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Polbeng Research Vessel Comfort Study in the Malacca Strait

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KEYWORDS
Polbeng Research Vessel
Ship Motion
HDPE Vessel
Ship Comfort

ABSTRACT – The Polbeng Research Vessel is a small research ship developed by Politeknik Negeri Bengkalis (Polbeng) in collaboration with CV. Fatih Bahari Engineering. The vessel is constructed from High Density Polyethylene (HDPE) and has principal dimensions of 9 m length overall (LOA), 2.2 m breadth, and 1.2 m depth, powered by an 85 HP outboard engine. This study aims to evaluate the seakeeping and motion comfort performance of the vessel to support research activities involving personnel and onboard equipment. The seakeeping analysis is conducted using a frequency-domain approach based on Response Amplitude Operators (RAOs), where ship motions are evaluated under regular wave conditions. Four operational cases are considered, involving two wave heights (0.2 m and 0.4 m) and two wave encounter directions, namely beam seas (90°) and head seas (180°). Three ship motions are analyzed: heave, roll, and pitch. The results indicate that roll motion in beam seas conditions exhibits the most significant response compared to other motions, which is consistent with the theoretical characteristics of small vessels having shorter restoring arms for roll motion. Overall, the vessel's motion responses remain within acceptable limits and satisfy established comfort criteria based on NORDFORSK 1987, STANAG 4154, U.S. Coast Guard (USCG), ISO 2631/1, ISO 2631/3, and BS 6841:1987 standards. The findings provide technical insight into the seakeeping behavior and comfort performance of HDPE-based small research vessels and serve as a reference for the design, evaluation, and development of environmentally friendly research and working vessels to enhance operational safety and effectiveness.

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INTRODUCTION

The Polbeng research vessel is a vessel designed and will be used by the Bengkalis State Polytechnic (Riau Province, Indonesia). As a research vessel and training vessel for students of the Diploma 3 Nautical study programmeme, this study programmeme belongs to the Bengkalis State Polytechnic. This ship uses High Density Polythene (HDPE) plastic material. This ship is a fast ship with a speed of more than 15 knots (engine power 85 HP). The length overall of this vessel is 9 meters. The principal dimensions of the vessel are presented in The urgency of this study lies in the need to ensure operational safety, human comfort, and the validity of measurement data produced by onboard research instruments. Excessive ship motions induced by wave excitations can lead to motion-induced discomfort, degradation of sensor performance, and increased operational risks during research activities .

Table 1, and the hull form is illustrated in Figure 1. The facilities owned by the Polbeng Research vessel include developing an AI system that will be integrated with the ship's navigation system, an underwater contour detection system, a water quality monitor, an underwater metal object detector, and an underwater pipe survey.

Currently, the analysis of ship resistance and stability for Sea-state 2 waters has been carried out; this is done because the Strait of Malacca is included in the waters in Sea-state 2. Furthermore, this ship is designed to carry several measuring instruments that must have good validation so that ship motion calculations are needed. With this calculation, it becomes a reference that later the ship's motion can be adjusted according to the needs for research calculations carried out by the ship during operations. The study of ship motion is closely related to the behaviour of the ship when hit by waves that have an impact on several ship disturbances and can cause discomfort to the ship, passengers [1], and the ship's mission equipment system [2, 3]. This is done to ensure that the measuring instrument equipment system and human ability to measure are still in the comfortable category.

The urgency of this study lies in the need to ensure operational safety, human comfort, and the validity of measurement data produced by onboard research instruments. Excessive ship motions induced by wave excitations can lead to motion-induced discomfort, degradation of sensor performance, and increased operational risks during research activities [4, 5, 6].

Table 1. The principal dimensions of the research vessel of Politeknik Negeri Bengkalis (Polbeng).

No.	Item	Dimentions	Unit
1	The length overall (LOA)	9	meters
2	Breadth (B)	2.2	meters
3	Height (H)	1.2	meters

This issue becomes more critical for small and fast vessels, which generally exhibit larger motion responses and higher accelerations compared to larger ships under similar sea conditions [7, 8]. Consequently, a comprehensive ship motion analysis is required to confirm that the Polbeng Research Vessel can operate effectively and safely within its intended environmental conditions [9, 10]. The objective of this study is to analyze the ship motion characteristics (seakeeping) of the Polbeng Research Vessel under wave excitation at Sea State 2 operating conditions, to evaluate the level of comfort and operational safety based on international ship comfort criteria, and to assess the suitability of the vessel’s motion responses with respect to the operational requirements of onboard research instruments and human activities. The results of this study provide a technical reference for developing small research vessels using HDPE, whose properties are comparable to fiber-reinforced materials, offering advantages in corrosion resistance, lightweight structure, and operational safety in the Malacca Strait [11, 12].

