International Journal of Marine Engineering Innovation and Research, Vol. 8(2), Jun. 2023. 179-190
(pISSN: 2541-5972, eISSN: 2548-1479)

Motions Analysis Investigation of a 12 Meter Catamaran Tourism Boat on Passenger Comfort Criteria Case Study "MV Garuda Ngelayang"

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(Received: 11 April 2023 / Revised: 14 April 2023 /Accepted: 04 May 2023)

***Abstract* - Bangsring Beach holds a prominent place among the top tourist attractions in Banyuwangi Regency. Bangsring Beach which focuses on underwater tourism (Bangsring Underwater) is a coral reef-based tourism that can only be accessed by diving and snorkeling. But only in that way to enjoy Bangsring Underwater tourism, the construction of a 12 m catamaran with a bottom glass is carried out so that tourists who cannot dive and snorkel can enjoy the beauty of Bangsring Underwater. To ensure the comfort and safety of passengers, a simulation analysis of the movement of the existing 12-merter catamaran is carried out. This simulation was carried out with the general design of a catamaran modeled 1:1 with a LOA of 12 m, B 5.6 m, H 1.85 m, and Vs 10 knots. On the 1:1 ship, an exsisting process is carried out at each ship station to get a line plan for the Garufa Ngelayang ship then 3D modeling is carried out based on the reference from the line plan drawing. Ship motion simulations are carried out to determine the ship's response when hit by waves from various directions which are presented in the RAO (Response Amplitude Operator) graph using the CFD method which is based on a 3D model. Simulations were carried out with a wave height of 1.25 m in Bangsring waters with a fully loaded ship with a wave direction of 0^o following sea; Stern Quarter 45^o, 315^o; Beam Sea 90^o, 315^o; Bow Quarter 135^o, 225^o; and Head Sea 180^o. With a comfortable ship condition with 2.052 s of ship shaky period.**

Keywords: Tourism Boat, CFD, Ship Motion, Wave Direction, Response Amplitude Operator.

I. INTRODUCTION

Bangsring Underwater (Bunder) is a tourism destination based on coral reef protection located in Bangsring Village, Wongsorejo District, Banyuwangi Regency. The beauty of Bangsring Underwater lies not in its beaches, but in the perfectly preserved Underwater Park. Tourists can see many types of fish, tourists can snorkel and dive [1].

Bangsring Underwater tourism has problems with the infrastructure supporting tourism activities [2]. Bangsring underwater attracting visitors with its breathtaking ocean view, cultural landmarks, and opportunities for snorkeling and diving. The snorkeling and diving method is quite inconvenient and tiring to enjoy the beauty of it, especially for tourists who want to enjoy it in an easier way. In addition, a permit from the competent authority is required for snorkelling and diving. So, this problem reduces the interest of tourists to reduce the interest of tourists to visit this place.

In Ahmad Hidayat's research [3] which focuses on overcoming the above problems by making a bottom glass catamaran ship design concept with a flat plate concept, which aims for tourists to enjoy the beauty of Bangsring Underwater from the boat without having to snorkel and dive.

II. METHOD

The research employs problem-solving techniques such as redrawing and simulation methods to address the research questions effectively. Redrawing involves visualizing the problem or data in a new way to gain a fresh perspective, while simulation creates a model of the problem or system to observe its behavior under different conditions. These methods can be valuable tools for gaining insights and developing solutions in various fields, ranging from engineering to social sciences.

2.1 Redrawing

The redrawing method is a method used to obtain ship designs from existing ships. This method is carried out by re-measurement of the hull, making a line plan design from the measurement results and 3D modeling which is used for software simulation analysis.

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Figure 1. Garuda Ngelayang Tourism Ship

2.1.1 Garuda Ngelayang Tourism Ship

The Garuda Ngelayang tourism ship is a tourism ship designed in Bangsring waters, at Bangsring under water tourist sites. The Garuda Ngelayang ship is designed with a bottom glass hull so that tourists can enjoy the beauty of coral reefs and various species of fish from the ship. The Garuda Ngelayang ship is designed with a speed of 10 knots, an overall length of 12 m, a width of 5.6 m, a draft of 0.7 m, a deck height of 1.85 m.

2.1.2 Hull Measurement

Hull measurements are carried out using the existing method using a laser distance meter (LDM), where the ship is positioned in a balanced position where the left and right hull levels must be the same. To measure the hull of the ship, a vertical line is drawn at each station on the hull, and 7 points are aimed at each station using LDM (Laser Distance Measurement) tool. The LDM tool measures the distance from the tool to the shot point on the ship's hull and the angle of fire at each point, which are then used to obtain accurate hull measurements.

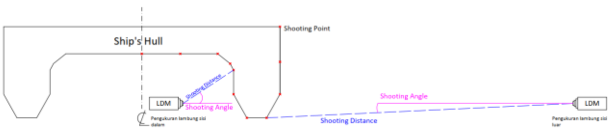

Figure 2. The Schematic of the Gliding Garuda Ship's Hull Shooting Method

2.1.3 Lines Plan

The results of measurements using a laser distance meter (LDM) are in the form of coordinates at each point of the 7 shot points which are connected using a line to form a ship's body plan at each ship station. From the Body Plan image projected up and sideways to a ship line plan drawing.

