# Life prediction analysis of patrol vessel made from FRP with variations of wave height and wave direction

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**Abstract.** The Fiber Reinforced Plastic (FRP) material used in ships has advantages such as lighter weight, resistance to corrosion, and lower maintenance costs. However, transitioning from materials like steel and aluminum, commonly used in production, requires knowledge of the lifetime of FRP as a ship structure, allowing for an estimation of how long the ship can operate. Additionally, predicting the ship's lifetime is also necessary to meet ship safety factors. This study employs numerical testing using the Finite Element Method to predict lifetime of patrol boats in Bangka Belitung waters. Wave height variations (0.5-2 meters) and wave direction (following sea, head sea, and beam sea) are considered at a constant speed of 22 knots. Fatigue life calculation is done by determining the bending moment load at various wave heights. The bending moment is in an Ansys static structural analysis to calculate stress and deformation. The highest stress occurs in the stern frame with the value of 18.347 MPa while the lowet is in the bow frame with the value of 16.682 MPa. By calculating the stress on each variation, the life prediction can be calculated. The life prediction of a patrol vessel is 32 years and 8 months.

Keyword: Life Prediction, Finite Element Method, Fiberglass Reinforced Plastic, Seakeeping, Reliability.

## 1 Introduction

Bangka Island is located to the east of Sumatra and separated by Bangka Strait, while Belitung Island is located to the northeast of Bangka Island separated by Gaspar Strait. By looking at the geographical conditions of Bangka Belitung Island, this island provides strategic advantages in shipping and trade routes, and with these advantages that can grow economic value must be balanced with adequate security. Patrol vessel are made with the aim of maintaining the security of an area, and also conducting surveillance of illegal activities. Patrol ship is a ship designed to have high speed, have good manoeuvrability and have good structural strength, and light weight [1]. The factor that determines whether a ship can have a strong structure, has a light weight is from the material used. Patrol vessel can be built with various types of lightweight but strong materials, one of which is Fibre Reinforced Plastic (FRP). FRP is a composite consisting of glass fibres reinforced with a polymer resin matrix

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[2]. The advantage of FRP is that it has a light weight, and is able to save fuel consumption and allow operation at high speeds. In addition, FRP has good resistance to corrosion, making it an ideal material choice for applications in maritime construction [3]. Due to its light weight, FRP has a risk of experiencing cyclic loads that can cause fatigue fracture, material failure that occurs in FRP risks reducing the life of the ship [4]. One way to predict the life of a ship is with the life prediction method. Life prediction is a method to estimate the life of a material based on an analysis of the repeated loads received by the structure. The life prediction method on materials can use the S-N curve which is a comparison curve of the strength and life of the material structure.

Studies on fatigue life prediction for FRP materials are still minimal, especially for applications for patrol vessel that are much needed to maintain marine security. The S-N curve approach has also been used to examine the prediction of material fatigue life, for example, testing stiffeners with various designs using cyclic loads [5] and the study of five longitudinal side specimens on a Floating Production, Storage and Offloading (FPSO) used on offshore[6]. Other studies have also used S-N curves to predict life. Studies on S-N curves have been applied to stiffeners and transverse tusks [7]. The hotspot S-N curve approach was also carried out to analyze the structural hotspot stress in the welding area using Finite Element Analysis [8]. The work steps in this study start from modeling a patrol vessel with predetermined dimensions, then making transverse construction and deck beams. After that, find the bending moment resulting from the ship's response to the wave spectrum which will be used as external. From the accumulation of external and internal loads, the total stress and deformation will be generated. From the stress results, it will be used to get the cycle value which will then be made for the S-N curve. The purpose of this research is to determine the magnitude of the stress experienced by the ship and the location of its occurrence based on the bending moment values obtained from variations in wave height and wave direction, as well as to predict the ship's life prediction.

## 2 Methodology

This work step starts from a literature study which looks for literature on FRP ships, such as FRP material characteristics, structural fatigue mechanisms on ships, application of the Finite Element Analysis (FEA) method in analyzing patrol vessels with FRP hull material [9]. This literature study is used to gain an in-depth understanding of the factors that affect the fatigue life of patrol vessels made from FRP so that they are able to predict fatigue using the FEA method. Next is to collect data that will be used to make ship models in the form of lines plan, general arrangement, ship’s principal dimension, ship construction size and material properties of FRP type E with Yukalac 157 [10]which is used as FRP hull material [11]. The redrawn lines plan and general arrangement are then used as the basis for modeling FRP patrol vessels in 3D using the Maxsurf Modeller and Autdesk Fusion applications. In this chapter, the stages of the ship structure life testing process on FRP patrol vessels are described in the flowchart in Fig. 1.

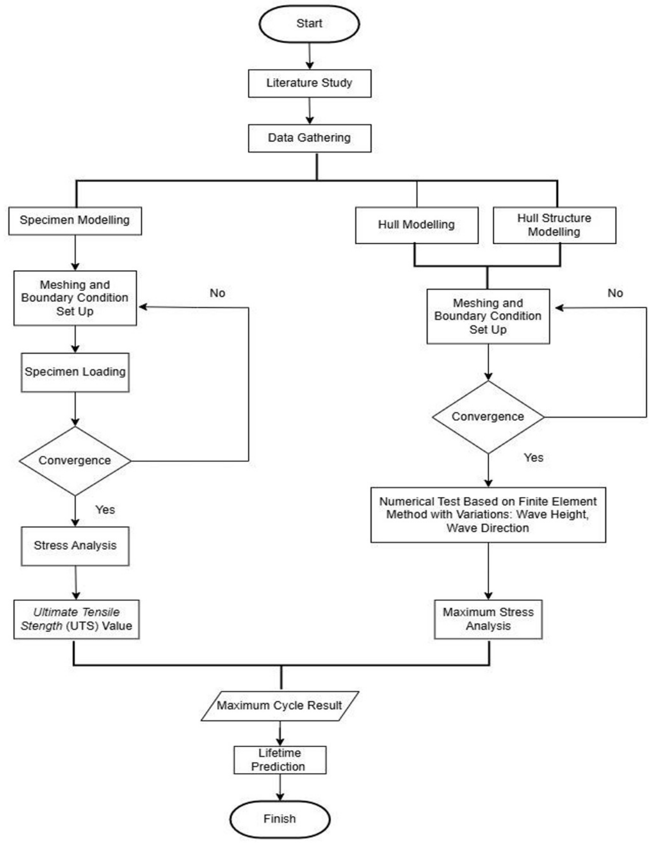



**Fig. 1.** Flowchart of Methodology

Wave direction and wave height data are obtained from the Metraweather website, and this test variation uses wave directions from head sea, beam sea and following sea with a wave height range of 0.5 – 2 meters. The reason for determining the maximum wave height variation of 2 meters is because for ships < 24 meters and operate in coastal areas, the maximum wave height is 2 meters [12]. In this test variations, the load applied to the ship's hull consists of the maximum number of passengers on the ship which is 9 people, the maximum volume of Fuel Oil Tank (FOT) and the maximum volume of Fresh Water Tank (FWT). The ship's speed used for these variations is constant, at 22 knots. The variations are shown in Table 1.

**Table 1.** Test Variation

| Wave Height (m) | Wave Direction | Passenger | FOT (L) | FWT (L) | Speed (Knot) |
|---|---|---|---|---|---|
| 2 | Head Sea | 9 | 150 | 50 | 22 |
| 1.5 | Beam Sea | | | | |
| 1 | | | | | |
| 0.5 | Following Sea | | | | |

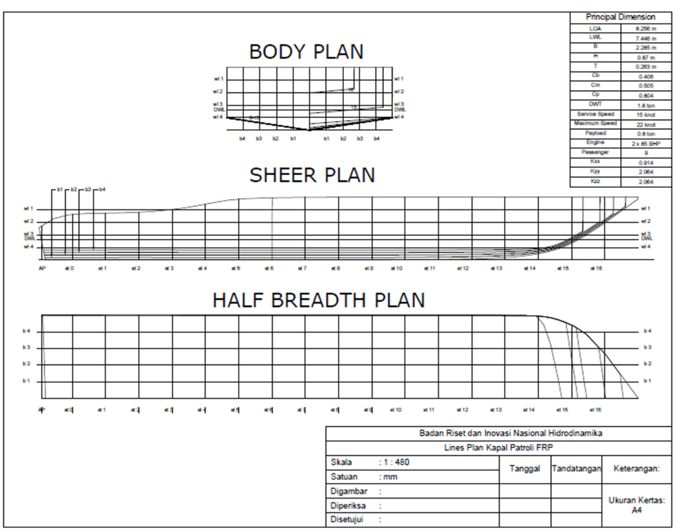
## 2.1 Hull Modelling

This FRP patrol vessel operates on the coast of Bangka Belitung. The ship model used in this study is a representation of the actual patrol vessel design with the main dimensions shown in Table 2.

