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Sea-keeping analysis of hospital catamarans for handling COVID-19 patients on remote islands with a numerical approach

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ABSTRACT

This study used a catamaran hospital ship to handle the COVID-19 pandemic in Indonesia, particularly in remote islands where the virus has spread. This study aims to examine the design of hospital catamarans with good stability and sea-keeping using a numerical method with the help of CFD. The study was carried out by simulating the hull design of a catamaran using the diffraction panel method under three moving conditions, namely steady state condition, running at service speed (8 knots), and running at speed faster than service speed (11 knots), and analyzing it numerically using CFD and comparing the results with the standards set by IMO and previous research. Based on the study results, the design of the catamaran hospital ship for COVID-19 has good stability and seaworthy characteristics and follows existing standards.

1. Introduction

The outbreak of the novel coronavirus disease in 2019 (COVID-19) caused a significant public health crisis worldwide. It challenged health care systems, especially now that Indonesia is one of the hotspots for spreading covid-19 almost evenly throughout the region. In December 2019, the capital of China's Hubei province, the city of Wuhan, witnessed an outbreak of "pneumonia from an unknown source" attributed to its newly identified culprit: The new coronavirus (Purcell and Charles, 2020).

As of now, the majority of severe outcomes have been documented in low- and middle-income countries (LMIC) (Dong et al., 2020), where factors such as age distribution, medical comorbidities, and access to quality care can significantly influence trends. The use of hospital ships that can reach coastal areas and islands that do not have complete hospital facilities can be a solution to this problem, considering that Indonesia is an archipelagic country. Until now, Indonesia only has two hospital ships, namely K.R.I. dr. Soeharso belongs to the Navy, and the Floating Hospital Ship "Ksatria Airlangga" belongs to Universitas Airlangga. K.R.I. dr. Soeharso (990) (previously named K.R.I. Tanjung Dalpele (972)) is a Hospital Assistance (B.R.S.) type ship. This ship is classified as an L.P.D. (Landing Platform Dock) ship. Initially, this ship functioned as Personnel Transport Assistance (B.A.P.) named K.R.I. Tanjung Dalpele (972), due to a change in function, then on September 17, 2008, at Tanjung Emas Port, Semarang. Indonesia's number of hospital ships is undoubtedly not sufficient to help overcome the COVID-19 pandemic in Indonesia. Considering the vastness of the Indonesian archipelago and the current pandemic phenomenon, there is still no sign that this pandemic will end in the near future.

Research on the development of hospital ships in Indonesia has not been done much. Kiryanto et al. (2020) have researched the design of a catamaran to become a hospital ship that helps to handle COVID-19 in Indonesia. Amiadji et al. (2017) designed the hospital ship catamaran propulsion system. Abdillah et al. (2020) designed a hospital ship to serve as a supporting health facility for Indonesia's foremost, outermost, and remote areas. Ray and Naidu (2017) wrote about the history of the development of the US Navy hospital ship, and Negus et al. (2010) wrote about determining medical staffing requirements for humanitarian assistance missions. Based on several studies on hospital ships, there has not been much research that has focused on developing hospital designs, especially hospital ships for handling COVID-19 patients mainly Covid-19 patients need to be isolated to prevent transmission and monitor

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their health conditions, especially for patients with symptomatic SARS-CoV-2 for ten days (CDCP, 2021).

Researchers have done a great deal of research using catamarans, Sugianto et al. (2021) researched ships to collect garbage at sea and reported that the performance of catamarans was better than monohull ships. Utama et al. (2020) stated that the viscous resistance of catamarans was slightly higher than that of monohull vessels. In a study by Samuel et al. (2015), it was found that the capacity of a catamaran is almost doubled when it is converted from a monohull vessel. Catamaran advantages include a wider deck area, better stability, and more comfort than monohulls, according to Seif and Amini (2004). Tuck and Lazauskas (1998) suggested that at speeds up to Fn∇=3.4, The resistance of monohull ships is higher in this region than that of catamaran ships. Still, after this region, the monohull will become less resistant.

