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Stability of Mobile Floating Harbor Container Crane

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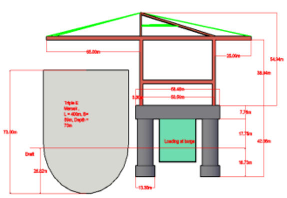
Graphical abstract



Model of MH

Abstract

Stability of the mobile floating harbor is an important criterion to avoid an accident in port operation during lifting, loading, and uploading container. The stability of a mobile floating harbor which completed with a container crane was analyzed by study the structure's rolling amplitude at several sea conditions. Factors considered in the study as follows: size and height of crane and the location of the container during loading and unloading. The mobile floating harbor was constructed using a semi-submersible model on a scale of 1:70 with a specified gantry crane with maximum outreach length 65 meters (Actual size). Using the model, inclining test, swing and oscillating tests was carried out to obtain hydrostatic particulars. By using the experimental result, the roll amplitude for several sea conditions was simulated using the Morison equation. The simulation results showed that the highest roll amplitude occurs when the crane for mobile floating harbor loaded with container in any sea condition.

Keywords: Stability mobile floating harbor; semi-submersible model; morison equations; rolling motion

1.0 INTRODUCTION

A mobile floating harbor is a movable floating structure located in the middle of the sea which is designed to load and unload containers from container ships. The mobile floating harbor is not attached to any fixed static ground but mooring system is applied to hold it in position. The mobile floating harbor concept was foreseen as an alternative in port development and expansion. This innovative concept also helps to overcome the restriction of environment or geography such as insufficient areas to build new infrastructure in handling global shipping volume and mega-sized container ships.

In our design, the mobile floating harbor is mainly constructed by four columns and two pontoons same as semi-submersible and a crane on the deck was made of steel. Semi-submersible is chosen because the structure size is the most appropriate for mobile floating harbor and it consists of enormous boxes section deck. In additional, semi-submersible has multiplied-hull shape which is one of the requirements for this new designed mobile harbor. The free space between the pontoons is designed as a passageway for the pusher barge.

From the safety point of view, floating structure stability is an essential element must be considered when designing the mobile floating harbor. Stability of the mobile floating harbor gives significant effect on the safety of port operation because better safety design could help to prevent the accident occurrence during container travelling, loading and uploading processes. In addition, a stable mobile floating harbor can ensures crane operators safe from any hazards such as capsizing, collapse and falling from height. Thus, high stable structure design is required for reducing the risk during operation. Therefore, the stability of the mobile floating harbor is an unexceptionally important issue to be studied.

However, the mobile floating harbor located at a seaway is predicted will frequently experience oscillatory motion and this undesired motion of the structure are induced by environmental disturbances. The tendency of undesired motions due to the environmental disturbances is relatively high, especially the formation of the unsteady wave force act upon the floating structure. The oscillation motions related to the equilibrium position of the floating structure are heaving, pitching and rolling. One of the important issues must be considered in the mobile floating harbor is the stability of the structure. Instead of the floating structure platform, the biggest infrastructure on the platform is container crane. Obviously, the larger crane size occupies more space and the structure weight is heavier. Hence, the stability problem of the floating structure arose. Weight and height of the crane also directly affect the motion of the floating structure which leads to instability. Besides, the location of the crane is also another factor to be considered here because different crane location impulses different moment amplitude. Therefore, all the three factors were emphasized in this study.

In this paper, the effect of crane's weight and height as well as the location of the container to the stability of the mobile floating harbor were identified by experiment and numerical method. As a case study, Port of TanjungPelepas (PTP) is selected for innovation of the mobile floating harbor. The port is located at the Pulai River mouth in the South-Western Johor, Malaysia. The size of the crane in this study was selected based on the capacity of PTP. The main part of this study is focused on motion of the floating structure due to the crane. Besides that, the location of the container during loading and unloading condition is also a scope of the study. In the first approximation, only uncouple motion is focused. Coupling between motions is neglected in order to simplify the preliminary analysis

2.0 LITERATURE REVIEWS

Usually, floating structures' stability is related to their motion directly. It is necessary to define the floating structure's motion in order to identify their stability. Large stability variations can be governed by wavelength, wave height, general hull form, bow flare and stern shape. Jovanoski and Robinson had introduced a simple differential equation known as Mathieu's equation. This equation identifies the ship's motion from the stability point of view.[6]In that study, two types of rolling are discussed. These two motions are natural rolling and parametric rolling. In natural rolling, position of center of buoyancy and metacenter are assumed static. Whereas, parametric rolling assume the GM value is varying during roll motion. GM is varies due to the different wave's longitudinal position along the ship. As a conclusion, GM is a periodic function with encounter period. This is then introducing Mathieu's equation to solve the parametric rolling equation.