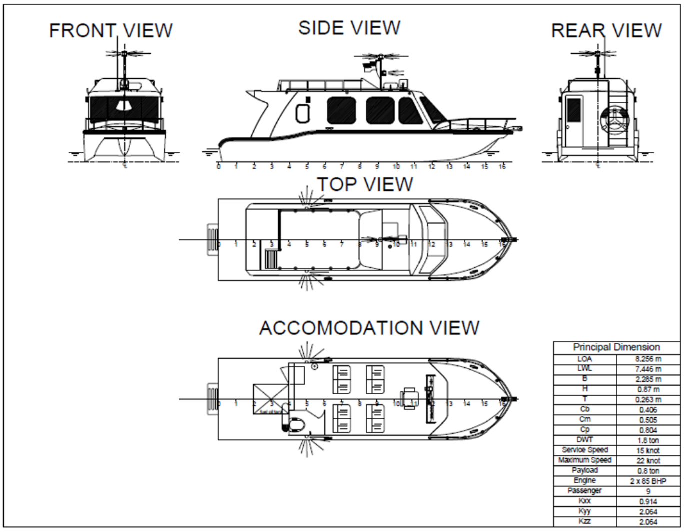
**Table 2.** Principal Dimension FRP Patrol Ship

| Principal Dimensions | | | |
|---|---|---|---|
| LOA | = | 8.256 | m |
| LWL | = | 7.446 | m |
| B | = | 2.285 | m |
| H | = | 0.87 | m |
| T | = | 0.263 | m |
| Cb | = | 0.406 | |
| Cm | = | 0.505 | |
| Cp | = | 0.804 | |
| DWT | = | 1.8 | ton |
| Service Speed | = | 15 | knot |
| Maximum Speed | = | 22 | knot |
| Payload | = | 0.8 | ton |
| Engine | = | 2 x 85 | BHP |
| Passenger | = | 9 | |
| Kxx | = | 0.914 | m |
| Kyy | = | 2.064 | m |
| Kzz | = | 2.064 | m |

This ship is designed to face coastal water conditions with varying wave directions and heights so that the ship's structure, geometry and materials must be considered in detail. The process of modeling this ship by collecting main dimensions, weight distribution (Kxx, Kyy, Kzz), and material properties. Lines plan and General Arrangement are shown in Fig. 2.




(A) Lines Plan




(B) General Arrangement

**Fig. 2.** (A) Lines Plan, (B) General Arrangement of FRP Patrol Ship

The data that has been collected is then used as the basis for 3D modeling of FRP patrol vessels using Autodesk Fusion and Maxsurf Modeller. After modeling the ship, an analysis of the ship's response to variations in wave height and direction will be carried out in accordance with the ship's operational conditions. The purpose of this analysis is to obtain the bending moment value which will be used to find the stress and deformation values. FRP material properties with Yukalac 157 and ship construction sizes are shown in Table 3 and Table 4.

**Table 3.**Material Properties FRP Patrol Ship

| | | |
|---|---|---|
| Density | 1.39 | $g/cm^3$ |
| Young Modulus | 3200 | MPa |
| Poisson's Ratio | 0.3 | |
| Bulk Modulus | 2666.7 | MPa |
| Shear Modulus | 1230.8 | MPa |
| Tensile Yield Strength | 190 | MPa |
| Tensile Ultimate Stength | 105 | MPa |

**Table 4.** Hull Construction FRP Patrol Ship

| Description | Dimensions | Unit |
|---|---|---|
| Longitudinal Deck Beams | 40 x 30 x 4 | mm |
| Main Frame | 30 x 30 x 4 | mm |
| Bottom Thickness | 10 | mm |
| Side Thickness | 8 | mm |
| Main Deck Thickness | 4 | mm |
| Deck Beam | 60 x 60 x 12 | mm |

After obtaining the data needed to create a 3-dimensional FRP patrol vessel model, the next step is modeling the hull on Maxsurf Modeller and creating a structure on Autodesk Fusion. The FRP patrol vessel model is shown in Fig. 3.

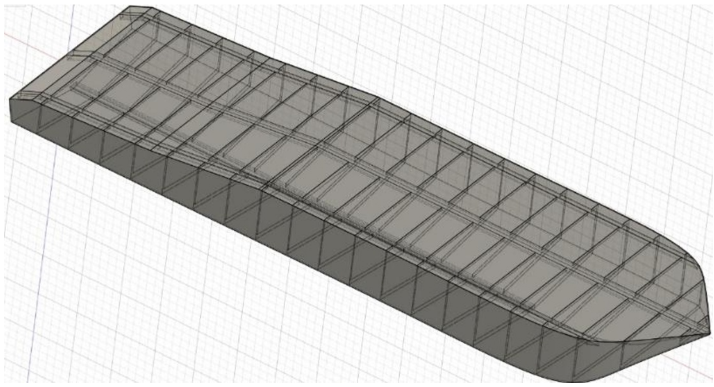
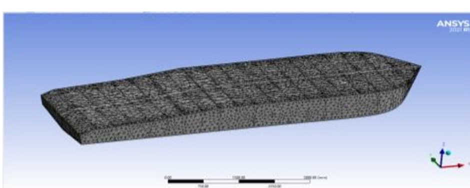


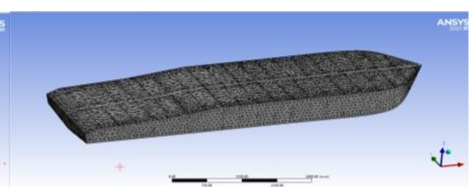
**Fig. 3.** FRP Model Patrol Vessel

## 2.2 Meshing and Boundary Condition Set Up on Hull

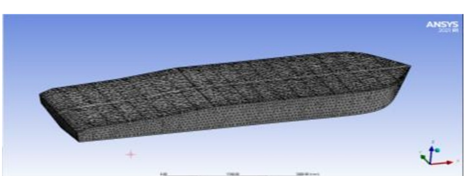
The meshing used to find stress and deformation must also be mesh convergence, where the number of elements and nodes is greater than the number of elements and nodes in the previous mesh size. The smaller mesh size will produce more accurate stress and deformation results. The mesh sizes used in this study are 100 mm to 60 mm mesh sizes shown in Fig. 4 and Table 5.



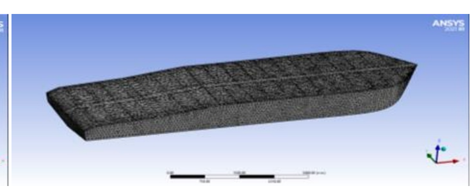
(A)Mesh 100 mm



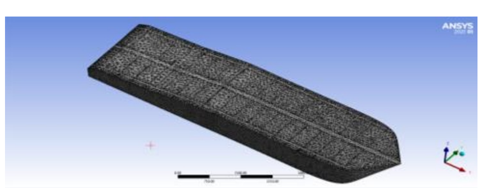
(B) Mesh 90 mm



(C)Mesh 80 mm



(D) Mesh 70 mm



(E) Mesh 60 mm

**Fig. 4.** Mesh Convergence

**Table 5.** Mesh Convergence

| Mesh Size (mm) | Number of Nodes | Number of Elements |
|---|---|---|
| 100 | 136619 | 71677 |
| 90 | 155555 | 81293 |
| 80 | 173329 | 90032 |
| 70 | 206438 | 106774 |
| 65 | 228472 | 118302 |
| 62 | 238545 | 123223 |
| 60 | 239381 | 123923 |

Determining the optimal mesh size is essential to ensure accurate to ensure stress and deformation calculations without excessive computational costs. Mesh convergence is a critical step in numerical analysis to balance accuracy and computational efficiency [13]. After finding the right mesh size, the next step is to determine the boundary conditions on the ship. Boundary conditions are used to limit the response of the hull to a given load. In this study, the boundary conditions placed on the ship are Remote Displacement placed at points C (Fore peak) and B (After peak), Force placed at point G, Bending moment (Rx and Ry) placed at points A (Rx), E (-Rx), D (Ry), F (-Ry). The boundary conditions on the ship are shown in Fig. 5.