2.1.4 3D Model

Line plan drawings serve as the foundation for generating 3D models using modeler software, where the size and dimensions depicted in the drawings are used as a reference to create a precise and detailed representation of the object or structure in a digital format.

2.2 Ship Motion

In essence, a ship that is above sea level is subjected to external forces that cause it to move, as depicted in the accompanying image. The primary factor contributing to this movement is the presence of waves and other environmental factors that affect the ship's stability and balance. (Ship Six Degree of Freedom) [4].

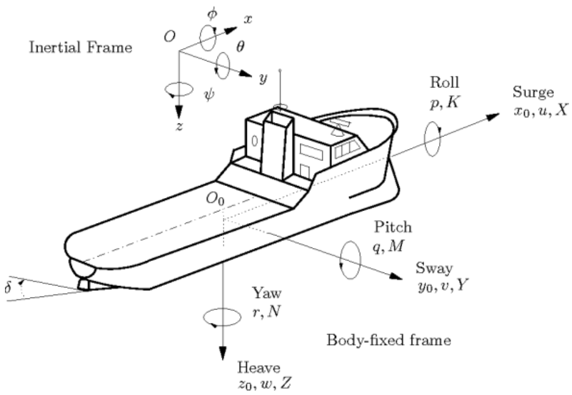

Figure 3. Ship Degrees of Freedom

Six Degrees of Freedom refers to the ability of an object or system to move freely in three-dimensional space along three translational axes (X, Y, Z) and three rotational axes (roll, pitch, yaw). The term is commonly

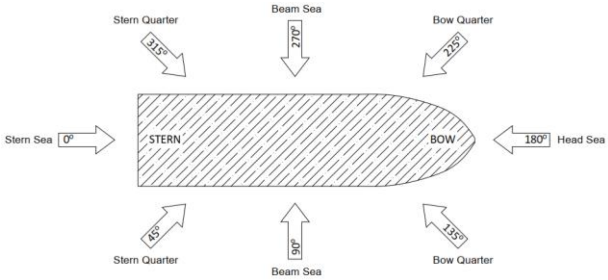

Figure 4. Wave Direction

used in engineering, robotics, and physics to describe the full range of motion that a system can achieve. The translational degrees of freedom describe movement in a straight line along each axis, while the rotational degrees of freedom refer to the ability of the system to rotate around each axis. Understanding the six degrees of freedom is important in designing and analyzing complex systems, such as spacecraft, robots, and other mechanical devices. (Figure 3)

As a result of these external forces the ship has a movement called six degrees of freedom. The six freedom movements are surging movement, which is the back and forth movement of the ship in the direction of the x axis (bow and stern direction), swaying movement is the movement of the ship to the side (port and start board direction / on the y axis direction), heaving movement is an up and down movement. ship (up and down on the z-axis), rolling/heeling movement is the rotational movement of the ship with the x-axis as the axis of rotation, the surging motion is the nodding motion of the ship/ship rotation with the y-axis as the rotational axis, and yawing motion is the rotational movement of the ship, with the z-axis as a spice twist. The motion of the ship in six degrees of freedom describes the type of ship balance, where the heaving, surging sway, and yaw movements are stable/indifference balances, while the roll and pitch movements are unstable, indeterminate balances [5].

2.2.1 Wave Direction

In Figure 4, the direction of the waves is classified into five different directions in relation to the ship. These directions include head sea, which approaches the ship at an angle of 180 degrees; bow quarter waves that approach the ship at angles of 135 degrees and 225 degrees; beam sea waves that approach at angles of 90 degrees and 270 degrees; stern quarter waves that approach the ship at angles of 45 degrees and 315 degrees, and stern sea waves that approach the ship at an angle of 0 degrees. This information can be useful in understanding the effect of waves on the ship's stability and motion, particularly in terms of how the waves impact the ship's bow, stern, and sides. [4].

2.2.2 Response Amplitude Operator (RAO)

The assessment of ship motion is conducted solely on oscillatory movement, out of the six possible types. The three types of motion that can be considered pure oscillatory are heave, pitch, and roll, as they bring the ship back to its original position if it is not in equilibrium. Such movements occur under the influence of either a force or a returning moment. Conversely, the remaining three ship motions - surging, swaying, and yawing - do not return the ship to its initial position when it is out of balance, unless there is a counteracting force or moment that causes it to operate in the opposite direction. This differentiation is significant when examining the impact of these movements on a ship's stability and motion. [6].

In most cases, predictions of motion for floating buildings are expressed by comparing the amplitude of the incoming wave with the amplitude of a specific type of motion, typically as a function of changes in wave frequency. This comparison is typically presented in the form of a Response Amplitude Operator (RAO), which illustrates the relationship between the amplitude of the input wave and the motion of the floating building in a particular direction. [7].

