure probability simulation, when compared to more conventional methods such as LEM and FEM, should present us with tools to take the effect of residual dyke strength on the probability of flooding into account.

Output

A book chapter containing the explanation of Random MPM in more detail, together with 2D and 3D example simulations of dykes:

Remmerswaal, G., Hicks, M.A., and Vardon, P.J. (2019) Slope reliability and failure analysis using random fields. In Fern, J. et al. (Eds.), The Material Point Method for geotechnical engineering. A practical guide. Washington D.C, USA, CRC Press: Taylor & Francis Group.

Interactions

Once Random MPM has been applied for smaller failure probabilities, user friendly methods (requiring less computation cost) can, and most likely will, be developed or modified to take residual dyke strength into account (methods similar to the 'zoneringsmethode').

Time-dependence piping and interactions

Joost Pol

Practical information

University	TU Delft
Supervisors	prof. S.N. Jonkman, prof. M. Kok, dr. W. Kanning,
AllRisk project	D
Duration	From September 2017 to March 2022

Introduction

In both the reliability assessment and design of flood defences, we use simplified models to describe the failure processes. However, these models are often conservative in the calculation of the reliability. For example, in piping assessments we use a steady state assumption although the process in fact is time dependent and can take several days to complete. Another example is that we assess failure mechanisms separately, although the beginning of one failure mechanism may influence another one. The goal of the research project are (1) to quantify the time dependent processes of backward erosion piping and their impact on the reliability assessment, and (2) to investigate the possibilities and benefits of including interactions between failure mechanisms.

Research approach and method

With respect to time-dependence, the majority of the work will be on piping. Together with the flood duration, the pipe progression rate determines the time-dependent resistance against piping. Therefore, this progression rate is the focus of this research. It is studied in small and large scale experiments with varying soil properties and hydraulic loading. Subsequently, both the pipe progression and the flood duration are incorporated in a probabilistic safety assessment of a primary flood defence in The Netherlands to show how it contributes to dike safety.

Interactions between mechanisms are studied using a case study of the Grebbedijk, in cooperation with Rijkswaterstaat, Deltares and HKV. Focus will be on the possibilities of probabilistic methods to quantify these interactions, such as event trees, simulation methods and FORM.

Research activities

The main activities are:

- Analysis of existing laboratory and field data on the progression rate of piping
- Experimental quantification of the progression rate of piping
- Large scale test to validate the progression rate
- Development of a framework to include time dependence in backward erosion piping reliability analysis.
- Failure mechanism interaction case study

Results up to now

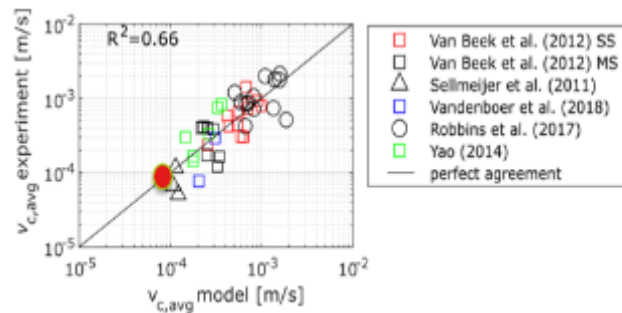
Progression rates in existing experiments

For a first prediction of the progression rate, existing backward erosion piping experiments from various researchers were analyzed. The results show that the order of magnitude of the progression rate can be predicted by the hydraulic gradient and the hydraulic conductivity (figure below). These predictions were also applied in a probabilistic safety analysis of river and sea dikes. Results show that including the progression rate can decrease the failure probability with several orders of

magnitude in sea dikes. For river dikes, the effect on failure probability is much smaller, but it can still delay the moment of failure with several days.



(1a) top view of small scale piping experiment



(1b) progression rate in existing experiments

Large scale experiment

The progression rate was also studied in a full scale dike constructed at Flood Proof Holland. The average rate (about 10 m/day) agrees with expectations based on the existing experiments. It is also shown that the pipe cross section was much larger than is observed in small scale tests, which implies that one should be careful to relate sand boil volume to pipe length or level of criticality.



(2) Large scale piping experiment in Flood Proof Holland

Output

Conference proceedings:

- Pol, J., Van Beek, V., Kanning, W., & Jonkman, S. (2019). Progression rate of backward erosion piping in laboratory experiments and reliability analysis. In J. Ching, D. Li, & J. Zhang (Eds.), *7th international symposium on geotechnical safety and risk*. Taipei, Taiwan.
- Yagisawa, J., van Damme, M., Pol, J., & Bricker, J. (2019). Verification of a predictive formula for critical shear stress with large scale levee erosion experiment. In *11th icold european club symposium*. Chania, Crete.

Interactions

Currently, Rijkswaterstaat, Deltares and HKV are actively involved in the research project through the 'Faalpaden' project and the experimental research on piping. From the 3rd year of the research, it will be useful to work with other users such as water authorities on the application of the knowledge in dike assessments at specific locations.

Incorporating past performance and Service Limit States

Mark van der Krogt

Practical information

University	Delft University of Technology
Supervisors	Matthijs Kok, Timo Schweckendiek
AllRisk project	D
Duration	From 01-09-2017 to 01-09-2021

Introduction

Reliability estimates of dikes are usually dominated by large uncertainty in soil parameters. One way to reduce the uncertainty and improve the reliability estimates is by incorporating information of the performance of dikes. Examples of such *performance information* is a survived load or monitoring of the behaviour. This research focuses on incorporating this performance information into reliability estimates of the slope stability, using Bayesian methods. The goal is develop and use these methods in order to improve safety assessments and designs.

