Robust inversion under uncertainty for risk analysis – application to the failure of defences against flooding

CHARLIE SIRE
École des Mines de Saint-Étienne, IRSN, CNRS LIMOS

Supervisor(s): LE RICHE Rodolphe (CNRS, LIMOS (Mines St-Etienne and UCA)), RULLIERE Didier (CNRS, LIMOS), RICHET Yann (IRSN), PHEULPIN Lucie (IRSN), ROHMER Jérémy (BRGM)

Ph.D. expected duration: Sept. 2020 - Sep. 2023

Adress: 1 rue Gager Gabillot 75015 Paris

Email: charlie.sire@irsn.fr

Abstract:

The risk of coastal or fluvial flooding is aggravated by the failure of defences (either natural like dunes or artificial like dykes). The study of flood hazard on the Dutch River System illustrates this [2], as do several events that occurred in the last decade such as the hurricane Katrina in 2005 in New Orleans [4]. The failure of defences is a factor of flooding risk whose importance will keep increasing in the future because of climate change. Our analysis of coastal and river flooding takes into account the following variables:

- Controlled variables, related to the geometry and location of the flood protection embankments.
- Uncontrolled variables capturing the randomness of natural phenomena, such as hydrograph parameters for river flooding and offshore hydrodynamic conditions (e.g wave characteristics). These variables have known probabilistic laws.
- Drastically uncertain variables, that are uncontrolled and not well characterized neither probabilistically nor in regulations. They are related to the dyke breach parameters.

In this work, we investigate a mathematical procedure based on inversion to characterize the possible combinations of controlled parameters (named excursion set, see Figure 1) that lead to flooding with a probability greater than a given threshold α, a standard safety limit.

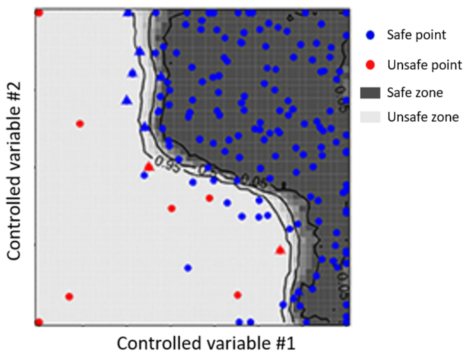

Figure 1: Example of an excursion set in two dimensions [3], with isocontours indicating the probability to be an unsafe point according to the metamodel

If the flooding event is defined as the water level at a specific location, modelled as the result of a function F, exceeding a threshold T, the probabilistic excursion set to be investigated can be defined as $\mathrm{S}_\alpha = \{x_c,\ P(F_{x_c} > T) > \alpha\} = \{x_c,\ q_{1-\alpha}(F_{x_c}) > T\}$, where F_{x_c} is a random variable giving the water level at a specific location for a combination of controlled parameters equal to x_c.

Several questions are addressed:

1. First, how to represent excursion sets when there are more than two controlled variables and some uncertain variables do not have a known density. Parallel coordinates plots are considered and the relationship between the probabilistic excursion set S_α and the random excursion set $S(X_u) = \{x_c,\ F_{x_c}(X_u) > T\}$ (where X_u represents the uncontrolled variables) is theoretically investigated.
2. Second, the numerical simulations of the flooding are expensive to compute (typically several hours): metamodeling techniques (mainly kriging aka Gaussian Process) combined with active learning [1] specifically designed to the estimate of the excursion set are used to reduce the computational cost. The idea is to replace the numerical simulations with an inexpensive surrogate model, that interpolates a few simulations points which are iteratively chosen to reduce uncertainty in the identification of the excursion set.
3. Third, the inversion needs to be robust in the sense that it needs to consider the random nature of the uncontrolled variables. We generalize previous studies that dealt with uncontrolled variables through a worst-case scenario [3] by considering rare events, as the threshold α previously introduced must be very small.
4. Fourth, the drastically uncertain variables need to be integrated in the probabilistic framework. Thus, the inversion will be combined with an optimisation to investigate here the worst-case scenario, ie the scenario leading to the highest probability of flooding.

References

[1] J. Bect, D. Ginsbourger, L. Li, Picheny, V., and E. Vazquez. Sequential design of computer experiments for the estimation of a probability of failure. *Statistics and Computing*, 22(3):773–793, 2012.

[2] A. Curran, K. M. De Bruijn, W. J. Klerk, and M Kok. Large scale flood hazard analysis by including defence failures on the dutch river system. *Water*, 11(8):1732, 2019.

[3] Yann Richet and Vito Bacchi. Using an inversion algorithm for the optimization of civil defense against flooding: application to bi-dimensional numerical model of the garonne river. *Frontiers in Environmental Science*, 2019.

[4] G. L. Sills, N. D. Vroman, and Schwanz N. T. Wahl, R. E. Overview of new orleans levee failures: lessons learned and their impact on national levee design and assessment. *Journal of Geotechnical and Geoenvironmental Engineering*, 134(5):556–565, 2008.

Short biography – My 3 years at Ecole Centrale de Lyon and especially my Master Degree in Mathematics and Risk Engineering, combined with my one-year experience as a Data Scientist in the cranes industry, has given me a strong motivation to keep studying mathematics and statistics applied to industrial problems. Thus, my current PhD is part of the research-industry consortium CIROQUO that aims at gathering academical and technological partners to work on problems involving costly-to-evaluate numerical simulators for uncertainty quantification, optimization and inverse problems. Funding is shared between IRSN and BRGM.