WAVE ATTENUATION IN A PARTIALLY VEGETATED WAVE FLUME

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INTRODUCTION

The study of wave attenuation in coastal vegetation aims to understand the role of coastal vegetation in attenuating wave energy and the impact of incoming waves, with implications for shoreline protection, ecosystem health, and coastal management. In recent years, extensive research has been conducted on wave attenuation of various types of coastal vegetation, such as seagrass (Bradley and Houser, 2009) and mangroves (Horstman et al., 2014). For instance, Lei and Nepf (2019) used the effective length to integrate the flexibility of seagrass blades into wave damping theory. Much of this research has focused on environments with complete vegetation coverage. However, there is a growing body of research focusing on flow development over partially vegetated waters (Chen et al., 2010, Huai et al., 2019, Li et al., 2022). Employing analytical and experimental methodologies, these studies comprehensively explore flow characteristics, velocity profiles, and turbulent structures within partially vegetated open channels. By focusing on partial vegetation cover, the research seeks to identify optimal vegetated regions that can effectively mitigate coastal erosion and enhance shoreline stability without the need for extensive vegetative plants. Nonetheless, wave attenuation in partial vegetated flumes remains an unexplored domain.

In the present study, we developed an analytical solution based on the energy balance principle as outlined by Dalrymple et al. (1984), taking into account wave diffraction. All experiments were conducted at the National University of Singapore.

ANALYTICAL MODEL

Since the vegetation is partially covered, the interaction between waves and vegetation includes not just typical wave attenuation but also diffraction processes. Our analytical solution has been developed with the principle of energy balance following Dalrymple et al. (1984) with the consideration of these diffraction processes.

In our study, we examined both the longitudes (along the X axis) and cross-sectional (along the Y axis). Additionally, the mixing and turbulence at the interface between the vegetated and non-vegetated areas are assumed to be linearly distributed. The shear coefficient in the cross-section will be determined empirically.

EXPERIMENTS

Experiments were conducted at the NUS Hydraulic Laboratory, using a ferrocement wave flume with a piston-type wavemaker. The wave flume measures 36m in length, 2m in width, and 1.3m in depth. The rigid wooden stick is used to mimic mangroves. The diameter of the rigid wooden stick is 5mm, and the shoot density is 325.5 $stem/m^2$. Artificial flexible vegetation were used to mimic the seagrasses. All these vegetation models were mounted on perforated PVC boards that are 5mm thick and have a density of 1.4 g/cm^3. To counter the wave inducted buoyancy of the PVC boards, 3mm aluminum boards were affixed beneath them. As shown in Figure 1, the vegetated section is located at the flume's center, 13m away from the wavemaker. This vegetated area spans 6m in length and 1m in width.

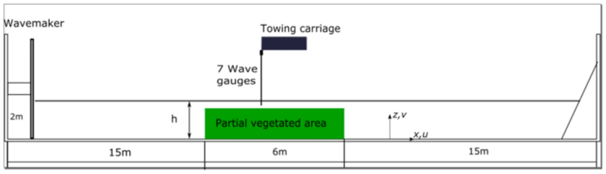

Figure 1: A sketch of experimental setup of the partially vegetated flume (not to scale). The rigid model occupies half the width of the flume. Seven wave gages were placed above the partially vegetated model.

Figure 2 illustrates the placement of seven wave gauges, all mounted on the towing carriage and set at a uniform elevation. These gauges are used to measure surface level across the flume's cross section, such that differences in wave height can be directly observed. The towing carriage is mobile, and for this study, it was set to move at intervals of 0.2m. Over the 6m vegetated stretch, measurements were taken at 31 locations in the direction of wave propagation.

