INTECHBIZ2025
International Conference on Industrial Technology and Business

Vibration Analysis Using Experiment Method on HDPE Boat Structure

Muhammad Sidik Purwoko[1], Muhammad Alimul Hafiz[2*], Fazrian[3], Rizky Chandra Ariesta[4], Jamal[5], Maful Suranto[6], Arief Teguh Pribadi[7], Diki Arnanda[8], Mhd Vikri Ardiyanto[9]

[1,2,3,5,6,7,8,9]Department of Naval Architecture, Politeknik Negeri Bengkalis, Indonesia
[4]Department of Naval Architecture, Institut Teknologi Sepuluh Nopember, Indonesia
m.sidikpurwoko@polbeng.ac.id[1], mhafiz@polbeng.ac.id[2], fazrian@polbeng.ac.id[3], chandra@its.ac.id[4], jamal@polbeng.ac.id[5], maful@polbeng.ac.id[6], arief@polbeng.ac.id[7], dikiarnanda6@gmail.com[8], ardiyantovikri@gmail.com[9]

Abstract

As a relatively new material in the maritime industry, there has been limited discourse regarding the response of HDPE (High Density Polyethylene) structures to vibrational loads. This study performed direct vibration measurements on the HDPE structure of the Politeknik Negeri Bengkalis (POLBENG) research vessel, with the vibration generated from the operation of the main engine. The engine was operated at roughly 4,000 RPM and 950 RPM, labeled as Measurement 1 and Measurement 2, respectively. Vibrations were measured utilizing an accelerometer sensor, WitMotion WTVB02-485 sensor. The safety of the structure was evaluated by identifying the occurrence of resonance phenomena and whether the Root Mean Square (RMS) values surpassed the standards established by the American Bureau of Shipping (ABS). The peak excitation frequencies for Measurements 1 and 2 were 83.34% and 52.61% lower than their respective native frequencies. The RMSs of vibration velocities for Measurements 1 and 2 are 0.0200 mm/s and 0.0478 mm/s, respectively. The measurement findings indicate that the HDPE construction can endure vibrations from the main engine's operation at both high and low RPMs, as resonance is absent and the RMS value remains within standard limits.

Keywords : High Density Polyethylene, Vibration, Direct Measurement.

1. INTRODUCTION

The utilization of High Density Polyethylene (HDPE) as the primary material for ship construction has gained significant popularity recently. This plastic material possesses adequate tensile strength to endure several excitation loads on small ship structures, exhibiting an average yield stress of 18.34 MPa (D. Setiawan et al., 2024). This material is recyclable, lightweight, environmentally friendly, and exhibits resilience to impact loads, weather fluctuations, scratches, filth, and corrosion (Kadhim, 2017; Kafalı, 2023; Patel et al., 2023; Santos et al., 2024; Sözen & Neşer, 2022). Nevertheless, due to its prevalent use in the shipbuilding industry, additional research is required to examine the impacts of various excitation loads on HDPE ship structures, including vibrational loads.

Vibration is a complicated phenomenon that profoundly affects ship construction (Fahim, 2025). Neglecting the possibility for resonance in local structures caused by vibrational loads can lead to structural failure (Imron, 2014). In this study, resonance is defined as the occurrence when the vibration frequency of a structure matches its natural frequency. Consequently, it is crucial to avert the occurrence of this problem. A source of excitation is ship machinery, including the main engine load (F. P. Setiawan et al., 2020). It is essential to examine this phenomenon by taking direct measurements throughout the shipbuilding process.