Instead of wind and wave effects, there are two basic forces acting on the floating structure there are weight force and buoyancy force. Weight force is designed as acceleration of floating structure's mass acting vertically downward due to gravity force. Meanwhile, buoyancy force is acting vertically upward against weight force. Amount of the buoyancy force act to the structure is equal to the weight of fluid displaced as stated in Archimedes' principal. When floating structures are rolled or trimmed, the center of buoyancy will changed and thus a couple or moment will occur which tend to upright the floating structure back to the equilibrium position. Gamo *et al*. had also successfully proved this mathematical model for the roll motion.[4]A satisfactory good correlation is found in phase and amplitude for the tested fishing trawler. Besides, a loaded condition was also tested by him and good results were formed by using Runge-Kutta differential method. On the other hand, Levadou and GuilhemGaillarde had decrypted parametric motion as a motion resulted from periodic variation of some parameters for oscillating system, instead of direct excitation by the external force and moment.[7]Individual time traces for each condition were used in order to analyses the probability of occurrence of parametric rolling.

Maziah Suraya developed a computational programming code to predict the motion characteristics of the semi-submersible due to dynamic wave-induced loads.[9] In her study, she was strongly suggested the Morison Equation as an accurate analysis approach compared to deterministic analysis. In case to analyze the wave spectrum, two type of sea state (PM and JONSWAP) were considered. Lok conducted an experiment test on semi-submersible, GVA 4000 in UTM marine laboratory to validate the simulation program developed by Suraya Maziah.[8,9] During the experiment, Planar Motion Mechanism (PMM) was selected as a captive model testing and 6 component force measuring system was used to measure both the heave force and sway force. Results obtained from PMM were slightly varied with to result from simulation made. As an example, the heave force obtained from experiment was much lower compared to the simulated results. Yassir and Kurian had presented time domain hydrodynamic analysis for semi-submersible platforms in regular sea waves.[13] The semi-submersible model was constructed by several cylindrical columns and twin rectangular pontoons. In their study, they were applied Airy wave theory and a hybrid approach incorporating Morison modified equation. Airy wave theory was used to evaluate the wave kinematics since the diameter of columns and pontoons is relatively small compared to the wave length of incident gravity waves. Meanwhile, Morison equation was used for calculating wave forces in all six degree of freedom. However, Yassir and Kuria had neglected the effect of vortex induced vibration in order to simplify the study.[13] Another experiment related to twin hulled semi-submersible was done by Abbas, Kurian, Harahap and N. Abu Bakar.[1] They used both the numerical and experimental dynamic analysis to study semi-submersible's hydrodynamic characteristic in regular and irregular waves. In the numerical model, an iterative incremental numerical scheme had developed to solve the equilibrium condition in time domain. Again Morison equation was applied at the instantaneous position of the structure to determine the wave force. Besides that, effect of mooring system to structure dynamic behavior was evaluated numerically using nonlinear catenaries equations. They emphasized on the mooring system for the structure due to pretension on the mooring lines was maintained by attaching small buoys which designed to provide the desired net buoyancy. Based on this study, it is found that numerical responses were lower than the physical model responses at low frequency waves. However, the only exception is the heave response. This is because of the ignorance upon potential damping, where the effects of second orders cross modulation low frequency interactions were considered in the mathematical formulation.

Jaswar *et al.* had discussed dynamic analysis on Floating Production Storage Offloading (FPSO) LNG Operated in East Timur Sea which is affected by wind, wave and current.[5] The FPSO was designed to have a double hulled FLNG production vessel which must be able to support topside liquefaction facilities and storage containment tanks of 400 kilometers cubic. The vessel design included an external turret-mooring system. Cha *et al.* had published a paper of dynamic response simulation of heavy cargo suspended by floating crane.[2] Dynamic equations of motion were also generated to estimate the motion of the floating crane and the heavy cargo. Total 12 degrees of freedom were considered based on the multi-body system dynamics which are the 6 DOF at floating crane and the 6 DOF at cargo. The motion of the floating crane and the heavy cargo operation is synchronized due to constraint force between the floating crane and the cargo through the wire rope.

