

MULTIPHASE SPH SIMULATION FOR INCHAMBER IMPACT PRESSURE ON VERTICAL BREAKWATER WITH WAVE ABSORPTION CHAMBER

Krisna Adi Pawitan, Princeton University, krisna.pawitan@princeton.edu

Hamid ElDarwich, Princeton University, hse@princeton.edu

Maria M. Garlock, Princeton University, mgarlock@princeton.edu

SUMMARY

A numerical model of a vertical breakwater integrated with wave absorption chamber has been tested against regular wave in a virtual wave flume. The open source Smoothed-Particles Hydrodynamics, or SPH, (*Lagrangian* type) software called DualSPHysics was deployed for the simulation. Both the multiphase (air-water) and single-phase (water only) fluid were considered and compared with an experimental result. Single-phase and multiphase capture the water column elevation in an open chamber within a ratio of 0.92 and 0.70, respectively, when compared to experiments. However, single-phase is not able to capture the fully closed chamber effect. It is found that inside the fully closed chamber, the multiphase SPH captures the maximum (compressed) water elevation well but overestimates the air compression by a factor of 1.5.

INTRODUCTION

An accurate prediction of wave pressure acting on a coastal structure, such as breakwater with wave absorption chamber, is crucial to test the effectiveness of a design in the real ocean. To simulate the air and water interaction in the real ocean, researchers often need to rely on physical models which is expensive and not very flexible. This is because the commonly used computation fluid dynamics may not correctly model an extreme fluid deformation, such as breaking wave or water sloshing, and a chaotic air-water interaction. Furthermore, recent observations show that air trapped inside a breaking wave plays an important role in generating the impulsive loads (Cuomo *et al.*, 2010). Because of this, a meshless *Lagrangian* method, which simulate fluid flow as particles trajectory, is preferred due to its ability to model complex fluid movements while adhering to conservation of mass requirements.

Current research explores the application of *Lagrangian* Smoothed-Particle Hydrodynamics (SPH) to simulate a regular wave acting on a vertical breakwater integrated with a wave absorbing chamber. Two cases will be considered: a fully open chamber where the air pressure inside the chamber remains near atmospheric, and a fully closed chamber, where the air inside the chamber is unable to escape, creating a theoretical highest air damping possible for such structure. Both the single-phase (water) and multiphase (air-water) simulations will be done and compared with the physical testing for validation purposes.

METHODOLOGY

A 101m long and 7m deep 2D virtual wave flume with piston type wave generation was deployed using an open-source SPH software called DualSPHysics, for both single-phase and multiphase method. A water depth

of 3.5m is selected, with a 1:10 steepness beach leading to a 1.9m water depth at 97.5m distance from the wave maker, after Pawitan *et al.*, (2020). An additional 3m high boundary condition was implemented for the multiphase method, creating a total of 10m high closed area consisting of both air and water phase, while for the single-phase method, only water phase is simulated and anything above the water is empty (void). A 4m high vertical breakwater with wave energy absorption capabilities is placed 97.2m away from the piston wave generator, as demonstrated by Figure 1 (a) for multiphase and (b) for single-phase. The red to light blue color represents the generated air particles for Fig.1 (a), while the light blue to dark blue gradation color represents the generated water particles for both cases.

For the multiphase simulation, a particle distance (dp) of 0.025m was selected based on a prior particle density stability exploration, which then resulted in about 2.6 million particles. For the single-phase simulations, on the other hand, a closer particle distance (dp) of 0.01m was selected, resulting in about 3.4 million particles. These were selected under the consideration of computational power and time, plus an accurate prediction. The vertical breakwater with wave absorption capabilities was constructed based on the cross-section of the one proposed in Viviano *et al.*, (2016) and shown in Figure 2. Two opening diameters were selected to represent both an open chamber conditioning (0.3m diameter, Fig. 2), and closed chamber. A regular wave with wave height (h) equal to 0.78m and wave period (T) equal to 3s was selected as the generated wave condition.

In the simulation, virtual wave gauges (WGs) were placed both inside and outside the wave absorption chamber to measure wave elevation and the water column elevation. A set of three WGs was placed inside the chamber with x-axis distance of 98.1m, 98.8m, and 99.5m from the piston. The 98.8m distance was the middle of the water column. The water column movement was calculated based on the average of each wave gauge measurement. Furthermore, a set of three digital pressure sensors was placed inside the chamber at the height of the in-chamber's ceiling and the same x-distance location with the wave gauges.



Figure 1 - Numerical wave flume set up of (a) multiphase and (b) single-phase with colors indicating the particles generated.