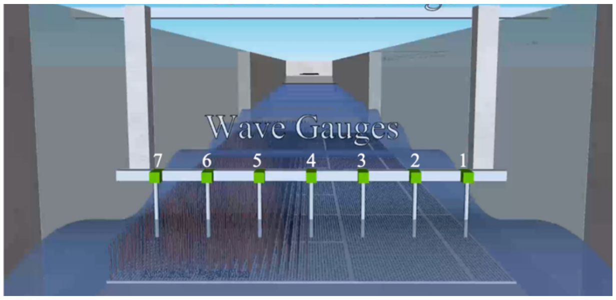

Figure 2: Experimental setup of the partially vegetated flume. Seven wave gauges were installed on the towing carriage with adjustable arms in the vertical direction. Also, the wave gauges were placed above the partially vegetated model.

To examine the influence of the partial vegetation under different wave conditions, the experiments were conducted with wave heights ranging from 0.04 m to 0.12 m, and wave periods between 0.8 and 2 seconds. Initially, the experiments were conducted with empty PVC boards to measure wave damping caused by bed and side-wall friction. Subsequently, experiments were repeated with the vegetation model at the same wave conditions. The discrepancy in results obtained with and without the presence of vegetation was used to validate our analytical model.

RESULTS

In this section, the results for incoming waves with T=1.25s and H=0.08m under mangrove scenario are shown as an example. Figure 3 shows the results of the wave height variations along the longitudinal direction recorded by the seven wave gauges, comparing findings from the laboratory experiments to those of the analytical solutions.. The corresponding wave gauge numbers are shown in Figure 2. x=0m stands for the leading edge of the vegetation area. The analytical solution generally aligns well with the experimental data, although the beat pattern is not replicated by the analytical prediction.

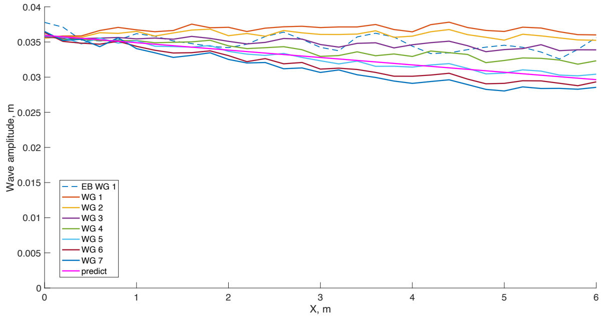

Figure 3 – The vegetated experimental data compared analytical solutions and reference data. The dashed line represents the empty boards test. The pink solid line represents for the analytical solutions. The other solid lines denote the experimental data.

Figure 4 displays the variation in wave height across the cross-section at various points along the wave propagation direction. y=0m denotes the right sidewall boundary as indicated in Figure 2. It is evident that the wave attenuation in the cross-section direction intensifies as wave propagation distance increases. Interestingly, the presence of vegetation exerts a substantial influence on wave height reduction, even within the non-vegetated area.

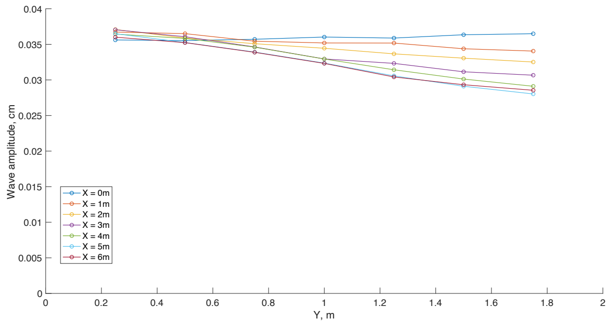

Figure 4 – Differences in wave height across the cross-section direction from experimental results. Each line represents the wave height distribution within a distinct cross-section along the wave propagation direction.

CONCLUDING REMARKS

Overall, the new study on wave attenuation over a partially vegetated flow shows a significant impact that extends beyond vegetated zones and extends into non-vegetated areas. In our forthcoming research, we aim to empirically determine the shear coefficient. The subsequent step will entail a systematic exploration of varying vegetation densities. Particularly, different types of vegetation, such as seagrass, will be studied. Also, the ideal level of vegetation density that yields optimal outcomes will be determined. This multifaceted approach promises to advance our understanding of the interplay between vegetation, wave attenuation, and its broader implications in coastal ecology and engineering.

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