Physical Modeling of Coastal Protection by Mangrove Trees against Storm Waves

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Mangrove trees, mainly existing along tropical and subtropical coastlines, are featured by a complex root system. Their capability of dissipating wave/flow energy has been well recognized in historical events. Danielsen et al. (2005) and Tanaka et al. (2007) indicate the essential role of mangrove trees on reducing damage from Indian Ocean tsunami in 2004. Plantation of mangrove vegetation was suggested by Kathiresan and Rajendran (2005) based on their study in several coastal hamlets after the 2004 tsunami. Das and Vincent (2009) also evidently presented a connection between mangrove shields and death reduction during the attacks from storm waves in 1999. More recently, the mangrove effects mitigating the damage of typhoon Haiyan was also reported in Villamayor et al. (2016).

Given the vital role of mangrove trees for shore protection, numerous studies on wave-vegetation interactions have been carried out via physical and numerical modeling to understand the physical process over the past decade. Most of the existing works simplified the problem by idealizing vegetation as rigid/flexible cylinders. In fact, mangrove's prop roots are essential in the energy dissipation process, which were only addressed in a few recent works, e.g. Husrin et al. (2012) and Maza et al. (2017), and still warrants further investigation. To better quantify the mangrove effects and the associated wave damping, a series of laboratory experiments on both model and prototype scales were conducted at the *Port and Airport Research Institute* (*PARI*) in Japan. We aim to provide a more comprehensive investigation of wave forces on mangrove trees under storm wave conditions.

Model-scale Experiments

We first used 3D-printed model trees, which were based on the scanned image from the field, to build a mangrove forest as shown in Fig.1. It was a new attempt of adopting real geometry of mangrove trees in laboratory experiments. Totally 13 wave gauges were employed to measure the free surface evolution along the model forest. Besides, one directional force transducer was installed to record the wave forces while two Acoustic Doppler Velocimeters (ADVs) were mounted to capture the fluid velocity over the water depth (Fig.2). A sketch of the experimental setup can be found in Fig.3.

Fig.1: Side view of the model mangrove forest

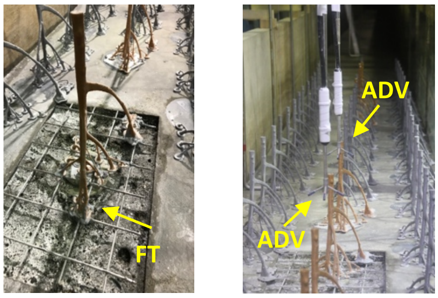

Fig.2: Force transducer and ADVs

According to the Morison's equation, the wave forces exerting on a mangrove tree include the drag and inertia forces as:

$$F = F_D + F_M = \frac{1}{2}\rho \int_{-h}^{\eta} C_D\, u|u| dA + \rho \int_{-h}^{\eta} C_M \frac{\partial u}{\partial t} dV \quad (1)$$

in which C_D and C_M respectively denote the drag and inertia coefficient. Due to the complex root system, the projected frontal area A and the submerged volume V are both varying over the water depth. Targeting at a proper relationship between the force coefficients and wave parameters (e.g. *Reynolds number / Keulegan-Carpenter number*), a typical least-square fitting is applied to compute the drag/inertia coefficients with the use of the measured velocity. Fig.4 gives an example of the comparison between measured force and the estimated force based on the Morison's Eq.(1).

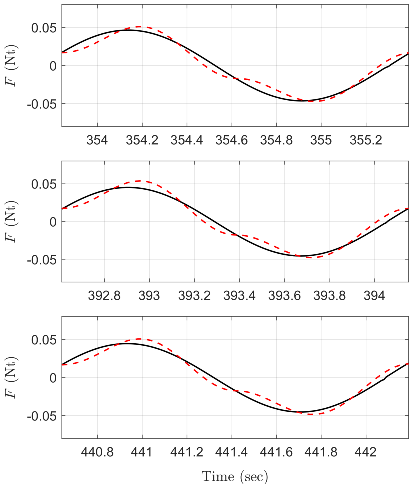

Fig.4 Measured (solid) vs. estimated (dashed) forces

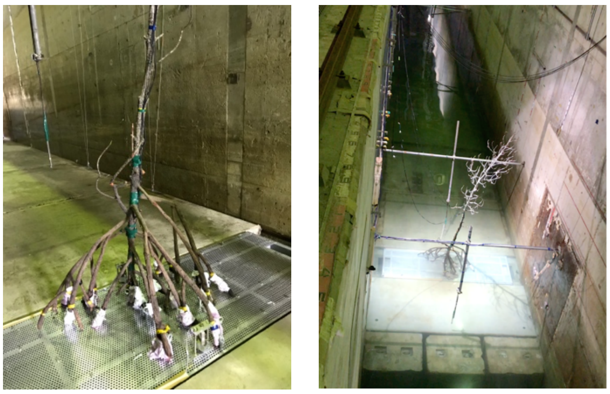

Fig.5 Real mangrove tree in prototype-scale tests

Prototype-scale Experiments

In addition to the model-scale experiments, we used real mangrove trees (Fig.5) to further investigate the flexibility of mangrove trees and the potential damage under extreme wave conditions. Focusing on the wave forces on the mangrove tree, we consider only the single-tree condition in the prototype-scale tests. Similarly, a force transducer along with multiple pressure gauges were applied under various wave conditions in which extreme wave conditions were also included. More detailed analysis will be discussed in the presentation.

References

1. Danielsen et al. (2005). The Asian tsunami: A protective role for coastal vegetation. *Science*, 310:643.
2. Das and Vincent (2009). Mangroves protected villages and reduced death toll during Indian super cyclone. In *Proceedings of the National Academy of Sciences of USA*, 7357–7360.
3. Husrin et al. (2012). Experimental study on tsunami attenuation by mangrove forest. *Earth, Planets and Space*, 64:973–989.
4. Kathiresan and Rajendran (2005). Coastal mangrove forests mitigated tsunami. *Estuarine, Coastal and Shelf Science*, 65:601–606.
5. Maza et al. (2017). Velocity and drag evolution from the leading edge of a model mangrove forest. *Journal of Geophysical Research: Oceans*, 122:9144–9159.
6. Tanaka et al. (2007). Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian ocean tsunami. *Landscape and Ecological Engineering*, 3:33–45.
7. Villamayor et al. (2016). Impact of Haiyan on Philippine mangroves: Implications to the fate of the widespread monospecific Rhizophora plantations against strong typhoons. *Ocean & Coastal Management*, 132:1–14.

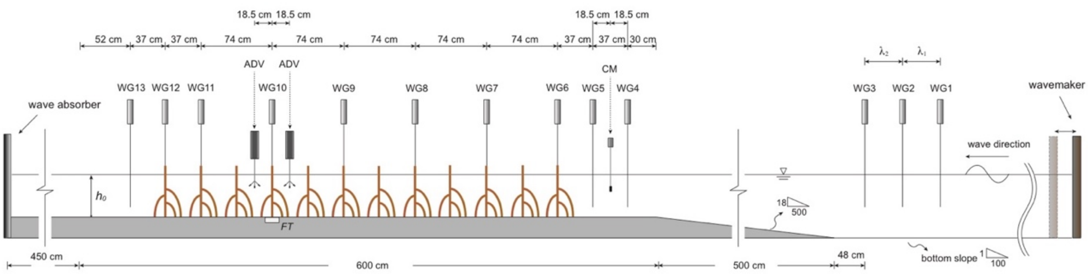

Fig.3: Sketch of the model-scale experimental setup (WG: wave gauge, FT: force transducer)