ABSTRACT

The coupling between vessel motion and inner-tank sloshing is investigated by a potential-CFD (Computational Fluid Dynamics) hybrid method in time domain. Potential-theory-based 3D diffraction/radiation panel program is used to simulate vessel motions in time domain. The liquid sloshing in tanks is simulated with smaller time steps by using the improved MPS (Moving Particle Simulation) method. The two programs are coupled at each interactive time step. The calculated sloshing tank forces and moments are applied to the vessel motion as excitation forces and moments. The ship motion, which is influenced by sloshing-induced tank forces, is in turn inputted to the MPS system as forced motions. For the verification of the coupling, a barge-type FPSO hull with two partially filled inner tanks is selected and the numerically simulated results correlate well against the measurements done by MARIN for various fill ratios. It is seen both in prediction and experiment that the roll RAOs (Response Amplitude Operators) are sensitive to the amount of liquid cargo and can be increased or decreased by a factor of 2 or 3 in some wave frequency range compared to the bare-hull case. It is also shown that the nonlinear sloshing effects can alter the vessel-motion characteristics in relatively high waves. The simulation is extended to dual vessels in side-by-side arrangement to simulate LNG offloading operation.

KEY WORDS: MPS, Ship and liquid tank interaction, CFD, Meshless, Sloshing effect, Coupled dynamic analysis, Navier-Stokes solver, Time-domain potential-viscous hybrid method, multiple vessels

INTRODUCTION

In conventional ship-motion analyses, the effects of inner free surface have been usually simplified/neglected due to the unavailability of well-developed vessel-motion/liquid-sloshing coupled dynamic analysis computer programs. However, recently built complex vessels, such as LNGCs (Liquefied Natural Gas Carriers), LNG-FPSOs (Floating Production Storage Offloadings), and FSRUs (Floating Storage Re-gasification Units), are equipped with large inner tanks, so the inner-sloshing effects can no longer be ignored in many applications. Especially, in the case of side-by-side arrangement i.e. two floating units are operated in close proximity to each other, the hydrodynamic interactions may further increase the liquid sloshing motion and its effects on ship responses. The coupling between vessel motion and liquid sloshing has been studied in time domain by Kim et al. (2003), Kim et al. (2007), Lee et al. (2007) and Lee and Kim (2008) by using the potential-theory-based ship-motion program and 2-D/3-D viscous FDM (Finite Difference Method) sloshing codes. Cho et al. (2007) studied the sloshing-motion coupling effects including two-body interactions in beam waves with a 2-D-sloshing CFD code. Lee and Kim (2010) solved the similar two-body problem in side-by-side arrangement by using a 3-D tank-sloshing FDM code. In these studies, however, there is limitation for violent free-surface motions with overturning and splashing in the CFD codes. So, they are not directly applicable when ship motions are large to generate more violent liquid-sloshing motions. In this regard, MPS method based on Lagrangian treatment is implemented in the present study to solve sloshing/vessel-motion interactions with a wide variety of liquid motions including overturning and splashing. The ship and sloshing motions are coupled in time domain by kinetic and dynamic relations. In this procedure, the ship motions excite the tanks motions. Meanwhile, the sloshing-induced loads influence ship motions. The dynamic coupling, therefore, has to be solved at each time step. To validate the developed coupling program, the calculated ship motions with partially filled sloshing tanks are compared with the model-test results by MARIN as a part of SALT JIP (Gaillarde, Ledoux, and Lynch, 2004).

The MPS method was originally proposed by Koshizuka and Oka (1996) for incompressible flows. In the original MPS method, however, there were several defects including non-optimal approaches, such as source-term model, gradient/collision model, and search of free-surface particles, which led to less-accurate fluid motions and non-physical pressure fluctuations, as pointed out by Gotoh (2009), Lee et al. (2010)