Research approach and method

Methods that will be used in the research are: Bayesian Updating (Bayes, 1763), Decision Analysis (Raiffa & Schleifer, 1961), Probabilistic methods (Monte Carlo, FORM, and possibly more advanced techniques such as Subset Simulation or Metamodelling.) Case studies of real and fictive situations will be used as the main research method to answer the research questions.

Research activities

The research plan is split into 4 parts:

1. Uncertainty in a spatial average parameter, when using a transformation model to indirectly estimate soil properties. This research particularly focusses on the averaging of variability and measurement and transformation errors.
2. Incorporating survival of the construction stage in the reliability estimate for flood loading. Furthermore, explore possibilities how to take advantage of this improved reliability in a design or assessment.
3. Slope reliability updating with multiple types of performance data (survival, several types of monitoring, e.g. settlements, pore water pressures)
4. Reinforcing dikes using the Observational Method: optimizing dike design while using survival of the construction stage(s), several different types of monitoring and a contingency plan.

Results up to now

Below, the main findings are summed:

- The propagation of uncertainty into the spatial average parameter has been studied, when we estimate undrained shear strength from cone resistance measurements. A method has been proposed to estimate the uncertainty in the spatial average undrained shear strength, particularly focusing on the role of averaging of all spatially variable error components. The main finding is that if a considerable share of the measurement and transformation errors is random or spatially variable, the uncertainty estimates for spatial average parameters can be considerably lower compared to methods proposed earlier, and hence, characteristic values can be considerably higher.
- Furthermore, we investigated the impact on the reliability estimate, by incorporating construction survival (i.e. no instability during the construction) into reliability assessments

and designs. The construction of new dikes and dike reinforcements can be the critical loading condition for slope stability, see Figure 1. Although the loading conditions 1, 2 and 3 are not entirely the same, the failure mechanism is similar between the loading conditions. Surviving the construction should tell us something about the minimum strength along the potential slip planes. Since the uncertainty in soil properties is typically due to a lack of knowledge (e.g. because little soil investigation), we can reduce uncertainty and improve reliability estimates. We found that incorporating construction survival in probabilistic analyses can significantly improve reliability estimates. For newly built dikes on soft soil blankets, the a-posteriori failure probability (with construction survival) was a factor 2-1000 lower than the a-priori failure probability (without construction survival). This will lead to fewer dikes that do not comply with the statutory safety standards, hence fewer dike reinforcements are necessary. So, incorporating survived construction not only improves reliability assessments, it also leads to lower costs of flood protection.

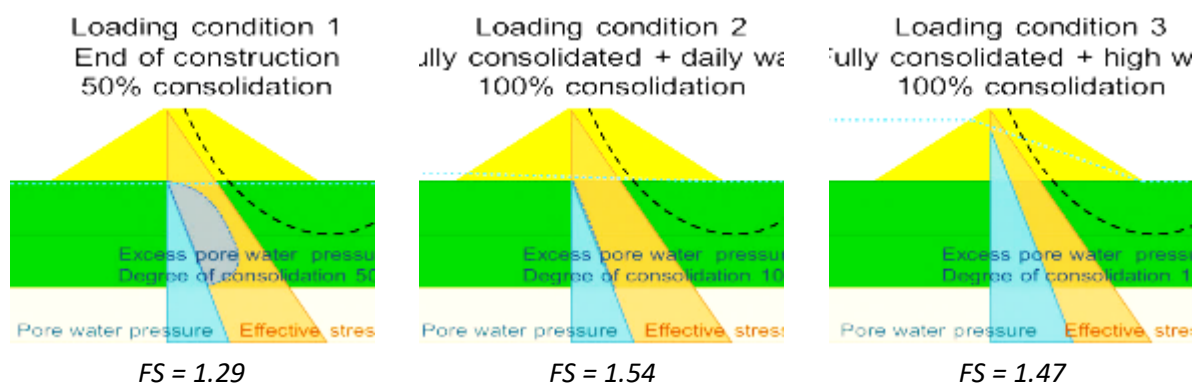


Figure 1: Stability FS (Factor of Safety) at the end of the construction can be lower than the stability at high water conditions.

Output

- Journal articles
 - Van der Krogt, M.G., Schweckendiek, T., Kok, M. (2018) Uncertainty in spatial average undrained shear strength with a site-specific transformation model”). Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards. <https://doi.org/10.1080/17499518.2018.1554820>
- Conference papers
 - Van der Krogt, M.G., Schweckendiek, T., Kok, M. (2019) “Do all dike instabilities cause flooding? 13th International Conference on Applications of Statistics and Probability in Civil Engineering, Seoul, South Korea.
 - Van der Krogt, M.G., Schweckendiek, T. (2019) Systematic Transformation Error in the Depth-Average Undrained Shear Strength. 7th International Symposium of Geotechnical Safety and Risk, Taipei, Taiwan. (submitted)

Interactions

The main findings and possible utilization possibilities are:

- When a large if a considerable share of the measurement and transformation errors is random or spatially variable, the uncertainty estimates of indirectly measured soil properties can be considerably lower compared to methods proposed earlier, and hence, characteristic values can be considerably higher.
- The construction of dikes on soft soils is a critical situation for slope stability, in some cases even more critical than a high water load. Survival of the construction can therefore be used to improve reliability estimates. Anticipating on survival of the construction of a dike

reinforcement could be particularly interesting for dike reinforcements with a lack of space, where otherwise expensive structural solutions (such as sheet pile walls) are required.