Direct measurement is an experimental method that accurately characterizes actual field conditions. The subsequent studies examine vibrations in ship structures utilizing this methodology, including an investigation into the vibration damping coefficient of deck plate layers on ships (Nugroho, 2019); an analysis of structural damage resulting from often-overlooked local vibrations on vessels (Imron, 2014); and an assessment of the effects of vibrations on ship structures through measurements taken with MEMS (Micro-Electro-Mechanical Systems) sensors (Fahim, 2025). Nevertheless, research examining the effects of vibrations on plastic ship structures has been limited. This material has been examined

extensively across various themes, including Finite Element Analysis (FEA) of load criteria aggregated by multiple classes, exemplified by a case study of a 38-foot HDPE vessel (Moon et al., 2023); a feasibility analysis of the outcomes of HDPE structural welding processes concerning welding-induced thermal distortion (Lee, 2023); and an inquiry into the design and fabrication of HDPE boats (Kafalı, 2023).

This study performed a vibration analysis on an HDPE ship structure, with vibrations emanating from the main engine, by direct measurements. Sensors were installed in the accommodation area, and the main engine was run at high RPM (about 4,000 RPM) and low RPM (around 950 RPM). Direct measurements were obtained by assessing the excitation vibrations on the ship's deck plate with an accelerometer sensor, specifically the WitMotion WTVB02-485. The natural frequency was determined by analyzing the number of engine revolutions performed. The evaluation was conducted by determining if the resonance phenomenon manifested in relation to the load generated by the main engine's operation. A comparison of the excitation RMS value with the class criteria value serves as an extra evaluation in vibration analysis. This research serves as guidelines for conducting vibration measurement investigations on HDPE ship structures with accelerometer sensors. The findings of this study may serve as a benchmark for future research employing the Finite Element Analysis (FEA) approach, hence facilitating the advancement of modeling techniques to achieve more efficient and dependable structural designs.

2. REVIEW OF LITERATURE

High Density Polyethylene

High-density polyethylene (HDPE) is a linear thermoplastic polymer composed of ethylene monomers (Alias et al., 2024). Polyethylene is categorized into three primary types: low-density polyethylene (LDPE), medium-density polyethylene (MDPE), and high-density polyethylene (HDPE), according to its molecular density and structural crystallinity (Amjadi & Fatemi, 2020). The mean density of HDPE is 0.96 g/cm³ (Merah et al., 2006), rendering it less dense than water. The melting point of this material is 128.78°C, the heat flow is -3.84 W/G, and the heat of fusion is 203.5 J/G (Hassan Awad et al., 2019). The tensile test findings from 11 samples indicated an average maximum load of 2.68 kN, a yield stress of 12.58 MPa, an ultimate tensile stress of 20.67 MPa, and a strain of 21.91 mm (Tesfaw et al., 2022). The maximum stress value attainable, according to impact test findings, is 40 MPa (Kroon et al., 2024). This plastic variant surpasses other forms, specifically Low Density Polyethylene (LDPE) and Linear Low Density Polyethylene (LLDPE), regarding strength, economic viability, and environmental sustainability (Dallé et al., 2024).

Vibration

The oscillatory movement of an object or its surface in relation to its equilibrium position is termed 'vibration'. The equilibrium position is the state in which the object remains steady and is unaffected by external forces (Vorus, 1988). The maximum displacement from the equilibrium position is termed the amplitude. Frequency refers to the quantity of deviations that transpire within a specified time frame. Frequency can be divided into two types: excitation frequency and natural frequency. The excitation frequency is determined by the excitation load. On vessels, this excitation may be induced by the operation of the main engine, propeller, auxiliary engine, and wave motion (ABS, 2023). The natural frequency is the frequency at which a system oscillates in free vibration without dampening, inherent to any object possessing mass and rigidity (Thomson, 2010).

A structure sustains damage if resonance transpires upon receiving an excitation force. Resonance occurs when the excitation frequency matches the natural frequency of the structure (Vorus, 1988). During this occurrence, the amplitude of vibration escalates, leading to heightened dynamic stress. If this situation persists for an extended duration, it may result in

weariness (Shabana, 2019). The subsequent domino effect is the emergence of fissures, which propagate until the building collapses or fails (Karnovsky & Lebed, 2016). This result indicates that the impact of vibration frequency on ship constructions is significant. The American Bureau of Shipping (ABS) has established criteria for permissible vibration in maritime buildings. At frequencies up to 5 Hz, the allowable displacement is under 1 mm, with potential structural damage occurring if the displacement surpasses 2 mm. In the frequency range exceeding 5 Hz, the allowable vibration velocity is below 30 mm/s, with a risk of structural damage if the velocity surpasses 60 mm/s (ABS, 2023).

