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ASSESSING FISHING VESSEL OPERABILITY UNDER CHANGING LOADS: A CASE STUDY IN THE JAVA SEA

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ABSTRACT

In this study, an operability assessment was conducted on three different sizes of the same fishing boat's hull form. The fishing boat initially had a length of 5 metres, which was then doubled to 10 metres and subsequently scaled up again to 20 metres. The investigation aimed to determine the extent to which changes in size influenced the percentage of operability in the Java Sea, the same region of operation. The assessment involved various loading conditions, a characteristic feature of fishing boats where displacements and centre of gravity constantly change during operations. The boat speed for each load case was adjusted to three conditions: departure, fishing activity, and arrival. After determining the percentage operability for each load case, a weighting factor based on the time spent in each loading condition was implemented to calculate a single percentage operability for a fishing boat. The results demonstrate that the initial size (L = 5 m) achieved a low percentage operability of 58.04%. The value increased to 67.75% when the boat size was doubled (L = 10 m), and the highest length (L = 20 m) achieved the highest value of 84.03%. Considering the frequent occurrence of high waves in the Java Sea during low peak periods, a length of 20 metres or more is considered ideal for fishing vessels operating in this region. This paper showcases the influence of boat size on percentage operability and presents a methodology that can be utilised to select the best vessels with optimal seakeeping performance from a range of options, using the single percentage operability metric.

KEY WORDS

Fishing boats, Ship operability, Java Sea.

1. INTRODUCTION

Operability index assessment is used to assess the seakeeping performance based on the operational area (represented in Wave Scatter Diagram data) in a certain period (monthly, seasonally, or annually). Operability assessment is essential, especially for fishing vessels, to assess the safety and comfort of the fishing vessels.

Many ship accidents occur on fishing vessels, most of which are small in size (Wang et al., 2005), (Ugurlu et al., 2020). This operability assessment is carried out to anticipate the accident from the point of view of environmental factors or operational area.

Regardless of the ship speed and wave direction, the operability assessment is typically used in one loading condition, i.e., full load. This condition is suitable for merchant ships whose loading condition is usually unchanged during the voyage. However, this is not suitable for a fishing vessel. The loading condition of a fishing vessel changes during her voyage. Then, the operability assessment should be carried out by involving many loading conditions.

The influence of changes in loading condition, such as the displacement and longitudinal and vertical load position, towards the percentage operability of small fishing boat was investigated by Iqbal et al. (2023). Due to changes in loading conditions, the natural period of the boat is altered. Certain loading conditions result in a low percentage of operability, as they lead to high response levels that exceed the seakeeping criteria limits.

However, altering the loading condition is not the sole method of modifying the natural period of vessels. The size of the vessel also plays a role in determining the natural period, which subsequently impacts the percentage of operability. The current inquiry pertains to determining the degree to which vessel size modifications improve the fishing boat's seakeeping performance, leading to an increase in the operational effectiveness expressed as a percentage operability.

On the other hand, the percentage of operability outcomes vary significantly due to the presence of numerous loading conditions. Therefore, deciding on the most representative value of the operability index is not straightforward. The objective of this research is to develop a comprehensive operability metric that considers multiple loading conditions for fishing vessels. Additionally, it aims to evaluate the performance of three fishing vessels, obtained by scaling up the original hull form to two different sizes. This study demonstrates the extent to which vessel size influences the improvement in percentage operability. Moreover, based on each operability index of different vessel size, this research can assess the seakeeping performance among many options and will also provide information to the stakeholders on the best size suitable for the same operational region, in this case, the Java Sea.

2. METHODOLOGY

The main dimensions and body plan of the fishing vessel used in this research are shown in **Figure 1** and **Table 1**. The initial hull then was scaled up double to create two other vessels. The study compares the operability index assessments of the three boats proposed in this research.