A number of recent papers were devoted to modeling catamaran motion in waves numerically and experimentally, Zakki et al. (2021) conducted sea-keeping analysis on catamaran fishing vessels and reported that catamaran hull had shown excellent rolling motion. Castiglione et al. (2011) conducted a numerical investigation of catamaran sea-keeping behavior in regular head waves. Bouscasse et al. (2013) have investigated the fast catamaran sea-keeping behavior advancing in the head sea. Piscopo and Scamardella (2015) investigated the overall motion sickness incidence in the wave-piercing catamaran. Pandey and Hasegawa's (2016) study on the turning maneuver performance of catamaran surface vessels.

When operating in the waters, the vessel's movement has a significant influence and role, especially on the ship's seaworthiness. The ship is declared unfit for sea. One of the unacceptable aspects is the hydrodynamic aspect of poor quality, which causes the ship and crew to experience bad things, causing material loss and loss of life (O'Hanlon and McCauley, 1974). Ocean waves cause vessels to respond in the form of ship movement or sea-keeping. The motion of the ship will affect the performance and comfort of the crew (Fadillah et al., 2019). The effect of sea-keeping performance on crew comfort is closely related to the vertical and horizontal acceleration experienced. Discomfort is caused by seasickness as a relationship between acceleration variables, acceleration frequency, and induration (O'Hanlon and McCauley, 1974).

In this study, the author will continue previous research from Kiryanto et al. (2020). They got the design of the covid-19 hospital catamaran with the results of the analysis of ship resistance and intact stability. Several different ship conditions will be considered in this study's numerical analysis of sea-keeping catamarans. Hypothesis obtained based on previous research; catamarans have good sea-keeping even though their viscous resistance is slightly higher than monohulls. This research aims to apply ship technology to help manage the COVID-19 pandemic in Indonesia by utilizing efficient and safe technology through engineering catamaran hospital ship designs. As a result of this research, Indonesia's ship technology is expected to be positively affected in the future.

2. Method

The research was conducted by making the shape of the hull of the hospital catamaran from Kiryanto et al. (2020) the object of study. This research was conducted by calculating with numerical simulation. The type of data used is presented in Table 1. Ship data analysis is carried out using Maxsurf software to analyze the hydrostatic characteristics of the ship and then for processing ship motion data using CFD software. ANSYS-AQWA is used to investigate motion characteristics and performance of the catamaran ship hospital under normal wave conditions. This numerical software is based on the potential flow and diffraction theory. Here, an incompressible, inviscid, and irrotational flow is calculated.

Table 1: Principal dimension of the catamaran ship hospital (Kiryanto et al., 2020)

Item	Value	Unit
Length over All (LOA)	33.84	m
Catamaran beam (B)	16.03	m
Height (H)	4.26	m
Draught (T)	2.55	m
Cruising Speed (Vs)	8.54	knots
Length between perpendicular (Lpp)	33.84	m
Ship Displacement (Δ)	488.27	ton

The equation of motion of the ship on the CFD software is expressed as Eq. 1:

$$\{m + A\infty\}\ddot{X}(t) + cX(t) + K\ddot{X}(t) = F(t) \quad (1)$$

where, m is the structural mass matrix; A is the fluid added mass matrix at infinite frequency; c is the damping matrix including the linear radiation damping effects; K is the total stiffness matrix, and $F(t)$ is the external force.

Response Amplitude Operator (RAO) is a transfer function that describes how the motion response of the module and raft varies with wave frequency. These are generally non-dimensionalized with wave height. RAO can help determine the frequencies at which the maximum amount of power can theoretically be extracted (Bosma, 2013). The equation of RAO is expressed as Eq. 2:

$$RAO = \frac{F_e\omega}{K-\omega^2\left(M+M_a(\omega)\right)+j\omega C(\omega)} \quad (2)$$

where, F_e ω is the excitation wave force (both incident and diffracting forces); K is the hydrostatic stiffness; M is the mass of the structure; M_a (ω) is the added mass; $C(\omega)$ is the radiation damping, and ω is the wave frequency.

