Experimental Study on Coupled Motion of Floating Crane Barge and Lifted Module in Irregular Waves

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Abstract. Installation and decommissioning activities of offshore structures often applied a floating crane barge for a lifting operation. The excessive movement response of lifted module affected by the motion of floating crane barge in waves can increase a large amplitude. However, the coupled motions of a floating crane barge and lifted module are not easy to predict accurately due to the dynamic movement of a lifted module and the complex coupling system. The coupled motion responses of a floating crane barge and a lifted module during lifting operation were investigated based on time domain by experimental method in this study. The model tests are carried out at Manoeuvring and Ocean Basin of Indonesian Hydrodynamic Laboratory, BRIN. The experimental conditions include the load cases of without and with a load of lifted module in crane tip, and the lifting operation was evaluated under irregular wave conditions. The experimental results show in that the phenomena of shift resonant frequency for the dynamic responses are clearly observed on the coupled motion of multibody system. The dynamic oscillations of the lifted module have a significant effect on the motion response of the floating crane barge. And the hoisting of lifted module has an obstructed effect on the rolling motion of crane barge.

1. Introduction
The Indonesian government had made efforts to remove some offshore platforms that are no longer used for operations in oceans. The offshore platforms do not carry out an exploration because oil and gas production has decreased from year to year. The expired platform in the middle sea can disrupt the trajectory of shipping activities. According to SKK MIGAS data [1], there are around 102 units of the offshore platform that are no operated and 6 units are ready to be abandonment. Generally, an offshore platform of expired services life and no generated economic benefits must undergo a decommissioning process [2].

Due to many opportunities of installation and decommissioning activities in Indonesian oil dan gas business, the demand for lifting operations with floating crane barge increase correspondingly. The application of a crane barge can be a solution of transportation technology in relocating and moving platforms that are no operated. The floating crane is a sea transportation of more flexible and faster technology for relocation of offshore structure in marine operations [3], [4].

The operation of floating crane in oceans is strongly influenced by wave conditions. The relatively small wave height can have a significant effect on the coupled motion response of floating crane during
lifting operations. A collision between the lifted module and the boom of floating crane often occurs due to wave-induced external forces in the installation and decommissioning process [5]. Therefore, it is important to study the motion response of floating crane in waves which aims guarantee a safety and a security for marine operations.

The coupled motion response in multibody system for lifting operation occurs due to an interaction on both the responses of floating crane barge and lifted module. [6] investigated the dynamic response of floating crane in waves by experimental method. They reported the existence of the large resonant oscillations to a strongly coupled motion of swinging load. [7] conducted a time domain simulation for the dynamic response of heavy cargo with a floating crane by multibody system dynamics. The results show that there was the interaction between the cargo suspended and the floating crane. [8], [9] carried out an experimental and numerical study on coupled motion of a lifted manifold by a crane vessel during installation operation in waves. Generally, the crane vessel response experienced the significant motion due to the interaction with the hoisting of lifted subsea equipment via wire rope on crane tip. [10] studied the coupled motion of the topside module by the floating crane vessel in following waves during the installation of offshore platform. They presented the phenomena of resonant frequency on the coupled motion by a clearly observed.

In the present paper, a lifting operation by a floating crane barge is experimentally studied in the laboratory. A series of model tests for the lifting operation of lifted module were performed under irregular wave conditions. As a comparatively analytic study, the experimental testing includes the load cases of without and with a lifted module. The analysis of time-series responses will be presented on the graphics of the spectral response by frequency domain. This paper describes about the coupled motion on 6 degrees of freedom of the floating crane barge and 3 translational movements of the lifted module. The results can serve a reference for a lifting operation of the decommissioning or the installation activities in ocean waves.

2. Methodology

2.1. Experimental Model

In this paper, a series of model tests were examined to study the lifting operations of a lifted module by a floating crane barge. The physically model tests were scaled down by the ratio of 1:28. In the experimental model, a floating barge model is made of plywood with the lamination fiberglass. The crane system was made of the mild steel construction and reinforced with the wire rope of stainless-steel. The model of crane structure was placed on the deck between the midship and the bow of barge ship with a position in front of the direction of the ship. And the lifted module was simplified as a small square box with ballast load. The luffing jib angle of crane was set at the fixed angle of 60 degrees during the tests. The floating crane barge in the model test was equipped with the mooring line system in which four linear springs about of 44.53 N/m were connected from the fairlead at each end of the corner of the ship’s deck to the pulley systems with a horizontal link which is presented in Figure 1. However, the stiffness of mooring line mostly has the non-linear characteristics. The mooring system spread a symmetrically mooring scheme. The length of the mooring line is about 2.2 times of the crane barge. The experiments were carried out in Manoeuvring and Ocean Basin of The Indonesian Hydrodynamic Laboratory.

