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Comparative Analysis of Slamming Phenomenon Prediction between U and V Hulls using Strip Theory Method

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Abstract

Choosing the right hull shape is important in designing a ship, for example, a U-section or V-section of the hull. The hull shape will affect various aspects, such as design, resistance, seakeeping, structure and production. The ship hull must be properly designed so that it can operate according to the ship's mission. From the seakeeping aspect of the ship's motion at sea, the difference in the hull shape will result in different motions and dynamic effects such as the slamming phenomenon. Based on the difference in the hull shape cases, this study analyzed the difference in the probability of slamming between the U and V hulls. Both hulls were made based on Formdata and almost all parameters were made the same. Parameters that cannot be forced to be the same are WSA (wetted surface area), C_{WP} (coefficient of waterplane area), and K_B (distance of keel to buoyancy), where those parameters determine the difference in the results. The calculation of RAO (operator amplitude response) was obtained using the strip theory method which assisted by Maxsurf Motion software. The results became the input for the calculation of the slamming probability. The study results show that the U hull has a higher probability of slamming occurrence than that of the V hull, with the difference in values ranging from 20% to 35%. Therefore, the U hull will get more frequent slamming loads, so it has the potential to have a higher structural failure (fatigue) than that of the V hull.

1. Introduction

The hull is the heart of the ship itself, where it must be made as good as possible by considering aspects of technical science and applicable rules. The hull has very important functions, such as buoyancy, stability, sea keeping, resistance, etc. A naval architect must design the hull properly so that the ship can be operated according to its mission. For example, the hull of a tanker is made fatter because its mission is to be able to transport large amounts of oil without prioritizing sailing time. In contrast to passenger ships, which prioritize travel time, the hull is made slimmer to minimize drag [1].

The shape of the hull according to FORMDATA [2, 3] there are three forms, namely the V, U and N shapes. The variations in these shapes are expressed in the form of the letters U, V, and N. It means that the U hull means the cross-sectional shape has more curvature than that of the V hull. Meanwhile, the hull V has a straighter cross-sectional shape, so that the hull is more like the letter V. The N hull has a shape between the U hull and the V hull. The difference between the U and V hulls can be seen in Figures 1, 2 and 3.

Variations in the shape of the hull of course have different characteristics, seen from various aspects [4]. These characteristics influence the designer to choose the right hull shape according to the ship's mission. All of that will have a small to large impact on the design, hydrodynamics [5], construction and production aspects of the ship itself. From a design aspect, for example, the U hull has a wider base area than the V hull [6]. The wider bottom area can be maximized for cargo arrangement from bottom to top [1], while the wider top area can be maximized for the wider deck area. In terms of ship resistance, for a displacement ship type, the U hull will cause better wave resistance than the V hull for a certain Froude number [7-8]. Reducing drag by choosing the correct hull shape can contribute to increased energy efficiency on ships [9, 10], where it can help fight climate change [11-13]. In terms of construction, the U hull has greater strength than that of the V hull with the same structural size [14]. In terms of production, of course, the V hull is easier to produce because it does not need to bend the plate too much [15].

The ship's hull is never separated from the problem of the ship's motion in the wavy sea so the hull form design must be able to overcome it [16]. One of the dynamic effects of the ship's motion in the wavy sea is the slamming phenomenon

[17]. Slamming is an event where the hull of the ship experiences a phase difference with the phase of the ocean waves, which causes the bottom of the bow to be lifted from the surface and down to hit the waves [18]. Some literature describes the shape of the hull on the seakeeping performance of the ship, one of which is the modified hull shape which is optimized by linear regression [19] and a inverse design method [20]. The optimization of the shape of the hull with the transformation method [21] to improve the seakeeping of fishing boats was conducted [22]. The optimization with shape transformation on fast boats has also been carried out [23]. The shape of the hull that resembles the letters U and V has a difference in the WPA (Water Plan Area) value where the WPA will greatly affect seakeeping performance, including slamming events [24].

Based on the problems above, this study analyzed how the differences in the slamming phenomenon between the U hull and the V hull. The study begins with making the two linesplan models compared with their hydrostatic characteristics so that the comparative analysis became relevant. The ship's motions simulation uses the strip theory method, then the results of which were calculated how the value of the slamming probability between the U and V hulls. It is hoped that the results of this study will become a reference for ship designers to consider the shape of the hull from the view of the slamming phenomenon.

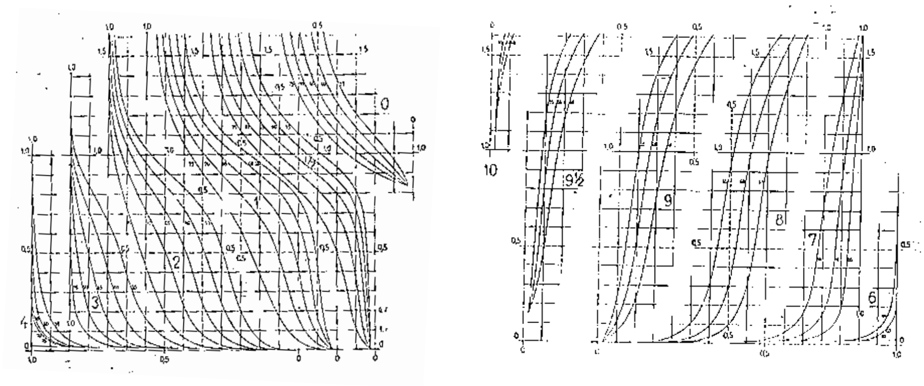

Figure 1. Body plan for the stern (left) and bow (right) for the U hull [3].