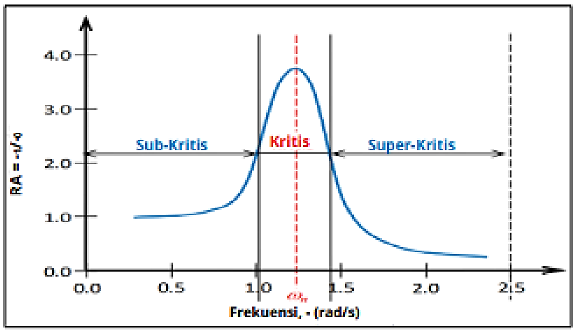

Figure 5. General Form of RAO Graph

TABLE 1.
SHOOTING POINT DISTANCE AND ANGLE

STATION	**SHOOTING POINT ($\frac{L}{\theta}$)**													
	P1		**P2**		**P3**		**P4**		**P5**		**P6**		**P7**	
	in	**out**	**in**	**out**	**in**	**out**	**in**	**out**	**in**	**out**	**in**	**out**	**in**	**out**
AP	1,927 177°	2,924 2°	1,930 175°	-	2,012 163°	-	2,108 156°	-	1,996 150°	-	1,835 143°	-	1,705 136°	3,402 31°
1	1,875 177°	2,865 2°	1,811 176°	2,801 3°	1,779 168°	2,757 8°	1,846 160°	2,818 14°	1,942 154°	2,929 21°	1,888 148°	3,056 27°	1,705 136°	3,240 33°
2	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
3	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
4	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
5	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
6	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
7	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
8	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
9	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
10	1,811 177°	2,802 2°	1,678 175°	2,668 3°	1,582 166°	2,557 8°	1,657 158°	2,624 15°	1,763 151°	2,742 23°	1,772 146°	2,887 29°	1,705 136°	3,072 35°
11	1,801 3°	2,811 178°	1,688 5°	2,678 177°	1,573 14°	2,566 172°	1,648 22°	2,634 165°	1,755 29°	2,751 157°	1,764 34°	2,882 152°	1,698 45°	3,080 146°
12	1,801 3°	2,811 178°	1,688 5°	2,678 177°	1,573 14°	2,566 172°	1,648 22°	2,634 165°	1,755 29°	2,751 157°	1,764 34°	2,882 152°	1,698 45°	3,080 146°
13	1,801 3°	2,811 178°	1,688 5°	2,678 177°	1,573 14°	2,566 172°	1,648 22°	2,634 165°	1,755 29°	2,751 157°	1,764 34°	2,882 152°	1,698 45°	3,080 146°
14	1,801 3°	2,811 178°	1,688 5°	2,678 177°	1,573 14°	2,566 172°	1,648 22°	2,634 165°	1,755 29°	2,751 157°	1,764 34°	2,882 152°	1,698 45°	3,080 146°
15	1,801 3°	2,811 178°	1,688 5°	2,678 177°	1,573 14°	2,566 172°	1,648 22°	2,634 165°	1,755 29°	2,751 157°	1,764 34°	2,882 152°	1,698 45°	3,080 146°
16	1,801 3°	2,811 178°	1,688 5°	2,678 177°	1,573 14°	2,566 172°	1,648 22°	2,634 165°	1,755 29°	2,751 157°	1,764 34°	2,882 152°	1,698 45°	3,080 146°
17	1,801 3°	2,811 178°	1,688 5°	2,678 177°	1,573 14°	2,566 172°	1,648 22°	2,634 165°	1,755 29°	2,751 157°	1,764 34°	2,882 152°	1,698 45°	3,080 146°
18	1,903 3°	2,893 178°	1,724 4°	2,714 177°	1,582 14°	2,557 172°	1,657 22°	2,596 167°	1,763 29°	2,713 159°	1,772 34°	2,881 151°	1,705 44°	3,072 145°
19	2,002 3°	2,936 178°	1,858 4°	2,848 177°	1,748 12°	2,725 172°	1,770 19°	2,741 165°	1,823 26°	2,797 158°	1,885 32°	2,942 149°	1,977 37°	3,072 145°
FP	2,094 16°	3,058 169°	2,112 19°	3,073 165°	2,130 22°	3,101 162°	2,155 24°	3,140 158°	2,187 27°	3,190 155°	2,215 29°	3,255 152°	-	3,323 148°

The picture above, it is explained that the image provided illustrates that the response curve for the movement of a floating building can be categorized into three sections: sub-critical, critical, and super-critical. The sub-critical region corresponds to low-frequency waves or waves with long periods. In this region, the motion of marine structures will follow the contours of the long wave elevation pattern, resulting in movement amplitudes that are roughly equal to the wave amplitude. This phenomenon is known as contouring. In hydrodynamic correlation equations, the motion in the sub-critical region is dominated by the stiffness factor.[8].

The critical region, which spans from the mid-arm of the curve on the low-frequency side to the peak of the curve and extends to the mid-arm on the high-frequency side, constitutes the second region. The peak of the curve, which corresponds to the natural frequency of the floating structure, is referred to as the resonance region. In this region, the response amplitude of the motion is amplified, and the amplitude of the motion can be several times larger than the amplitude of the wave. Hydrodynamically, in the natural frequency region, the motion is primarily controlled by the damping factor.

