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SHIP PERFORMANCE INVESTIGATION DUE TO DEADRISE MODIFICATION: A CASE STUDY PASSENGER SHIP

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Speed is the main factor that is always considered when designing a ship. Also, a ship designer will try to make a good design regarding the ship's fuel efficiency and seakeeping performance. One example is the operation of passenger ships on the Ketapang – Gilimanuk crossing route in Bali, Indonesia. The Bali strait area has uncertainty waves and ocean currents; the determination of environmental characteristics is needed for an investigation. In this paper, a review is carried out on the primary parameters of ship hydrodynamics performance, i.e., hull changes to reduce ship resistance by modifying the bilge radius from angles of 10º, 15º, and 20º. This modification affects the geometric parameters. Two indicators are used to measure the effect of changes: resistance and seakeeping performance. Numerical methods were used to obtain the results, the calculation of the resistance was approached by the Holtrop process of investigation, and the NORDFORSK criteria validated the feasibility seakeeping assessment. The results of model Z show that when the deadrise angle is large, the ship reduces the resistance by approximately 8.2% at a service speed of 12 knots. Therefore, modification of the hull by raising the radius of the bilge results in a reduction in resistance, which affects the ship's rolling, but with an increase in speed, it can reduce the heave and pitch significantly with the resulting hull with good performance obtained.

Keywords: deadrise, seakeeping performance, efficiency, ship, bilge radius

1 INTRODUCTION

Passenger ships for crossings are an important means of transportation in Indonesia. As an archipelagic country, Indonesia is connected to the sea to move from one island to another. In this study, the crossing ships in the Straits area of Bali for passengers simultaneously carrying cargo. The ship has a landing craft tank-type hull character modified to transport cars and passengers. The operational process of the ship through the Strait of Bali needs to be considered environmental conditions. The uncertainty of waves and currents is the background for the need to investigate the condition of the ship's performance, both in terms of speed and feasibility of processing motion. Passenger ships dominate the density of the current in the water [1], [2]. As a result, there are always accidents in 1-2 years in the strait of Bali [3], [4]. Most accidents occur due to collisions, grounding, and collapse due to loss of balance [5]. Performance improvement efforts have been made by considering the ship's displacement factor.

However, the performance condition of the ship must be excellent and stable to meet the need for transportation. The solution to this problem is increasing speed to provide time efficiency and fast travel time. Investigations based on the hull's shape influence hydrodynamic factors are very significant. Recently, a study on improving efficiency by keeping the coefficients block parameter manageable [6]. The hull modification is limited to changing the displacement parameters [7]. The indicators that can be changed from the hull's surface include deadrise corners; optimization of the hull shape at deadrise angles will indirectly reduce the wetted surface area (WSA) to minimize the obstacles and increase stability [8][9]. The influence of resistance on ships is generally analyzed using a numerical approach and calculation analysis; for large displacement vessels, the Holtrop formula is used [10].

In terms of dimensions, the hull design is essential to enhance the performance of the ship's operations. The determination of the appropriate deadrise angle will influence the reduction in resistance which has implications for the speed increase; besides that, it can specifically improve efficiency in fuel consumption. An investigation of the effect of shape on resistance reduction has been carried out and obtained 10% and 16.87%, respectively [6][7]. Furthermore, it is crucial to examine the change in the angle of the deadrise on the influence of the ship's movement must fulfill the acceptance criteria for passenger ships.

Therefore, this study plans to investigate the effect of motion exercise on changes in deadrise angles in the hull. The assessment uses two parameters, i.e., ship resistance and ship motion criteria for operations [11]–[13]. In this study, mathematical calculations of the model using the Holtrop equation were used since this ship belongs to the full displacement ship. In addition, to ensure passengers' safety and comfort, the results of motion processing were validated, which was analyzed with NORDFOSK benchmarks [14]. Specifically, the influence of deadrise changes in motion will be summarized in the appearance of polar diagram images on each change in deadrise angle, heading angle, velocity variation, and wave influence analyzed on sea state conditions 3, approximately 0.5 to 1.25 meters.

