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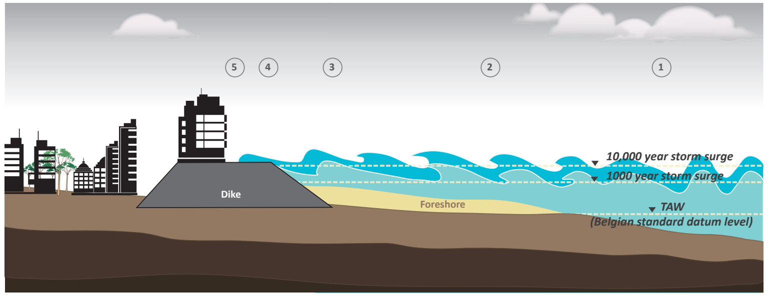
Figure 1 (right). Full process of overtopping waves and their impact on a building on the crest of a multifunctional flood defense.

Figure 2 (below). Typical configuration of a Belgian coastal town, in this case Wenduine along the North Sea coast (photo courtesy Koen Trouw).



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PREDICTING WAVE IMPACT ON STRUCTURES ON TOP OF A LEVEE

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Thesis title:
'Impacts of overtopping waves on buildings on coastal dikes'.

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In low-lying countries like the Netherlands and Belgium, coastal areas are often highly urbanized, and buildings are often built on or close to the flood defenses (Figure 2 shows a typical Belgian seaside town). This is an example of multifunctional flood defense, where urban functions are integrated with flood defense structures. In this example, the wide crest of the coastal dike is used as a promenade with building frontage. However, policy makers as well as the users and owners of the properties may be unaware of possible overtopping effects, and they may lack records of wave overtopping and the potential direct damage it can cause. The goal of this research project was to develop a tool that can measure the risks and potential cost of wave overtopping events on buildings.

If waves overtop the dike crest, the overtopping flow can have a severe impact on the buildings on the dike crest. Using a typical Belgian coastal dike with buildings on the top as a case study (see following pages), this research attempts to understand the hydraulic impact of overtopping waves. An overtopping wave is a mixture of moving water and air. In order to develop practical approaches to design and assess structures, understanding physical force-generating mechanisms is necessary. We developed a practical approach to assess the vulnerability of structures built on coastal dikes caused by an overtopping wave. This approach can be used to design and assess coastal MFFDs in low-lying, highly populated coastal urban regions.

Figure 1 shows the full process of overtopping waves and their impact on a building on the crest of a multifunctional flood defense:

1. Wind generates waves far away from shoreline.
2. Offshore waves reach the foreshore area, increasing wave-height and decreasing wave-length. Ultimately, most waves break.
3. A turbulence bore runs up on the seaward slope of the dike and overtops the crest of the dike.
4. Part of the overtopping waves continues across the dike crest, and the other part flows back into the sea.
5. Overtopping flow hits the building, with some of the water being reflected seaward, and some of it passing through the gaps between buildings.

Most buildings built on coastal multi-functional flood defenses in Belgium are low- and medium-rise masonry structures. Thus, a masonry building with a seaward external wall panel on the ground floor was selected as the representative structure for the case study. The most common failures caused by overtopping waves were structural collapse and local damage of non-structural elements.

Structural collapse can occur by two causes:
- The support or foundation can fail, making the structure lose stability
- A key structural element can fail, causing a collapse.

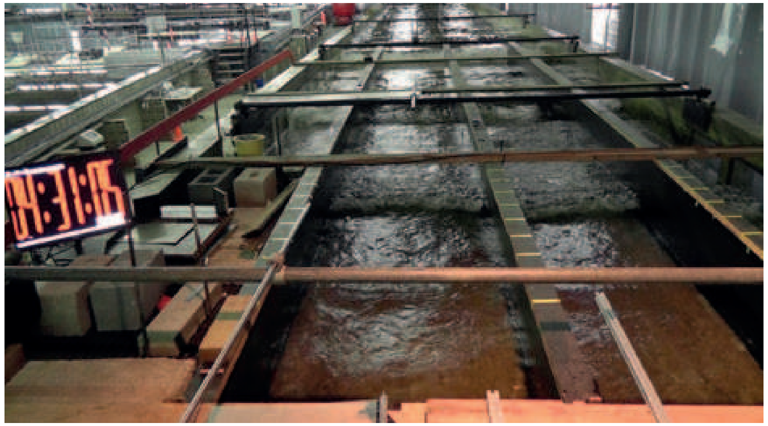
Local damage includes failures that do not lead to collapse, but which do result in the inundation of the ground floor. Local damage primarily concerns two failures:
- The failure of windows and doors;
- The failure of façade walls (i.e., non-load bearing walls).

In this case study, we considered both local damage and the collapse of a key structural external wall, which could lead to the collapse of the building.

Two-dimensional physical model tests were conducted using a typical Belgian coastal configuration (such as the one in figure 1).

Figure 3. Image of flume in Antwerp: wave breaking on the foreshore (photo courtesy Xuexue Chen).

Figure 4. Image of flume in Antwerp (photo courtesy Xuexue Chen).



These permitted us to study wave overtopping and overtopping wave impact in the situation where a shallow foreshore affects the wave overtopping of a coastal dike. Based on experiments done in a flume (see Figures 3 and 4), the results show that Generalized Pareto (GP) distribution gives a suitable fit among commonly used distributions for the extreme overtopping forces. The three key parameters of the GP distribution are threshold, scale, and shape. These were empirically determined by using incident wave conditions at the toe and dike geometry parameters. Based on the results of physical model tests, a new 7-step procedure was suggested as a simple tool for predicting the maximum force occurring during a certain storm peak; the tool shows an overall satisfactory performance (Chen et al., 2016a).

Using this tool, typical overtopping wave impact loads, expected to occur during 1 in 1000-year and 1 in 10,000-year storms, were calculated for the Belgian case. We assessed the vulnerability of buildings on coastal dikes caused by overtopping waves, by comparing the calculated impact load of overtopping waves and the strength of the buildings. We found that the masonry buildings on the coastal dike can withstand a 1 in 1000-year storm, but ground floor inundation can be expected from broken windows. If the building is located 10 to 15 meters from the seafront, non-structural walls are expected to fail during a 1 in 10,000-year storm. However, full collapse of the building may occur during a 1 in 10,000-year storm if the beach becomes badly eroded at the toe of the seaward side of the dike.

The findings of this study on the propagation of overtopping waves on a dike were applied to the case of a Belgian seaside town. By characterizing the resulting impact load on a vertical wall, a model is developed to assess the vulnerability of existing and newly designed buildings on dikes that are exposed to the impact of overtopping waves in low-lying coastal regions. By extending the model to include the impact of overtopping waves on the foundation of the buildings and on potential dike failure, and different type of buildings, the model can become more general applicable.

Figure 5. Wave flume in Flanders Hydraulic Research (Antwerp, Belgium). (a) is a top view of the flume, below are the respective sections: (b) 'Outer section', (c) Section A, and (d) Section B.