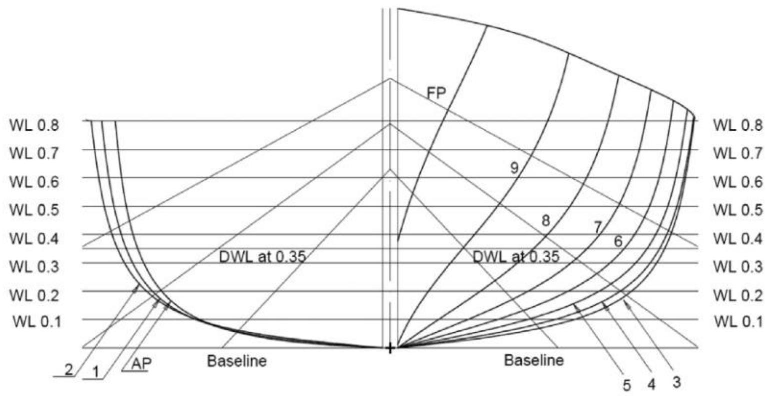

Figure 1: The body plan of the fishing vessel (Liu et al., 2019).

Table 1: Main Dimension of Fishing Vessels

Parameters	Initial,	2x Scale,	4x Scale,
Length between perpendicular, LPP (m)	5.000	10.000	20.000
Breadth at water line, B (m)	1.934	3.868	7.736
Loaded draft, T (m)	0.350	0.70	1.40
Displacement, Δ(ton)	1.858	14.864	118.912
Block coefficient, Cb (-)	0.537	0.537	0.537
Mid-boat section coefficient, Cm (-)	0.764	0.764	0.764
Froude number, Fr (-)	0.590	0.590	0.590
Working Area Location from AP (m)	1.828	3.656	7.312
Working Area Location from Base Line (m)	1.10	2.20	4.4

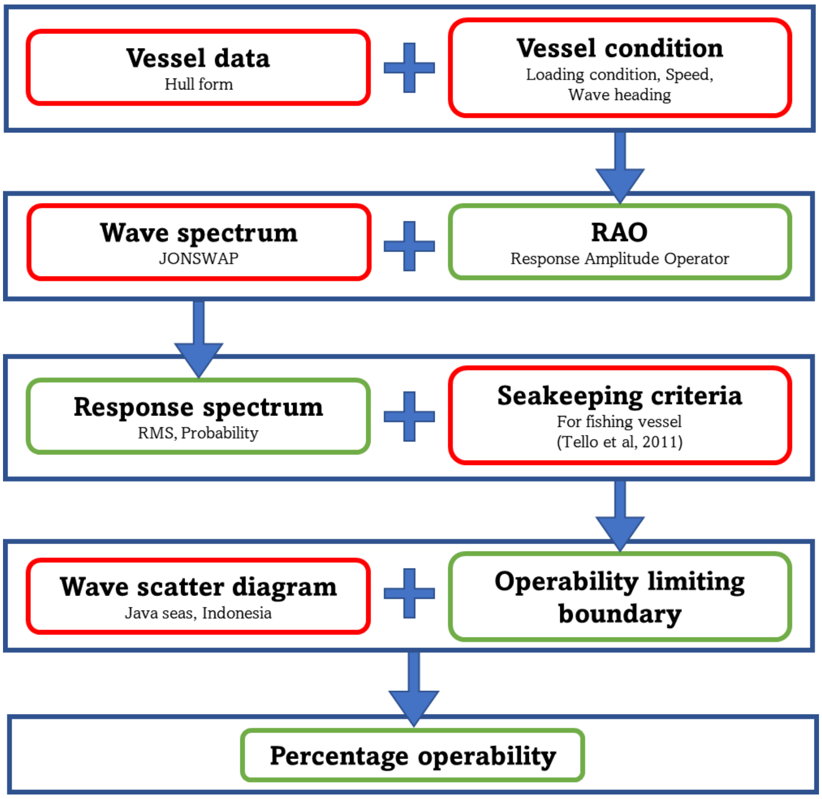

Figure 2: Overview of percentage operability analysis procedure.

