The Influence of mangrove arrangement on wave transmission using smoothed particle hydrodynamics

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Abstract. Mangroves have been proven for their role as a natural barrier to various environmental risks such as abrasion and erosion. It helped improve water quality, reducing storms and providing habitat for marine species. Not only playing an essential role in maintaining the water surface, Mangroves have a crucial role in several aspects such as ecology, economy, and socio-culture. This study aims to understand the effects of the arrangement and length of mangrove trees in wave transmission. The present study is performed on the mesh-free CFD method, i.e., the smoothed particle hydrodynamics (SPH), which was developed for free surface flow problems and complex interactions. Three variations of mangrove trees are used,i.e., uniform 0.3 m, random 0.3 m, and random 0.15 m. The piston wavemaker is based on a previous study that has been validated with experiments. The simulation results indicate 0.15 m variations in a gap for the transverse line on the longitudinal provide maximum wave transmission reduction. The wave transmission value produced by the mangrove forest is relatively small. Additionally, the wave energy result decreased significantly after passing through the mangroves.

Keywords: Mangrove, SPH, arrangements, density

1 Introduction

Mangroves have been proven for their role as a natural barrier to various environmental risks such as abrasion and erosion in coastal protection, moreover, the mangrove tree could be an ecological tourism that provides economic benefit. Mangrove trees as natural protection in coastal areas have been studied by Maria Maza for tsunami waves [1], the study indicated mangroves significantly reduce tsunami waves and decrease the energy. In addition, mangroves could reduce the emissions from the ship as one of the sources of emissions [2]. A lot of studies have been performed both experimental and numerical for mangroves as natural protection, in this paper a numerical approach of mesh-free CFD was employed to carry out mangroves as natural protection from sea waves.

The numerical approach of mesh-free CFD in this paper employed smoothed particle hydrodynamics (SPH), which has merited for large deformation of free surface such as water wave propagation is well reproduced [3]. SPH has been applied to real engineering problems and the progress in decades significantly improved complex fluid flow such as sloshing, fluid structure interaction and so on. The findings indicated that SPH captured the free surface deformation and easy-to-handle sharp interface. Furthermore, the fluid-structure interaction (FSI) of waves and coastal structure has been performed by Altomare et. al. [4], [5], moreover, solitary wave in large wave tanks has been successfully performed by Domínguez et al.[6] later on incompressible smoothed particle hydrodynamics (ISPH) model developed for numerical wave tank with silinder [7] that waves generated from SPH were well reproduced and validated. The study of mangrove has been performed both experimental and numerical approach, Wang et al. [8] conducted a laboratory study on the drag coefficient in regular waves with a scale of 1:10. The study revealed that Keulegan-Carpenter (KC) has a relation to local drag coefficient and velocity. Wang and Chang performed an SPH simulation of mangroves with breaking waves and validated it with an experiment [9]. The findings indicated that SPH is one of the promising tools for the analysis of FSI with mangrove trees.

The aims of this study carry out the numerical approach for mangrove trees with variations of two longitudinal arrangements and three variations of dense mangroves. The wave was based on a previous study with open-source SPH solver DualSPHysics [10], [11]. The remainder of the section is as follows: section 2, Method and Numerical Setup; Section 3, results and Discussion; and Section 4, conclusion.

2 Method and Numerical Setup

The mangrove models in this paper were based on Maria Maza's model [12] the dimensions of mangrove trees are illustrated in Table. 1. The model is based on real mangroves then it is modeled in an experiment to study the drag coefficient, it illustrated that the model mimics the real mangrove trees that could be used for preliminary study of interaction wave with mangroves. The model illustrated the tree model with a scale of 1: 11, the diameter main branch tree, root, and maximum root are 0.35 cm, 1.81cm, and 18.34 cm, respectively. Figure 1 illustrates the mangrove tree whose main branch is a cylinder with the root of the mangrove shape as quadrants of a circle.

Figure 2 illustrates the model of three variations in different tree densities, with Figure 2 (c) being the very dense variations. Figure 3 illustrates the numerical wave tank (NWT) based on previous works. The variations of mangrove trees are 1.2 m and 2.7 m as shown in Figure 3 with wavelengths is 2 m and a period of waves is 1.15 s (see Figure 4). It indicated SPH has a promising method for wave cases as shown in Figure 4, SPH could reproduce waves in medium tanks that overall wave profiles such as the first wave arrive at the wave probe at the same time indicating the celerity has the same magnitude. Table 2 indicates the numerical setup for SPH computation, the time simulation is 30 seconds with a coefficient speed of sound is 20.0, a coefficient of smoothing length is 1.2, an artificial viscosity coefficient is 0.001, particle distance (*dp*) 0.01 m, Wendland kernel function and symplectic time-step algorithm was used in all simulation. The numerical setup is based on the previous studies of three-dimensional water wave propagation in large wave basins .

