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A systematic approach to improve reliability of storm surge barrier closures

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Coastal defenses must be upgraded to combat increasing flood risk due to climate change and other factors. Storm surge barriers, large movable hydraulic structures that close temporarily during storm surges to prevent coastal floods, play a vital role in protecting estuaries. Due to the complexity of their risk analyses, important improvements are sometimes overseen. Our objective is to develop a systematic approach which is more likely to find these important improvements. We tested the method to three historic cases where important improvements were initially overlooked. We anticipate that our method can be applied to other safety systems with a large number of failure modes as well.

Keywords: Climate change adaptation, risk reduction measures, coastal flood, safety system.

1. Why adapt storm surge barriers?

Increasing coastal flood risk is caused by climate change, growing populations, and the value of assets in coastal zones (Hallegatte et al., 2013). In the regions they protect, a failure to close the barrier is often the most likely cause for such a catastrophic flood (Mooyaart et al., 2023). To adapt to the rising coastal flood risk, reducing the probability of a failed barrier closure is a promising strategy (Fig. 1). However, the failure to close consists of over a thousand potential failure modes with similar (low) probability. As a result, dominant failure factors and important improvements are sometimes overseen. We propose a systematic approach which is more likely to incorporate these important improvements. To develop this approach we 1) explore dominant failure factors and 2) propose a comprehensive list of principle improvements.

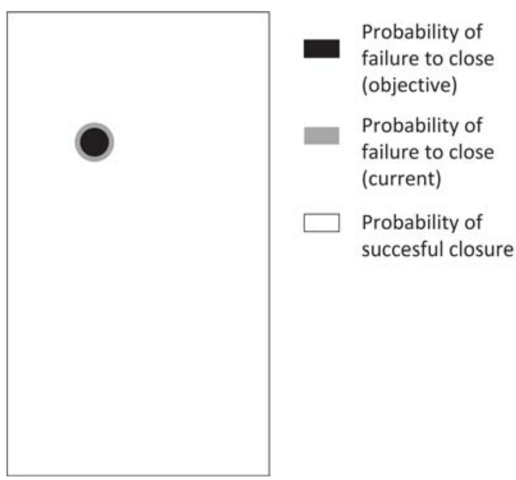

Fig. 1. Venn diagram with a current probability of non-closure of 1/100 on demand and a probability of non-closure objective of 1/200 on demand

2. Dominant failure factors

In the Netherlands, the probability of a failed closure is assessed using large fault trees. Well-known methods such as sorting minimal cut-sets and importance measures often result in long lists of failure modes with a similar probability. Several scientists (e.g Cheok et al., 1998; Borgonovo and Apostolakis, 2001) recognize the importance of grouping to find dominant failure factors. However, no literature was found how to best group failure modes. Therefore, we group failure modes in four ways: 1) type-based (i.e., hardware/software/human), 2) formula-based (e.g. test interval, failure frequency), 3) phase-based (design/construction/maintenance) and 4) object-based (using an object tree).

3. Comprehensive List of Principle Improvements

Even when dominant failure factors are identified, important improvements can be missed. For instance, failure model improvements can be overlooked while focussing on tangible improvements. We propose to use an comprehensive list of principle improvements. We discuss and extend upon the twelve principle defences against common cause failures as proposed by Paula et al. (1990). Examples of principle improvements are adding redundancy or improve staff training.

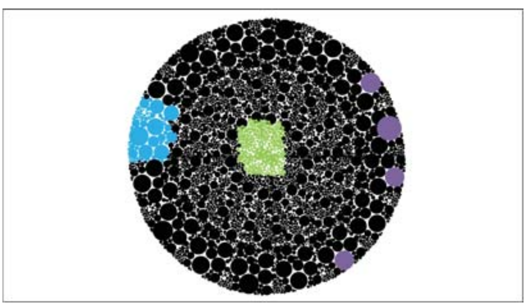

Fig. 2. Zoom in of Venn Diagram of fig. 1 showing that the probability of a failed closure consists of many failure modes. Several groups of failure modes are indicated with blue, green and purple colors to emphasize the importance of grouping failure modes. The blue group could, for instance, correspond to failure modes which all are influenced by a specific yearly test

4. Case studies

The approach is applied to three cases of Dutch storm surge barriers. In two cases, the improvements were initially overlooked, but later found and implemented. In the last case, no improvements were required as the risk was found to be acceptable. Some improvements were, however, suggested based on sorting minimal cut-sets. We compare this initial list, with the possible improvements we found with our approach. We discuss whether important improvements were missed.

5. Implications

We expect that our approach can assist in identifying effective solutions to reduce the probability of a failed storm surge barrier closure, thereby adapting these structures to climate change and increasing flood risk. The method may also be useful for other industries using Quantitative Risk Assessment (QRA) and dealing with a large number of failure modes.

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