The floating crane barge, shown in Figure 2, is 84 m in length and 21 m in breadth. The weight of its is about 3,468,358.00 kg. The lifted module is 5.6 m both in length and breadth, and 0.5 m in depth. The Lifted module weight is about 4.0 % of weight of the floating crane barge. The principal dimension and mass properties of the floating crane barge are listed in Table 1. The damped natural frequencies of crane barge motion were adjusted by free decay test with calm water. The measurement of pitch gyration was performed by a swing table test. The metacentric height of transversal (\(GM_T\)) of crane barge was measured by the inclining test method in ocean basin.
2.2. Experimental Condition
In study of coupled motion on multibody system, the motion responses of floating crane barge are influenced by wave load and dynamic movement of lifted module. The interaction force between the lifted module and the floating crane barge are connected through the hoisting rope of crane during the lifting operation. The model motions of the crane barge and the lifted module are measured by the Qualisys tracking motion capture system. Figure 3 shows the Qualisys camera equipment and Figure 4 shows the small ball of marker sensors for rigid body models. Three Qualisys cameras will capture the motions of

| Item                  | Prototype   | Model     |
|-----------------------|-------------|-----------|
| Length                | 84.00 m     | 3.000 m   |
| Moulded Breadth       | 21.00 m     | 0.750 m   |
| Moulded Depth         | 6.16 m      | 0.220 m   |
| Draft                 | 2.40 m      | 0.107 m   |
| Displacement/Weight   | 3468.36 ton | 0.154 ton |
| Lifted Module Weight  | 139.53 ton  | 0.006 ton |
| Hoisting Rope Length  | 34.16 m     | 1.220 m   |
6 degrees of freedom from each model in real time. The motion measurement of tracking system based on the rigid body formed from the marker sensor on the ship and the lifted module. Definition of the lifted module movement at its COG: the translational movement mode along the direction $x\text{-}$, $y\text{-}$, and $z\text{-}$ axis are respectively denoted as the translational motion of the floating crane barge. The sampling frequency of the motion time series is 50 Hz.

The model testing of floating crane barge was performed the seakeeping test with and without a lifted module load. The motion responses of the models were investigated under variation of irregular wave parameter. Table 2 shows a summary of irregular wave conditions. The wave spectra model in this experiment are the Jonswap spectra. This is because there is a suitability for archipelagic waters such as Indonesian [11]. The equation of Jonswap spectra model used to generate the irregular waves in ocean basin can be seen from this reference [12]. The wave spectra used in the present experimental condition are shown in Figure 5. The generated irregular wave condition in the basin, the wave spectra from the measured time series were directly compared to theoretical wave spectra for verification purposes. The wave heading on the experiment of lifting operation is focused on the beam sea or 270 deg. This wave heading provide a greater excitation force and moment heave and roll motion of the ship than in other headings. The experimental results based on time domain are converted to the frequency domain using the Fast Fourier transform method which is presented in the response spectra as performed by [13], [14]. Furthermore, the hydrodynamic response results of model tests in irregular waves are analysed using the statistical value.

| Wave ID | Spectra | Hs   | Tp   |
|---------|---------|------|------|
| IR01    | Jonswap | 0.50 | 4.00 |
| IR02    | Jonswap | 1.00 | 5.50 |
| IR03    | Jonswap | 1.50 | 1.50 |
| IR04    | Jonswap | 2.00 | 2.00 |

**Figure 5.** The wave spectra for experimental test
3. Results and Discussion

![Surge](image1)

![Sway](image2)

![Heave](image3)

![Roll](image4)

![Pitch](image5)

![Yaw](image6)

Figure 6. Comparison of motion response spectra of the floating crane barge between without and with the lifted module in wave condition of IR02

