Value of Information in Levee Monitoring and Inspection

Dr.ir. Timo Schweckendiek
Department of Hydraulic Engineering, Delft University of Technology

Objectives

The aim of this poster is to provide a glance of how value of information concepts can provide decision support in the realm of flood risk management, flood defenses and levees. The concepts and results presented here have been published elsewhere and should not be considered as original contributions.

The most relevant failure mechanisms for flood defenses – besides overtopping – are of geotechnical nature (e.g. slope stability, internal erosion). The uncertainties in the relevant ground properties are usually large, certainly when compared to structural engineering. Additional information from inspection (site investigation) or monitoring of a levee system's response to loading can make much of a difference in safety assessment as well as in reinforcement designs. However, quantitative guidance site investigation and monitoring planning is lacking.

This poster highlights recent approaches to provide methods to quantitatively underpin the impact of information from site investigation and monitoring on the reliability (estimate) of levees and the value of information in terms of expected savings in reinforcement costs.

General approach

The approach to quantifying the value of information in levee monitoring and site investigation followed here is based on **Bayesian decision analysis**. In the Dutch context, where the approach was developed, the basic requirement for flood defenses is an acceptable probability of flooding (i.e. failure of the flood defense). Levees not meeting the reliability target need to be reinforced. Uncertainty reduction by means of monitoring and site investigation can lead to cost savings in these reinforcement efforts, sometimes reinforcement can even be avoided by being able to show that a levee is safe after all.

In this context, the decision problem becomes a **constrained optimization problem**. The optimal decision is determined by the **minimum expected total cost** to meet the **reliability target**. The total cost consists of two main components, namely the cost of inspection or monitoring and the cost of retrofitting. The a-priori uncertain outcomes of the monitoring or site investigation and their effects on the reliability (estimate) can be accounted for through pre-posterior analysis. A typical workflow to do such analysis for site investigation problems is illustrated in the figure below.

The **definition of the value of information (VoI)** in the given context is the difference of the a-priori needed retrofitting cost minus the expected (pre-posterior) total cost, similarly we can define a benefit –cost ratio (BCR):

$$saving = a\ priori\ retrofitting\ - preposterior\ retrofitting$$
$$VoI = saving\ - inspection$$
$$BCR = \frac{saving}{inspection}$$

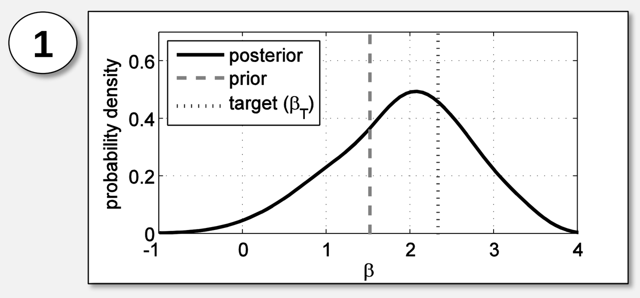
Applications and results

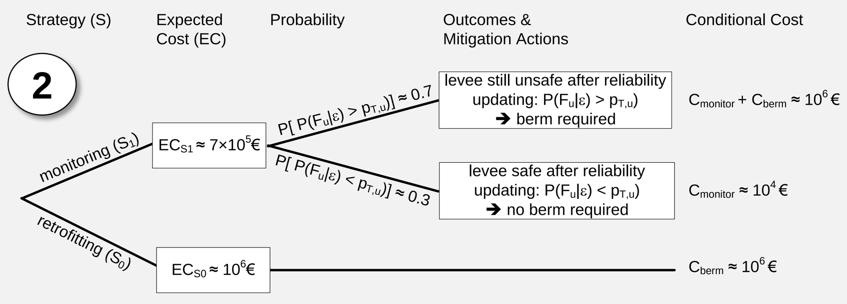
The examples below illustrate the type of typical results obtained from Bayesian Updating and VoI-analysis for river dikes and levees with respect to geotechnical failure mechanisms (here: internal backward erosion). For detailed discussions refer to Schweckendiek (2014b).

Monitoring (pore water pressures) [1,2]

A major uncertainty in the assessment of dikes and levees is the pore pressure response in the structure and its foundation to loading from increased outside water levels (e.g. river water levels during floods). This uncertainty can be reduced significantly by monitoring the pore pressure response .

Figure 1 is the result of a pre-posterior analysis, displaying the pre-posterior distribution of the reliability index after incorporating (uncertain) future monitoring results. The wide range of beta-values reflects the high degree of uncertainty in subsoil conditions typical in geotechnical engineering. In the given example, there is roughly a 30% chance that the posterior reliability will be higher than the target value (probability mass of the right-hand side of the dotted line), in which case the levee would be safe and no retrofitting necessary. The decision tree of this simplified example in figure 2 shows the difference in expected costs per decision option, which can be easily expressed in terms of VoI and BCR as indicated.



