Comparison of Wave Impact Tests at Large and Full Scale: Results from the Sloshel Project

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ABSTRACT

Wave impact tests were conducted at two different scales within the Sloshel Joint Industry Project. In 2009 unidirectional breaking waves were generated in a flume at scale 1:6. The waves impacted on an instrumented wall. These tests were repeated at scale 1:1 in 2010. The piston motions were scaled by maintaining the Froude number. At both scales, the tests were performed with water and air at atmospheric pressure and ambient temperature. The compressibility of the liquid and the gas, and other properties such as the surface tension of the liquid were therefore equal at both scales.

The measured impact pressures at scale 1:6 and 1:1 are compared deterministically in this paper to define by how much the Froude-scaling of the impact pressures is biased by the fact that the properties of the liquid and the gas are not scaled.

This deterministic comparison requires that the global flow at scale 1:1 starting from the wave piston to the instant just before the first contact with the wall is Froude-similar to the flow at scale 1:6. Only then the differences between the measured pressures at the two scales can entirely be attributed to the fact that the properties of the liquid and the gas were not scaled. Froude-similar global flows were obtained for these tests by carefully controlling the piston motion and the water depth at both scales and by minimising the effect of the wind at full scale.

The comparison of the impact pressures for the Froude-similar global flows shows that the loading processes ‘building jets along the wall from the impact area’ and ‘compression of entrapped air’ are not Froude-similar when the compressibility of the gas is not scaled. The one-dimensional model of Bagnold (1939) is used to correct the loading process ‘compression of entrapped air’ measured at scale 1:6, resulting in a similar load to the one measured at scale 1:1.

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

INTRODUCTION

Sloshing model tests are the basis of any sloshing assessment for a new membrane LNG carrier project (Gervaise et al. (2009)). These sloshing model tests are performed at GTT with model tanks at scale 1:40 (λ=40), installed on the platform of a six-degree-of-freedom hexapod. The excitation motions are scaled from calculated ship motions at full scale by maintaining the Froude number. This means that the time is scaled by $1/\lambda$, as the length is scaled by $1/\lambda$, and the gravitational acceleration is maintained. The tanks are filled with water and a mixture of nitrogen and sulphur hexafluoride such that the ratio between the density of the gas and the liquid is equal at model and full scale. The tank walls are flat and rigid. Up to 300 pressure sensors are used to capture the sloshing pressures in the impact areas. Long duration tests are required in order to obtain converged statistical pressures.

The statistical pressure results have to be scaled to full scale in order to derive design loads. The approach for scaling is not obvious as multi-physics occur within the impacts. An important step forward has recently been made: through several investigations the physics involved in these impacts could be linked to loading processes.

First of all it is useful to consider the flow inside a partially filled tank in two parts: the global flow and the local flow in the vicinity of and during the impacts.

Global flow

The global flow involves the propagation of the surface waves in the tank which defines the initial conditions of the local flow. The division between the global and the local flow is based on the reasonable assumption that the local flow does not affect the global flow statistically. Repeating the same excitations several times leads to impacts at the same time instants and locations, even for long duration tests.

The wave propagation is governed by the balance between the inertial and gravitational forces, i.e. the Froude number. Since the excitations of the hexapod are set by maintaining the full scale Froude number, sloshing model tests generate a statistical sample of initial conditions for the local flow that is representative of the full scale conditions.

Local flow

In contrast to the rather deterministic behaviour of the global flow, the local flow and corresponding impact pressure appear to be randomly distributed. Only statistical post-processing of long duration tests enables getting repeatable sloshing loads.

The loading processes involved in the local flow are unravelled in Lafeber et al. (2012). Three Elementary Loading Processes (ELP) have been identified as the building blocks of any load possibly induced by a wave impact. This means that any part of a pressure or a force signal recorded on a structure is a result of one or a combination of these three ELPs. They are: the direct impact (ELP1) characterized by instantaneously loaded area, the building jet along the structure (ELP2)