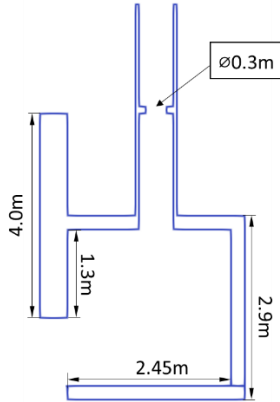


Figure 2 - Vertical breakwater with wave absorption chamber numerical model, with dimension in m

RESULTS AND ANALYSIS

Open Chamber case. Open chamber defined as the condition where the air is freely moving in and out of the chamber, with the pressure inside the chamber remains atmospheric. Figure 3 shows the water column movement inside the absorption chamber between the experiment (solid black line, after Pawitan *et al.*, (2020)), multiphase SPH (dotted blue line), and single-phase SPH (dashed red line). The x-axis in Figure 3 indicates a non-dimensional time t^* ($t/\text{wave period}, T$), while the y-axis indicates the water elevation measured relative to the still water level (swl). As can be seen from Figure 3, the multiphase results show an underestimation of the water column movement by a factor of 0.7, while the single-phase can match the experiment quite well with a factor of 0.92. This result may happen because the dualSPHysics models the air as weakly compressible, which is inline with Lu *et al.*, 2021. Because of that, the existence of air suppresses the extent to which the water column can move. This is proven by the fact that single-phase results, which model the air above the water as a void, was able to closely match the experimental results. One of the advantages of the multiphase simulation is the ability to model the air movement in and out of the chamber, as demonstrated by Figure 4 (a), with the color above the solid blue water line indicates the air velocity. The figure shows the condition at $t^*=0.5$ where the water column is moving down (inhale) and the air velocity is at maximum of 8.0m/s, corresponding to Figure 4 (b).

Closed Chamber case. For the closed chamber case, the absorption chamber's outlet is closed; thus, the air inside the chamber is unable to escape and compressed and decompressed by the water column movement. Figure 5 shows the water column movement measured inside the chamber of the closed case for experimental result (solid line), multiphase SPH result (dotted line) and single-phase SPH result (dashed line). Based on the results, the water column behavior can be divided into two behaviors: compressing (positive y-axis) and decompressing (negative y-axis).

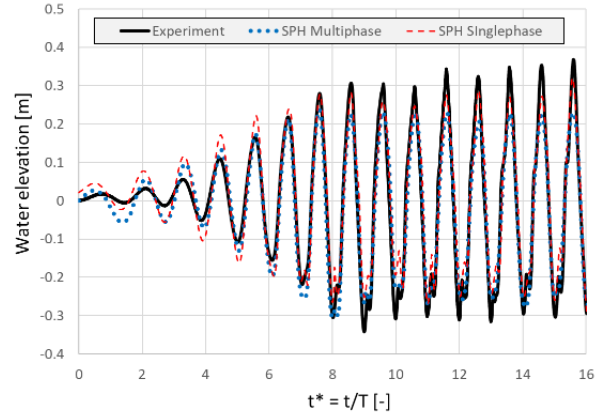
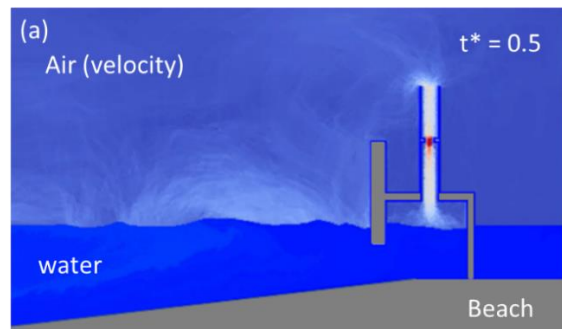


Figure 3 - Open chamber case: water column movement comparison between experiment, multiphase SPH, and single-phase SPH

As can be seen from Figure 5, the compressing movement yields similar results for both the experiment and the multiphase SPH of about 0.04m. The single-phase SPH, on the other hand, shows an overestimation by about a factor of 6. This single-phase overestimation may happen because there is no particles generated above the water, thus both open chamber case and closed case resulted in similar water column movement. In the decompressing movement, however, both SPH simulations show a very large negative movement, when compared to the experiment. Further investigation showed that SPH is unable to keep the particle in place in the case of large negative pressure, thus resulting in a void (area with zero particle) generation inside the fluid particles. This phenomenon is demonstrated by Figure 6 where during compressing water column movement (Figure 6 (a)), the air is compressed indicated by the dark red color in the image. During decompressing movement, on the other hand, the air and the water column move downward creating a void (white area) in the upper part of the chamber as shown in Figure 6 (b). Because of this phenomenon, chamber remains atmospheric even during decompressing movement. For the positive compressed pressure, on the hand, multiphase SPH simulation shows average pressure of 12kPa, compared to the experimental average of 8.5kPa, or an over-estimation factor of 1.5.



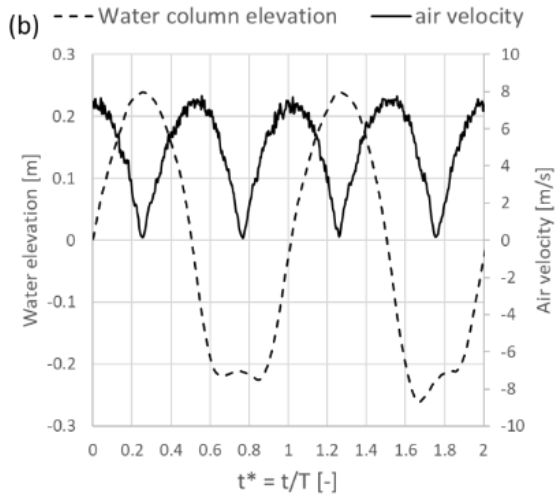


Figure 4 - Open chamber case: (a) flow visualization for multiphase model and (b) the water column movement (dashed line) and air velocity at the chamber outlet (solid line).