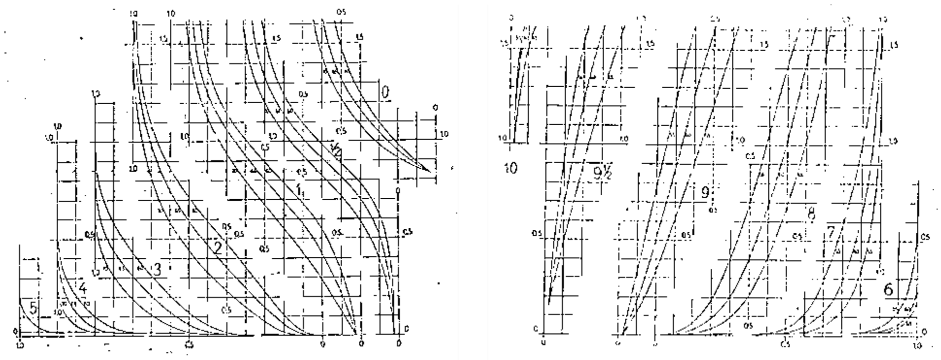

Figure 2. Body plan for the stern (left) and bow (right) for the V hull [3].

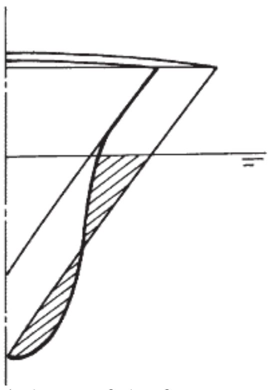

Figure 3. The difference in the cross-sectional shape of the front U and V with the area under the same draft [6].

2. Materials and methods

The method for this comparative analysis is described in this chapter. The study started with making the lines plan based on Formdata II [3]. Then, the hull characteristics were compared for both hulls. After that, their heave and pitch motions were simulated using the strip theory that assisted with Maxsurf software. After getting the RAO of heave and pitch motions, then the next step was to calculate the RAO of relative bow motion. Then, it calculated the wave spectrum of

JONSWAP and transformed it into the wave encounters form. Finally, it calculated the difference in the probability of slamming from the two hulls.

2.1. Making both hull models

The lines plan models were made based on Formdata II for the U and V hulls, as shown in Figures 1 and 2. It started with selecting the body plan or station line based on the available lines. The selection of the line also considered the desired C_B and L_{CB} values, where the values of the main dimensions for the two models are described in Table 1.

The difference in cross-sectional lines for the U hull and the V hull models can be seen in Figure 4. The red lines show the station lines for the U hull, and the blue lines show the station lines for the V hull. It can be seen that the station lines for the U and V hulls have different characteristics, which are the same as that described in Figure 3. The U hull has a larger area at the bottom part than that of the V hull, while the V hull has a larger area at the draft part than that of the U hull. The 3D hull models can be seen in Figure 5, where the red is the U hull model and the blue is the V hull model. The 3D modelling is assisted by Maxsurf software.

Table 1. The main dimensions of both hull models.

Item	Value	Unit
L_{PP}	60	m
B	12	m
H	4	m
T	2.7	m
C_B	0.6	

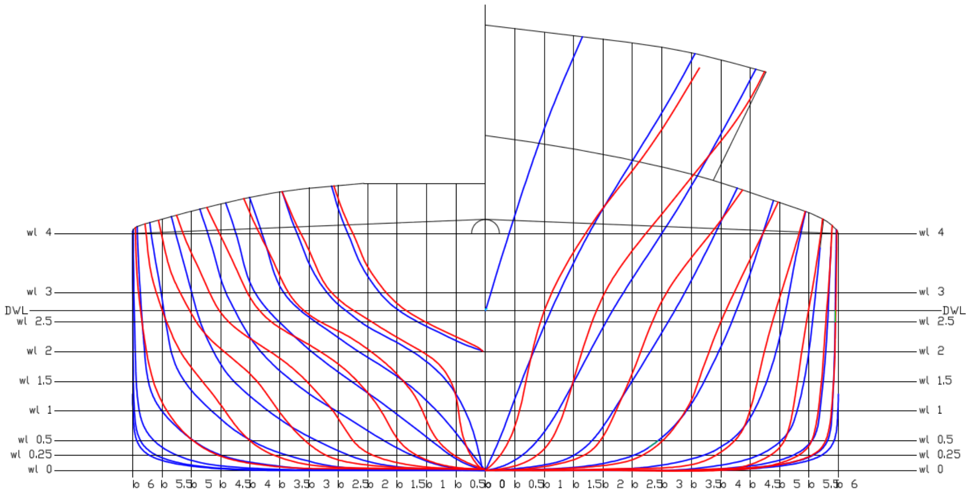

Figure 4. Comparison of cross-sectional or body plans (stations) of the U hull (red) and V hull (blue line) models.

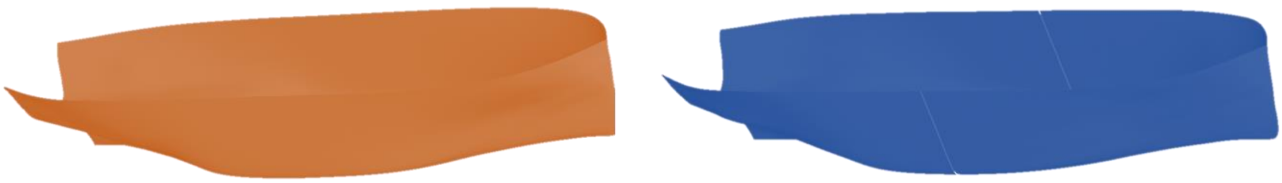
Figure 5. 3D models of the U hull (red) and the V hull (blue).

