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RESEARCH ARTICLE

Structure design and strength analysis of the glass reinforcement plastic (GRP) Malay traditional "Perahu Bedar"

Nik Mohd Khairuddin Nik Ismail[1*] • Mohd Azhari Johan[1] • Nur Ain Abd Rahman[1] • Ahmad Najmie Rusli[2] • Shaharudin Ahmad[3] • Mohd Saberi Muda[4]

[1] *Universiti Teknologi MARA, Mechanical Engineering Studies, College of Engineering, Terengganu Branch, Bukit Besi Campus, Malaysia*
[2] *Universiti Teknologi MARA, Mechanical Engineering Studies, College of Engineering, Johor Branch, Pasir Gudang Campus, Malaysia*
[3] *Universiti Teknologi MARA, School of Mechanical Engineering, College of Engineering, Shah Alam,Selangor, Malaysia*
[4] *Terengganu State Museum, Malaysia*

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ABSTRACT

The Perahu Bedar, a traditional fishing boat in the Terengganu region of Malaysia, has been historically crafted from Cengal wood. In response to challenges posed by wood scarcity and limitations in skilled craftsmen, this study pioneers the exploration of Glass Reinforced Plastic (GRP) as a novel alternative material for constructing the traditional Perahu Bedar, measuring 4.32 meters in length. Through a rigorous analysis, the research delves into the structural design intricacies and strength attributes of the GRP Perahu Bedar, marking a significant departure from conventional wood-based construction methods. The study conducts a comprehensive analysis of the structure design and strength characteristics of the GRP Perahu Bedar. The weight, buoyancy force, and load distribution along the boat are analyzed. The data shows varying weight and buoyancy forces along the stations, with positive load values indicating upward forces contributing to buoyancy and negative load values representing downward forces. This analysis provides insights into the boat's stability and distribution of forces. The sheer force and bending moment along the Perahu Bedar are evaluated. The sheer force values gradually increase or decrease along the boat, while the bending moment is highest at the midsection and decreases towards the ends. These results indicate the distribution of forces and stress on the boat's structure, aiding in understanding its integrity and stability. The Factor of Safety (FoS) analysis demonstrates a FoS value of 2.2368, indicating a safety margin greater than 1. This suggests that the GRP Perahu Bedar design meets safety requirements and can withstand applied

* Corresponding author
E-mail address: nmkhairuddin@uitm.edu.my (N. M. Khairuddin)

stresses without exceeding yield strength. The FoS value provides assurance of structural integrity and safety during normal operating conditions. In summary, this study underscores the groundbreaking potential of Glass Reinforced Plastic (GRP) as a viable alternative to traditional wooden Perahu Bedar due to very high cost of Cengal Wood (wood that been used to build Peahu Bedar). By meticulously analyzing critical factors such as weight, buoyancy, load, shear force, bending moment, and Factor of Safety (FoS), the research offers invaluable insights into the structural integrity and safety aspects of GRP Perahu Bedar. These revelations not only herald a new era of sustainable and cost-effective boatbuilding practices but also serve as a crucial step towards safeguarding and perpetuating the rich maritime heritage of the region.

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Introduction

The Perahu Bedar, a traditional fishing boat with a rich maritime heritage, has been an integral part of the coastal communities in the Terengganu region of Malaysia for centuries. Traditionally crafted from Cengal wood, these boats have played a vital role in the livelihoods of local fishermen, enabling them to navigate the shallow coastal waters and venture into the open sea for fishing and pearl diving expeditions. However, the increasing scarcity and high cost of Cengal wood, coupled with the diminishing availability of skilled boat craftsmen, have prompted the need for exploring alternative materials and construction methods. Some research from Bahri et al. (2022) and Abd Wahab et al. (2023) has been conducted about the diminishing availability of skilled boat craftsmen. For the purpose of preservation of the traditional boat, Rahman et al. (2021) has constructed the blueprint for the traditional boat using the reverse engineering methods. Kamaruddin & Rosli (2023) attempts to discover how traditional boats are made in Terengganu.

The present study aims to investigate the use of Glass Reinforced Plastic (GRP) as a potential substitute for Cengal wood in the construction of the Perahu Bedar. GRP, commonly known as fiberglass, is renowned for its high strength-to-weight ratio, corrosion resistance, and ease of molding into complex shapes. Its advantageous properties make it an appealing candidate for boat construction, especially in regions where traditional boatbuilding materials face limitations.

The research will involve a comprehensive analysis of the structural design and strength characteristics of the GRP Perahu Bedar. By leveraging modern engineering techniques, the study seeks to ensure that the GRP version retains the essential features and performance of its traditional wooden counterpart. Special attention will be given to factors such as buoyancy, stability, and load-bearing capacity, which are critical for the safety and seaworthiness of the boat.