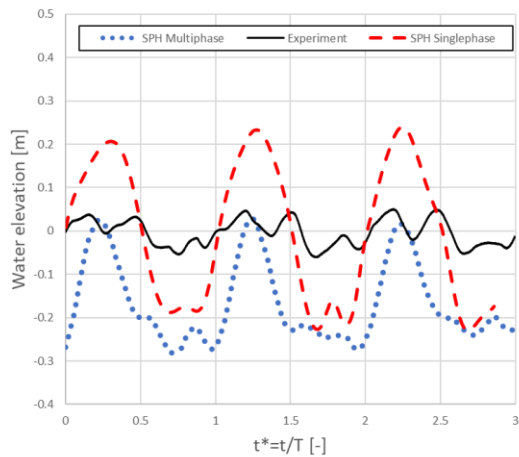


Figure 5 - Closed chamber case: water column movement comparison between experiment, multiphase SPH, and single-phase SPH).

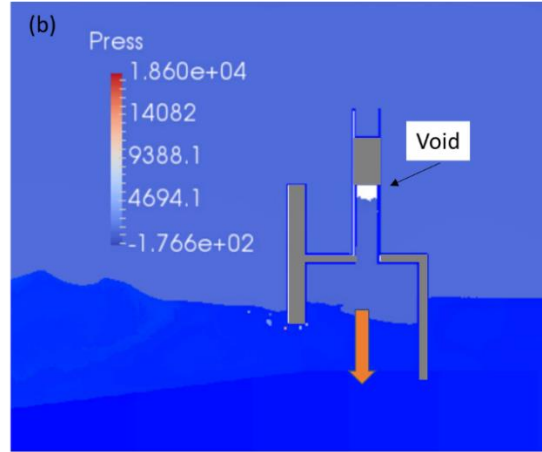
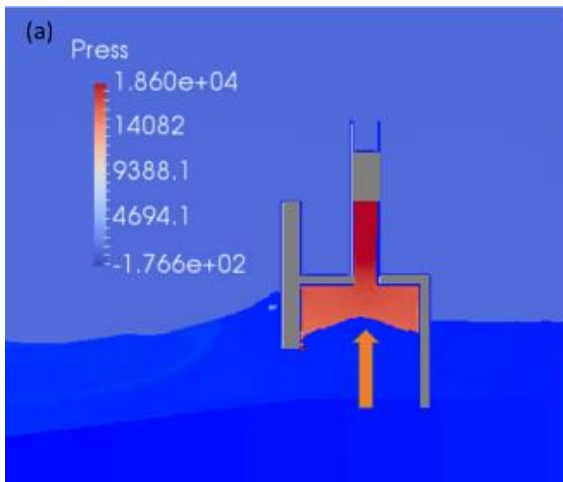


Figure 6 - Closed chamber case: The simulation air pressure results during (a) compression (upward water column movement), and (b) decompression (downward water column movement). Can be seen a void appears inside the chamber during decompression.

CONCLUSION

Open chamber case. Single-phase SPH simulation is able to closely simulate the water column movement inside an open wave absorption chamber when subjected to a regular wave with $H = 0.78\text{m}$ and $T = 3.0\text{s}$, while multiphase SPH analysis showed an underestimation by a factor of 0.7 (Figure 3). The multiphase SPH, however, is able to simulate the air movement in and out of the chamber, with air velocity of up to 8m/s measured at the chamber's outlet during inhalation and exhalation (Figure 4 (b)).

Closed chamber case. Only multiphase SPH results can capture the closed chamber case. Single-phase will show the same result as the open chamber case due to the absent of particles above the still water level. Water column movement shows similar results between multiphase SPH and experiment during compression (upward water column movement) (Figure 5). During decompressing movement (downward water column movement), the multiphase SPH is unable to hold the air particles in place, creating a void which allowed the water column to move further, without change in air pressure (Figure 6). An over-estimation factor of 1.5 is also found for the maximum air pressure simulated.

REFERENCES

Pawitan, Vicinanza, Allsop, Bruce (2020). Front wall and in-chamber impact loads on a breakwater-integrated oscillating water column. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 146(5), p.04020037.

Viviano, A., Naty, S., Foti, E., Bruce, T., Allsop, W. and Vicinanza, D., 2016. Large-scale experiments on the behaviour of a generalised Oscillating Water Column under random waves. *Ren. Energy*, 99, pp.875-887.

Lu, X., Cherfils, J.M., Pinon, G., Rivoalen, E., Kimmoun, O. and Brossard, J., 2021. SPH numerical computations of wave impact onto a vertical wall with experimental comparisons. *Comptes Rendus. Mécanique*, 349(1), pp.117-143.