Table 2 describes the numerical parameters for the calculation of seakeeping based on the recommendation of ITTC (ITTC, 2011), the computational domain as seen in Fig. 1 is established with a dimension of -2.3L < x < 2.7L (22 m) in length,

-2.3L < y <2.3L (20 m) in width, and -2.3L < z <1.1L (15 m) in height. The coordinate origin is set at the same height level as the calm water surface. Its longitudinal and transverse position, respectively, coincides with the after perpendicular and centreline of the ship—the positive x-axis, y-axis, and z-axis point to the ship's bow, port side, and sky. The velocity inlet boundary condition is applied at the four vertical sidewalls and bottom boundary of the numerical wave tank. A pressure outlet is applied at the top boundary, which represents the hydrostatic pressure in the sky. The ship surface is selected as a no-slip wall boundary condition. The distance between the ship hull and the sidewalls should be greater than one wavelength or one and a half ship lengths (whichever is greater). Required waves can be appropriately generated before encountering the vessel. A relatively large area is provided behind the ship to simulate and observe the wake flow of the ship. A water depth of 10 m (2.3L) is used, which can be regarded as an infinite water depth condition as seen in Fig. 1.

Table 2: Numerical parameter for seakeeping calculation

Item	Value
Domain	
Length	22 m
Width	20 m
Height	15 m
Boundary Condition	
Inlet	Velocity inlet
Outlet	Velocity inlet
Bottom	Velocity inlet
Top	Pressure outlet
Wall	Velocity inlet
Ship surface	No-slip wall

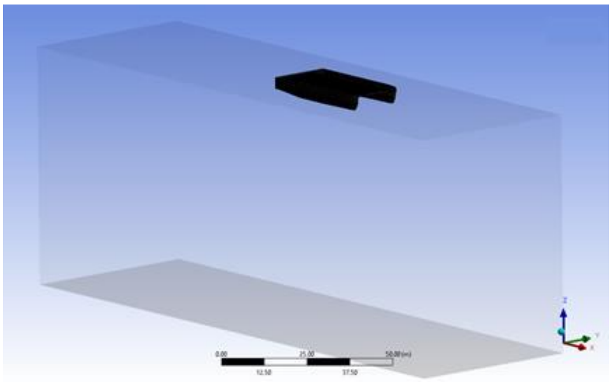


Fig. 1: Computational domain of ship on CFD pre-processor phase

In this study, for the sake of simplification, the wavelength and wave height of the two-component regular waves are designed to be identical, and they come from two orthogonal directions with zero phase difference. The wave heading angle of 0 ∘ corresponds to the head wave, 90 ∘ corresponds to the port beam wave, and 180 ∘ corresponds to the following wave. Typical wave heading angles are defined in Fig. 2.

Three moving ship conditions will be analyzed: Steady-state conditions (0 knots), service speed (8 knots), and 11 knots. The ship is planned to sail around the Java Sea so that the wave height is adjusted to the water area with a wave height of 1.25 meters.

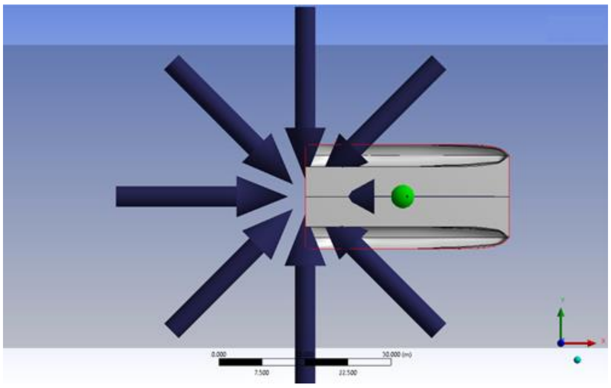


Fig. 2: Wave heading angles of Ship on CFD pre-processor phase

The data in the Table 3 is still an estimate, which means it can change at any time depending on weather conditions. For the wave height and wind speed range, data is taken based on the highest frequency that appears on the weather forecast platform.

Table 3: Data assumption of Java Sea wave characteristic

Wave period (s)	Wave height (m)	Wind speed (knots)
2.0	0-0.2	1.0-4.0
3.0	0.1-0.5	3.0-9.0
4.0	0.1-0.5	1.0-10.0
5.0	0.2-0.4	2.0-9.0
6.0	0.2-0.5	8.0-12.0
7.0	0.3-0.5	6.0-10.0