- The potential savings must outweigh the additional risk and cost of control measures, because during the construction you expose the structure to a (more) critical load. In fact, this is the interpretation of the Observational Method (Eurocode 7) for dike reinforcements.

Interactions with users:

- Presented the findings of ‘incorporating construction survival’ at Vakdag Actuele en Bewezen sterkte and the geo-unit at Deltares.
- Furthermore, discussed the utilization possibilities of ‘incorporating construction survival’ with Alliantie Markermeerdijken, Waterschap Rivierenland, and Brabantse Delta.

The influence of berms, roughness and oblique waves on wave overtopping at dikes

Weiqiu Chen

Practical information

University	University of Twente
Supervisors	Suzanne Hulscher, Jord Warmink, Marcel van Gent
AllRisk project	D
Duration	From 27.09.2017 to 01.10.2021

Introduction

With the background of enhanced hydraulic loads due to climate change, sea level-rise and land subsidence, there will be an increasing risk of coastal flood disasters all over the world. Dikes are important coastal structures in the flood defense system protecting infrastructure and people in the coastal areas from storm attack. Wave overtopping is often used to determine the crest level and cross-section geometry of dikes by ensuring that the average overtopping discharge is below acceptable limits. Hence, a reliable prediction of the average overtopping discharge is highly important.

The amount of wave overtopping is affected by berms, roughness and oblique waves that are parameterized as influence factors in empirical overtopping formulae. The combination of these factors has not been validated systematically and therefore the goal of this research project is to investigate the influence of the combination of the various influence factors on the predicted wave overtopping by performing physical model tests and numerical modelling.

Research approach and method

The combined influence of a berm and roughness on wave overtopping is studied by conducting physical model tests and numerical modelling. New formulae will be developed for berm and roughness influence. Furthermore, the new formulae will be extended to take the influence of oblique waves into account by analyzing the experimental data from 3D physical model tests. Finally, an improved method of estimating the combined influence of berms, roughness and oblique waves on the overtopping discharge will be developed. This method will be applied and validated for a case study, like Afsluitdijk.

Research activities

In this project 2D physical model tests have been carried out, systematically varying the seaside configuration and revetments in order to study the influence of combinations of a berm and roughness transitions on overtopping discharge. A numerical model as applied by Jacobsen et al. (2015) is being validated and applied to further investigate the combined effects of a berm and varying roughness along the slope.

Results up to now

New empirical formulae are derived from the analysis of the experimental data in order to provide more accurate estimations of the berm influence and roughness influence on the reduction of the wave overtopping discharge. Additionally, a new formula is developed to estimate the reductive influence of varying roughness along the waterside slopes with a berm. The new equations show a significantly better performance within the tested range when compared with existing formulae for

the average overtopping discharge (Figure 1). A paper has been submitted to *Coastal Engineering* in March 2019.

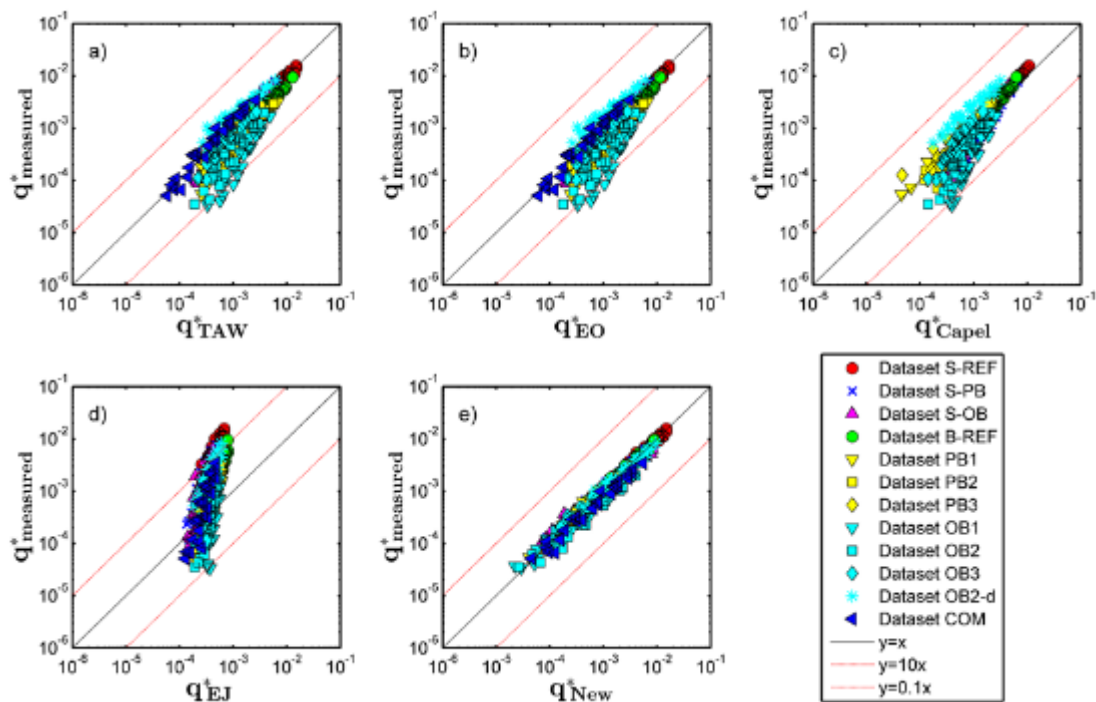


Figure 1 Comparison between measured dimensionless overtopping discharges and calculated values by using a) TAW (2002), b) EurOtop (2018) (EO), c) Capel (2015), d) Etemad-Shahidi and Jafari (2015) (EJ) and e) modified methods (New).