2.2. Ship Motions

Seakeeping is a measure of whether a ship is operating well in certain environmental conditions. These environmental conditions can be planned in advance with the alleged extreme conditions in a design operating sea area. The better the motion of the ship in passing the waves, the better the seakeeping value of the ship. Seakeeping ability is often associated with seasickness experienced by crew or passengers.

Each ship has a different characteristic of motion when it comes to the force of the waves, depending on the shape of the hull, the location of the centre of gravity and other factors. The ship's motion itself is divided into 6 types based on the axis of motion, namely 3 translational and 3 rotational, which are described in Figure 6. The X-axis translational motion is Surge, the Y-axis direction is Sway and Z-axis direction is Heave. While the rotational motion on the X-axis is Roll, on the Y-axis is Pitch and on the Z-axis is Yaw [17].

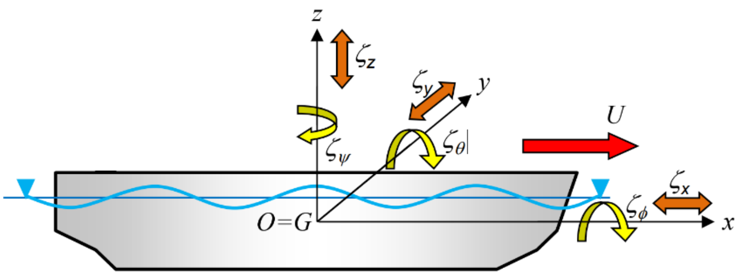

Figure 6. Axis system and ship movement definition [17].

2.3. Relative vertical motion in the centre of gravity

When the ship moves on the wavy sea, the ship will experience vertical motion with simple harmonic motion with the centre of motion at the centre of gravity. This motion consists of 6 motions described in Figure 6. Thus, the position of the centre of gravity and the buoyancy, then the value of mass or displacement, and the moment of inertia become important parameters that influence the motions.

The following describes the basic formulation of the motion of a floating structure, or ship, due to regular wave excitation. Assuming that the oscillating motions as shown in Figure 6. are linear and harmonic, the six differential equations for the coupling motion can be written as follows [17]:

$$\sum_{n=1}^{6}\left[(M_{jk}+A_{jk})\ddot{\zeta}_k+B_{jk}\dot{\zeta}_k+K_{jk}\zeta_k\right]=F_j e^{i\omega t}\,;j,k=1\,\ldots\ldots6 \quad (1)$$

where:

M_{jk}	=	matrix of ship′ s mass and moment of inertia
A_{jk}	=	matrix of hydrodynamic added mass coefficients
B_{jk}	=	matrix of hydrodynamic damping coefficients
K_{jk}	=	matrix of hydrostatic restoring force and moment coefficients
F_j	=	excitation force matrix and excitation moment in a complex function (expressed by $e^{i\omega t}$)
ζ_k	=	motion elevation on k mode
$\dot{\zeta}_k$	=	motion velocity on k mode
$\ddot{\zeta}_k$	=	motion acceleration on k mode

The ship's motion of heave, pitch and roll is oscillating, which is due to the restoring force created by the changes in buoyancy involved in these movements. The motion of the ship in response to waves can be thought of as a system of forcibly damped spring masses. To focus on the case of slamming events, it is sufficient only the heave and pitch equations are used in this case [25]. So, the equation for heave is as follows:

$$(M+A_{33})\ddot{\zeta}_3+B_{33}\dot{\zeta}_3+K_{33}\zeta_3+A_{35}\ddot{\zeta}_5+B_{35}\dot{\zeta}_5+K_{35}\zeta_5=F_3e^{i\omega t} \quad (2)$$

and for pitch is as follows:

$$(I_5+A_{55})\ddot{\zeta}_5+B_{55}\dot{\zeta}_5+K_{55}\zeta_5+A_{53}\ddot{\zeta}_3+B_{53}\dot{\zeta}_3+K_{53}\zeta_3=F_5e^{i\omega t} \quad (3)$$

where:

M	=	mass of the ship
I_5	=	moment of inertia for the pitch of the ship
A_{33}	=	the hydrodynamic added mass coefficient for heave due to heave
A_{55}	=	the hydrodynamic added mass coefficient for pitch due to pitch
A_{35}	=	the hydrodynamic added mass coefficient for heave due to pitch
A_{53}	=	the hydrodynamic added mass coefficient for pitch due to heave
B_{33}	=	the hydrodynamic damping coefficient for heave due to heave
B_{55}	=	the hydrodynamic damping coefficient for pitch due to pitch
B_{35}	=	the hydrodynamic damping coefficient for heave due to pitch
B_{53}	=	the hydrodynamic damping coefficient for pitch due to heave
K_{33}	=	the hydrodynamic restoring coefficient for heave due to heave
K_{55}	=	the hydrodynamic restoring coefficient for pitch due to pitch
K_{35}	=	the hydrodynamic restoring coefficient for heave due to pitch
K_{53}	=	the hydrodynamic restoring coefficient for pitch due to heave
F_3	=	excitation force that causes heave
F_5	=	excitation moment that causes the pitch
ζ_3	=	heave motion displacement = Z_a
$\dot{\zeta}_3$	=	heave motion velocity = $\dot{Z}_a$

$\ddot{\zeta}_3$ = heave motion acceleration = $\ddot{Z}_a$
ζ_5 = pitch rotation displacement = θ_a
$\dot{\zeta}_5$ = pitch rotation velocity = $\dot{\theta}_a$
$\ddot{\zeta}_5$ = pitch rotation acceleration = $\ddot{\theta}_a$
ω = frequency

In order to solve these matrix equations, it is necessary to obtain the coefficients and excitation force and moment. These numerical calculations were assisted using Maxsurf motion software [25].