The Perahu Bedar has been the subject of various studies, primarily focusing on its historical significance, traditional construction techniques, and cultural importance within the Terengganu region. Abd Wahab et al. (2021) explored the historical evolution of the traditional boat and highlighted its role in shaping the maritime identity of the local communities. Similarly, Kamaruddin & Rosli (2023) documented the traditional boatbuilding techniques used by skilled craftsmen to construct the wooden boat.

Figure 1. Measurement of Perahu Bedar on dry land

In the search for alternative boatbuilding materials, researchers have turned their attention to composite materials like GRP. Chalmers (1994) conducted a study on the mechanical properties of GRP composites and emphasized their potential for marine applications. Furthermore, Sen (2003) investigated the durability and corrosion resistance of GRP materials in marine environments. The aspects of composite material evolution have been covered by Pasăre et al. (2019), and a review of the marine application of GRP was conducted by Rubino et al. (2020).

To ensure the structural integrity of the GRP Perahu Bedar, strength analysis becomes imperative. Ruzuqi (2020) performed analysis to study the tensile strength of fiberglass boat structures with variations in the amount of fiberglass lamination. Additionally, Iqbal & Shifan (2018) presented a comprehensive modelling and simulation of finite element techniques in boat design, emphasizing their application in optimizing hull structures.

Methodology

The research study on the structure design and strength analysis of the GRP traditional Perahu Bedar boat was conducted through several sequential phases. The initial phase involved precise boat measurement, which included assessing various components such as the stem profile, stern profile, and cross-sections at multiple locations. The measurements were performed on dry land at a boat maker yard, ensuring the keel's levelness. To facilitate accurate measurement, reference lines were established, with the keel line serving as the baseline. The distance between the forward perpendicular and aft perpendicular was divided into ten sections, known as stations, with equal lengths. Figure 1 showed the measurement activity on dry land.

The design specifications of the Perahu Bedar, as measured on dry land, provide valuable insights into the boat's physical dimensions and characteristics as shown in Table 1. The overall length (LOA) of the boat is determined to be 4.32 m, while the length between perpendiculars (LBP) measures 3 m. The boat's overall breadth (B) is recorded as 0.83 m, and the overall depth (D) is measured at 0.29 m. The draft (T) of the boat is found to be 0.2 m, indicating the depth of the boat below the waterline. The common interval for station measurements (h) is set at 0.432 m, ensuring consistent and uniform data collection along the boat's length. Additionally, the water density (ρ) is estimated to be 1025 kg/m^3, which is crucial for accurate buoyancy and stability calculations. These design specifications serve as a foundation for further analysis and design considerations, enabling a comprehensive understanding of the Perahu Bedar's structural characteristics and performance.

Table 1. Design specification of Perahu Bedar

Overall Length, LOA	4.32 m
Length Between Perpendicular, LBP	3 m
Overall Breadth, B	0.83 m
Overall Depth, D	0.29 m
Draught, T	0.2 m
Common interval for station, h	0.432 m

Digitalization Phase

In the digitization phase, the shape of the Perahu Bedar hull was digitally rendered using Rhinoceros 5, a 3-D modeling software. This involved placing the stem and stern profiles in the profile view to determine the overall length of the boat. The measured cross-sections were then positioned along the length, and the deck line was created by connecting the edges of each cross-section, terminating at the stem and stern as shown in Figure 2. Subsequently, a surface was generated by lofting along the measured cross-sections, and the software automatically generated the ten stations as shown in Figure 3.

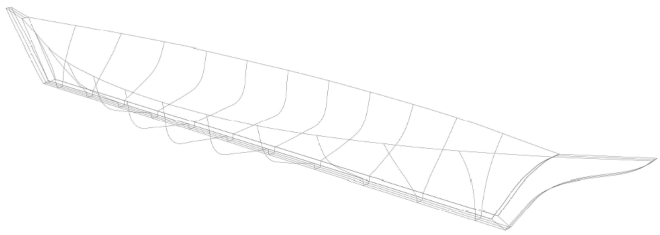

Figure 2. 3-D wireframe modelling of Perahu Bedar

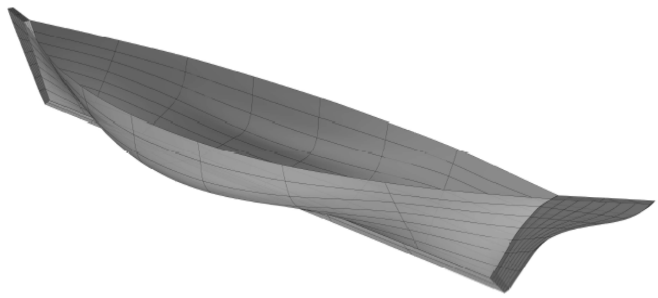

Figure 3. 3-D surface modelling of Perahu Bedar

Structure Design Phase

Moving on to the structure design phase, several crucial aspects were determined. This included calculating the cubic numeral and loaded displacement, estimating the weight of the hull laminate based on the framing system, panel width, thickness, and weight, and evaluating the weight of the deck laminate if applicable. Additionally, the study considered the weight and width of additional reinforcement on the keel, stem, chine, and deck edge. The determination of section modulus was performed for both the hull and deck stiffeners, considering the spacing and span of the stiffeners. The sizing of top hat stiffeners involved assessing the appropriate section modulus, stiffener glass weight, plating thickness, and the dimensions of the stiffeners.

