Concept design and cost–benefit analysis of pile-guide mooring system for an offshore LNG bunkering terminal

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ABSTRACT

This study proposes a pile-guided floater, a new mooring concept, for large offshore floating structures such as an offshore liquefied natural gas (LNG) bunkering terminal. The economic feasibility of the new mooring system was demonstrated through a cost–benefit analysis. The environmental loads acting on the floaters were computed using wave data at the target location. The mooring system was designed using finite element analysis to estimate the additional investment. An LNG ship-to-ship bunkering operation that included an LNG bunkering terminal, LNG carrier, LNG bunkering shuttle, and LNG receiving ship was adopted. To estimate the technical feasibility and economic benefit of the proposed mooring system, the availabilities of two types of LNG bunkering terminals were compared considering the acceptance criteria for LNG ship-to-ship transfers. One LNG bunkering terminal was a typical barge-type floater and the other was the pile-guided floater. The relative motion of the terminal with the LNG carrier and the LNG bunkering shuttle was analyzed. The limiting wave height was determined from the maximum relative vertical motion between the floaters at the position of the LNG loading arms. The availability of the pile-guided LNG bunkering terminal was significantly improved owing to the reduced vertical motion. Finally, a cost–benefit analysis verified that the new mooring concept for an offshore LNG bunkering terminal was economically feasible.

1. Introduction

The requirements and regulations concerning ship emissions are expected to be strengthened to protect the global environment. The International Maritime Organization (IMO) revised the MARPOL Annex VI, which consists of two standards for ship emissions. The first standard is a global standard applied to all types of ships in signatory countries of the MARPOL treaty, and the second standard pertains to emission control areas (ECA) subject to rigorous limitations (IMO, 2009). In addition to the regulations, the Marine Environment Protection Committee (MEPC) concluded at its 59th session in 2009 that an energy efficiency design index (EEDI) for new ships was required. The committee established an EEDI formula to measure the CO2 efficiency of new ships (MEPC, 2009). Devanney (2011) studied the impact of the EEDI on very large crude carriers (VLCCs), therein recommending that a newly developed VLCC should be designed to comply with the EEDI formula, to ensure that their CO2 emissions could be reduced by 19% compared to the current design by 2013, by 36% by 2018, and by 47% by 2023. To meet these requirements, liquefied natural gas (LNG) is increasingly considered as an alternative fuel, as it is environmentally friendly and cost effective. For LNG to be used as a marine fuel on a global scale, various equipment and infrastructure, including the volume-efficient onboard LNG storage tanks, large-size gas engines, and LNG bunkering facilities, should be developed. Adachi et al. (2014) proposed a concept of 9300-TEU container ships fuelled by LNG and performed an economic analysis to compare the concept for existing technologies for oil-fuelled ships to comply with Tier III. Wang and Notteboom (2014) reviewed several studies on the use of LNG as a bunker for ship propulsion, presented recent perspectives and challenges, and suggested future studies by analyzing the limitations of the current studies. Economic feasibility, safety, and reliability are the key issues for the new LNG technologies. Many studies have addressed fuel LNG supply chains and related infrastructure from an economic perspective. Brett (2006) expected that LNG would be used for a bunker in compliance with rigorous regulations of IMO and investigated the LNG market, the current and potential fleet of LNG-fuelled marine vessels, and the LNG bunkering terminal.
(LNG-BT). Many uncertainties can arise in a reliability analysis of a new technology. Komal et al. (2015) estimated the fuzzy reliability of a dual-fuel steam turbine propulsion system for LNG carriers (LNGC) using the proposed methodology to address uncertain data.

LNG bunkering at ports is receiving increased attention from many interested parties, including the port authorities, LNG distribution companies, shipping companies, and societies. These parties will prefer not only to comply with the expected regulations but also reduce the cost of the supplied LNG fuel for ships in a safe and environmentally friendly manner. According to the recent articles and reports, although the market for LNG bunkering has not been fully activated because of various uncertainties, it is expected to grow stably up to 2020. The four types of LNG bunkering approaches have been considered: truck-to-ship (TTS), port-to-ship (PTS), portable tank transfer (PTT), and ship-to-ship (STS). Currently, TTS and PTS are generally employed; however, STS LNG bunkering is attracting interest because of the limitations in terms of the size and sites of the other methods, as the oceangoing ships continue to grow in size, and the high complexity of the ship traffic near the main ports.

Although the STS type of LNG bunkering provides various benefits in terms of accessibility, capacity, improved safety, space application in ports, and initial investment, it faces challenges related to the stability and operational availability of floating bodies during LNG transfer (Choi, 2014). To further consider the economic feasibility of the novel LNG-BT concept, operational availability must be evaluated based on the motion study of the main floating bodies (Yun et al., 2015).

The relative movements of two floating bodies and availability are crucial issues for the LNG STS operation. Recently, several studies have been conducted on the side-by-side LNG floating systems. Naciri et al. (2007) performed time-domain simulation between a floating LNG (FLNG) and a vessel for side-by-side LNG offloading. Bunnik (2014) also conducted a simulation of the large relative movements of multibody STS operations. Ewans and Jameson (2015) evaluated the availability of offloading with respect to an LNG barge, where long-term datasets of wave, wind, and current were used to estimate the availability. The results and engineering criteria were compared for three locations (Nigeria, the North West Shelf of Australia, and the southern North Sea). The coupled motion responses of the LNG floating systems were analyzed and the numerical and experimental results were compared for two cases. One case was the motion study between two similar shuttle tankers and the other case considered a floating production storage and offloading system for LNG (FLNG) with a shuttle tanker (Pessoa et al., 2015). A procedure for computing the reliability of the offloading operation was studied. Two identical LNGCs were considered as the case study. Limiting weather conditions were analyzed in compliance with failure probability criteria (Hagen et al., 2015). Pessoa et al. (2016) performed a numerical and experimental study on the wave-induced responses with respect to FLNG and shuttle tankers that were moored side by side. The second-order wave effects were considered for the coupled dynamic analysis. The relative motions and loads on the mooring lines were considered in terms of the system operability.

Mega-scale floaters play a significant role in various LNG supply chains. An LNG-BT is a mega-scale floater that contains many tanks for storing a large amount of LNG. Many supporting and mooring technologies have been developed to support huge floaters. Although the jacket structure and jack-up rig type are typical support structures, they are inappropriate for an LNG-BT because of its enormous self-weight. The gravity-based structure suffers from limitations in terms of economics, STS transfer, and soil conditions at target locations. In the case of the spread mooring system, the use of many cables obstructs the access by vessels. Thus, these forms of mooring systems are unsuitable for an offshore LNG-BT. Lee et al. (2016) introduced the pile-guide mooring system for the LNG-BT and proposed a decision procedure for its target reliability from the whole life-cycle cost perspective.

An offshore LNG-BT is a key infrastructure of the LNG fuelled ships, and the stable STS LNG transfer is one of the most challenging issues. This study designs a new mooring system for an offshore LNG-BT and...
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