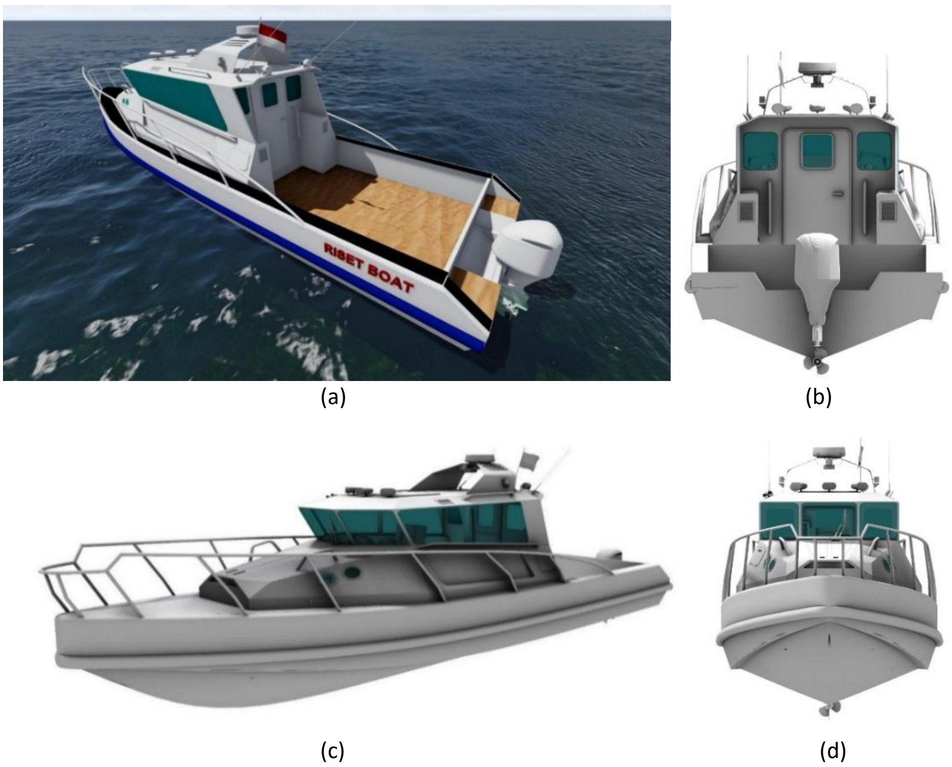

Figure 1. Polbeng Research Vessel Design, (a) isometric view from the stern, (b) view from the stern, (c) isometric view from the forward, (d) view from the forward

There are six ship motions known as degrees of freedom (DOF) [5] that occur due to external ship forces, as shown in Figure 2. The six motions are three translational motions, namely surge, sway, and heave. The other three motions are rotational motions, namely roll, pitch, and yaw. Of the six motions, there is a standard measure of ship motion that is defined in several ship comfort criteria that are often used, namely root mean square (r.m.s). This standard is also used in NORDFORSK 1987 [13,14] STANAG 4154 [15], U.S. Coast Guard (USCG) [16], ISO 2631/1, ISO 2631/3 [17], and BS. 6841:1987 [18]. Root mean square (r.m.s) is a standard deviation that can explain the magnitude of variance or depression relative to the average. These values can also explain the characteristic values of random waves along with wave spectra [19]. Formula r. m. s. according to Equation (1) [20].

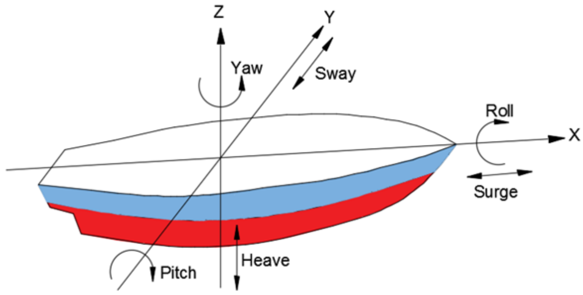

Figure 2. The six degrees of freedom [15]

$$r.m.s = \sqrt{m_o} \quad (1)$$

Where:

$$m_o = \frac{\sum_{n-1}^{N}(\zeta_0 - \xi)}{N} \quad (2)$$

$$\xi = \frac{\sum_{n-1}^{N} \zeta_n}{N} \quad (3)$$

Where: ζ_n as the nth elevation, m_o as the variance, ξ as the mean elevation, and N is the number of samples.

METHODS

In this study, the ship motion (seakeeping) analysis is performed using numerical methods, whereas the parameters for each experimental case are defined based on experimental data obtained from direct field measurements at sea. This approach is adopted to ensure that the numerical simulations realistically represent the actual operating conditions of the vessel. To predict the wave spectra corresponding to the experimental data, the Joint North Sea Wave Project (JONSWAP) method is employed, which is widely used to model wave spectra in fetch-limited and semi-enclosed sea conditions.

