PERFORMANCE STUDY OF A LOW-PASS FILTER TO MODEL ENERGY DISSIPATION DUE TO MULTIDIRECTIONAL WAVE BREAKING IN HOS-NWT

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INTRODUCTION

The open-source available High Order Spectral - Numerical Wave Tank (HOS-NWT) (Ducrozet et al., 2012) is an extensively validated and widely used model to simulate waves in a wave basin. For instance, Vyzikas et al. (2021) proved a very good performance of HOS-NWT for the surface dynamics of steep focused wave groups. However, since the model is a free surface potential flow solver, modelling breaking waves within this framework is far from straightforward. Yet, if one's interest is in capturing the effect of breaking on the overall wave-field evolution, rather than in deterministically replicating extreme breaking events, applying a simple low-pass filter in the wavenumber space could already give reasonable results (Slunyaev and Kokorina, 2020). The aim of this study is to verify the performance of such a low-pass filter to replicate the wave statistics in a numerical twin of the Coastal & Ocean Basin (COB) in Ostend (Belgium) for various sea states. To do so, experiments in the COB have been done on long- and short-crested waves of different steepness's and peak periods. The realized paddle motions during these experiments are then used as input for the numerical twin of the COB based on HOS-NWT in which the low-pass filter proposed by Xiao et al. (2013) is included. By comparing the resulting wave statistic in the physical and numerical basins, it will be decided whether the low-pass filters give acceptable results for the practical applications envisaged for the numerical twin of the COB or if more elaborate breaking models need to be included.

EXPERIMENTAL SETUP

Experiments were done in the COB, a 30 m x 30 m wave basin equipped with segmented, piston type wavemakers on two adjacent sides. The considered experiments were done at the basins maximum water depth, which equals 1.4 m. JOWSWAP spectra with two peak periods are considered: T_p = 0.8, and 1 s. For both peak periods, four distinct peak steepness's were targeted: k_pA_s = 0.10, 0.15, 0.2, and 0.25, where k_p is the peak wavenumber considering the linear dispersion relation and A_s is defined as the significant wave amplitude. Irregular waves are generated by assigning a set of random complex coefficients to all frequency components, resulting in random phases and amplitudes. 1500 waves are realized for all spectra with four different directional spreading scenarios: one unidirectional case and three cases where a cos2s distribution is applied with s = 25, 10, and 3.

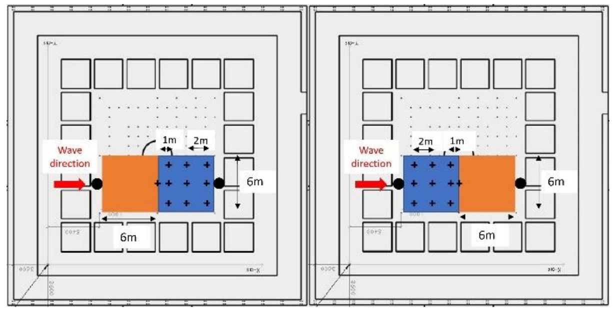

Figure 2 - Schematic overview of the experimental setup during the first (left) and second (right) half of the campaign

To measure the evolution of the spectrum along the basin, nine equally spaced wave probes were attached to a 6 m x 6 m measurement truss. A picture of this truss can be seen in Fig. 1. To cover a larger area of the basin, the truss was moved halfway through the experimental campaign, after which the exact same sea states were realized in the second measurement setup. To guard over the repeatability of the two realizations, a single probe stayed in position right in between the two distinct truss positions. Furthermore, a five-probes directional array is located both in front of and after the area of interest to check the generated directional spectrum. This is clarified in Fig. 2, where the crosses indicate the location of a single probe and the circles represent the directional arrays.