2 RESEARCH METHOD

2.1 Hull Resistance

Resistance in the hull is influenced by two main components: friction resistance and residual resistance. Friction resistance works on the hull's surface and is influenced by the density of the acceleration of the fluid. Meanwhile, residual resistance is influenced by the working pressure factor. The normal force will form the viscosity pressure and wave-making resistance. The resistance value is determined by Eq. (1) and (2). If the hull is fully immersed, the value of the wave-making resistance is equivalent to zero. Moreover, the water's density influences the hull's pressure resistance [15].

$$R_T = R_F + R_R + R_A \quad (1)$$

$$R_T = R_F + (R_{VP} + R_W) + R_A \quad (2)$$

Where (R_T) is total resistance, composed of (R_F) friction resistance coupled with (R_R) residual resistance, and (R_A) air resistance. Then, a residual resistance is formed from (R_{VP}) viscous pressure resistance and (R_W) wave-making resistance. The resistance elements are expanded from several non-dimensional coefficients, which will be concerned further.

2.1.1 Resistance Coefficient

The resistance coefficient (C_T) is a formulated non-dimensional value with several aspects of parameters, including density (ρ), the wetted surface area (S) of the hull and the speed of the ship (v) see Eq. (3).

$$C_T = \frac{R_T}{0{,}5 \rho S V^2} \quad (3)$$

The resistance coefficient equation can be assumed to be Eq. (4).

$$C_T = C_F + C_R \quad (4)$$

A friction resistance (C_F) value can be estimated from the surface area of the dyed hull and the speed of the ship model. The value of the residual resistance (C_R) is built from wave making (C_w) and the influence of hull form (C_{VP}). Then, Eq. (4) can be rewritten as Eq. (5).

$$C_T = C_F + C_{VP} + C_w + C_A \quad (5)$$

This paper assumes that the influence of (C_A) wind and (C_w) wave resistance is zero. Hence, the form factor (1+ k) is the main influence determining the magnitude of the total resistance.

2.1.1 Holtrop formulation

Holtrop is numerical calculations to estimate resistance on commercial ships, such as general cargo, tankers, containers, and passenger ships. Order to the total resistance of the ship has been subdivided into Eq. (6).

$$R_T = R_F(1 + \mathrm{k}) + R_{APP} + R_W + R_B + R_{TR} + R_A \quad (6)$$

2.2 Seakeeping

Seakeeping is influenced by external forces, e.g., water conditions. The motion of seakeeping on ships is based on six degrees of freedom. Motion is separated into two parts: in the translational is a surge, heave, and sway, while in the rotary dimension is pitch, roll, and yaw. Ship motions will affect the state of the heel, trims, and draft on the bow and stern. Performance investigations assess the ship's ability to withstand operational conditions. This analysis is carried out using a strip theory approach for method. Irregular wave considerations are included by following the distribution of a wave of recommendations from ITTC [16]. Six degrees of freedom determine the movement of the vessel. In this paper, the focus of the analysis follows the standard criteria from NORDFORSK, which includes roll motion RMS and heave vertical acceleration assumed in passenger accommodation areas.

2.1.2 Ship Responses

Seakeeping analysis has data inputs such as waves, and filters are the hull's shape and response motion [17]. In calculating the response to the ship's direction, it is carried out through several stages, i.e., (i) the determination of the response amplitude operator (RAO) serves to determine the working force affected by the waves in the dynamic response forms the frequency. RAO can also develop a transfer function generally presented on a graph with y-axis amplitudes being motions. Response Amplitude Operator (RAO) is calculated with Eq. (7).

$$RAO\ (\omega) = \frac{\zeta_{k0}(\omega)}{\zeta_0\ (\omega)} \quad (7)$$

Value of $\zeta_0\ (\omega)$ dan $\zeta_{k0}(\omega)$ are wave and ship amplitudes, respectively. Meanwhile, when the ship experiences rotational motion from the wave, a wave amplitude will be obtained, which is summarized in Eq. (8) and (9).

$$RAO\ (\omega) = \frac{\zeta_{k0}(\omega)}{\zeta_0\ (\omega)} \tag{8}$$

$$RAO\ (\omega) = \frac{\zeta_{k0}(\omega)}{\left(\frac{\omega^2}{g}\right)\zeta_0} \tag{9}$$

(ii) The parameter influencing ship responses is wave spectra have two indicators, significant wave height (Hs) and period (Tz). The analysis of this investigation used the Piersen-Moskowitz spectrum obtained from Eq. (10).