2.4. Response amplitude operator (RAO)

Response Amplitude Operator (RAO) is commonly referred to as a transfer function, which is a response function that transfers the wave force into a dynamic response to the structure in the frequency range (ω). The RAO graph contains the frequency parameter at its abscissa and the ratio between the amplitudes of floating structure motion and the amplitude of the wave. The RAO on translational motion is formulated as follows [17]:

$$RAO_{Z_a}(\omega) = \frac{Z_a}{\delta_a}(\text{m/m}) \tag{4}$$

While the RAO on the rotational motion is the ratio between the amplitude of the rotational motion and the slope of the wave, namely the product of the wave number and the wave amplitude ($k\omega = \omega^2/g$) is formulated as follows [17]:

$$RAO_{\theta_a}(\omega) = \frac{\theta_a}{(\omega^2/g)\delta_a}(\text{rad/rad}) \tag{5}$$

where:
δ_a = wave amplitude
g = acceleration of gravity

2.5. Wave spectrum

Irregular wave is random waves that occur as a result of the sum of many waves that have different frequencies, heights and wave phases. Studying the behavior of ocean waves that have non-constant motions needs to use a statistical approach, which this approach can represent the actual situation [18]. Random waves are superpositions of regular waves in a very large number (theoretically up to infinity), with a combination of variations in H wave height (m) and ω frequency (rad/sec).

In the design of the floating structure, the information on the wave spectrum where the structure operated is required. However, not all oceans have been observed to collect wave data. It can choose environmental data that are considered similar to the operating area. In addition, it can also use the wave spectra formula that has been developed by several institutions. Among them are: Pierson & Moscowitz, Bretscheneider. Ochi & Hubble, JONSWAP, ITTC & ISSC spectrum. For this study, the wave spectrum uses JONSWAP, the function as follows [26, 27]:

$$S_{\delta_a}(\omega) = f(\alpha, g, \omega, \omega_0, \gamma, \tau) \tag{6}$$

where:
δ_a = wave amplitude
α = $0.076(X_0)^{-0.22}$
X_0 = $gX/{U_w}^2$
X = fetch length
U_w = wind speed
γ = peakedness parameter
τ = shape parameter
ω_0 = $2\pi(g/U_w)(X_0)^{-0.33}$

2.6. Wave encounter

The wave frequency (ω) changes when the ship moves at a certain angle to the wave direction which is known as the frequency of the wave encounter (ω_e) [17]. Therefore, the wave frequency is transformed into the encounter wave frequency with the following Equation [18]:

$$\omega_e = \omega\left(1 - \frac{\omega V_s}{g}\cos\mu\right) \tag{7}$$

where:
V_s = ship speed
μ = heading angle

2.7. Relatively vertical bow motion

The vertical motion along the length of the ship will vary. This happens because the heave and pitch motions occur simultaneously. This movement is called the coupled heaving and pitching motion. According to Bhattacharyya [18], the vertical motion along the ship is illustrated in Figure 7.

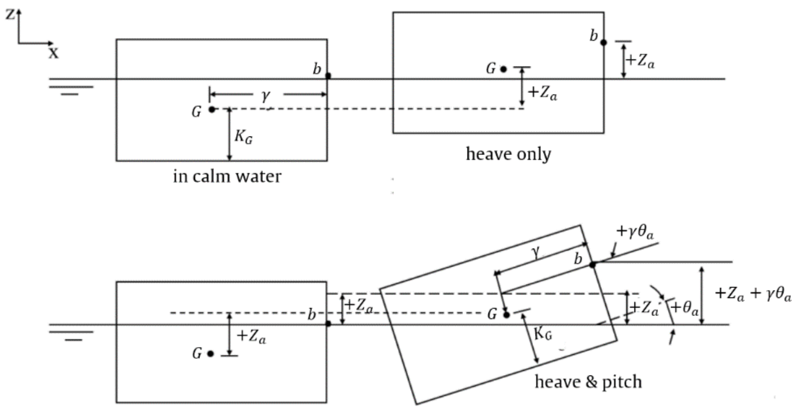

Figure 7. Relative bow motion [18].

If heave and pitch are coupled in the regular wave, then the equation becomes as follows:

$$Z_b = Z_a \cos(\omega_e t + \varepsilon_z) + \gamma\theta_a \cos(\omega_e t + \varepsilon_\theta) \tag{8}$$

$$Z_b = (Z_b)_a \cos(\omega_e t + \varepsilon_b) \tag{9}$$

$$(Z_b)_a = \sqrt{{Z_a}^2 + (\gamma\theta_a)^2 + 2Z_a\gamma\theta_a \cos(\varepsilon_z + \varepsilon_\theta)} \tag{10}$$

$$\varepsilon_b = \frac{Z_a \sin\varepsilon_z + \gamma\theta_a \sin\varepsilon_\theta}{Z_a \cos\varepsilon_z + \gamma\theta_a \cos\varepsilon_\theta} \tag{11}$$

where:

Z_b	=	vertical relative motion on the bow
ε_z	=	the phase angle of heave
ε_θ	=	the phase angle of pitch
γ	=	distance of the bow to the centre of gravity
$(Z_b)_a$	=	motion amplitude of the bow
ε_b	=	the phase angle of the bow motion