In addition, experimental tests were carried out to obtain the motion response of semi-submersible structured. A model test related to single body motion without a crane and interaction between semi-submersible and TLP was carried out to identify the structure response in waves. In this model test, wave periods were carefully selected to cover the models' natural period. Wave slope selected in this motion test are 1/20, 1/40 and 1/60. The range of wave frequency selected in this model test is varied from 0.4 Hz to 1.2 Hz while the maximum wave height in this test 0.186 meters.[14]

3.0 MATHEMATICAL MODEL

Basically, a common semi empirical formula known as the Morison equation was implemented in the computation to estimate the wave loading on the offshore structure. Morison equation illustrated a harmonic flow force on a body in a function of time. The total hydrodynamic force experienced by the semi-submersible is same as a summation of the forces due to the columns, pontoons and bracing.

3.1 Roll Moment and Motion Response

Total roll moment (M_{Roll}^{Tot}) of floating body can be expressed as

$$M_{Roll}^{Tot} = M_{col} + M_{Pon} + M_{Crane} \quad (3)$$

Where,

$$\begin{aligned} M_{col} &= M_R^{Col} + M_A^{Col} \\ &= \left[a_z|_{x=\pm\frac{B}{2};z=z_{col}} x \right] + \left[\int_z^0 a_z|_{x=\pm\frac{B}{2};z=z_{col}} zdz. A_S^{Pon} \right] \\ &\quad + \left[M_{add,z}^{Col}. a_z|_{x=\pm\frac{B}{2};z=z_{col}} x \right] \\ &\quad + \left[m_{add,x}^{Col} \int_z^0 a_x|_{x=\pm\frac{B}{2};z=z_{col}} zdz \right] \end{aligned} \quad (4)$$

$$\begin{aligned} M_{Pon} &= M_R^{Pon} + M_S^{Pon} \\ &= \int_{-L/2}^{L/2} a_z|_{z=zpon} xdxA_S^{Pon} + \int_{-L/2}^{L/2} m_{add,z}^{Pon}. a_x|_{z=zpon} xdx \end{aligned} \quad (5)$$

$$M_{Crane} = \sum Wgh \times d \quad (6)$$

Where; W = weight of container, g is gravity which is 9.81m/s^2, h is height of container and d = distance of container to center point.

From the Equation (6), it is shown that the moment due to the crane is affected by the height of crane. If the crane height is increased, the moment due to the crane will become higher when it is loaded by container. This is because the higher crane will cause the moment arm increase; hence the moment due to the container weight is magnified by the moment arm. Besides, the distance of the container to the center point of the structure also as a factor considered in this research as shown in Equation (6). If the container is shifted to the end of the crane from the center point, the moment contributes by crane to generate roll motion will be larger. This is because the moment arm is longer if the container located at end of crane compare to it located in center of the crane. Therefore, the moment can be generated become larger.

Finally, The roll amplitude (θ) can be expressed as

$$\theta = \frac{(M_{Roll}^{Tot}/C)}{\sqrt{\left[1-\left(\frac{\omega}{\omega n}\right)^2\right]+\left[2\xi\left(\frac{\omega}{\omega n}\right)\right]^2}} \quad (4)$$

3.2 Effect of Crane

The effect of the crane installed on the top of a platform deck can significantly change the KG value of the platform floating structure. If platform weight was modified, it is undoubted that the stability of the platform will be affected. The radius gyration about an axis is inherent with the KG value. However it was difficult to identify these values due to few uncertainties such as the fabrication material of the crane and the specified material thickness. Few assumptions were made to simplify the model. Firstly, it is assumed that the crane volume is exactly in box shape. Secondly, the crane has well balanced by itself with the KG value located at the centroid of the semi-submersible model. Lastly, the container loading is only affecting to roll motion.

4.0 RESEARCH METHODOLOGY

4.1 Research Flow

Research methodology for analyzing stability of a mobile floating harbor due to effects of crane is outlined. Experiment of a floating harbor experiment was conducted using a semi-submersible owned by UTM Marine Technology Center, whilst the crane's structure was fabricated from steel. A mathematical model is designed by using computer software, Microsoft Excel and Microsoft Visual Basic Studio.

