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Experimental and Numerical Study on Roll Damping Structure of Floating Crane Catamaran in Free Floating and Moored Conditions

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ABSTRACT

This research discusses the experimental study of free decay test This research discusses related to the experimental study of free decay test motion roll on the catamaran floating crane structure which is reviewed from free-floating and moored conditions. Experiments were conducted on the facilities of Maneuvering and Ocean Engineering Basin owned by the BTH – BPPT. The structure used as an experiment was a model of the catamaran floating crane with a scale of 1:36. The test is carried out with a horizontal mooring link system Taken from mooring system modelling, spring stiffness is used as a reference for mooring rope stiffness in numerical analysis. The analysis carried out in this final project is to compare the experimental results of the decay test with the results of the analysis using Moses software. From the results of the experiments obtained a comparison of free-floating conditions to tethered to decay tests of 38%, 8%, and 9% for linear damping values, then 93%, 12%, and 13% for quadratic damping values. Comparison of experiment results to numerical results found a difference of 128.39% for decay test 1 for quadratic damping value, then in decay test 2 and decay test 3 against the numerical got difference of 60.80% and 66.83% in linear damping value.

Keywords: *Floating Crane Catamaran, Roll Damping, Linear Damping, Quadratic Damping*

1. INTRODUCTION

Floating Crane Catamaran is a floating structure that is used as one of the unutilized platforms over facilities or offshore structures. It is an innovation carried out on crane vessels in general which use a double hull or 2 hulls combined into one. The transfer of loads carried out in the barge crane can affect the stability of the vessel. The load transfer operation can add an outer load on the vessel itself, resulting in a displacement of the Center of Gravity (CoG). This displacement can cause capsizing if not accompanied by an analysis of the stability of the barge crane.

At the time of the move, there was a movement in the barge crane inflicted by outside forces such as wind, wave, and current. The movement that occurs on the ship is a motion response that is depicted in the form of a 6-degree movement of freedom. Where the 6 movements include heave movements, surge, sway, pitch, roll, and yaw. From the 6 motion above, the roll motion is very difficult to predict [1]. The roll movement itself is an important phenomenon on vessels caused by marine conditions while sailing, coupled with little other coefficients can cause serious accidents on the vessel.

The purpose of this research is to predict the magnitude of the value of roll damping in a catamaran floating crane structure on free-floating conditions and also in moored conditions. The analysis is conducted by conducting experiments and numerically calculations using approaches to existing studies to determine the magnitude of the attenuation of structures in roll motion. As it is known prediction of rolling movements is very difficult compared with other modes of movement, this is because the prediction does not include a viscosity effect in it [2].

In roll damping analysis, the viscous components of the damping play an important role, as the damping component produced by the wave effect is usually smaller than the viscous damping component. Therefore theoretical calculations are difficult to predict the damping roll so that the experimental results are used using the empirical methods as a general reference [5]. From the results that have been obtained in the study studies and numerical analysis, the next will be compared to see if the approach made with numerical analysis can resemble the results of experimental studies conducted.

2. BASIC THEORY

2.1 Catamaran Ship

In the shipping world, various types of vessels have been made, including ships with more than one ship such as a catamaran that has 2 vessels, a trimaran vessel that has 3 vessels and so on [4]. Of course, these types of vessels have advantages and disadvantages. The advantages of the catamaran among others are to have a wider deck to carry the capacity of passengers, vehicles or goods in large quantities, then with the form of a different body of vessels compared to monohull vessels, the form of 2 vessels is an important role in reducing the resistance on the ship, resulting in a high speed and reduce consumption in fuel [9]. Another advantage is the form of multi-hull vessel that shows good stability, proven by the magnitude of the damping value produced when compared with mono-hull vessel [7]. Of these advantages, multi-hull vessels also have a deficiency in terms of manoeuvring on vessels that are assessed less well compared to mono-hull-type vessels.

2.2 Roll Decay Test

Free decay test is one of the test methods for determining the damping value of a structure. Free decay test itself is done with a model in the water that is only tested on movements that have a style or moment of hydromechanical such as heave movement, pitch, and roll only, but can also be done for surge, sway, and yaw movements.

In the test of decay motion roll, the test decay motion of motion roll itself is one technique to estimate the value of roll damping of a floating structure [10]. The decay test procedure is by tilting the vessel to the angle (ϕ), the power of the vessel's buoyancy will result in restoring moment to achieve the ideal condition again, this condition leads to periodic oscillation movements. This periodic oscillation motion will continue to run until the energy of the vessel movement disappears due to the attenuation effect [8]. During the test, the model was only engaged in the roll motion mode by minimizing other modes of motion and the water condition at the time of testing should be quiet [1].