2.8. Response spectrums

After getting the response of the floating structure on regular waves, the next step is to calculate the response on irregular waves. The response of the floating structure on irregular waves is arranged in the form of a response spectrum so that the equation for each motion response on the irregular wave is formulated as follows:

$$S_{Z_a}(\omega_e) = [RAO_{Z_a}(\omega_e)]^2 \times S_{\delta_a}(\omega_e) \tag{12}$$

$$S_{\theta_a}(\omega_e) = [RAO_{\theta_a}(\omega_e)]^2 \times S_{\delta_a}(\omega_e) \tag{13}$$

$$S_{Z_b}(\omega_e) = [RAO_{Z_b}(\omega_e)]^2 \times S_{\delta_a}(\omega_e) \tag{14}$$

2.9. Slamming occurrence

A slamming phenomenon is characterized by a sudden load of relatively short duration imposed on the hull. This event occurs when the hull enters the water with a relatively small angle between the hull surface and the water surface. In this case, the contact area between the hull and the water surface occurs at a high speed, even though the hull's movement speed is moderate [28].

Slamming occurs because there is a phase difference between the ship's structure and the wave phase. This phase difference causes the structure of the ship to be lifted out of the sea surface and after that, it falls to hit the sea surface. The occurrence of the entry of the hull into the sea surface occurs so quickly that it produces an impact load which is called a slamming load. Slamming events can occur repeatedly and are categorized as dynamic loads [29].

According to Bhattacharyya [18], slamming will occur when the following 2 (two) conditions are met:

1. The bottom of the bow rises over (emerge) the waves or in other words the relative vertical movement of the bow (Z_b) exceed the water draft at the bow ($Z_b > T_b$), and

2. The relative vertical speed of the bow ($\dot{Z}_b$) has a value that exceeds the slamming threshold velocity. It should be noted here, that the actual slamming effect only occurs or is experienced by floating structures when at the time the bottom of the bow re-enters the water or the waves have a certain speed. If the speed is too low then the bow can be said to just submerge back into the water, so that the slamming effect will not be felt.

Thus, the probability of slamming occurring must also meet these 2 (two) conditions. The first criterion is described as follows:

$$\text{Pr(forefoot emergence)} = \text{Pr}(Z_b > T_b) = e^{-\left(T_b{}^2/2m_{0_b}\right)} \tag{15}$$

The second is the probability that the relative vertical speed of the bow is greater than the threshold slamming velocity:

$$\text{Pr(threshold velocity)} = \text{Pr}(V_b > V_0) = e^{-\left(V_0{}^2/2m_{2_b}\right)} \tag{16}$$

So, the probability of slamming is thus a combination of Equation (15) and Equation (16), which can be written as:

$$\text{Pr(slamming)\%} = \text{Pr}(Z_b > T_b \text{ and } V_b > V_0) = e^{-\left(T_b{}^2/2m_{0_b}+V_0{}^2/2m_{2_b}\right)} \times 100\% \tag{17}$$

Bhattacharyya [18] gives a reference for the threshold velocity = 12.0 ft/s (= 3.65 m/s) for ships with a length of 520 ft (= 158.5 m), if the length of the ship has different length values, it can be obtained by taking into account the law of scale, namely ft/s. For example, the vessel under study has 550 ft (= 167.6 m) then the threshold speed is = 12.6 ft/s (= 3.84 m/s).

Meanwhile, the frequency of slamming per unit time (N_{slam}) can be predicted by the equation:

$$N_{slam} = \frac{1}{2\pi}\sqrt{\frac{m_{2_b}}{m_{0_b}}} \times \text{Pr(slamming)} \tag{18}$$

where:

T_b	=	draft at bow
V_b	=	vertical velocity at the bow
V_b	=	threshold velocity for slamming occurrence
m_{0_b}	=	area of the response spectrum of bow vertical motion, see Equation (19)
m_{2_b}	=	area of the response spectrum of bow vertical velocity, see Equation (20)

$$m_{0_b} = \int_0^\infty S_{Z_b}(\omega_e)d\omega_e \tag{19}$$

$$m_{2_b} = \int_0^\infty\int_0^\infty S_{Z_b}(\omega_e)d\omega_e \tag{20}$$

3. Result and discussion

3.1. Differences in the hydrostatic of the U hull and the V hull

After obtaining a body plan for the U and V hulls from Formdata method, the two hulls were modelled in the 3D model using the Maxsurf software. With the help of the software, the calculations of hydrostatic characteristics could be calculated and compared. The results of the calculations are presented in Table 2. As a comparative analysis tool, Equation (21) was used here and also for the next comparations.

Based on the calculation results shown in Table 2, it can be seen that the hull U and hull V have a very slight difference in the volume displacement value, which is 0.2 m3 or 0.02%. The values of L, B, T, and C_B, for both models also have the same value. Parameters C_P, C_M, L_{CB}, and L_{CF} have very small differences, which are below 0.3%. With this slight difference value, the two hulls can be considered to have the same value for some parameters, so that the comparative resistance value can be analyzed properly.

$$\Delta\% = \frac{\text{result of U} - \text{result of V}}{\text{result of V}} \times 100\% \tag{21}$$

The values that are strikingly different from the two hulls are the values of wetted surface area (WSA), C_{WP}, and K_B. The WSA for the U hull is greater than that of the V hull. This is because, following the description of the different body plan lines in Figure 4, it can be seen that the U hull has a longer line than that of the V hull. Next, the V hull has a higher C_{WP} value than that of the U hull, because the V hull has a wide shape at the top part and a narrow shape at the bottom. The K_B value for the V hull is also higher than that of the U hull, because the V hull has a wide area at the top part and a narrow area at the bottom part, unlike the U hull which has a wide area at the bottom part than that of the V hull.

