

Analysis of Heaving Motion of Purse Seine Vessel Against Regular Waves Following Seas

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Abstract

The study aims to (1) analyse the technical characters of ship (design, principal dimension, and hydrostatic parameters) and the characteristics of wave (wave length) in connection with heaving motion, and (2) heaving amplitude and encounter frequency that influence the convenience of the ship's crew, its speed and safety. The study was conducted from April to June 2021 at Papandangan Island of Pangkep Regency, South Sulawesi. The data were analysed with numeric analysis, Attwood's formula and Lewis from based on Strip Theory. The study indicates that ships with larger number of characters and ships with a ratio of $Lw/Ls = 1.0$ (16.75 m, 16.85 m, and 16.95 m) or the wavelength that occurs equals to the length of the ships, the potential of the heaving motion to occur is feeble. Heaving amplitude and encounter frequency with a ratio of $Lw/Ls = 1.5$ (25.75 m, 25.85 m, and 25.95 m) or the wavelength is larger than the length of the ship. Will influence the convinience of the ship crews, the speed and safety of the ship.

Keywords: heaving, purse seine vesel, following seas.

INTRODUCTION

Most of the traditional fishing vessels in Pangkep district, South Sulawesi, particularly purse seines, are built using traditional methods without planning design drawings (Hasriyanti & Syarif, 2022). These vessels are functional, but there is no operational feasibility standard issued by the authorized body, the Indonesian Classification Bureau (BKI). It is important to carefully design and construct fishing boats to ensure the comfort and safety of employees. The vessel

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should be stable on the water surface during use, capable of different speeds and maneuverability, and strong enough to withstand unpredictable weather conditions, thus ensuring its durability (Pamuji et al., 2014; Purwanto et al., 2018; Sutulo & Guedes Soares, 2021).

The safety characteristics of purse seine vessels differ from other fishing vessels due to their operations far from the shore and the search for schools of fish (Wati & Primyastanto, 2018). These vessels are particularly vulnerable to adverse sea weather conditions. Additionally, the presence of the crew and the positioning of the fishing gear cause the weight of the vessel to be centered on one side of the hull during operations, resulting in a tilt or bow when the fishing gear is retracted or lowered. To ensure the safety of purse seine vessels during sea operations, good stability under these conditions is required.

During sailing, a ship experiences six motions based on the axes of symmetry (x, y, and z), including three translational motions (swaying, surging, and heaving) and three rotational motions (rolling, pitching, and yawing).

The heaving motion is one of the most important factors determining a ship's performance (seakeeping) on ocean waves. The ship's level of effectiveness in the short and long term can be assessed through its seakeeping quality, which reflects its operating techniques. Currently, the makers of fishing boats, particularly purse seine vessels in South Sulawesi, have only relied on techniques and forms passed down through generations without testing the ships using a ship testing model. This is because theoretical knowledge is lacking, there are no testing facilities for ship models, and it requires significant costs. Based on the aforementioned reasons, this research aims to study the factors that influence the heaving motion of purse seine vessels. The author will adopt a theoretical approach using the simulation method to obtain these values.

RESEARCH OBJECTIVES AND BENEFITS

This research was conducted on Papandangan Island and Kulambing Island, Pangkep Regency, South Sulawesi, and the research time was two months, from April to June 2021. The main research materials were purse seine vessels and wave characteristics. The purse seine vessel data used are data from direct measurements in the field on purse seine vessels commonly operated in the waters of Pangkep Regency (Table 1).



Table 1. Specifications of Purse Seine Vessels A, B, and Cnefits

No.	Description	Ship		
		A	B	C
1.	LOA (m)			
2.	Lpp (m)	17.98	20.02	15.99
3.	Lwl (m)	16.86	19.00	14.78
4.	BOA (m)	3.70	3.38	3.36
5.	D (m)	1.16	1.04	1.03
6.	d (m)	0.90	0.92	0.92
7.	L/B	4.86	5.92	4.76
8.	L/D	15.50	19.25	15.52
9.	B/D	3.19	3.25	3.26
10.	Cb	0.45	0.58	0.52
11.	Δ (tonnes) Full loaded	24.50	34.14	24.58
12.	Longitudinal centre of Bouyancy	-0.25	0.27	0.05
13.	KG distance (m)	0.92	0.94	0.92
14.	Ship speed (m/sec)	5.154	5.154	5.154
15.	Coordinate Distance (m)	0.98	0.99	0.97

In the measurement of sample vessels, the following tools were used: roller meter, pendulum, pole ruler, small hose, nylon rope, small nails, waterpass, stationery, and drawings. The wave data used was obtained from real-time data provided by the Makassar Meteorological and Geophysical Agency (BMG).