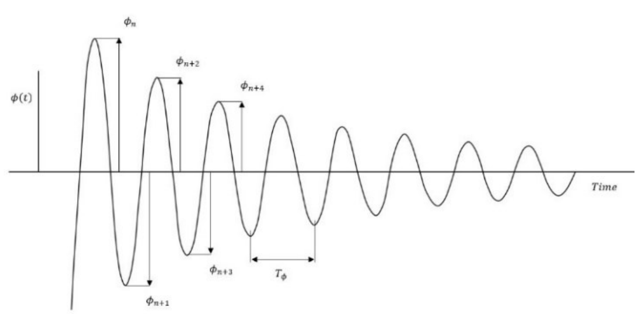

Figure 1. Result of free decay test

According to Froude [3], the process of decreasing the amplitude of the motion of the decay test is a $\Delta\phi$ (delta angle) coefficient which is the difference between the initial amplitude ($\zeta\phi_n$) to the next amplitude ($\zeta\phi_{n+1}$), where the decrease in the amplitude of the motion is defined as the mean polynomial function of ϕm [1,6].

$$\Delta\phi = a\phi m + b\phi m^2 \tag{1}$$

It is assumed that the motion of ϕ *(t)* of the results of the free decay test can be described as a motion equation, the equation of the motion is as follows:

$$(I+\Delta I)\frac{d^2\phi}{dt} + B_1\frac{d\phi}{dt} + B_2\frac{d\phi}{dt}\left|\frac{d\phi}{dt}\right| + k\phi = 0 \tag{2}$$

After the results of the experimental decay test that has been found, can be determined damping linear coefficient and damping quadratic by assuming that $\phi = \phi m \cos \omega t$, then ϕ is a function graph obtained from the resulting decay motion roll test. The equation (1) and (2) it will be obtained by the following equation. Where energy is lost on the oscillation motion decay test for each 1/2 period of roll motion is integral to the equation (2).

$$\int_0^{T/2}\left((I+\Delta I)\frac{d^2\phi}{dt} + B_1\frac{d\phi}{dt} + B_2\frac{d\phi}{dt}\left|\frac{d\phi}{dt}\right| + k_\phi\right)\frac{d\phi}{dt} \tag{3}$$

So the results are obtained as follows.

$$\int_0^{T/2}\left((I+\Delta I)\frac{d^2\phi}{dt}\right)\frac{d\phi}{dt}\,dt = 0 \tag{4}$$

$$\int_0^{T/2}\left(B_1\frac{d\phi}{dt}\right)\frac{d\phi}{dt}\,dt = B_1\frac{\pi^2\dot{\phi}^2}{T} \tag{5}$$

$$\int_0^{T/2}\left(B_2\frac{d\phi}{dt}\left|\frac{d\phi}{dt}\right|\right)\frac{d\phi}{dt}\,dt = B_2\frac{16\,\pi^2\dot{\phi}^3}{3\,T^2} \tag{6}$$

$$\int_0^{T/2}(k\phi)\frac{d\phi}{dt}\,dt = -k\dot{\phi}\,\Delta\phi \tag{7}$$

Equation 4-7 above has resulted in the equations below:

$$B_1\frac{\pi^2\dot{\phi}^2}{T} + B_2\frac{16\,\pi^2\dot{\phi}^3}{3\,T^2} - k\dot{\phi}\,\Delta\phi = 0 \tag{8}$$

$$\Delta\phi = \frac{1}{k}\left(B_1\frac{\pi^2}{T}\right)\dot{\phi} + \frac{1}{k}\left(B_2\frac{16\,\pi^2}{3\,T^2}\right)\dot{\phi}^2 \tag{9}$$

So if from equations (9) and equations (1) is known when $\dot{\phi} = \phi m$, it will be obtained the value of coefficient A and B in the decrement roll decay equation which is alluded to in the equation (1). So the values a and b can be formulated as follows:

$$a = \frac{1}{k}\left(B_1 \frac{\pi^2}{T}\right) \text{ and } b = \frac{1}{k}\left(B_2 \frac{16\,\pi^2}{3\,T^2}\right) \qquad (10)$$

3. RESULTS AND DISCUSSION

3.1 Structural Modelling

Structural modelling in this study refers to a catamaran floating crane which has been modelled earlier by BTH-BPPT. Here is the main data to use.

Table 1. Main dimensions of Floating Crane Catamaran

Principal Dimension	**Actual Scale**	**Model Scale**	**Unit**
Length Overall (LOA)	111	3.08	m
Length of Perpendicular (Lpp)	108	3.08	m
Breadth (B)	37.8	3.00	m
Depth (H)	14.4	1.05	m
Draft (T)	4.7	0.40	m

Then from the data is done modelling using a scale of 1:36 to the actual size of the structure. Then the structure will be tested in the pool facilities of Maneuvering and Ocean Engineering Basin (MOB) of BTH-BPPT with the following pond dimensions.

