Titre de la thèse : Robust inversion under uncertainty for risk analysis – application to the failure of defences against flooding

Résumé : 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 (Curran et al, 2019), as do several events that occurred in the last decade such as the hurricane Katrina in 2005 in New Orleans (Sills et al, 2008). 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) that lead to flooding with a probability greater than a given threshold α, a standard safety limit. 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 $S_\alpha = \{x_c, P(F_{x_c} > T) > \alpha\} = \{x_c, Q_{1-\alpha}(F_{x_c}) > T\}$, where F_{x_c} is a random variable giving the water level at a specific location for a combination of controlled parameters equal to xc.

Several questions are addressed:

1. First, the numerical simulations of the flooding are expensive to compute (typically several hours): metamodeling techniques (mainly kriging aka Gaussian Process) combined with active learning 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.

2. Second, 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 (Richet, Bacchi, 2019) by considering rare events, as the threshold α previously introduced must be very small.

3. Third, 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.

4. Fourth, how to vizualise the random flooding event. Showing flooding maps, describing the water depth at several location in a chosen zone, is a relevant way to communicate with decision makers and urban planners, and the idea here will consist in providing them with a set of best "representative flood maps" i.e. the maps that best represent the probability law associated to the flooding event.