Output

- Chen, W. (2019). Study of wave overtopping of flood defences: Literature report. Enschede
- J.J. Warmink, V.M. Van Bergeijk, W. Chen, J.P. Aguilar-Lopez, A. Bomers, S.J.M.H. Hulscher (2018), Modelling wave overtopping for flood defense reliability. Proceedings 3th international conference on Protection against Overtopping, 6-8 June 2018, Grange-over-Sands, UK, pp 1-5.
- Warmink, J. J., Van Bergeijk, V. M., Chen, W., Van Gent, M. R. A. & Hulscher, S. J. M. H., (2018). Modelling wave overtopping for grass covers and transitions in Dike Revetments. International Conference Proceedings of Coastal Engineering. 1, 36, p. 53 7 p.
- van Bergeijk, V. M., Chen, W., Warmink, J. J., van Gent, M., & Hulscher, S. J. M. H. (2018). Wave overtopping on dikes: The effect of transitions on the flow and dike cover erosion. *ConcepTueel*, 27(3), 32-35.

Interactions

The predictive formulas developed in the project can be used to estimate the efficiency of reinforcement measures to confirm that limiting tolerable discharges are not exceeded. For example, applying roughness elements on parts of the seaward slopes is one way to reduce the overtopping discharge. However, most of the existing overtopping predictors are limited to one type of revetment on the slopes. The methods proposed in this project can deal with varying roughness along the seaward slope and give some information on the optimal location and combination of the roughness elements, which can save costs.

Modelling the effects of transitions on wave overtopping flow and dike cover erosion

Vera van Bergeijk

Practical information

University	University of Twente (UT)
Supervisors	Jord Warmink, Suzanne Hulscher
AllRisk project	D
Duration	From 01/10/2017 to 01/10/2021

Introduction

Wave overtopping is one of the main failure mechanisms of dikes. The introduction of multifunctional flood defenses results in an increase of transitions on dikes, such as a roughness transition from grass to asphalt in case of a road. Numerical models and experiments have shown that transitions are weak spots for dike cover erosion by overtopping waves. However, no suitable method exists to include the effects of transitions on dike failure. Transitions influence the flow and erosion downstream, thus, it is important to model the flow and the erosion depth along the entire dike cross-section. The goal of this project is to develop a model for the wave overtopping flow and dike cover erosion that takes the effects of transitions into account. The model can be used to find the weakest point along the dike profile to optimize dike design.

Research approach and method

In this project, two models are developed: an analytical model and a detailed hydrodynamic model. New analytical formulas for the wave overtopping flow velocities are developed (Van Bergeijk et al., 2019) and coupled to an erosion model that is adapted for transitions. This analytical model is computational fast and easy adjustable, so the erosion depth can be calculated for a wide range of dike configurations and several storms scenarios. Currently, the analytical model is extended to calculate the probability of failure for a river dike in the Netherlands.

To improve our knowledge on the erosional processes at transitions, a detailed hydrodynamic model is developed in the open source software OpenFOAM. This model simulates the overtopping flow as a function of time in the cross-dike and vertical direction. Currently, the modelled flow is compared to data of overtopping experiments. In the future, the model will be coupled to an erosion model and the results of the detailed model will be used to further improve the analytical model.

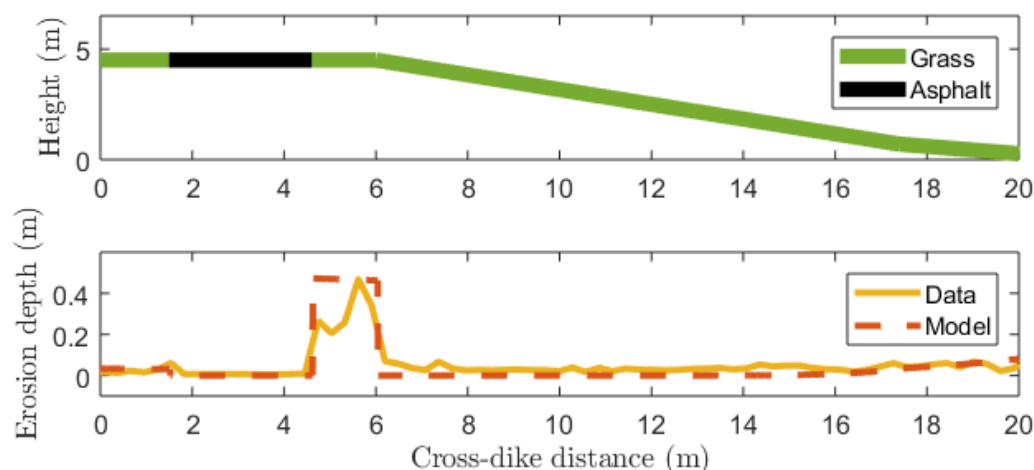


Figure 4: Comparison of the measured and modelled erosion depth using the analytical model for a grass-covered dike with an asphalt road on top of the crest.

Results up to now

The analytical flow model was validated with measurements of several overtopping experiments (Van Bergeijk et al., 2019). Next, the model is coupled with an erosion model and validated using a case study of a grass-covered river dike with an asphalt road on top of the crest (Figure 1). The model is able to accurately simulate the large erosion depth at the transition from asphalt to grass. The model is applied to the Afsluitdijk and several other dikes by master students at Witteveen +Bos and the UT. The results look promising and currently we are developing new formulations for the erosion parameters to make the model generally applicable without site-specific calibration.