$$S_{(PM)} = \frac{Hs^2}{4\pi}\left(\frac{2\pi}{T_Z}\right)\omega^{-5}exp\left[-\frac{1}{\pi}\left(\frac{2\pi}{T_Z}\right)^4\omega^4\right] \tag{10}$$

Wave spectra are defined by $S_{(PM)}$, and ω wave frequency in this investigation operating under three conditions between 0.5 m to 1.25 m. Furthermore, (iii) response spectra interact with added mass, damping, and external forces. The random motion condition is transformed into a wave spectrum to the response spectrum $S_{\zeta r}(\omega)$, so that response energy is obtained due to the load determined by Eq. (11).

$$S_{\zeta r}(\omega) = [RAO\ (\omega)]^2 x\ S_{\zeta}(\omega) \tag{11}$$

Then, (iv) the ship's motion is known using the Root Mean Square (RMS) method to determine the ship's motion in roll, heave, and pitch modes. Eq. (12). Summarizes the determination of RMS in motion vessels [18].

$$RMS = \sqrt{m_0} \tag{12}$$

Numerical calculations can know the value of m_0 under the curve with the Eq. (13).

$$m_0 = \int_0^{\infty} \omega_e{}^0 S_{\zeta} d_{\omega} \tag{13}$$

A ship's motion is presented as a polar diagram to determine the unsteady response due to environmental conditions.

2.3 Passenger Ship Model

Identification of the effect of hull modifications is intended to enhance the vessel's performance. The examiner compared the results of the analysis of the existing hull with the two modified hulls. Hull models will be stated to be the current model (O), modification (X), modification (Y), and modification (Z). Lines plan model represented in Figure 1.

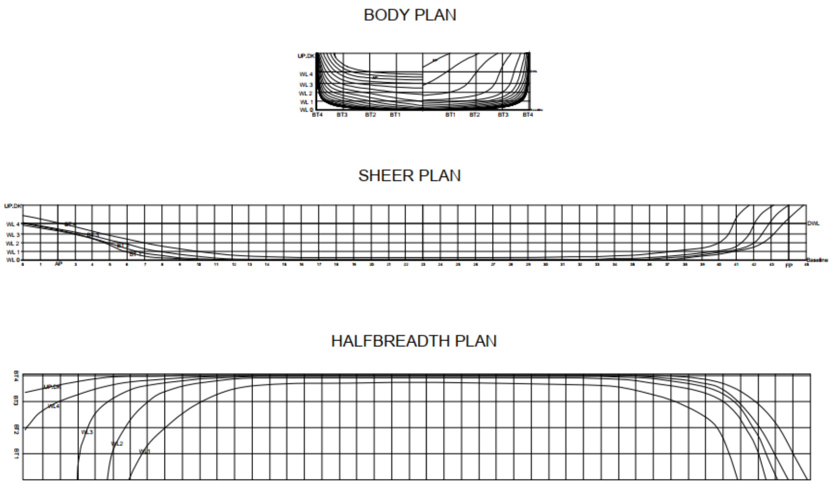
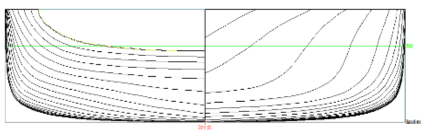
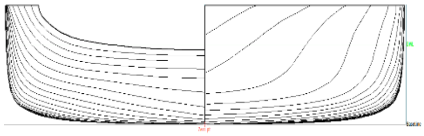


Fig. 1. Linesplan of ship

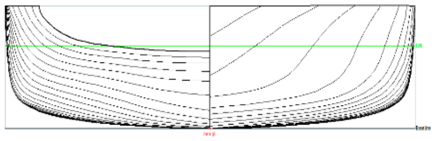
An increase in the deadrise angle is carried out to reduce the resistance to the hull. As has been done in previous investigations, it is known that changes in this modification can reduce obstacles. The novelty of this aspect is its correlation to the performance of ship motion. The difference in the shape of the deadrise in detail is shown in Figure 2.



