Aerated wave impacts on an overhang: simulations and experiments

Peter R. Wellens and **Martin van der Eijk**
Maritime & Transport Technology, Delft University of Technology, The Netherlands
p.r.wellens@tudelft.nl

HIGHLIGHTS

In previous abstracts for the workshop, impacts of flows with aeration were considered, i.e. a homogeneous mixture of water and air bubbles. Surrogate models for wave impacts were evaluated, such as the dambreak and the wedge entry, but never a wave impact. In this abstract, actual aerated wave impacts on an overhang are simulated by means of a numerical method of our own design. The simulation results are validated by means of a purpose-built experimental setup.

INTRODUCTION

Heavy seas feature breaking waves. Wave overturning causes air pockets to be enclosed, which break up under water to form clouds of air bubbles. The small air bubbles remain entrained for several wave periods [1, 2]. We refer to the process of air entrainment as aeration, and we call the mixture of water and air aerated water.

Due to aeration, the assumption of incompressibility of water is not always justified in modelling impulsive interaction of water with fixed structures [3, 4, 5]. Also for moving structures, experiments have demonstrated that aeration affects the results [6, 7, 8]. A small amount of air in water, say 1% by volume, already leads to a significant increase in the compressibility of the mixture [9].

Support structures for renewable energy at sea are built with limited redundancy in order not to compromise the economic perspectives of its implementation. Some concepts for floating solar keep the solar panels away from the free surface by means of an air gap. An air gap that is so large that wave impacts with the solar panels never occur will likely lead to an uneconomical support structure. If an occasional impact is allowed, it becomes important to assess the wave impact forces on these panels. Including the aeration that is sure to be present in heavy seas in the evaluation of the impact force, may be more realistic than modelling wave impacts without air-content and aerated wave impacts may have lower impact pressure magnitudes than impacts with pure water.

To investigate the effect of aeration on wave impact pressures, simulations were performed with a novel numerical method of our own design. Also a purpose-built experimental setup was constructed to measure impact pressures so that they may validate the simulations.

MATHEMATICAL MODEL

The one-fluid approximation is applied yielding a single velocity and a single pressure field [10]. For the air in aerated water, we neglect bubble interaction and effects of surface tension. The air bubbles are assumed to be sufficiently small [11]. The mixture is assumed to be homogeneous.

The equation for the conservation of mass for the aggregate fluid is obtained from the sum of the equations for each phase

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0, \quad \rho = \frac{C_b - C_f}{C_b}\rho_a + \frac{(1-\beta_g)C_f}{C_b}\rho_l + \frac{\beta_g C_f}{C_b}\rho_a. \tag{1}$$

Parameter ρ is the aggregate fluid density that is used together with the algebraic relations

$$\begin{aligned} \beta_g + \beta_l &= 1, \\ C_f + C_a &= C_b, \end{aligned} \tag{2}$$

Although not required, we now say that $\rho_g = \rho_a$ because for all our applications the gas entrained in water originates from the air above it.

The equations for the conservation of momentum, using again a single velocity field and a single pressure field read

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u} \otimes \mathbf{u}) + \nabla p + \rho \mathbf{g} = 0. \tag{3}$$

Here, p is the pressure in the aggregate fluid and $\mathbf{g}$ the vector of the acceleration of gravity. Note that the viscous term has been omitted from the momentum equation as mainly short-duration events will be considered, in which viscous effects such as the formation of boundary layers can be ignored.

NUMERICAL MODEL

The governing equations for conservation of mass (1) and conservation of momentum (3) of the fluids are discretized into a system of equations for solving the pressure p. The fluid velocities $\mathbf{u}$ are solved from the pressure gradients. The fluid and body velocities are used to transport the interface between fluids. Density ρ and the fraction of air in water β_g (aeration) are solved algebraically. The equations are combined into a solution algorithm.

The solution algorithm is an extension of the incompressible two-phase flow method in [12], that uses the same discretization techniques for the mass, momentum and interface transport to obtain a consistent method. Without consistency, momentum losses and distortion of the interface are found for high-density ratio flows. A temporary continuity equation was used to obtain consistency, solving it on momentum control volumes to prevent momentum losses as a result of the staggered grid.A one-step projection method [13] is used for solving the pressure.