A comprehensive evaluation of the seakeeping performance of the Polbeng Research Vessel under representative operational conditions is conducted in this study by considering four experimental cases. Two cases correspond to a wave height of 0.2 m, while the remaining two cases correspond to a wave height of 0.4 m. The selection of these wave heights is based on the findings reported by Jamal et al. [15], which were obtained from direct calculation data derived from previous in situ field measurements of fast vessels operating in the waters of the Malacca Strait [15,17]. A detailed description of each experimental case is provided in Table 2, while the corresponding calculation locations are illustrated in Figure 3, encompassing the Bengkalis Strait, the Selat Panjang Strait, and the Malacca Strait. Likewise, this design will be used in the 3 waters because the position of Polbeng is on Bengkalis Island. So that the 2 wave heights can represent the testing of this Polbeng Research vessel. The four test cases carried out in detail can be seen in Table 2. The experiment was carried out during the highest waves in August [15,18], and that month is the Australian monsoon, which is one of the seasons that causes high sea waves in Indonesia [19,20].

Table 2. Polbeng Research Vessel Seakeeping Experiment Case

No.	Experiment Case	Significant Wave	Wave Direction
1	Case 1	0.2 meter	Beam seas (90^0)
2	Case 2	0.2 meter	Head seas (180^0)
3	Case 3	0.4 meter	Beam seas (90^0)

4	Case 4	0.4 meter	Head seas (180^0)

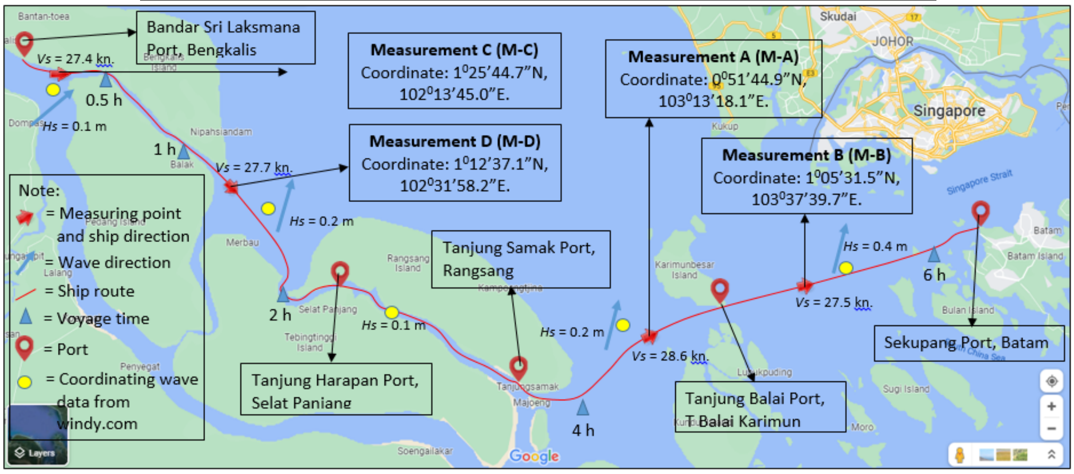

Figure 3. Significant wave height based on Dumai Line 12 ship route [17]

Prediction of wave spectrum in the Malacca Strait is done using the JONSWAP method. The JONSWAP method is an abbreviation of the Joint North Sea Wave Project, a project carried out jointly by a number of countries to conduct wave research in the North Sea waters. According to a report from Hasselman et al. [23, 24], the JONSWAP spectra formulation is a modification of the P-M spectra, by including parameters that will accommodate the characteristics of closed water or archipelago waves. This shows that the Malacca Strait waters are suitable for using the JONSWAP method. The JONSWAP spectra equation can be seen in Equation (4) below:

$$S_{\zeta}(\omega) = \alpha g^2 \omega^{-5} \exp\left\{11.25 \left(\frac{\omega}{\omega_0}\right)^{-4}\right\} \gamma^{exp\left\{-\frac{(\omega-\omega_0)}{2\pi\omega_0{}^2}\right\}} \quad (4)$$

Where: $\alpha = 0.076(X_0)^{-0.22}$, $X_0 = gX/U_w{}^2$, X = fetch length, U_w = wind speed, $\alpha = 0.0081$ if X is unknown, γ = peakedness parameter, which value can vary between 1.0 and 7.0. For the North Sea it has a value of 3.3, τ = shape parameter, $\tau = 0.07$, if $\omega \le \omega_0$, $\tau = 0.07$, if $\omega > \omega_0$, $\omega_0 = 2\pi(g/U_w)(X_0)^{-0.33}$.

The first passenger comfort analysis conducted by the researcher was based on the passenger operability value using the ship motion calculation method numerical simulation. The operability value was taken from the calculation responses of 3 oscillatory motions (heave, roll, and pitch). The motion responses (heave, roll, and pitch motions) are calculated by Equation (5), which are determined by multiplying the irregular wave spectra (JONSWAP Spectra) with the squared of Response Amplitude Operator (RAO). The RAO are calculated by Equation (6).

