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Experimental and numerical study on coupled motion responses of a floating crane vessel and a lifted subsea manifold in deep water

B.W. Nam*, N.W. Kim, S.Y. Hong

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

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Abstract

The floating crane vessel in waves gives rise to the motion of the lifted object which is connected to the hoisting wire. The dynamic tension induced by the lifted object also affects the motion responses of the floating crane vessel in return. In this study, coupled motion responses of a floating crane vessel and a lifted subsea manifold during deep-water installation operations were investigated by both experiments and numerical calculations. A series of model tests for the deep-water lifting operation were performed at Ocean Engineering Basin of KRISO. For the model test, the vessel with a crane control system and a typical subsea manifold were examined. To validate the experimental results, a frequency-domain motion analysis method is applied. The coupled motion equations of the crane vessel and the lifted object are solved in the frequency domain with an additional linear stiffness matrix due to the hoisting wire. The hydrodynamic coefficients of the lifted object, which is a significant factor to affect the coupled dynamics, are estimated based on the perforation value of the structure and the CFD results. 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 tension of the hoisting wire were evaluated under the various wave conditions. Final discussion was made on the effect of passive heave compensator on the motion and tension responses.

Keywords: Coupled motion; Crane vessel; Subsea manifold; Model test; Lifting operation

1. Introduction

There are various installation methods for subsea equipment in deep water. Conventional crane-wire installation method has been widely used in real-sea operations. 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. As for the subsea installation, the water depth is a critical parameter of the vertical resonance of the hoisting system. Recently, new installation methods such as pendulum installation method, pencil buoy method and sheave method, also have been devised to overcome the limitation or disadvantage of the crane-wire installation method.

A typical crane installation operation in deep water consists of four main phases (DNV, 2011). First phase is lifting off from deck of a transportation barge and maneuvering the object, in which the transient behavior of the lifted object should be suppressed to avoid collision. Second phase is lowering operation through the wave zone. In this stage, various external forces including weight, buoyancy, slamming force, wave force are acting on the lifted object, changing in time according to the lifting locations of the object. The slack condition of the hoisting wires also should be check. Third phase is deep-water lowering (or lifting) operation, in which vertical oscillation of the lifted object can be a significant factor. As the hoisting wire is getting longer, the first eigen

* Corresponding author. Fax: +82 42 866 3919.
E-mail address: bwnam@kriso.re.kr (B.W. Nam).
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period of the hoisting system can be getting longer up to the operational wave period. In this case, the resonant vertical motions of the lifted object and the large dynamic tension of the hoisting wire can occur during the lowering operation. Final phase is touching down on sea bed and retrieval, which is landing stage. Horizontal offset and motions of the lifted object, which are mainly affected by the low-frequency horizontal motions of the vessel as well as ocean current, can be important considerations related to the accurate positioning of the subsea equipment. Appropriate weather conditions should be screened before the real-sea operation.

During the deepwater lowering or lifting operation, a heave compensation system can be employed to mitigate the vertical resonant motion of the lifted equipment and reduce the dynamic loads in the hoisting wire system. Three types of heave compensators have been used in deep water lifts: Passive, active and combined heave compensators. A Passive Heave Compensator (PHC) is a kind of spring-damper systems which shift resonant frequency of vertical motion of hoisting wire system. The passive heave compensator is also designed to reduce impacts on offshore cranes by adding damping in the hoisting wire. An Active Heave Compensator (AHC) uses either controlled winches or hydraulic pistons, and reference signals. The active heave compensation systems generally use information from vessel Motion Reference Unit (MRU) to control payout length of winch line.

Regarding the real-sea deepwater installation operation of subsea equipment, dynamic analysis method is widely used in design stage to predict the motion responses of the subsea equipment and determine the capacity of the installation equipment and the weather windows. For example, Galgoul et al. (2001) described the analyses and all the problems encountered during the installation project of a PETROBRAS manifold in a 1860 m water depth, at the Roncador field in the Campos Basin, offshore Rio de Janeiro. They also pointed out the axial resonance can be a major concern as the installation depths increase to 3,000 m. Kimiaei et al. (2009) presented a simplified numerical model for the accurate estimation of hydrodynamic forces on subsea platforms and compared the results of the DNV guidelines. They carried out a series of sensitivity analyses using DNV guideline and OrcaFlex models. Vries et al. (2011) described the monitoring campaign on a typical example of a deep water lowering operation. They suggested the monitoring results about the subsea behavior of two suction piles during the installation operation in 2700 m water depth using a support vessel. They also compared the monitoring results with numerical models used for dynamic analysis and concluded that dynamic analysis methods can be applicable to prediction of the motion and load for subsea structure in deepwater installation operation. 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. Wang et al. (2011) carried out pipeline installation analysis and jumper lowering analysis by using the commercial software OrcaFlex. They discussed the technical challenges to install the rigid pipeline with PLET, jumper and flying leads. 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.

Only a few model tests related to subsea installation or floating crane can be found in literature survey. Clauss et al. (2000) showed an experimental study of the nonlinear dynamics of floating cranes. Fujarra et al. (2008) carried out a seres of simplified model test in order to dimensioning the launching cables and to define the limit environmental conditions for the subsea installation. 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.

In this study, coupled motion responses of a floating crane vessel and a lifted subsea manifold during deep-water installation operations were investigated. A series of model tests for the deepwater lifting operation were performed at Ocean Engineering Basin of KRISO. To validate the experimental results, a frequency-domain motion analysis was carried out. Under various irregular wave conditions, the motion responses of the vessel as well as the lifted object were examined. The dynamic tension of the hoisting wire were also evaluated under the different wave period conditions. Discussion is made on the effect of passive heave compensator on the motion and tension responses.

2. Model test

2.1. Experimental models

A floating crane vessel named ‘HD2500’, which has been used in real-sea installation project by Hyundai Heavy Industry (HHI), was selected in this model test. The main dimensions of the crane vessel are 130 m(L)*36 m(B) *10.5 m(D). The displacement of the vessel is about 15,000 ton. Fig. 1 shows the image and experimental model for the crane vessel. The scale ratio of the model is 1:50 and the scaled vessel model was made of wood. The crane vessel is equipped with dynamic positioning system for the deepwater operations. Four azimuth thrusters are located at each corner of the vessel. The GM value and roll natural period were adjusted by inclining and free-decay tests. The pitch gyration was measured with a swing table test. There is a single crane system with maximum capacity 2500 ton on the deck of the vessel.

Among various types of subsea equipment, a typical subsea manifold was considered in this model test. Fig. 2 shows CAD image and experimental model of the manifold. The present manifold has complex geometry, which consists of complex

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