Experimental and Numerical Investigations of Internal Global Forces for Violent Irregular Excitations in LNGC Prismatic Tanks

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ABSTRACT

This paper presents experimental and numerical investigations on global forces exerted by violent irregular fluid motions during a 5-hour period (at full scale) on LNGC prismatic tanks' boundaries at a low partial filling (R=30%H). First, the experimental set-up (test rig and weighing device) is described. Second, the hydrodynamic calculation of the test case is presented. Third, the model tests with empty tank (which allow to validate the weighing device) and with the filled tank (R=30%H) are presented. Finally, the CFD (Computational Fluid Dynamics) calculations using OpenFOAM are compared to the experiments and are shown to be in very good agreement in the case of the multi-step simulation.

KEY WORDS: Sloshing, sloshing model tests, CFD, partial fillings, coupling seakeeping/sloshing, Offshore LNG Floating Units.

1 – INTRODUCTION

The paper deals with researches of Bureau Veritas that aim at improving methodology and procedures for the analysis of hydrodynamic and sloshing responses of LNG vessels operating as offshore LNG floating units in wide range of operational conditions. This paper contributes to a better numerical evaluation of the fluid global forces exerted on LNGC prismatic tanks' boundaries.

In the current methodology of Bureau Veritas, partial fillings (when allowed) are to be investigated in details for all sea-states conditions (see Diebold 2010) that can be faced by the studied vessel (LNGRV, LNG FPSO, FLNG & FSRU). Events at sea have demonstrated that low partial fillings generate the most critical sloshing cases for which coupling effects have a great influence.

Seakeeping/sloshing coupling effect can be studied by the help of model tests’ campaign involving the construction of the model of the ship with its cargo filled of liquid in a wave basin. This is typically what was done by the past for roll response enquiry (see Gaillarde 2004). But this type of useful experiments is expensive, time-consuming and linked to specific ship or a specific scenario.

Ship motion and induced cargo tank liquid motion are driven by liquid global forces on tanks’ boundaries and hydrodynamic ship motion response. Ship motion response can be easily calculated on one side thanks to a validated seakeeping code based on linear potential theory (HydroStar©) while inner tank global forces can be evaluated with CFD calculations on the other side. The ultimate purpose being to numerically couple ship motion response with inner tank liquid motions (see Zalar 2007), the first step is to demonstrate the accuracy of the CFD global forces calculations for realistic violent irregular fluid excitations during a sea state duration.

The validation of CFD was successfully started with the roll motion of an academic quasi-2D tank model during the MARSTRUCT project (see Moirod 2009). Then this CFD validation continued with the study of fluid global forces caused by harmonic sway motions of a 3D tank model (see Moirod 2010). The numerical results obtained with CFD codes (OpenFOAM & Flow3D) were shown to be in very good agreement with the measurements for different filling levels, amplitudes and periods. However, these very good results were obtained for harmonic sway motion and for a short duration (around 100 s) required to reach the steady state.

The objective of the present paper is to achieve this CFD validation by studying fluid global forces caused by realistic violent sloshing flows (irregular motions at a low partial filling R=30%H) for a 5-hour duration at full scale (more than a real sea state duration). For the sake of simplicity, only sway motion is considered.

The experimental campaign consists in measuring the fluid global forces due to the above mentioned motion on a 3D tank model. The model is filled with water. The violent realistic irregular sway motions are generated by a hexapod on which a weighing device is mounted. This 5-hour (at full scale) motion is then reproduced using the CFD code OpenFOAM. The measured and calculated fluid global forces are then compared and shown to be in very good agreement.

2 – MODEL TEST SET-UP

Sloshing model tests are based on the measurements of the global efforts exerted on tank (empty tank + water).

2 - 1 Model Tank & Hexapod

The 3D tank model (courtesy of GTT, Fig.1) corresponds to the tank N°2 of BV reference vessel with standard cargo capacity of 138 000 m³, scaled to 1 to 70 and made of a 20 mm thick Plexiglas®. Motions