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BREAKING WAVE STATISTICS IN SHORT-CRESTED SEAS

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1. INTRODUCTION

The accurate prediction of loads to allow for a safe yet efficient design of coastal and offshore structures requires a thorough understanding of the distribution of crest heights. Although deep water waves are relatively well understood and accurately modelled by existing wave and crest height models, the same cannot be said for waves in intermediate and shallow waters (Tayfun & Alkhalidi, 2020). This work addresses this gap by analysing long, random records of laboratory-generated short-crested seas. The analysis focuses on the application of a novel method to identify waves that undergo significant nonlinear amplification and breaking. Following their identification, the associated energy transfers and dissipation are calculated per wave and probabilistically approximated. A modelling suite is proposed to describe the probability of wave breaking and associated dissipation in short-crested seas. This is then converted into a mixture model to recover crest height statistics. The success of the proposed approach is demonstrated through comparisons between model predictions and measurements.

2. METHODOLOGY

The experimental data, which forms the basis of the analysis in this study, was generated in the Imperial College London wave basin, with plan dimensions of $10m \times 20m$ and a water depth, $d = 0.5m$ by Karmpadakis et al., (2019). A summary of the generated sea-states is given in Table 1. In total, 54 sea-states have been considered, each comprising of 20 random simulations, i.e. approximately 20,000 waves per sea-state. Each sea-state is defined on the basis of its significant wave height, H_s, peak period, T_p, and standard deviation of the (wrapped-normal) directional spreading, σ_θ.

Table 1. Laboratory test cases (expressed in field scale).

Sea-state	$T_p\ [s]$	$H_s\ [m]$	$S_p = \frac{2\pi H_s}{g{T_p}^2}$	$\sigma_\theta [°]$	$k_p d$
A1-A7	12	2.2, 4.4, 6.7, 8.9,11.2, 13.4, 15.7	0.01-0.07	0, 10, 20	1.53
B1-B6	14	3, 6.1, 9.1, 12.2, 15.3, 18.3	0.01-0.06	0, 10, 20	1.22
C1-C5	16	3.9, 7.9 11.9, 15.9, 19.9	0.01-0.05	0, 10, 20	1.02

The experimentally generated data are simulated numerically using potential flow theory correct to $(\mathrm{ak})^2$ and excluding wave breaking effects. Following the time-space alignment methodology of Karmpadakis & Swan (2020), we obtain an exact match between lab and numerical data for low steepnesses and any deviations are observed for steeper cases (e.g. $S_p > 0.03$). As such, a robust wave classification on effects above $(\mathrm{ak})^2$ may be quantified. This coupled dataset is utilised to categorise experimentally generated crest height, η_c, into three populations based on the ratio between the laboratory crest height and the corresponding numerically simulated crest height, r. This methodology is summarised by Figure 1(a).

Based on this definition, a value of r >1 indicates that laboratory waves are amplified due to effects beyond second-order, whereas a value of $r < 1$ indicates that the laboratory waves are dissipated due to breaking. However, to account for experimental uncertainties, a buffer of 5% is added either side such that three wave populations are defined as “amplified”, “unchanged” and “broken”. The distribution of “broken” and “amplified” waves is shown in Figure 1(b).

"Broken" waves are negatively skewed, whereas "amplified" waves are positively skewed. Based on these observations, the Beta distribution is employed to model "broken" waves and a Gamma distribution is utilised for "amplified" waves. The same ratio is used to quantify the energy gain/dissipation between the second-order predictions and lab measurements.