Basically the methodology divided into few sections as shown in Figure 1. At the beginning, a simple simulation of the structure motion at calm water was made before proceeding to more complex condition. The purpose is to compare the different of the structure motion before and after installation of crane. Apart from that, it is to strengthen and enlighten the importance of stabilization during design process.

4.2 Fabrication and Experimental Model

A semi-submersible physical model was made from a wooden plate with the scale of 1:70 compared to actual scale. The model consists of 4 round columns and 2 pontoons immersed in water. Particular of actual ship and scaled model for the semi-submersible is shown in Table 1. On the deck, a crane model was made by steel. Typically the entire crane design was based on the largest crane infrastructure owned by PTP as shown in Figure 2 and Figure 3. The experiment was carried out in the Marine Technology Center's (MTC) towing tank in UniversitiTeknologi Malaysia. The tank has total length of 120 meters by width of 4.0 meters and depth of 2.5 meters. Wave generator inside the MTC has capability to generate maximum wave height of 0.44 meters for wave periods of 1.7 second.

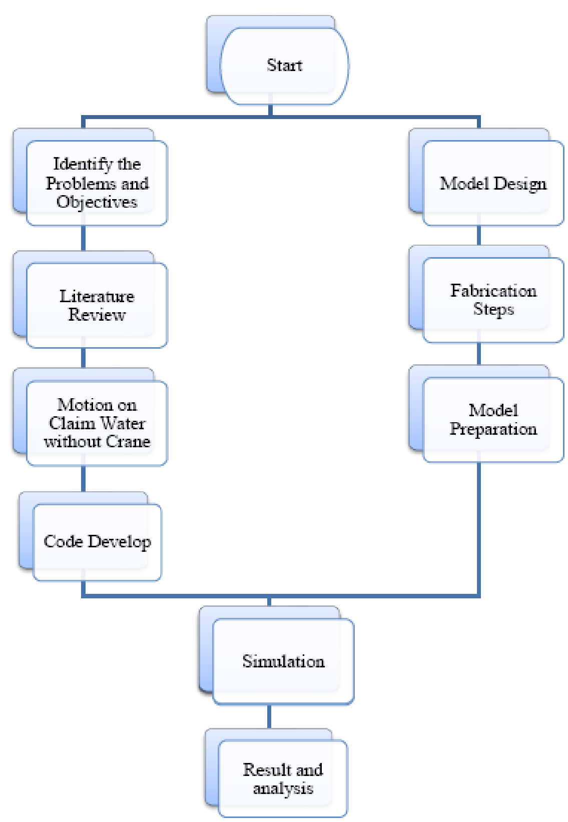


Figure 1 Methodology flow

Several preparations were completed in order to obtain the hydrostatic particulars. These included crane fabrication, inclining test, swing frame test and oscillating test as shown in Figure 4 and Figure 5. It is necessary to do both testing in order to obtain the parameter required by the simulation program. For example, inclining test is to obtain GM value, and swing frame test is to identify the KG and oscillating test is to define Kxx (radius gyration at x-axis). In addition, regular wave tests for this model structure without crane was also carried out to obtain the model response amplitude. The regular wave generated for this experiment is ranged from 0.4 Hz to 1.2 Hz for wave frequency and wave height is 4.4 cm to 18.6 cm.

Table 1 Particular of actual ship and scaled model

Particular		Model	Ship
Scale		1	70
Overall Length		83.50cm	58.45m
Overall Breath		83.50cm	58.45m
Draught		23.90cm	16.73m
Depth		60.00cm	42.00m
Column	Diameter	15.13cm	10.59m
Diameter	Length	40.00cm	28.00m
	Length	95.30cm	66.70m
Pontoon	Breath	19.00cm	13.30m
	Depth	9.00cm	6.30m
Displacement		43.4kg	14886.2 tonne
KG		24.40cm	17.08m
GMt		2.10cm	1.47m
Kxx		2.76cm	1.93m

