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Experimental and numerical study on mating operation of a topside module by a floating crane vessel in waves

Y.J. Ha [a], B.W. Nam [a,*], S.Y. Hong [a], D.W. Jung [a], H.J. Kim [b]

[a] Korean Research Institute of Ship & Ocean Engineering, 104 Sinseong-ro, Yuseong-gu, Daejeon 305-343, Republic of Korea

[b] Samsung Heavy Industry, 217 Munji-ro, Yuseong-gu, Daejeon 305-343, Republic of Korea

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ABSTRACT

In this study, an experimental and numerical study was conducted for investigating the mating operations of a topside module onto a FLNG by using a floating crane in waves. A series of model tests were performed in Ocean Engineering Basin at KRISO with a model set-up of 1:45 scale ratio. The floating crane vessel was equipped with a crane system and dynamic positioning system. The topside module was simplified as a rectangular box of about 2000 Tonf. Four leg mating units(LMUs) were introduced to model the interface units between the FLNG and the topside module. While the interaction forces between the crane vessel and the topside module are transferred via the crane wires, the topside module interacts with the FLNG through the LMUs. Experimental conditions include four different mating stages, i.e. 0%, 20%, 50% and 93% load transfers, under regular and irregular wave conditions. To validate the experimental data, a time-domain numerical simulation method is applied to solve the coupled dynamics of three bodies. The discussions were made on three main points. First, the motion characteristics of the lifted object as well as the crane vessel were investigated by comparing the simulation results. Second, the dynamic tensions of the crane wires were evaluated under the various wave and mating conditions. Final discussion was made on the LMU impact forces.

1. Introduction

Regarding the installation operation using a floating crane vessel, the safety as well as the operability should be checked before real-sea operation. For the safety of the crane lifting operations, it is required to check the crane capacity, rigging design and the structural strength of the lifted object. If the weight of the lifted object is considerable, the coupled dynamics of the crane vessel and the lifted object become quite important. Dynamic amplification factor of hook load can be increased by the coupled dynamic effect. In particular, as for the cooperation operations by multiple floating vessels, not only the hydrodynamic interactions but also mechanical interactions from various mooring lines and fenders should be taken into account. In such case, much attentions should be paid on the installation scenarios and the assurance of safety and operability of installation operations under combined environmental conditions. In the recent times, the nonlinear time-domain numerical simulations are widely used to validate the designed installation operation. Sometimes, related to new complex installation operations, model tests also can be used to ensure the safety of the operations.

Only a few model tests related to crane lifting operation or float-over mating operation can be found in literature survey. Clauss and Vannahme (1999) showed an experimental study of the nonlinear dynamics of floating cranes. Johansen et al. (2004) presented the wave synchronizing crane control during water entry phase based on the model tests. Fujarra et al. (2008) carried out a series of simplified model test in order to dimensioning the launching cables and to define the limit environmental conditions for the subsea installation. Koo et al. (2010) reported model test data for float-over installation of spar topsides using a catamaran. They measured motion and load responses during transportation and installation operations and demonstrated the feasibility of the installation method for the Gulf of Mexico. Recently, Nam et al. (2015) performed an experimental study on deepwater crane installation of subsea equipment in waves. They carried out a model test for deepwater lowering and lifting operation of subsea equipment under both regular and irregular wave conditions. They also discussed the effect of passive heave compensator on the deepwater lowering operation of a manifold. To overcome the limitation of water depth in basin, new experimental technique using truncated hoisting system was introduced. Jung et al. (2016) have developed dual-lifting technique for installation of topside mega-modules and performed a model test to ensure the safety of the

* Corresponding author.
E-mail address: bwnam@kriso.re.kr (B.W. Nam).