Figure 2 shows the overview of the operability analysis procedure. The first step in the procedure is to determine the Response Amplitude Operator (RAO) from vessel data (wave heading and vessel speed) and the loading condition. The RAO was determined using VERES, the plugin from ShipX Software, which used linear potential theory that is solved using strip theory method. The method was introduced by (Salvesen et al., 1970). Then the response spectrum is obtained by using the combination of RAO's and wave spectrum for a single significant wave height (H_s) and wave peak period (T_p). This study used the JONSWAP spectrum (Hasselmann et al., 1973) in equation (1) with γ = 2.5, which represents the Java Sea where the boat is operated.

$$S_{\zeta}(\omega) = \left[\frac{\alpha g^2}{\omega^5} exp\left\{-\frac{5}{4}\left(\frac{\omega_p}{\omega}\right)^{-4}\right\}\right] \gamma^{exp\left\{-\frac{(\omega-\omega_p)^2}{2\sigma^2 \omega_p{}^2}\right\}} \quad (1)$$

The operability limiting boundary can be determined in each response spectrum using the seakeeping criteria based on Tello et al. (2011), as shown in **Table 2**. Slamming and green water points, for probability calculation, were measured from FP vertically to the baseline and deck, respectively. This simulation is iterated by changing H_s and T_p in wave spectrum calculation according to the wave scatter diagram data of Java Sea (**Figure 3**). Lastly, the percentage operability for each load case is selected based on the minimum percentage from all criteria.

Table 2: Seakeeping criteria for fishing vessels.

No	Criteria	Limit
1	RMS roll	6.00°
2	RMS pitch	3.00°

3	Probability of green water (GW)	0.05
4	Probability of slamming (SL)	0.03
5	RMS vertical acceleration at working area / bridge deck (VA)	0.20 g
6	RMS lateral acceleration at working area / bridge deck (LA)	0.10 g

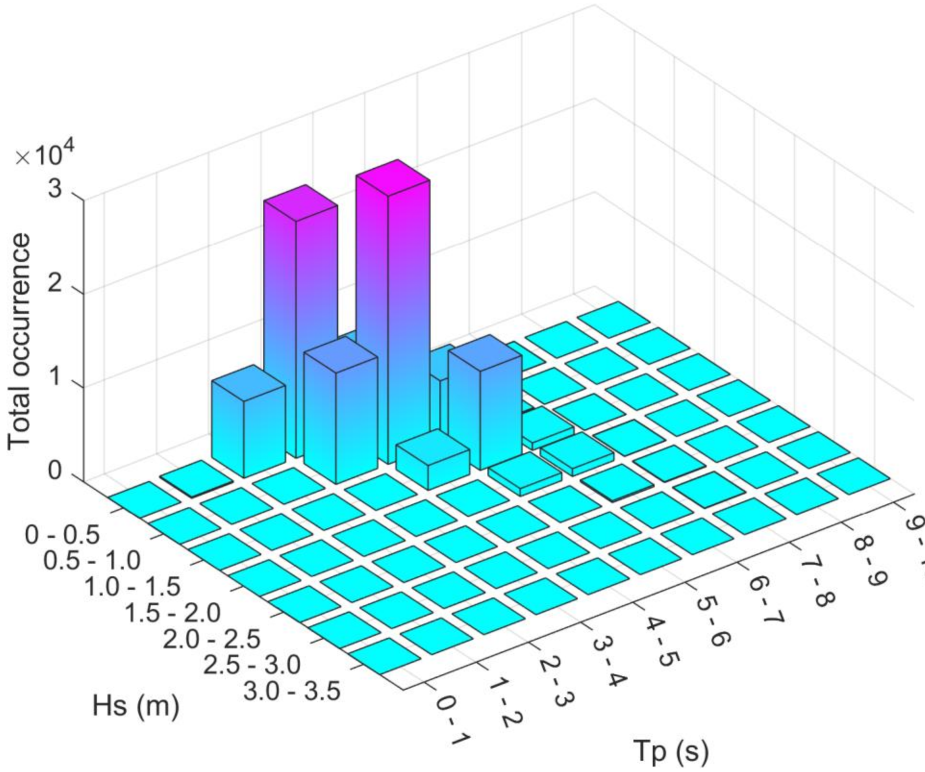

Figure 3: Wave Scatter Diagram of Java Sea for 2020 (https://app.metoceanview.com/hindcast/)

Based on Figure 2: Overview of percentage operability analysis procedure., one vessel condition (loading condition and ship speed) produces a single percentage operability. In this research, each loading condition is characterised by a weighting factor $\boldsymbol{w(LC_i)}$, which is obtained from the percentage of the total duration of the operation. The speed used in each loading condition is different and is characterised by the maximum vessel speed. Details of the different loading conditions are shown in **Table 3**. Finally, a single percentage operability $P_{op}(LC)$ from the combination of different loading conditions is shown in equation (2).