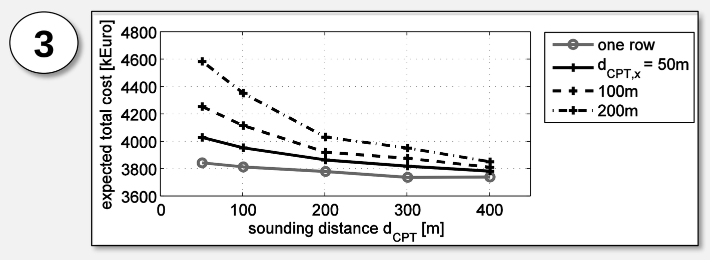


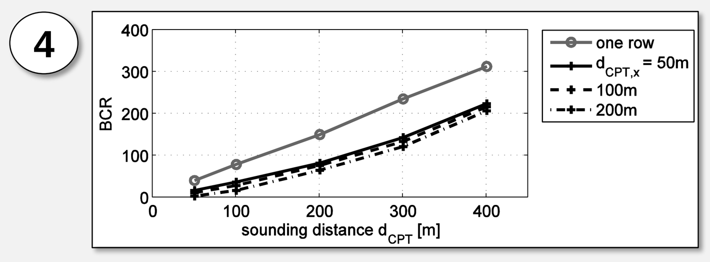
Inspection / site investigation (Cone Penetration Tests) [3,4,5]

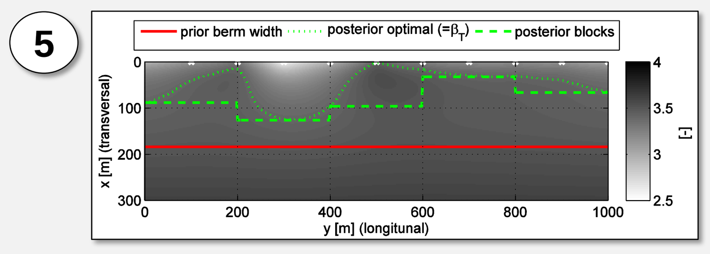
The second example is on the optimization of the sampling grid in a site investigation using Cone Penetration Tests (CPT) to (geostatistically) map the thickness of a land-side blanket layer, which is a very important parameters for uplift, heave and piping mechanisms.

Figures 3 and 4 show the expected total cost (expected retrofitting plus site investigation) over the sounding (or sampling) distance in two directions. For the particular example treated here it could be shown that one row of soundings would be enough (as opposed to two or several rows) and that the optimal distance would be around 300 to 400 meters. Notice that the BCR for these options is very high with values between 200 and 300, implying that the expected savings outweigh the cost of the CPT campaign by far.

For an impression of how savings are realized, Figure 5 shows a top view of the a-posteriori required levee berm width (i.e. levee toe line on top) as compared to the a-priori needed width (red line). Notice that the major contribution of the expected savings comes from the possibility of not needing a berm at all a-posteriori, implying that also the mobilization cost can be saved.