Parameterizations for the turbulence parameter are not required for a more detailed hydrodynamic model that accounts for the effects of turbulence. The detailed hydrodynamic model calculates the overtopping flow velocity along the dike as a function of time and depth and shows good agreement with the hydrodynamic measurements (Figure 2). Other possible output parameters of the model are the bed shear stress and the pressure, which can be used as input for existing erosion models. The next step is to validate the model with other data sets and with pressure measurements.

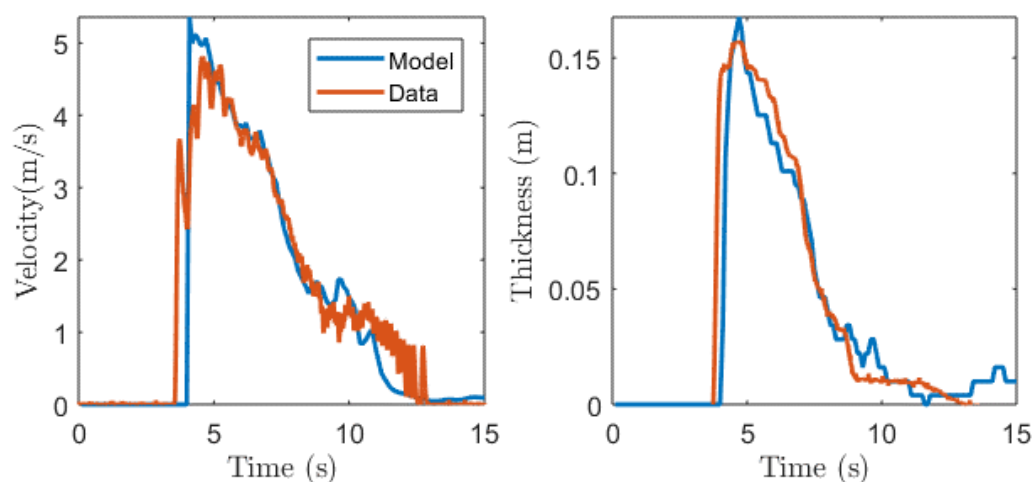


Figure 5: Comparison of the detailed hydrodynamic model with measurements of the maximum flow velocity (left) and the layer thickness (right) over time.

Output

- Van Bergeijk, V. M., Chen, W., Warmink, J. J., van Gent, M., & Hulscher, S. J. M. H., (2018). Wave overtopping on dikes: The effect of transitions on the flow and dike cover erosion. *ConceptTueel*, 27(3), 32-35.
- Van Bergeijk, V. M., Warmink, J. J., van Gent, M. R., & Hulscher, S. J.M.H., (2019). An analytical model of wave overtopping flow velocities on dike crests and landward slopes. *Coastal engineering*, 149, 28-38.
- Warmink, J. J., Van Bergeijk, V. M., Chen, W., Van Gent, M. R. A. & Hulscher, S. J. M. H., (2018). Modelling wave overtopping for grass covers and transitions in Dike Revetments. *International Conference Proceedings of Coastal Engineering*. 1, 36, p. 53 7 p.

Interactions

I am collaboration with Mark van der Krogt and Guido Remmerswaal (PhD Students in project D) to investigated the residual strength of dikes and the interaction between the failure by wave overtopping and macro-stability. The analytical model is used to determine the probability of failure by wave overtopping as a function of the water level. These failure probabilities are used in the failure definition for macro-stability to assess the residual strength of a dike after the first slide and to determine a combine failure probability both wave overtopping and macro-stability.

Performance-based design of sheet piles in levees

Arny Lengkeek

Practical information

University	TU Delft
Supervisors	prof.dr.ir. Bas Jonkman, dr.ir. Ronald Brinkgreve & dr.ir. Wim Kanning
AllRisk project	D
Duration	From 9-2017 to 9-2020

Introduction

In the national Flood Protection Programme, the Regional Water Authorities and the Ministry for Infrastructure and the Environment jointly take action (e.g. through levee reinforcements) to ensure that the Dutch flood defences satisfy the legal safety requirements. A frequently applied measure in densely populated areas to improve the levee stability under flood conditions and uplift conditions is the installation of a sheet pile wall (“damwand”). With this relatively expensive technique, houses, buildings and other values can be saved. An important motivation for keeping these strict requirements is, that real experience and reliable insight in the actual behaviour of a structurally reinforced levee under rarely occurring high water loading and downstream uplift conditions is missing. This is in particular the case due to the relatively high Dutch safety standards. Consequently, validation of the ultimate strength and deformation behaviour of this type of levee in the FEM calculation model is a knowledge gap. The research concerning sheet pile wall reinforcement is based on the hypothesis, that more insight into the actual behaviour in the EEMdijk test and the FEM modelling of the sheet pile reinforced levee will result in an improved definition of deformation performance criteria and ultimate failure, better definition of the reliability and more cost-effective design.

Research approach and method

The research will focus on parameter determination, critical state theory and constitutive models for FEM and finally the interpretation of the Eemdijk full-scale field test and validation with FEM models.

1) Investigation of Critical State Theory and SHANSEP theory.

The aim of the study is to determine the unique relation between effective stress parameters and undrained shear strength. This has been studied for a conventional Modified Cam Clay model and an advanced SClay-1 model. Both models are based on typical isotropic triaxial tests. In practice other test like 1D Oedometer and K0-TX or DSS are applied, which actually better reflects the conditions in the field. Currently a student (Tiemen Wegman) is doing his MSC on this topic and performing laboratory tests at Deltares. The planning is to write a publication Q3/Q4 of 2019 when all laboratory tests are finished.