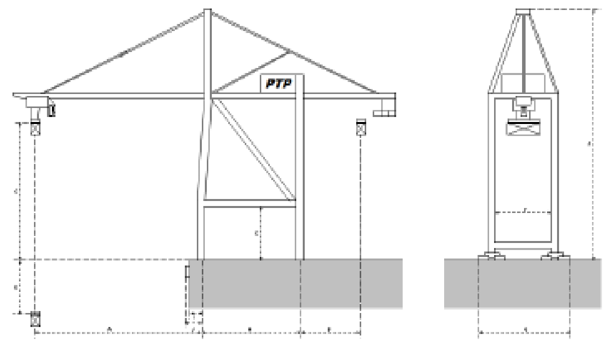


Figure 2 General drawing of gantry crane used by PTP

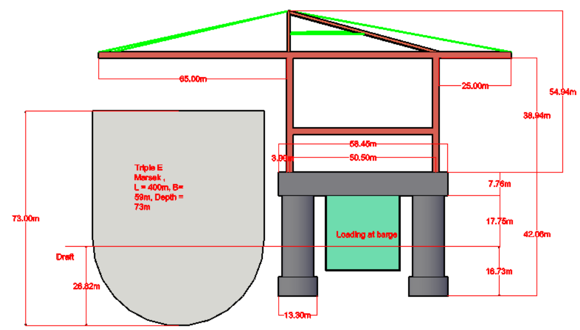


Figure 3 Model of mobile harbor

(a): Steel welding

(b): Drilling

(c): Mobile Harbor

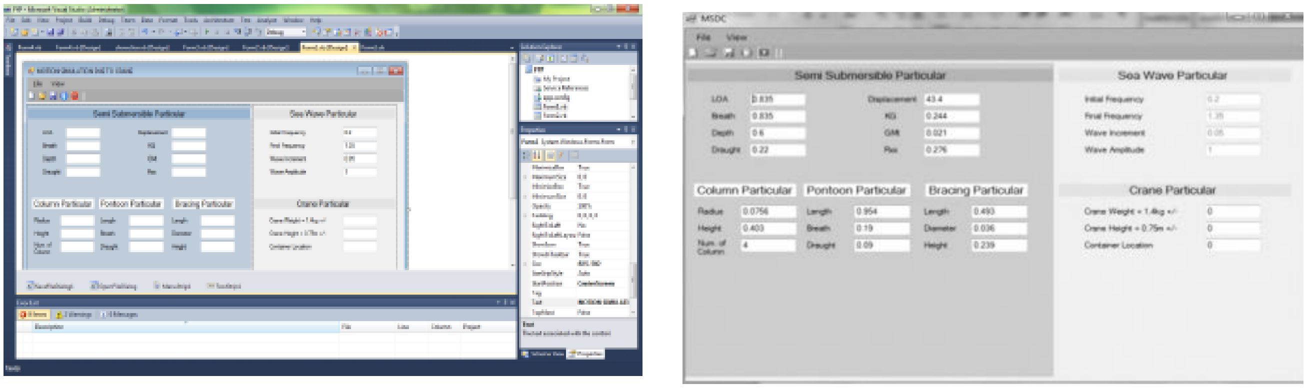
Figure 4 Crane fabrication and assembling

(a) Inclining test

(b) Swing test

(c) Oscillation Test

Figure 5 Model test



(a) Visual basic window application form (b) Input form in visual basic frame

Figure 6 Simulation run in Visual Basic 2010

4.3 Simulation Program

Simulation program was created in Visual Basic Microsoft Visual Studio 2010 due to require of visualization function. The simulation tool was named as Motion Simulation Due to Crane, MSDC. The simulation tool was designed to calculate roll moment due to column, pontoon and crane. Figure 6 shows the design of input form-frame which requires the basic dimensional particulars of the semi-submersible. Different types of tables and graphs can be attained easily by a simple click. Apart from that, the tool can generate the comparisons among the crane weight, crane height and the container locations directly.

■5.0 RESULTS AND DISCUSSION

Figure 7 shows a left shifted trend when the structure's weight is increased. The maximum peak of roll amplitude (≈ 2.5 Degrees) for 2.4 kg crane weight is located approximately in wave frequency 0.32 Hz. However, for crane weight 1.4 kg, the peak roll amplitude (≈ 2.3 Degrees) is located at wave frequency of 0.58 Hz. Finally, the peak roll amplitude (≈ 2.2 Degrees) for crane weight 0.9 kg is located at wave frequency equal to 0.68 Hz. From the simulation result, it is observed that lighter weight able to withstand the higher wave frequency. Theoretically, weight is correlated with the overall structure's center gravity. As weight increases, the KG value will also increase. It is undeniable the changes of the weight will affect the draught of the structure. Thus, structure becomes less stable due to lowGM_tpoint.