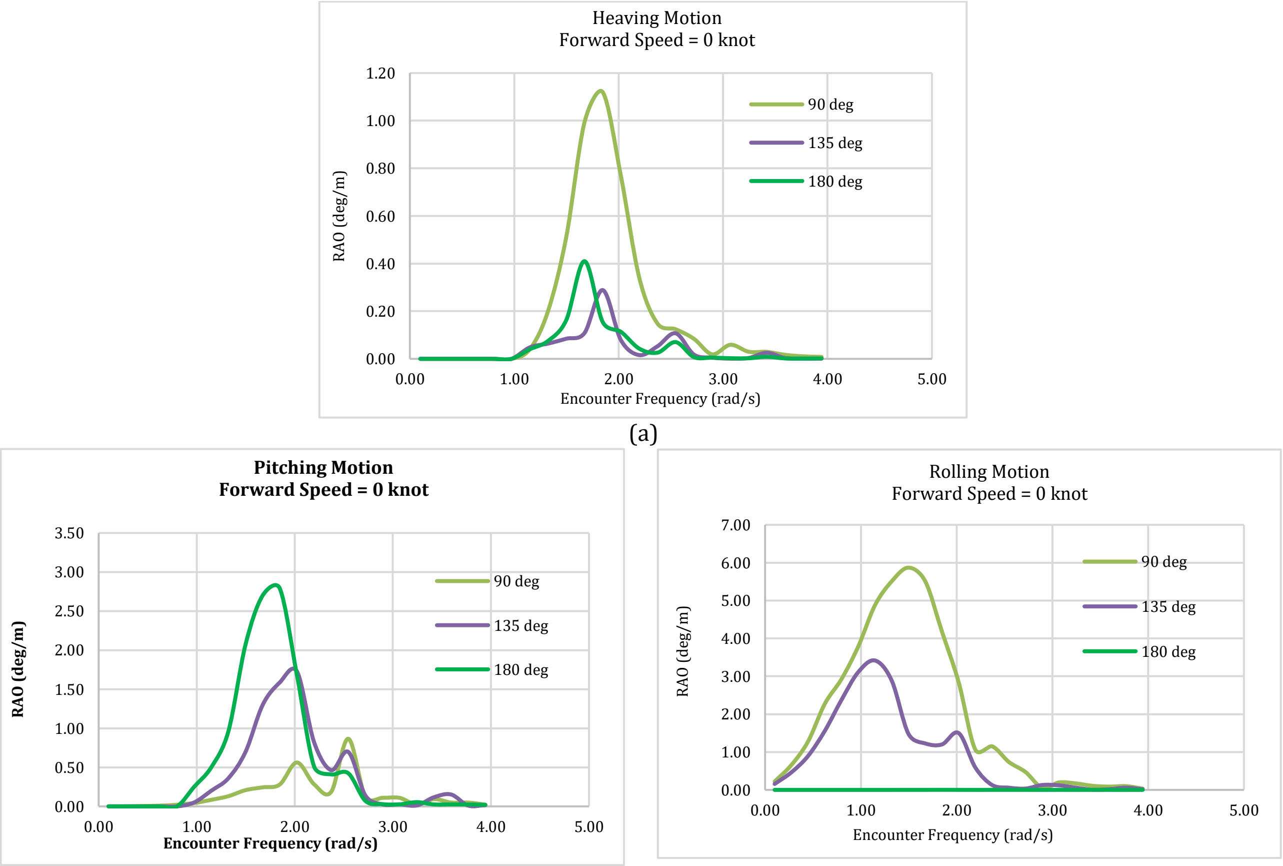
3. Results and discussion

In this section, based on the validated potential flow of the diffraction theory, sailing in head regular waves were simulated. The selected velocities were 0, 8, and 11 knots, and the operating wave characteristics are shown in the previous section. Sea-keeping tests have been conducted on steady-state conditions to simulate rolling, heave, and pitch. The calculation of sea-keeping in this study is focused on finding the response amplitude operator (RAO) value using a numerical method on ANSYS AQWA, which means the ship's response when receiving waves per 1 m amplitude. This analysis uses sea-keeping software in the form of ANSYS AQWA. The resulting data is in the form of a graph that is presented below.