2) Investigation on correlations for organic soils.

The aim of this study is to determine the unique properties of organic soils as encountered to a large extend in The Netherlands. Databases with field and laboratory test have been collected from various levee strengthening projects, partly making use of the STOWA data sheets. The following parameters have been collected: Unit weight, Water content, Organic content, Compression ratio, Consolidation coefficient, Effective friction angle, Normally consolidated S-ratio, Overconsolidated undrained shear strength. The relation between these parameters is further investigated and illustrated in figure. In addition, the key parameters are correlated to the CPT measurements: cone resistance, sleeve friction, pore pressure and calculated parameters such as qnet, Ic etc. Finally, an

alternative concept for the cone factor is proposed (under development) in order to reduce the error in the current approach. The planning is to write a publication Q2/3 of 2019 when all data has been processed. Some results are attached in the appendix.

3) Evaluation of sheet pile behavior based on Eemdijk monitoring data.

The aim of this research was check if the fiber-glass strain gauge measurement are reliable to be used for the research and to find alternative ways to verify the sheet pile forces and deformations in the Pull-over test of Eemdijk. The study has been performed together with MSc student Friso Meijer. Conclusions are formulated with respect to the plastic capacity and the edge effect which are useful for engineering practice. Furthermore an alternative method based on SAAF measurements and numerical 4-points bending tests has been successfully applied to determine the sheet pile forces. The planning is to write a publication Q4 of 2019.

Results up to now

On subject #1:

A new model has been worked out to describe this stress path and determine the unique relation between effective stress parameters and undrained shear strength. The model only requires five soil parameters and three state parameters. In addition, it can also account for anisotropy in a simplified manner and calculates the anisotropic undrained strength ratio for triaxial compression and extension. With this model actual TXCU laboratory tests can be back calculated and evaluated. It also improves the determination of the S-ratio by defining it in terms of effective strength parameters. The model can be downloaded from the google Appstore [SHANSAPP].

On subject #2:

All data has been processed but not yet published.

On subject #3:

The test results have been published in conferences, the interpretation will be published.

Output

- H.J. Lengkeek J. de Greef S. Joosten 2018 CPT based unit weight estimation extended to soft organic soils and peat, CPT2018, Delft.
- Lengkeek, H.J., Naves, T., Post, M., Bredeveld, J. 2019a. Eemdijk full-scale field test programme: sheet pile pullover tests. Proceedings, ECSMGE 2019 Congress. Reykjavik.
- Lengkeek, H.J., Post, M., Bredeveld, J. Naves, T. 2019b. Eemdijk full-scale field test programme: ground dike and sheet pile dike failure test. Proceedings, ECSMGE 2019 Congress. Reykjavik.
- Bredeveld, J., Zwanenburg, C., M. Van, Lengkeek, H.J. 2019. Impact of the Eemdijk full-scale test programme Proceedings, ECSMGE 2019 Congress. Reykjavik.
- Floris Besseling, Arny Lengkeek, Huig de Waard, Kees Nieuwenhuis. Ice actions for hydraulic structures of primary flood defense Afsluitdijk - "Applying ISO 19906 at home", POAC 2019, Delft.
- https://www.researchgate.net/profile/Hj_Lengkeek
- <https://orcid.org/0000-0003-4181-9090>

Interactions

Frequent interaction has taken place with the POVVM and various HWBP projects. Furthermore the following students are involved with the research:

Understanding cross-sector collaboration in flood risk management: the case of National flood protection programme in the Netherlands

Emma Avoyan

University	Radboud University Nijmegen
Supervisors	Sander Meijerink, Peter Ache
AllRisk project	E
Duration	May 2017 - April 2021

Introduction

The Netherlands is protected against coastal and river flooding by a flood defense infrastructure built over centuries. The infrastructure, consisting of primary and secondary dikes, storm barriers and dunes, requires regular maintenance, upgrade and adaptation to changing climate and socio-economic conditions. Recently, the Dutch government has introduced new safety standards for primary flood defense systems by taking into account the predictions regarding further climate change and socio-economic development. It is expected that more than 50% of the primary flood defenses have to be reinforced to meet the new safety standards.

The National Flood Protection Programme (NFPP) has been launched to accomplish this task by realization of innovative reinforcement measures. In addition to dike reinforcement, the NFPP assigns exploration of integrated “smart combinations” to link and combine flood safety with other societal goals, such as spatial quality and sustainability. The exploration of linking opportunities entails intensive collaboration between different levels of government, sectors and interested parties. However, cross-sector collaboration is neither easy nor always effective. Public authorities increasingly face demands for results: cost-effective creation of public value. Although the NFPP provides time, necessary resources and institutional capacity for collaboration and exploration of efficient integrated measures, joint decision-making process raises number of coordination issues. Combining the flood protection agenda with its own funding and procedural arrangements with the regional spatial development agenda or with other sectoral agendas is still a challenge in the Netherlands. Ambiguous actor responsibilities and rigid governance arrangements across sectors often challenge the effectiveness and efficiency of collaborative process. Moreover, the current flood safety institutional arrangements and procedures stand by traditional, strongly legalized policies being designed based on unilateral approach to flood prevention, rather than a collaborative approach to flood risk management (FRM).

This PhD project aims at assessing the challenges and benefits of cross-sector collaboration. Studying particularly the exploratory phases of dike reinforcement projects in the Netherlands, the research ultimately supports the NFPP by providing recommendations on institutional and procedural arrangements for achieving effective, legitimate and collaborative implementation of the new safety standards.