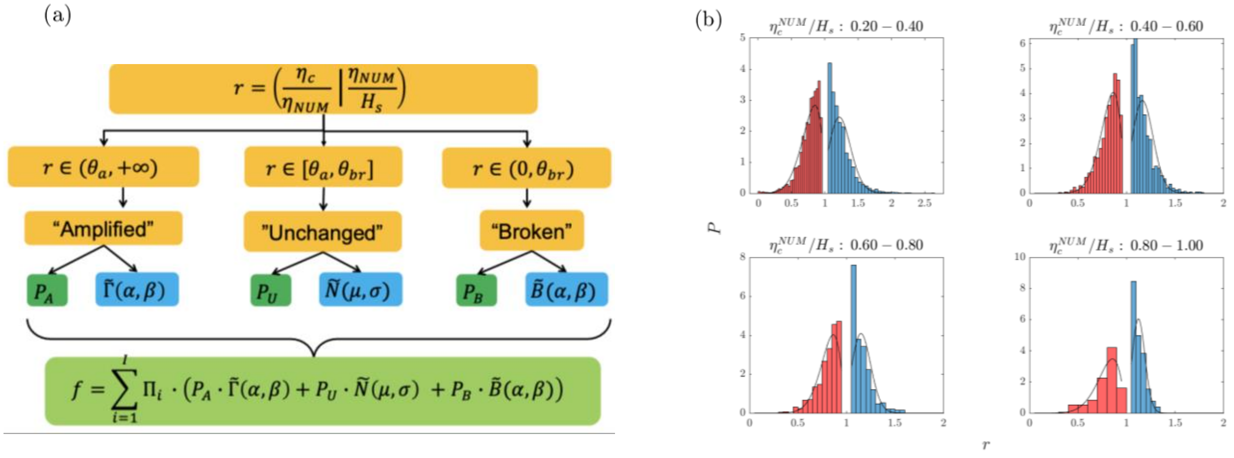

Figure 1. (a) Wave classification algorithm and mixture model. (b) Histogram of r in sea-state A3 with $\sigma_\theta = 10°$, for different $\eta_c{}^{\text{NUM}}/H_s$ bands, indicating broken (red) and amplified (blue) waves and associated distributions (black).

3. Discussion and conclusion

Figure 2 demonstrates the application of the newly-proposed mixture model outlined in Figure 1(a). Within this figure, the proposed model shows good agreement with observations and a major improvement from state-of-the-art modelling for nonlinear (case B3) and breaking (case C5) sea-states. More broadly, good agreement is observed across a wide range of conditions with notable improvements in the prediction of extreme waves lying at the tail of the distribution. In addition, the proposed approach carries additional information relating to the occurrence probability of wave breaking. This becomes increasingly important for wave loading calculations where breaking leads to disproportionally larger structural loads (Karmpadakis & Swan, 2022).

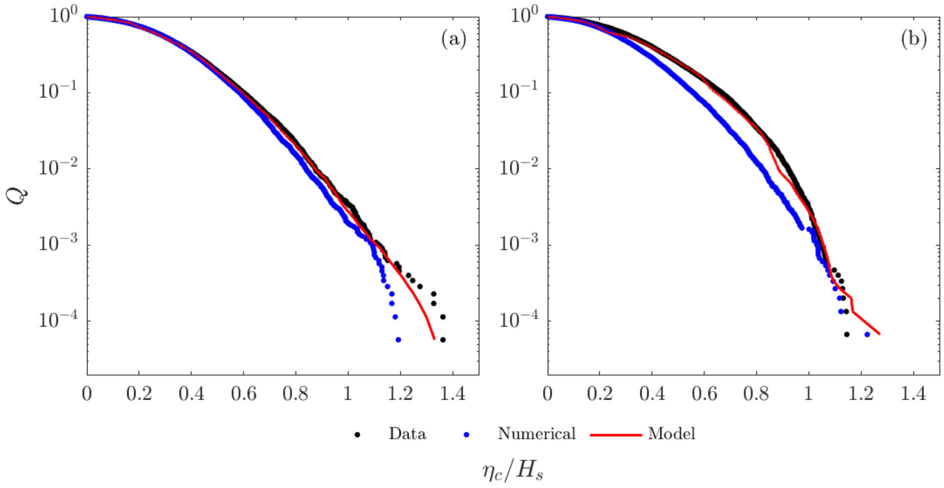

Figure 2. Normalised crest height distribution $\left(\frac{\eta_c}{H_s}\right)$ of laboratory data, numerical simulations and proposed mixture model predictions relating to (a) case B3 and (b) case C5, both with $\sigma_\theta = 10°$.

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