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EXPLORING WAVE-VEGETATION INTERACTION AT BLADE SCALE: A COMPREHENSIVE ANALYSIS OF A FLEXIBLE CYLINDER THROUGH EXPERIMENTAL DATA AND A DIRECT NUMERICAL SIMULATION

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1 INTRODUCTION

Aquatic vegetation in the littoral zone, particularly seagrass, is gaining increasing recognition for its net positive impact on the hosting environment. This recognition is rooted in its capacity to absorb wave energy, regulate water flow, and manage nutrient levels, sedimentation and accretion. Thus, there is a growing interest in integrating seagrass as a key component of a comprehensive climate-conscious strategy (Ondiviela et al., 2014). An effective approach to quantify the positive potential of seagrasses in altering coastal wave dynamics is by using numerical models. These numerical models operate at various spatio-temporal scales, ranging from large domains and multiple years to just a few regular waves in high resolution CFD numerical simulations. Zeller et al. (2014) classified these models, operating at different scales into three categories, each addressing the wave-vegetation interaction at a distinct scale: (1) blade scale, (2) meadow scale, and (3) ecosystem scale. The aim of the present study is to investigate the interaction between waves and vegetation at the blade scale. The primary objectives are two: first, to introduce a direct numerical technique that involves a two-way coupling between a fluid solver and a structural solver, and second, to present novel experimental data for a single flexible cylinder (Reis, 2022) serving as validation for the present (and future) numerical model(s).

2 EXPERIMENTAL DATA

Wave flume laboratory testing was carried out in a wave flume at the National Laboratory for Civil Engineering (LNEC) in Lisbon, Portugal. Flexible sponged rubber cylinders, designed to mimic real seagrass properties at an approximate scale, were utilized in the study. The mimics were placed in a regular configuration forming a 5 m long by 0.5 m wide patch. Second-order regular waves were generated until the mimics developed a consistent swaying motion under the action of the waves. Data collection was designed to reflect the (i) hydrodynamic forcing and (ii) the vegetation response at the blade scale. Therefore, the surface elevation, water particle velocity, and flexible cylinder feedback were recorded for a single cylinder at half the patch length (Reis, 2022). Building upon this experimental data set the objective is to develop a blade-scale numerical model able to directly resolve the energy transfer mechanisms.

3 NUMERICAL MODELLING

Numerical modelling is conducted using the meshless Smoothed Particle Hydrodynamics (SPH) code, DualSPHysics (Domínguez et al., 2021). To handle elastic structure interactions, the model is also coupled with a Finite Element Analysis (FEA) library (Martínez-Estévez et al., 2023), which has been used to simulate flexible vegetation (El Rahi et al., 2023). The code is very highly parallelized on GPU and can simulate multiple waves in a 3-D domain using high resolutions. The numerical flume configuration, shown in Figure 1, includes a wave generation paddle at one end and a numerical beach with velocity damping for absorption at the opposite end. In the center of the flume, the cylinder is configured using a flexible cantilever sponged rubber beam, with section and mechanical properties (flexural rigidity, density, dimensions) specified according to the experimental data without employing free parameters. The numerical model is applied to resolve the wave-vegetation interaction at the blade scale, for a single flexible cylinder. As such, the hydrodynamic data acquired in the laboratory at the location of the central solitary cylinder is used to achieve the target wave field in the numerical domain. Throughout the simulation, data on markers, including the swaying velocity and distance of the flexible element, as well as transferred forces, is recorded.

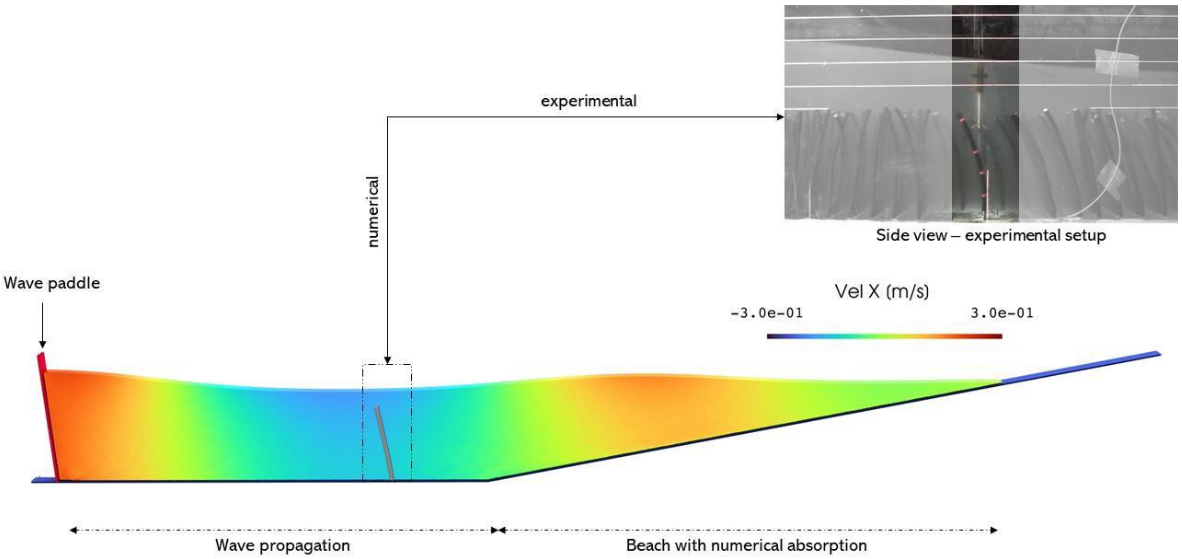

Figure 1: A composite graphic displaying a side-view snapshot from the laboratory alongside a digital replica (numerical flume) generated using the coupled SPH-FEA model. The horizontal water velocity is plotted using a jet color gradient, while the flexible cylinder is represented in grey color.

4 RESULTS AND FUTURE WORK

Extended experimental data and numerical results will be showcased at the conference. Initial model outputs validate the numerical technique's capacity to resolve flow properties, swaying motion, and energy transfer at the blade scale. Numerical force computations align perfectly with experimental data and offer detailed force distribution, surpassing single-point experimental measurements. This agreement extends to swaying distance. Our next phase involves conducting larger simulations with multiple cylinders to explore their interactions.

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