Extended Abstract

The Influence of Dynamic Water Level Changes in Physical Model Tests on the Wave Overtopping

Nils B. Kerpen [1,*], Karl-Friedrich Daemrich [1], Oliver Lojek [1] and Torsten Schlurmann [1]

[1] Leibniz University Hannover, Ludwig-Franzius-Institute for Hydraulic, Estuarine and Coastal Engineering; kerpen@lufi.uni-hannover.de

* Correspondence: kerpen@lufi.uni-hannover.de; Tel.: +49-511-762-3740

The required design freeboard height of a costal defense structure is usually determined by hydraulic model tests. Also prediction formulae are frequently used which are empirically derived and based on analysis of data stemming from hydraulic model tests. Laboratory standard routines focus on wave overtopping prediction by means of translating a corresponding static design water level (*SWL*) in a wave flume or basin without mimicking the real non-stationary water level or change of wave steepness during storm surges conditions. Experiments in laboratory environments are typically conducted with waves of varying height and steepness. Subsequently, processes and magnitudes of wave run-up and overtopping on the coastal defense structure are investigated for a pre-determined structural exposure time frame. Collected data are usually normalized over time and width of the structure's crown length in order to yield a robust design estimate that is comparable with other modelling approaches or for conversion to prototype scale of the structure.

It is a common standard in laboratory facilities that a typical time series for of a representative wave spectrum in a single hydraulic test focusing on wave overtopping contains (at least / at most) 1,000 individual waves whereas this value by itself is worthy of discussion [1]. A larger number of incident waves, i.e. longer time series in laboratory facility, allows a more statistically representative data set ([2], [3]) by means of attenuating the weight of individual extreme waves on run-up and overtopping in the data series. Nonetheless, the recommended design parameter of 1,000 waves represents a kind of artificial commodity in laboratory wave experiments which is capable to represent a typical storm and storm surge of ~ 3 hours in the North Sea, e.g. at the German coast. Yet, it is obvious that the *SWL* during a natural storm surge is always not constant, but simplified in the present model approximation in laboratory facilities. Astronomical tides as well as global and local wind fields, meteorologically induced pressure fluctuations as well as infragravity and swell waves from the north east (NE) Atlantic affect and subsequently alter the near-shore *SWL* – particularly during a storm surge – and lead to an oscillation with corresponding periods from hours to days [4].

