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PRE-CONFERENCE SHORT COURSE & LAB WORKSHOP: PHYSICAL MODELLING OF COASTAL VEGETATION TO IMPROVE GREEN INFRASTRUCTURE DESIGN

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1 INTRODUCTION

Salt marshes are important coastal ecosystems that provide food and habitat for fish and invertebrates and also mitigate coastal erosion and flooding due to storm waves and surge (e.g., Sutton-Grier et al. 2015). Given sufficient sediment supply, marshes may be resilient in responding to sea-level rise (e.g., Duarte et al. 2013). Recent studies suggest that hybrid (green-grey) shoreline that combines natural marsh habitat (green) and engineered infrastructure (grey), can enhance coastal protection, while also preserving ecosystem services (Sutton-Grier et al. 2015; Vuik et al. 2016). Natural and farmed kelp may have a similar potential for hybrid coastal solutions (e.g., Zhu et al. 2021). To improve the design and management of nature-based and hybrid coastal defense, it would be useful to improve modelling tools to represent vegetation drag.

2 METHODOLOGY

Most marsh plants are composed of flexible leaves attached to a comparatively less flexible stem. Because of their flexibility, both the leaves and stem reconfigure (bend) in response to water motion, and the reconfiguration reduces the drag on the individual plant elements. Because of its influence on drag, plant flexibility should be considered in the prediction of wave damping by marshes. For a simple flexible structure, such as a flat leaf or circular stem, wave-induced drag is characterized by two dimensionless parameters, which are defined for each plant element, stem and leaf (Luhar and Nepf 2016). The Cauchy number, Ca, is the ratio of hydrodynamic drag to the restoring force due to structural rigidity. The length ratio, L, is the ratio of the plant element length, l, to the wave orbital excursion, A_w=w/ω, in which U_w is the maximum horizontal wave orbital velocity and ω is the wave angular frequency.

$$Ca = \frac{\rho A U_w^2}{EI/l^2} \qquad (1)$$

$$L = \frac{l}{A_w} = \frac{l\omega}{U_w} \qquad (2)$$

$\Delta\rho$ is the density difference between water (ρ) and plant material (ρ_p). g is gravitational acceleration. The frontal area is $A = bl$ for a flat leaf of width b and $A = Dl$ for a circular stem of diameter D. E is the elastic modulus. I is the bending moment, with $I = bd^3/12$ for a leaf of thickness d and $\pi D^4/64$ for the stem.

To describe the reduction in drag associated with reconfiguration, Luhar and Nepf (2011) introduced the effective length, l_e, defined as the length of a rigid vertical leaf (or stem) that generates the same horizontal drag as a flexible leaf (or stem) of total length l. That is, $l_e/l = F_d/F_r$, with F_d and F_r representing the drag on a flexible plant and on a rigid plant with the same geometry, respectively. For $Ca > 1$ (indicating that the structure bends) and $L > 1$ (indicating that the structure can follow the wave motion), the drag on the flexible structure, F_d, relative to the drag on an equivalent rigid structure, F_r is,

$$\frac{l_e}{l} = \frac{F_d}{F_r} = K(CaL)^{-1/4} \qquad (3)$$

This scale relation has been validated with force measurements on individual live and model plants with both seagrass and marsh-plant morphology (e.g., Lei and Nepf 2019, Zhang and Nepf, 2021), revealing K to be O(1).

Previous studies have described the dissipation of wave energy by a rigid canopy by describing the work done by the waves against the vegetation drag (e.g., Dalrymple et al. 1984, Mendez et al. 1999, Mendez and Losada, 2004). These formulations can be modified by replacing the rigid canopy height with the effective canopy height described by Eqn 3. This modification has produced good predictions of the evolution of wave amplitude over a canopy of flexible plants (e.g., Zhang et al 2021).

3 RESULTS

This presentation describes recent work validating the flexible plant force model against measurements from a field site. The model is then used to estimate the economic benefit of marsh in terms of an avoided cost of seawall heightening that would otherwise be required to deliver the same overtopping rate without vegetation. However, the field application of the model is limited by our ability to map the geometric characteristics of the vegetation. A recent study suggests that biomass distribution measured remotely (e.g., by drone) may provide a solution for characterizing wave attenuation by marshes (Maza et al. 2022). The integration of biomass measurements with models that capture plant morphology (frontal are per biomass) and flexibility could provide further improvement.

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