Experimental and numerical 2D wedge entry in water with entrained air

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HIGHLIGHTS

Air entra in water has a significant and reducing effect on the maximum forces during extreme (wave) impacts. Experimental and numerical methods used together can lead to a better understanding of physics. Combined results show that the difference between aerated impacts and those without air can be 12% for 5% air content.

EXPERIMENTAL & NUMERICAL COMPARISON

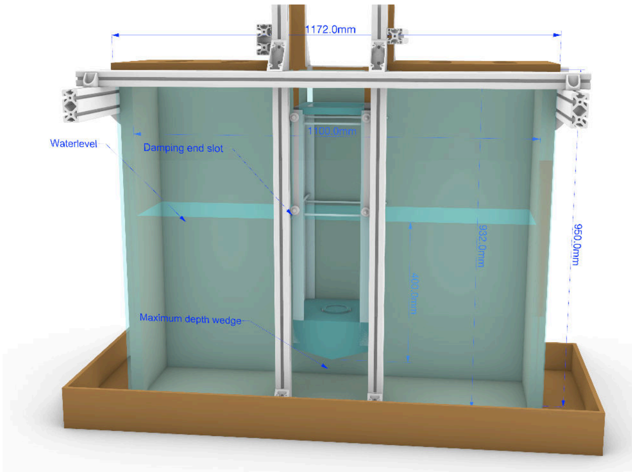
Maritime floating bodies are often designed to endure extreme water wave events. Examples of these impact loading events are hull entries, waves slamming onto the hull, or green water onto the deck. A simplification of such an event can result in a better understanding of the physics involved. An example is a 2D simplified cross-section of the floating body [1, 2, 3, 4], a wedge, in a drop test.

A high-speed falling wedge experiment is conducted at the Delft University of Technology. The experiment is built to investigate the effect of air in water on the impact. The experimental results are used to validate our numerical model. The literature, we found, does not yet feature data of high-speed 2D entries followed by emergences, including compressible effects. The wedge used for this experiment has a deadrise angle of 15 degrees. A Froude number up to 6.5 (≈7.0[m/s]) is reached.

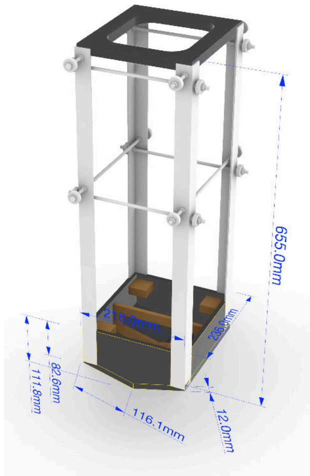
The experimental setup is illustrated in fig. 1. The domain size and the water level are designed such that their influence on the initial impact is negligible and a large impact speed is reached. The experimental tests are done for three different weights of the wedge; 4.0[kg], 5.0[kg], and 10[kg], representing 0.8, 1.0 (neutrally buoyant), and 2.0 times the buoyancy. Every weight is released at least five times. The measurement equipment are two light gates for measuring the speed, two accelerometers of 100g and 200g (AS28E and ADXL377), and a camera.

The numerical method is an extension of [5]. The method is a Volume-of-Fluid based method that uses a cut-cell method and full geometric piecewise linear reconstruction. The governing equations for fully-compressible two-phase flows are solved. The fluid-structure interaction is solved monolithicly. Second-order integration schemes to capture the dynamics during the impact are used. The method makes use of the one-fluid formulation and matches the mass and momentum flux to prevent momentum losses [6].

The acceleration signals are filtered using Fourier analysis. The frequencies caused by the structure of the setup are removed. The speed measurement is used as calibration for the acceleration time signals. The variation between the impact speeds of the different weights (6.65, 6.80, and 7.03[m/s] respectively) is up to 5.5%, caused by friction losses during falling. The maximum accelerations, including the variation, are illustrated in fig. 2a.



(a) Box domain.

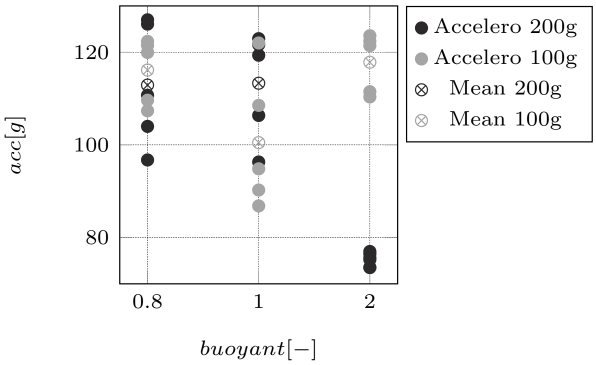


(b) Wedge.

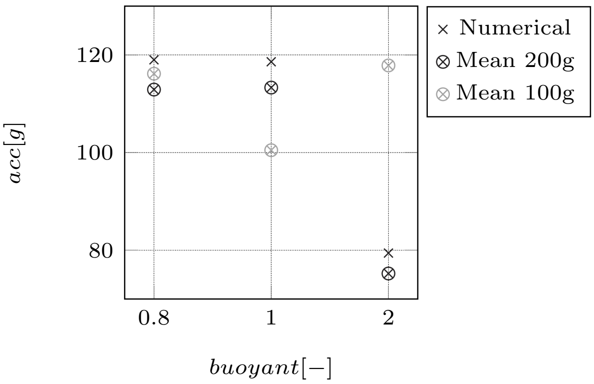
(c) Droptower.

Figure 1: Experimental setup.