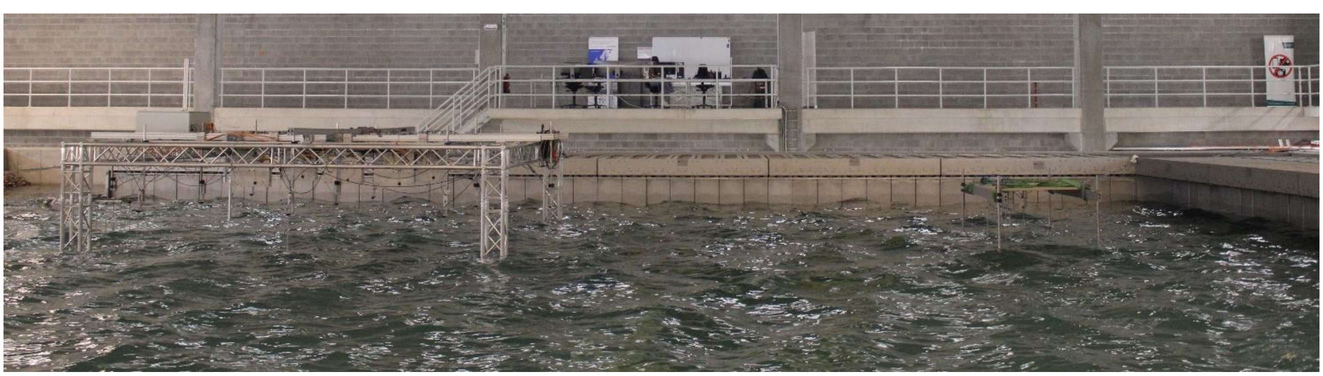
Figure 1 - Picture of the experimental setup during first half of the campaign

MODELLING BREAKING IN HOS-NWT

The difficulty of accounting for breaking waves is one of the major drawbacks of HOS models. Recently, work has been done on finding a reliable parametrization for breaking events in unidirectional HOS models. The breaking criterium of Barthelemy et al. (2018) shows good performance in HOS models (Seiffert et al., 2017). When breaking waves are detected, one can use parametrized breaking models to estimate the associated energy dissipation. Two unidirectional wave-breaking energy dissipation models have been included in HOS-NWT. Their performances are extensively compared in different wave conditions (Seiffert and Ducrozet, 2018). The first one is the Tian dissipation model (Tian et al., 2012). The parameterization used in the Tian model is barely dependent on the wave conditions. The second one is the Chalikov breaking model (Chalikov and Babanin, 2012; Chalikov and Babanin, 2014). For this dissipation model, the parameters are very dependent on both the domain and wave conditions, but when calibrated properly it can handle even the most extreme conditions.

Given the multidirectional character of the COB, it is essential that its numerical twin can handle short-crested breaking waves. One way to do so is by trying to translate the unidirectional breaking criterium and dissipation models to a multidirectional case. On the other hand, it is well known that energy dissipation due to breaking generally takes place in the high-frequency range of the spectrum (Rapp and Melville, 1990). Following these observations, one can try to include the effect of wave breaking by simply applying a low-pass filter at each time step of the HOS scheme. Xiao et al. (2013) propose subsequent filter in the wave number space:

$$\wedge\left(\boldsymbol{k} \middle| k_p, \beta_1, \beta_2\right) = \exp\left(-\left|\frac{k}{\beta_1 k_p}\right|^{\beta_2}\right)$$

where $k = |\boldsymbol{k}|$, $\boldsymbol{k} = (k_x, k_y)$ and β_1, β_2 are filter parameters. Since this approach is more simple and convenient to implement, in the first instance the performance of this low-pass filter for the performed experiments is investigated. Although Xiao et al. (2013) concluded that the estimation of the energy dissipation is somewhat insensitive to the values of β_1, β_2, these parameters are first calibrated based on the data of some preparatory experiments in the COB. Thereafter, the model is run using the realized paddle displacements during the experimental campaign.

PERFORMANCE OF THE LOW-PASS FILTER

The performance of the chosen low-pass filter to model wave-breaking energy dissipation will be assessed by comparing the wave statistics at the different probe locations in the physical and numerical wave tanks. For the long-crested cases, a comparison with the more elaborate breaking models discussed in the previous section will be made as well. This comparison gives an indication of the gain in accuracy that can be achieved by translating these breaking models into a multidirectional case. To compare the spectra with one another, the significant wave height, peak period, skewness and kurtosis are calculated. Furthermore, the Improved Surface Similarity Parameter (ISSP) is determined, as well as the normalized difference between the spectral densities in the interval $\left[\frac{3}{4}f_p, \frac{3}{2}f_p\right]$.

CONCLUSIONS

The performance of a low-pass filter to model energy dissipation due to breaking waves in HOS-NWT is examined by comparing the results of simulations with physical experiments in various sea states.

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