Table 2. Test pool data

Parameter	**Dimension**	**Unit**
Long	45	m
Width	30	m
Depth	1.5	m
Maximum Wave Period	0.5 – 3	second
Waves Direction	0° - 90°	degree

3.3 Eksperimental Results

From the results of the free decay test that has been done on the model of the catamaran floating crane structure. Obtained the test chart results decay on the motion roll to function time as the following image.

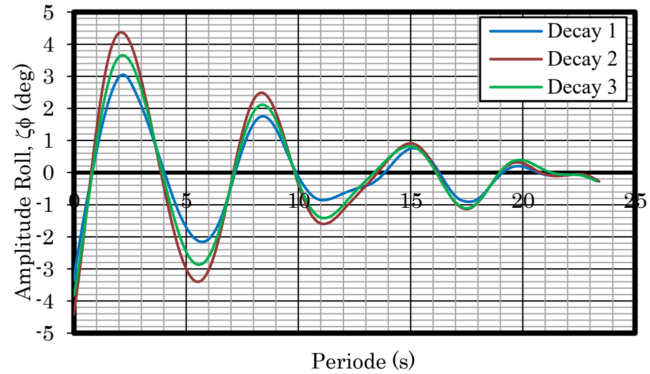

Figure 2. Decay test results on free-floating conditions

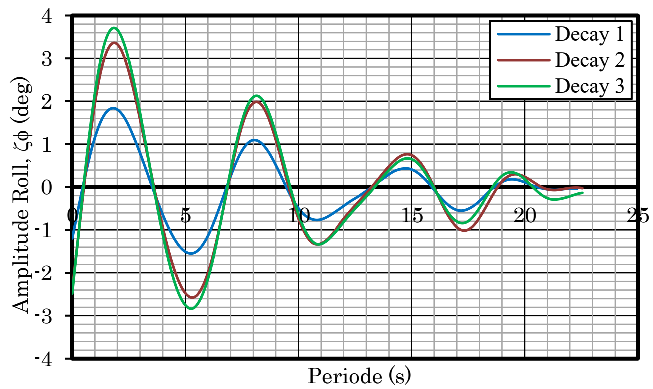

Figure 3. Decay test results on moored conditions

3.4 Numerical

Modelling of the catamaran floating crane structure is done using the help of software Maxsurf and Moses, here is the result of modelling structure of floating crane catamaran:

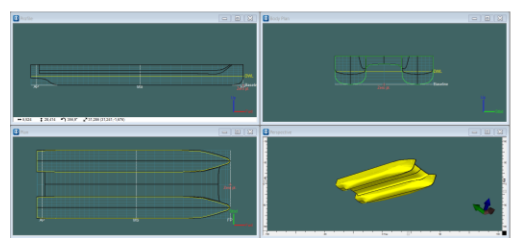

Figure 4. Maxsurf Floating Crane Catamaran models

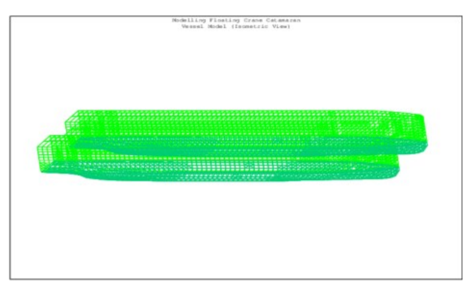

Figure 5. Moses Floating Crane Catamaran models

3.5 Numerical Results

This numerical result is a result of the decay simulation already done on Moses software using pre-made models. Then simulated test decay on the motion roll as done during the experiment process. Then the output of this simulation will be compared with the experiment results. The numerical results of the test simulation decay using the Moses software are as follows:

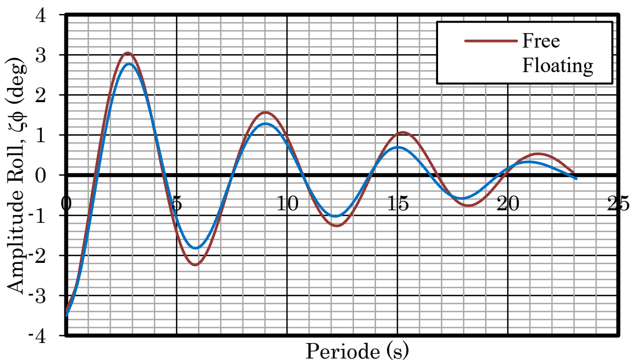

Figure 6. Decay test result on Moses software

3.6 Calculation of Natural Period

From each of the results that have been obtained, both from the results of the experiment and numerical will be done by calculation of the natural period of motion roll. The process for obtaining the natural period value of the motion roll in each decay test result is to do the average of the crests period, through the period, zero-up crossing period, and zero-down crossing period. Where these values are obtained from each test graph decay the results of the experiment and numerically. The values of the natural period of motion roll obtained from each test are as follows.

