TIME-DEPENDENT ANALYSIS OF WAVE OVERTOPPING: DISTRIBUTION OF INDIVIDUAL VOLUMES IN VARIABLE WATER LEVELS

Yuri Pepi, Ghent University, Ghent, Belgium, yuri.pepi@ugent.be
Maximilian Streicher, Ghent University, Ghent, Belgium, Maximilian.Streicher@UGent.be
Leopoldo Franco, Roma Tre University, Rome, Italy, leopoldo.franco@uniroma3.it
Giorgio Bellotti, Roma Tre University, Rome, Italy, giorgio.bellotti@uniroma3.it
Steven Hughes, Retired, formerly, Colorado State University, Fort Collins, USA, shughes2@engr.coloste.edu
Peter Troch, Ghent University, Ghent, Belgium, Peter.Troch@UGent.be

INTRODUCTION

The rising probability of extreme wave and storm surge events poses ever greater risks to coastal structures and populations (Toimil et al., 2020).
Central to the assessment of function ability of these coastal structures and cost-effectiveness in their construction is the wave overtopping. In this context, two aspects of wave overtopping are distinguished: the average wave overtopping discharge and the individual wave overtopping volume. Understanding both aspects are essential for a proper safety assessment. Recent studies emphasize the need to delve deeper into these aspects, especially by exploring the overtopping volumes of individual waves and in particular the maximum value, V_{max} (Koosheh et al., 2021).
Storms are dynamic events, and their effect on the still water level (SWL) can be represented as a time-varying hydrograph. As SWL changes during a storm, it is expected that also the (maximum) individual wave overtopping volumes are variable during storm events. Typically, in laboratory experiments, wave overtopping of coastal defense structures has been investigated for constant water level (CWL) conditions and a predetermined structural exposure time frame. In this approach, any variable water level (VWL) conditions are largely ignored, except in few recent studies (Pepi et al. 2022; Kerpen et al., 2020). The impact of this oversight can be substantial, as (smaller) individual wave volumes in the early stages of a storm, when the SWL rises, can pre-load or saturate the dike, potentially weakening it before the largest overtopping volumes occur during the storm's peak. No research exists yet on the study of individual overtopping volumes for a VWL situation.

AIM OF THE RESEARCH

Given these challenges and gaps in current research, this study aims to address the following objectives:

First, to calculate the individual volume distribution parameters for wave overtopping during CWL tests. Compare these parameters with existing literature to assess their validity and applicability, to serve as a reference framework for the study of individual overtopping volumes distributions with VWL. Second, to determine the individual volume distribution parameters for wave overtopping for VWL conditions, considering varying storm durations Δt and relative freeboards $R_c\backslash H_{m0}$ in the analysis. Third, to compare the individual volumes distribution parameters and V_{max} for CWL and VWL conditions, by keeping the average discharge or the cumulative volumes constant. Fourth, to analyze the individual overtopping volume distributions for different time increments during a storm. This should result in a time-dependent realization of overtopping volumes to better understand the dynamics of individual wave overtopping events for the duration of a storm with VWL's.

PHYSICAL MODEL AND RESULTS

The experimental campaign carried out in the wave flume facility at the Coastal Engineering Laboratory of Ghent University involved a total of 149 tests, incorporating both CWL and VWL conditions on a smooth slope (Figure 1). These tests featured a range of storm durations (minimum 635 waves) and VWL situations achieved through linear changes in water depth as well as changing wave conditions. A detailed description of this campaign and the collected dataset (UG17) can be found in Pepi et al. (2022).
In Figure 2, a CWL and a VWL tests are compared, both having a similar average discharge and tested under the same time series over a 15-minute duration. In the CWL test, the water depth remained constant at h = 0.55 m, while the VWL test involved a water level decrease linearly from 0.60 to 0.50 m. Importantly, the tests demonstrate the critical impact of water level variability on maximum volume. Despite having the same average discharge and average water depth, the figure illustrates significant variations in maximum volume between CWL and VWL tests, underscoring the importance of considering water level fluctuations when assessing extreme overtopping events.

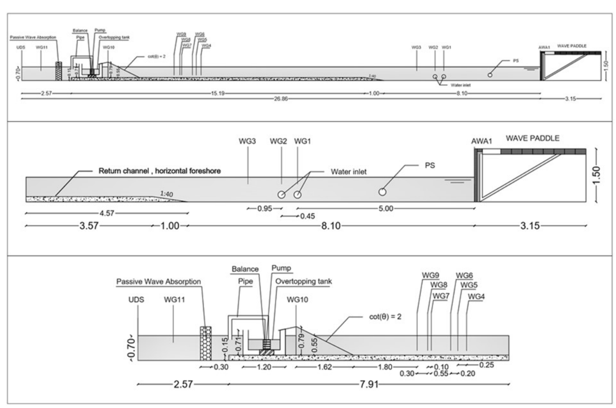

Figure 1 - Cross section of the wave flume and model set-up (Dimensions in meters).

