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Effect of Inner Free Surfaces and Multi-Body Hydrodynamic Interactions on Motions of LNG Carrier and Floating Terminal

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The hydrodynamic interactions between an FT (Floating Terminal) and LNGC (Liquefied Natural Gas Carrier) in a side-by-side offloading arrangement as well as the dynamic coupling between the floating-body and inner-liquid motions 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 3D diffraction/radiation panel program in the frequency domain. The ensuing simulations of vessel motions in time domain are carried out by using the convolution-integral method. The liquid motions in inner tanks are simulated in time domain by an FDM Navier-Stokes solver with a 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 inputted as the excitation force for liquid tanks; this 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 overpredicted compared to the experimental and time-domain results. The liquid-sloshing and vessel-motion interaction effects can further be intensified in the case of multiple floating bodies.

INTRODUCTION

In conventional ship-motion analysis, the effects of the inner free surface have usually been 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 a 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 an LNG terminal. The coupling effects are expected to become more important as the size of LNG carriers and liquid tanks significantly increases with rapidly growing demand.

The coupling between ship motion and sloshing has been studied by Molin et al. (2002), Malenica (2003) and Newman (2005) based on linear potential theory in the frequency domain. Huang et al. (2009) applied the linear potential frequency-domain code with the artificial free-surface damping and showed that it can produce reasonable results compared with their experiments. The disadvantage of this approach, however, is the need of calibration of the free-surface damping parameter against experimental measurement. In time domain, Kim et al. (2003, 2007) studied the sloshing effect on the motion of a single ship with 2D and 3D viscous FDM sloshing codes. Lee et al. (2007) also investigated the sloshing effect of multiple tanks on a ship's roll motion with a 3D FDM calculation, which is further extended in this paper to include 2 floating-body interactions. A similar 2-body interaction problem in beam waves with 2D tank-sloshing code was also investigated by Cho et al. (2007). Despite the rapid progress of CFD techniques for the simulation of liquid sloshing inside a tank with given motions, the capability of simulating coupled interactions between multiple vessels and multiple tanks in irregular waves is still very rare. In particular, when hawsers and fenders are used between the 2 floating bodies, time-domain numerical models must be much more realistic (Koo and Kim, 2005).

In this 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 the hydrodynamic coefficients obtained from potential theory and the 3D panel method with the exception of including hull viscous damping. On the other hand, the liquid sloshing in the inner tanks is solved by the 3D-FDM Navier-Stokes solver including free-surface nonlinearity through a 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, especially when viscous effects are small.

In this 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 for the floating FPSO (its shape is similar to the FT here) with 2 liquid tanks by the *Marin* as a part of SALT JIP (Gaillarde, 2004). The numerical results by the present hybrid method generally compare well with the measured data.

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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.