Typical dynamical features of the *SWL* is exemplarily depicted in Figure 1 a) by the hydrograph of the gauge 'Lighthouse Old Weser' (*LAW*) in the North Sea in vicinity of the artificially maintained outer estuary of the river Weser [5]. The gauge has a standard elevation zero of *NHN16* = – 4.96 m and is located about 10 km NE of the German island Wangerooge. The three storms Christian (10/2013), Xaver (12/2013) and Elon (01/2015) are analyzed for reference. The locally gathered non-stationary water level $h_s(t)$ is presented ± 3 hours before and after the maximum peak of the storm surge and normalized by the maximum water level $h_{s,max}$ in subfigure a). The temporal evolution of the wave steepness (b), wave height (c) and wave period (d) are given additionally (dt = 60 s, corresponding time window for spectral analysis: 15 minutes). Obviously, the water level of each individual storm surges varies significantly ($\Delta h_s \approx 3.0$ m) as well as the intensity in the analyzed time interval. For all three storm surges the wave steepness reaches its maximum at the peak water level and is attenuated with decreasing water level (b). Within three hours, the mean wave steepness increased from 0.01 to 0.015. The maximum wave height is reached about 1 hour before the storm surge peak water level and is almost constant until the peak water level and decreases afterwards (c). During the three hours before the peak water level the wave height increased about 1.0 m for storm Xaver and storm Elon and 2.5 m for storm Christian. The wave period was almost constant for storm Xaver ($T_p \approx 7.5$ s) and storm Elon ($T_p \approx 7.5$ s) whereas for storm Christian the wave period increased significantly from 3 to 2 hours before the peak (4 s < T_p < 7.5 s, with a temporary maximum of $T_{p,\max} = 11.4$ s) and is from there on almost constant. Re-analysis of storm surge characteristics and associated wave conditions for the three exemplarily picked storms and data at gauge LAW is far from being representative for all locations and storms on the German North Sea coastline, but should rise awareness of non-stationary quality of typical water level and wave condition during storm conditions. The evidently identified dynamical features of *SWL* and the associated time-varying hydraulic parameters are not represented in any commonly acknowledged hydraulic model test configuration. It is therefore necessary to revisit and understand the underlying processes and elucidate the role of non-stationary water level and wave steepness on the robustness of wave overtopping estimation. The proper adjustment of temporal alterations of design parameter in laboratory facilities is a chief attribute in order to determine the means and quality of non-stationarity on the determined wave overtopping volumes as it is well known that the remaining freeboard height R_c is directly related to the mean wave overtopping discharge q. The wave overtopping discharge increases for decreasing freeboard heights and a decreasing wave steepness. Figure 1 indicates that both quantities fluctuate in nature during a time interval of 3 hours (10,800s/~7.5s (T_p) ≈ 1,400 waves). As many findings regarding the wave overtopping are based on hydraulic model tests with a comparable number of waves but a constant characteristic wave steepness and a constant water level the meaning of this model approximation shall be discussed in in this paper. A special set of hydraulic model tests is designed and conducted in a mid-sized laboratory facility in order to refer to the initial question whether dynamically altered water level changes and a varying wave steepness are robustly represented in existing design formulae originating from static configurations in experimental facilities.

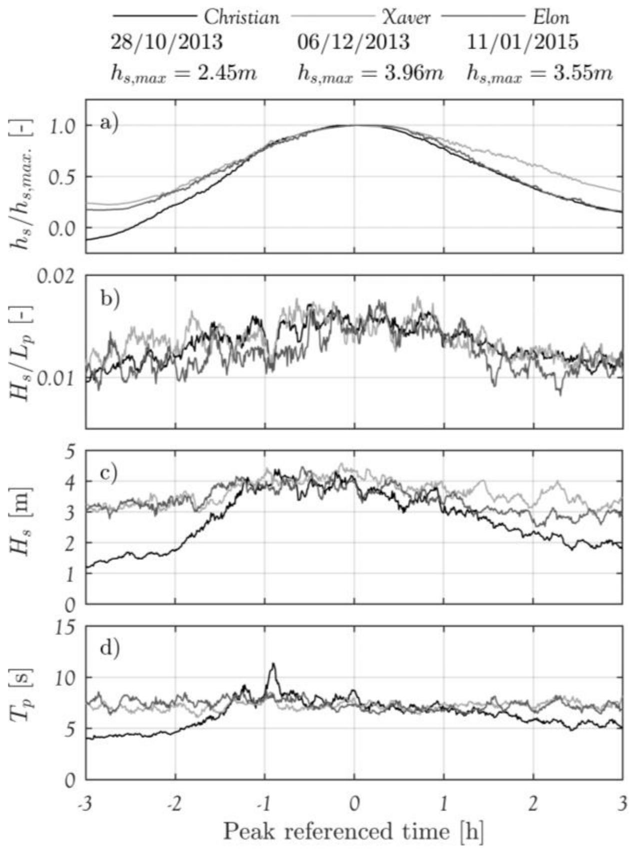

Figure 1. Non-stationary characteristics of storms Christian (10/2013), Xaver (12/2013) and Elon (01/2015) measured at gauge 'Lighthouse Old Weser' [5] (Estuary of the river Weser in the German bight) ± 3 hours before and after the maximum peak of the storm surge with a discretization of 60 measured data per hour. Time series of a) Water level $h_s(t)/h_{s,max}$, b) wave steepness $H_s(t)/L_p(t)$, c) wave height $H_s(t)$, d) wave period $L_p(t)$.

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