RESEARCH METHODS

The research method used in this study is numerical analysis/simulation. The field data obtained were processed theoretically and calculated based on naval architecture calculations (Fyson, 1985). These calculations were used to obtain hydrostatic parameters as an initial assessment in the study, as well as heaving movements in regular following seas.

The analysis of static stability values was conducted through the GZ curve using Attwood's Formula method (Hind, 1982). This method analyzes the static stability of the vessel within an angle range of 0° - 90°. The results of the stability analysis were then compared with



the ship stability standards issued by the United Kingdom Regulation (Hind, 1982; International Maritime Organization (IMO), 1977; The Fishing Vessels, 1977).

The values of added mass coefficient, damping coefficient, restoring force, and exciting force were determined using the Lewis form method based on strip theory. This method involves dividing the ship into 10 longitudinal sections (Figure 1).

The tools used for the research included 1 personal computer (PC) equipped with EXCEL software for mathematical calculations and graphical representation of amplitude and frequency encounter values.

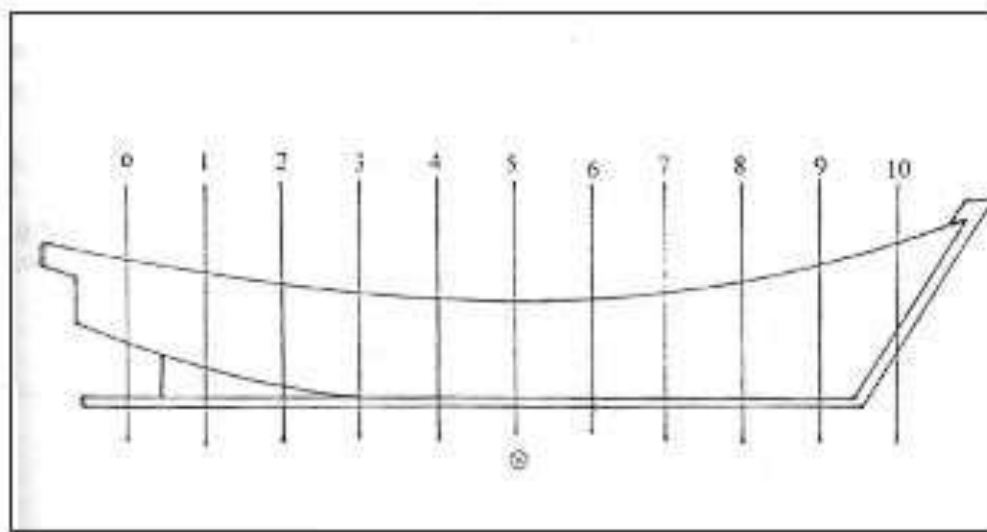


Figure 1. Division of the Ship into 10 sections

Data Analysis

Data analysis was conducted to obtain the frequency and amplitude values of heaving motion of purse seine vessels in regular following seas. These values are determined based on the combination of wavelength, vessel speed, and time duration of the vessel's motion against the waves. The data were analyzed using theoretical ship seakeeping calculation formulations.

The formula used for ship seakeeping analysis (Rameswar, 1978) is as follows:

$$\text{Wave frequency } (\omega_w) = 2\pi g/L_w \quad (1)$$

where L_w is the wavelength and g is gravity

Wave number (k) = $2\pi/L_w$ (2)

Encountering frequency (ω_e) = $\omega_w - \omega_w^2/gv \cos \mu$ (3)

where v is the vessel speed and μ is the angle of encounter

Calculation formula for heaving parameters in regular waves:

Added mass (a) = $\frac{1}{3} \times s \times \text{SUM1}$ (4)

where s = distance between ordinates

$\text{SUM1} = \sum (a_n \times s_n)$ (5)

s_n = Simpson's multiplier

$a_n = C \times \rho p / 8 \times B_n^2$ (6)

where C = coefficient of added mass

ρ = seawater density (1.025 tonnes/m³)

$p = 3.14$

B_n = vessel width at each station

Damping coefficient (b) = $\frac{1}{3} \times s \times \text{SUM2}$ (7)

where $\text{SUM2} = \sum (b_n \times s_n)$ (8)

$b_n = (\rho x g^2 x A^2) / \omega_e^3$ (9)

where A = amplitude ratio for two-dimensional shape

g = acceleration of Earth's gravity (9.8 m/sec²)