The third region, known as the super-critical region, pertains to the high-frequency or short (period) waves. In this region, the response of the floating structure to the wave motion is reduced. As the frequency of the waves increases or the crests of successive waves become closer, the movement of the marine structure over relatively flat water becomes more apparent. This phenomenon is known as platforming.

Hydrodynamically, in the high-frequency region, the motion is mainly influenced by the mass factor.

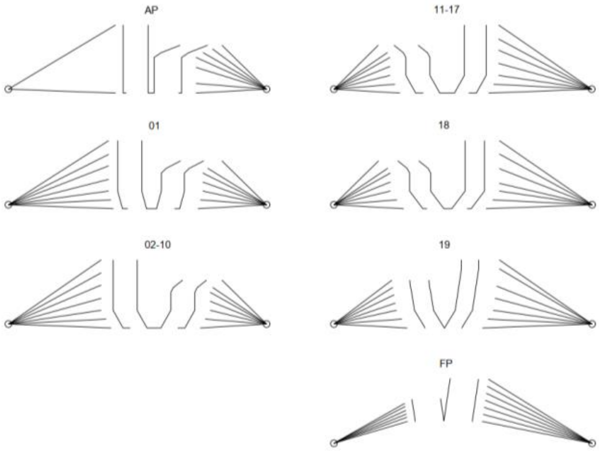

Figure 6 Hull Shape of Each Station Shot

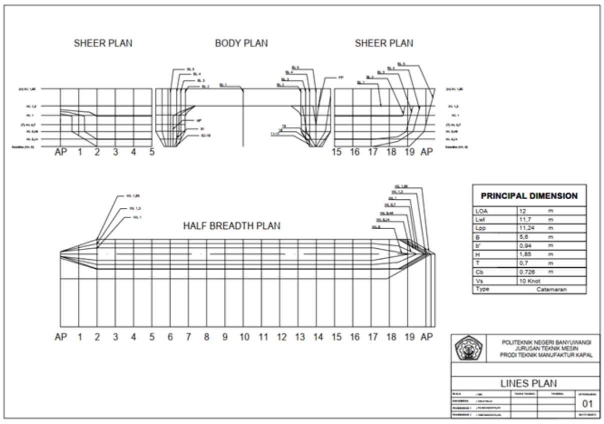

Figure 7. Lines Plan of Garuda Ngelayang

III. Results and Discussion

3.1 Hull Mesurement

Measurement of the hull is carried out by aiming using LDM carried out at each hull station. And from the results of the shooting, the body plan form of each ship station is formed, which is shown in Figure 6 below.

3.1.1 Lines Plan

From the results of shots at each station, a body plan is obtained at each ship station which is combined into one body plan image. The body plan is then projected to make half breadth plan and ship sheer plan until the ship line plan is complete. The line plan generated from the Garuda Ngelayang ship is shown in Figure 7 below.

3.1.2 3D Model

3D modeling is made based on ship outline plans. The 3D model is made with modeler software which is created according to the line plan offset table. This 3D model is used as an object for analysis of ship motion. The 3D model of the ship obtained is shown in Figure 9 below.

3.2 RAO Numerical Simulation

Strip theory is a widely used method for performing numerical calculations of hydrodynamic factors such as added mass, damping, stiffness, excitation force, and wave diffraction. This method involves solving hydrodynamic problems for each 2D section of the underwater frame of the elongated floating building and then integrating the results longitudinally. [8]. The current simulation employs a numerical approach of strip theory that utilizes the conformal mapping-based Lewin method to compute the hydrodynamic properties of every cross-sectional area of the hull. [9]. The following table shows the numerical parameters used in the simulation, which include load line, frequency limit, ship speed, wave direction, and wave characteristics.

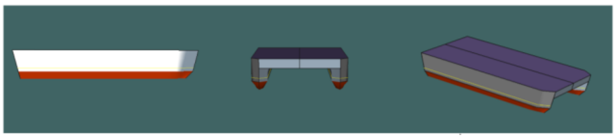

Figure 8. 3D Model Ship of Garuda Ngelayang

TABLE 2.
PARAMETERS USED IN NUMERICAL SIMULATION

Parameters	**Value**	**Parameters**	**Value**
Load Line		Wave Characteristic	
Full Load	0,7m	Type	Johnswap
Frequency Limit	21 frequencies	Char. Height	1,25m
Vessel Sped	10 knot	Modal Period	4,597s
Wave Direction		Average Period	3,80s
Following Sea	0º		
Stern Quarter	45º, 315º		
Beam Sea	90º, 270º		
Bow Quarter	135º, 225º		
Head Sea	180º		

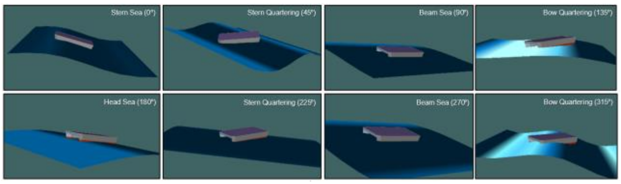

Figure 9. Display of Wave Simulation Results Using Numerical Methods

The numerical simulation results include RAO graphs and boat motion displays, which are shown in the figures 10 - 17.