Table. 1 Dimensions of mangrove tree for SPH computation (units in cm)

Dimension	**Full Scale**	**Model Scale**

Diameter root trees	3.85	0.35
Diameter trees	20	1.81
Maximum root tree	201	18.34

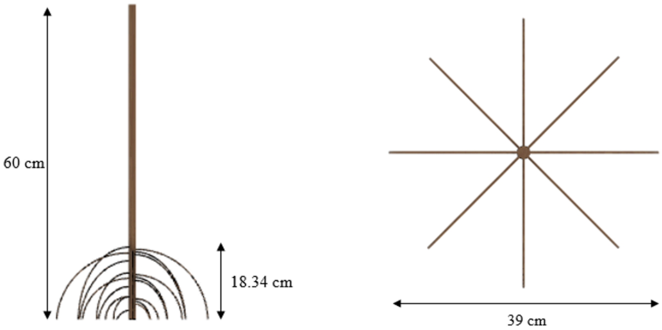
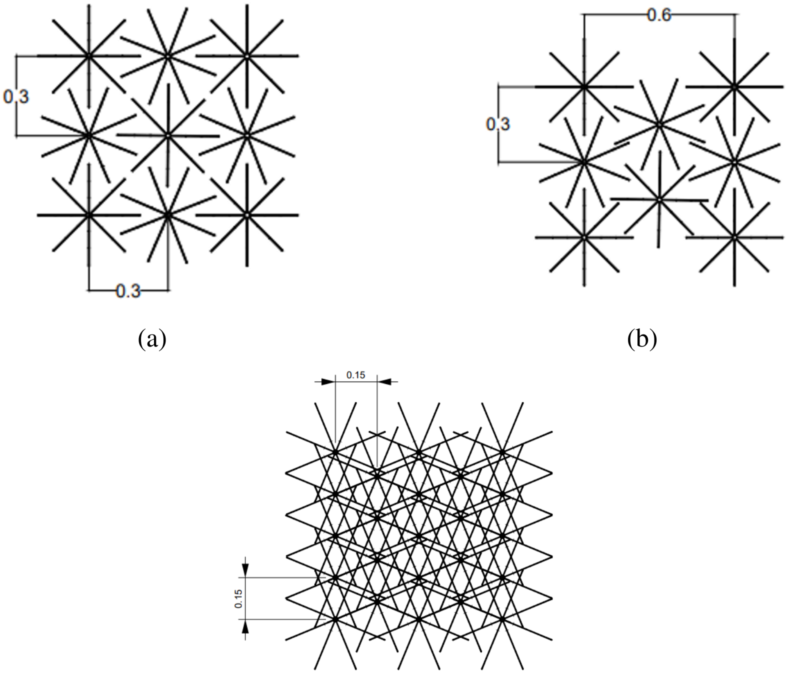


Fig. 1. Model of mangrove tree based on previous study



(a)

(b)

(c)

Fig. 2. Setup of mangrove tree with arrangement (a) uniform 0.3 m, (b) random 0.3 m, (c) random 0.15 m

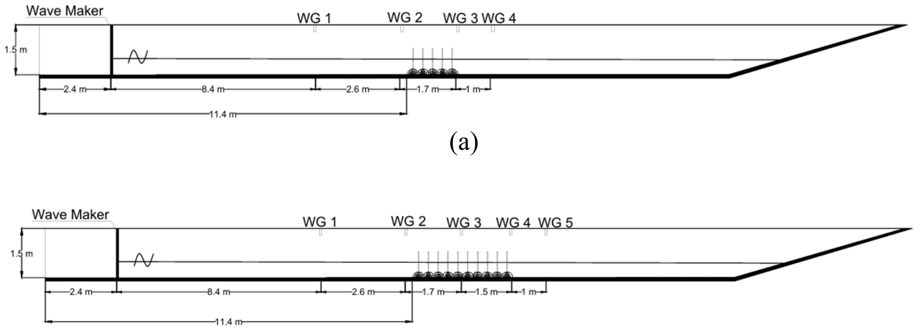


Fig. 3. Numerical wave tank for testing mangrove (a) 1.2 m, and (b) 2.7 m

Table 2. Parameters setup for SPH simulation

Parameter	
Kernel Function	Wendland
Time Step Algorithm	Symplectic
Distance Particle	0.01 m
Artificial Viscosity coefficient	0.001
Coefsound	20
Coefh	1.2
Simulation Time	30 s