Table 3: Loading condition of fishing vessel.

Loading condition	Departure	Fishing activity			Arrival
	LC 1	LC 2	LC3	LC 4	LC 5
Ship weight (kg)	712	1285	1285	1858	1858
LCG (m)	1.550	1.751	1.751	1.828	1.828
KG (m)	0.844	0.914	0.557	1.064	0.57
$\boldsymbol{V_i}$	Vmax	0.3*Vmax	0.3*Vmax	0.3*Vmax	Vmax
$\boldsymbol{w(LC_i)}$	35%	10%	15%	10%	30%

$$P_{op}(LC) = \sum_{i=1}^{N_{LC}} P_{op}(\beta, V_i) w(LC_i) \tag{2}$$

where $P_{op}(LC)$ is Percentage Operability that considers many different load cases, $P_{op}(\beta, V_i)$ is Percentage Operability for all wave headings (β) at a particular speed (V_i) in each load case. $w(LC_i)$ is the weighting factor that is taken from the percentage of total duration of fishing vessel operation.

3. RESULTS AND DISCUSSION

3.1. RESPONSE AMPLITUDE OPERATOR (RAO) FOR VARIOUS FISHING BOAT SIZES AND LOAD CASES

Based on the wave scatter diagram of the Java Sea in **Figure 3**, the highest occurrences of H_s are observed between T_p values of 3 and 5 seconds. When the RAO peak is situated in that region, the boat exhibits a significant response. As a result of this condition, there is a decrease in the percentage operability, as the boat's responses exceeded the limit of the seakeeping criteria.

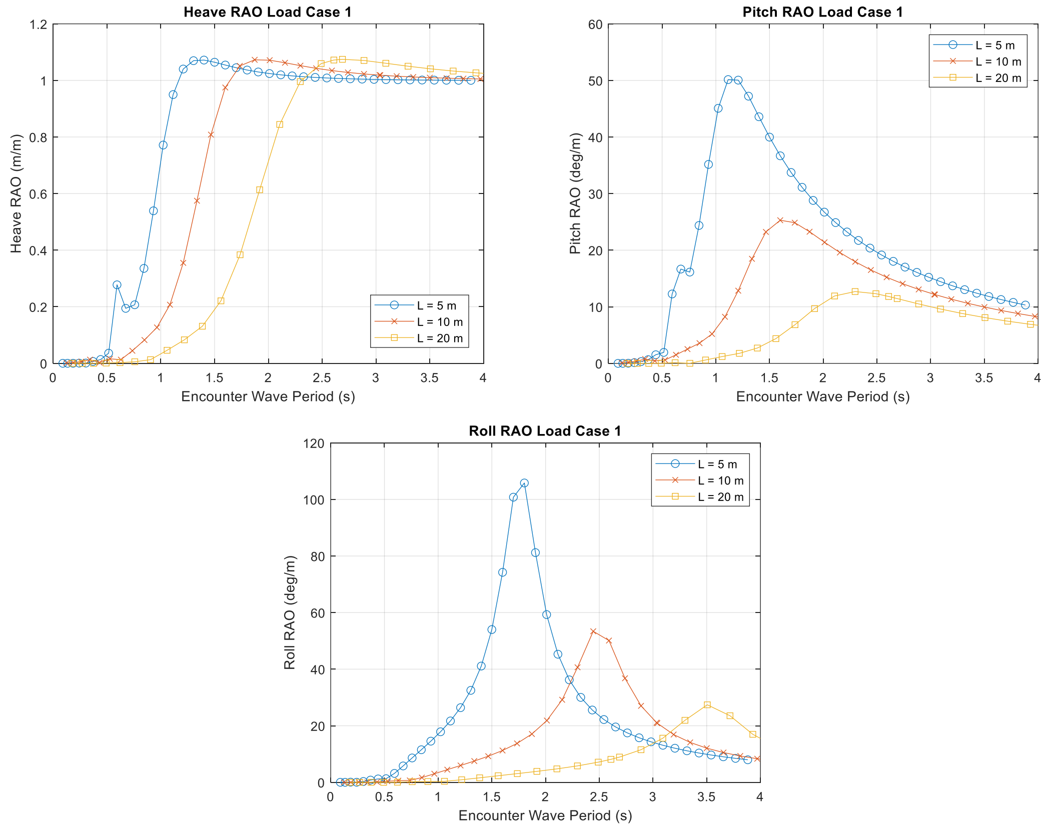

Figure 4: RAO of heave, pitch, and roll of load case 1 for various fishing boat sizes at a wave heading of 30°.

