

Coupled Behavior of Sloshing and Ship Motion of an LNG Carrier with Prismatic Chamfered Tanks

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An experiment was carried out using a liquefied natural gas carrier model with two prismatic chamfered tanks. The coupled behavior of the ship motion and the liquid inside the tanks was studied, and the experimental data were compared with numerical results. The ship motion was calculated with the strip method, and the liquid motion was calculated with a finite difference method. The tanks used in the experiment have a length-to-breadth ratio near 1, and in addition to a two-dimensional liquid sloshing, a rotational motion of the liquid was also observed when the excitation was near the tank natural frequency. The effects of these different modes on the coupled motion are discussed.

INTRODUCTION

When a partially filled tank is excited near its natural frequency, a violent liquid flow, known as sloshing, may occur and damage the tank internal structure. To avoid this, membrane-type liquefied natural gas (LNG) carriers are only allowed to operate with almost full or almost empty filling levels. However, in some applications, operations with partially filled tanks are inevitable, such as in the floating LNG (FLNG) offloading and in ships powered by LNG. In addition, when the ship moves, the liquid motion is excited, resulting in loads on the tank wall, which is then transferred back to the hull. Therefore, a coupled analysis of the tank liquid motion and ship motion is necessary.

In Nam et al. (2009), the ship motion was calculated with the impulse response function method, and the nonlinear sloshing flow was calculated with a finite difference method (FDM). Regular flow was tested, and the response amplitude operator (RAO) was compared with an experiment. It was found that the sloshing-induced loads are not linear with respect to the motion amplitude. Wang and Arai (2011a, 2011b, 2015) developed a numerical method for the coupled sloshing and ship motion problem, solving the ship motion problem with strip theory and the sloshing flow with an FDM method. The ship motion and sloshing responses of an LNG carrier have been studied in regular and irregular wave conditions. It was found that sloshing has a significant effect on the transverse motions, whereas the effect on longitudinal motions is rather negligible. Jiang et al. (2015) used a similar method to that of Nam et al., but they used the volume of fluid method to capture the free surface. It was concluded that

the coupling effects are especially larger for lower filling levels. Hu et al. (2017) studied the sloshing effect on an FLNG system, using a potential method to calculate both the ship motion and the internal flow. The influence on pitch, yaw, and heave were negligible, whereas a noticeable effect was observed near the tank's natural frequency for sway and surge.

In the present study, a model experiment was carried out using an LNG carrier model with two partially filled prismatic chamfered tanks. A load cell was installed in one of the tanks to measure the horizontal forces, and the ship motion was measured at its rotation center. The results were then compared with the numerical simulations. In the numerical simulation, the strip method was used for computing the ship motion, and an FDM was used for computing the liquid motion. The tanks used in the experiment have a nearly square horizontal cross section; that is, the tank length-to-breadth ratio (L_t/B_t) is close to 1.0. Thus, on top of sloshing, swirling, which is the rotational motion of the liquid, was observed.

Swirling in spherical tanks was studied by many authors, such as Faltinsen and Timokha (2013), Arai et al. (2016), and Hata et al. (2017). There are some works concerning swirling in rectangular tanks, such as Chen and Wu (2011) and Faltinsen et al. (2005), who examined the conditions in which different liquid motion modes occur in a squared-base tank.

Tanks that use the GTT MARKIII and NO96 systems have a similar cross section, with the tank length varying depending on the design. Some of the designs have tanks' length-to-breadth ratio near 1. Tanks located near the aft and forward in special tend to be shorter in order to accommodate the hull geometry.

To the authors' knowledge, few works are available on the liquid flow in a prismatic tank with L_t/B_t close to 1 and the occurrence of swirling in the coupled problem. Therefore, this problem is discussed.

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