3.3 CFD (Computational Fluid Dynamic) RAO Simulation

The CFD method is a computational method used to determine the characteristics of fluid dynamics. The application of this method involves several stages, starting from design, modeling, application of conditions, and simulation based on the chosen model and conditions. The parameters utilized in the simulation include load line, frequency range, ship speed, wave direction, and wave characteristics.

TABLE 3.
PARAMETERS USED IN CFD SIMULATION

Parameters	**Value**	**Parameters**	**Value**
Load Line		Wave Direction	
Full Load	0,7m		
Frequenc Range		All Direction	180º, 135º, 90º, 0º, -45º, -135º, -90º, -180º
Lowest	0,1rad/s	Wave Characteristic	
Highest	4,686rad/s	Height	1,25m
Vessel Speed	5,1444m/s	Period	3,80s

The ship motion display and RAO graphic data are obtained from the simulation using the parameters specified in Table 4. The obtained data is presented in the figures 18-25.

3.4 Ship Motion Simulation Result

The results of this simulation are carried out by calculating the average value of the ship's maneuverability in the same frequency range between the two simulation methods. To facilitate the reading of the graph of the simulation results, the results are presented in the tabulation in table 4.

3.5 Ship Stability Analysis

This stability analysis was carried out under two conditions, namely the full load condition (100%) with 3 crew members and 10 passengers, the second condition, namely the 60% condition with 3 crew members and 4 passengers. The two conditions are divided into each loadcase, loadcase 1 with 100% and loadcase 2 with 60%. The results of the stability simulation are presented in the following table 5.

3.6 Passenger Comfort Aspect Analysis

The passenger comfort aspect is based on the ship's shaky period. In the analysis of the shaky period, what is needed is the GM value of several ship conditions. In the 100% condition the GM value is 9.072 m, in the 60% condition the GM value is 14,531 m.

Shaking Period Formula

$$T = \frac{2\,C\,B}{\sqrt{GM}}$$

Loadcase Condition 1 (100%)

$$T = \frac{2\,x\,0{,}55\,x\,5{,}6}{\sqrt{9{,}072}}$$

$$T = 2{,}052\ s$$

Loadcase Condition 2 (60%)

$$T = \frac{2\,x\,0{,}55\,x\,5{,}6}{\sqrt{14{,}531}}$$

$$T = 1{,}621\ s$$

TABLE 4.
TABULATION OF SHIP MOTION

Ship Motion	**Wave Directoin**	**Method**	
		Numerik	**CFD**
Heave	0º	0,560	0,558
	45º	0,601	0,584
	90º	0,769	0,730
	135º	0,533	0,552
	180º	1,045	1,010
Surge	0º	0	0,045
	45º	0	0,116
	90º	0	0,028
	135º	0	0,003
	180º	0	0,008
Sway	0º	0	0,0074
	45º	0	0,0843
	90º	0	0,2795
	135º	0	0,00618
	180º	0	0,00019
Pitch	0º	0,093	0,109
	45º	0,0473	0,0405
	90º	0,29834	0,291395
	135º	0,02512	0,038515
	180º	0,00679	0,00402
Yaw	0º	0	0,000416
	45º	0	0,011116
	90º	0	0,01908
	135º	0	0,00739
	180º	0	0,000057
Roll	0º	0	0,0000564
	45º	0,043338	0,043338
	90º	0,12975625	0,1404575
	135º	0,008394	0,006542
	180º	0	0,00062

TABLE 5.
RESULT OF STABILITY ANALYSIS

Code	Criteria	Value	Unit	Actual	Status
HSC multi. Intact	1.1: Area from 0 to 30	3,2498	m.deg	40,9399	Pass
HSC multi. Intact	1.2: Angle of maximum GZ	10,0	deg	29,1	Pass
HSC multi. Intact	1.5: HTL: Area between GZ and HA				Pass
	Hpc + Hw	1,6043	m.deg	8,7883	Pass
	Ht + Hw	1,6043	m.deg	12,8743	Pass
HSC multi. Intact	3.2.1: HLI: Angle of equilibrium				Pass
	Wind heeling (Hw)	16,0	deg	1,5	Pass
HSC multi. Damage	2.1.1: HL4: Area between GZ and HA				Pass
	Hpc + Hw	1,6043	m.deg	10,6186	
HSC multi. Damage	3.2.2: HL3: Angle of equilibrium				Pass
	Wind heeling (Hw)	20,0	deg	0,4	Pass
HSC multi. Intact	1.1: Area from 0 to 30	3,5860	m.deg	32,4563	Pass
HSC multi. Intact	1.2: Angle of maximum GZ	10,0	deg	26,4	Pass
HSC multi. Intact	1.5: HTL: Area between GZ and HA				Pass
	Hpc + Hw	1,6043	m.deg	6,0827	Pass
	Ht + Hw	1,6043	m.deg	11,4059	Pass
HSC multi. Intact	3.2.1: HLI: Angle of equilibrium				Pass
	Wind heeling (Hw)	16,0	deg	2,0	Pass
HSC multi. Damage	2.1.1: HL4: Area between GZ and HA				Pass
	Hpc + Hw	1,6043	m.deg	8,4376	
HSC multi. Damage	3.2.2: HL3: Angle of equilibrium				Pass
	Wind heeling (Hw)	20,0	deg	0,6	Pass

