

DURCWAVE “AMENDING THE DESIGN CRITERIA OF URBAN DEFENCES IN LECZS THROUGH COMPOSITE-MODELLING OF WAVE OVERTOPPING UNDER CLIMATE CHANGE SCENARIOS”

BY XAVIER GIRONELLA & CORRADO ALTOMARE

Coastal zones are exposed to a series of hazards, such as sea-level rise (SLR) and intensified storminess^[1], which are estimated to increase due the effects of the climate change. According to IPCC^[2], the sea water level has been rising about 3.2 mm/year since 1993 - three times faster than the rates observed over most of the 20th century! - and this increase is expected to continue. At the same time, population in coastal zones is expected to grow into the future^[3]. This is true especially in low elevation coastal zones (LECZs) - areas contiguous with the coast that are 10 m or less in elevation - where population will grow from 625 million to nearly a billion people by 2060^[4], 56 million of which in Europe. Two-thirds of world's largest cities are located in LECZs; in Europe, urban areas represent actually the 40% of the population in LECZs, values that will reach the 58% by 2060. Will coastal cities and urban areas in LECZs survive the SLR and flood events in the near future? How much the risk for people living in LECZs will increase? How to tackle it? Over the last century, the growing number of extra-tropical cyclones led to more frequent and disastrous flooding events: waves overtopped and breached coastal defences, causing major economic damages and loss of life. The “1953

North Sea flood” was one of these events, considered the worst natural disaster of the 20th century in The Netherlands, the U.K. and Belgium, recording over 2,500 lives and widespread property damage (around 10,000 buildings were destroyed). Unfortunately, similar severe storms are likely to occur again as a result of climate change. A clear evidence is the intensive stormy weather that is affecting Europe over the last 10 years (e.g. the “2013–14 Atlantic winter storms”), causing severe flooding and casualties from Scotland to Spain, from Sweden to Poland (Figure 1). Very recently, between January and February 2017, storms characterized by exceptional wave heights (>6-7m) hit the southern coast of Spain, washing away entire parts of the coastal protections and causing major damages (≈36.131.000€) to ports, promenades and other infrastructure. Under these scenarios, the performance of coastal defences in the next 20-100 years will become increasingly important to prevent flooding due to extreme overtopping events.

Recently the DURCWAVE project (<https://cordis.europa.eu/project/id/792370>) was granted within the European Union's Horizon 2020 research and innovation programme

under the Marie Skłodowska-Curie (grant agreement No 792370). The project is ongoing at the Maritime Engineering Laboratory of Universitat Politècnica de Catalunya-BarcelonaTech (LIM/UPC). Its scope is to contribute to long term solutions *to cope with climate change in terms of requirements regarding coastal safety for LECZs*.

The main scientific objective of DURCWAVE project is to define new design criteria for wave action by modelling wave overtopping and post-overtopping processes of these urban defences. Specific objectives (SOs) are defined as follows:

1. To study post-overtopping processes by characterising overtopping flows on urban defences.
2. To explore the influence of structural geometries on post-overtopping processes.
3. To relate overtopping flow characteristics to maximum exerted loads.
4. To determine the most appropriate overtopping flow characteristics in terms of design purposes.
5. To define new design criteria for overtopping wave action as upgrade of European Standards.

To reach these objectives, the project is implementing a composite-modelling approach: physical modelling (hereafter “PM”) and numerical modelling (hereafter “NM”) are combined and applied to wave overtopping and overtopping loading assessment. The complementary use of PM and NM is essential since each approach counterbalances the drawbacks of the other. On the one hand, PM is an established and reliable method for studying wave loads and wave overtopping of arbitrary coastal structural geometries. However, PM is often a costly and time-consuming solution with further practical shortcomings due to limitations in measurement techniques. On the other hand, NM is less restrictive in structure configurations and provides much more detailed information on the overtopping and post-overtopping flows (velocities, pressures, forces and overtopping



Figure 1. Examples of winter storms that struck the northern Europe over the last 6 years (a & b) and damages to the sea frontages (c & d)

volumes). However, NM requires high computational effort and preliminary validation phases. Hence, a composite-modelling allows overcoming the aforementioned limitations and attaining a level of detail of the analysis that, otherwise, would be partial or incomplete.

PM focusses on sea dikes and vertical quay walls with main defence elements (storm walls, still wave basins, parapet walls) and secondary elements (buildings located behind the main defences). Overtopping discharge, individual overtopping volumes, thickness and velocity of overtopping flows, pressure and forces exerted by the overtopping waves are measured. The NM employs the meshless DualSPHysics model^[5]. DualSPHysics is based on the Smoothed Particle Hydrodynamics method and is released open-source under a LGPL licence. The code has been already proved to provide accurate and realistic modelling of wave-structure interaction phenomena (see Figure 2).

The project is organised in 5 synergic Work Packages (WPs) that focus on science development, dissemination and public engagement and project management. The WPs are listed as follows:

- **WP1: Physical modelling of post-overtopping processes**
- **WP2: Numerical model development and application to new case studies through secondment**
- **WP3: Integration of PM and NM data**
- **WP4: Dissemination and public engagement**
- **WP5: Project Management**

Physical modelling is carried out at LIM/UPC and comprises both large and small scale modelling. LIM/UPC experimental facilities were considered well suited for accomplishing all PM



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proposed in this project as they include two different and complementary wave flumes. On the one hand, the **large-scale flume “CIEM”** (Canal de Investigación y Experimentación Marítima), has been recognized since 1996 as a “Large Scale Facility” by the European Commission and since 2006 as an ICTS (Infraestructuras Científicas y Técnicas Singulares) by the Spanish Ministry of Science and Education. The participation of the CIEM flume in the Infrastructure Network HYDRALAB and in the Spanish ICTS programme allows other Spanish and European researchers to

access this infrastructure and share know-how and equipment. The flume is 100m long, 3m wide and 7m high. On the other hand, the **small-scale flume “CIEMito”** (18m x 0.38m x 0.56m), represents the perfect complement for CIEM, maximizing the typology test variability while minimizing costs, without affecting the quality of the results.

