ATTENUATION AND LONGITUDINAL MIXING IN VEGETATED WAVE-CURRENT FLOW

Nipuni Odara Merenchi Galappaththige, University of Warwick, N.Merenchi-Galappaththige@warwick.ac.uk
Jonathan Pearson, University of Warwick, J.M.Pearson@warwick.ac.uk

INTRODUCTION

The material quantities and associated costs of adaptation infrastructure for climate change is expected to rise, in the coming century (Jonkman et al., 2013). Therefore, using nature-based soft coastal defences to safeguard coastlines will result in economic advantages in addition to environmental benefits. Coastal vegetation (mangroves, salt marshes, sea grass, etc.) is a source of drag, and hence waves propagating over them lose energy. By damping near bed velocities, seagrass reduce local resuspension and promote the retention of sediment, stabilizing the seabed (Fonseca and Cahalan, 1992). Coastal vegetation can be used alone to minimize disturbances caused to day-to-day activities by rough sea conditions, and sometimes soft coastal defences can be coupled with hard coastal defences (Jackson, 2014) to reduce the wave loads induced on hard defences (e.g., a salt marsh in front of a seawall). Seagrasses grow mainly in physically dynamic regions which are exposed to both tide and wave generated currents, such as shallow regions along coastal margins and within estuaries (Thomas and Cornelisen, 2003).

Knowledge on pollution mixing in different hydrodynamic conditions will help implementing appropriate water quality control measures, as dissolved pollutants do enter coastal waters from seaward and shoreline boundaries (marine outfalls, storm overflow discharges, natural events, etc.). Although vertical mixing is dominant in pure wave conditions, longitudinal mixing can become significant when waves and currents coexist.

The dissolved compounds behave as passive tracers in low concentrations (James, 2002). Therefore, their pathways are dominated by the hydrodynamic processes such as, turbulence (e.g., breaking waves), particle oscillation due to waves, velocity shear from currents and submerged vegetation, etc. Wave attenuation and mixing in coastal waters in the presence of tidal currents are not studied in full, and this paper aims to provide an insight based on experimental findings.

EXPERIMENTAL STUDY

The experiments were conducted in a 20 m long, 34 cm wide, and 1.5 m deep flume. A photograph of the flume is shown in Figure 1 and the detained experimental setup is shown in Figure 2.