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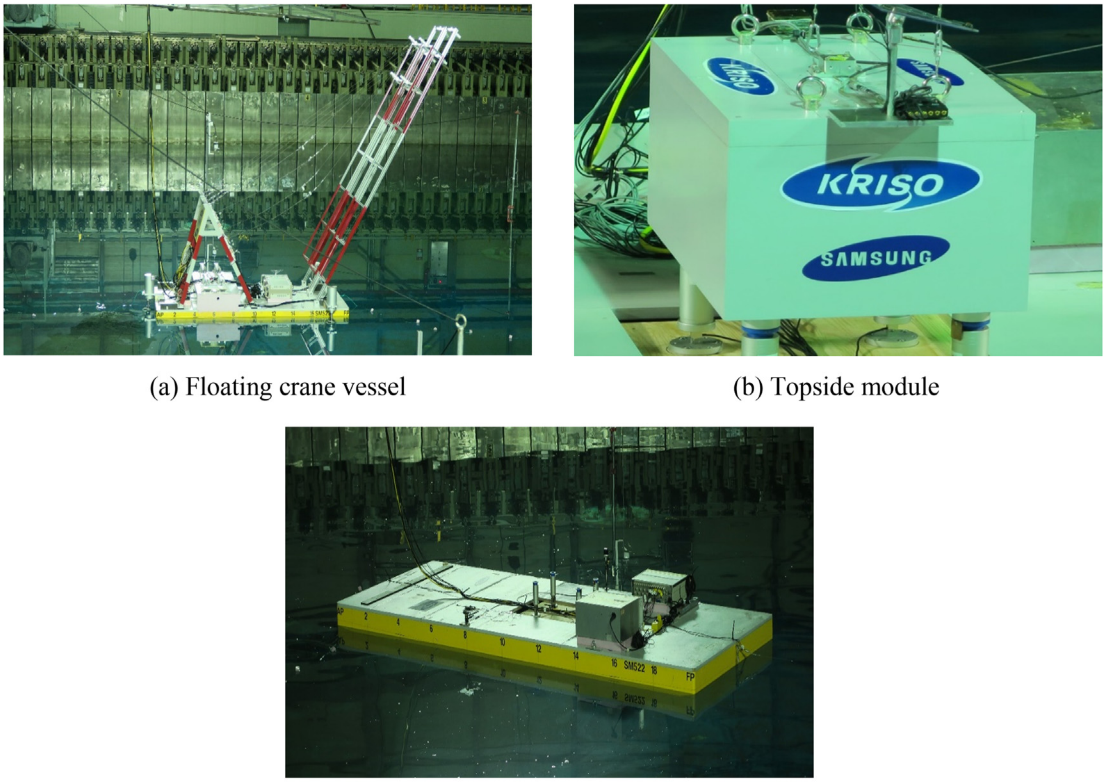

(a) Floating crane vessel

(b) Topside module

(c) FLNG

Fig. 1. Experimental models.

dual-lifting operations. They focused on the dynamic tension at sling wires in various operating scenarios and suggested the possible operating limit environmental conditions based on the model test data.

Time-domain dynamic analysis has been widely used in design stage to predict the motion responses and determine the capacity of the installation equipment and the weather windows. Clauss et al. (2000) presented a comparative study of the operation capabilities of floating cranes. They also reported nonlinear phenomena of the coupled system of floating structure and swinging load. Ellermann et al.(2002) discussed the nonlinear dynamics of a floating cranes. Cha et al. (2010) applied multibody system dynamics to study the dynamic response simulation of heavy cargo suspended by a floating crane. They solved the coupled motion equations between the floating crane and the heavy cargo by considering the nonlinear hydrostatic force and mooring forces. Similarly, Park et al. (2011) presented dynamic factor analysis based on multibody dynamic simulations of a floating crane and a cargo, considering an elastic boom. In their study, the boom was modeled as an elastic body using finite element formulation. They showed that the dynamic factor analysis showed a 1.0–4.3% difference between the elastic boom and the rigid boom according to the wave direction and the cargo mass. Legras and Wang (2011) suggested a new method to determine criteria for lowering operations based on real time monitoring of the vessel motion and time-domain simulation. They also described the application of the method on an installation vessel for lowering operations in West Africa. Nam et al. (2013) developed a time-domain analysis program for floating crane vessel systems. They investigated the effect of heave compensator during lowering operation of subsea equipment.

In this study, a series of model tests were carried out to study the mating operations of a topside module onto a FLNG by using a floating crane. The model tests were performed in Ocean Engineering Basin at KRISO with a model set-up of 1:45 scale ratio. The floating crane vessel was equipped with a crane system and dynamic positioning system. The topside module was simplified as a rectangular box of about 2000 Tonf. Four leg mating units(LMUs) were introduced to model the interface units between the FLNG and the topside module. While the interaction forces between the crane vessel and the topside module are transferred via the crane wires, the topside module interacts with the FLNG through the LMUs. Experimental conditions include four mating stages, i.e. 0%, 20%, 50% and 93% load transfers, in regular and irregular waves. To validate the experimental results, a time-domain numerical simulation is applied to solve the coupled dynamics of three bodies. The discussions were made on three main points. First, the motion characteristics of the lifted object as well as the crane vessel were studied by comparing the calculation results. Second, the dynamic tensions of the crane wires were evaluated under the various wave and mating conditions. Final discussion was made on the LMU impact forces. The comparisons between the experiments and calculations validate the present numerical simulation method.

2. Model test

2.1. *Experimental models*

In this study, a series of model tests were carried out to study the mating operations of a topside module by a floating crane. Three experimental models, i.e. a floating crane vessel, a FLNG and a topside module, were used together. Fig. 1 shows the experimental models. The floating crane vessel, shown in Fig. 1(a), is 110 m in length and 48 m in breadth. It is equipped with crane and dynamic positioning system. A winch system is installed on the deck for the hoisting operation. During the tests, crane boom angles were fixed as 57deg. The FLNG, shown in Fig. 1(c), is 170 m in length, 65 m in breadth and 11 m in depth. The weight of the FLNG is about 50,000 ton. In the model test, the FLNG was positioned with soft spring mooring system in which four soft springs were attached to the vessel to prevent the excessive drift motion. The connection points of the soft springs are both ends of the vessel centerline