The results of the subsequent calculations were compared with the seakeeping criteria according to the type and type of ship studied, where the type of ship was the Polbeng Research ship with a planning and monohull. The seakeeping criteria used were NORDFORSK 1987, STANAG 4154, U.S. Coast Guard (USCG), ISO 2631/1, ISO 2631/3, and BS. 6841:1987.These seakeeping standards are used as various analyses related to ship comfort, namely:

a. Ship Operability Assessment: Ship operability assessment uses seakeeping criteria used are NORDFORSK 1987, STANAG 4154, and U.S. Coast Guard (USCG). The selection of seakeeping criteria is based on the type and type of ship being measured, namely the type of fast passenger ship that has a planned hull shape. This seakeeping criterion regulates the maximum ship motion limits for ship operability.
b. Comfort Level Assessment: Analysis of passenger comfort levels is intended to determine how much comfort is experienced by passengers during the trip. This analysis is carried out using the ISO 2631/1 (1997) and BS. 6841:1987 standards to determine the level of comfort from the calculation results.
c. Motion Sickness Zone Assessment: This Motion Sickness Area Assessment is used to determine the motion sickness region experienced by the ship's crew or passengers. Determination of the motion sickness area is done by measuring the amount of motion experienced by the ship. This analysis is carried out using the ISO 2631/3:1985 standard.

$$S_{\zeta r}(\omega) = S_{\zeta}(\omega).RAO^2(\omega) \quad (5)$$

$$RAO(\omega) = \frac{F_e(\omega)}{K - \omega^2\big(m + a(\omega)\big) + J.\omega.C(\omega)} \quad (6)$$

Where: $F_e(\omega)$ is excitation force, K is hydrostatic stiffness, m is mass, $a(\omega)$ is added mass, J is imaginary unit, and $C(\omega)$ is radiation damping.

RESULTS

The wave spectrum used in this study is the JONSWAP method. Figure 4 shows the difference in wave spectra of 0.2 meters and 0.4 meters. This wave height data was selected based on climatological data taken based on direct calculations of the motion of passenger ships on the Bengkalis to Batam route in the Malacca Strait [15]. Where the dashed black line depicts the significant wave spectrum of 0.2 meters, this spectrum has a peak wave spectral density of 0.005 m^2/rad/s and a wave frequency of 1.5 rad/s. Furthermore, for the wave spectral 0.4 shown in the continuous blue line, this spectrum has a peak wave spectral density of 0.035 m^2/rad/s and a wave frequency of 0.85 rad/s.

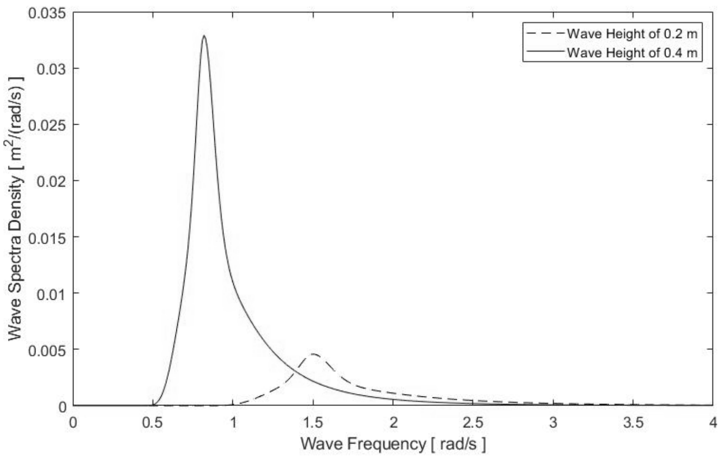

Figure 4. Significant wave height spectrum of 0.2 meters and 0.4 meters, JONSWAP method

Ship response motion analysis is carried out for ship oscillation motion, with 3 main motions, namely heave, roll, and pitch. Data is recorded using numerical analysis. The ship is running at a speed of 5.144 m/s on waves of 0.2 meters and 0.4 meters, according to the case. Ship motion is recorded for 90 seconds and has a number of data samples (N) of 900 samples. Testing is carried out on all motions with the same time and number of samples. This number of samples (N) has followed the International Towing Tank Conference (I.T.T.C.) reference. ITTC provides a limit on the number of cycles (N), namely a minimum of N = 50 or more than N = 100 as a commonly used standard, while N = 200 and above are considered very good calculations [7, 23]. The following is a detailed discussion of the three ship response motions simulated in the time domain:

Acceleration and Heave Motion

Heave acceleration data is plotted in the time domain as shown in Figure 5. The magnitude of the heave acceleration elevation value is measured in m/s^2. This acceleration data is taken and used to determine the magnitude of the r.m.s value of heave acceleration; this is used to be compared with existing seakeeping criteria. It can be seen from 0 to 50 seconds that the heave acceleration values between Cases 1, 2, 3, and 4 do not have a high elevation difference, but after 50 seconds the elevation difference is increasingly visible. Cases 3 and 4 have greater elevation than Cases 1 and 2. The largest value of heave acceleration occurs in Case 3, namely at ship waves of 0.4 meters and the direction of the waves coming from beam seas or the angle of arrival of the wave direction is 90^0. The following are the maximum elevation values in order from case 1 to case 4, namely 0.341 m/s^2, 0.259 m/s^2, 1.386 m/s^2, and 0.634 m/s^2.