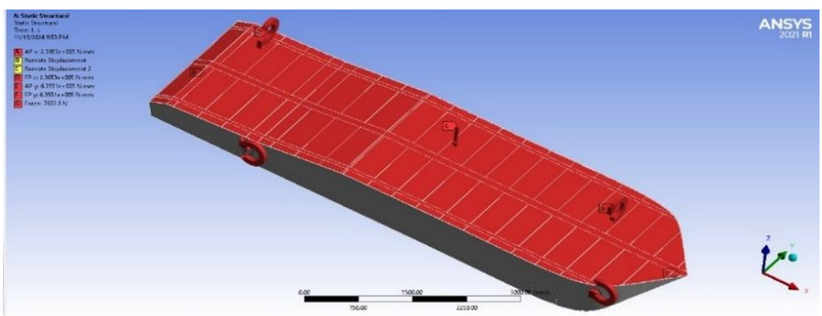



**Fig. 5.** Boundary Condition

### 2.3 Bending moment

Bending moment is the force that causes the ship to bend due to the load distribution along the ship. Bending moment is generated by the difference between the weight of the ship and the buoyancy of seawater [10]. The force from outside the ship is ocean waves that have different height and direction variations. The value of the wave due to the height and direction of the wave is sought using Ansys Hydrodynamic Diffraction and Hydrodynamic Response. On ships whose overall length is < 24 m, the ship only experiences one bending moment, namely the local bending moment [14], The formula for finding the local bending moment value is shown in Equation (1).

$$M = 83.33 \text{ x } P \text{ x } b^2 \text{ x } 10^{-6} \quad (1)$$

Where:

M = Local bending moment (N mm)
P = Force (N)
b = Unsupported length (m)

## 2.4 Maximum Stress Analysis on Ship Hull

After obtaining the mesh size and determining the boundary conditions, the next step is to determine the stress and deformation values. Stress is the amount of force acting on an object per unit surface area where the force acts. After getting the stress, the next step is to find the deformation value. Deformation or strain is a change in shape that occurs due to external loads [15]. Stress and deformation in FRP patrol vessels occur due to waves or external forces. Therefore, the bending moment that has been obtained earlier is used to find the value of stress and deformation on the ship.

## 2.5 Maximum Cycle Result

When the maximum stress value occured, the next step is to find the maximum cycle value which refers to the maximum number of load cycles that the FRP hull can experience before material failure due to fatigue. What is inputted to find the maximum cycle value is the iteration of max dynamic load until material failure.

## 2.6 Result Validation

Validation is carried out by modeling the specimen used as validation, using FRP material which has a layer configuration of 3 CSM 450 + 2 WR800 which is the same layer used in the patrol vessel hull. This specimen has an overall length of (L) 250 mm, width ($b_1$) 25 mm, thickess (h) 8 mm. This specimen will then be modeled in Ansys Static Structural to obtain the Ultimate Tensile Strength (UTS) value. Based on experimental tests, the ultimate tensile strength value is 105.3 MPa [16]. The results obtained from the numerical analysis will then be compared with the experimental test results for convergence. The tensile test specimen model is shown in Fig. 6.

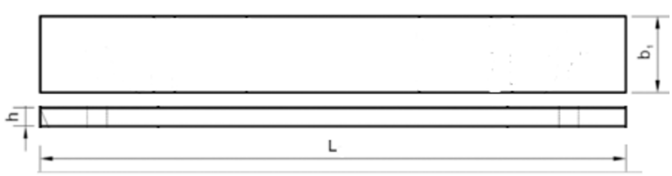



**Fig. 6.** Bending Test Specimen

The specimen is given the same load as the load received by the load on the hull. The reason for giving the same load is to get the same stress and deformation values as those received by the hull and to compare the results for further validation. The results can be said to be valid if the stress generated from the mesh size has a difference of < 2% with the mesh size [16].

## 2.7 Lifetime Prediction

Lifetime prediction is carried out using S-N curves which will be used to determine the relationship between stress and the number of load cycles until failure occurs.In the calculation of lifetime prediction, the spectral fatigue value is required. [17]. The equation for finding spectral fatigue is shown in Equation (2).

$$\mathrm{N}\,S^{m} = \mathrm{k} \tag{2}$$

Where:

N = Number of failure cause event cycles
S = Stress range (MPa)
m,k = Constant value

Cummulative damage can be found with the equation created by IACS R-56. Cumulative damage describes the process of accumulating damage to a structure or material due to cyclic loads [17] using the Palmgren-miner law shown in Equation (3).

$$D = \sum \frac{ni}{Ni} \tag{3}$$

Where:
D = Design life
$n_i$ = Damage cycle at stress range
$N_i$ = Maximum cycle of material

Next step is to find the value of the wave spectrum. The wave spectrum in this study uses Pierson - Moskowitz. The equation used to calculate the Pierson - Moskowitz wave spectrum is shown in Equation (4).

$$S(f) = \propto \frac{g^2}{(2\pi)^4} \frac{1}{f^5} \exp - \left( (\frac{5}{4})(\frac{f_0}{f})^4 \right) \tag{4}$$

Where:
S (f) = Energy spectrum density at frequency $(m^2/\text{rad s})$
α = 0.081 ; Spectrum parameter
f = Wave frequency
$f_0$ = Spectrum wave peak
$H_s$ = Wave Height (m)

In addition to using the wave spectrum, a stress spectrum is also required. The stress spectrum is a representation of the stress energy distribution as a function of frequency. This spectrum is used to analyse the stress variations that occur cyclically [18]. The stress spectrum equation is shown in Equation (5).

$$S_\sigma = RAO_\sigma{}^2 \text{ x } S_\zeta(\omega) \tag{5}$$

Where:
$S_\sigma$ = Stress Spectrum $(MPa^2/\text{rad s})$
$RAO_\sigma$ = Stress Response Amplitude Operator (MPa/m)
$S_\zeta(\omega)$ = Wave Spectrum $(m^2/\text{rad})$
ω = Angular Frequency (rad/s)

The moment spectrum is a representation of the bending moment distribution as a function of frequency, the moment spectrum is used to analyze the effect of moments occurring due to dynamic loads such as ocean waves [19]. The moment spectrum $(m_o)$ equation is shown in Equation (6).

$$m_o = \int_0^\infty S_\zeta(\omega)\, d\omega \tag{6}$$

By getting the moment spectrum value $(m_o)$, The next step is to find the second order spectrum moment value $(m_2)$ is shown in Equation (7).

$$m_2 = \int_0^\infty \omega^2\, S_\zeta(\omega)\, d\omega \tag{7}$$

By getting the values of the spectrum moment and second order spectrum moment, the next step is to look for the short term events shown in Equation (8).

$$n_0 = \frac{1}{2\pi}\sqrt{\frac{m_2}{m_0}} \tag{8}$$

Short term Probability Density Function (PDF), is calculate using Rayleigh distribution [19], shown in Equation (9).

$$p_s(s) = \frac{S}{m_0}\exp\left[\frac{-S^2}{2}\right] m_0 \tag{9}$$

Where:
S = Stress Range (MPa)

Short term PDF can be use to find the value of long term PDF, shown in Equation (10).

$$p_L(s) = \quad p_s(s) \text{ x } S \tag{10}$$

By getting the short term PDF value, it can be use to get the long term event value ($n_L$) shown in Equation (11).

$$n_L = \left(\sum_i \sum_j \sum_k no \text{ x } p_i\ p_j\ p_k\right) \text{x } T_L \tag{11}$$

Calculation of long term events requires loading conditions that contain wave probability values, service area probabilities and loading probabilities. Wave probability is a description of the likelihood of waves with certain characteristics, and will be used to understand the frequency of wave occurrence in a given time period. The equation to find the wave probability is shown in Equation 12.

$$\text{Wave Probability} = \frac{\text{Total number of events in wave height variation}}{\text{Total number of events}} \tag{12}$$

The probability of service areas is the possibility of ships operating in certain areas. This FRP patrol vessel operates on the Bangka Island Coast, Belitung Island Coast and Gaspar Strait. The equation for finding the probability value of the service area is shown in Equation 13.

$$\text{Probability of Service Area} = \frac{\sum(\text{frequency x route distance})}{\text{Total Route Distance}} \tag{13}$$

Loading probability is the possibility of the load received by the ship. The loading probability equation is shown in Equation 14.

$$\text{Loading probability} = \sum(\text{Operation Area Prob. x Wave Prob.}) \tag{14}$$

The fatigue life obtained should be close to or greater than the design life of the ship. In this FRP patrol vessel, the design life is 25 years. When the value of $D_{fat}$ is obtain, the fatigue life of this ship can be calculated by Equation (15) [20].

$$\text{Fatigue Life} = \frac{\text{Design Life}}{D} \tag{15}$$

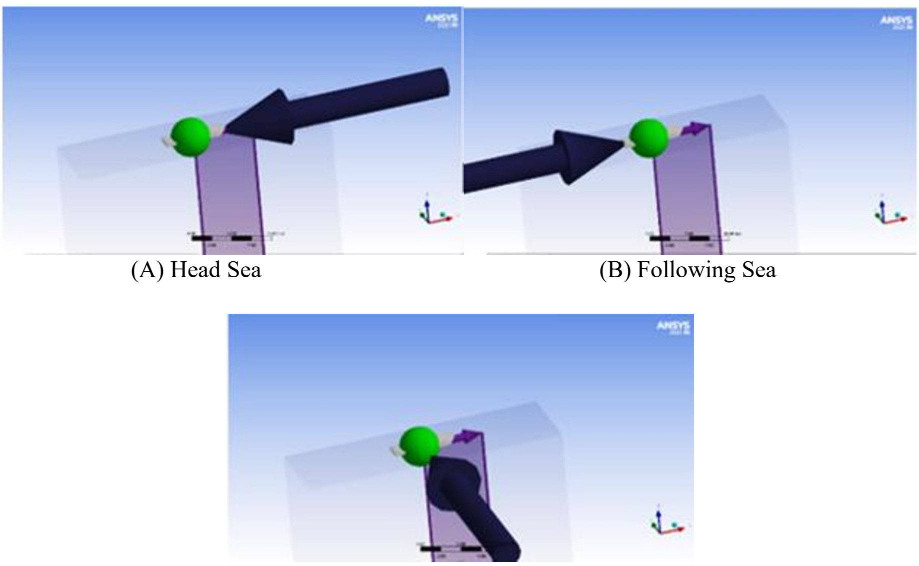
Where the results are expressed in years.