Direct Measurement

Direct measurement constitutes one of the methodologies employed in experimental procedures. An experiment is a research methodology that entails the direct observation of dependent variables while regulating independent factors (Hinkelmann et al., 2008). This work involved direct measurement of vibrations on HDPE ship constructions subjected solely to excitation forces from their operational main engines. The independent variables assessed were the RPM of the primary engine and the measuring point's location, whilst the dependent variables were the magnitude and frequency of the recorded vibration. This strategy was selected due to its capacity to elucidate the field circumstances.

3. METHOD

Boat Description

The subject of this case study for direct monitoring of vessel vibration was a research vessel owned by the Bengkalis State Polytechnic (PolBeng). Constructed from eco-friendly materials, specifically HDPE, this vessel exemplifies the Bengkalis State Polytechnic's dedication to environmental preservation. The vessel was constructed to fulfil the research requirements of the PolBeng academic community. **Table 1** presents the main dimensions.

Table 1. Main dimensions.

Parameter	Dimension
Length of overall	9.00 meters
Length between perpendicular	8.94 meters
Breadth	2.20 meters
Draught	0.45 meters
Service speed	15 knots
Engine power	85 horsepower
Number of propeller blade	3 blades

Experimental equipment

The instruments used to support this research are grouped into hardware and software. Both are used to support the measurement stage and the data processing stage. The following is the software used:

a. Witmotion.exe, software developed by WitMotion Shenzhen Co. Ltd., is used to operate the accelerometer sensor, which is the WitMotion WTVB02-485, and it outputs data in a ".csv" file type.
b. MATLAB.exe is software used for data processing in this study. It is also used for data presenting, for example, in two-dimensional graphs.

The following are some of the hardware used to support this research:

a. The WitMotion WTVB02-485 accelerometer sensor is utilised for measuring vibration. This gadget possesses a sampling frequency range of 1 Hz to 200 Hz. It can subsequently quantify displacement, velocity, and acceleration over three axes.
b. The DT-6236B tachometer is an instrument that quantifies the RPMs of the primary engine. This instrument can measure RPMs ranging from 2.5 to 99,999. The measurement use a photosensor.

c. The Benetech GM816 anemometer is an instrument that quantifies wind velocity and ambient temperature. It can quantify wind velocities from 0 to 30 m/s.
d. The GM320 thermogun is an instrument that quantifies water temperature. This instrument can gauge temperatures from -50°C to 380°C.

Study cases

This study assessed ship vibrations induced by the main engine as the excitation source. The engine was run at two distinct RPMs: approximately 4,000 for high RPM and 950 for low RPM. According to these two RPM differences, the case studies were designated as Measurement 1 and Measurement 2, respectively. Six peoples were aboard the ship, with their places depicted in **Figure 1**. The weights were as follows: P1 - 69 kg, P2 - 85 kg, P3 - 42 kg, P4 - 122 kg, P5 - 83 kg, and P6 - 77 kg. **Figure 1** illustrates the position of the vibration sensor, situated 3.8 meters from the transom, 0.3 meters from the centerline, and 0.5 meters from the baseline.

