Prototype-scale physical model of wave attenuation through a mangrove forest of moderate cross-shore thickness: LiDAR-based characterization and Reynolds scaling for engineering with nature

Kiernan Kelty[1], Tori Tomiczek[2], Dan Cox[1], Pedro Lomonaco[1], William Mitchell[1]
[1]*Oregon State University, 101 Kearney Hall, Corvallis, OR 97331, USA*
[2]*United States Naval Academy, 590 Holloway Road, 11D, Annapolis, MD 21402, USA*

The study constructed a prototype-scale physical model in the Large Wave Flume at the NHERI Experimental Facility (EF) O.H. Hinsdale Wave Research Laboratory, Oregon State University. The model trees were constructed based on field observations and parameterizations from Ohira et al. (2013), where the diameter at breast height, D_{BH}**,** was 0.1143 m, and the diameter of the roots, D_{Root}, was 0.0286 m with 14 roots per tree. A baseline case with no mangroves and two model forest densities of 0.75 trees/m^2 (high density) and 0.375 trees/m^2 (low density) were tested for a forest with 18 m cross-shore width. Half of the experimental tests included a vertical wall representing an idealized coastal structure on the landward side of the model forest. The three forest conditions (high density, low density, and baseline), with and without the test wall, resulted in six total layouts for this experiment:

Layout 1: High Density Mangrove Forest, No Wall
Layout 2: High Density Mangrove Forest, Wall
Layout 3: Low Density Mangrove Forest, Wall
Layout 4: Low Density Mangrove Forest, No Wall
Layout 5: Baseline, No Wall
Layout 6: Baseline, Wall

For each layout, water surface elevations were measured seaward, throughout, and landward of the model forest test section. Velocities were measured within the model forest located at the seaward side of bay 10. Refer to the Instrumentation README for details on the experimental layout. For layouts with the test wall, wave-induced pressures on the wall were measured to determine the model mangrove forest’s effect on attenuating wave forces. Regular and random waves were tested at four water depths that ranged from shallow inundation to storm surge conditions within the model forest. Transient (tsunami-like) wave cases were also tested for the two lower water depths of the study. In total, 298 tests were completed for the study.

Files:

KiernanKeltyM2021.pdf

Masters thesis of Kiernan Kelty from Oregon State University. In the thesis, a detailed description of the experiments is included, and a methodology using LiDAR measurements is presented to quantify the projected area and associated uncertainty of the idealized mangrove forests. The LiDAR results had an error of 5% from the known value for the model tree trunk section. These measurements were used to find an effective diameter, D_e. The method can be practically applied for field applications where destructive or traditional measurements using calipers would be cumbersome or unfeasible.

The results of the regular and random wave cases for the tested layouts without the wall are presented in the thesis with the focus on estimating the wave attenuation and parameterized drag coefficient, C_D. Wave height decay coefficients for the model trees, $\tilde{\alpha}_m$ were calculated for each case. The drag coefficients, C_D, for the study ranged from 0.40 to 3.75 and were related to the Reynolds number, $Re_{U,De}$, in the range 4.5E3 < $Re_{U,De}$ < 29.0E3. The largest C_D values were associated with the lowest water depth. Uncertainties for C_D values for the study were also found based on the variability seen in the measured mean projected area per unit height per tree, $A_{t,m}$, of the model forest and the best fit for the wave height decay coefficients, $\tilde{\alpha}_m$. The uncertainties from these two parameters were combined to determine the overall uncertainty for the C_D values. Results of two previous reduced-scale studies of wave attenuation by mangroves compared well with the present study when their Reynolds numbers were re-scaled according to Froude similitude by $\lambda^{3/2}$, where λ is the prototype to model geometric scale ratio, and the Reynolds number was estimated using the diameter at breast height, D_{BH}, and the depth averaged velocity, U. An empirical equation of the form $C_D = a_1 + (a_2/Re_{U,DBH})^{a3}$ gave a best fit to the combined data. The coefficients of a_1 = 0.6, a_2 = 30,000, a_3 = 1.0 and R^2 =0.63 were suggested for engineering design so that the asymptote is 0.6, consistent with the work of Sarpkaya and Isaacson (1981) for waves on vertical piles.

Experimental_Info.xls

The excel workbook contains information on the experimental conditions tested. The workbook contains the following information for each experimental trial:

- Date
- Time tested
- Trial number
- Water depth at vegetation, h_v
- Wave type
- Target wave height, H or H_s or Scale Factor for transient waves
- Target wave period, T or T_p or Stroke Duration for transient waves
- Wave duration
- Number of waves run
- Test wall installed in flume
- Overhead video recorded
- Stereo video recorded
- Presence of wave breaking
- Experimental and analysis comments

Some trials were rerun for repeatability analysis or due to erroneous measurements from instrumentation, movement of the test wall, or insufficient seeding material in the Large Wave Flume for the ADV's. **Please read the comments for each trial of interest before using the data.**

The excel workbook includes the incident and reflected wave analysis for wave gauge array 1 (seaward of the mangrove forest) and array 2 (landward of the mangrove forest) for all experimental trials. The incident and reflected wave analysis used methods presented by Gornbech et al. (1997) and Zelt and Skjelbreia, (1993). Analysis for the individual wave gauge and pressure gauge instruments for the regular and random wave trails for the layouts without the wall is also included. **Please refer to Chapters 4 and 5 from 01_KiernanKeltyM2021 in Reports or Physical Model Design and Layout for a detailed description of the analysis procedures and methods.**