## 3 Results and Discussion

In this chapter, the results of the analysis of life prediction on patrol vessels made of FRP with variations in wave height and wave direction in Bangka Belitung waters are explained. The results obtained are analyzed in depth to determine the effect of the test variations on the ship. This chapter also includes a comparison of numerical test results with experimental results so as to ensure the validity of the test results.

### 3.1 Bending Moment

To get the bending moment value, this ship analysis uses Ansys Hydrodynamic Diffraction and Hydrodynamic Response. The simulation of getting the bending moment value on the ship is shown in Fig.7.



(A) Head Sea (B) Following Sea

(C) Beam Sea

**Fig. 7.** The process of obtaining bending moment values with variations in wave direction

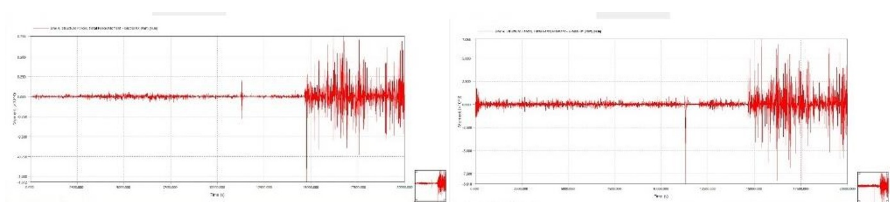
The results obtained from Hydrodynamic Diffraction and Hydrodynamic Response are in the form of graphs that must convergent. The results obtained must be confirmed to converge in order to obtain accurate values. The average value of bending moment is shown in Table 6.

**Table 6.** Bending Moment Result from Wave Direction Variation

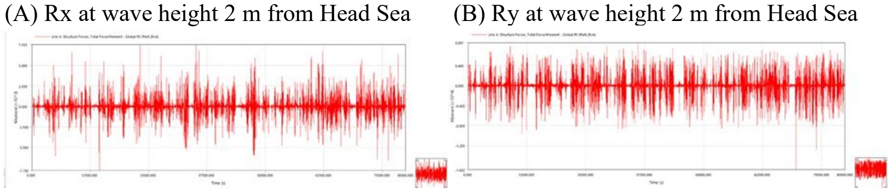
| Wave Direction | Wave Height /Hs (m) | Speed (knot) | Passenger Load (N) | FOT Load (kg) | FWT Load (kg) | Total Weight (kg) | Total Weight (N) | Wave Load (N.mm) | Wave Load (N.mm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Rx | Ry |
| Head Sea | 2 | 22 | 630 | 115.5 | 50 | 795.5 | 7803.9 | 238527.58 | 635507.77 |
| | 1.5 | | | | | | | 585449.3 | 1174048.9 |
| | 1 | | | | | | | 552294.12 | 883894.97 |
| | 0.5 | | | | | | | 416465.55 | 570816.73 |
| Beam Sea | 2 | | | | | | | 1101575 | 625627.61 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1.5 | | | | | | | 1448003.1 | 768000.04 |
| | 1 | | | | | | | 1329802 | 794885.66 |
| | 0.5 | | | | | | | 901206.12 | 690895.72 |
| Following Sea | 2 | | | | | | | 1210335 | 1536350.6 |
| | 1.5 | | | | | | | 816526.42 | 1538448.1 |
| | 1 | | | | | | | 837238.03 | 1598186.3 |
| | 0.5 | | | | | | | 855171.95 | 1218664.9 |

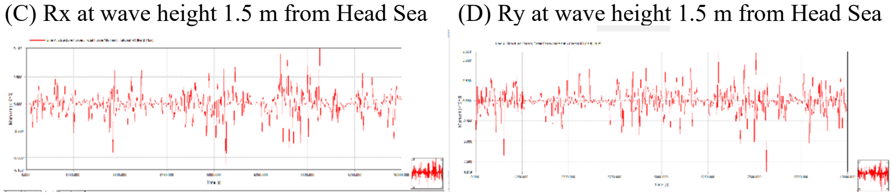
The reason for using the average bending moment value to find the stress value is so that the bending moment value provides a general picture that directly represents the effect of this load, this average data also helps in calculating stress cycles that are more representative of actual conditions, besides that many guidelines on classification bodies such as BKI, ABS, DNV use the average bending moment value to calculate stresses because it is considered representative enough for design purposes. The setup used in Ansys Static Structural uses n/mm units, therefore it is necessary to convert the value from n/m to n/mm units. The result of bending moment graph is shown in Fig. 8-10.



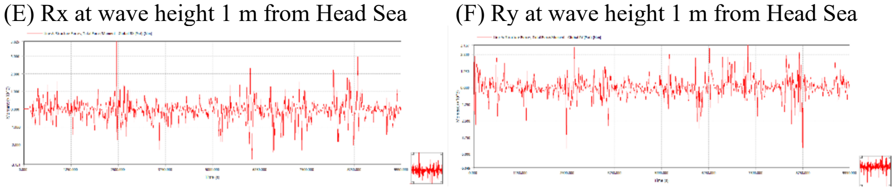
(A) Rx at wave height 2 m from Head Sea (B) Ry at wave height 2 m from Head Sea



(C) Rx at wave height 1.5 m from Head Sea (D) Ry at wave height 1.5 m from Head Sea

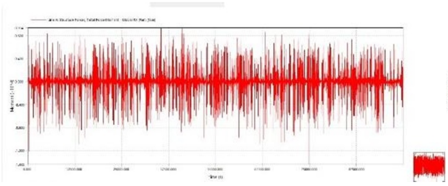
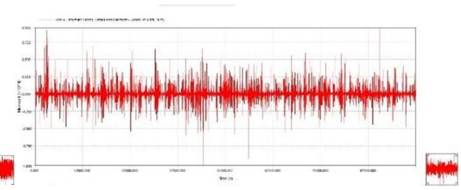


(E) Rx at wave height 1 m from Head Sea (F) Ry at wave height 1 m from Head Sea

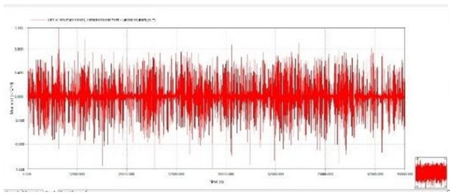
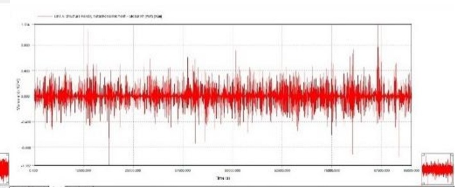


(G) Rx at wave height 0.5 m from Head Sea (H) Ry at wave height 0.5 m from Head Sea

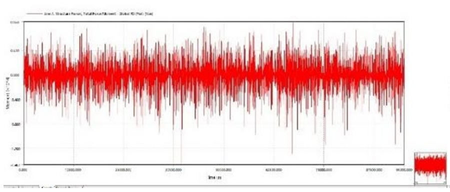
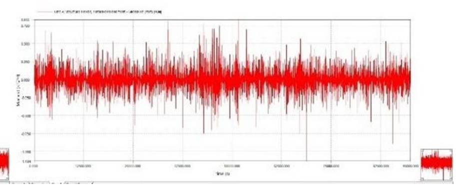
**Fig. 8.** Bending Moment from Head Sea

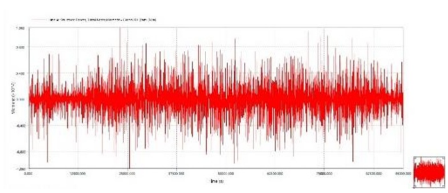
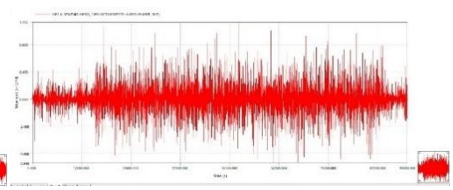
(A) Rx at wave height 2 m from Beam Sea (B) Ry at wave height 2 m from Beam Sea