Figure 8 shows three parallel peak values for three different height conditions. The maximum peak values are approximately 2.3Degrees due to the constant weight or water plan area. However if the crane is elevated to a higher position, the container handling process will cause the exponential rise of the roll amplitude for the structure as shown in Figure 9. For example, the maximum roll amplitude for crane height of 1.25 m can reach up to 3.9 Degree.

Figure 10 shows the damping effect and roll angular displacement due to the container's handling locations. Two important observations were obtained. First, if the distance of container is further from the center point, the angular displacement will be increased. 0.12 m loading distance from center point was cause approximately 0.015 rad angular displacements. Second, the damping coefficient for this structure is low thus the time for the angular motion return to zero is long. This observation was expected because the damping coefficient for semi-submersible structure is relatively small where mostly the researchers ignore the damping effect.

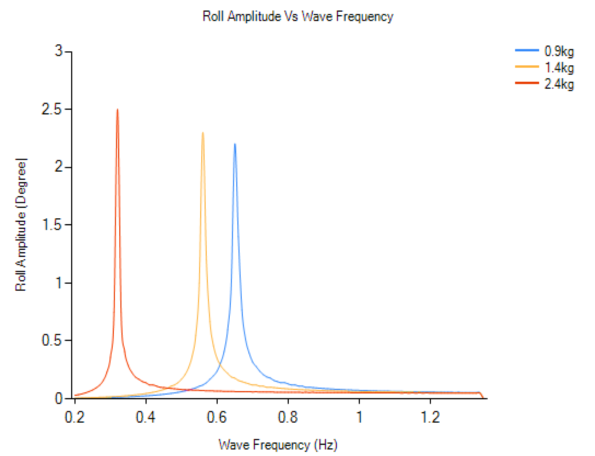


Figure 7 Roll amplitudes of several crane weights

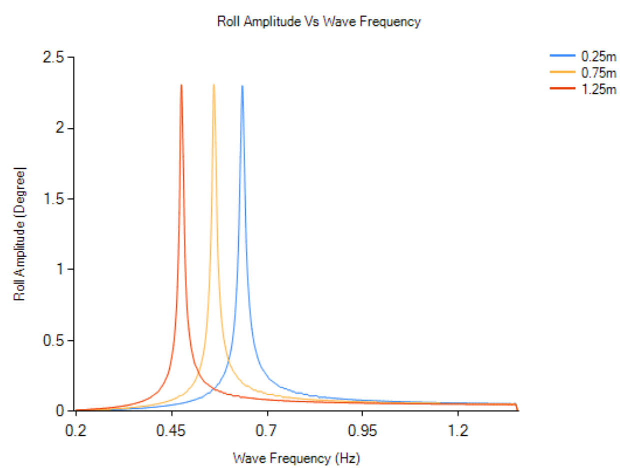


Figure 8 Roll amplitudes of several crane heights

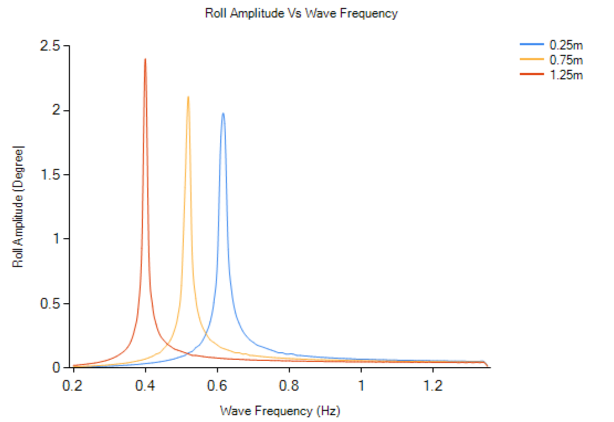


Figure 9 Roll amplitude of crane height with 0.12 m container loading location

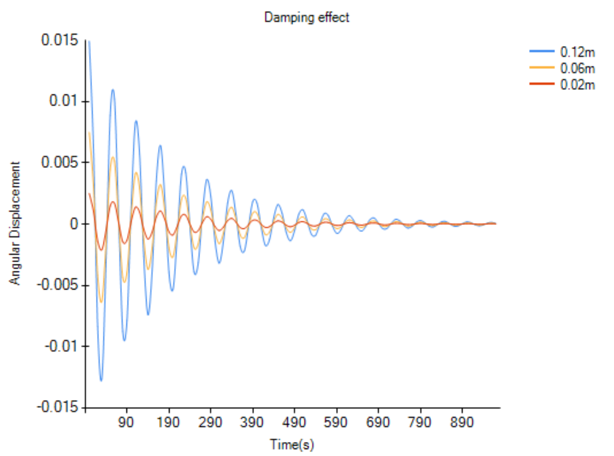


Figure 10 Damping of several container locations

Lastly Figure 11 shows that the roll amplitude is slightly increased after the crane is installed on the deck. However exponential situations occur when the crane is loaded with containers. The highest roll amplitude (3 degree) is experienced when the crane is loaded with containers. This amplitude is relatively higher compared to the other two conditions. As the result, it is concluded that loading and unloading operations will cause the roll amplitude increase exponentially.

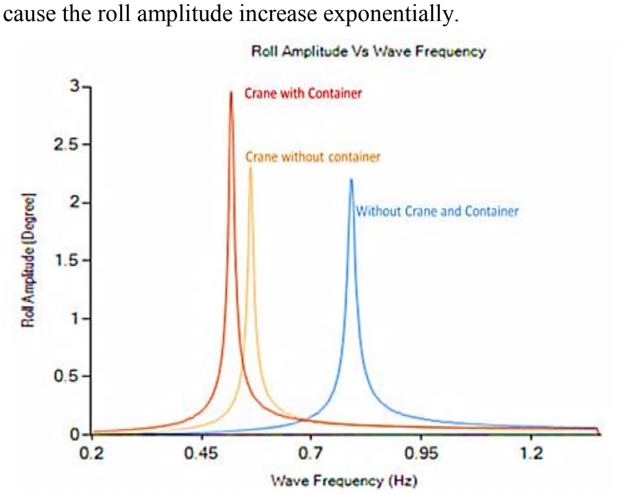


Figure 11 Overall roll amplitude analyses

