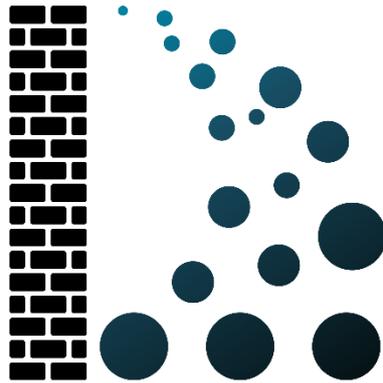*amending the Design criteria of URban defences in LECZs through Composite-modelling of WAVE overtopping under climate change scenarios*

Wave overtopping flow properties: proposal for integration of EN 1191-1-8

Project Information

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Document objective

This document represents a proposal for Eurocodes amendment, with particular focus on wave overtopping assessment and overtopping flow properties on coastal defences in urbanized low-elevation coastal areas.

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Disclaimer

Document History

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Contents

1   Premises

Wave overtopping represents a major criterion for the design of coastal defenses. Since the 80s', several experimental campaigns have been carried out worldwide, leading to semi-empirical models (i.e. formulas), which are nowadays largely used for overtopping assessment. These methods usually employ simplified sections of coastal defenses. Different methods are based on artificial intelligence techniques and genetic programming (Zanuttigh et al., 2016): these techniques overcome many limits of the semi-empirical formulae, but they rely on training databases, which need to be "homogeneous and wide-enough" (EurOtop, 2018). Yet, the aforementioned approaches are meant to assess mean overtopping discharge, which is defined as the ratio between the total volume overtopped during a sea storm and the storm duration. Even when experimental model campaigns are required for final design of coastal defenses, they target at characterizing average discharges and/or overtopping volumes associated to individual maximum overtopping events and compare these values with tolerable values proposed in literature. However, overtopping is a dynamic, complex, stochastic and temporally variable phenomenon, characterized by episodic and very diverse individual events during an entire sea storm duration.

Owen (1980), who laid the groundwork for the assessment of wave overtopping, chose the average discharge as design value for a specific practical reason, stating that *"there is no such thing as an absolute discharge: because the wave heights and periods exhibit a random distribution about a given mean, the discharge will also vary randomly"*.

A few studies related to induced wave overtopping damages and instabilities (e.g. Endoh and Takahashi, 1994; Sandoval and Bruce, 2017) **demonstrate that one single value of admissible mean discharge or individual overtopping volume is not a sufficient indicator of the hazard**. More and more attention is nowadays directed toward the characterization of overtopping flow properties on coastal structures (e.g. Mares-Nasarre, 2019). Recent studies reveal that the risk for pedestrians is better characterized by the time dependent flow depth and flow velocity, which, in turn, are strongly influenced by the dike layout (Altomare et al., 2020; Suzuki et al., 2020). It seems reasonable to extend these results to the impact of overtopping waves on vehicles, urban furniture and major infrastructures along the coastline (railroads, bike paths, etc).

1.1   EN 1191-1-8 (Draft)

For design of civil engineering buildings and infrastructures exposed to the action of sea waves and currents, the European Union has issued the mandate M/515 to amend the existing Eurocodes (European Standards for the design of civil engineering structures) and extend their scope. The new **EN 1191-1-8 "Wave and currents"** has been drafted by Technical Standardization Committee (CEN/TC 250). Knowhow from the International Standards ISO 21650 and EurOtop (2018) has been collected, summarized and employed in the EN 1191-1-8 draft. Nevertheless, the ISO 21650 does not add any further knowledge to the current state-of-the-art, focusing only on average discharge values.

In the new standards, empirical formulae based on model tests for the calculation of average overtopping discharge are recommended to be used for a preliminary assessment. However, due to the importance of wave overtopping, the EN 1191-1-8 recommends to perform physical model tests, when the existing formulae incorporate high uncertainties. Finally, the EurOtop (2018) overtopping thresholds are indicated in the norms. **These thresholds are expressed in terms of average discharges and individual overtopping maximum volumes**. Maximum volumes and volume distributions are determined by employing a two-parameter Weibull distributions.