Table 3. The calculation result of the natural period roll motion experiment

Condition	Decay Test	Natural Period (s)
Free Floating	1	6.28
	2	6.24
	3	6.20
Moored	1	6.25
	2	6.27
	3	6.26

Table 4. The calculation result of natural period roll motion numerical

Condition	Decay Test	Natural Period (s)
Free Floating	1	6.15
Moored	1	6.08

3.7 Comparative experiments and numerical results

In comparison to the results of these experiments and numerists will be the result of each decay test results in each condition. From this comparison will be the comparison between the numerical results to the experiment results, whether the decay graph of the numerical approaching the outcome of the experiment. The results of the comparison of numerical results to the experiment results are as follows.

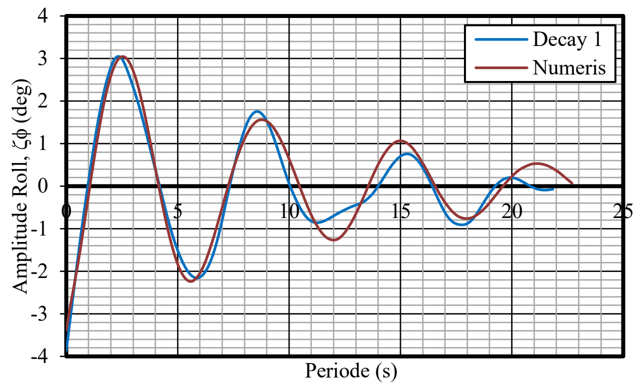

Figure 7. Comparison results Decay 1 experimental and numerical of free-floating conditions

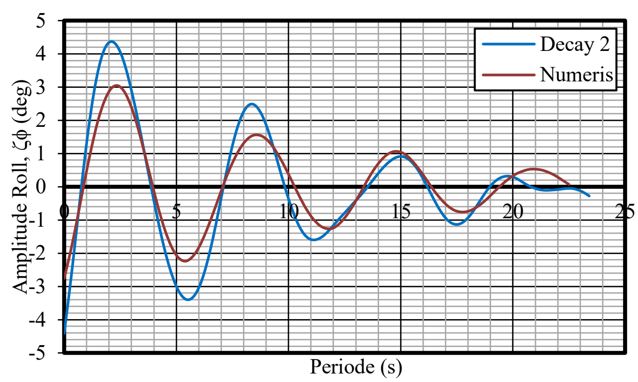

Figure 8. Comparison results Decay 2 experimental and numerical of free-floating conditions

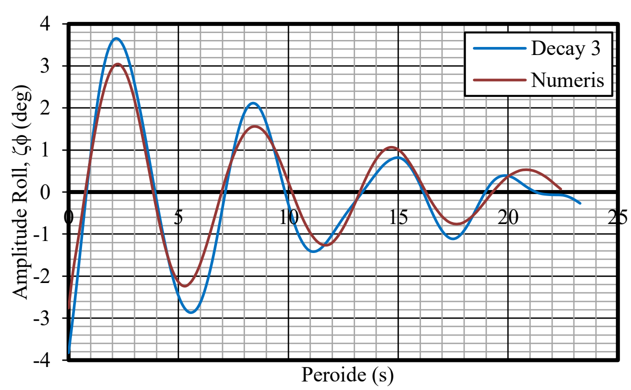

Figure 9. Comparison results Decay 3 experimental and numerical of free-floating conditions

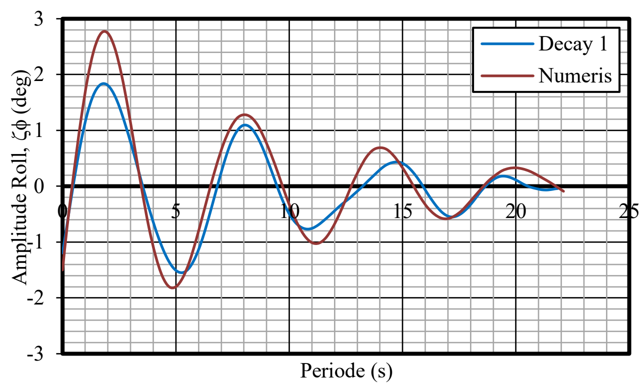

Figure 10. Comparison results Decay 1 experimental and numerical of moored conditions