(C) Rx at wave height 1.5 m from Beam Sea (D) Ry at wave height 1.5 m from Beam Sea

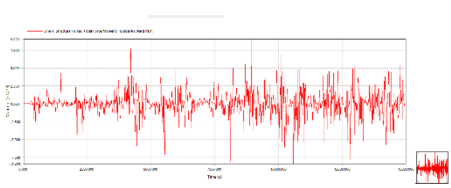
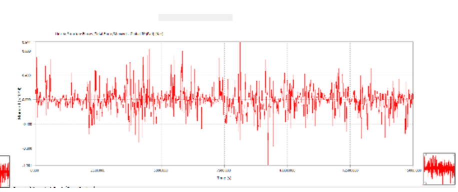



(E) Rx at wave height 1 m from Beam Sea (F) Ry at wave height 1 m from Beam Sea

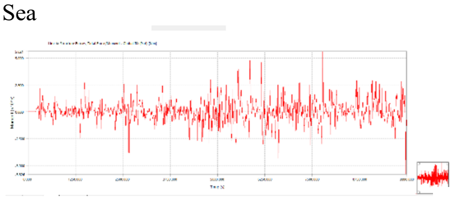
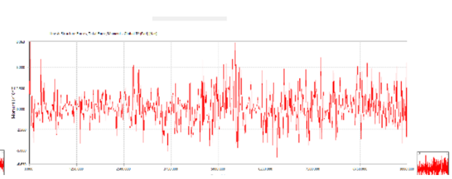



(G) Rx at wave height 0.5 m from Beam Sea (H) Ry at wave height 0.5 m from Beam Sea

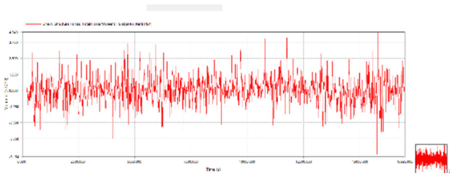
**Fig. 9.**Bending Moment from Beam Sea

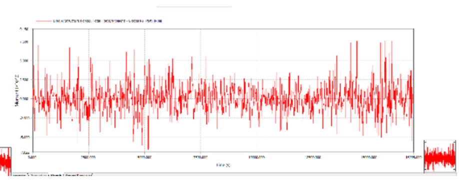
(A)Rx at wave height 2 m from Following Sea (B) Ry at wave height 2 m from Following Sea

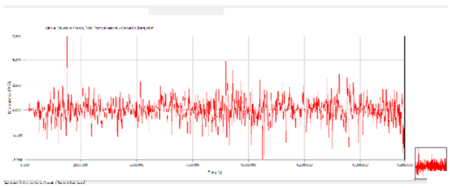
(C)Rx at wave height 1.5 m from Following Sea (D) Ry at wave height 1.5 m from Following Sea



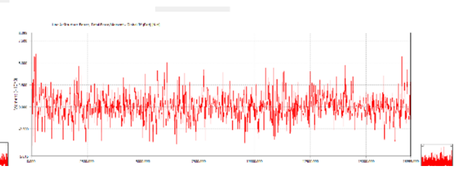
(E)Rx at wave height 1 m from Following Sea



(F) Ry at wave height 1 m from Following Sea



(G) Rx at wave height 0.5 m from Following Sea



(H) Ry at wave height 0.5 m from Following Sea

**Fig. 10.** Bending Moment from Following Sea

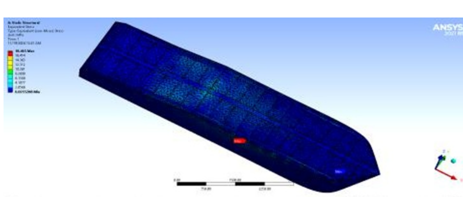
## 3.2 Stress, Deformation, and Cycle

Bending moment is used as a torsional load on the ship in the X and Y axes. The illustration of the boundary condition setting is in accordance with Fig. 5. After analyzing the structure in Ansys Static Structural, the stress values shown in Table 7 and Fig. 10-19 are obtained.

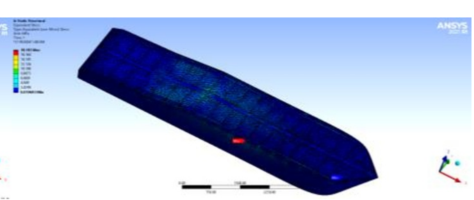
**Table 7.** Stress and Deformation with variation of wave direction and wave height

| Stress (MPa) | Deformation (mm) | N (cycles) | Description |
|---|---|---|---|
| 18.347 | 53.515 | 361390 | Head Sea (180°) |
| 18.346 | 53.925 | 362370 | |
| 18339 | 53.666 | 363040 | |
| 18.251 | 53.429 | 363790 | |
| 18.204 | 53.340 | 364910 | Beam Sea (90°) |
| 18.193 | 52.699 | 365350 | |
| 18.183 | 52.735 | 366160 | |
| 17.249 | 52.756 | 372450 | |
| 16.846 | 53.220 | 380510 | Following Sea (0°) |
| 16.698 | 53.296 | 387070 | |
| 16.682 | 53.334 | 390160 | |
| 16.5 | 53.063 | 391700 | |

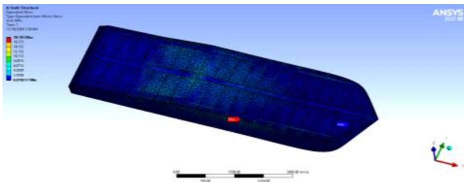
The results of stress and deformation occur on patrol ship hull with variations of wave direction and wave height are shown in Fig. 11-19.



(A) V = 22 knot, Hs = 2 m



(B) V = 22 knot, Hs = 1.5 m


(C) V = 22 knot, Hs = 1 m

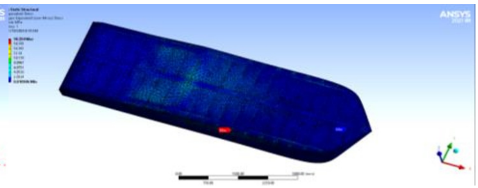
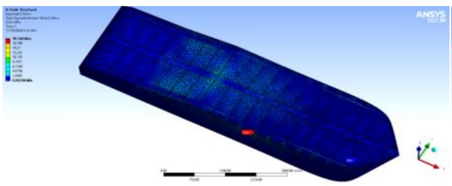
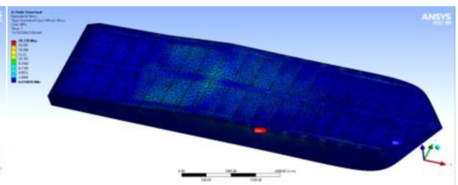
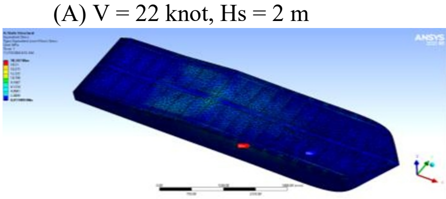

(D) V = 22 knot, Hs = 0.5 m

**Fig. 11.** Resulting stress at 180° waveform


(A) V = 22 knot, Hs = 2 m


(B) V = 22 knot, Hs = 1.5 m


(C) V = 22 knot, Hs = 1 m

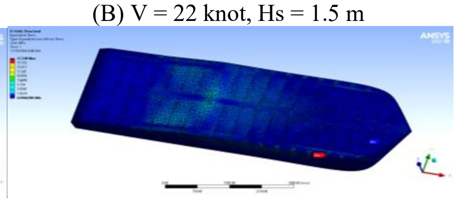
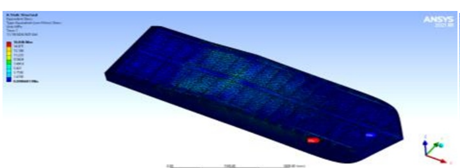
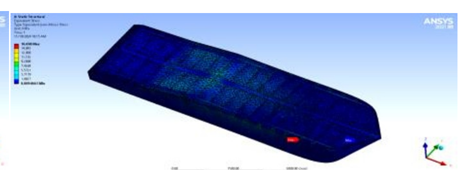
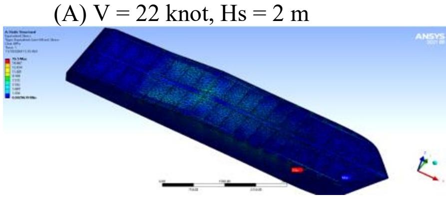

