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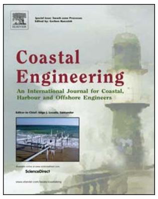

Impacts on a storm wall caused by non-breaking waves overtopping a smooth dike slope

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ABSTRACT

Will coastal towns survive the rising pressure, or better, the rising sea level in future decades? Waves overtop dikes, and the overtopping flow on the crest of the dike can cause damage. Wave impacts from these overtopping flows already became of interest in coastal engineering the past few years, but very little literature and almost no design formulae are available yet for irregular waves. This paper gives such design formulae for practical use. Experimental modeling at three different scales (small, middle and large scale) has been carried out to measure such impacts. The tested geometry was a smooth sloping dike (only non-breaking waves) with a promenade at crest level and a storm wall at the end of this promenade.

The outcome of this paper are three methodologies to a) calculate wave impact forces on such a storm wall as a function of the hydraulic parameters; b) determine the (Weibull) distribution of all impacts in one test, with the shape and scale parameters also linked to the hydraulic parameters; and c) to provide an indirect approach to calculate the impact forces on the storm wall. In this last approach, the (distribution of the) individual overtopping waves are linked to the (distribution of the) overtopping flow parameters, which are then linked to the (distribution of the) impact forces.

Finally, the empirical formulae from the aforementioned three methodologies are compared; analogies and differences are discussed, and guidance is provided to design storm walls against post overtopping impact forces.

Results show that forces from waves overtopping the dikes are in the order of 20 to 40 kN/m prototype scale in the dimensionless freeboard (R_c/H_{m0}) range of 1 to 2. This is (much) lower compared to impact forces on vertical walls as calculated by the Shore Protection Manual.

1. Introduction

Many researchers have studied wave overtopping over a variety of coastal structures for over decades now. Rubble mound structures, smooth sloping structures and quay walls have been tested with a variety of geometrical and hydraulic parameters, and from these studies reliable methods have been developed to calculate wave overtopping. EurOtop [11], PC-overtopping (www.overtopping-manual.com/calculation_PC.html) and the Neural Network tool [41] are the most common ways to do a preliminary study of average overtopping discharges. Detailed studies can best be performed by experimental or numerical modeling.

But what is the damage that can occur due to overtopping waves? This was studied and documented less in the past, but has become of increasing interest in the last few years within the coastal engineering community. The literature study in chapter 2 shows that some knowledge is available on impacts on crown walls on top of rubble mound breakwaters. Also, there is information on damages of the landward side of overtopped (mostly grass or clay) dikes. Unfortunately, for the crest of smooth sloping dikes very few information is available. What happens when waves overtop a smooth sloping sea dike with a promenade at crest level and buildings or other structures on this promenade? Do these structures provide sufficient safety against structural failure during storms with severe wave overtopping? When storm walls are built on the promenade to protect the structures behind them or to prevent flooding of the low-lying hinterland: what impacts will these storm walls face during their lifetime?

Just like Vietnam, The Netherlands and other low-lying countries,

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Fig. 1. Oostende, a city along the Belgian coastline, has the waterfront close to its apartment buildings (pictures: Masterplan Coastal Safety Belgium – Flemish Government – Coastal Division).

the Belgian coastline is a textbook example of this problem: a tidal sea with about 4m tidal range, smooth sloping sea dikes with a fairly low crest level in comparison to the expected storm surge levels, a touristic promenade at crest level and apartment buildings at the end of this promenade at about 20-30 m behind the crest of the dike (see Fig. 1). The hinterland is often below the crest level of the dike, and in some cities even below the storm surge level. This means that nearly all overtopped water over the crest of the dike hits the facades of the apartment buildings (damage?) or runs into the low-lying hinterland via the streets between the apartment buildings and almost perpendicular to the dike (flooding?). To avoid this to happen, the Belgian government launched a study in 2007 to determine the most endangered areas and how to protect them on short-term (by 2010) and on long term (by 2050), against a storm with a return period of 1000 years. In the margin of these studies, Van Doorslaer et al. [36] have published a study investigating all kinds of measures at crest level to reduce wave overtopping: a storm wall at the seaward crest, a storm wall with bullnose, a stilling wave basin, a promenade, and a storm wall (with and without bullnose) at the end of the promenade at crest level.