Research approach and methods: historical analysis, two case-studies and survey research

The first step of this project is to analyze how cross-sector collaboration within flood risk governance in the Netherlands has evolved over time, and how this development can be explained. The analysis synthesizes the literature on Dutch FRM to illustrate the impact of external conditions in shaping past and present dynamics of cross-sector collaboration for integrated FRM in the Netherlands. It traces the extent to which policy and legal frameworks, socio-economic circumstances, political realities, power relations as well as situations of conflicts have influenced the attempts of collaboration between flood safety, spatial planning, environmental protection and other sectors.

The second step of this PhD project follows with an in-depth examination of two case-studies: Grebbedijk and Varik- Heesselt. These project cases having both intensive collaborative exploratory phases are examined for the organization and the main output (preferred alternative) of collaborative exploratory process. The integrative framework for collaborative governance is used as an analytical tool to study the cases as collaborative governance regimes with the involved formal/informal sectors as regime participants. The collaborative process is studied by analyzing the principled engagement (behavioral interaction between the participants), shared motivation (interpersonal and relational components of interaction process) and capacity for joint action (cross-functional elements of establishing institutional arrangements and consolidating knowledge and resources). The analysis distinguishes between two levels of analysis: (1) the participant level, and (2) the collaborative governance regime (i.e. project) level. At the participant level, the study measures the extent to which participants gain net organizational benefits and improvements attributable to the project participation as well as the extent to which they are satisfied with the collaborative process. At the collaborative governance regime level the study measures the project's external legitimacy as well as the extent to which collaborative process and actions are consistent with the project's preset intentions.

And finally, the last step of this project entails a survey research. It is planned to survey formal participants of dike reinforcement projects with completed or ongoing exploratory phases. The objective of the survey research is to study the extent to which the attributes of collaborative process of exploratory phases influence the effectiveness and efficiency of process output (preferred alternative) as well as satisfaction of participants with the process and its outcome. It will be tested which components of collaboration most affect the quality of preferred alternative and its expected impact of the local environment. Ultimately, the results of the survey combined with the findings of the previous steps of this research will result in recommendations on improving the effectiveness, efficiency and legitimacy of collaborative exploratory phases of dike reinforcement projects in the Netherlands.

Results and publications so far

This PhD project entails a paper-based (4 scientific papers in total) dissertation. The *first paper* titled: "Cross-sector collaboration within the Dutch flood risk governance: historical analysis of external triggers" is being accepted for publication by the International Journal of Water System Development. The results of this analysis indicate that there is a noticeable trend towards enhanced cross-sector collaboration in the Dutch FRM in which flood safety measures are being connected to other issues such as spatial planning and ecological development. Currently, necessary time, resources and institutional capacity are provided to explore innovative smart combinations as well as alternatives to dike reinforcement. However, cross-sector collaboration can develop as long as it does not compromise flood safety. "Safety first" is a continuous factor in the Netherlands. What has changed is the arsenal of strategies used. The FRM includes not only technical infrastructure, but also river restoration, room for the river, and in some cases multi-layer flood safety measures, which increase the dependencies between policy sectors.

The *second paper*, the working title of which is "Measuring the process performance of collaborative governance regimes: case of Grebbedijk project in the Netherlands" is now well in advance stage of writing to be submitted to the Environmental Science and Policy international journal.

Utilisation possibilities

The findings of this research contribute in sharing knowledge and experiences between dike reinforcement projects' management and participants. In depth understanding of the challenges and opportunities of collaborative exploratory phases would also help corresponding authorities decide upon attributes of cross-sector collaboration to prioritize for effective and legitimate implementation of the new safety standards.

Implementation of A Risk-based Approach in the HWBP

Monica Lanz en Willemijn van Doorn-Hoekveld

Practical information

University	Universiteit Utrecht, departement Rechtsgeleerdheid
Supervisors	prof. dr. H.F.M.W. van Rijswick, mr.dr. H.K. Gilissen
AllRisk project	E
Duration	1-11-2017 to 31-10-2022

Introduction

The introduction of a risk-based approach in Dutch flood risk management (FRM), including its inherent uncertainties and innovations, gives rise to legal questions, such as issues about the scope and division of responsibilities, the interrelations between relevant actors, the coordination of relevant legal regimes, enforcement, monitoring and inter-administrative supervision, and liability and compensation (see www.starflood.eu; Kaufman et al., 2016). The central question is how the risk-based approach and its related innovative solutions can effectively be implemented within the current/future FRM framework, respecting its specific institutional and instrumental features.

Research approach and method

Subproject E1 applies a combination of research methods. The traditional legal research method, which comprises qualitative thematic analysis of primary and secondary sources (legislation, explanatory memoranda, policy documents, case law, literature) will be combined with action research (through internships at end users, explorative and evaluative expert and stakeholder meetings and/or focus group sessions) in order to specify (practically) relevant issues and test the feasibility of research findings and recommendations. In order to foster the integration between the four work packages (projects A to D), an interdisciplinary assessment method will be developed and applied in a number of thematic cases derived from these work packages.

Research activities

The main scientific challenge is to implement the risk-based approach and related innovations within the broader flood risk governance arrangement (FRGA) due to its specific legal challenges and tensions. Innovative solutions ask for a degree of flexibility, whilst at the same time legal certainty should be provided. Finding a balance between flexibility and certainty ask for legitimate, transparent and proportionate implementation; it should comply with the rule of law and international legal requirements; and should guarantee an high and equal level of safety to all.

