SPH modelling of vegetation-induced wave dissipation: implementation and applications

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INTRODUCTION

Wave attenuation under coastal vegetation results from complex hydrodynamics, where energy is removed from the mean flow due to the resistance created by the vegetation. At the scale of an individual plant, this decrease is directly linked to the transformation of energy into turbulent kinetic energy. Numerical models can capture this turbulence shedding when using very high resolutions, but not without a cost. Their applications will be limited to small spatiotemporal scales with regular waves and a single vegetation. This is sufficient for estimating the drag coefficient and investigating flexibility at the blade scale but does not provide a direct computation of wave attenuation over a densely populated vegetation patch. To enhance the scalability of numerical models used to study wave propagation over vegetation meadows, a well-established approach in literature is to implicitly account for energy transfer in the system by introducing an energy sink term into the flow equations. This method is computationally efficient and can overcome the spatiotemporal limitations inherent in direct models. The initial description of wave dissipation was presented by Dalrymple et al. (1984), estimating the energy transfer by integrating the force on a cylinder across its vertical span. An extension of this method to account for varying depths and stochasticity was published by Mendez and Losada (2004). Numerically, these formulations have been widely adapted and implemented in both time and frequency domain models, such as the vegetation model in SWAN and in SWASH by Suzuki et al. (2012) and Suzuki et al. (2019) respectively.

RESEARCH OBJECTIVE

The objective of this present research is to extend the governing equations of the meshless Smoothed Particle Hydrodynamics (SPH) method within the opensource DualSPHysics Domínguez et al. (2022) software to incorporate the phenomenon of wave attenuation over vegetation fields. In our approach, we subtract energy from the system by estimating the work done on vegetation using the cylinder approach. The proposed method is computationally efficient and benefits from the ability of the SPH method to resolve violent flows in turbulent coastal environments.

NUMERICAL IMPLEMENTATION

The governing equations in the SPH method are spatially discretized using particles, which represent data points where physical attributes such as velocity, pressure, position, and density are defined. Using a distance function, a neighbor list is defined and the physical quantities are calculated using the following momentum equation:

$$\left.\frac{dv}{dt}\right|_a = -\sum m_b \left(\frac{P_b + P_a}{\rho_a \rho_b}\right) \nabla W_{ab} + (\Gamma)_s + \boldsymbol{f} + F_{veg} \qquad (1)$$

where the attributes of particle *a* are calculated using a list of neighboring particles *b* with pressure P, density ρ, and mass m. A kernel function W is used to identify the neighboring particles, while the dissipative terms are represented by Γ and the external forces by *f*. The energy exchange between the waves and the vegetation is denoted by F_{veg} and is calculated as follows:

$$F_{veg} = \frac{1}{2}\, \rho\, C_d\, A_{veg}\, u\, |u| \qquad (2)$$

where C_d is the drag coefficient, A_{veg} is the drag area and u is the horizontal component of the flow velocity.

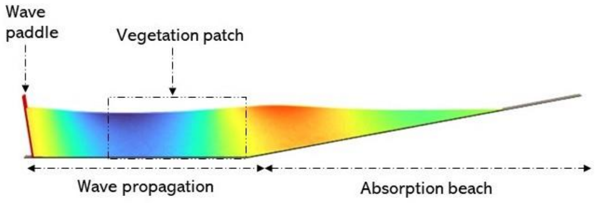

Figure 1 - Sketch of the Numerical wave tank with a vegetation patch.

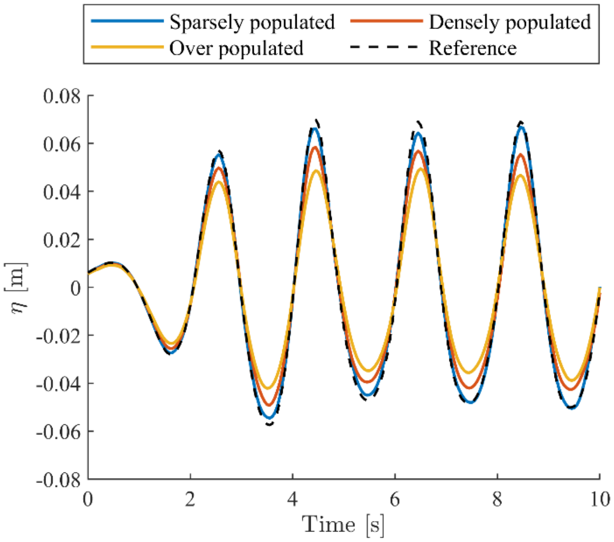

Figure 2 - Surface elevation downstream from the vegetation patch, color-coded for different vegetation densities, with a dashed line denoting benchmark data without vegetation.

RESULTS AND PROSPECTS

A numerical wave tank was employed for the validation of the code implementation, as depicted in Figure 1. The wave tank consists of a piston-type paddle for wave generation and a beach designed for wave absorption.

First, a reference simulation was conducted to establish benchmark data for wave propagation in the absence of vegetation. Subsequently, three scenarios were explored, each with varying spatial densities of vegetation. Across all three scenarios, regular waves were generated and the vegetation patch extended over a length of 2 wavelengths and was positioned one wavelength away from the wave generation point. As illustrated in Figure 2, the results clearly demonstrate that the wave attenuation at the downstream end of the vegetation patch increases with higher vegetation density. Importantly, the code accurately captures wave decay while incurring no additional costs. To further advance this research, the next phase of numerical validation will involve the use of irregular waves and parameters as described in Stratigaki et al. (2011). Following this, we will conduct simulations utilizing the implicit vegetation module presented in this work to investigate violent flows and coastal processes, including overtopping and fluid-structure interaction. The main advantage of this implicit method for wave-vegetation interaction is its ability to handle simulations that would be computationally infeasible using a direct method,

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