ω_e = encounter frequency (rad/sec)

Restoring force coefficient (c) = $\frac{1}{3} \times s \times \text{SUM3}$ (10)

where $\text{SUM3} = \sum (c_n \times s_n)$ (11)

$c_n = \rho x g x B_n$ (12)

Exciting force (F) = $F_o \cos \omega_e t$ (13)

where F_o = amplitude of the total exciting force

= $\rho x g x \zeta_a \times L x B x f_o$ (14)

where f_o = nondimensional force amplitude

$f_o = 2 / (L x B) \times \frac{1}{3} \times s \times \text{SUM4}$ (15)



where $SUM4 = \sum (B_n/2) \times \cos(k\chi \times \cos \mu) \times \sin \chi$ (16)

where χ = distance from LCG

k = wave number = $2\pi/L_w$

Natural heaving period (T_z) = $2\pi \times a/c$ (17)

Heaving amplitude (Z_a) = $Z_{st} \times \mu_z$ (18)

Z_{st} = static heaving amplitude = F_0/c

μ_z = Magnification factor = $z_a/z_{st} = 1/\sqrt{(1-\Lambda^2)^2 + 4\kappa^2 \Lambda^2}$ (19)

where Λ = Turning factor = $\omega_e/\omega_z = \omega_e/vc/a$ (20)

κ = nondimensional damping factor = $b/2a \omega_z$ (21)

where a = virtual mass = Δ/g

ω_z = natural frequency = c/a

b = damping force

Phase angle between wave motion and heaving motion:

$d = d_1 + d_2$ (22)

where

d_1 is the phase angle between the wave motion and the exciting force caused by waves,

d_2 is the phase angle between the exciting force and heaving motion. Since $d_1 = 0^\circ$, then $d_2 = \tan^{-1} (2\kappa\Delta/1-\Delta^2)$.

$\zeta = \zeta_a \times \cos \omega_e \times t$ (23)

$z = z_a \times \cos (\omega_e \times t - d)$ (24)

DISCUSSION

Main Dimensions of the Vessel

The purse seine vessels in Pangkep Regency that were used as research objects share a similar design and construction. The only difference lies in the size of the main dimensions, which is illustrated in Table 2 below:

Table 2. Main dimensions of purse seine vessels in Pangkep district

SHIP	Main Dimension			
	Lpp	B (m)	D (m)	d (m)
A	15.60	3.70	1.16	0.90
B	17.80	3.38	1.04	0.92
C	13.58	3.36	1.03	0.92

The main dimension ratios, including L/B, L/D, and B/D, along with the reference values derived from the average of these ratios for other purse seine vessels, are presented in Table 3.

Table 3. Main Dimension Ratios of Purse Seine Vessels

Ship	L/B	L/D	B/D
A	4.86	15.50	3.19
B	5.92	19.25	3.25
C	4.76	15.52	3.26
Reference Value*)	< 4.30	< 10.0	> 2.15

*(Ayodhya, 1972)

In Table 3, it can be observed that the L/B and L/D values for ships A, B, and C do not fall within the reference value range specified by (Ayodhya, 1972). However, the B/D value range for these ships aligns with the reference values.

Deviation of the L/B and L/D values of the sample vessels (A, B, and C) from the reference range provided by (Ayodhya, 1972) can have implications on the ship's performance. A larger L/B value tends to decrease maneuverability and stability, but it increases speed and offers a better space-to-price ratio. On the other hand, a larger L/D ratio value tends to decrease the longitudinal strength of the ship.

In the case of the purse seine vessels used as research objects, it is evident that ships A and B exhibit a U-shaped body form from the midsection to the stern, while displaying a V-shaped form at the bow. Ship C, on the other hand, features a V-shaped body form at the bow, a round-type shape in the middle, and a U-shaped form at the stern.



Stability of Purse Seine Vessels

The calculation results for the ratio between KG and D, as well as the metacentric radius (GM) of the researched purse seine vessel, are presented in Table 4.

Table 4. KG/D and GM Values of Purse Seine Vessel

Ship	KG/D ratio	GM (m)
A	0.79	0.956
B	0.91	0.765
C	0.90	1.078
Reference Value	0.75 – 0.91*)	> 0.31**)

*) (Fyson, 1985)

**) (Nomura & Yamazaki, 1975)

Hydrostatic parameters such as BM (Buoyancy Moment) and KM (Keel Moment) values are essential for assessing the initial stability of a ship. The KM value represents the distance between the metacentric point and the keel, which is the point of rotational coupling. On the other hand, the BM value refers to the distance between the buoyancy point and the metacentric point. Alongside the metacentric point, there are also the buoyancy point (B) and the weight point (G), and the positions of these three points significantly influence the static stability of a ship.