Figure 4 displays the RAO curves of heave, pitch, and roll for various boat sizes. All calculations were performed with a wave heading of 30° and under the same load case, LC 1. The figure clearly illustrates how the size of the boat affects the peak values of the RAO. With the same wave amplitude, the pitch and roll amplitudes reduce when the boat size is larger, except for heave, as it is linear with wave amplitude. The peak location for heave, pitch, and roll RAOs shift to higher wave period. The

RAO curve and the position of its peak are influenced by a combination of factors, including speed, wave heading, and loading conditions. Changes in these factors result in alterations to the RAO curve and the position of its peak.

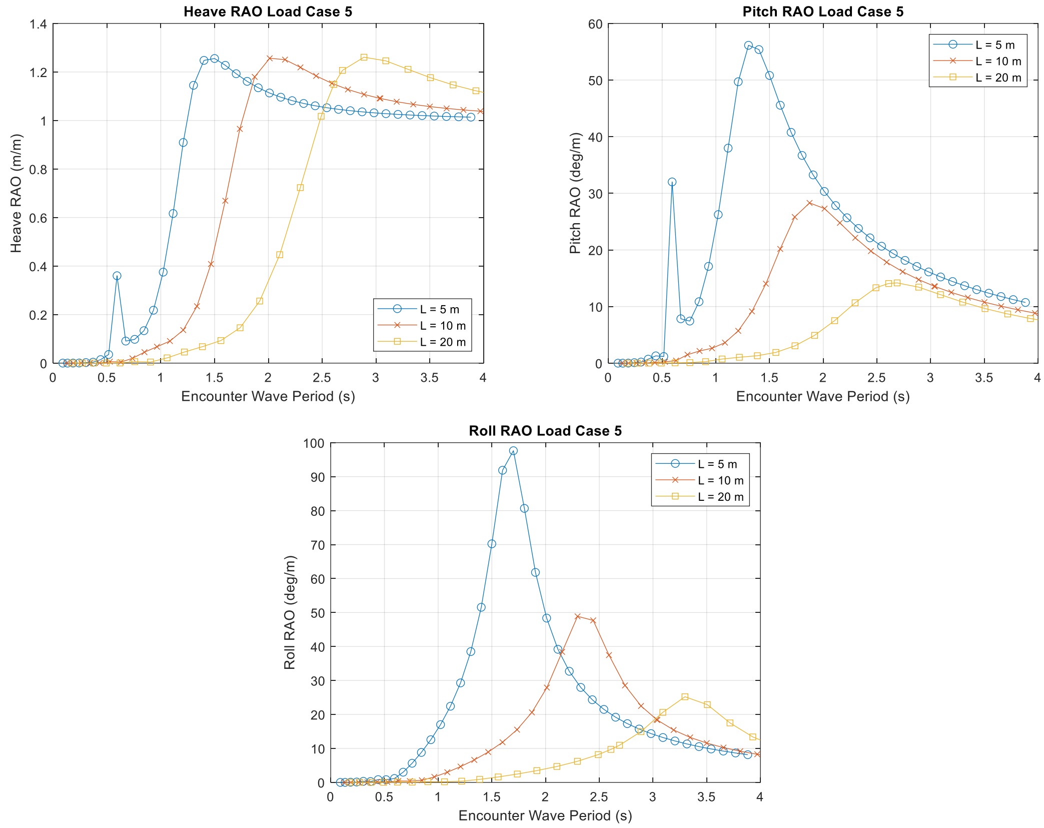

Figure 5: RAO of heave, pitch, and roll of load case 5 for various fishing boat sizes at a wave heading of 30°.

Figure 5 shows the RAO curve with the same wave heading as **Figure 4** but under a different load case, LC 5. A comparison between both figures reveals that changes in loading conditions impact the characteristics of the RAO curve, whereas the size of the boat primarily alters the peak location and lowers the peak. The next subsection will discuss the influence of loading conditions and boat size on the percentage operability.