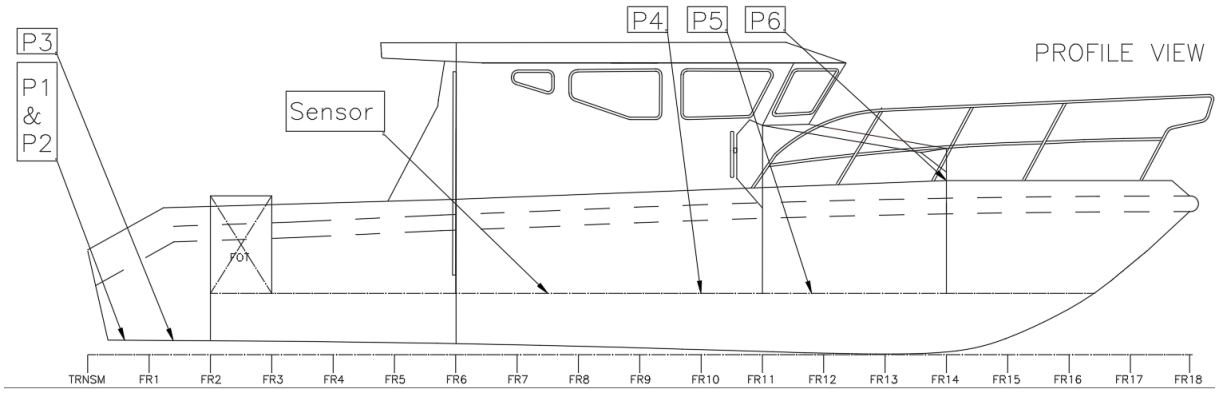


Fig. 1. The diagram illustrates the outlines of the sensor and the people involved.

The subsequent phase involves the testing protocol, data processing, natural frequency computation, and assessment, as detailed in a previously published work (Hafiz et al., 2025). This article simply presents the measurement findings from different cases; nonetheless, the complete protocols until the assessment are identical to those in the cited article.

4. RESULT & DISCUSSION

Environmental Observation result

Measurements were conducted on August 12, 2025, at the Mini Shipyard, Department of Naval Architecture, Polytechnic of Bengkalis. Measurement 1 was conducted from 09:32 WIB to completion at 09:38 WIB. Measurement 2 was conducted from 10:20 AM to 10:26 AM WIB. During the measurements, it was ensured that no vessels traversed the area, as the waters were restricted. The aim was to guarantee that the ship's structure got excitation forces solely from the running of its primary engine. **Table 2** encapsulates the measurement and observation outcomes from Measurement 1, whereas **Table 3** presents the data from Measurement 2.

Table 2. Summary of observations of environmental conditions in Measurement 1.

Time (WIB)	Air Temp. (°C)	Water Temp. (°C)	Wind Velocity (m/s)	Water Ripple
10.20	31	30	1.1	Very small ripples
10.21	31	30	1.1	Very small ripples
10.22	31	30	1.2	Very small ripples
10.23	31	30	0.8	Very small ripples
10.24	31	30	0.4	Very small ripples
10.25	31	30	0	Very small ripples
10.26	31	30	0	Very small ripples

Table 3. Summary of observations of environmental conditions in Measurement 2.

Time (WIB)	Air Temp. (°C)	Water Temp. (°C)	Wind Velocity (m/s)	Water Ripple
09.30	30	29	0.7	Very small ripples
09.31	30	29	1.2	Very small ripples
09.32	30	29	1.0	Very small ripples
09.33	30	29	0.8	Very small ripples
09.34	30	29	0.7	Very small ripples
09.35	30	29	0.2	Very small ripples
09.36	30	29	1.0	Very small ripples

The observations of water and air temperatures indicate values that remain rather stable throughout the duration of the assessment. The water temperature remained stable at 30°C for Measurement 1, whereas Measurement 2 recorded 29°C. The air temperature in Measurement 1 was stable at 31°C, whereas Measurement 2 recorded 30°C. The water and air temperatures were recorded and presented to convey the temperatures of both at the time of measurement. This article does not clarify whether these two temperatures influence the HDPE structure.