For the sake of understanding of the new standards, it is worthy to report here that the Eurocodes define their verbal forms as follows:

- *"The verb **"shall"** expresses **a requirement strictly to be followed** and from which no deviation is permitted in order to comply with the Eurocodes.*
- *The verb **"should"** expresses a **highly recommended choice** or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.*
- *The verb **"may"** expresses a course of **action permissible** within the limits of the Eurocodes.*
- *The verb **"can"** expresses **possibility and capability**; it is used for statements of fact and clarification of concepts"*

2   DURCWAVE Outcomes

Here we refer to two articles recently published in international peer-reviewed scientific journals, namely Altomare et al. (2020) and Suzuki et al. (2020). Both articles represent two of the major outcomes of the EU-funded Marie Sklodowska-Curie Action "amending the Design criteria of URban defences in LECZs through Composite-modelling of WAVE overtopping under climate change scenarios" (**DURCWAVE**), grant agreement No 792370 (https://durcwave.es/).

2.1   Altomare et al. (2020)

Altomare et al. (2020) analyze the relationship between overtopping flow parameters (i.e. discharges, volumes, flow depth and flow velocity) and possible correlation with the people safety. The authors carried out physical model tests in a wave flume facility for a case-of-study from the Catalan coast, north of Barcelona.

The authors observe a clear dependence of overtopping flow velocity and flow depth on the individual volume, as also reported in Trung (2014) and Hughes (2015). Looking at overtopping flow properties, Altomare et al. (2020) highlight that overtopping safety criteria based on mean discharge and maximum volume are not sufficient for coastal structure design. Hazards related to overtopping events might be over-predicted for the specific case-of-study. Besides specific considerations for the studied area, some general conclusions can be drawn from the work of Altomare et al. (2020):

- *"Tolerable discharge values proposed by EurOtop (2018) vary depending on the local wave height at the toe of the coastal structure. On the contrary, a fixed value corresponding to 600 l/m is reported as a threshold for individual overtopping volume.* **It is not clear from EurOtop (2018) whether this value corresponds to some specific value of overtopping flow velocity** *… omissis …*

- *Experimental values of overtopping flow velocities and flow depth have been compared with stability curves for pedestrians (adults and children) placed on the sea dike and subjected to overtopping waves.* **The results show a clear influence of the dike crest width**, *… omissis …*

- *Volumes bigger than 600 l/m do not always determine unsafe conditions for pedestrians. … omissis …*

- ***EurOtop's tolerable limits and stability curves lead to discordant results***. *In fact, due to the non-two-way relationship between volumes and corresponding flow parameters, it can be observed that flow parameters related to 1,000 l/m maximum volumes can be located in the unsafe area, while the same parameters related to bigger volumes can even be included in the safety range for a large enough crest.*

Concluding, the experimental campaign suggests that further research is needed in terms of design criteria for wave overtopping, if related to people's safety. **The proposed tolerable discharge and volume values from EurOtop (2018) are still valid, but not sufficient to clearly identify a safe or unsafe scenario**. *Overtopping flow depth and velocity provide further insight and are advised to be employed, together with EurOtop's criteria, for coastal safety assessment."*

2.2   Suzuki et al. (2020)

In Suzuki et al. (2020) the SWASH model (an acronym of Simulating WAves till SHore) is employed in 2DV (i.e., flume like configuration) to reproduce overtopping flow in different wave conditions and bathymetries. While the authors recognize that mean discharge and maximum volume values "*are still very important parameters to have the first idea to estimate how severe will be the overtopping event*", their results suggest that "*the overtopping risk is better characterized by the time dependent h (overtopping flow depth) and u (overtopping flow velocity)*". Suzuki et al. (2020) show the time dependent u and h are strongly influenced by the coastal structure layout. **The width of a crest berm or promenade is proved to have a significant influence on the overtopping flow properties**: eventually, the forcing on pedestrians, vehicles, and structures would be reduced. Besides, *"the simulation shows that the vertical wall induces seaward velocity on the dike which might be an extra risk during extreme events"*.