3.1. Response amplitude operator

3.1.1. Steady-state condition (0 knots)

Figs. 3a to 3c show the comparison of RAO response on three different motions at steady-state conditions. From ANSYS AQWA results are the highest heaving response value when the ship is in steady-state occurs at 90° wave heading as shown in Fig. 3a with an encounter frequency value of 1.85 rad/s, which has a response value of 1.16 deg/m, this happens because of the characteristics of catamarans that have a wide breadth of the ship, thus when there is a current that leads the ship perpendicular to the direction of the ship's motion, the ship will respond with high heaving compared to the current that leads to the ship from another angle. For the pitching movement, as shown in Fig. 3b, the highest pitching response value when the ship is in steady-state occurs at 180° wave heading with an encounter frequency value of 1.8 rad/s, which has a response value of 2.70 deg/m. For the rolling movement, the highest rolling response value when the ship is in steady-state occurs at 90° wave heading with an encounter frequency value of 1.5 rad/s, which has a response value of 5.8 deg/m as shown in Fig. 3c.



(a)

(b)

(c)

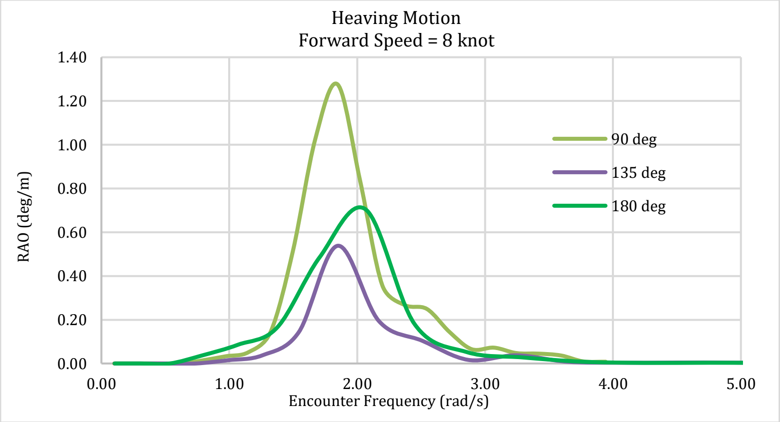
Fig. 3: Response amplitude operator (RAO) of steady-state condition (0 knots) on three different motions (a) heaving motion, (b) pitching motion, and (c) Rolling motion

3.1.2. Service speed (8 knots)

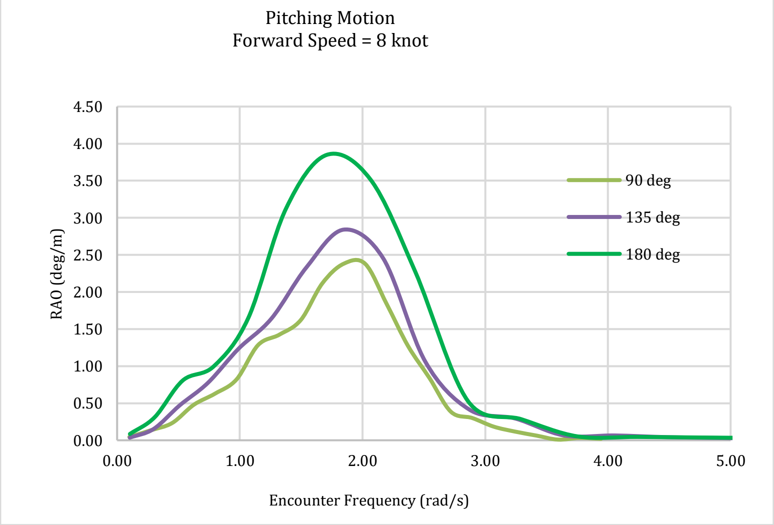
Figs. 4a to 4c show the comparison of RAO response on three different motions at service speed (8 knots). For heaving movements, as shown in Fig. 4a, the highest heaving response value in the condition of the ship moving at a service speed of 8 knots occurs at 90° wave heading with an encounter frequency value of 1.85 rad/s, which has a response value of 1.36 deg/m this happens as when the ship is state condition but the heaving value is higher because in this case, the ship is in motion which causes the ship to experience a higher heaving response. For pitching movements, the highest pitching response value in the ship's condition moving at a service speed of 8 knots occurs at 180° wave heading with an encounter frequency value of 1.71 rad/s, which has a response value of 3.83 deg/m. When the ship pitches in the direction of the wave at 180 degrees, the value of pitching motion is higher than when it pitches in the other direction because it follows the wave surface which comes in the same direction as the ship's length. For rolling movements, the highest rolling response value in the ship's condition moving at a service speed of 8 knots occurs at 90° wave heading with an encounter frequency value of 1.62 rad/s, which has a response value of 5.6 deg/m.

