Correlation impact in piping erosion for safety assessment of multi-functional flood defences

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Introduction

Adaptation to climate change is one of the main concerns for cities in deltaic areas. For a country such as the Netherlands where two thirds of the land are located under sea level, reliability of the flood defence system is a top priority. Flood defences are exposed to different deterioration processes (*also known as failure mechanisms*) which might compromise the water retaining capacity during a flood event. In the state of the art of safety assessment for flood defences, a failure mechanism known as "Piping erosion" is considered one of the most probable and uncertain threats for the Dutch dike system. This type of failure consists in the formation of longitudinal cavities in aquifers located underneath the foundation of flood defences. This type of failure is one of the challenges that planners and engineers must cope with when high reliable flood defence systems are conceived.

Multifunctional flood defences are one of the many solutions proposed for urban areas, where factors such as sea level rise, global warming and demographic explosion are the main concerns in future planning. In principle, the addition of extra functions and the strengthening of the existent flood defence system will signify an increase in the dimensions such as height and width (Fig 1.)

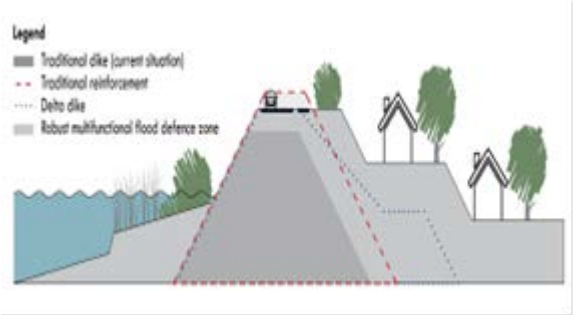

Figure 1. Dimension variation in representative cross section for the different multifunctional flood defence proposed solutions. (extracted from van Loon-Steensma and Vellinga (2014)).

In longitudinal systems designed by the probabilistic approach, the correct assumption of the different statistical parameters and their correlation is one of the main sources of uncertainty. If the model used to assess the occurrence of the failure mechanism is highly sensitive to errors in the estimated statistical parameter, the final design can either be unsafe or over dimensioned.

Correlation between statistical parameters is a source of uncertainty that is often neglected during probabilistic assessments, because determining its degree and topology can be a difficult task. The present study shows that if sufficient data is available, correlation between different parameters should be taken into consideration for achieving an optimal cost effective design for piping failure mode.

Correlation effect

Correlation effects in flood safety assessments have been studied in the past. However, they mostly considered the possible relationship between water related parameters (Diermanse and Geerse, 2012) or the effect of spatial autocorrelation (*Length effect*) of piping associated variables (Kanning, 2012). For safety assessment of piping failure mechanism of multifunctional flood defences, the possible correlation that might exist between grain size and hydraulic conductivity, might change the estimated failure probability by orders of magnitude. If that is the case, the investment required for such a large system can be unbearable for a government to finance.

Methodology

Using bivariate correlation models (fig. 2), different degrees of dependence where induced during a probabilistic Monte Carlo failure estimation for the piping failure mechanism. The revised Sellmeijer limit state equation was used (Sellmeijer, et al. 2011). This method was repeated for different flood defence widths. The method was tested in a hypothetical case study which preserves real order of magnitude values of the statistical parameters used for the safety assessment in the Netherlands. A global sensitivity analysis is performed in order to

estimate how much of the failure function variance is explained by the combined effect of the correlated variables.

The estimated cost of the required defence for different degrees of correlation given a fixed required failure probability is calculated in order to illustrate the error cost of neglecting the correlation effect.

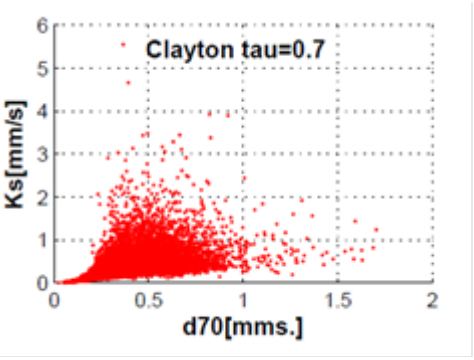

Figure 2. Bivariate clayton copula model for particle diameter versus hydraulic conductivity (Aguilar López, et al., 2013)

Results

After assuming a bivariate model that represents the possible topology of the correlated variables it can be observed that the actual Dutch assumption of low degree of correlation can be quite conservative. Structures with required low failure probabilities such as multifunctional flood defences can be over dimensioned if correlation is not taken into account during the probabilistic assessment.

Future work

Further research will include the bivariate model selection and correlation degree estimation for a real case study.

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References

Aguilar López, J. P., Warmink, J. J., Schielen, R. M. J., and Hulscher, S. J. M. H. (2013). "Flood defence design parameters correlation influence on failure probability - Case study of piping (Paper)." *3rd IAHR Europe Congress - Water Engineering and Research* Porto, Lisbon.

Diermanse, F. L. M., and Geerse, C. P. M. (2012). "Correlation models in flood risk analysis." *Reliability Engineering & System Safety*, 105(0), 64-72.

Kanning, W. (2012). *The Weakest Link: Spatial Variability in the Piping Failure Mechanism of Dikes*, TU Delft, The Netherlands.

Sellmeijer, J., López de la Cruz, J., van Beek, V., and Knoeff, H. (2011). "Fine-tuning of the backward erosion piping model through small-scale, medium-scale and IJkdijk experiments." *European Journal of Environmental and Civil Engineering*, 15(8), 1139-1154.

van Loon-Steensma, J. M., and Vellinga, P. (2014). "Robust, multifunctional flood defenses in the Dutch rural riverine area." *Nat. Hazards Earth Syst. Sci.*, 14(5), 1085-1098.