EXPERIMENTAL SETUP

For the experiments, the sloshing rig at Delft University of Technology is used. The sloshing rig has two degrees of freedom. The transnational motion in the longitudinal direction of the tank and the rotational excitement on the transverse axis located in the middle of the tank. The longitudinal excitement has a maximum amplitude of 60[mm] and the rotational excitement has a maximum amplitude of 10[deg]. Both excitations have a maximum frequency of 1.5[Hz].

Preinstalled at the sloshing rig is the water tank in which the experiment will take place. This tank is made of 20 mm thick acrylic glass. The inner dimensions of the current tank setup are a length of 700[mm], a height of 496[mm], and a width of 200[mm]. The tank has a front and back plate that are preinstalled with multiple cable entrees. The tank is also fitted with a sealing cover. This cover prevents water from sloshing out of the tank. The cover of the tank also has preinstalled cable entries near the front and back wall.

The novel part of the experimental setup will be the inner construction of the tank. This consists of the overhang, the back plate, and the aeration system. The dimensions of the structure are h=300 mm, L=100 mm, w=200 mm, see Fig. 1. The thickness of the overhang is 20 [mm], and made from PVC.

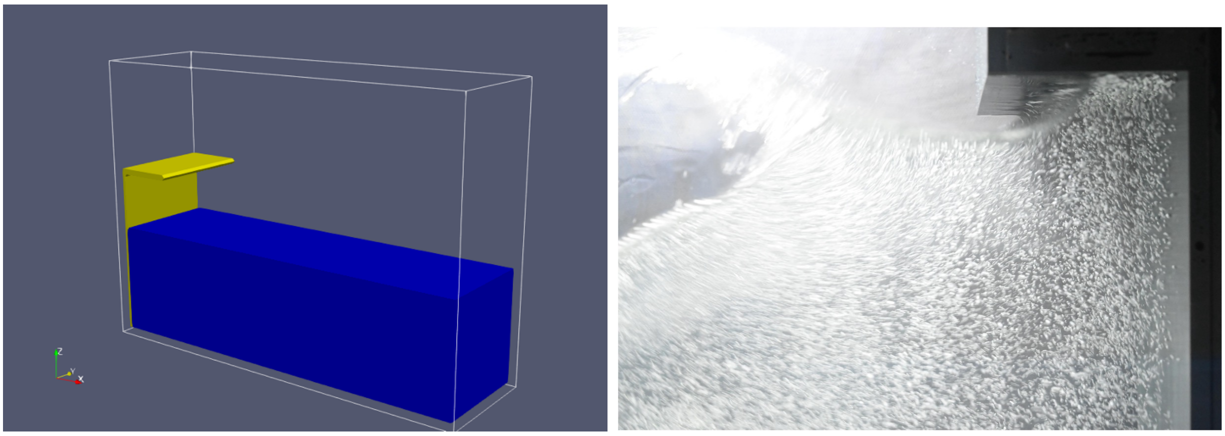

Figure 1: Experimental setup with overhang in (a) and an aerated wave impact on overhang in (b).

PRELIMINARY RESULTS

The first results in Fig. 2 compare the maximum impact pressure on the overhang for a sloshing frequency of 0.93 Hz at aeration levels ranging from 0% to 4%. The variation in the simulation results was obtained by starting with different initial free surface configurations before applying the sloshing accelerations. The experiments always started from rest before applying sloshing accelerations. From the results it is found that in both the simulations and in the experiments the maximum impact pressure on the overhang goes down as the aeration level goes up. The variation of pressure in the experiment is significantly larger than the variation of maximum pressure as a result of the different initial free surface configurations in the simulations.

