Wave-in-deck and vapour pocket model tests

Fresh insight into impact load assessment has been gained following two BreaKin JIPs and the IMBOL project, which is a continuation of the SLING programme.

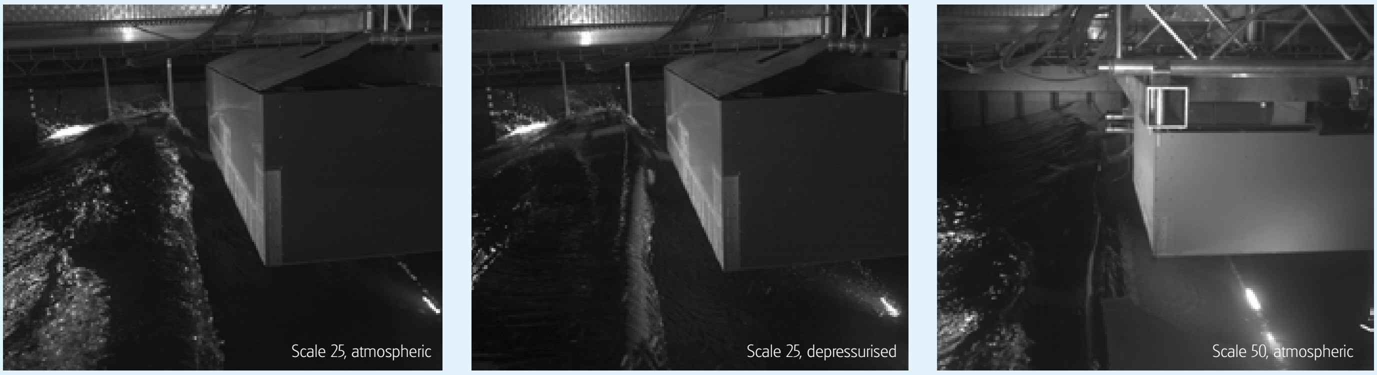

Figure 1: Observations based on high-speed video images

▸ Wave-in-deck impact event in atmospheric condition (left) and depressurised condition (right), measured at scale 25 in MARIN's Depressurised Wave Basin

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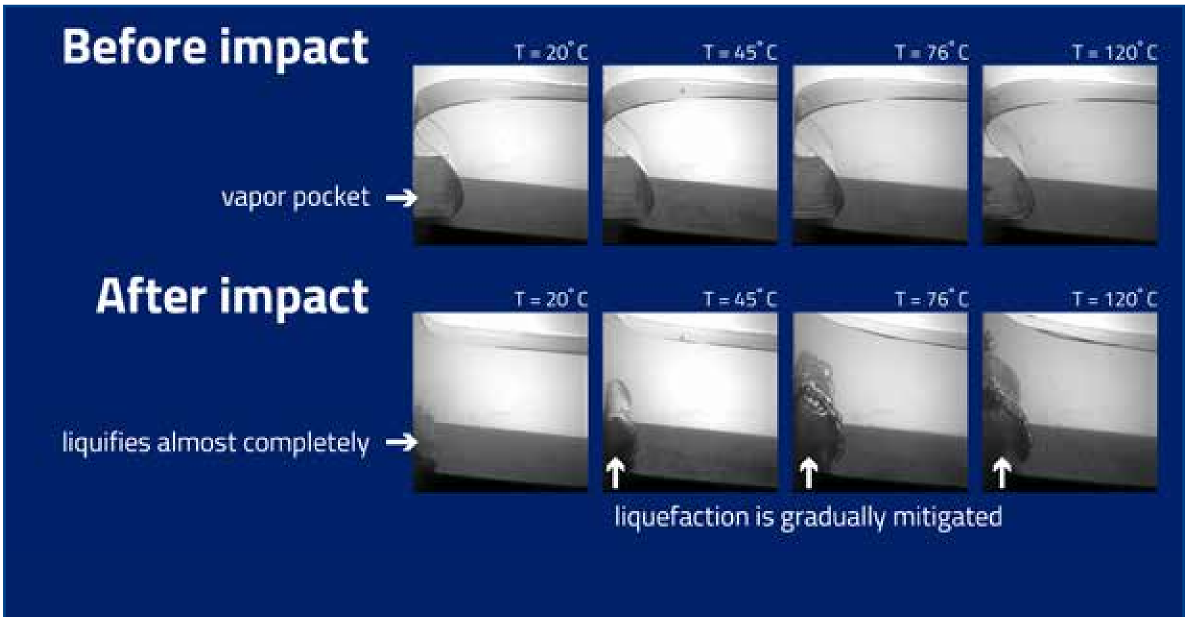
BreaKin and BreaKin CFD JIP During the BreaKin JIP (2016-2018) wave-in-deck model tests were carried out in MARIN's Depressurised Wave Basin (DWB) at two scales (25 and 50), and in atmospheric and depressurised conditions. The objective of the JIP was to get more insight into the scale effects involved in wave-in-deck model tests and to take the first steps towards linking wave kinematics with measured impact loads.