The water's surface during the test was very tranquil, with no significant winds present. The ship's position undoubtedly influenced this outcome. In conjunction with visual observation, wind speed measurements indicated that the maximum recorded wind speed was 1.2 m/s for both Measurements 1 and 2. The wind speed is categorized as Beaufort 1, characterized by negligible alterations in the smoke direction, indicating a very faint breeze (Hasse, 2015). The observations and measurements of environmental circumstances indicated that the HDPE structure was not appreciably influenced by excitation forces apart from those generated by the ship's primary engine.

Measured RPM number result

The RPM was quantified with a tachometer during the vibration measurement. **Figures 2a** and **2b** present the RPM measurement outcomes for Measurements 1 and 2, respectively. The minimum and maximum RPM recorded in Measurement 1 were 3,702 and 4,348, respectively. The mean and Root Mean Square (RMS) of RPM for Measurement 1 were 4,007.3 and 4,011.5, respectively. In Measurement 2, the recorded RPM varied between 751 and 1,200. The mean and RMS of RPM for measurement 2 were 966.22 and 975.51, respectively.

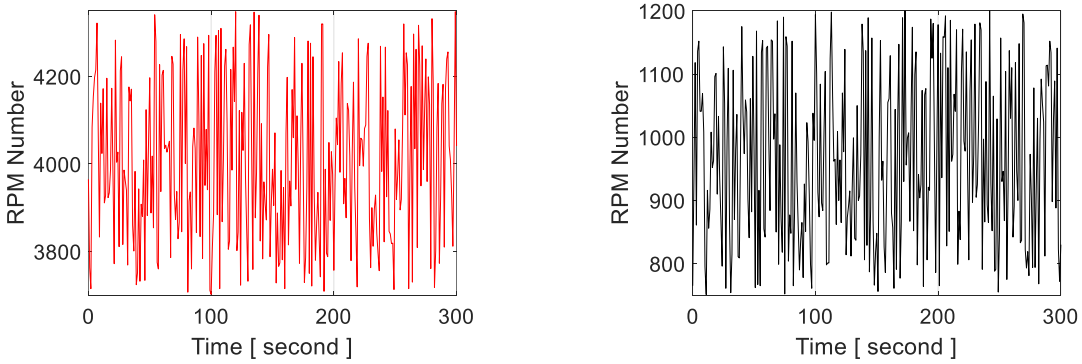
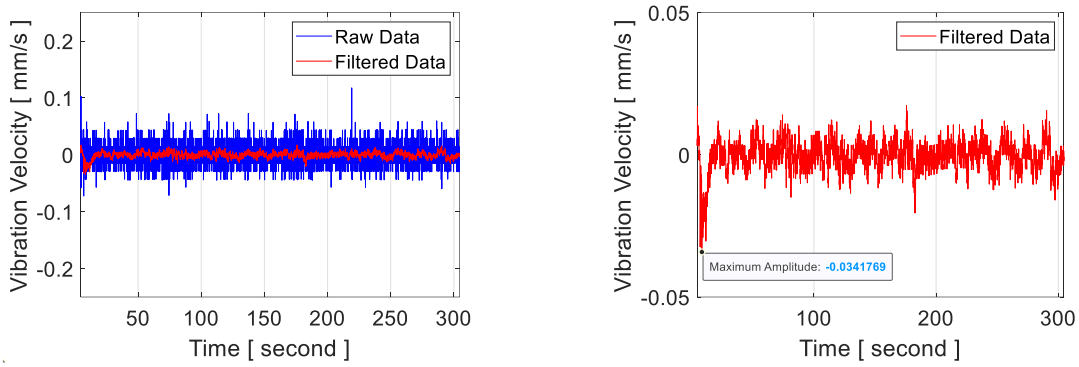


Fig. 2. Measured RPM number: (a) Measurement 1 and (b) Measurement 2.