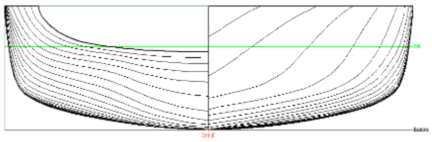
(O)



(X)



(Y)



(Z)

Fig. 2. Variation of Hull Deadrise Geometry: (O) Existing; (X) 10º; (Y) 15º; (Z) 20º

The modification model referred to Molland that the form factor can influence the reduction in resistance. Shifts in displacement parameters were tested at quiet, medium, and extreme conditions to see the ship's performance capabilities are shown in Table 1.

Table 1. Parameter Displacement

No.	Parameter	Modification of hull				Unit
		O	X	Y	Z	
1	Displacement (ton)	843	835.5	793.1	722.2	Ton
2	Reduction (ton)	0	7.5	49.9	120.8	ton
Deviation		0	0.88	5.97	15.23	(%)

Hull optimization investigations using displacement parameters were not necessarily the hull with a reduction in the wetted surface area with the most satisfactory hull. Therefore, analysis is required in terms of resistance and ship motion to accept the modification in the hull. Moreover, if the hull is changed, it is crucial to consider the shipbuilding process. Details of the main dimensions of the ship model are summarized in Table 2.

Table 2. Ship model characteristics

Main Dimensions	Modification of hull				Unit
	O	X	Y	Z	
β	-	10	15	20	Degree
LWL	43.728	43.728	43.728	43.728	m
Beam	11.961	11.961	11.961	11.961	m
Draft	2,15	2,15	2,15	2,15	m
Volume Displacement	822.4	815.1	773.8	704.62	m^3
Mass Displacement	843	835.5	793.1	722.2	ton
Wetted Surfaces area	578.2	575.1	562.8	539.1	m^2
Block coeff. (C_B)	0.731	0.725	0.691	0.636	-
Prismatic coeff. (C_p)	0.783	0.783	0.776	0.765	-
Midship coeff. (C_M)	0.934	0.926	0.89	0.832	-
Waterpl. area coeff. (C_{wp})	0.92	0.919	0.917	0.912	-

2.4 Numerical Setup

The boundary conditions used in this numerical analysis are influenced by several parameters: speed, heading angle, wave height, gravity, density, and temperature. The ship's speed is selected from 6 – 12 knots, with the direction of the limit angle being 90º (beam seas), 135º (quartering seas), and 180º (head seas). Based on the 1975 ITTC recommendations, the value of water density is 1025 kg/m^3, gravity is 9.8 m/s^2, and water temperature is 15 ºC [16][19]. Water data was taken for ten years. The data processing technique uses the short-term analysis method. The results represented in Table 3 show the number of wave events (Hs) and periods (Tz).

Table 3. Bali Strait waves occurancy

Hs (m)	Tz (s)		
	5	6	7
1.0	5887	58061	14947
1.5	0	3856	8493
2.0	0	2	460
2.5	0	1	18

Wave dominant is 1-1.5-meter or an average of 1.25 meter, ranging from 5-6 seconds. In seakeeping analysis, the model is simulated in the numerous significant waves is 1.25-meters, with a period of 5 seconds. Seaworthy assessment is developed using generalship from NORDFORSK. The minimum criteria must be met for the roll criterion should not exceed 6 degrees. In addition, the heave and pitch conditions should not exceed 0.275 g and 0.150 g, in this case, g gravity exists.

3 RESULT AND DISCUSSION

3.1 Resistance Analysis

Generally, resistance factors effect by the magnitude of the load carried and wetted surface area. Changing deadrise angles to the bilge area has been investigated and has been shown to reduce the resistance size. However, on the other hand, this condition will affect the ship's movement. In this analysis, the Holtrop approach for displacement vessels and experiments prove that this method is suitable for displacement hulls. The study of the use of the process by considering the influence of deadrise obtained simulation results as seen in Fig. 3, where the comparative effects of numerical and empirical analysis have an error below 10% [20],[21].

