WAVE OVERTOPPING PERFORMANCE ANALYSIS OF THE RESEARCH DIKE RAVERSIJDE, BELGIUM

Peter Troch, Ghent University, Peter Troch@UGent.be
Vincent Gruwez, Ghent University, Vincent.Gruwez@UGent.be
Marc Willems, Flanders Hydraulics, Marc.Willems@mow.vlaanderen.be

INTRODUCTION

Low-lying countries typically have mildly-sloping beaches as part of their coastal defense system. Many countries in north-western Europe have coastal urban areas that rely on this type of defense system, which consists of a low-crested impermeable sea dike with a relatively short promenade, and a long (nourished) beach in front that acts as a very/extremely shallow foreshore as defined by Hofland et al. (2017). Along the cross-section of this hybrid beach-dike coastal defense system, storm waves are forced to undergo many transformation processes before they finally overtop the dike. These hydrodynamic processes include shoaling, sea-swell (SS) wave energy transfer to sub- (also infragravity or IG waves) and superharmonics via nonlinear wave-wave interactions, wave dissipation by breaking and bottom friction, reflection against the dike, wave run-up and overtopping on the dike, bore impact on a wall or building, and finally reflection back towards the sea interacting with incoming bores on the promenade. Due to breaking of the SS waves and growth of the IG waves on the shallow foreshore, the IG waves can become as important or even dominant at the toe of the dike (Hofland et al., 2017; Lashley et al., 2020), which influences the overtopping process (van Gent, 1999).

Field measurements of all these processes at the same time are very challenging but necessary since field observations do not suffer from scale nor model effects. Field data are therefore crucial to evaluate design methodologies, which rely on physical and numerical modelling. Measuring wave overtopping at existing dikes has been reported before (Wenneker, 2016; van der Meer, 2019). However, in Belgium none of the existing dikes are in contact with the sea because of beach nourishments, requiring a different approach. Overtopping is therefore measured on the beach using the Research Dike at Living Lab Raversijde (RDR) (Gruwez et al., 2022). This work presents the performance analysis of the RDR for the first storms measured in the winters of ’22-’23 and ’23-’24, and a first evaluation of empirical models with the field data.

FIELD SETUP WITH RESEARCH DIKE

The field measurement site “Living Lab Raversijde” is located in Ostend, Belgium (Figure 1), where wind, waves & overtopping, water levels, bathymetry and beach profiles are measured over 10 years (2021-2030). It consists of (1) the RDR to measure the wave overtopping and impact on storm walls on the dike, and the wind (Figure 1a); (2) three intertidal measurement poles (MP) with collocated pressure (P) and current (horizontal velocity components, U and V) sensors, and sediment suspension meters to measure the wave transformations and beach profile changes; (3) offshore measurements using two collocated directional wave buoys and ADCP’s with a shallow sand bank in between to investigate the generation of IG waves (Figure 1b). Topography and bathymetry surveys are also done on a yearly (offshore) and monthly (foreshore) basis.

The concept of the RDR is to bring the dike and instrumentation closer to the sea (lower, at about the high tide level on the beach), and was designed so that every storm season on average five events can be measured for a mean overtopping discharge q of up to 10 l/s/m. Constructed in 2021, the RDR was made operational in 2022, and consists of four typical dike cross-sections (Figure 1a), where the overtopping is measured at the dike crest (section A1) and at the end of a promenade (section B1). Both sections are repeated to include a storm wall where the impact forces are measured (in addition to the overtopping), at the crest (A2) and the end of the promenade (B2).

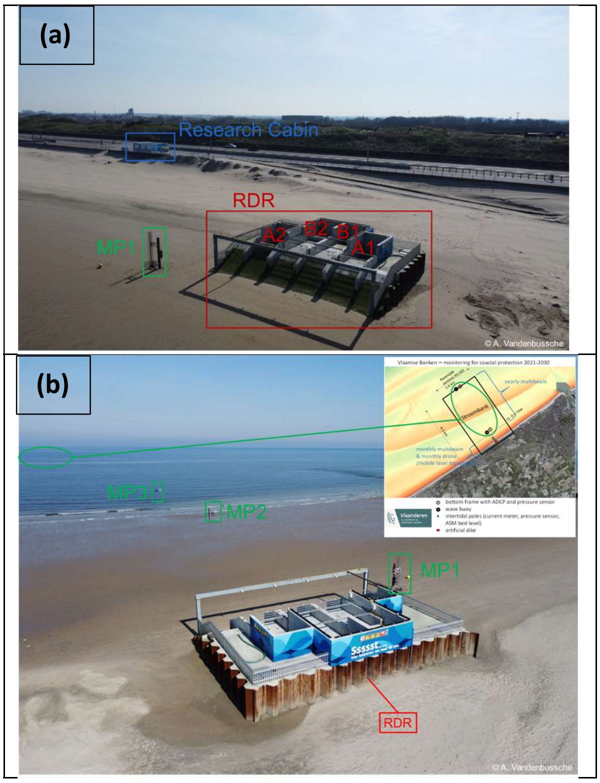

Figure 1 - Field setup “Living Lab Raversijde” at low tide, (a) Front view on the RDR (with indication of sections A1, B1, B2 and A2), research cabin and measurement pole 1 (MP1), (b) back view on the RDR, the three MP’s with PUV and the offshore wave sensors (two ADCP’s and buoys).