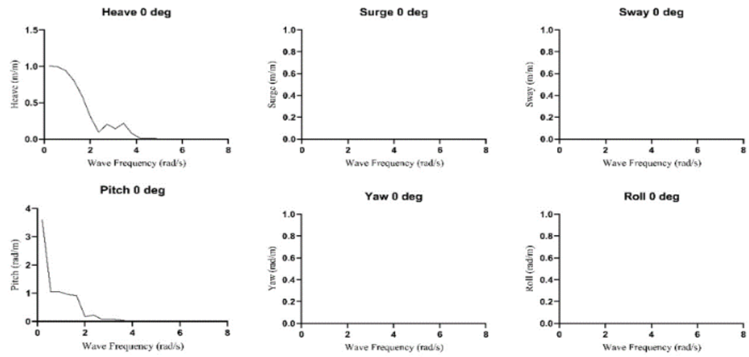

Figure 10. Result of RAO at 0° of wave direction

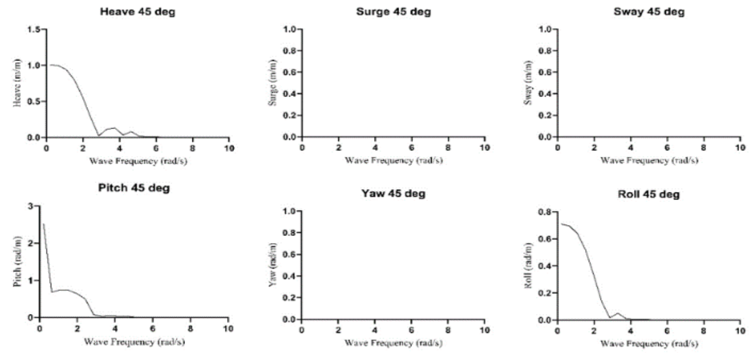

Figure 11. Result of RAO at 45° of wave direction

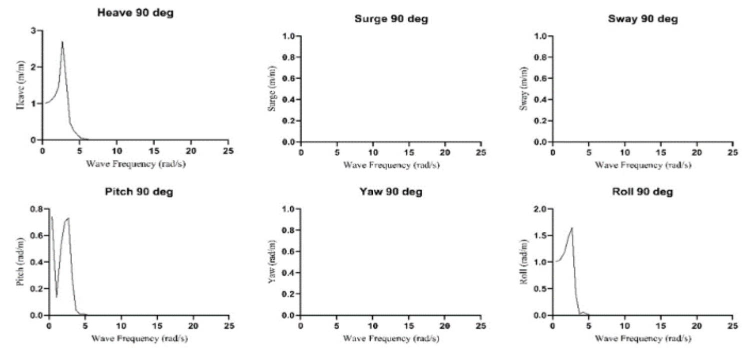

Figure 12. Result of RAO at 90° of wave direction

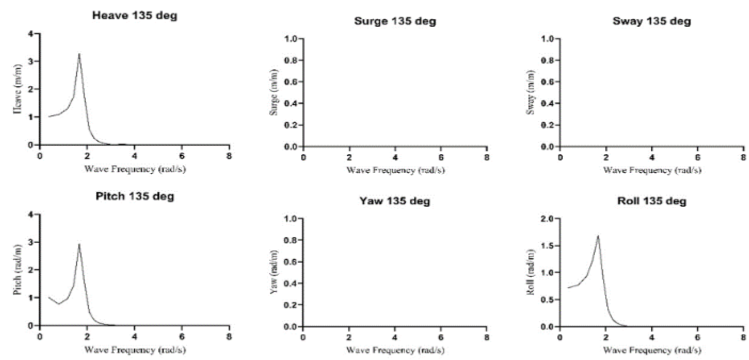

Figure 13. Result of RAO at 135° of wave direction

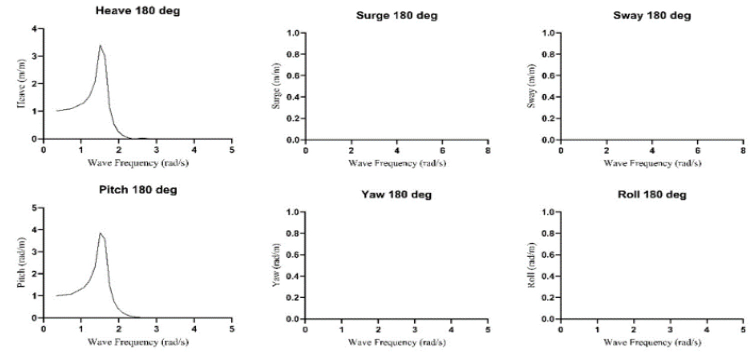

Figure 14. Result of RAO at 180° of wave direction

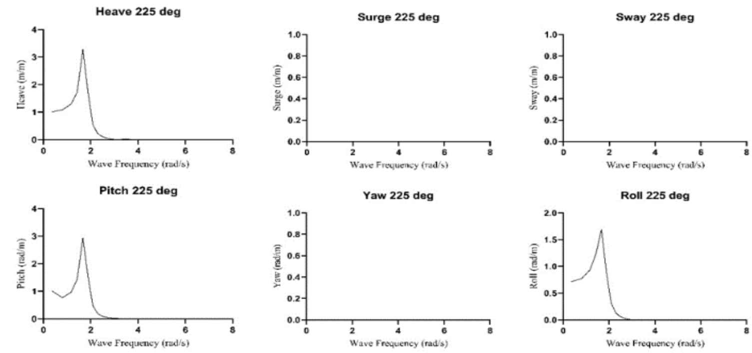

Figure 15. Result of RAO at 225° of wave direction