Table 2. Results of the differences in hydrostatic characteristics of the U and V hulls

Parameter	Units	Value		Δ%
		U hull	V hull	
Volume disp.	m^3	1188.40	1188.20	0.017
L_{WL} (L)	m	62.306	62.306	0.000
Breadth (B)	m	12.000	12.000	0.000
Draft (T)	m	2.700	2.700	0.000
WSA	m^2	735.331	726.387	1.231
C_B		0.586	0.586	0.000
C_P		0.600	0.600	0.000
C_M		0.979	0.979	0.000
C_{WP}		0.703	0.705	-0.284
L_{CB}	%	1.548	1.549	-0.084
L_{CF}	%	4.403	4.402	0.011
K_B	m	1.442	1.458	-1.097

3.2. RAO of heave and pitch results

The RAO for the U and V hull models were predicted using the strip theory method assisted by Maxsurf software. Each hull obtained RAO heave and pitch curves arranged in Figure 8. Each hull was simulated with three variations of speed, namely 8, 12, and 16 knots. From the differences in ship speed variations, it can be seen that the higher the speed, the higher the heave and pitch values at almost all frequency values, except for frequencies above about 1.8, where the difference of the values is very fluctuating.

Based on the simulation results on the RAO heave motion (Figure 8a), it can be seen that the heave of the U and V hulls vary widely. At low frequencies, where ω_e is less than about 1.3, the difference in the heave values for the two hulls is not visible, and it can be said to be less different. At frequencies between about 1.3 to about 1.8, it can be seen that the U hull produces a higher heave than that of the V hull. Meanwhile, for frequencies above about 1.8, there is a fluctuating difference in the heave value between the two hulls.

The simulation results for the RAO pitch are described in Figure 8b. At low frequencies, below about 1.3, the V hull appears to have a higher pitch value than that of the U hull. Then, at frequencies about 1.3 to about 2.0, the U hull appears to have a higher pitch value than that of the V hull. At frequencies above about 2.0, there is fluctuations in the pitch value difference between the two hulls.

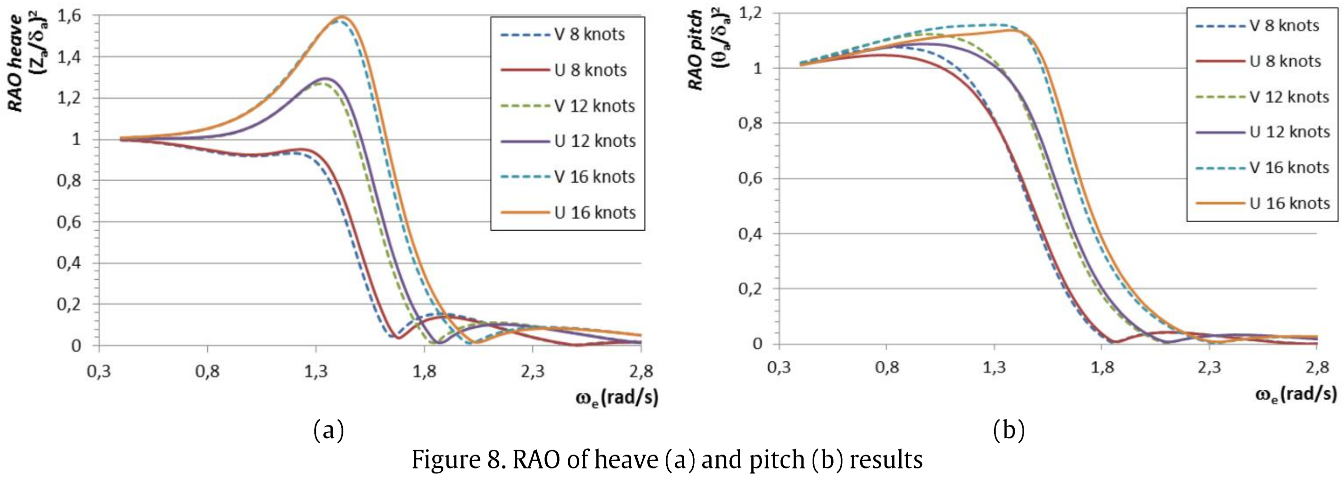

Figure 8. RAO of heave (a) and pitch (b) results

3.3. RAO of relative bow motion (RBM) results

The RBM value is obtained by combining the heave and pitch values based on Equation (8). The two hulls were calculated at each speed variation, where the results of the RAO RBM calculation are arranged in Figure 9. It can be seen from the speed variations that at frequencies below about 0.9, the higher the speed of the ship, the higher the speed of the ship. the RBM value is also high. While at frequencies above about 0.9, the opposite occurs, namely the higher the speed of the ship, the smaller the RBM value.

The results of the RAO RBM calculation show that there is a difference in the RBM value between the U hull and the V hull. At frequencies below about 0.9, the RBM value of the V hull is higher than that of the U hull. At frequencies above about 0.9, the RBM value of the V hull is lower than that of the U hull.

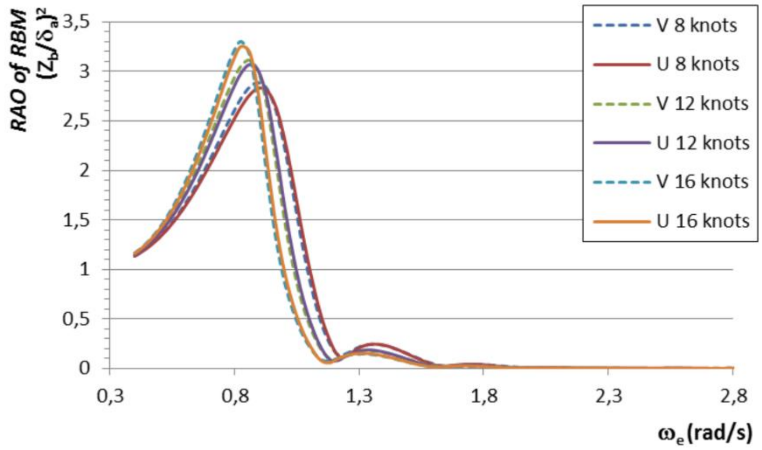

Figure 9. RAO of relative bow motion (RBM) results.