The direct comparisons of the motion response spectra of the floating crane barge in wave condition of IR02 between without and with the lifted module are shown in Figure 6. The resonant phenomena of coupled motion in a multibody system are clearly observed on the power spectra of floating crane barge in surge and yaw motion which is shown in the red curve. The resonant frequency affected by the horizontal movement of lifted module occurs around 0.55 rad/s. The power spectra of sway, roll and pitch indicate a small peak in the response spectra due to the horizontal movement of the lifted module.
In the surge, sway and yaw motion spectra, the horizontal motion response of the floating crane barge is highly dominated by low-frequency response. This response is influenced by the second-order wave drift force and the interaction with stiffness characteristics of mooring line. The vessel heave motion is mainly dominated by the wave frequency response. For the roll and pitch motion of floating crane barge, the peaks of response spectra are mainly dominated by the natural frequency of the vessel’s motion itself. The natural frequency of roll motion on the vessel with a lifted structural load slightly shifts at higher frequency than without a load due to the dynamic oscillation of pendulum connected in crane tip.

![Comparison of motion RMS values of the floating crane barge between without and with the lifted module.](image)

**Figure 7.** Comparison of motion RMS values of the floating crane barge between without and with the lifted module.
In order to determine the response performance of floating crane barge in irregular wave, the model tests were performed with 4 different wave conditions. Figure 7 shown the root mean square (RMS) or standard deviation of motion responses on the floating crane barge without and with the lifted module load. For all motion, the vessel’s motion responses increased with the increase of wave condition. The largest increase in heave, roll and pitch motion response both without and with a lifted structure occurs significantly from wave ID of IR01 to wave ID of IR02. The response increases greatly because the peak period of IR02 wave is close to the natural frequency of the vertical motion of the vessel system. The average increase in vessel motion response from IR01 to IR02 wave ID, the heave motion increases about of 395 %, the roll motion increases about of 212 % and the pitch motion increases about of 314 %.

The surge RMS values are less than 0.1 m. The surge motion on with a lifted module is slight smaller than without a lifted module in IR01 and IR04 wave ID. On the contrary, the surge motion on with a lifted module is bigger than without a lifted module in IR02 and IR03 wave ID. The heave motion response of floating crane barge in all condition generally has the same RMS value between the load cases of without and with a load of lifted module. On the sway and roll motion, both give similar response performance to different load cases in wave condition. Based on the experimental results, the sway and roll motion response of the case without a lifted structure are consistently greater than the case with a lifted structure. Different for IR01 wave ID, the case without a lifted structure shows slight smaller motion response rather than the case with a lifted structure. It can be understood that the dynamic oscillation of a lifted structure gives the external force and moment on the crane tip motion of vessel. So, the movement of lifted structure can inhibit the crane vessel’s roll motion for larger wave parameters. All wave condition, the pitch and yaw motion RMS values of the case with a lifted structure are clearly bigger than the case without a lifted structure. In principle, the motion responses of floating crane barge are significantly influenced by the dynamic movement of the lifted structure.

The movement statistical values of the lifted module response are shown Figure 8. From the graph of RMS value of the lifted module can be clearly seen that the movement responses increase with increasing wave condition. The vertical movement and horizontal movement along direction-y show more dominant than horizontal movement along direction-x. It can be understood that the heave, sway dan roll motion in beam sea gives the motion response bigger than the other motion modes. The vertical movement is more dominantly influenced by heave and pitch motion response of floating crane barge in this experimental study. While the horizontal movement along direction-y is more dominantly influenced by sway and roll motion response of floating crane barge. On the coupled motion in the lifting
operation, the motion responses of the floating crane barge and the lifted module affect each other in a multibody system.

4. Conclusion
The experimental study was carried out for determining the performance of a floating crane barge including load cases of without and with a lifted structure in irregular waves. From the series of experimental testing, the following conclusions can be drawn:

- The coupled motion in a multibody system is clearly observed in the motion response spectra of a floating crane barge due to the resonant frequency caused by the interaction of a lifted module movement connected to the crane tip.
- The motion responses of a floating crane barge and a lifted module become larger with increasing wave condition. The increased motion responses change significantly when the natural frequency of the vessel motion is near the peak period of the wave spectra.
- The floating crane barge during the lifting operation experienced the inhibited roll motion due to the dynamic oscillation of the lifted module in the beam sea for larger wave parameters. The hoisting of a lifted module by floating crane can generated the dynamic external forces and moments through the crane tip motion.

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