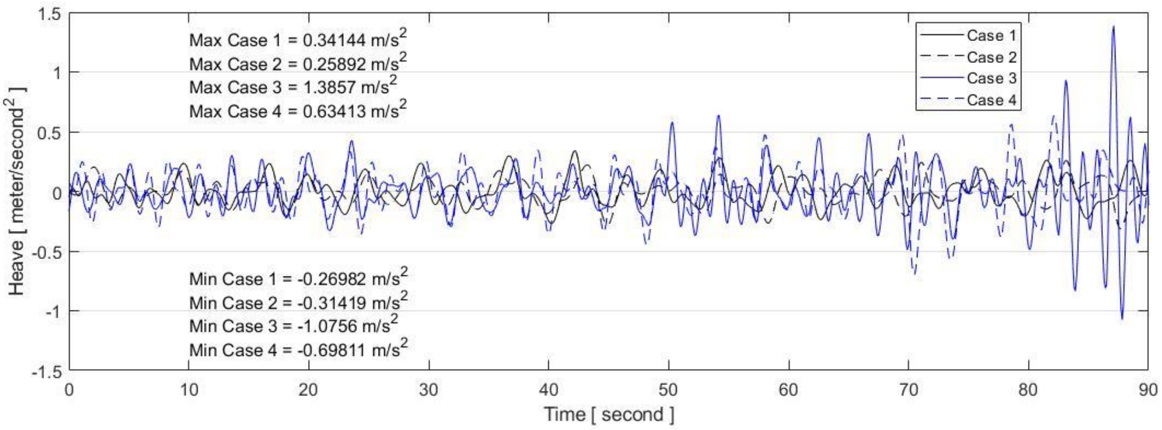

Figure 5. Heave acceleration of Polbeng research vessel in time domain

Figure 6 is the heave motion plotted in meters. Cases 1 and 2 appear to have smaller heave motions with maximum elevation motions of 0.071 meters and 0.076 meters respectively; this corresponds to the significant wave height passed through, which is 0.2 meters. The motions of Case 1 and Case 2 are shown in Figure 4 by the continuous black line and the dashed black line. Furthermore, Case 3 and Case 4 appear to have larger elevation motions compared to Case 1 and Case 2. This is because the wave height passed through is 0.4 meters. The maximum elevation motions of cases 3 and 4 are respectively 0.197 and 0.205 meters. From the 4 test cases, it is shown that the wave direction does not affect the heave motion of the Polbeng Research vessel. This is proven by the fact that Case 1 and Case 3 are cases where the wave direction of the beam seas (90^0) has a similar elevation motion to Case 2 and Case 4, which are cases where the wave direction of the head seas (180^0).

