Sloshing and Scaling: Results from the Sloshel Project

H. Bogaert(1,2), S. Léonard(3), L. Brosset(3), M.L. Kaminski(1)

1MARIN, Hydro Structural Services, Wageningen, The Netherlands
2Delft University of Technology, Ship Structures Laboratory, Delft, The Netherlands
3GTT (Gaztransport & Technigaz), Liquid motion department, Saint-Rémy-lès-Chevreuse, France

ABSTRACT

At the turn of 2007 full scale wave impact tests have been carried out by MARIN in the frame of the Sloshel project. Unidirectional breaking waves were generated in a flume in order to impact an instrumented transverse wall with embedded test structures. The main goals of these tests were to study the hydro-elastic effects associated with the NO96 membrane containment system for LNG carriers and to create a sound database for validation of numerical simulations. The preliminary results were overviewed in 2009 by Brosset et al. Since then the full scale tests have been repeated at scale 1 to 6 in order to study the scaling effects. These tests are referred to as the large scale tests.

The large scale test set-up mimicked as far as possible the full scale set-up. At both scales the instrumentation consisted of multiple pressure sensors, accelerometers and load cells. Special attention was paid to observe the shapes of the breaking waves while impacting. This was obtained by optical sensors at full scale and high speed cameras at large scale, both synchronized with the data acquisition systems. These recordings provided insight in the sloshing physics and enabled to determine characteristic quantities like the amount of entrapped air for air pocket impacts and the corresponding oscillation frequencies.

In order to compare deterministically measured impact pressures at both scales a similarity must be ensured on the global flow from the wave paddle to the instant just before the first contact with the wall. Such a similarity has not been achieved. Reasons for that are analysed and recommendations for further tests at full scale are given.

Nevertheless a comparison is proposed restrained to global parameters describing gas pocket impacts like pressure within the gas pocket, frequency of the oscillations when compressed and damping coefficient of these oscillations. The similarity at both scales is based on the surface of the gas pocket when closing.

So-called compressibility bias demonstrated theoretically and illustrated numerically by Braeunig et al., (2009) is confirmed experimentally. The 1D simplified model of Bagnold (1939) is presented to explain the process.

KEY WORDS: Sloshing, LNG carrier, Containment System, scaling, model test, Froude, impact pressure, flume tank, breaking wave

INTRODUCTION

Sloshing assessment of a new membrane LNG carrier is always based on sloshing model tests (see Gervaise et al., 2009). Such tests are performed in GTT (Gaztransport & Technigaz) with model tanks at scale 1:40 (\(\lambda = 40\)) installed on the platform of a six degree of freedom hexapod. The forced motions reproduce the calculated ship motions after Froude-scaling. This means that the linear amplitudes of the motions are scaled by \(1/\lambda\) and the time is scaled by \(1/\sqrt{\lambda}\). The tanks are filled with water and a mixture of gases that is chosen in order the density ratio between gas and liquid is equal to the real one on board LNG ships (around 0.004). Up to 300 pressure sensors enable to capture the sloshing pressures in the impact areas.

This approach raises the question of how to scale the measured pressures from scale 1:40 to full scale. Is Froude-scaling relevant?

It is useful to consider the flow inside a partially moving tank in two parts: the global flow and the local flow in the vicinity and during the impacts.

The global flow is rather deterministic. Repeating several times the same excitations lead to impacts at the same instants and locations even for long duration tests. When changing the scale, the global flow remains the same if Froude number and the density ratio are kept unchanged. The local flow involves several phenomena including the compression of the entrapped gas fraction (gas pocket and bubbles). The impact pressures are extremely sensitive to the impact input conditions and appear as randomly distributed even for simple harmonic one degree of freedom 2D tests. Only a statistical post-processing after long duration tests enables to get repeatable sloshing loads.

The sloshing experimental modelling with model tests is based on the reasonable assumption that, according to the Froude scalability of the global flow, tests with Froude-scaled excitations generate a statistical sample of local impact input conditions that are representative of the full scale conditions.

Now, even if the input conditions of the impacts are well scaled from the global flow, the local interactions during impacts, especially between liquid and gas, have no reason to behave according to Froude-scaling.

Braeunig et al., (2009) showed that Froude-scaling of the impact pressures would be relevant only if the liquid and the gas at small scale had properties in Froude agreement with the properties of respectively the liquid and the gas at full scale (Froude-scaled equations of state). Such list of properties start with Froude-scaled speeds of sound. As such technically challenging conditions are not fulfilled yet during model tests, a compressibility bias is inevitable.

In the present study, results of wave impact tests at two different scales are presented. Two different facilities were used. The test set-ups in both facilities are presented in next section. The objective was to