3   Reccomendations

Based on the aforementioned studies, a few observations must be made at this point.

OBSERVATION 1

In the EN 1191-1-8, the wave overtopping assessment is not always described as a mandatory procedure. It is a strict requirement for coastal dikes and embankments (§10.4.5 and §10.5.5) but rather a recommendation for mound breakwaters (§7.4.3) and vertical breakwaters (§8.4.3). For sea walls, the standards appear even less restrictive despite the significance of the phenomenon. Citing literally:

*"Wave-induced overtopping over seawalls can induce significant damage to the structure itself or any infrastructure behind the wall or can generate hazard for people living, travelling or working immediately behind the structure and should thus be examined in detail. Due to the complexity of some seawall geometries where no overtopping formulas are available hydraulic model tests or numerical modelling **may be required** to assess the mean overtopping rate as well as individual overtopping volumes. Semi-empirical formulas based on hydraulic model tests and prototype investigations **can be used**."*

The different strictness of the so-defined rules is questionable, since, mound breakwaters, vertical breakwaters and sea walls shelter operational areas, where not only regular operations, but also the same people safety might be at stake in case of extreme events. This has been dramatically proven by winter sea storms occurring during the last decade and weather conditions worsen by climate change, as for example the so-called "Gloria" that stroke the whole southern coast of Spain and France, leading to about 20 casualties and damages for more than 15 million euros (preliminary estimate): harbor and coastal defenses in urbanized areas were seriously damaged and entire beaches were washed away.

OBSERVATION 2

In the new standards it is stated that the coastal structure design "shall" be assisted by physical model testing (§12.1) *"when empirical design equations or numerical modelling are too uncertain or out of their range of application, or when the numerical modelling is not economically feasible (e.g. CFD modelling of breakwaters)."*

Related to wave overtopping, it is then specified that (§12.4.4):

- *"Wave overtopping **shall be analysed qualitatively** through visual observations and potential overtopping-induced damage to the rear side of the structures shall be reported.*

- ***Wave overtopping discharge should be analysed quantitatively*** *by dividing the total overtopping volume by the test duration.*

- ***Instantaneous volumes should be measured for the largest waves during overtopping tests***.*"

However, based on what reported in §2 of the present document, the following recommendations are here reported:

1. **The requirement on volume measurement must be strict** instead of highly recommended. Recent literature (e.g. EurOtop, 2018) indicates maximum volumes as threshold to assess structural stability and coastal safety, along with average discharge. Instantaneous volumes **shall** be measured for the largest waves during overtopping tests.

2. **Overtopping flow properties, namely flow thickness and velocity, should be at least quantified and results should be plotted versus stability curves for pedestrian and/or vehicles**. This aspect is actually not fully treated in the current standards, however it is proven that different coastal structure layouts lead to different "risk scenarios" that cannot be directly linked to the already existing and recommended overtopping thresholds as those proposed by EurOtop (2018) and employed in the EN 1191-1-8.

OBSERVATION 3

A final observation is made on a recommendation of the experimental test programme and procedures. In §12.3.1.2 of the new standards it is stated that:

"The duration of each individual wave condition should be about 2,000 waves (between about 4 and 6 hours prototype scale). The number of waves should be greater than 1,000 to be statistically relevant."

However, test durations can be decreased in those cases where only the response of coastal structures to extreme events is investigated. For example, focused wave groups (Hofland et al., 2014; Whittaker et al., 2017; Whittaker et al., 2018), while short in time, can provide further insight into coastal responses (such as overtopping and post-overtopping processing, wave loading, etc.), and therefore can represent more effective, cheaper and faster complementary approaches for experimental campaigns conceived for final coastal defense design. Within DURCWAVE project, for example, focused wave groups have been employed to assess wave overtopping and loading on a pier structure who was heavily damage by the aforementioned storm Gloria (Altomare et al., 2021). Results will be exploited for the reconstruction of the pier.

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