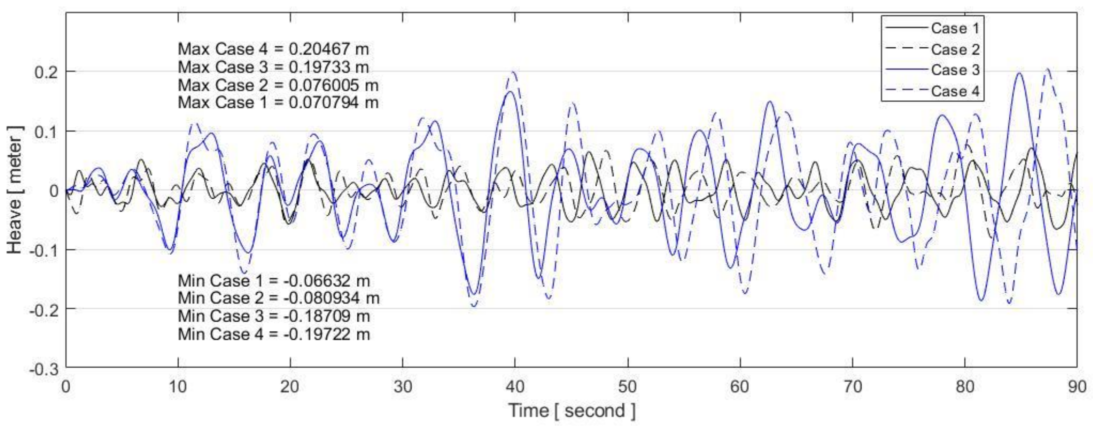

Figure 6. Heave motion of Polbeng research vessel in time domain

Roll Motion

The data of the Polbeng Research vessel roll motion in the plot according to Figure 7. The elevation unit used is degree and in the time domain function (in seconds). Case 1 and Case 2 have different motion elevations; Case 2 shows a greater elevation than Case 1, with maximum elevation values of 5.335 degrees and 0.028 degrees, respectively. Case 3 and Case 4 also have values similar to Case 1 and Case 2, the maximum elevation values are 0.799 degrees and 5.934 degrees, respectively. In the case of roll motion, it can be seen that the direction of the waves from the head seas (180^0) does not affect the roll motion much; on the contrary, the direction of the waves from the beam seas (90^0) has a very significant effect on the roll motion.

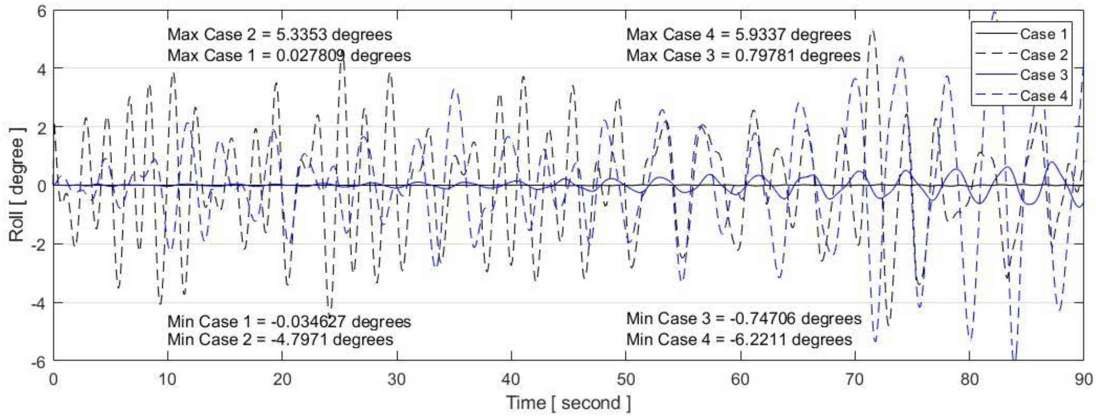

Figure 7. Roll motion of Polbeng research vessel in time domain

Pitch Motion

The pitch motion data of the Polbeng research vessel can be seen in Figure 8. The four test cases carried out showed almost similar values, with the maximum elevation motion values in order from Case 1 to Case 4 being 0.866 degree, 1.506 degrees, 1.055 degrees, and 3.209 degrees. Case 4 when viewed from second 0 to second 90 has other Case motions, but at 80 seconds it has a higher elevation motion than the others and reaches 3.309 degrees; this causes the pitch elevation motion for case 4 to have a much higher maximum motion.

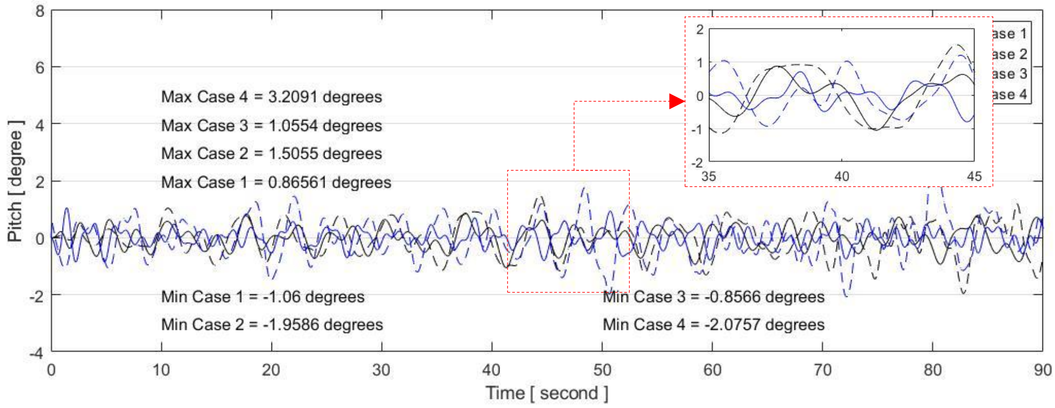

Figure 8. Pitch motion of the Polbeng research vessel in time domain

DISCUSSION

The ship's response presented in three motions, namely heave, roll, and pitch, in four test cases shows some temporary conclusions. First, graphically, the heave motion value of all cases looks insignificant and has similarities. Second, the roll motion for the case of the head seas wave direction has a normal motion, but for the beam seas wave direction it has a motion that tends to be more extreme, reaching 5,933 degrees, especially case 4. Third, the pitch motion of all cases shows similar results, with relatively small motions; however, further analysis is still needed to determine whether this ship is still included in the category of comfortable ships and also comfortable passengers.

