Numerical modelling of irregular wave transformation and breaking over a sloping seabed: validation against experiments and statistical distribution of extreme waves.

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Abstract

This study focuses on the statistics of wave heights and wave crests in the shoaling and breaking zones for irregular long-crested waves propagating on a smooth sloping bottom with a constant gradient of 1/50. A detailed experimental campaign was recently conducted in a wave flume at Imperial College London (Bellos et al., 2023); the flume is 23 m long, 0.60 m wide and the offshore water depth was set to 0.50 m in all cases. Four peak periods were considered from 1.2 to 1.6 s, and for each of them 4 to 6 increasing significant wave heights (and associated wave steepness) were tested. For each configuration, wave generation lasted 1024 s (roughly 3 hr at field scale) per run, and 20 runs were performed with different sets of random phases, thereby forming a large sampling space and enabling robust estimation of stochastic properties. Recently, these tests have been numerically simulated by Al Khalili et al. (2025) using the SWASH code. In the present work, we use the fully nonlinear potential flow (FNPF) code whispers3D (Zhang & Benoit, 2021) to simulate this set of experiments and analyse the spatial evolution along the bathymetric profile of characteristic wave heights, statistical moments of the free surface elevation (e.g. skewness, kurtosis), as well as the statistical distributions of wave heights and wave crest heights. The numerical code includes a model for depth-induced breaking, developed and validated in Simon et al. (2019).

We first present the steps involved in setting up and calibrating the numerical model, followed by an analysis of the results of sea-state parameters and integral statistics, and the evolution of wave distributions, with particular emphasis on the breaking zone, by comparing simulation results with experimental measurements. We also compare these results with existing models of statistical distributions in the surf zone (e.g. Battjes & Janssen, 1978; Thornton & Guza, 1983; Karmpadakis & Swan, 2022).

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