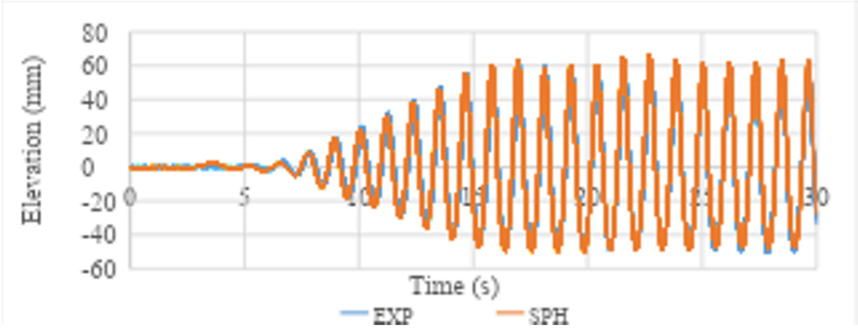


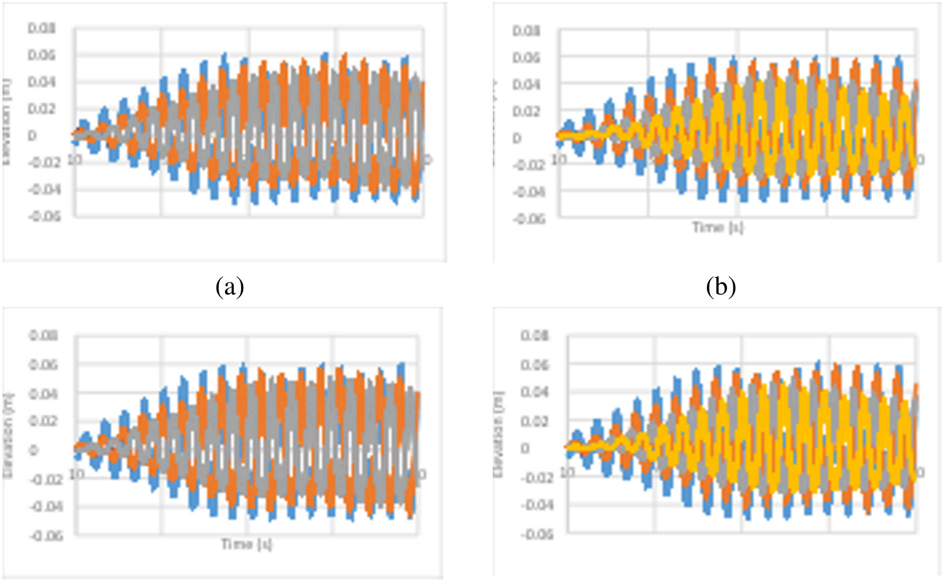
Fig. 4. Validation of wave profile with experiment

3 Results and discussion

The comparison between the results of the SPH simulation and the experiment shows that there is no phase difference, as can be seen in Figure 4. The wave height produced in the SPH simulation is not far from the experimental results, and it can be seen in the graph that the wave results between the SPH simulation and the experiment overlap, proving that the wave celerity has no difference. From these results, the SPH simulation results indicated the accuracy is reliable. In this study, a wave gauge is used to see the results of the wave elevation that occurs when the waves pass through the mangrove forest and after passing through the mangrove forest. Figure 5 shows the wave elevation in the variation of the mangrove forest