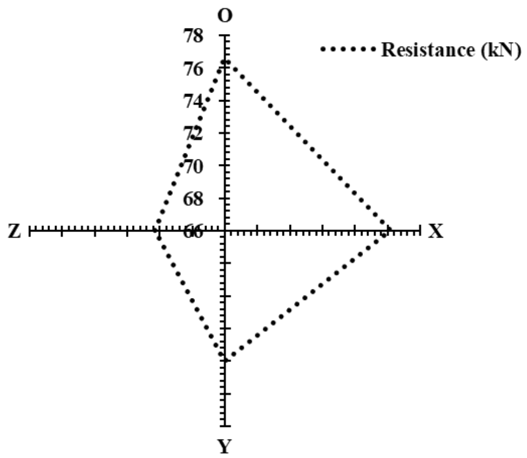


Fig. 3. Hull resistance: (O) Existing; (X)10º; (Y) 15º; (Z) 20º

Analysis of resistance conducted to the Holtrop method, displayed in the mapping diagram, shows the sharpness of the chart as an indicator of the magnitude of the resistance. Hull modifications can reduce the resistance presented by the obtuse of the mapping diagram. In more detail, the percentage of decreased resistance is summarized in Table 4.

Table 4. Resistance Reduction

No.	Parameter	Modification of hull				Units
		O	X	Y	Z	
1	Resistance	76.579	76.18	73.99	70.27	kN
2	Reduction	0	0.39	2.58	6.30	kN
Percentage		0	0.52%	3.38%	8.24%	(%)

In this analysis, the assumption of efficiency conditions used is 50%, considering the uncertainty of ocean circumstances in the environment. Therefore, following the minimum engine propulsion requirements can achieve more than 50% to voyage routes with optimal fuel use. This analysis is in line with the literature that has been analyzed on Roro ships with a block coefficient value of 0.8, with 50% being a good figure for achieving efficiency [7]. In addition, it increases efficiency and reduced fuel consumption, as evident from the analysis carried out with an increase in efficiency of Ro-Ro ships, which were able to save 2.4 tonnes of fuel consumption. The fuel consumption values for the O, X, Y, and Z models are 29.6 tonnes, 29.48 tonnes, 28.63 tonnes, and 27.2 tonnes, respectively.

3.2 Seakeeping performance

Improving transportation safety is a crucial point, especially on passenger ships. The investigation in this analysis was carried out in the Strait of Bali, where this area is strategic. Bali strait links the two islands that are Java and Bali, through the ports of Ketapang and Gilimanuk. A ship is the primary means of transportation used for crossing is roro-type [22]. The path density of the area is dense, with challenging waves, the average wave scale being at sea state 3. The existing hull and variations given were analyzed by considering the height and wave period defined in the data above. Then Figure 4 shows the results of the motion response of the existing hull model. Furthermore, seakeeping indicators are represented in blue, yellow, and red, representing the significance level of the movement response that occurs [23]. Where blue has a low level, yellow is medium, and red has a high response.