One key finding from the present study is the ability of existing literature prediction formulae, designed for CWL situations, to provide valuable insights for the VWL conditions as well, when appropriate upper fitting thresholds for the overtopping volume distributions are selected, to achieve the best prediction accuracy using the existing prediction framework.

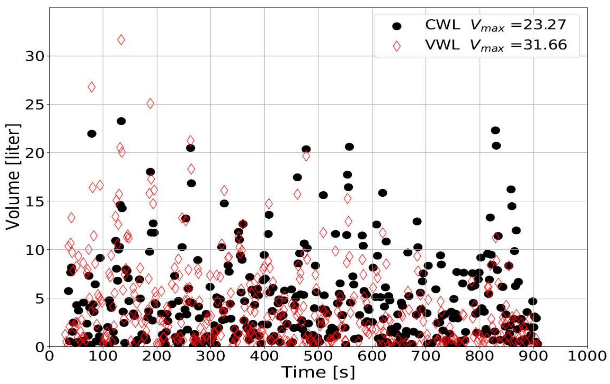

Figure 2 –Comparison between of individual volumes for a CWL (black) and a VWL (red) test under the same wave conditions (Hm0 = 0.10 m, Tp = 1.70 s).

The Figure 3 showcases the probability of overtopping waves (P_{ow}), defined as the ratio of overtopped waves to incident waves (N_{ow}/N_w), for both CWL and VWL. In the upper plot, the data is graphed against the relative freeboard. In the lower plot, a novel parameter termed the " equivalent non-dimensional freeboard," as introduced by Pepi et al. (2022), is applied. This novel parameter redefines the quantification of freeboard and is depicted in the lower plot to show its influence on the probability of overtopping waves.

The principal observation from this figure is the noticeable improvement in prediction accuracy when employing the equivalent freeboard, compared to the traditional relative freeboard. This suggests that the modified parameter proposed in the paper by Pepi et al. (2022) offers a valuable tool for Individual volume prediction too.

Notably, the utilization of the equivalent freeboard results in a slight overprediction of P_{ow}, mirroring the patterns observed in CWL results, suggesting a consistent pattern across diverse conditions that may offer valuable insights for the modeling of wave overtopping.

Based on the data collected in this study, the prediction performances of the existing empirical formulae are evaluated, and their limitations identified. Some evidence from conducted experiments will be presented to demonstrate the influence of VWL on the individual volume overtopping distribution parameters as it has not been considered in the EurOtop (2018) formulation. The findings will be presented at the conference and aim to enhance the practical understanding for the assessment of function ability and safety of coastal defense structures involving VWL's.

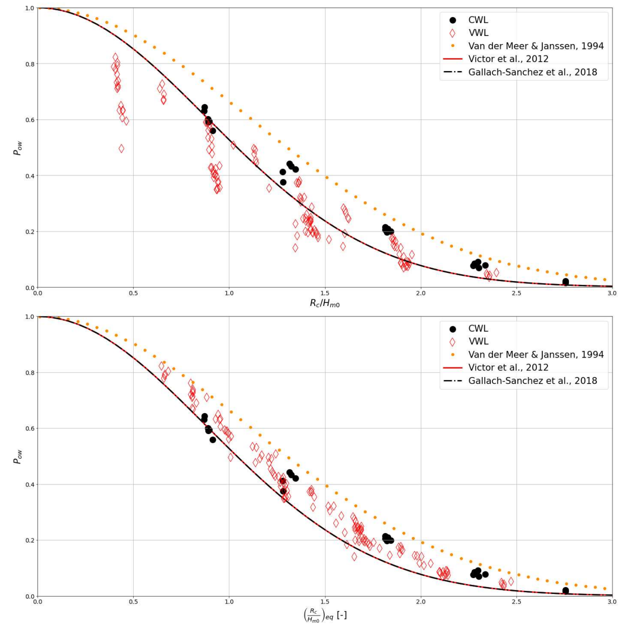

Figure 3 – Comparison of Overtopping Wave Probability (P_{ow}) with Relative Freeboard (top plot) and Equivalent Freeboard (lower plot) introduced by Pepi et al. (2022). Various prediction curves from previous studies and the test results with VWL (Red Empty Diamonds) and CWL (Black Circles) are shown.

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