NUMERICAL INVESTIGATION OF WAVE ATTENUATION IN MANGROVE FORESTS USING THE IMMERSED BOUNDARY METHOD

Fan Chen, The Hong Kong Polytechnic University, fan.chen@polyu.edu.hk
Huan-Feng Duan*, The Hong Kong Polytechnic University, hf.duan@polyu.edu.hk
Jinghua Wang, The Hong Kong Polytechnic University, jinghua.wang@polyu.edu.hk
* Corresponding author: Huan-Feng Duan, hf.duan@polyu.edu.hk

INTRODUCTION

Mangrove forests provide a natural barrier to waves in coastal regions. Their wave attenuation effect has been the research focus in the past decades. Numerical simulations as one of the important approaches, however, rely heavily on simplified geometries of mangrove forests (such as cylinder array) or involve a series of empirical coefficients (e.g., to approximate drag forces or permeability). This affects the accuracy of numerically reproducing such physical processes and limits the prediction of wave attenuation effect under complex scenarios. Therefore, this work aims to establish a numerical model accounting for the interactions between waves and mangrove forests with complicated geometries, so as for better understanding and quantification of the attenuation effect of mangrove forests on coastal waves. After careful calibration and validation of the proposed model, the obtained numerical results are systematically analyzed for the importance of different factors to the interactions of mangrove forests and waves.

APPROACH

This work develops a numerical model based on the open-source computational fluid dynamics (CFD) code OpenFOAM. In order to simulate the fluid-structure interactions (FSIs), the Immersed Boundary Method (IBM) is applied. The mangrove forests are firstly represented by the background cells. The geometry elements are obtained via an approximate cut-cell process. The values of these cells and their faces are then corrected based on different boundary conditions. These cells' corresponding matrix coefficients are also corrected according to the governing equations. This newly implemented IBM has been validated with the dam break cases, demonstrating good accuracy in simulating FSIs.

The mangrove forest model used in this work is created according to the widely used mangrove model proposed by Ohira et al. (2013). In this work, the main model parameter diameter of breast height is selected as 0.25 m. In order to facilitate the wave flume dimensions for later laboratory tests, a geometric length scale of 1:4.2 is chosen. The laboratory test (Wang et al., 2022) and numerical simulations (Maza et al., 2015) are referenced in the numerical setup (as shown in Figure 1a). To save the computational resources, a symmetry boundary condition is applied and the numerical wave flume is 16.0 m long, 0.75 m wide and 0.7 m high. The mangrove forest is composed of an array of 8 trees, covering an area of 6.00 m × 0.75 m. This corresponds to a realistic mangrove forest density of 900 trees per hectare (Wang et al., 2022).

RESULTS AND DISCUSSION

The solitary wave type is selected as the incident wave. The water depth is 0.4 m and the solitary wave height is 0.1 m. The preliminary numerical results are shown in Figure 1(b) and (c). The time history of water surface elevations η at different wave probes shows that the wave height generally decays with increasing distance, except for the locations at wave probes 5 and 6 due to the reflection by the front mangrove chunks. The wave attenuation coefficient H_i/H_0 is calculated and then compared with the theoretical formula proposed by Dalrymple et al. (1984) as shown in Figure 1(c). Note that the theoretical formula includes a drag force coefficient that cannot be directly obtained and the fitted value β = 0.021 from Yin et al. (2023) is thus applied.

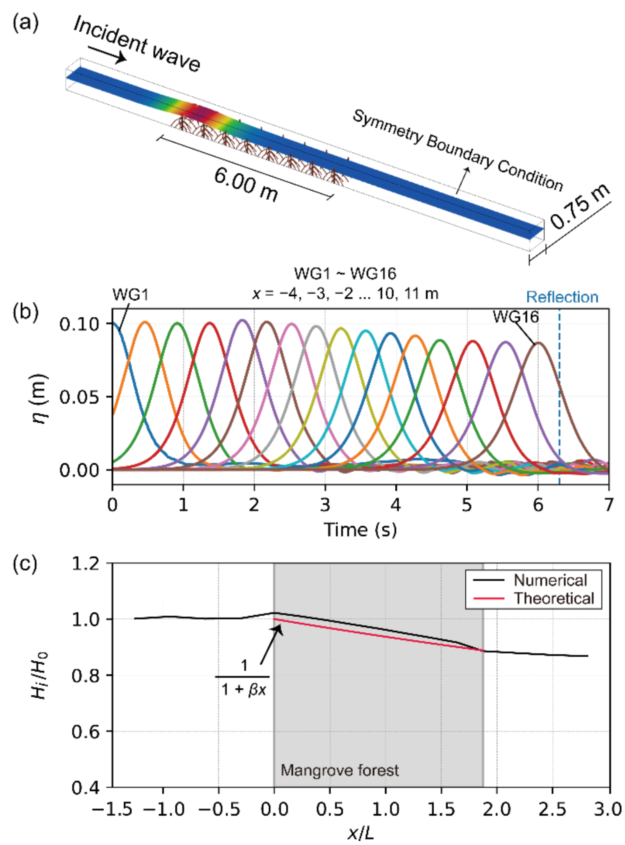

Figure 1 - (a) Snapshot of the numerical simulation, (b) time history of water surface elevations η at different wave probes and (c) comparison between numerical and theoretical wave attenuation coefficients H_i/H_0 along different locations

Overall, the result of Figure 1(c) shows a good agreement between the numerical and theoretical H_i/H_0, illustrating the capability of the developed numerical model to capture the wave attenuation effect. Future work will include the conduction of laboratory tests to further validate the numerical model and numerical investigation of the wave attenuation effect of mangrove forests under different layout parameters and wave conditions. More and extensive results will be presented in the conference sessions.

REFERENCES

Dalrymple, R.A., Kirby, J.T., Hwang, P.A., (1984): Wave diffraction due to areas of energy dissipation. Journal of Waterway, Port, Coastal, and Ocean Engineering, ASCE. vol. 110(1), pp.67-79.

Maza, M., Lara, J.L., Losada, I.J., (2015): Tsunami wave interaction with mangrove forests: A 3-D numerical approach. Coastal Engineering, ELSEVIER. vol. 98, pp.33-54.

Ohira, W., Honda, K., Nagai, M., Ratanasuwan, A., (2013): Mangrove stilt root morphology modeling for estimating hydraulic drag in tsunami inundation simulation. Trees, SPRINGER. vol. 27, pp.141-148.

Wang, Y., Yin, Z., Liu, Y., (2022): Laboratory study on the drag coefficient for mangrove forests in regular waves. Ocean Engineering, ELSEVIER. vol. 255, p.111522.

Yin, Z., Li, J., Wang, Y., Wang, H., Yin, T., (2023): Solitary wave attenuation characteristics of mangroves and multi-parameter prediction model. Ocean Engineering, ELSEVIER, vol. 285, p.115372.