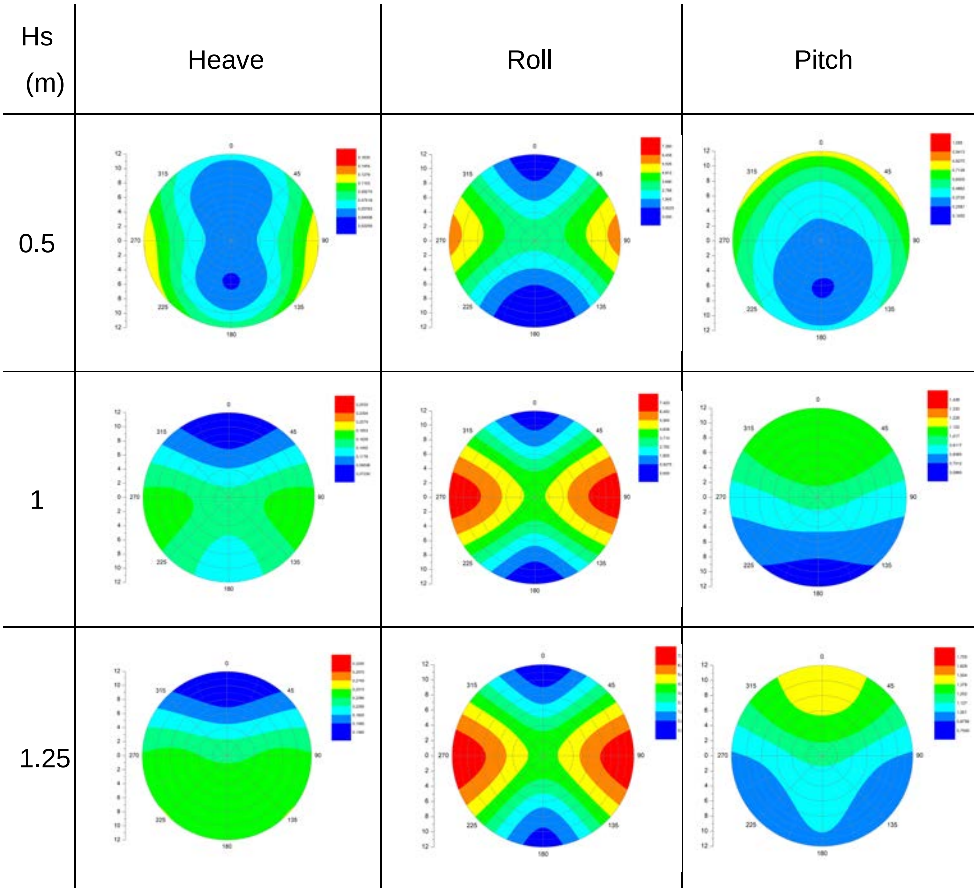
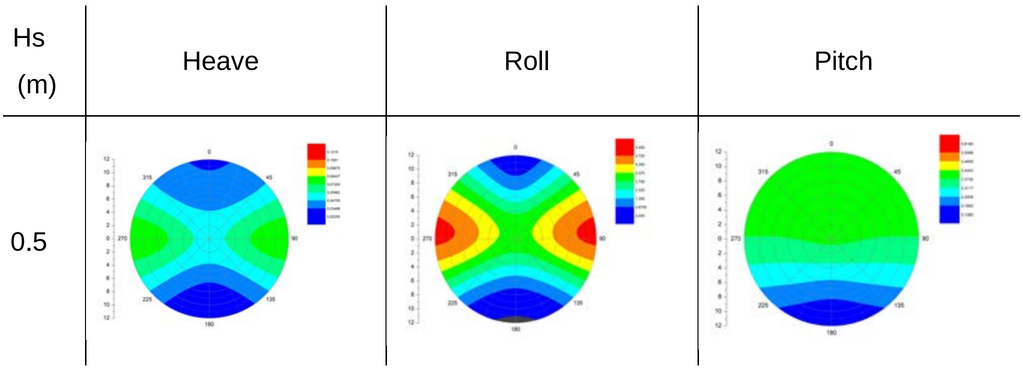


Fig. 4. Hull (O) Existing

Moreover, modifications to the 10-degree bilge condition are shown in Figure 4, the Influence of changes in motion response on heave motion in waves of 0.5 meters and pitch movements at wave heights of 0.5 and 1.25 meters. Ship motions become more dominant in heave. In comparison, pitches shrink slightly and only occur at 6 knots at wave heights of 1.25 meters.



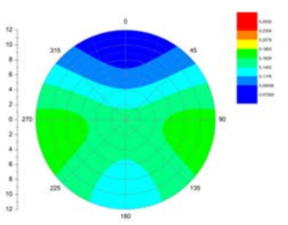
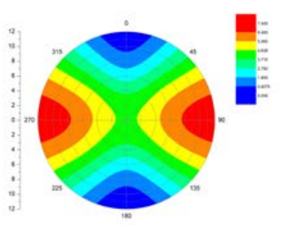
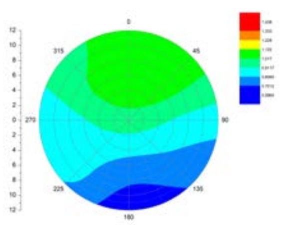
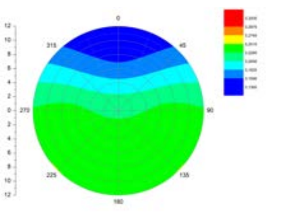
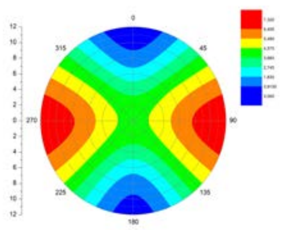
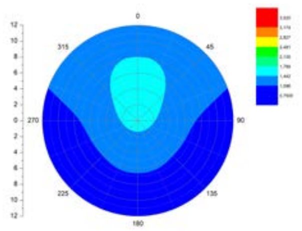
1			
1.25			

Fig. 5. Hull (X) Deadrise 10º

Also, analysis of the 15-degree modification showed a heave response with the same pattern in hull X. However, hull response changed at the wave-conditioned pitch of 0.5 degrees and 1.25 degrees with the same waters; the correct shape parameter affects the ship's motion with visualization, as seen in Figure 6.