3.1.3. Faster speed (11 knots)

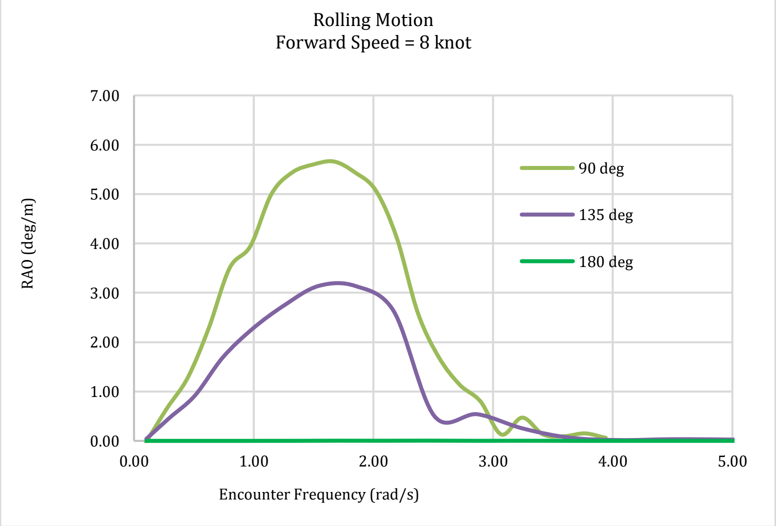
Figs. 5a to 5c show the comparison of RAO response on three different motions at service speed (11 knots). For heaving movements, as shown in Fig. 5a, the highest heaving response value in the condition of the ship moving with a service speed of 11 knots occurs at 90° wave heading with an encounter frequency value of 1.87 rad/s, which has a response value of 1.757 deg/m. For pitching movements, as shown in Fig. 5b, the highest pitching response value in the ship's condition moving with a service speed of 11 knots occurs at 180° wave heading with an encounter frequency value of 1.87 rad/s, which has a response value of 4.53 deg/m. For rolling motion, as shown in Fig. 5c, the highest rolling response value in the condition of the ship moving with a service speed of 11 knots occurs at 90° wave heading with an encounter frequency value of 1.53 rad/s, which has a response value of 7.35 deg/m. In this condition the heaving, pitching, and rolling values are higher than in the previous 2 conditions (steady state and service speed), one of which is because of the speed factor. The rolling motion value is the highest because of the wide shape characteristic of the catamaran so that when there is a wave from the direction perpendicular to the ship, the hull experiences resonance with the wave.



(a)



(b)



(c)