The theoretical calculations for the sample ships (A, B, and C) indicate that the weight point (G) is located below the metacentric point (M). This implies that the righting arm or the righting lever (GZ) has a positive value. A positive GZ allows the ship to return to its original position after being subjected to external disturbances such as waves, thereby maintaining a stable equilibrium condition. The positions of these three points align with the findings of (Nomura & Yamazaki, 1975), who state that for a ship to be in a balanced state in water, the buoyancy point (B) must lie in a vertical line with the weight point (G), and the weight point (G) must be situated below the metacentric point.

Based on Table 4, it can be observed that ship A exhibits better stability compared to ships B and C. This conclusion is drawn from the maximum righting arm (GZ max) obtained for ship A, which meets the stability criteria outlined by the (International Maritime Organisation



(IMO, 1983). According to the criteria, the maximum righting arm (GZ max) should be achieved at an angle of 30° and should not be less than 250 mm.

Regular Waves in Following Seas

Table 5 shows the theoretically calculated characteristics of the three regular waves for sample vessels A, B, and C.

Table 5. Theoretically Calculated Regular Wave Characteristics

Ship	Wavelength (m)	Wave Frequency (radian/detik)	Wave Speed (m/detik)
A	8.86	2.636	3.718
	16.86	1.911	5.129
	25.86	1.543	6.353
B	9.9	2.493	3.931
	19	1.800	5.445
	29	1.457	6.727
C	7.78	2.813	3.484
	14.78	2.097	4.674
	22.78	1.644	5.296

In Table 5, it is evident that as the wavelength increases, the wave frequency value decreases, while the wave speed value increases with the increasing wavelength.

Ship Heaving Motion in Regular Wave Following Seas

The heaving motion of the ship is influenced by both external factors, such as wave characteristics, and internal factors arising from the ship's own shape. These internal factors include added mass, damping coefficient, restoring force, and exciting force. In this study, the ship was observed under full load conditions, and the values of each factor were obtained for sample ships A, B, and C (Figures 2, 3, 4, and 5).



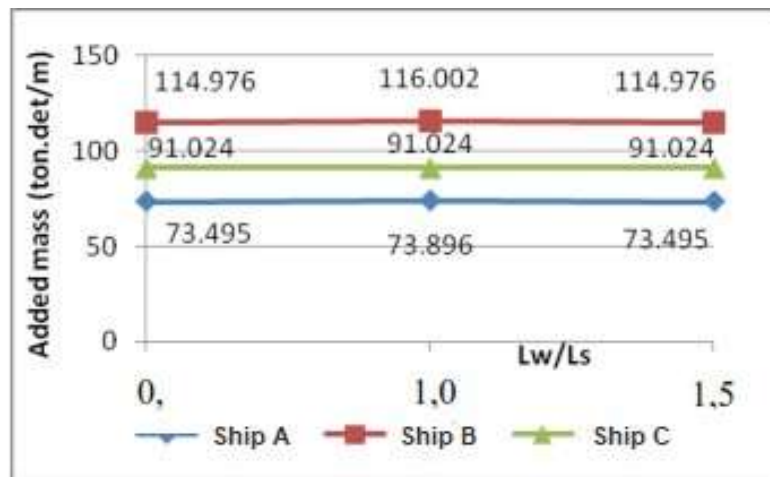


Figure 2. Added Mass of Purse Seine Vessels A, B, and C at Various Lw/Ls Ratios

In Figure 2, it is observed that the added mass values of ships A, B, and C increase at an Lw/Ls ratio of 1.0 and decrease at an Lw/Ls ratio of 1.5.

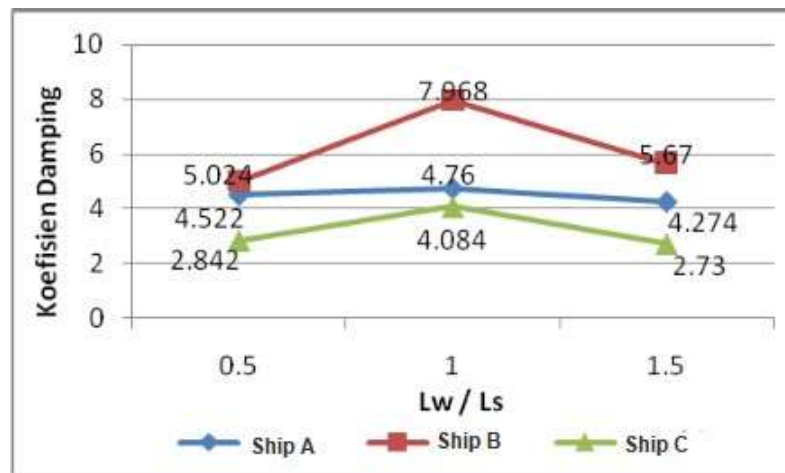


Figure 3. Damping Coefficients of Purse Seine Vessels A, B, and C at Various Lw/Ls Ratios

