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# A Study on the LNG Loading or Unloading Operability of Floating LNG Bunkering Terminal with Ship-to-ship Moored

Dong Woo Jung, Yun Ho Kim*, Seung Hoon Oh, Seok Kyu Cho, Bo Woo Nam, Dong Ho Jung and Hong Gun Sung*, Offshore Plant Research Division
Korea Research Institute of Ships and Ocean Engineering (KRISO), Daejeon, Korea

**The floating LNG bunkering terminal (FLBT) is a newly emerging offshore platform that can be regarded as a liquefied natural gas (LNG) station at sea. It has its own station-keeping system, and it is additionally moored to other vessels during LNG loading or unloading processes. The ship-to-ship mooring system is composed of a number of mooring ropes and fenders. The relative motion responses between loading arms and corresponding manifolds are crucial for the LNG transfer process, because they have their specified allowable displacement criteria. To investigate the multibody interactions, model tests were performed previously. Some hydrodynamic coefficients obtained from the model test were utilized in numerical simulations. The eigenvalue analysis on multibodies with the ship-to-ship mooring system was also conducted. The natural modes and periods induced by the mooring ropes and fenders were identified. A series of numerical simulations with various incident wave headings and configurations were conducted with the commercial program AQWA. Finally, we judged the operable incident wave heading range under allowable displacement criteria.**

## INTRODUCTION

Because of climate change caused by environmental pollution, the strict regulation of sulfur and nitrogen oxides emissions has been enhanced by the International Maritime Organization (IMO) as of 2020. One considerable approach is to use liquefied natural gas (LNG) as a marine fuel, which emits quite little sulfur. To develop the LNG-fueled ship market, infrastructures should be established properly. Because an onshore LNG supplying terminal has the potential danger of explosion, a new concept of offshore terminals has been considered.

In Korea, a national research and development (R&D) project has been conducted since 2014 to develop the core technologies of a floating-type LNG bunkering terminal (FLBT). It aims to be a moored target at a certain point in the sea or ocean and to receive LNG from an LNG carrier (LNGC) and give LNG to LNG bunkering shuttles (LNG BSs) simultaneously. FLBT is self-moored by the internal turret and catenary mooring lines, whereas LNGC and other LNG BSs are moored side by side to the FLBT with mooring ropes and fenders. Because LNG transportation is carried out from the ship-to-ship arrangement, the operability of FLBT strongly depends on the relative motion responses between the loading arm and corresponding manifold in waves. Also, it is necessary to figure out the effect of the ship-to-ship mooring system precisely.

A lot of works were carried out on the hydrodynamic characteristics in multibody configurations. The strip theory was initially applied to two floaters located in parallel by Ohkusu (1974), Kodan (1984), and Fang and Kim (1986). The two-dimensional problem was extended to the three-dimensional problem by Fang and Chen (2001). Choi and Hong (2002) utilized the higher-order boundary element method (HOBEM) with nine-node bi-quadratic elements for hydrodynamic interactions of two vessels. To name a few applications, Kim et al. (2003) focused on the relative motion responses and shielding effect in a two-body arrangement. Buchner et al. (2004) revealed an outstanding paper about the hydrodynamic performance of two vessels that were moored side by side in close proximity. Hong et al. (2005) evaluated the motion responses and drift force when two LNGCs are ship-to-ship moored to LNG floating production storage and offloading by an experimental and numerical method. Xin et al. (2012) conducted a study on the top-side installation using a floatover method on a jacket structure using two barges. Choi et al. (2018) studied the coupled motion between a tensioned leg platform and tender semi-submersible. Jung et al. (2018) conducted a number of numerical simulations for the four vessels in a side-by-side moored configuration to find out the optimized locations of loading arms and manifolds, where relative motions were minimized.

In this paper, we figured out the relative displacements between LNG loading arms and corresponding manifolds from the experiment. The additional damping coefficients obtained from experiments were extracted and inserted to numerical simulations as input data. The eigenvalue analysis was also conducted to identify the natural periods and modes induced by the ship-to-ship mooring system. We then conducted time-domain simulations by AQWA, varying incident wave headings and two-, three-, and four-body configurations. The three-hour most probable maxima (MPM) of relative motions between loading arms and manifolds were achieved and compared with the allowable displacement criteria.

## OCEAN BASIN EXPERIMENT

### Operating Vessels

A series of model tests on a 1:65 scale of the ship-to-ship (STS) moored four vessels were conducted in the ocean engineering basin (OEB) of the Korea Research Institute of Ships and Ocean Engineering (KRISO). Figure 1 shows the general arrangement of

*ISOPE Member.
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