3.2. PERCENTAGE OPERABILITY FOR DIFFERENT CRITERIA

Figure 6 displays the percentage operability, categorised by ship size, for different criteria. The definition of criteria 1 – 6 can be seen in **Table 2**. Based on this figure, it is shown that criteria 1-3 (RMS roll, RMS pitch, and Probability of Green Water) have low values compared to other load cases. However, the operability values are increased when the ship size increases.

The percentage operability values were obtained from 12 wave headings, from 0°-360° in 30° increments and have the same weight factor. Based on **Table 3**, the forward speed of LC 2 to LC 4 is lower than LC 1 and LC 5, but the percentage operability of LC 2 and LC 4 is higher than LC 1 and LC 5, except for criteria 1 (RMS roll). This result shows that reducing the speed can improve the operability. However, with the same speed, such as LC 2 and LC 3, having a low KG provided higher operability.

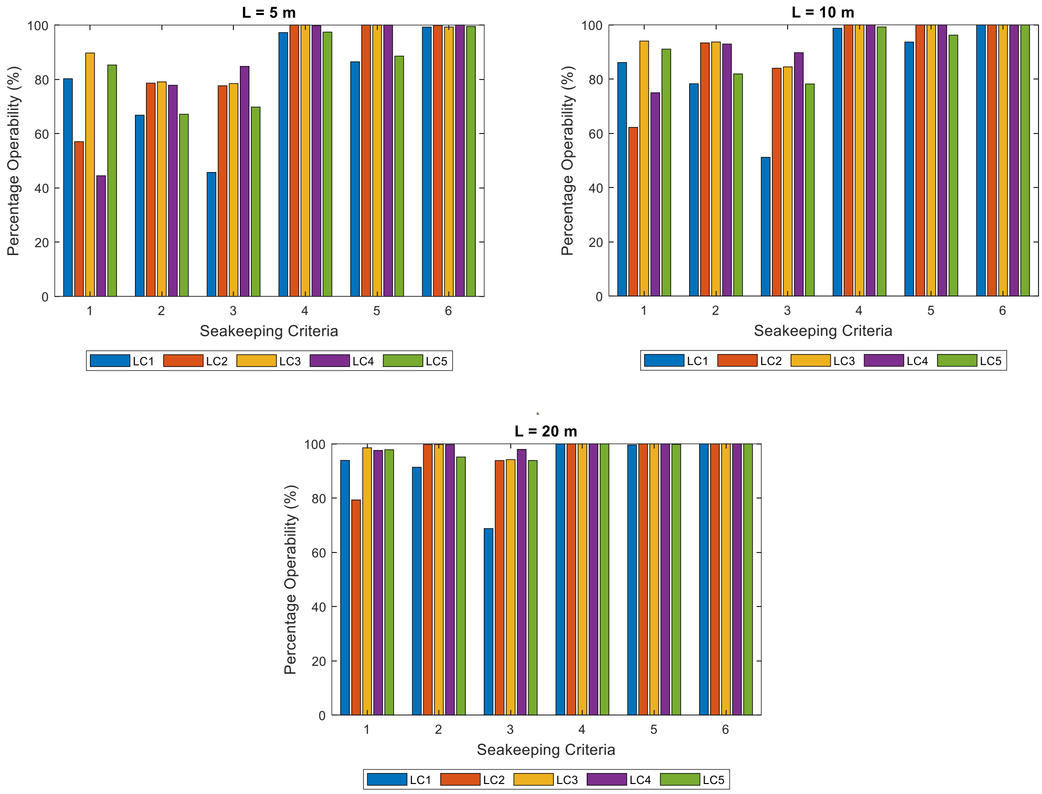

Figure 6: Percentage Operability for different criteria

In **Figure 6**, it is evident that among all criteria, criterion 3 (probability of green water) for Load Case 1 and a boat size of L=5m has the minimum value of 45.67%. The minimum value obtained, 45.67%, was selected as the percentage operability for Load Case 1. The same method was applied to determine the percentage operability for each load case.