Figure 3 shows that the damping coefficient values for sample vessels A, B, and C follow a similar pattern. They increase at an Lw/Ls ratio of 1 and decrease at an Lw/Ls ratio of 1.5.

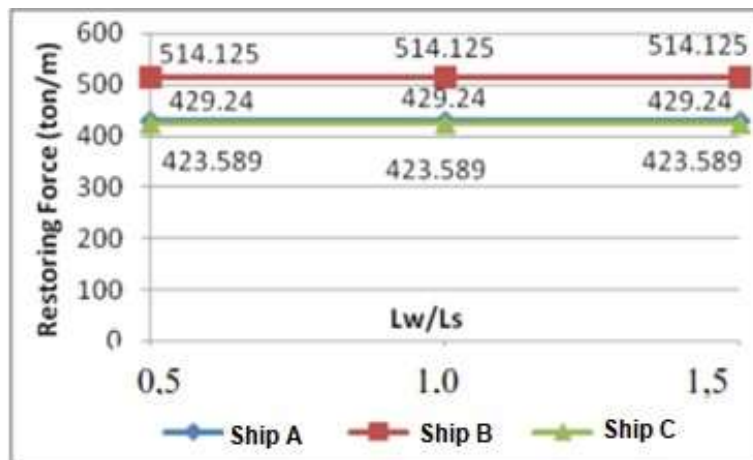


Figure 4. Restoring Force of Purse Seine Vessels A, B, and C at Various Lw/Ls Ratios

In Figure 4, the Restoring Force values for each sample ship A, B, and C at different Lw/Ls ratios are consistent.

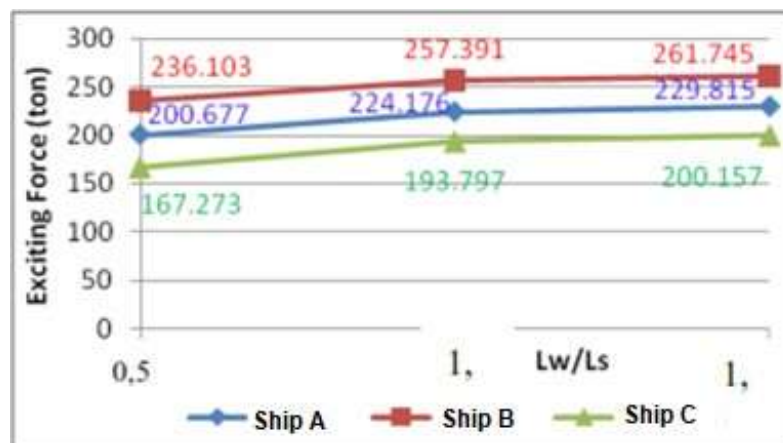


Figure 5. Exciting Force of Purse Seine Vessels A, B, and C at Various Lw/Ls Ratios

Figure 5 illustrates that the Exciting Force values for sample vessels A, B, and C increase with each increment in the Lw/Ls ratio.

The theoretical calculations, performed using equations (18) and (3), were simulated and

graphically presented in Figures 6 and 7. These graphs represent the estimated heaving motion of each ship at three L_w/L_s ratios over a duration of 50 seconds. The simulations were conducted at two different ship speeds: 5 knots (2.574 m/s) and 10 knots (5.148 m/s).

