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2D Simulations of Breaking Wave Impacts on a Flat Rigid Wall – Part 2: Influence of Scale

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Three different breaking wave impacts against a flat rigid wall have been numerically simulated in 2D at two different scales, scale 1 and scale 1:6, with Froude-similar inflow conditions but keeping the same fluids (water and air) at both scales. Sufficiently refined discretizations have been used in order to adequately capture the impulsive loads at wall. The simulations have been performed with SPH-flow, which solves the compressible Euler equations for liquid and gas, thanks to a Smoothed Particle Hydrodynamics (SPH) method. The three waves have been selected in order to generate wave shapes just before impact, representative of those leading to the largest loads during 2D sloshing model tests for low filling levels or during wave impact tests in flumes. Three gas-pocket impacts with different sizes of the gas cavity have been chosen. Results obtained at scale 1 have been presented in Part 1 of this work (Guilcher et al., 2014). Results at scale 1:6 are presented here in this Part 2. Pressure maps $P(y, t)$, where y is the vertical location of any point at wall and t is the time, and time-traces of the different components of the energy are presented in the same way as for results at scale 1, in order to enable an easy comparison. Results at both scales are compared after scaling the results from scale 1:6 as though the flows were in complete similarity. Inconsistencies are shown and explained by unscaled gas and liquid compressibility.

INTRODUCTION

Context

The context of this study is the sloshing assessment of LNG membrane tanks on floating structures based on sloshing model tests. Those tests are usually performed with model tanks at scale 1:λ ($\lambda = 40$), filled with water and a mixture of gases chosen in order to have the same gas-to-liquid density ratio as on board ships with Natural Gas (NG) and Liquefied Natural Gas (LNG). Irregular tank motions, calculated at full scale by a seakeeping software, are imposed to the model tank by a six-degree-of-freedom hexapod after having been downscaled according to Froude similarity. This downscaling simply means that amplitudes are divided by λ and times are divided by $\sqrt{\lambda}$.

This does not mean that the flow inside the model tank is in complete similarity with the full-scale flow. Actually, even disregarding the biases induced by phenomena that are present at full scale and not at model scale (phase change, hydro-elasticity, and influence of the protuberances of the metallic membrane on the wall), the gas and liquid used at model scale cannot fulfil the different similarity laws for the different phenomena they are involved in during sloshing periods: their properties are not relevantly scaled. In particular, the compressibility for both the gas and the liquid, involved during each impact, is too small at model scale.

The perfect match for the gas and liquid at model scale is not possible with real fluids, but it can be reached with virtual ones and numerically tested. If the numerical model only takes into account the density and the compressibility of the fluids, as is the case for solvers of the compressible Euler equations like SPH-flow, the complete similarity at both scales is reached if and only if three dimensionless numbers are kept the same at both scales: the gas-to liquid density ratio (DR), and both Mach numbers defined with the speed of sound into the gas and into the liquid, respectively. As the reference velocity to be involved in Mach numbers have to be in Froude similarity, this implies that speeds of sound into the gas and the liquid at model scale are $\sqrt{\lambda}$ times smaller than the corresponding ones at full scale (Braeunig et al., 2009).

With real gas and liquid at model scale, the perfect match is not possible. This includes the case for which the liquid and the gas are the same at both scales. In that case, a partial similarity is obtained with the right excitations (Froude), the right DR but different Mach numbers at both scales. The liquid and the gas are then too stiff at model scale with regard to the ideal properties for a perfect match.

Sloshing model tests are necessarily performed in partial similarity. Comparing 2D sloshing model tests for low filling levels performed at two different scales with Froude-similar irregular excitations, Karimi et al. (2015) showed that the impacts keep

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KEY WORDS: Sloshing, SPH, wave impact, compressibility, LNG tank, breaking wave, scaling, ELP, Bagnold.