Figure 6 also illustrates the areas of percentage operability that require improvement for each criterion. By addressing the criterion with the lowest value, the operability for all load cases can be enhanced. For instance, if the percentage operability for the probability of green water (criteria 3) is low, the vessel can be improved by increasing the freeboard to prevent green water from impacting the vessel.

3.3. PERCENTAGE OPERABILITY FOR DIFFERENT LOAD CASES

Based on **Figure 6**, the percentage operability for each load case can be determined by choosing the lowest value among all criteria. **Figure 7** shows the results of percentage operability in each load case. Based on the figure, each load case has a different percentage operability. The trend varies for each load case depending on the size, even though the shape of the boat remains the same.

In Iqbal et al. (2023), the percentage operability for each load case was calculated at the same speed value to observe the influence of loading condition and assess the worst loading condition during the operation. However, as the speed is the same for each load case, it is challenging to determine a single operability index of the vessel that considers all load cases. The operability cannot simply be averaged, as the speed for each load case is different depending on the activity in each load case.

The boat used in the present research was the same as Iqbal et al. (2023). However, the boat speed used in the calculation for each load case was adjusted according to three categories: departure, fishing activity, and arrival, as outlined in **Table 3**. Despite this condition, each load case still yields varying percentages of operability, similar to the findings reported by Iqbal et al. (2023). It is challenging to straightforwardly average the percentage operability for each load case due to the differing time durations associated with them. Consequently, this study addresses this issue by converting the duration of each load case into a percentage of the total duration. This percentage is then taken into account in the overall operability index calculation for a single fishing boat in question.

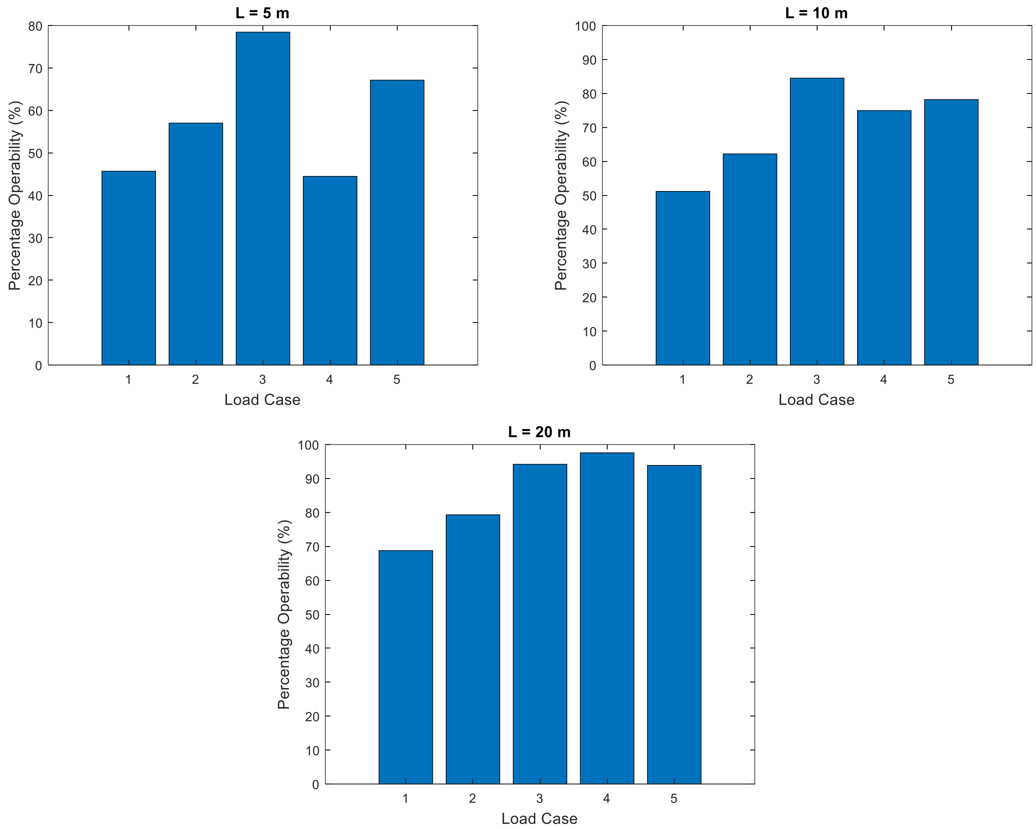

Figure 7: Comparison of the operability percentage of fishing boats across various sizes and load cases

3.4. PERCENTAGE OPERABILITY FOR DIFFERENT SHIP SIZES

The procedure used to calculate the percentage operability of a vessel typically ends at **Figure 7**, where percentage operability for a specific load case is successfully determined. However, the loading conditions for fishing vessels during operation constantly change. As a result, there are numerous percentages of operability for a single vessel, each depending on the total number of loading conditions.