The overtopping measurement is achieved in each section using the basin with V-weir approach (Troch et al., 2004). To prevent return flow via the V-weirs, the RDR is equipped with a buffer basin (of ~215m³) in the basement of the structure. Each V-weir also has the capability of being closed off, so that useful overtopping measurement can be done in at least one or more of the sections at the same time while not exceeding the buffer volume during the entirety of the predicted storm.

PERFORMANCE ANALYSIS

Overtopping is mostly determined by the still water level (SWL) (or specifically the freeboard), and the incident offshore significant wave height $H_{m0,o}$. Based on empirical and numerical modelling a threshold was determined above which a q of 1 l/s/m in section A1 is to be expected (green line in Figure 2). The dashed lines in Figure 2 are the estimated thresholds above which the closure of one or more V-weirs is recommended to obtain a useful q measurement in the remaining basins with open V-weir. The green dashed line is the threshold indicating the max. capacity of the RDR to measure overtopping (i.e., q = 10 l/s/m for section B2 and all other sections closed).

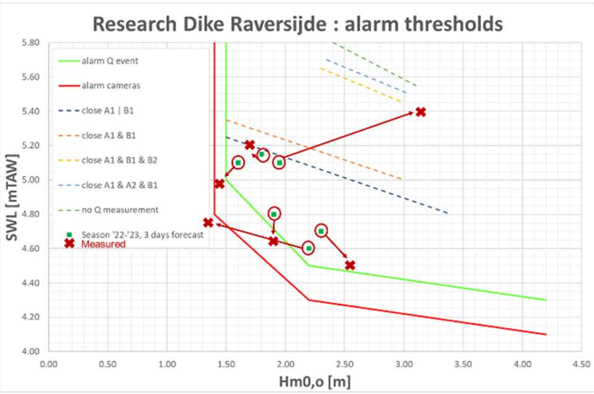

Figure 2 - Thresholds for SWL-$H_{m0,o}$ combinations, where overtopping is expected (green full line) and V-weirs need to be closed off (dashed lines). Comparison between the predicted (green squares) and measured (red x-markers) storm conditions for storm season '22-'23. TAW is a Belgian reference level.

Three-day forecasts of SWL and $H_{m0,o}$ are monitored four times daily for q-threshold exceedances. In Figure 2, the forecasts of all exceedance events of storm season '22-'23 are indicated (green squares). Even though six such events were forecast, most of these storms reduced on the day of the storm itself (red x-marks in Figure 2), and only two storms resulted in an overtopping measurement at the RDR. For Storm 1 (return period RP of ~1 year) the first threshold for closing off other sections was not exceeded (purple dashed line). Indeed, a useful overtopping measurement was obtained for all sections with a q of ~4.4 l/s/m for section A1, ~3.5 l/s/m for B1, ~0.5 l/s/m for A2, and ~0.03 l/s/m for B2. For Storm 2, the storm conditions increased significantly in the days leading up to the storm (RP of ~9 years) so that thresholds for closing off sections A1 and B1 were exceeded, but not realized due to time restrictions. No useful overtopping measurements were obtained because no V-weirs were closed off and the buffer capacity of the RDR was therefore quickly reached.

FIRST EVALUATION EMPIRICAL MODELS

Storm 1 provided useful overtopping data, of which the result from section A1 can be used to compare to the empirical model of Altomare et al. (2016). The empirical model predicts a q of 2.3 l/s/m, which is an underestimation of the observation, although the measured result does fall within the error bands of the empirical model.
At the conference, a first evaluation of other empirical models (e.g., Lashley et al. (2021) and others for wave conditions at the toe, wave force,…) will also be presented.

CONCLUSION

The RDR is shown to perform as designed, based on two storms in the first season of '22-'23. A first evaluation of an empirical model for overtopping discharge at sea dikes on shallow foreshore also shows a good correspondence, although with a slight underestimation. However, more data will follow (up to 2030) to further validate not only empirical, but also numerical and physical models. At the conference, the evaluation will be presented including the data of season '23-'24 as well.

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