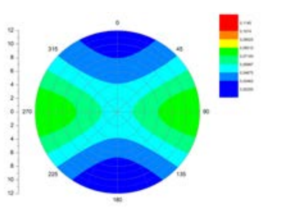
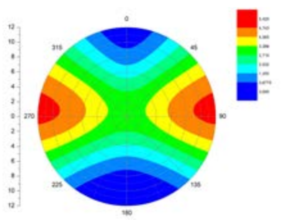
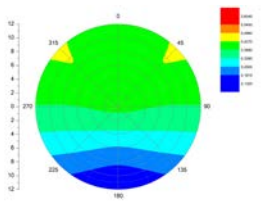
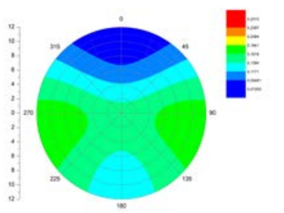
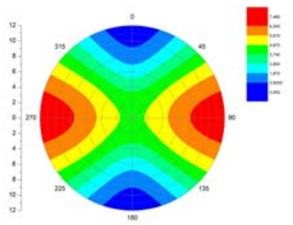
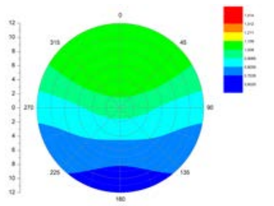
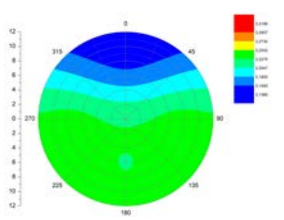
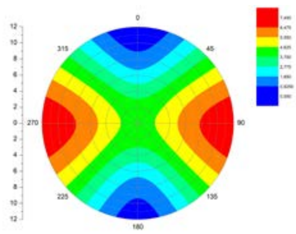
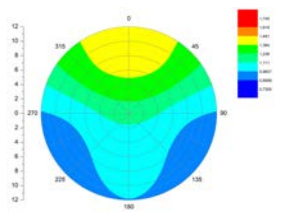
Hs (m)	Heave	Roll	Pitch
0.5			
1			
1.25			

Fig. 6. Hull (Y) Deadrise 15º

Hull characteristics in motion do not show extreme changes, but all movements should be analyzed. Hull Z's pattern in the heave condition response changes, shown in Figure 6. Generating responses show various conditions, and the assessment is carried out with a seakeeping approach to criteria under NORDFORSK, where each standard is determined by its operational feasibility. Then, this performance is measured to give passengers a sense of comfort and safety. The results and analysis show the correlation between the speed and movement of the ship. Furthermore, it is necessary to pay attention to the threshold value of the ship's safety. Therefore, operational ability limits for ships have been determined in the forecastle and deckhouse areas. Seaworthy and safety were evaluated based on several results from Fig. 4 to Fig. 7 as visualization response motions if the response is shown in the table for assessment of the seakeeping criteria.

