International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 21, No. 4, December 2011, pp. 256–263

http://www.isope.org/publications

A Study on Coupling Effect Between Seakeeping and Sloshing for Membrane-Type LNG Carrier

Xin Wang and Makoto Arai
Department of Systems Design for Ocean-Space, Yokohama National University
Yokohama, Japan

To evaluate the performance of membrane-type LNG carriers under half-loading conditions, simulation for coupled ship motion and sloshing has been carried out by using a newly developed time domain scheme. The external fluid field was solved by potential theory, while the internal fluid field was solved by a 3D finite difference method. The ship motions in different wave direction and frequencies were calculated. The coupling effect was found to have significant influence on transverse motions, while the longitudinal motions were not influenced. The slosh flow inside tanks was also investigated. Some nonlinear phenomenon at resonance sloshing was also identified and discussed.

INTRODUCTION

For a ship carrying liquefied natural gas (LNG), resonant sloshing may occur during the transportation and loading/offloading operations when the storage tank is under partial filling conditions. The ship motions excite liquid movement inside tanks, and the liquid movement affects the ship motions in turn. This makes the sloshing problem of LNG carriers (LNGC) become a coupled problem between ship motions and sloshing.

For this coupled problem, there has been much published research. Faltinsen and Timokha (2009) gave a general overview of sloshing in ship tanks. Malenica et al. (2003) solved the problem in frequency domain by using linear potential theory for both sloshing and the seakeeping hydrodynamic part; the numerical results for ship motions were shown in the paper. Kim (2002) carried out a computational study for an anti-rolling tank problem. The sloshing problem was solved by using a finite difference method, and the ship motions were calculated by using the software LAMP. The ship motion RAO were presented, and the nonlinearity of the coupled problem was discussed. Rognebakke and Faltinsen (2003) conducted experiments and computation for a 2D hull section containing tanks in sway motion by regular waves. The paper focused on the time domain results for ship motions. Both the steady-state results and the transient behavior of the hull were presented; the effect of convolution formulation for computation was also discussed. Molin et al. (2002) presented computational and experimental results for a barge with rectangular tanks in an irregular wave. The results of relative free surface elevation inside tanks were shown in frequency domain.

For the coupled ship motions and sloshing, the above mentioned research was mainly focused on the ship motions part except for the last paper. However, for a ship carrying liquid storage tanks, a major practical concern is about the local structural load due to sloshing. Thus, the sloshing inside the tanks with coupling effect considered needs to be investigated. In this paper, we not only showed the results of the ship motions, but also presented some discussion about the sloshing inside tanks of the coupled problem. Plus, as the tank models used in the computation are based on real designs, this paper may have practical meaning for membrane-type LNG carriers, especially for those carrying a fore tank with special shapes.

This study employed the linear strip method to calculate the ship motions, and a finite difference method to simulate sloshing flows. Both ship motions and sloshing were solved simultaneously in time domain. To verify the numerical method, we compared the numerical results with some experimental data and found good agreement.

As an application, the method was applied to calculate the coupled ship motions and sloshing of a 200,000m^3 membrane-type LNG carrier. The ship is not a real existing one, but a hull assumed to be a LNG carrier designed by the authors. The ship motions with coupling effect in different wave directions were calculated. Free-surface movement and internal wave amplitude were also investigated. Special free-surface movement inside the fore tank was also studied.

CALCULATION METHOD

The coupled system includes 2 distinct problems: the seakeeping problem and the sloshing problem.

Seakeeping Problem

The ship motions were calculated by using the well-known strip theory as shown in Eq. 1 (also considering sloshing loads):

$$\sum_{j=1}^{5} M_{ij}\ddot{X}_i + \sum_{j=1}^{5} C_{ij}\dot{X}_i + \sum_{j=1}^{5} K_{ij}X_i = F_{i\text{-}wave} + F_{i\text{-}slosh}, \quad i = 1, 2, \ldots, 5 \tag{1}$$

In Eq. 1, X_i represents a different mode of motions, including heave, pitch, sway, yaw and roll. M_{ij}, C_{ij} and K_{ij} indicate mass, damping and restoring coefficients calculated by 2D potential theory for each strip and integrated by applying the strip method. Besides, $F_{i\text{-}wave}$ indicates the force/moment due to external fluid, and $F_{i\text{-}slosh}$ indicates the slosh-induced force/moment.

Because of the nonlinearity of sloshing flow, simulation was carried out in time domain. To solve Eq. 1 in time domain,

Received March 23, 2010; revised manuscript received by the editors March 9, 2011. The original version (prior to the final revised manuscript) was presented at the 20th International Offshore and Polar Engineering Conference (ISOPE-2010), Beijing, June 20–25, 2010.
KEY WORDS: Sloshing, ship motion, coupling effect, nonlinear, LNG, membrane.