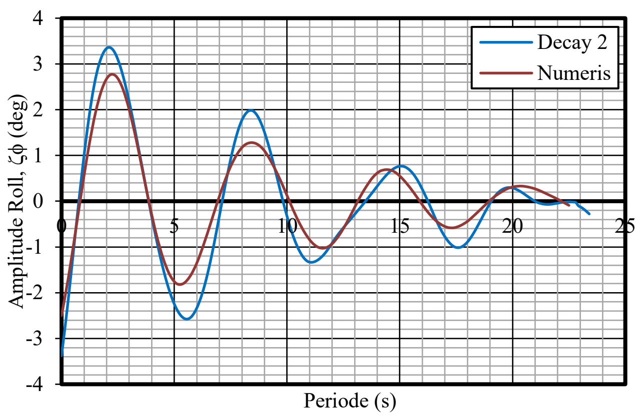

Figure 11. Comparison results Decay 2 experimental and numerical of moored conditions

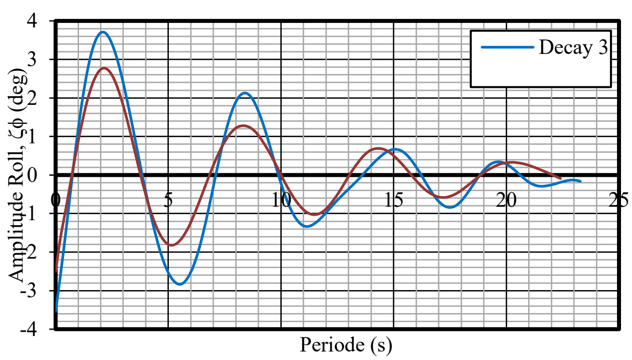

Figure 12. Comparison results Decay 3 experimental and numerical of moored conditions

From the comparison above can be seen if the numerical results close to the result of the experiment, can be seen for the condition of free-floating test results decay 1 and the numerical result is almost identical, but still there is a difference in the amplitude to the 3, where the results of the movement response pattern have begun to be muted, but for numerical results in the same Then for the moored conditions of each test comparison decay 1 compared to numerical results almost have similarities, but there is still a difference in the amplitude of the 1st peak where the numerical has a value that is still large. As for the details of the differences for each amplitude are as follows.

Table 5. Comparison of amplitude test Decay 1 experimental and numerical of free floating condition

ζϕ	Decay 1	Numerical	Difference
$\zeta\phi_0$	3.042	3.040	0%
$\zeta\phi_1$	2.158	2.240	4%
$\zeta\phi_2$	1.751	1.550	11%
$\zeta\phi_3$	0.858	1.260	47%
$\zeta\phi_4$	0.756	0.970	28%
$\zeta\phi_5$	0.908	0.760	16%

Table 6. Comparison of amplitude test Decay 2 experimental and numerical of free floating condition

ζϕ	Decay 1	Numerical	Difference
$\zeta\phi_0$	4.362	3.040	30%
$\zeta\phi_1$	3.401	2.240	34%
$\zeta\phi_2$	2.486	1.550	38%
$\zeta\phi_3$	1.599	1.260	21%
$\zeta\phi_4$	0.991	0.970	6%
$\zeta\phi_5$	1.134	0.760	33%

Table 7. Comparison of amplitude test Decay 3 experimental and numerical of free floating condition

ζϕ	Decay 1	Numerical	Difference
$\zeta\phi_0$	3.654	3.040	17%
$\zeta\phi_1$	2.866	2.240	22%
$\zeta\phi_2$	2.115	1.550	27%
$\zeta\phi_3$	1.418	1.260	11%
$\zeta\phi_4$	0.819	0.970	18%
$\zeta\phi_5$	1.114	0.760	32%

Table 8. Comparison of amplitude test Decay 1 experimental and numerical of moored condition

ζϕ	Decay 1	Numerical	Difference
$\zeta\phi_0$	1.839	2.740	49%
$\zeta\phi_1$	1.548	1.800	16%
$\zeta\phi_2$	1.096	1.280	17%
$\zeta\phi_3$	0.768	1.020	33%
$\zeta\phi_4$	0.435	0.690	59%
$\zeta\phi_5$	0.550	0.530	4%

Table 9. Comparison of amplitude test Decay 2 experimental and numerical of moored condition

ζϕ	Decay 1	Numerical	Difference
$\zeta\phi_0$	3.357	2.740	18%
$\zeta\phi_1$	2.575	1.800	30%
$\zeta\phi_2$	1.985	1.280	36%
$\zeta\phi_3$	1.335	1.020	24%
$\zeta\phi_4$	0.764	0.690	10%
$\zeta\phi_5$	1.013	0.530	48%

Tabel 10. Comparison of amplitude test Decay 3 experimental and numerical of moored condition

ζϕ	Decay 1	Numerical	Difference
$\zeta\phi_0$	3.702	2.740	26%
$\zeta\phi_1$	2.836	1.800	37%
$\zeta\phi_2$	2.128	1.280	40%
$\zeta\phi_3$	1.336	1.020	24%
$\zeta\phi_4$	0.667	0.690	3%
$\zeta\phi_5$	0.840	0.530	37%

The determination of the amplitude value above refers to the assumption of 1/2 T (period) of the test motion response decay, which has been discussed based on previous theory. The above tables are a comparison between the results of decay experiments with decay numerical simulation results.

