Wave impacts on an overhang: effects of angle, structural flexibility and aeration

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HIGHLIGHTS

At the previous workshop vertical wave impacts on a rigid, horizontal overhang were considered so that the difference in maximum impact pressure between water without entrained air and aerated water could be quantified. The difference was significant. Our recent work extends that work to a setup with an overhang that can take on different angles with respect to horizontal and is no longer rigid.

INTRODUCTION

Breaking waves at sea entrain air in water to up to 1 or 2% by volume. When aerated water interacts with structures during wave impacts, the maximum impact pressure is lower compared to the pressure in water without air due to compressibility [1, 2]. The amount to which the maximum pressure in impacts with aerated water is lower was 15% for wedges that were freely falling with 7[m/s] at the moment of impact with the free surface of water with an air-content of 1% by volume [3]. Similar results were obtained for vertical wave impacts against rigid, horizontal overhangs, presented at the previous workshop.

Hydroelasticity during impacts is also known to reduce the maximum pressure during impact [4, 5]. In order to investigate the effect of hydroelasticity on the maximum pressure, the setup with a rigid, horizontal overhang was redesigned compared to last year to be able to make the overhang elastic. The effect of hydroelasticity on the maximum pressure is likely higher when the maximum pressure is higher. In the setup the impact pressure during the same wave impact can be made higher by giving the overhang a more astute angle with respect to the wall.

It is necessary to perform simulations together with experiments. The experiments validate the assumptions that are made in modelling the fluid and the structure. The simulations, in turn, quantify the pressure distributions on the plates, which would be challenging to measure in an experiment without affecting the structural properties. The simulations can also straightforwardly show the density waves in the aerated water that propagate away from the impact and can be a cause of vibration of the structure. For this reason, first the model equations are presented before the setup of the experiment is discussed.

MATHEMATICAL MODEL AND NUMERICAL MODEL

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

The governing equations for conservation of mass (1) and conservation of momentum (5) 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 solution algorithm and an experiment with falling wedges in aerated water to validate the implementation can be found in Van der Eijk and Wellens [3].

The equation of motion of the structure is given as

$$\mu \frac{\partial^2 w}{\partial t^2} - EI \frac{\partial^4 w}{\partial s^4} = q(s,t), \tag{4}$$

in which w is the deflection of the plate, and μ and EI are the distributed mass and stiffness of the plate. The fluid exerts a pressure, integrated over the width, on the plate in the form of load q distributed in direction s along the plate. In turn, the plate imposes a boundary condition on the velocity $\mathbf{u}$ of the fluid in direction $\mathbf{n}$ perpendicular to the plate

$$\mathbf{u} \cdot \mathbf{n} = \frac{\partial w}{\partial t}. \tag{5}$$

The structure's motion is solved together with the fluid motion in separate domains that are strongly coupled through a quasi-simultaneous approach requiring only a few iterations per time step to converge.

EXPERIMENTAL SETUP

For the experiments, the sloshing rig at Delft University of Technology is outfitted with a support structure inside to which a wall, overhang and instrumentation are mounted. Only the translational degree of freedom of the rig is used up to an oscillation amplitude of the rig of

60[mm] and up to an oscillation frequency of 1.5[Hz].

Pre-installed in the sloshing rig is the water container in which the experiment will take place. The container is made of 20[mm] thick acrylic glass to prevent deformation of the container to interfere with the measurements of the deformation of the overhang. The inner dimensions of the container are a length of 700[mm], a height of 496[mm], and a width of 200[mm].

The support structure inside the container is built up of standard aluminium profiled beams and placed within the container, see Fig. 1. The wall is connected rigidly to the support structure. The overhang consists of a clamped plate that is connected to the support structure by means of force gauges. A thicker plate – that is assumed to be rigid so that the connection to prior work with impacts on an overhang can be made – is instrumented with pressure gauges. During tests in the experiment, water with different levels of aeration is forced into a sloshing motion that runs up vertically along the wall until an impact with the overhang occurs. The variation of water level is measured with a wave gauge mounted to the container wall opposite the wall with the overhang.

When thinner plates are used for the overhang, the plates deform while experiencing the wave impact. These plates are not instrumented with pressure gauges in order not to change the structural properties of the plates locally. The deformation of the plates is measured by means of laser vibrometers of which the measurement range is indicated in Fig. 1 with red and green light beams shining downwards. Just as with the rigid plate, we will continue to measure the vertical forces on the flexible plates as they deform while undergoing the hydrodynamic load. It was made sure that the force measurement system is stiff enough to have its first natural frequency outside of the range of first and second natural frequencies of the deforming plates.