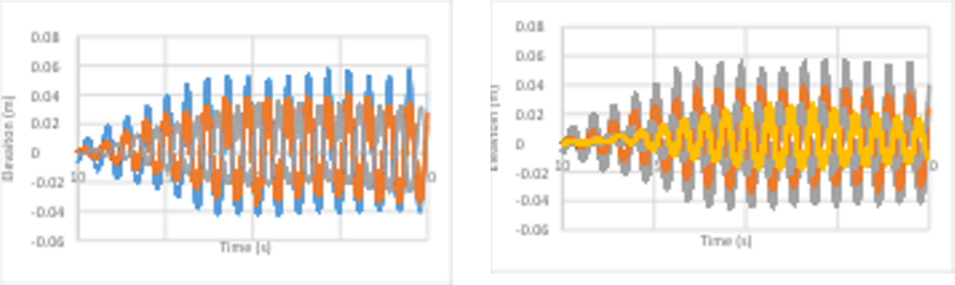
Figure 5 shows a decreasing trend in wave elevation on each wave gauge located between the mangrove forest and behind the mangrove forest compared to before passing through the mangrove forest. It can be seen in WG 2, namely the wave gauge located in front of the mangrove forest, which has a large wave elevation height compared to the elevation height on the wave gauge located between the mangrove forest and behind the mangrove forest. When the waves start to head towards the mangrove forest area, the wave elevation height experiences a different decreasing trend depending on the mangrove forest's composition, density and length.

Wave steepness is a non-dimensional variable influenced by wave height and wave period. The effect of wave steepness on the transmission coefficient is differentiated based on the variation of the arrangement and length of the mangrove forest. The results of the impact of wave steepness on wave transmission can be seen in Figure 6. It shows the change in the transmission coefficient to wave steepness. From these results, it is shown that the greater the value of the wave steepness, the smaller the transmission coefficient value and vice versa. When the value of the wave steepness is small, the transmission coefficient value is greater. The six mangrove forest models with differences in arrangement, density, and length of the mangrove forest, the most effective mangrove forest model in transmitting waves is the 3Y model. The composition, density, and length of the mangrove forest influence the effectiveness of wave attenuation. Figure 7 shows the effect of the number of mangroves on the transmission coefficient obtained, which is differentiated based on the length of the mangrove forest, namely 1.2 m and 2.7 m. Figure 8 cleary illustrates the wave decreased after pass the mangrove forest that the magnitude of wave height reduce by mangrove tree.



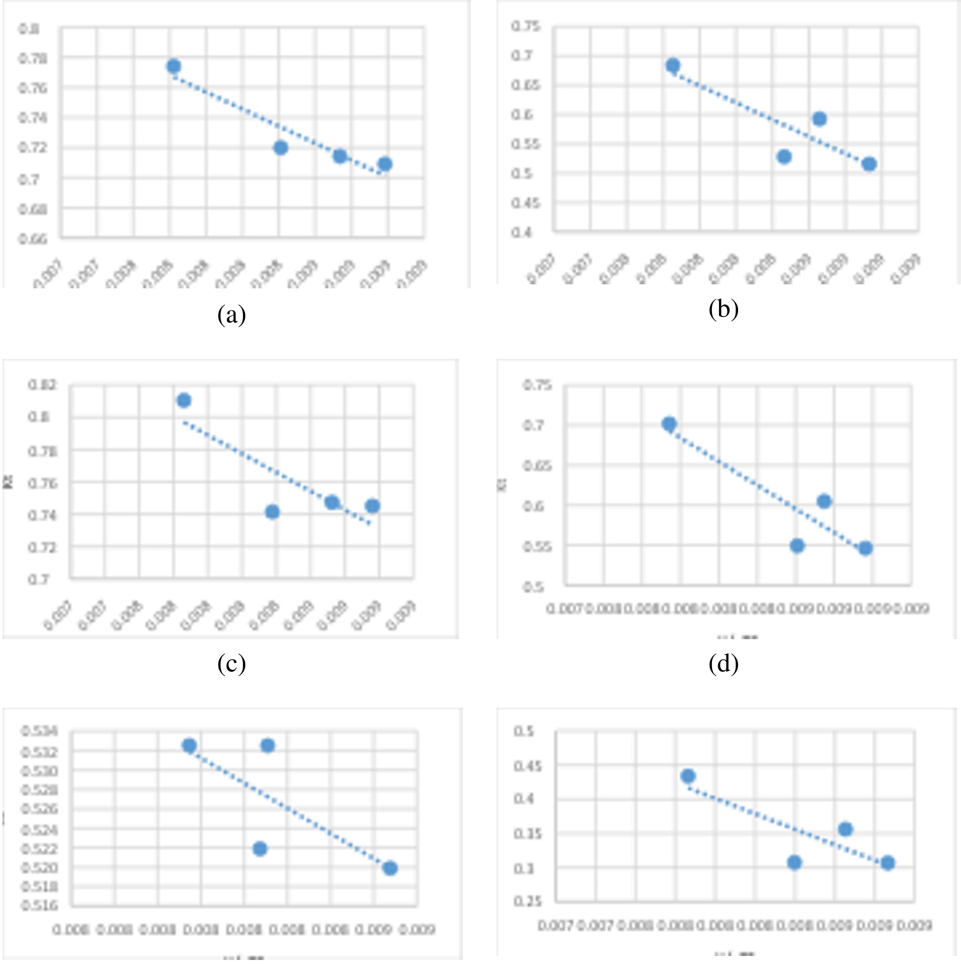
(a) (b)