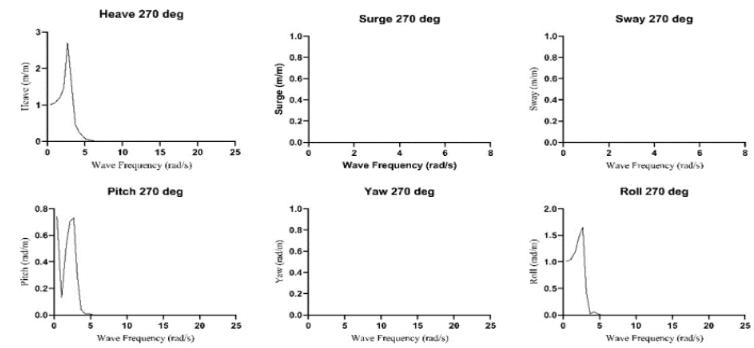

Figure 16. Result of RAO at 270° of wave direction

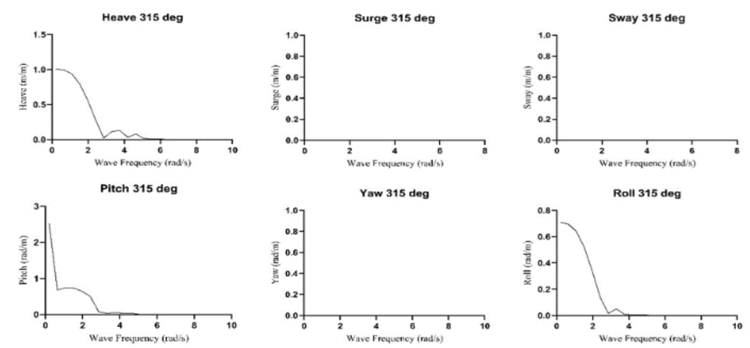

Figure 17. Result of RAO at 315° of wave direction

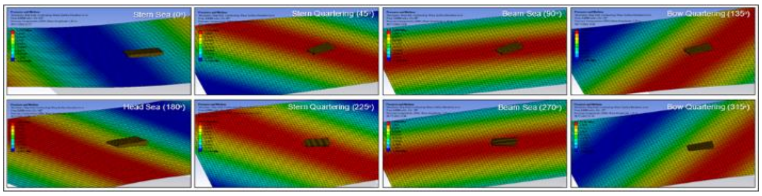

Figure 18. Display of wave simulation results using the CFD method

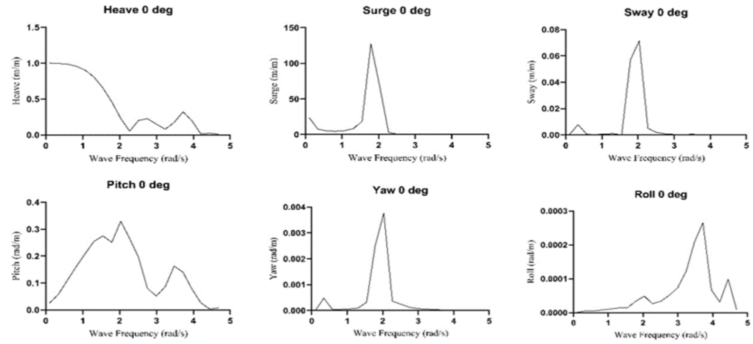

Figure 19. Result of RAO at 0° of wave direction (CFD result)

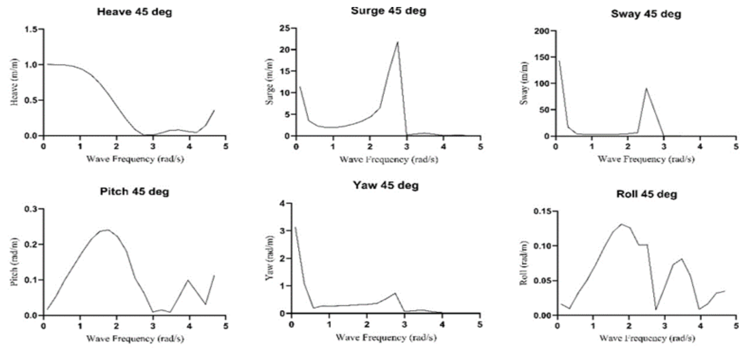

Figure 20. Result of RAO at 45° of wave direction (CFD result)