A first experimental campaign has been carried out in the CIEMito flume. The geometrical layout used for the experimental campaign resembles the beach and costal protection in the area of Premià de Mar, municipality in the comarca of the Maresme in Catalonia, Spain. In particular, the area nearby the railway station has been studied. This stretch of the coast, in fact, has both railways and a bike path very exposed to possible sea storms, being located at a few meters from the shore (see Figure 3). Besides issues related to people safety, the vicinity of the railway to the sea has already caused in the past several problems and service interruption of public transport for a line that is strategic for the zone, connecting it directly to the metropolitan area of Barcelona. Close to the railway station, the dike slope has been estimated equal to 1:1. In the physical model tests, the effect of the rubble mound has been neglected, considering a smooth slope, instead. Due to lack of bathymetric data in the area, two different foreshore slopes were considered, namely 1:15 (steep) and 1:30 (gentle). Different widths for the promenade between the dike edge and the station were considered to be representative of the different stretches along the coastline.

Preliminary results from small scale modelling show that overtopping flow velocities and flow depth turn to be significant parameters to

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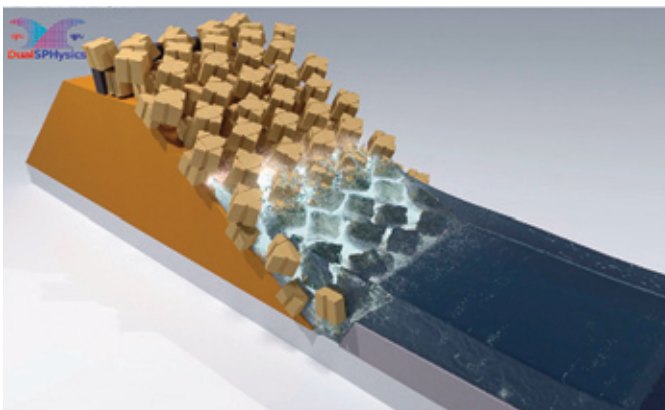


Figure 2. Run-up on a breakwater with DualSPHysics



Figure 3. Bike path and railway in Premià de Mar

showed that global TC waves would tend to decrease over the lower latitudes and increase over the higher-latitude regions. The 10-year return wave heights of TC-induced waves over the western North Pacific would either increase or decrease by 30 % maximally depending on the region. The spatial distribution of future changes in TC waves can be explained by an eastward shift of TC tracks. However, the number of extreme wave climate projection is limited. Therefore, even though a prediction of global mean wave heights is available, a quantitative assessment of expected changes in mean period, direction and extreme wave conditions, which are important for developing coastal protection measures, remains a future challenging task.

Storm surges

The impact assessment of the impact of climate change on storm surge at regional scale is difficult due to the scale differences between global/general circulation models (GCMs) and storm surge scales (less than O (1–100 km)). The impact of climate change on storm surge was discussed in the SROCC (2019) [1], which only used empirical projections based on observed data. A quantitative summary of the climate change impact at regional scale storm surge is expected to be included in the next assessment report. Assessing the impact of climate change on storm surge risk requires accounting for a number of factors besides the nature of the storm event itself (e.g. TC or

extra-TC); storm surge at a particular location is affected by several storm characteristics such as the moving speed and incident angles not only frequency and intensity of storm. Therefore, assessing the storm surge risk in a particular region is difficult even when considering the historical climate alone because landfalls are not very frequent (happening in many areas only once every few decades).

Figure 3 shows an example of the future percent change in storm surge heights and sea surface winds for 100-year return period events [9]. Extreme storm surges were obtained from over 5000-year GCM simulations [10] and a simple storm surge model. Future 100-year return values of storm surge increase about 20% along the East Asian eastern coast and the US western coast, although future 100-year return values of wind speed increase by only 10% due to TCs in these areas. A moderate, future change in storm surge within 10% increase is found in the higher latitudes; which is due to a change in polar circulation in both hemispheres. Changes in wind speed by extra-tropical cyclones will be stronger in the higher Western North Pacific, but they will not be significant in the higher Northern Atlantic. As such, it is necessary to analyze how extra-tropical cyclones and related storm surges will change in the near future. These changes in extreme storm surges depend on the length of return periods. The results in Figure 3 show one such example.

Conclusion

SLR and changes in wave heights and storm surge heights in coastal areas can have a significant impact on the development of coastal protection measures.

Combined projections of SLR, wave heights and storm surge heights are important for understanding and preparing coastal protection from the present to middle or end of this century. ■

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assess stability for pedestrian and vehicles in the vicinity of the sea dike, demonstrating that design criteria based just on average overtopping discharges and maximum individual overtopping volume are necessary but not sufficient conditions to be met. It is therefore necessary to investigate further the overtopping and post-overtopping processes taking into account the particular dike layout and protection countermeasures (e.g. storm walls) and go beyond or amend the current design methodology for wave overtopping. This will be achieved by the end of DURCWAVE project, foreseen for April 2021. ■

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Acknowledgment

The authors acknowledge funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No.: 792370