Several ship seakeeping criteria from NORDFORSK 1987, STANAG 4154, the U.S. Coast Guard (USCG), ISO 2631/1, ISO 2631/3, and BS. 6841:1987 use the root mean square (r.m.s.) value as the standard calculation. According to Equation (1), the r.m.s. value of all motions is calculated according to Table 3. This data is then used to analyse the ship's operability value, ship comfort level, placement of motion sickness zones, and motion sickness incidence (MSI) level. Table 3 shows that the highest r.m.s. Heave value occurs in case 4, which is 0.087 meter.

Table 3. Mean, variance, and r.m.s values of Polbeng research vessel motion

Value	Heave [g]	Heave [m]	Roll [deg]	Pitch [deg]	Heave [g]	Heave [m]	Roll [deg]	Pitch [deg]
	Case 1				Case 2			
Mean	0.000	0.000	0.000	-0.017	-0.000	0.000	0.009	-0.025
Variance	0.001	0.001	0.000	0.159	0.001	0.001	3.532	0.387
r.m.s	0.012	0.029	0.009	0.399	0.010	0.028	1.879	0.622
	Case 3				Case 4			
Mean	0.000	-0.001	-0.004	-0.010	0.000	0.003	0.056	-0.010
Variance	0.005	0.006	0.057	0.103	0.003	0.008	3.739	0.603
r.m.s	0.023	0.079	0.239	0.321	0.019	0.087	1.934	0.776

Note: 1 g = 9.80665 m/s^2

Based on the analysis of the heave motion of the Polbeng Research Vessel, it can be concluded that the vessel's heave response is primarily governed by the incident wave height, while the influence of wave heading is relatively insignificant. At a wave height of 0.2 m, the resulting heave motions are relatively small, whereas an increase in wave height to 0.4 m leads to a substantial increase in heave motion amplitude. This behavior is consistent with linear seakeeping theory, which states that the amplitude of vertical translational motions is approximately proportional to the wave amplitude [3]. Furthermore, the similarity of heave responses under beam seas and head seas conditions indicates that the heave motion is largely symmetric with respect to wave direction. According to Faltinsen [2], heave motion is mainly influenced by the vertical wave energy component and the encounter frequency, resulting in a limited sensitivity to wave heading compared with rotational motions such as roll and pitch. Similar observations have also been reported in classical ship motion studies, particularly for small vessels, where wave direction has a minor effect on heave response provided that the wave spectral characteristics remain unchanged [7, 16]. Therefore, the findings of this study are in good agreement with established seakeeping theory and confirm that, for the Polbeng Research Vessel, assessments of operational comfort and onboard instrument performance should primarily focus on variations in wave height rather than wave direction.

Ship Operability Value

Ship operability analysis is done by comparing the results of ship motion that occurs on the Polbeng research vessel with international seakeeping criteria. The seakeeping criteria used are: (i) NORDFORSK, 1987 for fast small craft, navy vessels, transit passengers, and cruise liner criteria; (ii) STANAG 4154, which historically this criterion is used for navy vessel operability; (iii) U.S. Coast Guard for coast guard vessels. The comparison results show that the calculations from Cases 1 to 4 are still within the criteria given by NORDFORSK, 1987 (fast small craft, navy vessels, and transit passengers), STANAG 4154, and the U.S. Coast Guard (USCG) for all heave acceleration criteria, roll motion, and heave. For Case 3, it appears to have the largest r.m.s. heave acceleration in this case, where the value is 0.023 g. However, this ship is still categorised as comfortable and still safe in terms of ship operability, according to the seakeeping criteria for small ships, which have the smallest criteria for transit passengers, which have a heave acceleration value of 0.05 g, according to Table 4. For the roll and pitch motion values of the Polbeng research ship as a whole, it is very safe and has a value far from the maximum criteria limits given.

Table 4. Comparison of Polbeng vessel motion results with seakeeping criteria.

Criteria	Heave	Roll	Pitch
Polbeng Research Vessel: Default Criteria [r. m. s]			
Case 1	0.012 g	0.009 deg.	0.399 deg.
Case 2	0.010 g	1.879 deg.	0.622 deg.
Case 3	0.023 g	0.239 deg.	0.321 deg.
Case 4	0.019 g	1.934 deg.	0.776 deg.
Comparison Criteria: Default Criteria [r. m. s]			
NORDFORSK, 1987			
Fast small craft	0.20 g	4.0 deg.	-
Navy Vessels	0.27 g	4.0 deg.	-
Transit Passengers	0.05 g	2.5 deg.	-

Criteria	Heave	Roll	Pitch
STANAG 4154			
Navy Vessels	0.20 g	4.0 deg.	1.5 deg.
U.S Coast Guard (USCG)			
Coast Guard Vessels	0.10 g	4.0 deg.	1.5 deg.