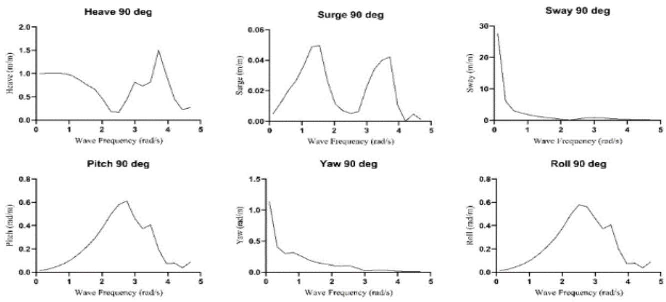

Figure 21. Result of RAO at 90° of wave direction (CFD result)

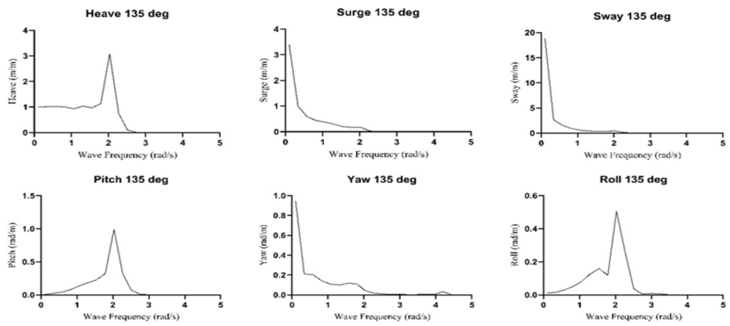

Figure 22. Result of RAO at 135º of wave direction (CFD result)

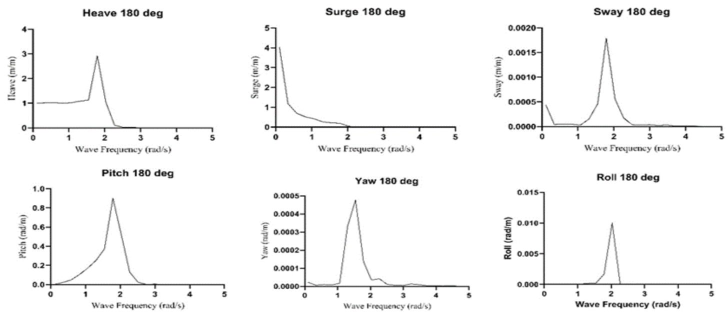

Figure 23. Result of RAO at 180º of wave direction (CFD result)

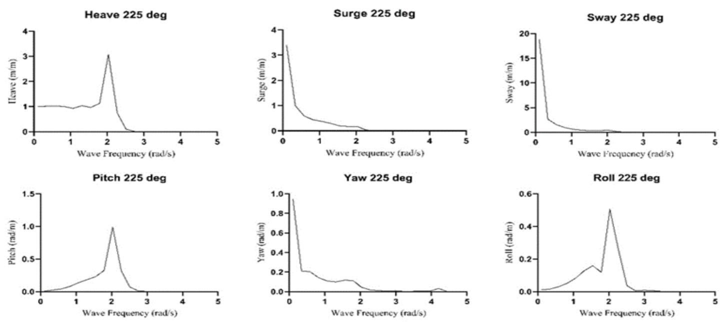

Figure 24. Result of RAO at 225º of wave direction (CFD result)

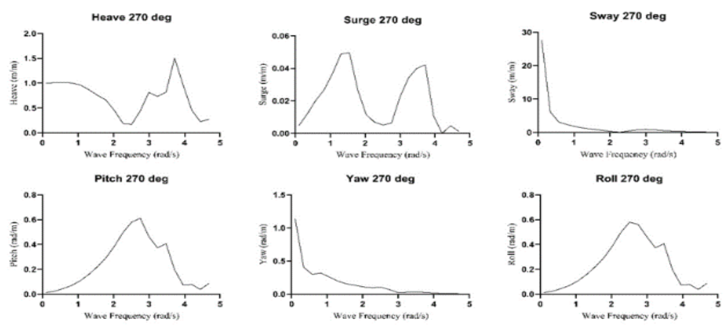

Figure 25. Result of RAO at 270º of wave direction (CFD result)

IV. Conclusion

Based on the simulation and analysis results presented above, this study concludes that.

- Based on the simulation results, the GZ value in both conditions meets the criteria of IMO A.749 (18) chapter 3 "Design criteria applicable to all ships" with the GZ value not exceeding 30º but not below 25º[10].
- The 12 m Garuda Ngelayang catamaran tourism boat has good comfort in full load/loadcase 1 because the ship has a wobbling period of 2.052 s which means that from the maximum inclination of the ship to a stable condition it only takes 2.052 s. This condition is said to be comfortable because the time required is not too fast to make passengers dizzy with the fast rocking of the ship.
- The 12 m Garuda Ngelayang catamaran tourism boat has sufficient comfort in conditions of 60% or loadcase 2 because the ship has a relatively faster sway period of 1.621 s than in condition 1.

V. Acknowledgement

We express our heartfelt gratitude to Kedaireka for their Matching Fund Program 2022, which played a significant role in facilitating this research and its subsequent implementation.

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