The Effects of Tank Sloshing on the Coupled Responses of LNG Vessel and Floating Terminal

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ABSTRACT

The hydrodynamic interactions between FT (Floating Terminal) and LNGC(Liquefied Natural Gas Carrier) in side-by-side offloading arrangement as well as the dynamic coupling between the floating-body motion and inner-tank sloshing are investigated by a potential-viscous hybrid method in time domain. For the time domain simulation of the vessel motion, the hydrodynamic coefficients and wave forces are obtained by a potential-theory-based 3-D diffraction/radiation panel program in frequency domain. The ensuing simulations of vessel motions in time domain are carried out by using an impulse response function approach. The liquid sloshing in inner tanks is simulated in time domain by a FDM Navier-Stokes solver with SURF scheme. The computed sloshing forces and moments are fed into the time integration of ship motion, and the updated ship motion is in turn used as the excitation force for liquid sloshing, which is repeated for the ensuing time steps. For comparison, we independently developed a sloshing-motion coupled analysis program based on linear potential theory in the frequency domain. The developed computer programs are applied to the side-by-side offloading operation between the FT and LNGC. The frequency-domain results qualitatively reproduce the coupling effects but the peaks are in general over-predicted compared to experimental and time-domain results. The liquid-sloshing and vessel-motion interaction effects can further be intensified in the case of multiple floating bodies.

KEY WORDS: Sloshing and motion interactions; Filling level vs. sloshing effect; Coupled dynamic analysis; Navier-Stokes solver with SURF; Peak frequency shift; Time-domain potential-viscous hybrid method; Frequency-domain coupled analysis

INTRODUCTION

In the conventional ship-motion analysis, the effects of inner free surface have been usually ignored. Recent experimental and numerical studies have shown that the coupling effect between liquid cargo sloshing and LNG(Liquefied Natural Gas) ship motion can be significant at certain frequency range of partially filled tanks. This is of great concern to the LNG FPSO/FSRU operation in the production site and offloading operation of LNG carriers close to LNG terminal. The coupling effects are expected to become more important as the size of LNG carriers significantly increases with rapidly growing demand.

The coupling between ship motion and sloshing has been studied by Molin et al(2002), Malenica(2003), Newman(2005) and Kim and Shin (2008) based on linear potential theory in the frequency domain. In time domain, Kim et al.(2003, 2007) studied the sloshing effect on the motion of a single ship with 2-D and 3-D viscous FDM sloshing codes. Lee et al.(2007) also investigated the sloshing effect of multiple tanks on ship's roll motion with 3-D FDM calculation, which is further extended in this paper to include two floating-body interactions. A similar two-body interaction problem in beam waves with 2D tank sloshing was also investigated by Cho et al. (2007).

In the present study, a potential-viscous hybrid method for multiple-vessel responses with multiple tanks is developed. The ship motion is solved in time domain by using linear potential theory and three-dimensional panel method, while the liquid sloshing in the inner tanks is solved by 3D-FDM (Finite Difference Method) Navier-Stokes solver including free-surface nonlinearity through SURF scheme. However, for simplicity, the single-valued surface profile is assumed in the sloshing calculation i.e. very violent free-surface motions such as overturning and splash are not considered. For comparison, an equivalent linear potential program in frequency domain is independently developed to solve the same interaction problem assuming small liquid motions. When the inner-fluid motion is mild, both approaches should produce similar coupling effects unless viscous effects are negligible.

In the present study, the ship and liquid-cargo motions are coupled in time domain by the kinematic and dynamic relations in that the vessel motions excite the tank sloshing, while the sloshing-induced loads in turn influence vessel motions. The calculated ship motions with or without considering liquid sloshing are compared with the model test results. The model test was conducted by MARIN as a part