Ship Operability Value

The analysis of the passenger comfort level based on the 4 calculation cases was carried out by comparing the heave acceleration calculations in r.m.s. with the acceleration criteria in ISO 2631-1:1997 and BS 6841:1987. The calculation results showed that all calculations were included in the comfortable category because the heave acceleration values were 0.012 g to 0.023 g, respectively, where the four calculation cases had calculation results still below 0.0315 g and included comfortable reactions, according to Table 5.

Table 5. Heave acceleration assessment of Polbeng vessel using ISO 2631-1:1997 and BS 6841:1987.

ISO 2631-1:1997 and BS 6841:1987		Results of calculations of the Polbeng research vessel
Acceleration in r.m.s [g]	Reaction	Acceleration in r.m.s [g]
< 0.0315	Comfortable	Case 1 = 0.012 Case 2 = 0.010 Case 3 = 0.023 Case 4 = 0.019
0.0315 – 0.063	A little uncomfortable	-
0.05 – 0.1	Quite uncomfortable	-
0.08 – 0.16	Uncomfortable	-
0.125 – 0.25	Very Uncomfortable	-

Placement of Motion Sickness Zones

ISO 2631/3, 1997 provides a mapping of motion sickness region on heave acceleration experienced by the Polbeng research vessel. The round blue dot is the vertical r.m.s acceleration from Case 1 Calculation, the red trapezium is the calculation result of Case 2, the blue triangle is the calculation result of Case 3, and the red square is the calculation result of Case 4. All calculation cases show the r.m.s value below 0.025 g or 0.25 m/s^2 (Note: 1 g = 9.80665 m/s^2), which indicates that this Polbeng research vessel for sailing operations above 8 hours is still in the comfortable category or that its passengers have not experienced motion sickness, according Figure 9.

CONCLUSION

The maximum elevation value of heave motion on research vessels has a value between 0.029 meters and 0.087 meters; the maximum elevation value of roll motion is between 0.009 degrees and 1.934 degrees; and the maximum elevation value of pitch motion is between 0.321 degrees and 0.776 degrees. Overall, this ship's motion is still common and still meets the ship's comfort criteria based on the criteria issued by NORDFORSK 1987, STANAG 4154, and the U.S. Coast Guard (USCG). The vertical acceleration (r.m.s.) values for each test are 0.012 g 0.010 g, 0.023 g, and 0.019 g, respectively, all of which comply with passenger comfort standards in accordance with ISO 2631/1, ISO 2631/3, and BS 6841:1987 criteria. In addition to providing passenger comfort, it can also be ensured that the on board equipment can operate safely. A slight increase in roll motion is observed; however, it remains well below the maximum allowable limit specified by the criteria. The permissible roll limit for transit passengers is 2.5 degrees (NORDFORSK criteria) [9], while the measured roll motion is relatively small, at 1.934 degrees. Therefore, the vessel can be considered safe and comfortable. Based on the test results, it is evident that the vessel is feasible for construction.

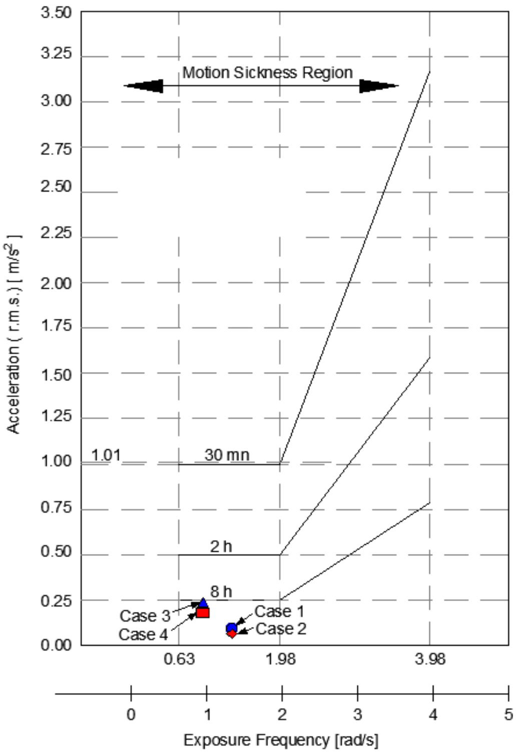

Figure 9. Comfort points of the Polbeng research vessel according to the ISO 2631-3, 1997 chart

Therefore, the results of this study are consistent with the stated research objectives, namely to analyze the seakeeping characteristics of the Polbeng Research Vessel, to evaluate its operational safety and human comfort based on international standards, and to assess the suitability of the vessel's motion responses for onboard research instruments and human activities. Based on the comprehensive evaluation of ship motions and comfort criteria, it can be concluded that the Polbeng Research Vessel is safe, comfortable, and suitable for construction and operation within its intended environmental conditions.

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