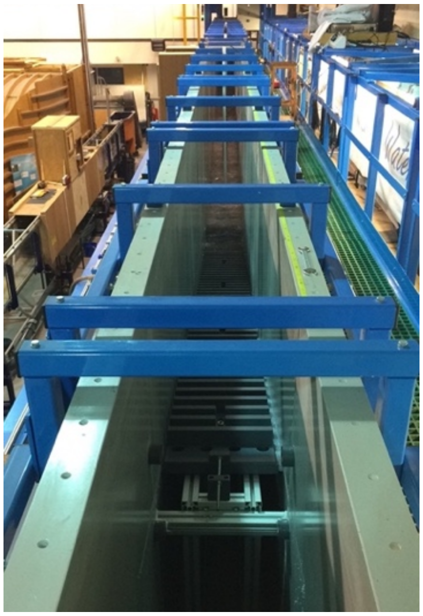

Figure 1 - Wave and fluorescence data collected along a model vegetation canopy

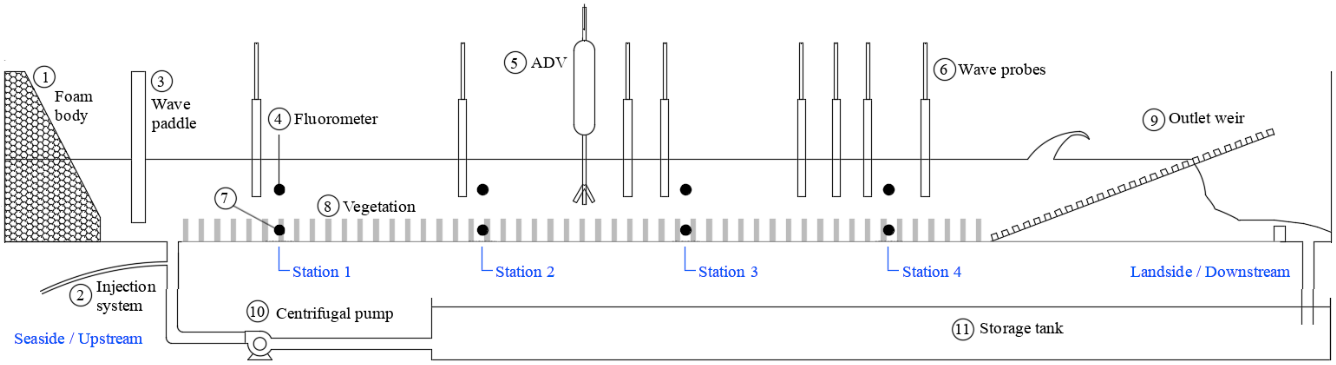

Figure 2 - Experimental setup. The numbered items are as follows. 1. Foam body to absorb the reverse waves created by the motion of the wave paddle 2. Injection system (the tube connects to a peristatic pump) 3. Piston wave paddle 4. Cyclops7 fluorometer (above the canopy) 5. Acoustic Doppler Velocimeter 6. Wave probes 7. Fluorometer (inside the canopy) 8. Artificial vegetation 9. Energy dissipating flow control weir 10. Centrifugal pump 11. Water storage tank.

The flow was generated by a centrifugal pump, and the regular waves were generated by a piston type wavemaker. The vegetation canopy was fabricated using plastic straws of 4 mm diameter, and two canopy heights of 0.1 m and 0.2 m were tested. The water depth was kept constant at 0.25 m, and the flow rates and wave periods were altered to test different wave-current combinations. To measure wave heights (and reflection), 8 wave probes were mounted along the vegetation canopy. The particle velocities were measured in the mid-length of the canopy using an Acoustic Doppler Velocimeter (ADV). To evaluate the coefficient of longitudinal dispersion, a soluble tracer (Rhodamine WT) was injected near the flow inlet, and the concentrations were measured using 8 fluorometers positioned at 4 stations along the canopy. In each station two fluorescence measurements were collected: one in the mid-height of the canopy and one in the mid-height of the clear water zone above the canopy. The tested waves correspond to non-linear conditions: Stokes II order, Stokes III order and Cnoidal.

RESULTS

The wave attenuation in combined wave-current flow behaves differently for the two canopy submergences. When the current increases, the wave attenuation decreases for the higher submergence $(\mathrm{h} = 0.1\mathrm{m}, \mathrm{R}_{\mathrm{sb}} = 2.5)$, and increases for the lower submergence $(\mathrm{h} = 0.2\mathrm{m}, \mathrm{R}_{\mathrm{sb}} = 1.25)$. Hu et al., (2014) suggested that the increase and decrease of wave attenuation in combined wave-current flow depend on whether $\alpha \gtrless 1$, where α is the ratio between the current velocity and the horizontal component of wave orbital velocity. The experimental findings compliment Hu et al., (2014), for α calculated using the velocities measured at the top of the canopy, as shown in Figure 3. α_{Dal} in Figure 3 is the wave attenuation coefficient (Dalrymple et al., 1984), which was derived using the reduction of wave heights along the canopy.