CONCLUSION

The first results in terms of impact pressures, for a sloshing frequency of 0.93 Hz, on an overhang representing a floating solar panel on a support structure with an airgap indicate that there is a

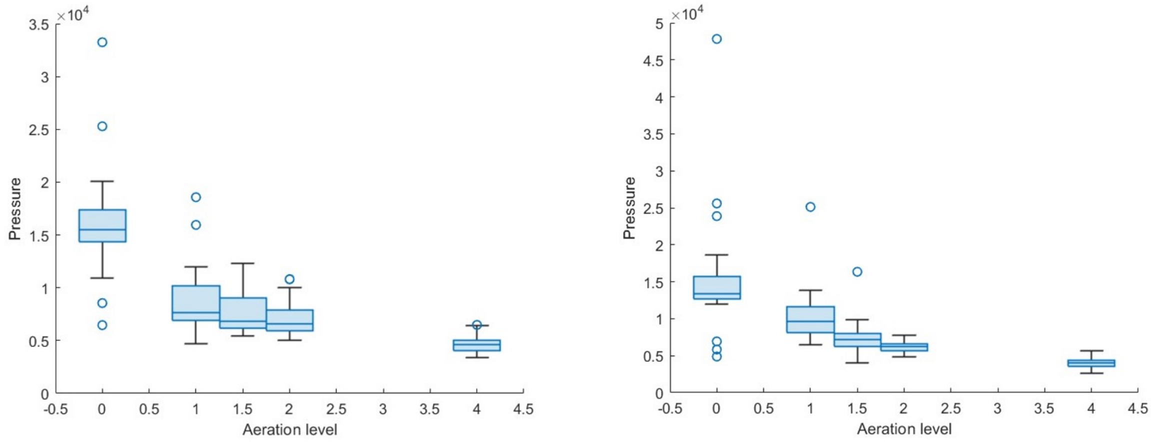

Figure 2: Maximum impact pressure on overhang for different aeration levels: numerical results in (a) and experimental results in (b).

significant effect of aeration on impact pressures on a overhang. The maximum impact pressure goes down when the aeration level goes up. More results will be shown at the workshop.

REFERENCES

[1] Scott, J. C. The role of salt in whitecap persistence. In *Deep Sea Research and Oceanographic Abstracts* (1975), vol. 22, Elsevier, pp. 653–657.

[2] Peregrine, D., and Thais, L. 1996. *The effect of entrained air in violent water wave impacts. Journal of Fluid Mechanics 325*, 377–397.

[3] Bullock, G., Obhrai, C., Peregrine, D., and Bredmose, H. 2007. *Violent breaking wave impacts. Part 1: Results from large-scale regular wave tests on vertical and sloping walls.* Coastal Engineering 54(8), 602–617.

[4] Bredmose, H., Bullock, G., and Hogg, A. 2015. *Violent breaking wave impacts. Part 3. Effects of scale and aeration. Journal of Fluid Mechanics 765*, 82–113.

[5] Mai, T., Mai, C., Raby, A., and Greaves, D. 2019. *Aeration effects on water-structure impacts: Part 2. Wave impacts on a truncated vertical wall. Ocean Engineering 186*, 106053.

[6] Mai, T., Mai, C., Raby, A., and Greaves, D. 2019. *Aeration effects on water-structure impacts: Part 1. drop plate impacts. Ocean Engineering 193*, 106600.

[7] Elhimer, M., Jacques, N., Alaoui, A. E. M., and Gabillet, C. 2017. *The influence of aeration and compressibility on slamming loads during cone water entry. Journal of Fluids and Structures 70*, 24–46.

[8] Eroshin, V., Plyusnin, A., Romanenkov, N., Sozonenko, Y. A., and Yakimov, Y. L. 1984. *Influence of the atmosphere on the magnitude of the hydrodynamic forces in the case of a disk in a flat encounter with the surface of a compressible liquid.* Fluid Dynamics 19(3), 350–355.

[9] Wood, A. 1941. *A textbook of Sound, 578 pp. Bell, London.*

[10] Murrone, A., and Guillard, H. 2005. *A five equation reduced model for compressible two phase flow problems.* Journal of Computational Physics 202(2), 664–698.

[11] Wilson, P. S., and Roy, R. A. 2008. *An audible demonstration of the speed of sound in bubbly liquids.* American Journal of Physics 76(10), 975–981.

[12] van der Eijk, M., and Wellens, P. R. 2023. *Two-phase free-surface flow interaction with moving bodies using a consistent, momentum preserving method. Journal of Computational Physics 474*, 111796.

[13] Chorin, A. J. 1968. *Numerical solution of the Navier-Stokes equations.* Mathematics of computation 22(104), 745–762.