Time domain results

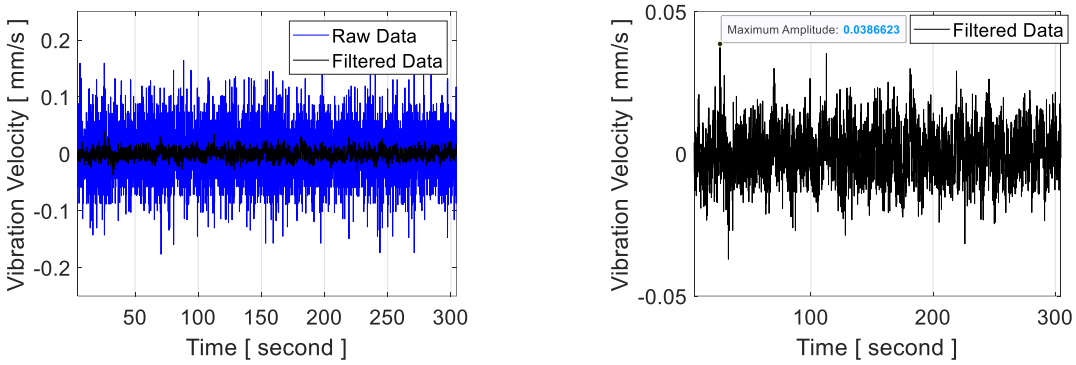
The WitMotion WTVB02-485 sensor measures vibration velocity in millimeters per second (mm/s). **Figures 3a** and **4a** present the unprocessed data for Measurements 1 and 2, respectively. This unprocessed data cannot be presented immediately; it necessitates a processing phase to mitigate measurement bias, specifically the filtering procedure. **Figures 3b** and **4b** present the filtered data for Measurements 1 and 2, respectively, derived from the resolution of Equation 1. The maximum amplitude values recorded are -0.034 mm/s for

Measurement 1 and 0.039 mm/s for Measurement 2. Despite Measurement 1 exhibiting a greater RPM variation setting than Measurement 2, its amplitude is inferior to that of Measurement 2.



(a) **(b)**

Fig. 3. The time domain results for Measurement 1: (a) raw data and (b) filtered data.



(a) **(b)**

Fig. 4. The time domain results for Measurement 2: (a) raw data and (b) filtered data.

Frequency domain results

The filtered data, initially in the time domain, was converted into the frequency domain to facilitate the identification of resonance occurrences. This transformation technique is known as the Power Spectral Density (PSD) estimate. The calculating phase in this technique pertains to the Fast Fourier Transform (FFT), executed via the Welch method. **Figures 5** illustrate the output from the transformation phase for Measurements 1 and 2, respectively. The results of this translation method indicate peak excitation frequencies of 33.31 Hz for Measurement 1 and 22.89 Hz for Measurement 2. A reduced number of RPMs operated by the machine correlates with a diminished recorded peak excitation frequency value.

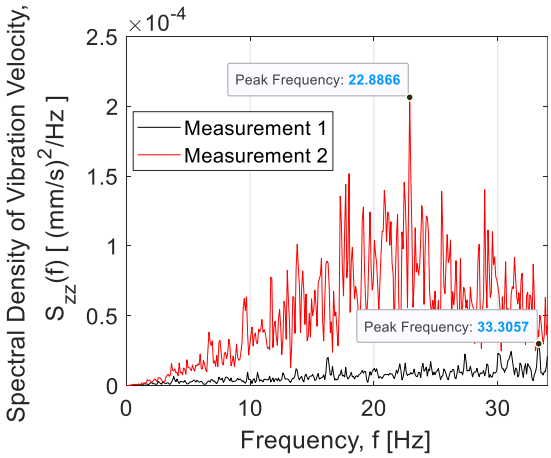


Fig. 5. Frequency domain results.