(D) V = 22 knot, Hs = 0.5 m

**Fig.12.** Resulting stress at 90° waveform


(A) V = 22 knot, Hs = 2 m


(B) V = 22 knot, Hs = 1.5 m


(C) V = 22 knot, Hs = 1 m

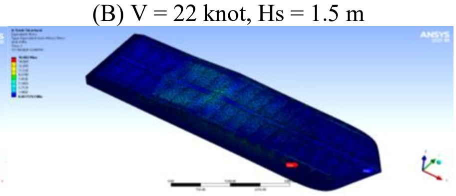
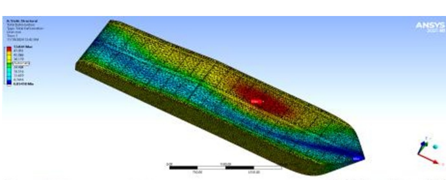
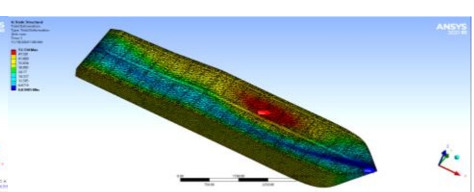
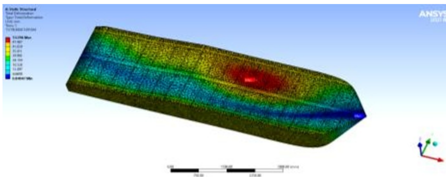

(D) V = 22 knot, Hs = 0.5 m

**Fig. 13.** Resulting stress at 0° waveform


(A) V = 22 knot, Hs = 2 m


(B) V = 22 knot, Hs = 1.5 m


(C) V = 22 knot, Hs = 1 m

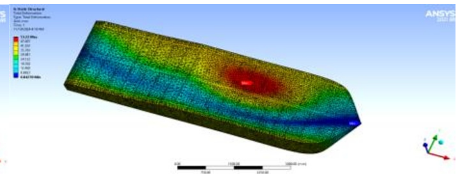
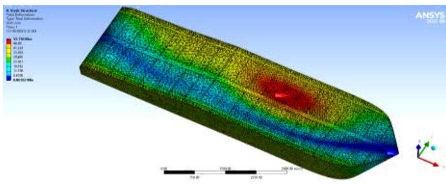
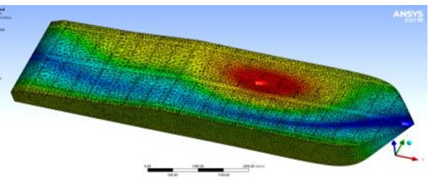
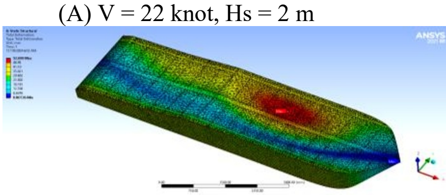

(D) V = 22 knot, Hs = 0.5 m

**Fig. 14.** Deformartion result at 180° waveform


(A) V = 22 knot, Hs = 2 m


(B) V = 22 knot, Hs = 1.5 m


(C) V = 22 knot, Hs = 1 m

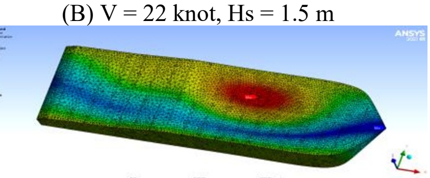
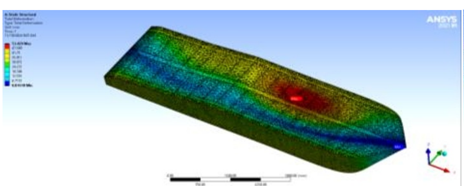
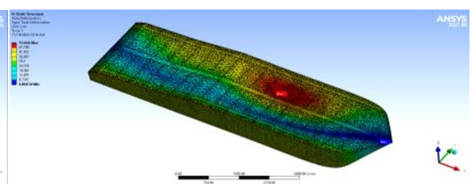
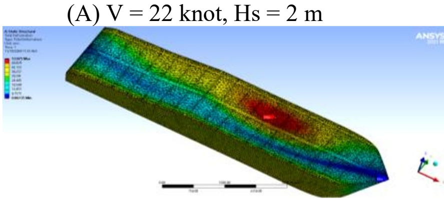

(D) V = 22 knot, Hs = 0.5 m

**Fig. 15.** Deformartion result at 90° waveform


(A) V = 22 knot, Hs = 2 m


(B) V = 22 knot, Hs = 1.5 m


(C) V = 22 knot, Hs = 1 m

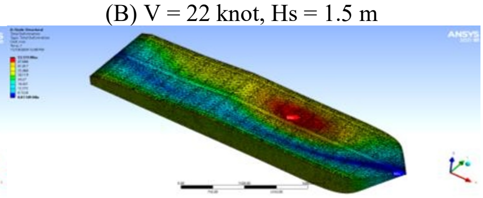
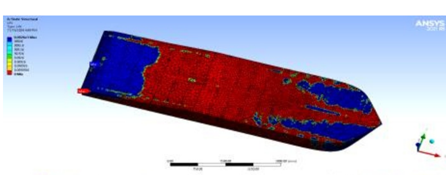
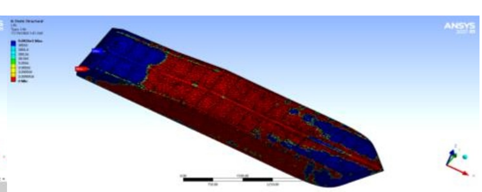
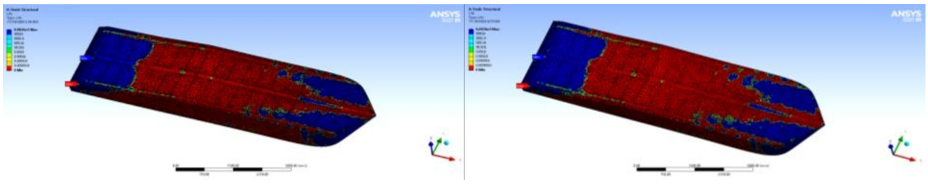

(D) V = 22 knot, Hs = 0.5 m

**Fig. 16.** Deformartion result at 0° waveform

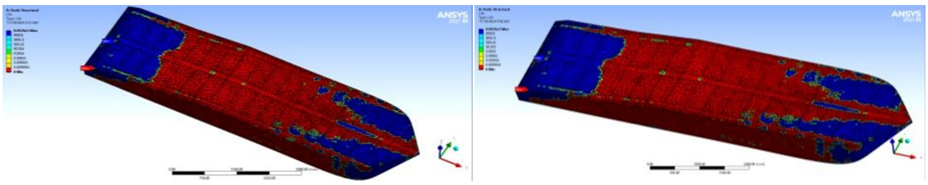

(A) V = 22 knot, Hs = 2 m


(B) V = 22 knot, Hs = 1.5 m

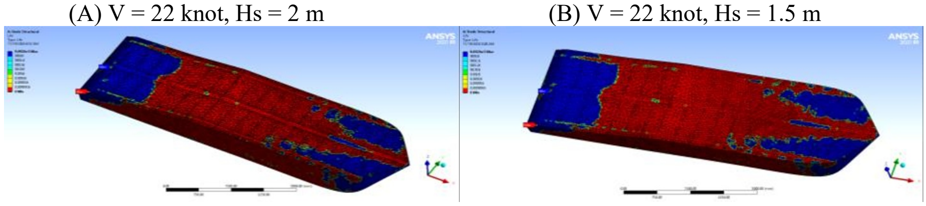


(C) V = 22 knot, Hs = 1 m (D) V = 22 knot, Hs = 0.5 m

**Fig. 17**. Cycle at 180° waveform

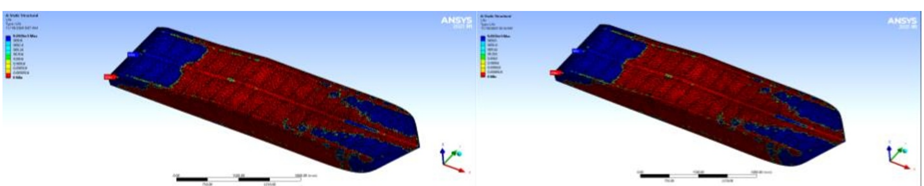


(A) V = 22 knot, Hs = 2 m (B) V = 22 knot, Hs = 1.5 m

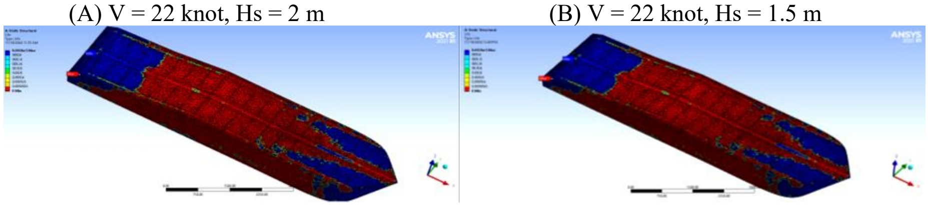


(C) V = 22 knot, Hs = 1 m (D) V = 22 knot, Hs = 0.5 m

**Fig.18.** Cycle at 90° waveform



(A) V = 22 knot, Hs = 2 m (B) V = 22 knot, Hs = 1.5 m



(C) V = 22 knot, Hs = 1 m (D) V = 22 knot, Hs = 0.5 m

**Fig. 19.** Cycle at 0° waveform

With the stress and cycle results found using Ansys Static Structure, the next step is to validate the results. The validation using specimens that have been experimentally tested [16]. The results of experiment test shows that the average bending strength result is 158.4 MPa, while the numerical analysis show that the ship's stress value has a smaller value which is 17.65 MPa. With this comparison, it can be shown that this patrol boat has a strong hull to sail in the waters of Bangka Belitung.