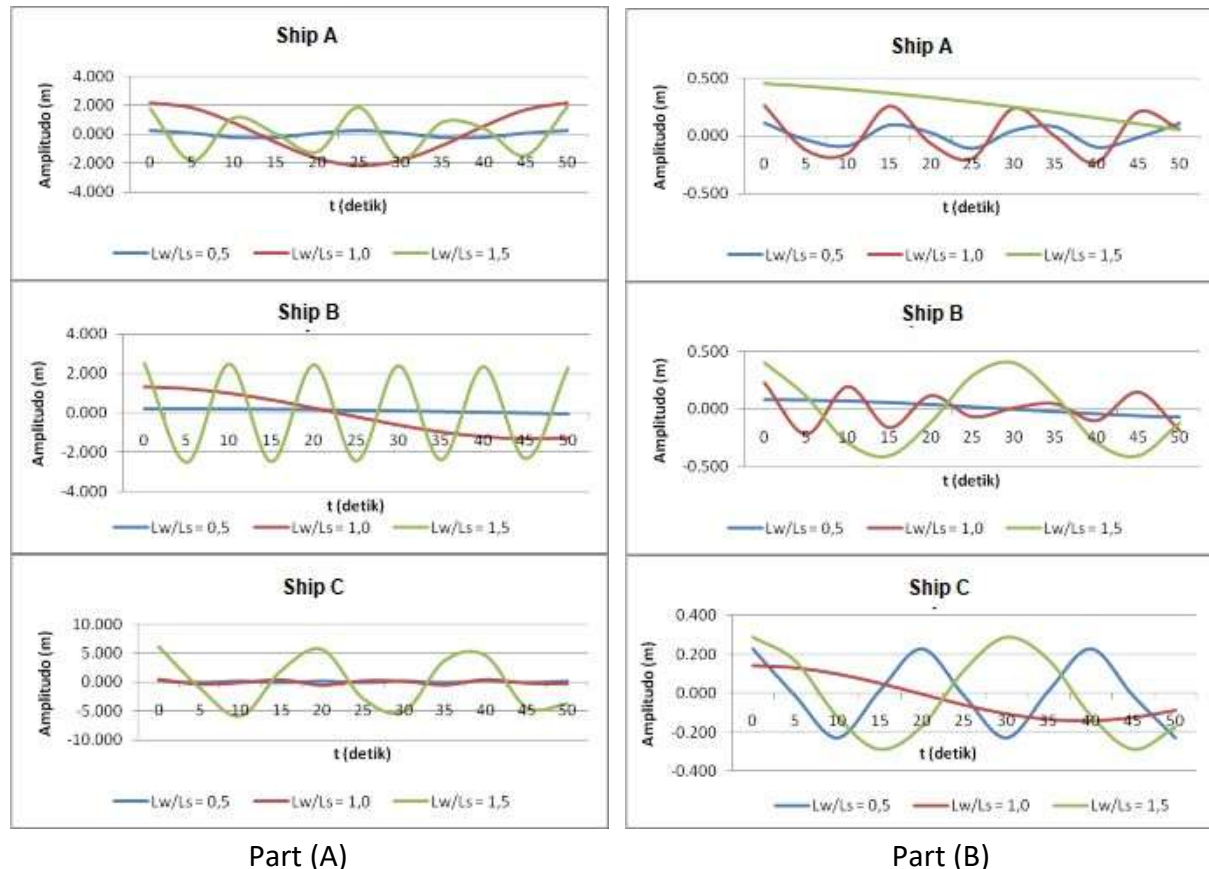
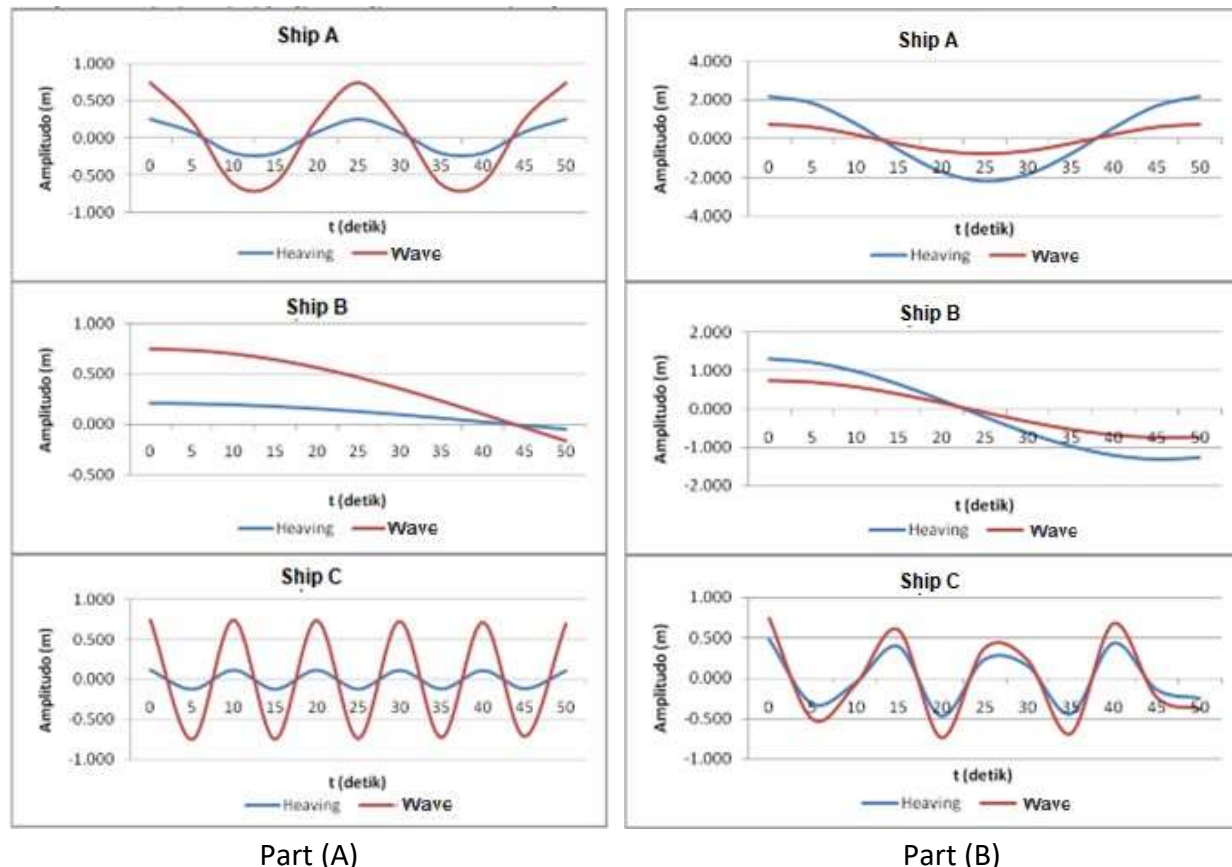