Discussions

The tachometer measurements indicate average RPM values of 4,007.3 for Measurement 1 and 966.22 for Measurement 2. Substituting both values into Equation 2 allows for the calculation of the natural frequency values, which are 200.4 Hz and 48.3 Hz, respectively. In comparing these two values to their respective peak excitation frequencies, Measurement 1 exhibits a peak excitation frequency that is 83.34% less than its natural frequency, whilst Measurement 2 demonstrates a peak excitation frequency that is 52.61% less than its natural frequency of 48.3 Hz. According to these findings, resonance did not manifest; hence, the HDPE construction is capable of enduring vibrations generated by the main engine functioning at both high and low RPMs. It is important to note that while the engine operates at low RPMs, the likelihood of resonance increases compared to high RPMs, as the disparity between the peak excitation frequency and the natural frequency is minimal.

The examined RMS output indicates vibration velocity, as the recorded peak frequency surpasses 5 Hz, in accordance with the parameters established by ABS. Measurement 1 exhibits an RMS vibration velocity of 0.0200 mm/s, and Measurement 2 records a value of 0.0478 mm/s. The HDPE structure remains intact throughout high- or low-RPM operation of the main engine, as the RMS values for both scenarios do not exceed the allowable limit of 30 mm/s. The RMS value for Measurement 1 is 99.93% below the permissible limit, whereas Measurement 2 is 99.84% below the permissible limit.

The diverse RPMs of the ship's primary engine yield a range of responses. In the assessment of peak excitation frequency, Measurement 1, exhibiting a higher RPM, demonstrates a peak frequency value that surpasses Measurement 2 by 31.28%. However, Measurement 1 exhibits a lower RMS value compared to Measurement 2, with a disparity of 58.16%. At low RPM, the engine's rotation is prone to instability (Masri et al., 2024). The observed peak excitation frequency approaches the natural frequency when the engine functions at its minimum RPM, resulting in heightened perceived vibration (AlQdah, 2013). Resonance at low RPMs is more likely to occur in the engine support system than in the primary structure, rather than at high RPMs (Shen et al., 2020).

5. CONCLUSION

An experimental approach—specifically, direct measurement—quantified the vibration phenomenon in the HDPE structure of the POLBENG research vessel. The entire measurement process was conducted systematically and methodically. The excitation force during the measurement process originated solely from the vessel's main engine, with minimal influence from other excitation loads on the vessel's structure. Two case studies, identified as Measurements 1 and 2, were differentiated by the RPMs of the primary engine, with each functioning at high and low RPMs. The excitation vibration and RPM count were measured utilizing a WitMotion WTVB02-485 sensor and a tachometer, respectively. An increase in RPMs correlates with a heightened peak excitation frequency. Measurement 1, with an RPM of around 4,000, exhibited a higher observed peak excitation frequency than Measurement 2, which had an RPM of about 950, at 33.31 Hz and 22.89 Hz, respectively. Despite the lower excitation peak frequency, Measurement 2 exhibits an RMS value for vibration velocity that is 139% more than that of Measurement 1. The HDPE structure can endure the vibrations produced by the ship's main engine at both high and low RPMs. The RMS values of both do not surpass the vibration velocity values specified by class. The resonance can be circumvented, as the peak excitation frequencies observed in both instances do not align with the natural frequencies. This study exclusively examines the excitation load generated by the ship's main engine at a designated RPM. The study excludes additional loads, including vibrations from the

ship's hull movement caused by its interaction with ocean waves. This study measured water and air temperatures but did not elaborate on how these temperatures influenced the qualities of HDPE material; instead, it merely presented information on the environmental circumstances during measurement. Consequently, additional research is required to address these issues. The findings presented in this study may serve as a reference for the development of HDPE ship construction designs and the numerical analysis of vibrations.

6. ACKNOWLEDGEMENTS

We would like to express our gratitude to Polytechnic of Bengkalis for their generous support in financing this research through the PNBP research scheme, namely Penelitian Penugasan with the contract number of 107/KT-PN/P3M-PB/2025. We would like to express our sincere gratitude for the support and resources offered by the Department of Naval Architecture, Polytechnic of Bengkalis, which have been instrumental in the successful completion of this research

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