## 3.3 Life Prediction

The results of the life prediction calculation using the RAO value obtained with Ansys Hydrodynamic Response and Hydrodynamic Diffraction. The purpose of finding the RAO

value is to determine the location of the stress that occurs on the ship. The RAO results are shown in Table 8.

**Table 8.** RAO on Midship

| RAO on midship | |
|---|---|
| Rx (N.mm) = | 6.3167 |
| Ry (N.mm) = | 306148.2 |

The results of the RAO graph show the location of the stresses that occur along the ship. The stern section experiences the highest stress value and the bow section experiences the smallest stress, so this result shows the need to increase the strength of the transverse structure. The image of the RAO results is shown in Fig. 20.

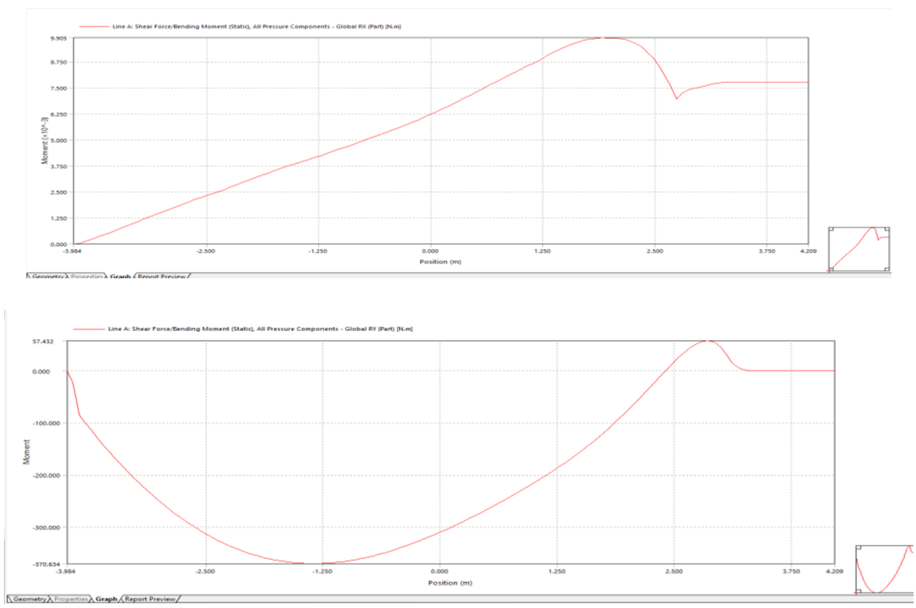



**Fig. 20.** RAO on FRP Patrol Ship FRP

By getting the RAO value, then we can find the stress value by using Rx and Ry which have been obtained from RAO. The stress result obtained is 18.391 MPa. The resulting stress image is shown in Fig. 21.

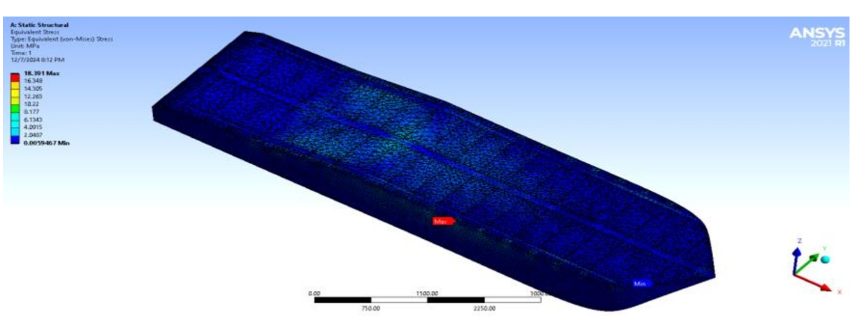



**Fig. 21.** Stress on FRP Patrol Ship using bending moment from RAO

The stress obtained will then be used to find the wave spectrum value. The wave spectrum used for this research is Pierson-Moskowitz. Pierson-Moskowitz Wave Spectrum is calculated using Equation (4). The results of the peak value with the Pierson-Moskowitz wave spectrum are shown in Table 9.

**Table 9.** Peak on wave height variation using Wave Spectrum

| | | |
|---|---|---|
| Peak 0.5 m | 1.86 | rad/s |
| Peak 1 m | 1.18 | rad/s |
| Peak 1.5 m | 0.87 | rad/s |
| Peak 2 m | 0.72 | rad/s |

By getting the peak value at each wave height variation, the next step is to find the value of the stress spectrum with Equation (5). The results of the stress spectrum are shown in Table 10.

**Table 10.** Stress Spectrum with Wave Height Variation

| | | |
|---|---|---|
| Stress Spectrum 0.5 m | 30.52906 | $MPa^2/rad/s$ |
| Stress Spectrum 1 m | 20.04619 | $MPa^2/rad/s$ |
| Stress Spectrum 1.5 m | 16.00017 | $MPa^2/rad/s$ |
| Stress Spectrum 2 m | 13.24152 | $MPa^2/rad/s$ |

Pierson-Moskowitz wave spectrum graph with wave height variation are shown in Fig. 22.

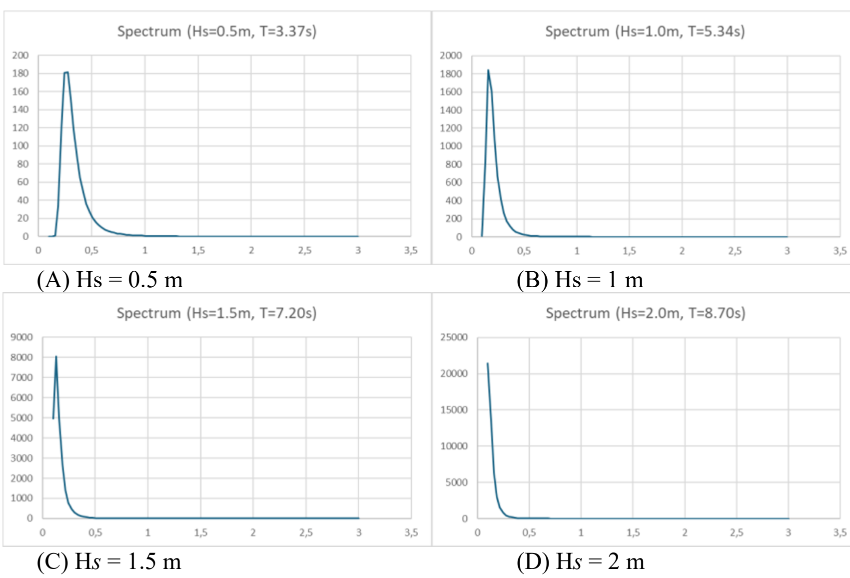



**Fig.22.** Pierson - Moskowitz Wave Spectrum

The value of the stress spectrum at various wave heights is then used to calculate the moment spectrum ($m_o$), $m_o$ value can be calculated with Equation (6). $m_o$ value are shown in Table 11.

**Table 11.** Moment Spectrum reulth with wave height variation

| | |
|---|---|
| $m_o$ 0.5 m | 7914.436826 |
| $m_o$ 1 m | 3316.623352 |
| $m_o$ 1.5 m | 1984.016628 |
| $m_o$ 2 m | 1370.265968 |

Finding the second order moment spectrum ($m_2$) using Equation (7). The results of the second order moment spectrum are shown in Table 12.

**Table 12.** Second Order Spectrum Momen with wave height variation

| | |
|---|---|
| $m_2$0.5 m | 26967.06198 |
| $m_2$ 1 m | 7134.623343 |
| $m_2$ 1.5 m | 3167.301582 |
| $m_2$ 2 m | 1811.50302 |

By obtaining the value of $m_0$ dan $m_2$, The value of short term events can be calculated using Equation (8). Short term event results are shown in Table 13.