In contrast, comparing the operational effectiveness of different vessels solely based on percentage operability poses challenges. To address this issue, the present study aimed to consolidate the various loading conditions into a single value of percentage operability, as illustrated in **Table 3** and described by Equation (2). By obtaining this consolidated value, it becomes possible to better compare it with other vessels and determine the most suitable choice.

Figure 8 shows the results of the percentage operability with various load cases for a different vessel size, starting from initial size (L = 5 m) which was then multiplied by two (L = 10 m) and then multiplied again by two (L = 20 m). The percentage operability for L = 5 m is 58.04%, while L = 10 m is 67.75% and L = 20 m is 84.03%.

Based on this finding, the percentage operability of the boat increases consistently with the boat size. The larger size alters the natural frequency, keeping one's distance from the most frequent peak wave period of the Java Sea and avoiding the resonant responses. As the boat responses are low, the percentage operability becomes higher by satisfying the seakeeping criteria.

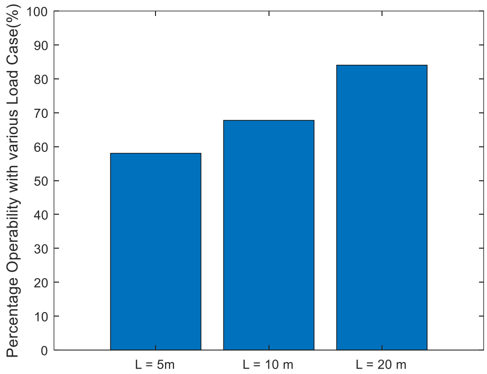

Figure 8: Percentage Operability for different vessel size

The size of the boat exerts a greater influence on the percentage operability compared to variations in the loading conditions for each size. This study reaffirms the appropriate size for fishing boats operating in the Java Sea. In general, fishing boats with a length of 20 metres or greater have a substantial natural period that exceeds the most common wave periods in the Java Sea. While loading conditions can affect the natural period, the impact of these changes is less significant compared to the alterations in boat size.

The single percentage operability resulted in this study can be a tool to assess the seakeeping performance of fishing vessels and select the best one among many vessel options. This single percentage operability has included the change in loading condition, which is a typical feature of fishing vessels during operation.

4. CONCLUSION

A comprehensive evaluation of operability was conducted on three distinct sizes of fishing boats. This assessment encompassed diverse loading conditions that simulated various fishing boat operations, considering alterations in displacement and centre of gravity. Each loading condition was accompanied by an appropriate speed corresponding to the specific fishing boat activity.

The percentage operability calculation in this research utilised seakeeping criteria for a fishing vessel. The lowest percentage operability among all the criteria was chosen as the representative operability for a single load case. As there are multiple load cases, each resulting in different percentages of operability, a weighting factor was introduced. This weighting factor was determined by considering the percentage of time spent in each load case relative to the total duration of the fishing boat's operation. By applying the appropriate weighting factors, a unified percentage operability value for a single vessel could be derived.

Based on the research findings, it was observed that increasing the size of the fishing vessels leads to an improvement in percentage operability. This improvement is attributed to the decreased RAO peak for pitch and roll motions and the altered natural period, which moves away from the most common peak period found in the Java Sea (3-5 seconds). The largest fishing vessel examined, with a length of 20 meters, exhibited the highest percentage operability of 84.03% compared to the other two fishing boats with smaller sizes but the same hull form. This suggests that fishing vessels measuring twenty meters or more in length are well-suited for operations in the Java Sea. The methodology presented in this paper offers a practical approach for selecting the most suitable vessel based on its seakeeping performance, as represented by a single percentage operability value.

5. ACKNOWLEDGEMENT

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