3.8 Damping Calculation

Calculation of this damping value is done in each test result, both from experiments and from numerists. The further calculation result of damping value will be compared to see the difference in the damping value obtained from the experiments and numerical for free-floating and moored conditions. This calculation of the damping value is done by taking into consideration the damping and quadratic linear factors [1.6]. From the results of the calculation will be obtained linear coefficient of damping (a) and the quadratic damping (b). In the picture below, you will be shown the curve of extinction roll decay test result of the experiment and numerical. The Plot of the data displayed is the result of the results of the roll decay test result data with the Froude method [3], from the curve of extinction so that the values of the coefficient a and b are obtained.

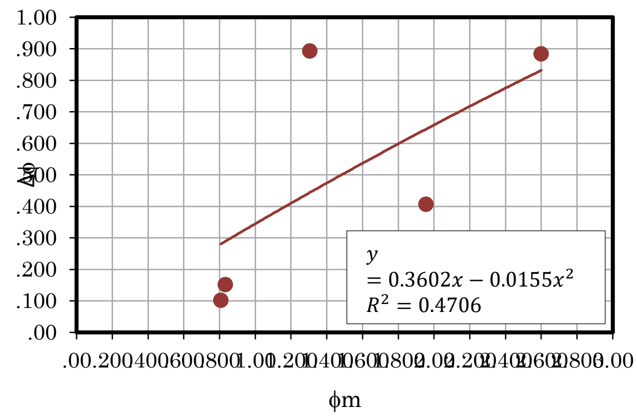

Figure 13. Fittings coefficient Roll Damping test Decay 1 Free Floating condition

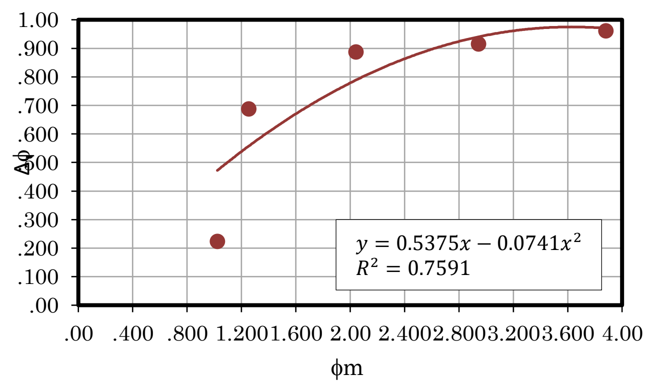

Figure 14. Fittings coefficient Roll Damping test Decay 2 Free Floating condition

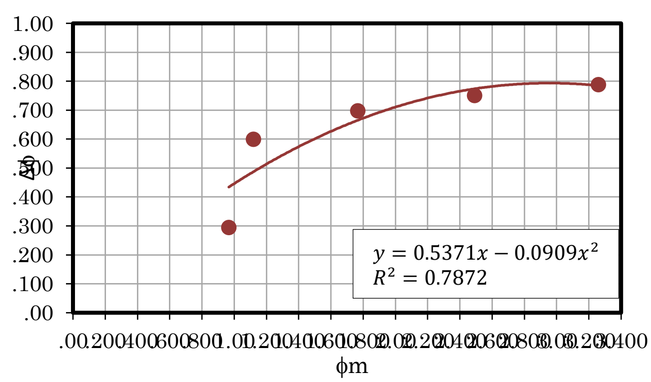

Figure 15. Fittings coefficient Roll Damping test Decay 3 Free Floating condition