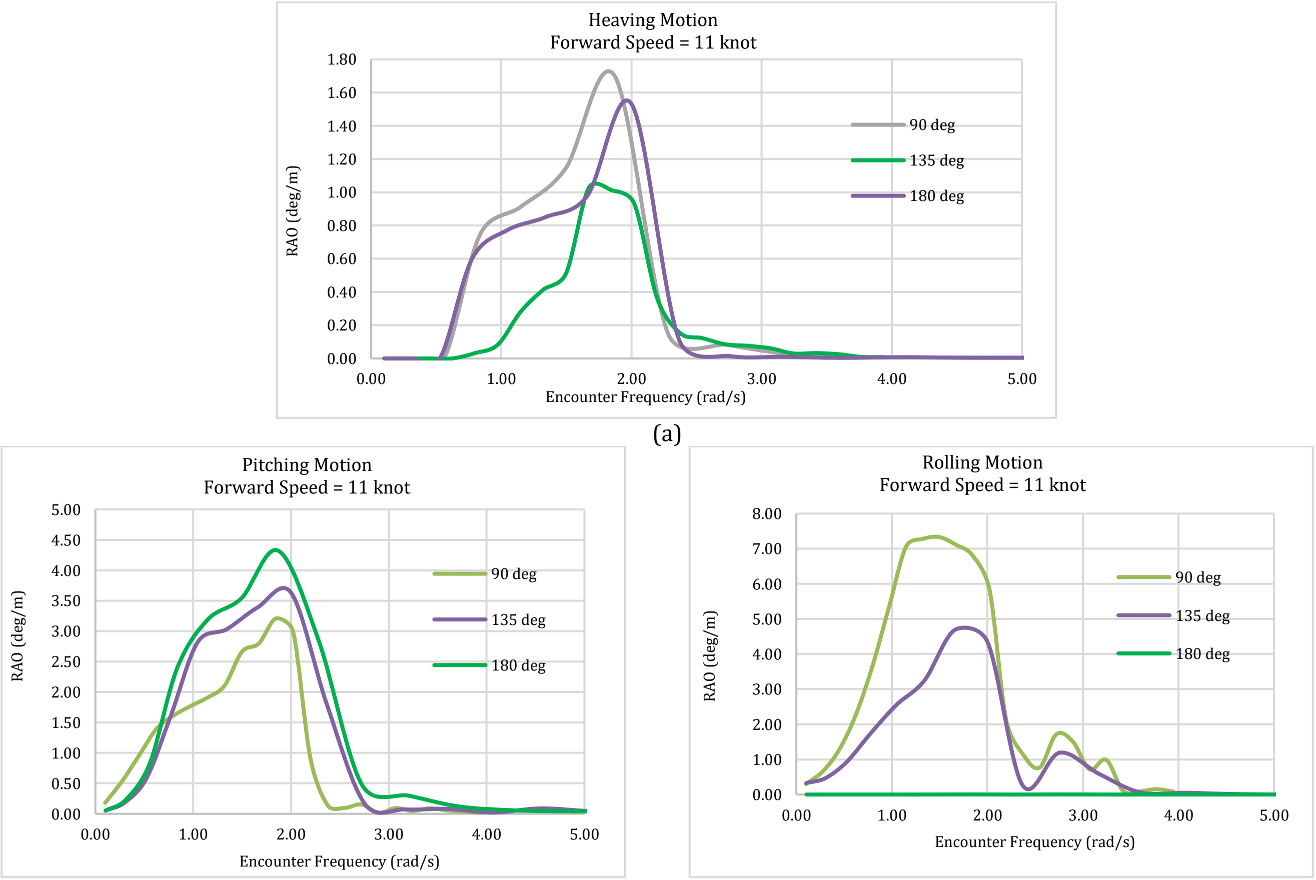
Fig. 4: Response amplitude operator (RAO) of steady-state condition (0 knots) on three different motions (a) heaving motion, (b) pitching motion, and (c) Rolling motion

3.2. Ship's response in random waves at steady condition

The Spectra formulation used in this study is the International Towing Tank Conference (ITTC, 2011) spectra because the formulation has been approved by several hydrodynamic experts from various hydrodynamic laboratories around the world who are members of the ITTC (2011) as the main standard in various tests of ship movement behavior in random waves.

The response of the structure to a random wave can be done by transforming the wave spectrum into a response spectrum. The response spectrum is defined as the energy density response to the wave structure. This can be done by multiplying the value of the square of the RAO (Response Amplitude Operator) by the wave spectrum. After the response spectrum is obtained, the intensity of the movement can be calculated as a function of the area under the response spectrum curve to obtain statistical values of the movement as a function of the variance of the movement's elevation.

In Figs. 6 and 7, it can be seen that the spectrum of waves with significantly different heights also has a different spectrum. The higher the significant wave, the larger the resulting spectrum. It is very interesting to observe the changing shape of the curve. At small important heights, the spectral curve has a wide shape, but at large important heights, the curve is narrow. This means that wave energy is provided by waves in a wider frequency range compared to large significant waves at the expense of small significant waves (Djatmiko, 2012).



(a)

(b)

(c)

Fig. 5: Response amplitude operator (RAO) of steady-state condition (0 knots) on three different motions (a) heaving motion, (b) pitching motion, and (c) Rolling motion

From the analysis results, it is explained that the response of the hospital ship to the direction of the arrival of the waves varies and is different at each speed. The highest wave response occurs when the vessel is in high-speed condition and exposed to sea waves perpendicular to the ship's direction with a response value of 1.757 deg/m for heaving movement. Furthermore, for the pitching movement, the highest wave response has a value of 4.53 deg/m at a speed of 8 knots. As for the rolling motion, the highest wave response occurs in ships that counter waves from the direction of 90° ships with a response value of 7.35 deg/m at higher than service speed, 11 knots. Based on the results of research conducted on a catamaran hospital ship, it can be concluded that when operating in the waters of the island of Java, the ship has good ship movement so that this ship can operate as a health facility without disturbing the activities of health workers. Therefore, this study warrants that the vessel is seaworthy. To get more convincing results, it is necessary to conduct trials using experimental methods.

