C06

Modeling of Wave Damping by Coastal Vegetation

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Coastal vegetation, serving as an eco-friendly means for shore protection, has been identified by its capability of reducing damage caused by extreme waves and surges. Among various types of vegetation, mangroves, featured by the complex root system, have been considered prominent for dissipating wave/flow energy especially along tropical and subtropical coastlines. To better understand the physical processes of wave attenuation within canopies, a great effort has been made over the past decade to study the interactions between waves and vegetation. Vast of literatures exist on laboratory/field observations and numerical/mathematical modeling. In most previous works, the vegetation was modeled by rigid or flexible cylinders for simplification. The effects of prop roots in mangrove environments were only addressed in a few recent works (e.g. Maza et al. 2017). However, the relationship between the drag effects and the associated wave damping within mangrove forests is still unclear. A reliable approach to predict the wave attenuation by mangroves under realistic conditions is also needed. Accordingly, this study aims to further investigate wave propagation through mangrove forests both numerically and experimentally.

Numerical Modeling

Boussinesq-type models (BTMs) have been widely used among the coastal engineering community to study surface waves propagating from deep water to nearshore regions. Including both dispersive effects and nonlinearity, two of the most well-known BTMs are COULWAVE and FUNWAVE. The application of BTMs to vegetation problem is relatively new. In most of the existing studies, the vegetation resistance was modeled by an add-on bottom friction (e.g. Augustin et al. 2009), which may not be adequate to represent the dissipation process within canopies. On the other hand, a few studies used an additional drag term based on the quadratic law (e.g. Huang et al. 2011, Chakrabarti et al. 2017); however, none of them considered the effects of prop roots, which should be essential especially in mangrove environments.

In this study, we aim to implement the vegetation dissipation effects caused by mangrove forests in the BTMs in which the governing equations can be written as:

$$\partial\eta/\partial t + \nabla[(h+\eta)\boldsymbol{u}_\alpha] + \mathrm{H.O.T}_1 = \mathcal{O}(\mu^4) \qquad (1)$$

and

$$\partial\boldsymbol{u}_\alpha/\partial t + \boldsymbol{u}_\alpha\cdot\nabla\boldsymbol{u}_\alpha + g\nabla\eta + \mathrm{H.O.T}_2 + R = \mathcal{O}(\mu^4) \qquad (2)$$

where η and h respectively denote the free surface elevation and water depth. $\boldsymbol{u}_\alpha$ is the horizontal velocity vector at the reference level $z = z_\alpha$ and the small parameter μ is defined as the ratio of water depth to wavelength. In Eq. (1) and (2), $\mathrm{H.O.T}$ represents the higher-order dispersive terms. The dissipation term R can include the effects from bottom friction (R_f), wave breaking (R_b), turbulence mixing (R_{ev}) and vegetation drag (R_{veg}), according to various test conditions. As mentioned above, vegetation resistance can be modeled by the drag effect using the Morison-type equation (Morison et al. 1950) as

$$\mathbb{R}_{veg} = \frac{1}{2(h+\eta)} C_D A_m N_m \boldsymbol{U}|\boldsymbol{U}| \qquad (3)$$

in which A_m denotes the frontal area of the submerged portion of a single mangrove tree, N_m gives the stem density, and $\boldsymbol{U}$ is the representative velocity (e.g. $\boldsymbol{u}_\alpha$ or pore velocity $\boldsymbol{u}_p$). Alternatively, the vegetation effect can also be modeled by including the variation of velocity:

$$\mathbb{R}_{veg} = \frac{1}{2(h+\eta)} \int_0^{h_s} C_D d_m N_m \boldsymbol{u}(z)|\boldsymbol{u}(z)| dz \quad (4)$$

where $h_s = \min(h+\eta,\ h_m)$ with h_m being the height of a single tree. In the above Eq. (3) and (4), the drag coefficient C_D is a constant bulk value, being assigned to the entire canopy while the inertia force has been neglected. The vertical variation of drag force due to the prop roots, which is vital for mangrove trees, is not addressed. Thus, in this study we intend to propose a drag coefficient $C_D = C_D(\boldsymbol{x}, z, t)$, which should vary vertically for each individual tree. The spatial variation over the mangrove forest is also considered. And the time dependence of the drag coefficient for a transient wave will also need to be taken in account. The significance of inertia force under different conditions will need to be studied as well. Accordingly, we need a comprehensive way to determine the drag coefficient for mangrove-type vegetation.

Laboratory Experiments

To investigate the drag effects on damping wave energy in mangrove environments, a series of laboratory experiments is planned to be conducted at the Port and Airport Research Institute (PARI). Different from the existing studies, a 3D printed model, based on the geometric structure of a real mangrove tree, is used to build up the forest. As presented in Fig.1, the model forest is located on the top of a false bottom such that the force transducers (FTs) can be mounted without disturbing the incoming waves. The wave forces (e.g. drag forces) on individual trees will be measured directly and the velocity profiles in the vicinity of model trees will also be obtained by Acoustic Doppler Velocimeters (ADVs). Different types of incident waves (e.g. regular/irregular waves, solitary waves) will be tested and the corresponding behaviors when propagating through the model forest will also be discussed. Multiple wave gauges (WGs) will be employed to collect the wave evolution along the model forest. Various submerged conditions of model mangroves will be included as well. The relationship between the wave forces and the dimensionless parameters (e.g. Reynolds number and Keulegan-Carpenter number) for mangrove-type environments will be studied.

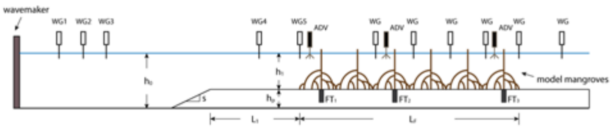

Fig.1 Experimental setup

Model Validation and Future Work

The simulated wave evolution through the mangrove forest will be first checked by the experimental measurements to validate the proposed drag model. To further investigate the effects of prop roots of mangroves, the experimental data will be compared with other data in the existing literatures for rigid cylinders. The numerical results by the present approach will also be compared with other model results. Once the validation is completed, the present model can be applied to large-scale problems with real conditions (e.g. real bathymetry and offshore wave conditions) and further discussion will be made.

References

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