Figure 6. Part (A) Heaving Motion of Vessels A, B, and C ($V_s = 2.574$ m/s) at Different L_w/L_s Ratios with a Time Duration of 50 seconds. Part (B) Heaving Motion of Vessels A, B, and C ($V_s = 5.148$ m/s) at Different L_w/L_s Ratios with a Time Duration of 50 seconds.

In Part (B), the heaving motions of the sample vessels show a sinusoidal pattern, except for vessel B at L_w/L_s ratios of 0.5 and 1.0. The main difference lies in the heaving amplitude and phase difference at each L_w/L_s ratio. Ship C has the largest heaving amplitude at a L_w/L_s ratio of 1.5 (Figure 7 shows that ship C exhibits the same motion pattern at various L_w/L_s ratios, except at a L_w/L_s ratio of 1.0), while the maximum heaving amplitude value is observed on ship B at a L_w/L_s ratio of 1.5.



Part (A)

Part (B)

Figure 8. Part (A) Heaving Motion of Vessels A, B, and C at Regular Waves with an L_w/L_s Ratio of 0.5. Part (B) Part (B) Heaving Motion of Vessels A, B, and C at Regular Waves with an L_w/L_s Ratio of 1.0.

In Figure 8 Part (A), vessels A and C exhibit the same sinusoidal pattern for heaving and wave motion. Ship B, on the other hand, shows motion from peak to valley. The difference between ships A and C lies in the amplitude value and phase difference when the heaving motion reaches its maximum and minimum positions against the wave movement. Figure 8 Part (A) also indicates that the heaving amplitude value is greater than the wave amplitude.

Figure 8 Part (B) demonstrates that vessels A and C display the same sinusoidal pattern for heaving and wave motion. Ship B follows a similar motion pattern from peak to valley. Figure 8 Part (B) also reveals that the heaving amplitude value is greater than the wave amplitude value, except for ship C.