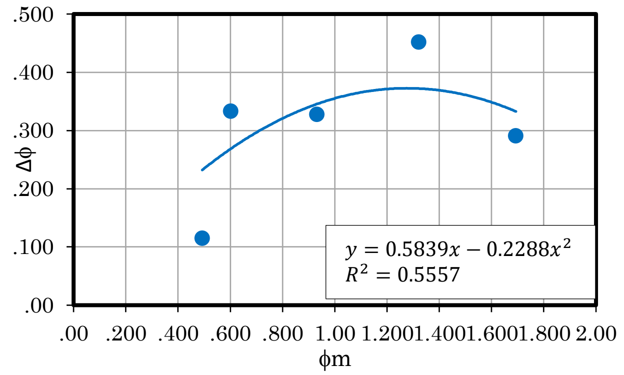

Figure 16. Fittings coefficient Roll Damping test Decay 1 Moored condition

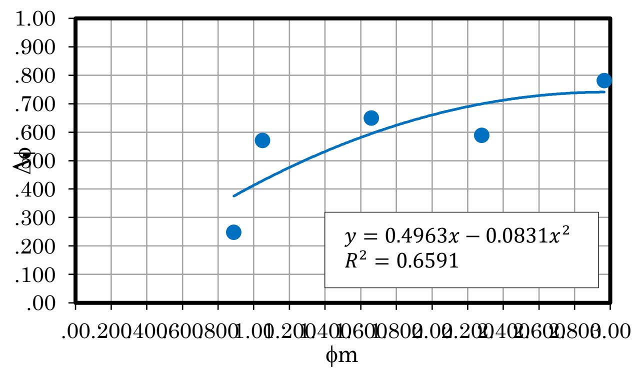

Figure 17. Fittings coefficient Roll Damping test Decay 2 Moored condition

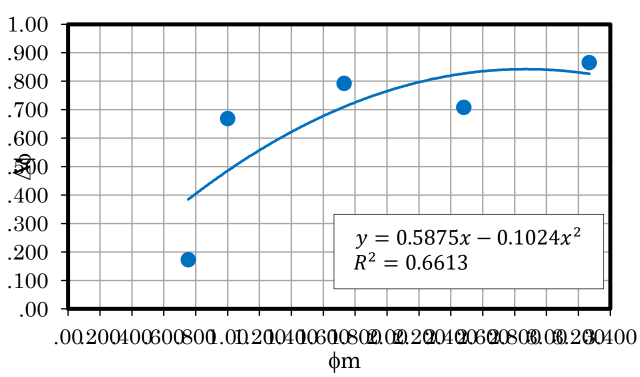

Figure 18. Fittings coefficient Roll Damping test Decay 3 Moored condition

From the plotting, results to obtain a linear coefficient of damping and limestone cubism of the experiments on free-floating and moored conditions obtained the following results.

Table 11. Value of the Linear Damping and Quadratic Damping of experiment results

Decay Test	Free Floating		Moored	
	a	b	a	b
Decay 1	0.3602	0.0155	0.5839	0.2288
Decay 2	0.5375	0.0741	0.4963	0.0831
Decay 3	0.5371	0.0909	0.5875	0.1024

After obtaining a linear coefficient of damping and a limestone damping for the results of the experiment, it is next to look for a linear damping and a quadratic value for numerical results. The results of decay numerical test data fittings are as follows.

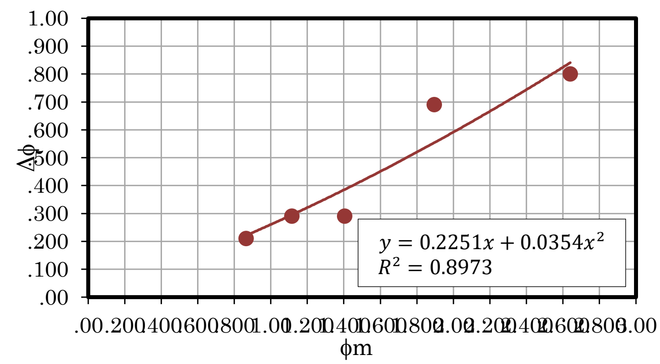

Figure 19. Fitting roll damping coefficient of decay numerical test results in free-floating conditions

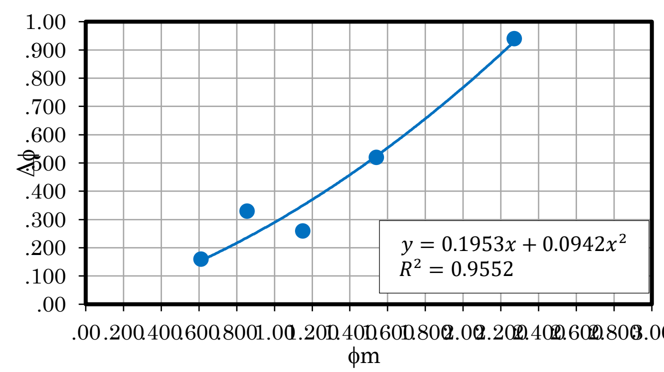

Figure 20. Fitting roll damping coefficient of decay numerical test results in moored conditions

As with the previous experimental results, the damping and quadratic damping coefficient values were obtained for the numerical decay test results. The results of the coefficient values are as follows.