In the ongoing follow-up project, the BreaKin CFD JIP (2020-2023), the model test results are being further analysed and compared to ComFLOW simulations.

Based on the preliminary results, two major observations have been made:

- The depressurisation of the testing facility results in a change in gas-to-liquid density ratio and due to this, in a change in air flow between the incoming wave and the deck box. This causes a change of wave shape. For the wave cases tested at scale 25, this resulted in an increase of measured horizontal global impact loads in depressurised conditions compared to atmospheric conditions.
- The unscaled surface tension results in changes of the free surface instabilities between the tests carried out at scale 25 vs scale 50. As a result, higher global horizontal deck loads are measured at scale 50.

The two observations based on high-speed video images are illustrated in figure 1.



High-speed video of a single impact wave in the Atmosphere facility (ATM) from two different angles. Here, the liquid phase is water and the gaseous phase is water vapour. The temperature increases from left to right.

Figure 2: Single wave impact as captured by a high-speed camera for four selected temperatures from The Atmosphere facility (ATM). The liquid phase is water and the gaseous phase is water vapour. Impact process before impact (top panels), impact process after impact (bottom panels)

IMBOL In 2019, MARIN together with the Phase Transition Consortium joined IMBOL (2019-2025), which is a continuation of the SLING programme (2015-2020). MARIN's contribution to IMBOL is based on an extensive experimental campaign in the Atmosphere facility (ATM) examining the impact dynamics of a boiling liquid.

In 2021, we conducted a series of single impact wave experiments along the liquid/vapour boundary for increasing temperature (up to 115 C) and thus, for increasing gas-to-liquid density ratio (DR). In contrast to the type of gases that are normally used in the ATM (condensable gases), these experiments looking at the vapour pressure of water further reveal the impact dynamics of a liquid that has contact with its own vapour – as is often the case in a cargo containment system (CCS) filled with a cryogenic liquid such as liquefied natural gas (LNG) or even liquid hydrogen (LH2). The experiments have shown that – when the DR is small (low temperatures) – a Rayleigh-type collapse of the vapour pocket takes place, which is accompanied by a short, large amplitude pressure peak whose magnitude can reach up to 70 bar! As the DR increases, we observed that this effect is mitigated, and the impacts resemble something similar to the oscillation of non-condensable gas pockets. These observations are illustrated in figure 2.

Currently, we are working on a better understanding of these results by placing our experiments in the context of a theoretical model of a vapour pocket that takes into account both pocket dynamics (Rayleigh-Plesset equation) and heat transfer (Plesset-Zwick formula). This phenomenon is of particular interest to the industry, as these short-pulse, large amplitude peaks could be potentially hazardous and thus, need to be considered when designing a CCS.

The Atmosphere is a test facility to unravel the complex physics of those wave impacts. A custom-built 12.5 m long, 0.6 m wide and 1.2 m tall flume tank with a heavy, instrumented impact wall is available at the facility to study wave impacts in different conditions.