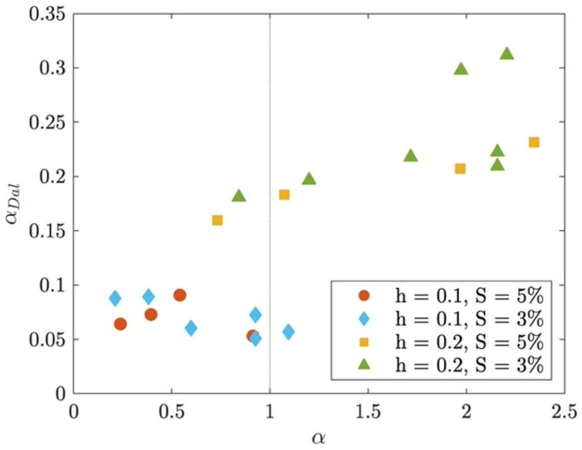

Figure 3 - Wave attenuation coefficient vs. α

The coefficient of longitudinal dispersion (D) measured in combined wave-current flows can be compared with that measured in pure currents to understand the effect from waves. Figure 4 presents the comparison of the coefficient of longitudinal dispersion (D) measured above the canopy with that measured inside the canopy for the canopy height of 0.1 m. According to Figure 4, the addition of waves on top of a current has increased the overall longitudinal mixing in smaller flow rates and decreased the overall longitudinal mixing in higher flow rates. When the longitudinal dispersion measured inside and above the canopies are compared, the addition of waves has made the two values to be more similar to each other. This suggests that the particle orbital motion due to waves increases vertical mixing and produces a distributed solute cloud throughout the water depth. The increased vertical mixing results in a reduction of the longitudinal dispersion in combined-wave current flow, compared to the vegetated channel flow.

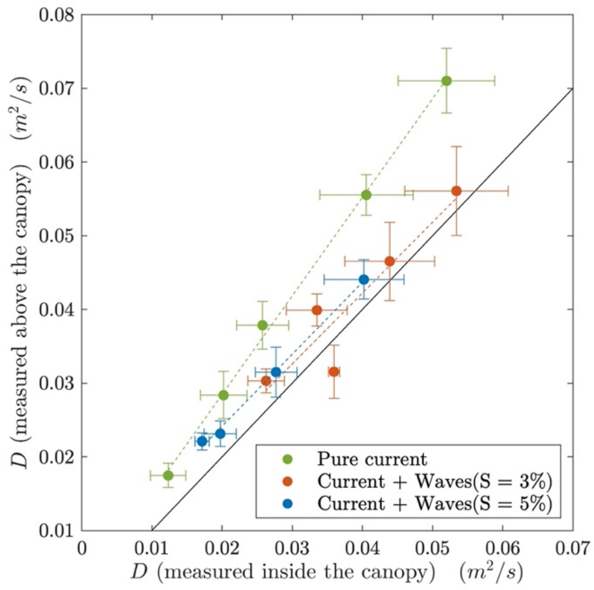

Figure 4 - Comparison of D measured above the canopy with D measured in the canopy, for canopy height of 0.1 m

REFERENCES

Dalrymple, Kirby, Hwang, (1984): Wave Diffraction Due to Areas of Energy Dissipation, Journal of Waterway, Port, Coastal, and Ocean Engineering, vol.110, pp. 67-79.

Fonseca, Cahalan (1992): A preliminary evaluation of wave attenuation by four species of seagrass, Estuarine, Coastal and Shelf Science, vol. 35, pp. 565-576.

Hu, Suzuki, Zitman, Uittewaal, Stive (2014): Laboratory study on wave dissipation by vegetation in combined current-wave flow, Coastal Engineering, vol. 88, pp. 131-142.

Jackson (2014): Coastal Management, Geography AS Notes, https://geographyas.info/coasts/coastal-management/ (accessed 2.28.18).

James (2002): Modelling pollution dispersion, the ecosystem and water quality in coastal waters: A review, Environmental Modelling and Software, vol. 17, pp. 363-385.

Jonkman, Hillen, Nicholls, Kanning, van Ledden (2013). Costs of Adapting Coastal Defences to Sea-Level Rise— New Estimates and Their Implications, Journal of Coastal Research, vol 29(5), pp. 1212-1226.

Thomas, Cornelisen (2003): Ammonium uptake by seagrass communities: Effects of oscillatory versus unidirectional flow, Marine Ecology Progress Series, vol. 247, pp. 51-57.