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Studies on the Coupled Dynamics of Ship Motion and Sloshing including Multi-Body Interactions

Seokkyu Cho, Sayoung Hong, Jin Kim, Ilrong Park
Maritime and Ocean Engineering Research Institute, KORDI
Daejeon, KOREA

ABSTRACT

The dynamics of LNGC and FSRU motions coupled with sloshing is simulated. The motions of two bodies are solved in the time domain by taking account of memory effects. The sloshing is simulated by a Navier-Stokes equation. For the analysis of violent free surface flow due to sloshing, Volume of Fluid (VOF) technique is adopted. The ship motions and sloshing are linked by explicitly coupling the ship motion and sloshing force. The coupled method is verified by comparing the results of free roll decay with the experimental results. The developed method is used to simulate the interaction of side-by-side moored LNG FSRU and LNGC for various partial loading conditions. The effect of sloshing on the two body interaction is studied.

KEY WORDS: Sloshing; Multi-body interactions; VOF; LNG; FSRU; Coupled dynamics.

INTRODUCTION

With the rapidly increasing needs of natural gas over the world, one of hot issues in LNG (Liquefied Natural Gas) industry has been moving from LNG carriers to LNG terminals. LNG terminals have been constructed onshore where frequent loading and offloading operations can be effectively carried out. Recently a concept of using floating LNG terminals in offshore attracts the attention of LNG industries. In environment and safety terms, floating terminals have advantages as compared with land based terminals; no money for land, no NIMBY, short construction time, etc. A key issue for any offshore LNG terminals is assurance of safe and reliable transfer of LNG from LNGC to FSRU (Floating Storage and Re-gasification Unit) or from LNG-FPSO to LNGC. The LNG offloading and loading operation is affected by many factors, including the sea state conditions, the mooring system, the fender arrangement, loading arm, loading conditions and hydrodynamic interactions between two bodies.
Offloading operation is usually performed in side-by-side mooring configuration. In the side-by-side mooring configuration, the distance between two bodies is very small and a violent hydrodynamic interaction can occur due to the resonance of trapped water known as Helmholtz resonance (Hong et al., 2002). Very closely located two bodies can collide and transfer loading equipments and mooring lines may fail due to the violent interactions. The hydrodynamics of two bodies in various loading conditions is very important to assure the safety of LNG transfer. The effects of interaction of two bodies are investigated by Buchner et al. (2001), Huijsmans et al. (2001), Kashiwagi et al. (2005) and Hong et al. (2002, 2005) and the influence of loading condition on the behavior of LNG ship is presented by Molen and Ligteringen (2005). Molen showed that although the draft change of between loaded and ballasted LNGC is small, the motion and mooring force can be large and the roll motion is strongly dependent on the loading condition. In case of including LNG, sloshing also become an important problem and sloshing can affect the LNG transfer process and the motion behaviors. The motion of LNGC considering sloshing is investigated by Lee et al. (2006) and Kim et al. (2005). Cho et al. (2006) also presented the coupled dynamics of ship motion and sloshing in time-domain using VOF for sloshing and Cummins model for ship motion. The simulation results agree with the experiment. But the previous studies considered single vessel and no interaction of multi-bodies including sloshing has investigated yet.
In the present study, the ship motion is solved in time domain and the sloshing is solved using VOF. Two independent programs are coupled by exchanging ship motions and sloshing forces. The developed program for solving coupled dynamics between FSRU and LNGC solves the interactions of FSRU and LNGC including sloshing in side-by-side mooring configuration. Loading condition of FSRU is set to be as full load and several loading conditions of LNGC such as partial and full loadings are considered. The characteristics of interactions and coupled effects of sloshing for various loading conditions are investigated numerically.

NUMERICAL METHOD

To analyze the coupled dynamics of ship motion and sloshing, two independent programs are used. The generalized mode concept is used for interactions of two vessel motions and the VOF technique is used for simulation of sloshing. The method of coupling is to link the ship motions and sloshing forces mutually.

Ship motion Program

To analyze fluid field, velocity potential is introduced and boundary