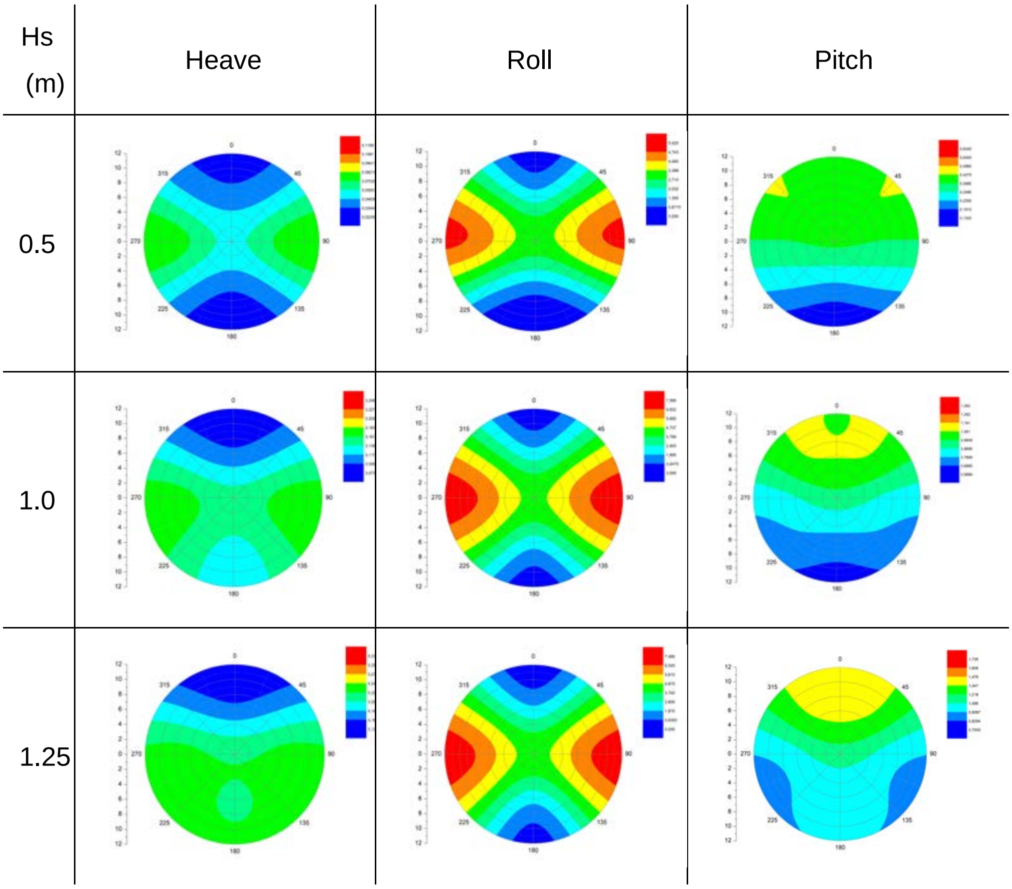


Fig. 7. Hull (Z) Deadrise 20º

In terms of operability, the strait area of Bali has a dense density. Judging from the traject and crossing activities from Java to Bali, it is necessary to consider the dynamic aspects of the waves [24]. A parameter that is supported by the performance and safety of the ship in reacting to environmental conditions, both from wave loads, motion response, and acceleration. The benchmark of operability must be met so as not to cause uncomfortable conditions for passengers. All criteria compaile with the NORDFOSRK criteria.

4 CONCLUSIONS

Investigation of the effect of the modification of deadrise angles on the correlation of resistance and motion is complete. Some of the results obtained from the analysis are presented at several points as follows:

- The first point is the reduction of resistance due to the addition of an indirect deadrise angle, the raised bilge radius, and the reduced wetted surface area.
- Configurations of the hull with modification changes increase the value of the rolling motion while still within the acceptance criteria below six degrees.
- The correlation of speed increase will significantly reduce heave motion and pitch.

5 ACKNOWLEDGEMENTS

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7 NOMENCLATURES

R_T	Total resistance, kN
R_F	Friction resistance, kN
R_R	Residual resistance, kN
R_A	Air resistance, kN
R_{VP}	Viscous pressure resistance, kN
R_W	Wave-making resistance, kN
R_{APP}	Appandages Resistance, kN
C_T	Resistance coefficient
C_F	Friction resistance coefficient
C_R	Residual resistance coefficient
C_A	Air resistance coefficient
C_{VP}	Viscous pressure resistance coefficient
C_w	Wave-making resistance coefficient
$(1+k)$	Form factorl
ρ	Density, $kg.m^{-3}$
S	Wetted surface area, m^2
v	Speed, m/s
RAO	Response Amplitude Operator
$\zeta_0(\omega)$	Wave amplitudes, m/m
$\zeta_{k0}(\omega)$	Ship amplitudes, m/m
H_s	Wave height, m
T_z	Wave period, s
ω	Wave frequency
$S_{(PM)}$	Wave spectra Piersen-Moskovitz
$S_{\zeta r}(\omega)$	Spectrum response
m_o	Area under curves
RMS	Root Mean Square

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