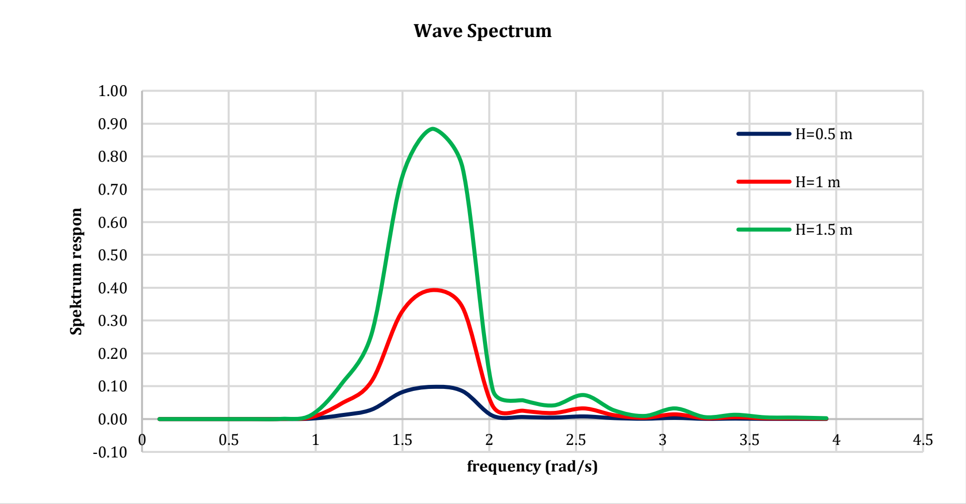


Fig. 6: Wave spectrum of hospital catamarans when 3 different wave conditions

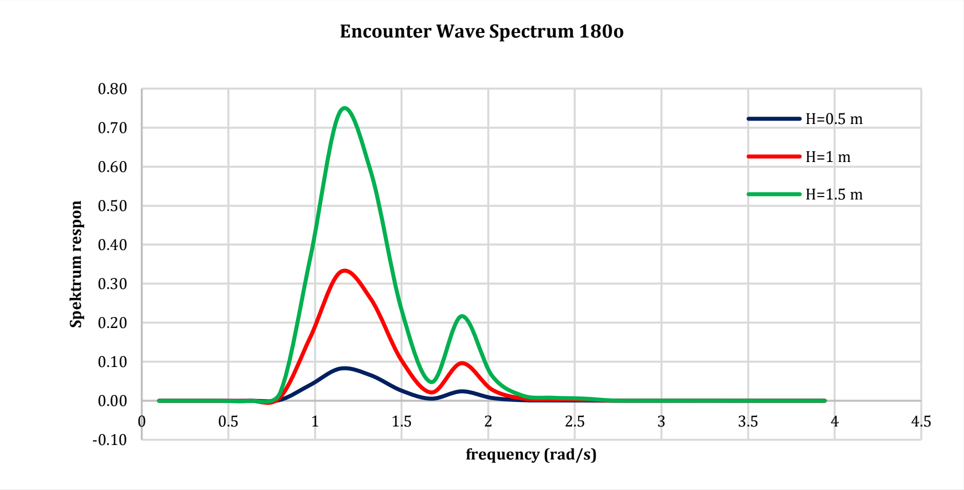


Fig. 7: Encounter wave spectrum from the direction of 180° hospital catamaran during 3 different wave conditions

4. Conclusion

In this research, an analysis of sea-keeping performance for hospital ships was conducted by numerical simulation. In the numerical simulation, Froude numbers were found to play a significant role in motion response, enabling the designers of the hospital ship to predict sea-keeping behavior with a satisfactory approximation during the very early design stages.

Based on the results of research conducted on a catamaran hospital ship, it can be concluded that when operating in the waters of the island of Java, the ship has good ship movement so that this ship can operate as a health facility without disturbing the activities of health workers. Therefore, this study warrants that the vessel is seaworthy.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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