Table 12. Value of the linear damping and quadratic damping of numerical results

Decay Test	Free Floating		Moored	
	a	b	a	b
Moses	0.2251	0.0354	0.1953	0.0942

From the results of linear damping and damping quadratic coefficients that have been obtained from both experimental and numerical results, later it will be used to obtain linear damping and quadratic damping values from each test result. Previously, from the fitting results for each decay test result both experimental and numerical, for the fitting results in the experimental results, there were differences in the obtained polynomial function. Where the trendline plot results show a different pattern with several journals that are used as references. As for the numerical results, the fitting results using the Froude method show the trendline plot according to the reference source. So it is necessary to review the experimental results that have been carried out both in free-floating and tethered conditions.

Then from the results of the linear damping and quadratic damping coefficients above, the results of the linear damping and quadratic damping values will be compared from each of the free-floating and tethered decay tests to the simulation results of the decay test on the Moses software. The results of the comparison of linear damping and quadratic damping values for numerical results against the results of the experiment are as follows.

Table 13. Comparison of experimental and numerical decay 1 test parameters

Parameter	Condition	Experimental	Numeric	Unit	Difference
Linear Roll Damping	*Free Floating*	7.578.E+05	4.736.E+05	kN/m/s	37.51%
	Tertambat	1.223.E+06	4.089.E+05	kN/m/s	66.55%
Kuadratik Roll Damping	*Free Floating*	3.839.E+04	8.768.E+04	$kN/m^2/s^2$	128.39 %
	Tertambat	5.613.E+05	2.311.E+05	$kN/m^2/s^2$	58.83%

Tabel 14. Comparison of experimental and numerical decay 2 test parameters

Parameter	Condition	Experimental	Numeric	Unit	Difference
Linear Roll Damping	*Free Floating*	1.124.E+06	4.736.E+05	kN/m/s	57.88%
	Tertambat	1.043.E+06	4.089.E+05	kN/m/s	60.80%
Kuadratik Roll Damping	*Free Floating*	1.814.E+05	8.768.E+04	$kN/m^2/s^2$	51.67%
	Tertambat	2.054.E+05	2.311.E+05	$kN/m^2/s^2$	12.50%

Table 15. Comparison of experimental and numerical decay 3 test parameters

Parameter	Condition	Experimental	Numeric	Unit	Difference
Linear Roll Damping	*Free Floating*	1.116.E+06	4.736.E+05	kN/m/s	57.56%
	Tertambat	1.223.E+06	4.089.E+05	kN/m/s	66.83%
Kuadratik Roll Damping	*Free Floating*	2.195.E+05	8.768.E+04	$kN/m^2/s^2$	60.06%
	Tertambat	2.523.E+05	2.311.E+05	$kN/m^2/s^2$	8.41%

From the comparison, it is found that the linear damping and quadratic damping values of the numerical results have a big difference from the linear damping and quadratic damping values of the experimental results. Where it can be seen that the resulting damping average value has a difference of more than 50%. From the comparison of the experimental decay 1 test to numerical, there is a difference of 128.39% for the damping quadratic value in the free-floating condition. Meanwhile, for the comparison of the results of the decay 2 experiment test to the numerical results obtained a difference of 60.80% for the linear damping value of tethered conditions. Then for the comparison of the results of the Decay 3 test to the numerical results, there is a difference of 66.83% in the linear damping value.

4. CONCLUSION

Based on the research above, The conclusion obtained are:

1. From the results of experimental studies conducted on the catamaran floating crane structure using the decay test with free-floating and tethered conditions. The results show that the addition of mooring systems can increase the damping value. This is evidenced by the difference in the response to the resulting motion for free-floating and tethered conditions. The difference in response to this motion can be seen from the 5th amplitude where the tethered condition looks damper than the free-floating condition. From the calculation results, the difference between the free-floating conditions and the tethered condition for the linear damping value of the decay 1 test results is 38%, then for the decay 2 test it is 8%, and the decay 3 test is 9%, then for the damping quadratic value of the decay test results 1 shows a difference of 93%, for the second decay test is 12%, and the 3rd decay test is 13%.

2. The comparison between the experimental results and the numerical results of the Moses software shows that there is a significant difference in each amplitude of the resulting roll motion so that it affects the results of the comparisons made. Then from the comparison of the analysis of the damping value of the experimental and numerical results for the decay 1 test against the numerical, it was found that a large difference in the damping quadratic value for the free-floating condition was 128.39%. Then for the comparison of the decay 2 test to the numerical results, the biggest difference occurred in the linear damping value for the tethered condition, which was 60.80%. Meanwhile, for the comparison of the decay 3 test to the numerical results, the biggest difference is the linear damping value of the tethered condition of 66.83%.

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