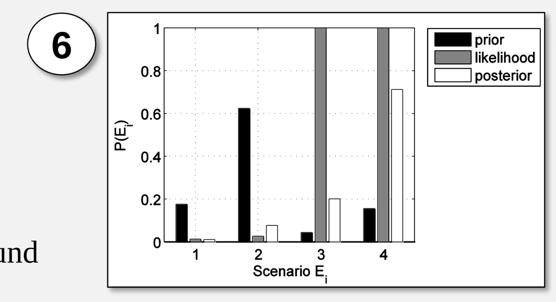


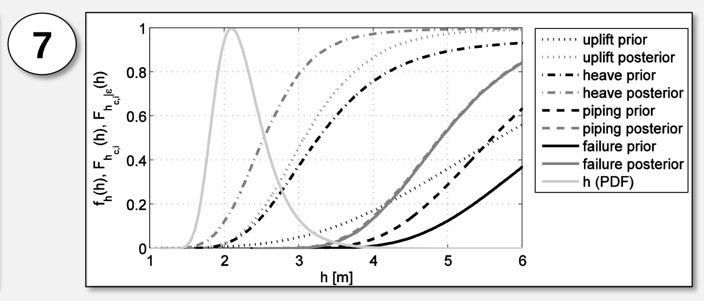


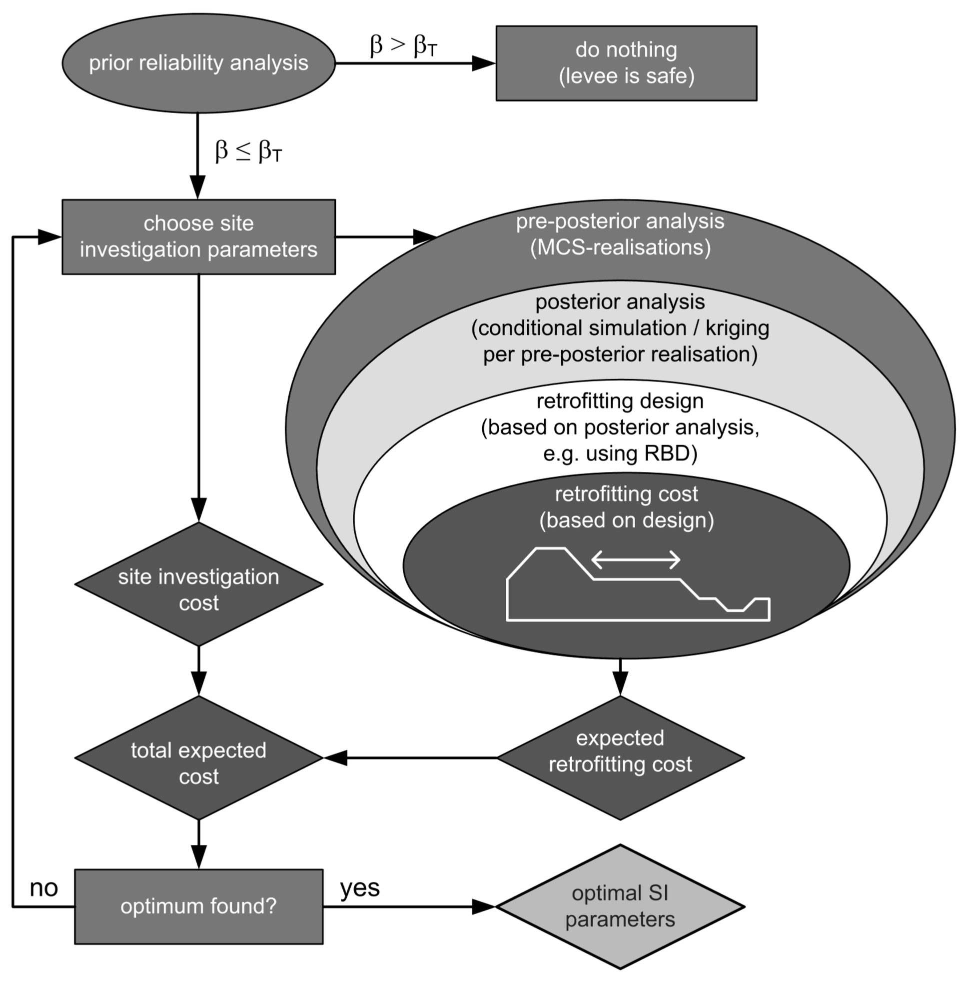


Survived loads ("load test") [6,7]

Often coastal dikes and river levees have already experienced considerable loading during storms and floods. This information can be used for reliability updating and for more efficient retrofitting designs. Figures 6 and 7 show how the information of an observed sand boil (i.e. bad performance) can be used to update the probability of subsoil scenarios (potential states of the ground conditions) or the fragility curves of different failure mechanisms respectively.







Conclusions and outlook

The cost effectiveness of investments in uncertainty reduction can be assessed by comparing the expected (pre-posterior) costs (to reach a pre-set reliability target) of different strategies with different types of site investigation and monitoring, incl. no monitoring or inspection at all. In the presented approach, the consequences of failures are only treated implicitly through the reliability target. Such an approach is more accessible to practitioners than a fully risk-based approach, but also has drawbacks (see Schweckendiek, 2014b).

Examples reported in the selected references have shown that the value of information can be very high, if the prior uncertainties are large, as is very typical in geotechnical engineering.

Future work in the theoretical domain should focus on the combination of multiple sources of information and on the analysis of staged strategies. Most importantly, besides theoretical developments, VoI-approaches need to be made more accessible for practitioners by providing guidance and simple tools.

For more information on current projects and research activities visit:
http://www.hydraulicengineering.tudelft.nl/

Selected references

Schweckendiek, T., & Vrouwenvelder, A. C. W. M. (2015). Value of Information in Retrofitting of Flood Defenses. Proc. of Applications of Statistics and Probability in Civil Engineering (ICASP 12), Vancouver, Canada, in press.

Schweckendiek, T., & Vrouwenvelder, A. C. W. M. (2013). Reliability Updating and Decision Analysis for Head Monitoring of Levees. Georisk, 7(2), 110–121.

Schweckendiek, T., Vrouwenvelder, A. C. W. M., & Calle, E. O. F. (2014a). Updating piping reliability with field performance observations. Structural Safety, 47, 13–23. doi:10.1016/j.strusafe.2013.10.002

Schweckendiek, T. (2014b). On Reducing Piping Uncertainties - A Bayesian Decision Approach. Department of Hydraulic Engineering. Delft University of Technology, Delft.

Schweckendiek, T., Gelder, P. H. A. J. M. van, & Calle, E. O. F. (2011). On risk-based geotechnical site investigation of flood defenses. Proc. of Applications of Statistics and Probability in Civil Engineering (ICASP 11), Zurich, Switzerlanc, pp. 1700–1708.

Contact information

Dr. ir. Timo Schweckendiek
Department of Hydraulic Engineering
Delft University of Technology
Stevinweg 1, 2628CN Delft, The Netherlands
E: t.schweckendiek@tudelft.nl, M: +31641777283
nl.linkedin.com/in/tschw/en