3.4. Wave and wave encounter spectrums calculation results

The irregular wave spectrum used is from JONSWAP, with a wave height of H_S = 1,502 m, and a wind speed of 15 knots. This calculation uses Equation (6). The spectrum of the random wave is described in Figure 10a, which is then transformed into an encounter wave described in Figure 10. The encounter wave spectrum is calculated for each speed variation.

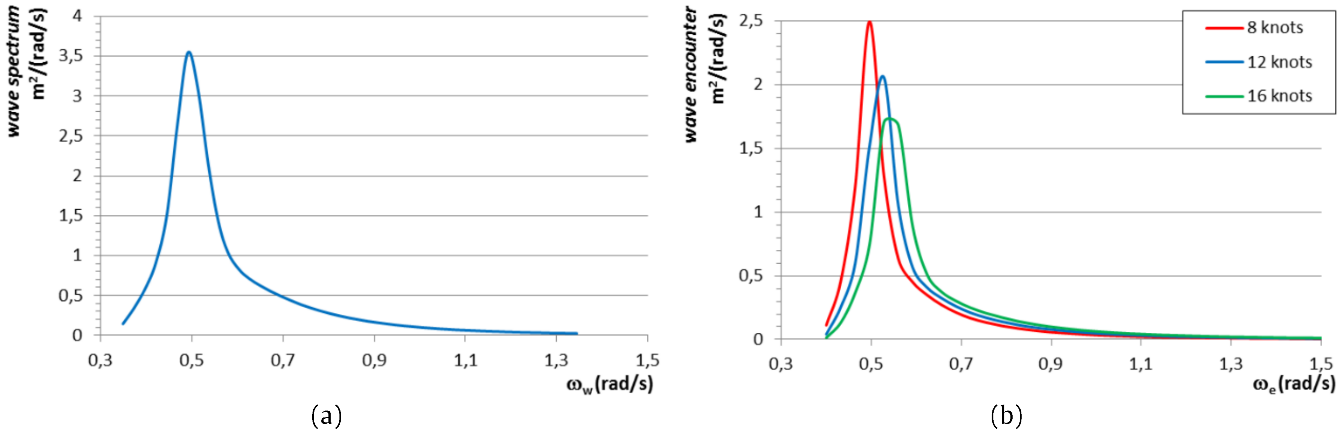

Figure 10. Wave (a) and wave encounter (b) spectrums calculation results

3.5. Amplitude, velocity and acceleration spectrums of RBM results

In this subsection, the results of the calculation of the motion spectra needed to calculate the slamming incident are explained. Figure 11 shows the vertical motion amplitude spectrum of the bow (RBM), which is calculated based on Equation (14). Figure12 is the vertical motion velocity spectrum of the bow calculated from the first derivative of the vertical motion amplitude spectrum. Fig. 13 is the spectrum for the acceleration of the vertical motion of the bow which is calculated based on the second derivative of the spectrum for the amplitude of the vertical motion. It can be seen from all the motion spectra, almost all of them show that the value of the motion spectrum in the U hull is higher than in the V hull.