The results of the 200g accelerometer in fig. 2 match better with the numerical results than the 100g accelerometer. The Fourier analysis of the 100g accelerometer data shows to be more sensitive to environmental effects, like structural vibrations, than the 200g accelerometer. The accuracy of the 100g accelerometer is debatable as the wedge impacts are higher than 100g.



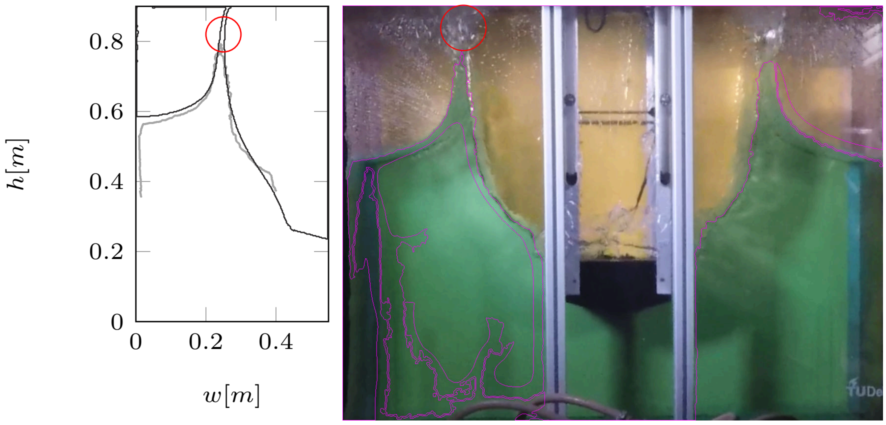
(a) Variation experiment.



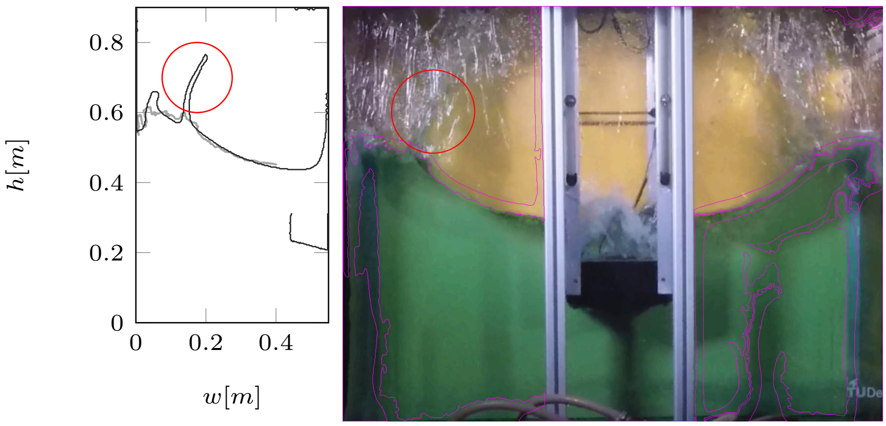
(b) Numerical and experiment.

Figure 2: Comparison max. accelerations experimentel data & numerical results.

In fig. 3 the free surface is extracted from the camera recordings and is compared with the numerical results. The contour extraction of the recordings has problems with representing the mixed air-water jets. The numerical results correspond well with the video frames. In fig. 3a and fig. 3b a circle is drawn showing the difference between the numerical free surface and the contour extraction. When comparing these to the video frames, the numerical results seems to be in good agreement. In fig. 3b a returning jet attached to the sidewall penetrates the free surface and is captured by both methods.



(a) Max. penetration depth.



(b) Upward motion.

Figure 3: Comparison free surface experimental data & numerical results for 0.8x buoyant; – experiment, – numerical result.

AERATION

In reality, breaking in heavy seas can lead to air entrainment. The air content can remain in the water for several wave periods. Assuming the mixture of air and water homogeneous modifies the compressibility up to several orders of magnitude. General methods used for the design stage of maritime floating bodies often do not account for the air content, which is likely to be one percent or higher [7, 8]. Our numerical method [5] has been modified to account for these compressible effects, including the air content.

Numerical simulations of the 0.8x buoyant wedge at a speed of 6.65[m/s] are performed. The numerical domain is the same as the domain illustrated in fig. 1a. The air content is varied, showing the effect on the maximum acting force. The results are shown in tab. 1.

The results show that an increase of air content for a constant impact speed results in a cushioning effect on the maximum acceleration. This cushioning effect corresponds to other experimental results [9, 10] The air content results in increased compressibility. The compressibility of a mixture can be indicated by a Mach number which is the ratio of the flow speed and speed of sound for a homogeneous mixture [10].

Air content [%]	Max. acc. [g]	Diff. with 0% air [%]	Mach number
0 (Exp., 200g)	113.7	-	0.02
1 (Exp., 200g)	109.1	-4	0.2
0 (Exp., 100g)	116.1	-	0.02
1 (Exp., 100g)	119.5	+3	0.02
0	119.0	-	0.02
0.1	115.5	-3	0.08
1	112.5	-6	0.2
5	104.6	-12	0.5

Table 1: Maximum acting accelerations.

CONCLUSION

An experimental setup has been presented that can be used to investigate the effect of aeration on the accelerations during impact with a 2D cross-section. Also, the results are used to validate an in-house numerical model. The numerical and experimental results are in good agreement regarding the maximum accelerations. The combination of the experiment and numerics gives a better insight into physics. Increasing the air content for the numerical simulations showed a large and nonlinear decrease of the maximum accelerations. Air in water should be considered in the final design process of maritime floating bodies enduring extreme water events.

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