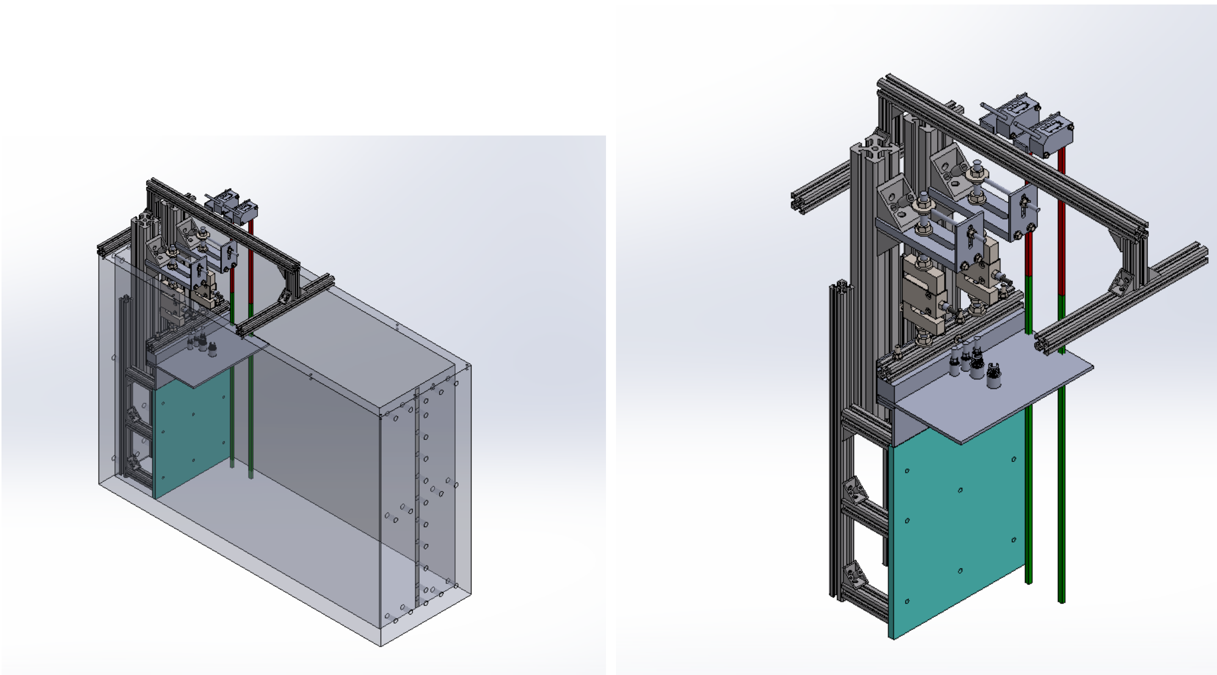

Figure 1: Experimental setup with the complete sloshing rig container (left) and a detailed view of the wall, overhang and instrumentation (right).

PRELIMINARY RESULTS

The left-hand side of Fig. 2 shows a simulation snapshot of a wave impact that takes place 1.26[s] after sloshing with 0.88[Hz] starts. The mean water depth is 145[mm] and at the position of the wall the overhang is 300[mm] above the bottom of the container. During the simulation the forces on the overhang are measured. The forces as a function of time on overhangs with various angles are shown on the right-hand side of Fig. 2. The maximum force when the overhang has a 45° angle with the horizontal is more than 3 times as large as the maximum force when the overhang is horizontal. These results confirm our initial thoughts that the forces, and hence pressures, become higher when the angle with the wall becomes more acute.

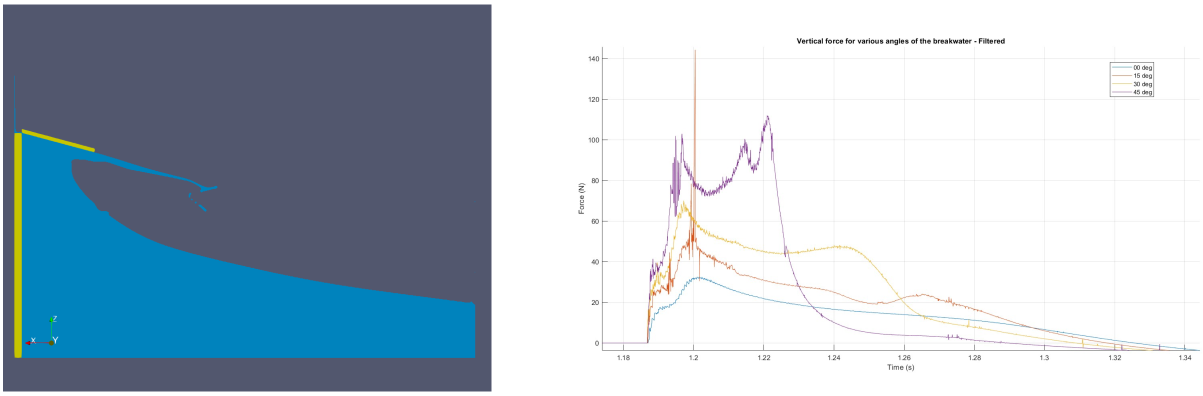

Figure 2: Simulated wave impact on overhang with 15° angle (left) and simulated force as function of time for various angles of the overhang (right).

CONCLUSION

The first results of simulations of wave impacts on an overhang with various angles show that there can be a factor of 3 between the maximum force on a horizontal overhang and one that is more acute. The effects of hydroelasticity and aeration on the maximum force during wave impacts will be shown at the workshop.

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