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Analytical and numerical modelling of wave dissipation over rigid and flexible vegetation in a flume: Drag coefficient calibration

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ABSTRACT

Data of wave dissipation over vegetation fields was collected from laboratory flume experiments, for different vegetation and wave conditions. An analytical model and a numerical model are applied to estimate the wave dissipation obtained in the experiments, through the calibration of the bulk drag coefficient (C_D). Results and conclusions will analyse and compare each model behaviour and obtained C_D values.

1. Introduction

Coastal vegetation can contribute to protect the coasts from sea wave action, as controlling local biology and morphodynamics. A common way to estimate the wave energy dissipation over vegetation is to use the Mendez and Losada (2004) analytical formulation in combination with the calibrated bulk drag coefficient parameter (C_D). However, an excessive range of C_D values is found in the literature related to same Reynolds (Re) or Keulegan-Carpenter (KC) numbers. This may be due to a lack of universality of the empirical equations proposed and/or limitations of the analytical model. The numerical model SWASH (Zijlema et al., 2011) characterises wave dissipation over vegetation fields (Suzuki et al., 2019, 2022; Reis et al., 2020) considering the influence of the drag, inertia, and porous effects on cylindrical structures. Potentially, SWASH offers enhanced capacities to describe the physical processes involved and to calibrate associated C_D values. Wave dissipation over vegetation data was collected by performing laboratory flume experiments, enabling an ideal control of the study conditions. The analytical formulation and the SWASH numerical model are applied to estimate the wave dissipation obtained in the experiments, through the calibration of the C_D.

The objective of this study is to investigate: i) how the analytical and SWASH models can represent the experimental wave dissipation, and ii) the calibrated C_D values obtained from each modelling approach.

2. Flume Experiments

Wave flume experiments of wave propagation over artificial vegetation fields were conducted in COI3 wave flume at Portuguese National Laboratory for Civil Engineering (Fig. 1).

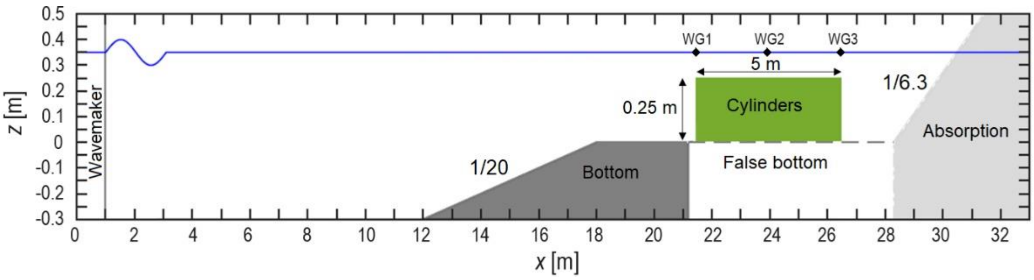

Fig. 1. Wave flume layout schematisation.

Vegetation fields were constructed from rigid (flexural rigidity EI = 6.5 N m^2) and flexible (EI = 4×10^{-4} N m^2) cylinders, regularly distributed with vegetation spatial densities N_v = 220 elm/m^2 (N220) and 440 elm/m^2 (N440). The cylindrical elements in rigid and flexible vegetation fields had the same dimensions (diameter $d_v = 0.01$ m, and length $l_v = 0.25$ m). The vegetation fields were exposed to non-breaking regular wave conditions with wave periods $T = 1.4$ s and 2.0 s, and several wave heights (H). Two still water depths were tested, $h = 0.35$ m and 0.25 m, corresponding to submergence ratios ($Sr = l_v/h$) $Sr = 0.7$ and 1.0. Measurements of the free-surface elevation (η) were taken using wave gauges (WG) at the edge, middle and back of the vegetation fields (Reis et al., 2024).

3. Analytical and Numerical Modelling

Experimental results of wave dissipation over vegetation obtained in the flume tests were modelled using the Mendez and Losada (2004) analytical formulation by calibrating/fitting the parameter C_D.

The SWASH model based on the nonlinear shallow water equations is applied to simulate the wave *dissipation by vegetation obtained in the experiments by performing a calibration to the* C_D*. Numerous* numerical simulations are run in order to obtain the final C_D result, corresponding to the best agreement between the numerical and experimental data, for each simulated experimental test condition. The SWASH model was run in nonstationary mode using a regular computational grid. At the boundary of the SWASH domain, the regular waves were generated imposing for each run the respective free-surface elevation (η) time series measured in the laboratory tests at the front-edge (WG1). A sponge layer was used to simulate the energy dissipation from wave breaking in the tests, that only occurred in the absorption zone at the flume end. Non-hydrostatic pressure was included using the Keller-box numerical scheme, and vertical discretization was considered.

4. Main Results and Discussion

Results are analysed for i) the wave dissipation obtained in the experimental tests, ii) the performance of both models to simulate the experimental data (Fig. 2) through the root mean square error (RMSE) and mean relative error (MRE) between the models' and experimental results, iii) empirical relations of the C_D results with the Re and KC numbers, and iv) differences in the C_D obtained from calibration of both models. Results for different tested vegetation fields and wave conditions will be presented. Preliminary results generally indicate that despite an overall similar estimation of the experimental data is obtained from the two modelling approaches, a difference in the corresponding C_D values is observed.

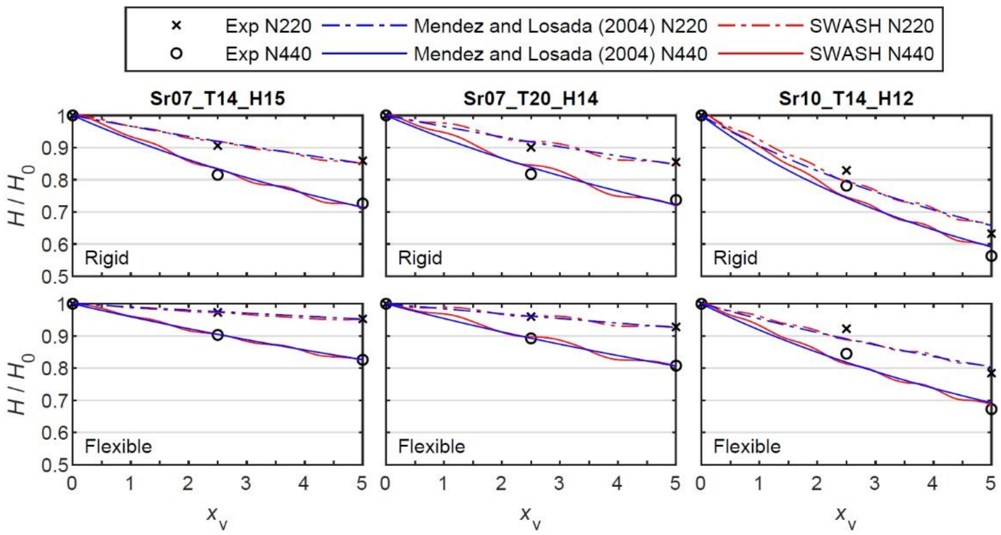

Fig. 2. Wave dissipation (H/H_0) over the tested vegetation fields: results of both calibrated analytical formulation (Mendez and Losada, 2004) and SWASH model against the experimental data.

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