(c) (d)



(e) (f)

Fig. 5. Wave elevation on each variation on mangrove trees (a) 1X (b) 1Y (c) 2X (d) 2Y (e) 3X (f) 3Y

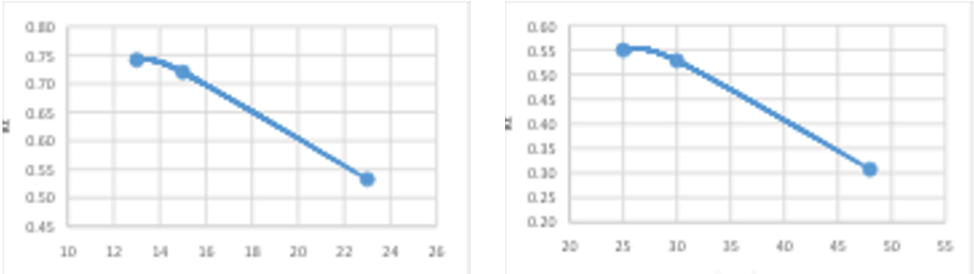


(a) (b)

(c) (d)

(e) (f)

Fig 6 . The effect of wave steepness on wave transmission in each variation (a) 1X (b) 1Y (c) 2X (d) 2Y (e) 3X (f) 3Y



(a) (b)

Fig 7. The effect of the number of mangroves on transmission coefficient at length (a) 1.2 m (b) 2.7 m

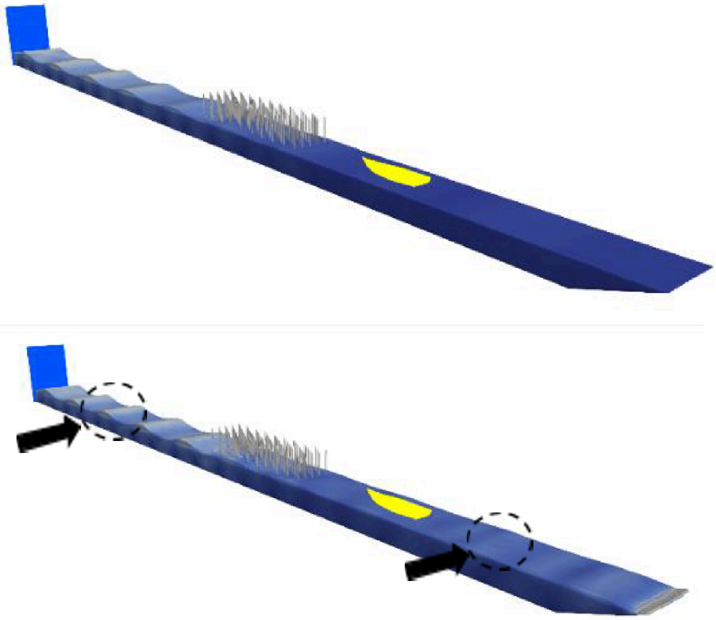


Fig 8. The effect of the number of mangroves on transmission coefficient at length.

4 Conclusion

Simulations of wave-passing mangrove trees were carried out on DualSPHysics ver. 5.2 with different variations of mangrove forests. It can be concluded that the height of the wave elevation will decrease due to the interaction between the mangrove forest and the waves, which causes the wave elevation between the mangrove forest and, after passing, the mangrove forest to experience a constant decrease in wave elevation. The effect of wave steepness influences the magnitude of the wave transmission coefficient value; a greater steepness will produce a smaller transmission coefficient value. The effect of the number of mangrove trees on the arrangement, density, and length of the mangrove forest is that a greater number of mangrove trees produces a smaller transmission coefficient value, and vice versa when the number of mangrove trees is small, it will produce a large transmission coefficient value

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