To meet these comprehensive requirements, a structured interdisciplinary evaluation framework must be developed, applied and tested. This framework will build upon the assessment method developed by part of the consortium members (Van Rijswick and Kok, 2014), the design principles for FRGA (www.starflood.eu), and water governance principles (OECD 2015). The evaluation framework will subsequently be applied in a number of thematic cases. The results of these applications will be at the basis of conclusions and recommendations for the implementation of the risk-based approach within the Dutch FRGA in a practically feasible manner.

Results up to now

Up to now the researchers advised various end-users. In this way the E1 project tends to integrate cases derived from work packages (A-D) with the implementation of the a risk-based approach.

The advice for the POV Voorlanden resulted in a legal document (*Juridisch Achtergronddocument Voorlanden*) and the researchers contributed to the *Handreiking Voorlanden*.

Furthermore, the researchers advised the Dutch Water Authorities regarding the new safety standards in relation to the coming Environmental and Planning Act (*Omgevingswet*).

In addition, the researchers advised regional water authority Noorderzijlvest regarding the responsibilities of different public authorities (regional water authority, Rijkswaterstaat and the province of Groningen) in an innovative project, the *Dubbele Dijk*.

With another end user, SoppeGundelachWitbreuk Advocaten, they organized an interactive workshop during the Dijkwerkersdag addressing the challenges of nature conservation legislation and the possibilities of the programmatic approach, that the Netherlands Commission for Environmental Assessment introduced.

Output

- H.K. Gilissen, F.A.G. Groothuijse, W.J. van Doorn-Hoekveld & H.F.M.W. van Rijswijk, 'De nieuwe systematiek van veiligheidsnormering voor primaire waterkeringen: niet eenvoudiger, wel beter', *Tijdschrift voor Bouwrecht* 2017/142.
- W.J. van Doorn-Hoekveld, H.K. Gilissen, F.A.G. Groothuijse, H.F.M.W. van Rijswijk, 'Je maintiendrai! Met de wettelijke normering van waterveiligheid in Nederland', *Tijdschrift voor Omgevingsrecht en Omgevingsbeleid* 2019:2, p. 155-164.

Interactions

- The interaction with users resulted in several advices for the POV Voorlanden, the Dutch Water Authorities and the regional water authority Noorderzijlvest.
- Legal Workshop: 'Working in N2000-areas and dike-reinforcement'. Case: Wide Green Dike (*Brede Groene Dijk*).
- Coming year, an evaluation framework will be developed. During the creation of the framework, input is asked from stakeholders and researchers of the projects A-D.
- From the 4th year of the research, E1 will integrate the project by applying the developed evaluation framework in several thematic cases. Therefore, it will be valuable to work with users such as regional water authorities and other stake holders.

Joint knowledge production in the implementation of new risk standards in the HWBP

Martijn van Staveren

Practical information

University	Wageningen University
Supervisor	prof. dr. Simon Bush (earlier prof. dr. ir. Jan van Tatenhove)
AllRisk project	E
Duration	From 9-2017 to 2-2020

Introduction

The governance of the transition towards the new risk approach in flood defence design and management requires a focused attention on joint knowledge production and knowledge exchange between various stakeholders in flood risk management. These concern, inter alia, ecological and safety aspects of innovative coastal engineering approaches, interactions between spatial and engineering measures, and the integration of functions around flood defences. The central aim of this subproject is to facilitate the implementation of the new risk approach in the Flood Protection program by reflecting on the production of scientific knowledge, the involvement of various stakeholders, and the political dimension of water-related knowledge. Both scientific knowledge and the experiential knowledge of practitioners is in constant flux. This dynamic situation requires well-organized processes of knowledge production, dissemination and learning, while the implementation of the risk approach may require new forms of knowledge integration, both between scientific disciplines and policy sectors. This project should result in “knowledge arrangements”, tuned to contribute to improved flood risk management.

Research approach and method

This research consists, in line with other subprojects in the E working package, of typical social sciences methods: interviews, observation, document analysis. A case study approach is adopted to provide detailed insights from actual projects. Literature on participatory processes, governance studies and the use of knowledge in environmental (including water) policy serves as a primary basis.

Results up to now

Research on one of the case studies (Grebbeidijk, Wageningen) is ongoing. In particular it highlights the central role of landscape architects/environmental designers in flood risk management knowledge: as an interface between ‘technical’ knowledge as provided by engineering consults and hydraulic experts on the one hand, and tacit or ‘soft’ knowledge provided by various stakeholders during participatory processes.

Output

- Van Staveren, M.F. Dike Relocation from an Environmental Policy Perspective 2019. P.181-185. In: Nature-Based Flood Risk Management on Private Land. Disciplinary Perspectives on a Multidisciplinary Challenge. Editors: Hartmann, Thomas, Slavikova, Lenka, McCarthy,
- Karen I. Sudmeier-Rieux, Hans Juergen Boehmer, Alejandro Casteller, Lucy Emerton, Daniel A. Friess, Michael Hagenlocher, Stephen Galvin, Carmen Lacambra, Peter Laban, Wolfram Lange, Brian G. McAdoo, Christine Moos, Jaroslav Mysiak, Udo Nehren, Fabrice G. Renaud, Pascal Peduzzi, Simone Sandholz, Louise Schreyers, Zita Sebesvari, Pieter Van Eijk, Martijn Van Staveren, Marta Vicarelli: Ecosystems for disaster risk reduction: what do we know? *Submitted to Environmental Research Reviews*
- Student supervision and articles in progress: 1) use of climate knowledge in mainstreaming adaptation in Dutch municipalities and 2) procedural justice in flood risk management