**Table 13.** Short Term Event

| | |
|---|---|
| $n_o$ 0.5 m | 0.293932186 |
| $n_o$ 1 m | 0.233548895 |
| $n_o$ 1.5 m | 0.201192784 |
| $n_o$ 2 m | 0.183086973 |

The short term Probability Density Function (PDF) is calculated using Equation (9). The short term PDF values are shown in Table 14.

**Table 14.** Short Term Probability Density Function (PDF)

| Description | Ps |
|---|---|
| Ps(S) 0.5 m | 0.002206222 |
| | 0.002418747 |
| | 0.002405166 |
| Ps(S) 1 m | 0.005476193 |
| | 0.006119539 |
| | 0.006057069 |
| Ps(S) 1.5 m | 0.009539667 |
| | 0.010957288 |
| | 0.010834542 |
| Ps(S) 2 m | 0.014915736 |
| | 0.015640769 |
| | 0.01691967 |

The short term PDF is then used as the basis for calculating the long term PDF and calculate using Equation (10). Long term PDF values are shown in Table 15.

**Table 15.** Long Term Probability Density Function (PDF)

| | |
|---|---|
| Ps(S) 0.5 m | 4.074892525 |
| | 4.46742659 |
| | 4.442341286 |
| Ps(S) 1 m | 10.1145284 |
| | 11.30278835 |
| | 11.18740691 |
| Ps(S) 1.5 m | 17.61976573 |
| | 20.2381103 |
| | 20.01139899 |
| Ps(S) 2 m | 27.54936417 |
| | 28.88849975 |
| | 31.25063055 |

Wave probability calculate using Equation 12. Wave probability result shown in Table 16.

**Table 16.** Wave Probability On Every Service Route

| **Bangka Island Coast** | |
|---|---|
| Wave Probability with Hs = 0.5 m | 0.19213974 |
| Wave Probability with Hs = 1 m | 0.52256186 |
| Wave Probability with Hs = 1.5 m | 0.1775837 |
| Wave Probability with Hs = 2 m | 0.1077147 |

| **Belitung Island Coast** | |
|---|---|
| Wave Probability with Hs = 0.5 m | 0.25257732 |
| Wave Probability with Hs = 1 m | 0.32989691 |
| Wave Probability with Hs = 1.5 m | 0.29896907 |
| Wave Probability with Hs = 2 m | 0.1185567 |

| **Gaspar Strait** | |
|---|---|
| Wave Probability with Hs = 0.5 m | 0.25375626 |
| Wave Probability with Hs = 1 m | 0.31218698 |
| Wave Probability with Hs = 1.5 m | 0.28881469 |
| Wave Probability with Hs = 2 m | 0.14524207 |

The probability of the ship's service area is calculated with Equation 13. The results of the service area probability shown in Table 17.

**Table 17.** Probability of Ship's Service

| No | Route | Frequency | Distance (nm) | Frequency x Distance |
|---|---|---|---|---|
| 1 | Bangka Coastal | 8 | 567 | 4536 |
| 2 | Belitung Coastal | 7 | 432 | 3024 |
| 3 | Gaspar Strait | 5 | 4 | 20 |
| Total | | 20 | 1003 | 7580 |

| Service Area Probability | |
|---|---|
| Bangka Coastal | 0.59841689 |
| Belitung Coastal | 0.39894459 |
| Gaspar Strait | 0.00263852 |

By obtaining all the probability data of the operating area and waves, the loading probability value is then obtained using Equation 14. The loading probability result is shown in Table 18.

**Table 18.** Loading Probability

| | |
|---|---|
| Hs 0.5 m Bangka Coastal | 0.114979664 |
| Hs 1 m Bangka Coastal | 0.312709843 |
| Hs 1.5 m Bangka Coastal | 0.106269083 |
| Hs 2 m Bangka Coastal | 0.000284208 |
| Hs 0.5 m Belitung Coastal | 0.100764355 |
| Hs 1 m Belitung Coastal | 0.131610587 |
| Hs 1.5 m Belitung Coastal | 0.119272094 |
| Hs 2 m Belitung Coastal | 0.118556701 |
| Hs 0.5 m Gaspar Strait | 0.000669542 |
| Hs 1 m Gaspar Strait | 0.000823712 |
| Hs 1.5 m Gaspar Strait | 0.000762044 |
| Hs 2 m Gaspar Strait | 0.000383224 |

After obtaining the probability of loading, the next step is to obtain the value of long term events in each operating area. The long term events in each operating area are shown in Table 19.

**Table 19.** Long Term Event with the Variation Of Service Area

| Long Term Event ($n_L$) in Bangka Coastal | |
|---|---|
| Ps(S) 0.5 m | 122375812.8 |
| | 134164264.9 |
| | 133410911.4 |
| Ps(S) 1 m | 496445906.5 |
| | 554768624.6 |
| | 549105420.1 |
| Ps(S) 1.5 m | 378748639.2 |
| | 435031705.6 |
| | 430158394.4 |
| Ps(S) 2 m | 283910211.8 |
| | 297710685.1 |
| | 322053644.6 |

| Long Term Event ($n_L$) in Belitung Coastal | |
|---|---|
| Ps(S) 0.5 m | 81583875.23 |
| | 89442843.28 |

| | |
|---|---|
| | 88940607.63 |
| Ps(S) 1 m | 330963937.7 |
| | 369845749.8 |
| | 366070280 |
| Ps(S) 1.5 m | 252499092.8 |
| | 290021137.1 |
| | 286772262.9 |
| Ps(S) 2 m | 189273474.5 |
| | 198473790.1 |
| | 214702429.7 |

| Long Term Event ($n_L$) in Gaspar Strait | |
|---|---|
| Ps(S) 0.5 m | 81583875.23 |
| | 89442843.28 |
| | 88940607.63 |
| Ps(S) 1 m | 330963937.7 |
| | 369845749.8 |
| | 366070280 |
| Ps(S) 1.5 m | 252499092.8 |
| | 290021137.1 |
| | 286772262.9 |
| Ps(S) 2 m | 189273474.5 |
| | 198473790.1 |
| | 214702429.7 |

The value of $n_L$ on each wave height and service area then is calculate to find the average value and use for cummulative damage (D) calculation. N value calculate with the Equation (2) with the value of m = 2.159 and K = 1.519 x $10^{12}$. The result of average value from $n_L$ and N are shown in Table 20.

**Table 20.** Cumulative damage (D) result with Service Area Variation

| **S** | **$S^m$** | **$n_L$** | **$N = k/S^m$** | **$D = n_L/N$** |
|---|---|---|---|---|
| 16.682 | 435.3451237 | 68166421.32 | 3489185745 | 0.01953648 |
| 16.5 | 425.1555332 | 74732887.13 | 3572810140 | 0.02091712 |
| 16.698 | 436.2471091 | 74313250.2 | 3481971498 | 0.02134229 |
| 16.846 | 444.6380075 | 276532919.7 | 3416262160 | 0.08094605 |
| 17.249 | 467.9218312 | 309020148.1 | 3246268711 | 0.09519241 |
| 18.347 | 534.6098628 | 305865600 | 2841324311 | 0.10764896 |
| 18.339 | 534.1067043 | 210972566.5 | 2844000998 | 0.07418161 |
| 18.346 | 534.5469541 | 242323657.3 | 2841658695 | 0.08527543 |
| 18.204 | 525.6542488 | 239609099.8 | 2889732183 | 0.08291741 |
| 18.193 | 524.9687186 | 158145165 | 2893505739 | 0.05465521 |
| 18.183 | 524.3459261 | 165832377.5 | 2896942504 | 0.05724393 |
| 18.251 | 528.5887429 | 179392021.3 | 2873689651 | 0.06242568 |
| Total Cumulative Damage (D) = | | | | 0.762282569 |

With the cummulative damage already obtained, the next step is to get the design life value. The ship is planned to operate for 25 years.

$$\text{Fatigue Life} = \frac{25}{0.762282569} = 32.\,8 \text{ Years.}$$

## 4 Conclusion

The operational scenario is represented by three points along the shipping route of this patrol vessel, with probabilities of sailing at the Bangka Coast at 0.59, the Belitung Coast at 0.39, and the Gaspar Strait at 0.0026. The highest RAO values recorded for the vessel are Rx = 6.3167 N.mm and Ry = 306.148.22 N/mm, resulting in a stress value of 18.391 MPa. Simulation results from ANSYS software indicate that the maximum stress occurs at the stern, suggesting the need for structural reinforcement in this area. Furthermore, calculations using the spectral method yielded a cumulative damage value of 0.762, corresponding to a fatigue life of 32 years and 8 months.

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