From the Figure 12, it is obtained that the roll amplitude for this structure is higher at low wave frequencies generally. However, from wave frequency 0.7 Hz, the roll amplitude is increasing slowly and achieves the lower peak at 0.8 Hz before falling down. The trend of change for roll motion amplitude obtained from this experiment is shown similar to the numerical result. In addition, this experimental result also shows that the rolling amplitude for this structure is higher for long wave. Hence, the stability for this mobile floating harbor has also become lower at this wave condition. In prediction, the roll amplitude for this structure will become higher if the crane is installed and when the crane is loaded with containers. This is because, the roll motion is increasing when the weight for topside facilities such as crane increase as shown from the simulation result (Figure 11).

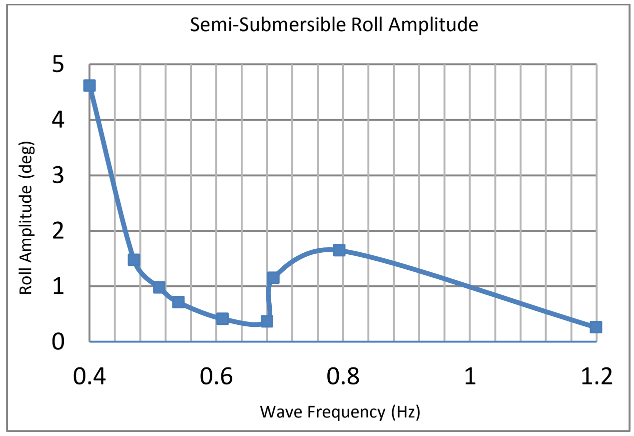


Figure 12 Roll Amplitude for semi-submersible obtained from regular wave test

6.0 CONCLUSION

Stabilization of semi-submersible mobile floating harbor container crane was investigated. Overall results had revealed the installation of container cranes will able to give significant impact on the mobile floating harbor roll stabilization. The maximum roll characteristic for the particular designed structure was found at frequency 0.56 Hz with roll amplitude of 2.3 degree. Apart from that, modifications against the crane structure design will affect the roll characteristics as explained as following:

i. The changes of crane design weight will alter the hydrostatics particulars of the entire Mobile Harbor, thus resulted different roll amplitude.
ii. If the overall weight is constant, the changes of crane height when it elevated or lowered is not influence Mobile Harbor's motion.
iii. Comparatively, effect of container location will greatly influence to the roll amplitude which rise with an exponential rate.
iv. Container handling operation should be as closer as possible to the center of gravity to reduce the damping effects.

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