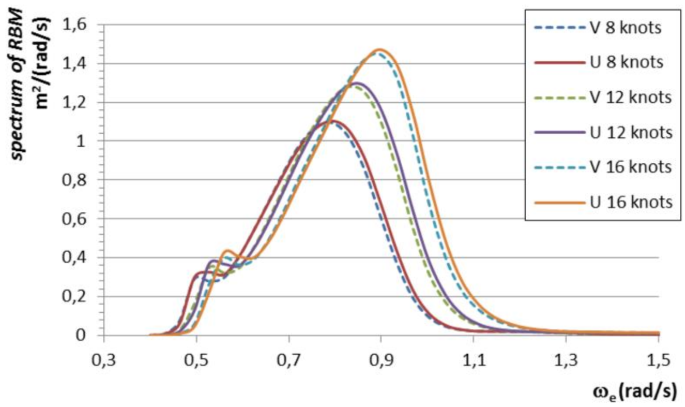

Figure 11. Spectrum vertical amplitude of RBM

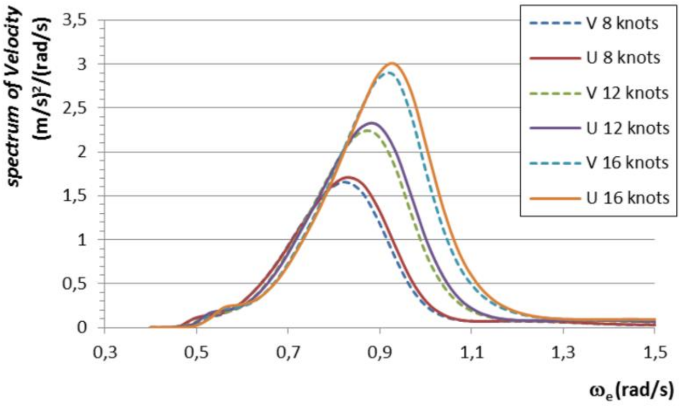

Figure 12. Spectrum vertical velocity of RBM

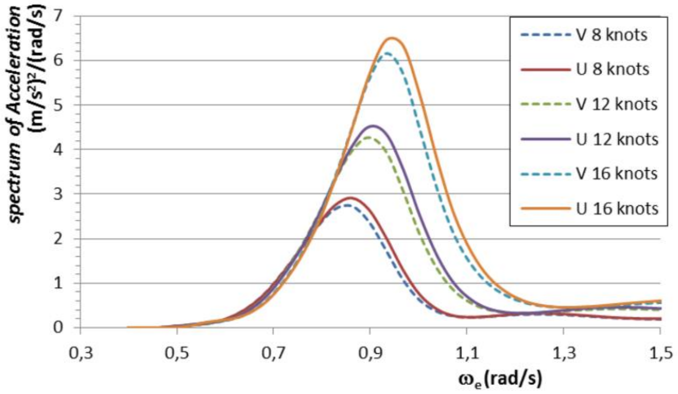

Figure 13. Spectrum vertical acceleration of RBM

3.6. Probability of slamming prediction results

After obtaining the RBM spectrum from each hull and the speed variations, this chapter describes the results of calculating the probability of slamming events. The probability of a slamming event is calculated based on Equation (17). The results of the calculation of the slamming probability are described in Table 3. The m_{0_b} value in the table is calculated using Equation (19), while the m_{2_b} value is calculated using Equation (20). The difference in the slamming probability value (D%) is calculated using Equation (21).

Based on the results of the calculations in Table 3, the higher the speed, the higher the probability of a slamming event. The increase in the probability of slamming due to the increase in speed is quite high. The probability of slamming increased more than 4 times from a speed of 8 knots to a speed of 12 knots. The slamming probability increased by more than 1.5 times for the increase in speed from 12 knots to 16 knots. This increase applies to both hulls, namely hull U and hull V.

In Table 3, it can be seen that the value of the difference in the probability of slamming the U hull is always higher than that of the V hull for each speed variation. It can be seen in the value of Δ%, where the highest difference occurs at low speed, which is 8 knots worth 34.48%. The difference keeps getting smaller as the ship speed value increases. To get a clear picture that the slamming probability values for the U hull and the V hull are described in Figure 14. Where it is clear that the U hull has a higher slamming probability than that of the V hull.

This study explains that the difference in the shape of the hull section, such as the U and V hulls, causes differences in the motion values. It can be seen in Table 2, that the parameters that cause the difference in the probability of this slamming occur due to differences in the values of C_{WP}, K_B, and WSA. This is in accordance with what was described by SNAME [16] that the V section has better seakeeping motion than that of the U section, but the V hull produces greater wave resistance than that of the U hull [6].

Table 3. Probability of slamming prediction results

ship speed [knots]	m_{0_b} [m²]		m_{2_b} [(m/s)²]		Pr (slamming) %		Δ%
	U hull	V hull	U hull	V hull	U hull	V hull	
8	0.69	0.668	0.983	0.936	0.039	0.029	34.48
12	0.838	0.813	1.393	1.326	0.210	0.167	25.75
16	0.958	0.93	1.808	1.718	0.549	0.455	20.66

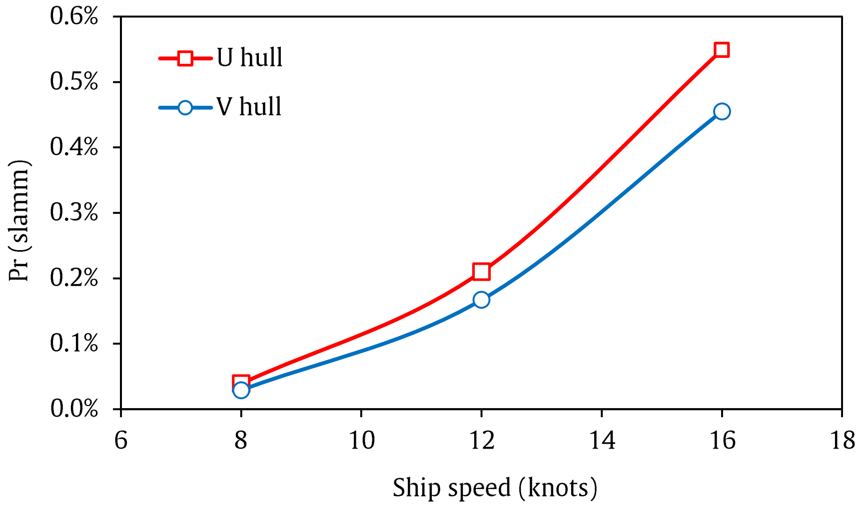

Figure 14. The difference in probability of slamming prediction results

4. Conclusions

A simulation of the calculation of the difference in the probability value of slamming events between the U and V hulls has been carried out. Both hulls were made based on Formdata. The two hulls made must have the same parameters, such as the main size, volume, C_B, L_{CB}, C_M and others, so that what cannot be forced to be the same is the value of WSA, C_{WP}, and K_B. This needs to be done so that the results of the comparative analysis were feasible.

The calculation results show that the U hull has a higher probability of slamming occurrence than the U hull at each speed variation. This difference, the hull is 20% to 35% superior to the V hull. The higher the speed, the higher the probability of a slamming event. With a higher chance of slamming, this will result in the structure being exposed to more slamming loads which are impact loads, in which case the consequences of a higher risk of damage must be considered. Then in terms of comfort, it is also a consideration, such as passenger ships that must have comfortable and safe seakeeping performance for passengers. With these results, it is hoped that the designers can consider the results of this study in designing ships.

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