This last geometry is the topic of the current paper: a smooth sloping dike with promenade at crest level and a storm wall at the end of this promenade. For the reducing effect on the wave overtopping the reader is referred to Van Doorslaer et al. [36]. The present research focuses on the impacts by the overtopped bores on the storm wall at the end of the promenade. Several experimental test campaigns have been carried out in different European laboratories in order to study wave impacts at different scales. Since all research projects were mainly based on the Belgian geometry, the promenade length and storm wall height have not been varied. An optimal geometry to reduce wave overtopping, based on the study by Van Doorslaer et al. [36], was chosen: see Fig. 2. Within the used range of dimensionless parameters, the results of this paper are also usable for geometries outside Belgium, e.g. for the design of storm walls on promenades at coastal dikes, or a safety assessment for residual safety of existing buildings or structures.

The following is shown in Fig. 2: deep water waves (1) progress towards the coastline, where they transform and break when approaching the shore (2). When facing the dike or coastal structure, wave run-up (3) and wave overtopping occurs (if the crest of the structure is lower than the maximal run-up height). Overtopping waves lead to an overtopped bore which progresses over the crest promenade with a certain flow depth 'h' and flow velocity 'U' (4), eventually leading to an impact on the storm wall (5) and possibly overtopping this wall. However, not every overtopped wave over the crest of the dike will lead to an impact (depending on the damping due to friction on the promenade and energy loss due to turbulence in the bore) and not every impacting bore overtops the storm wall (depending on the height of the storm wall).

The processes in zone 1 to 3 have been described in literature on coastal dynamics, and are not dealt with here. This paper focuses on what is called the post-overtopping processes (overtopping volumes at $x_c = 0$, flow depth and flow velocity in zone 4) and the related bore impacts (zone 5). Experimental test campaigns were set up to measure these impacts in zone 5 and relate them to the hydraulic parameters (zone 2) and to the overtopping flow parameters (zone 4). Three methods are explained to estimate the impacts on the storm wall.

Chapter 2 of this paper gives a literature overview on the post-overtopping processes. Flow depth, flow velocity and the available literature on wave impacts are described here. Danish research on

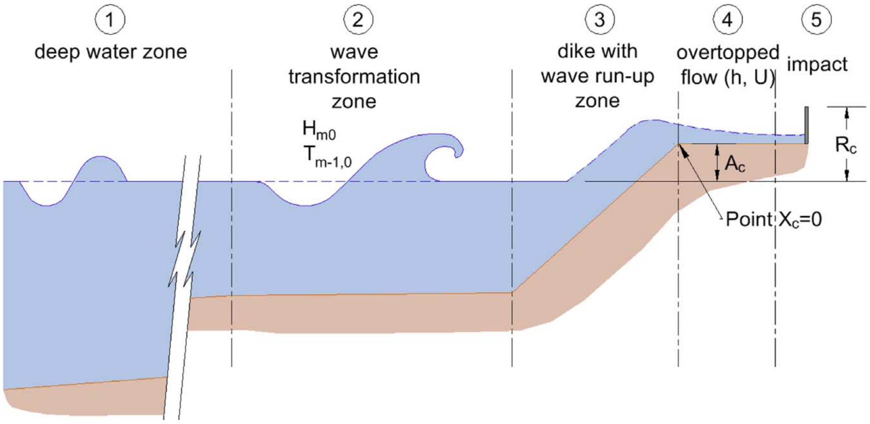

Fig. 2. Evolution from deep water waves to the post overtopping process of a bore impacting a storm wall. The water layer on the crest can be an incoming flow, or the accumulation of both incoming and reflected bores.