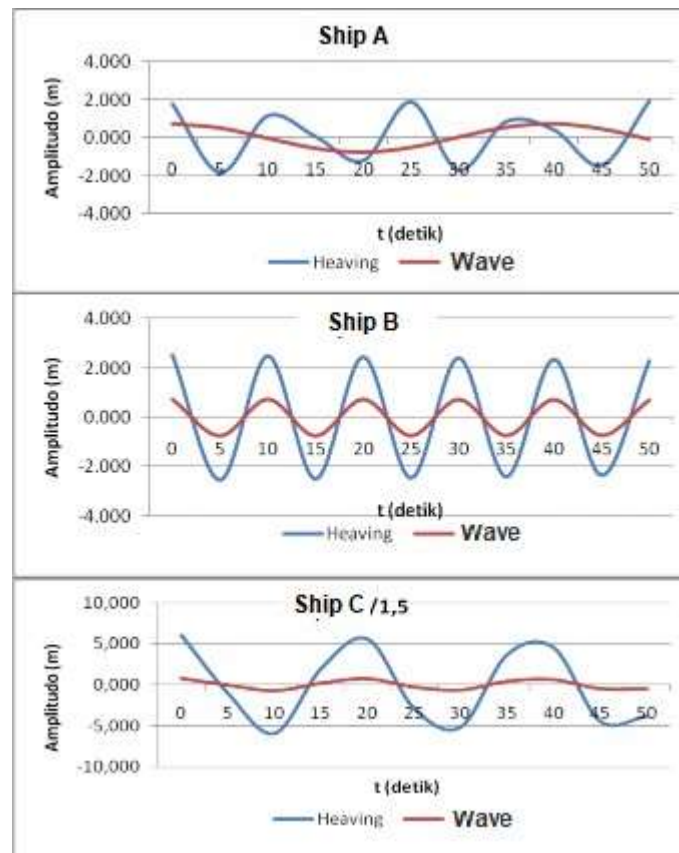


Figure 10. Heaving motion of vessels A, B, and C at regular waves with a ratio of $L_w/L_s = 1.5$. In Figure 10, it can be seen that the movement pattern that occurs between heaving and wave movements on ships B and C is the same, namely sinusoidal, the difference is seen in the resulting amplitude value. Figure 10 also shows that the heaving amplitude value is greater than the wave amplitude value.

Dynamics of Heaving Motion over Regular Waves Following Seas

Regular following seas waves are sinusoidal waves that originate from the stern of the ship, with the same wavelength and wave amplitude in each period. The encounter angle represents the angle between the ship's bow and the wave, and in this study, it is set at 15° . Regular following seas waves often pose difficulties in steering the ship.

The theoretical calculations reveal that an increase in wavelength leads to a smaller wave

frequency value.

In reality, regular waves following the ship's motion coincide with the ship's speed. If the ship is traveling at a speed greater than the wave speed, it tends to move ahead of the previous water mass.

In this study, based on theoretical calculations, when ship A and ship B are moving at a speed of 5.148 m/s (10 knots), they will move ahead of the wave motion when encountering regular waves with an L_w/L_s ratio of 0.5 (8.86 m and 9.9 m), and vice versa when encountering regular waves with an L_w/L_s ratio of 1.0 and 1.5 (16.86 m, 25.86 m, and 19.29 m). On the other hand, ship C will move ahead of the wave motion when encountering regular waves with an L_w/L_s ratio of 1.0 (14 m), and vice versa when encountering regular waves with an L_w/L_s ratio of 0.5 and 1.5 (7.78 m and 22.78 m). Even when the waves and the ship are traveling parallel in the same direction at the same speed, the ship will still move faster. The ship's final speed is a combination of the speed generated by the engine thrust and the speed caused by the thrust force exerted by the waves.

CONCLUSION

The main dimension ratios of purse seine vessels A, B, and C, except for the B/D value, do not align with the reference values. This suggests that these sample vessels may have compromised operational capability and stability, but they exhibit higher speed and pricing compared to standard ship designs. The average values of hydrostatic parameters, except for LCB, LCF, KM, BML, and KML, increase with the ship's draft for vessels A, B, and C. Ship A demonstrates superior stability feasibility compared to ships B and C. The maximum heaving amplitude for vessels A, B, and C occurs at the crest of the wave, while the minimum heaving amplitude is observed at the wave's valley. Ship B experiences the smallest encounter frequency when it is above the wave with an L_w/L_s ratio of 1.5, whereas ship C encounters the highest frequency when above the wave with an L_w/L_s ratio of 0.5.

Future Directions

In light of the study's findings, several suggestions can be made to improve the performance and stability of purse seine vessels:



1. Consider increasing the width and length of the ship in proportion to the dimensions of the encountered waves. This adjustment can help mitigate the heaving amplitude and encounter frequency, leading to improved vessel performance.
2. When navigating regular seas, it is recommended that vessels maintain a higher speed and carefully avoid waves that exceed the wavelength. Thus, the ship can minimise the impact of heaving amplitude and encounter frequency on its heaving motion, thereby improving overall stability.
3. To further validate the results of this study and gain a deeper insight, it is recommended to conduct additional research using tank tests specifically focussed on the heaving motion of the vessel. This experimental approach will provide valuable data and strengthen the understanding of ship behaviour in various sea states.

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