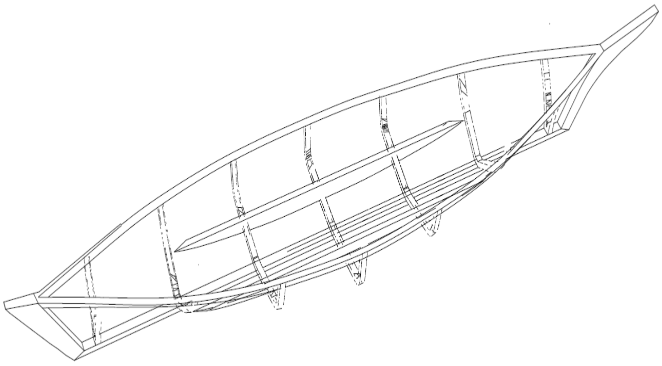

Figure 4. Perspective view of the structure and framing system of Perahu Bedar

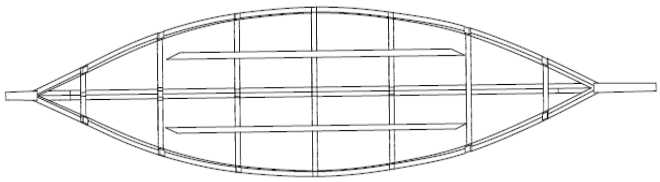

Figure 5. Top view of the structure and framing system of Perahu Bedar

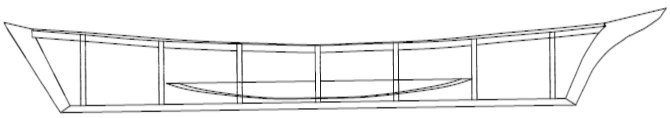

Figure 6. Side view of the structure and framing system of Perahu Bedar

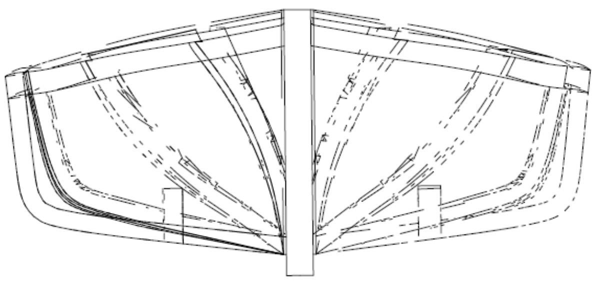

Figure 7. Front view of the structure and framing system of Perahu Bedar

In the crucial phase of structural design, where precision is paramount, a key determinant for ensuring the structural integrity of the vessel is the section modulus of the top hat stiffeners. This value serves as a critical guide in establishing the correct size of the top hat stiffeners, playing a pivotal role in fortifying the overall framework of the boat. The section modulus, derived from meticulous considerations of stiffener spacing and span, holds particular significance in navigating the complex interplay of forces and stresses that the vessel may encounter during its operational life.

The chosen values for stiffener spacing and span, set at 500mm each, are foundational parameters in this design framing system. These dimensions contribute directly to the calculation of the section modulus. This, in turn, aids in precisely determining the appropriate size of top hat stiffeners required for optimal structural support. The section modulus essentially acts as a compass, guiding the design team to strike a balance between the vessel's weight distribution, the imposed loads, and the intended performance. This careful calibration ensures that the top hat stiffeners are not only robust enough to withstand external pressures but are also streamlined to the specific demands of the vessel's design, enhancing both safety and functionality.

The scantling of the framing system has been design based on the standard rules from McVeagh et al. (2010). Figure 4 showed the perspective view of the structure and framing system of Perahu Bedar. Figure 5 showed the top view of the structure and framing system of Perahu Bedar. Meanwhile Figure 6 showed the side view of the structure and framing system of Perahu Bedar and Figure 7 showed the front view of the structure and framing system of Perahu Bedar.

Structure Analysis Phase

In the structure analysis phase, the study focused on strength calculations, constructing various diagrams, and conducting stress analysis. The strength calculations involved determining buoyancy, weight, load, shear force, and bending moment distributions along the ship or boat. Diagrams such as the weight and buoyancy diagram, load diagram, shear force diagram, and bending moment diagram were constructed accordingly. Stress analysis was carried out by considering parameters such as moment of inertia, section modulus, yield stress, and factor of safety.

In the intricate phase of structural analysis, the comprehensive evaluation of buoyancy, weight, load, shear force, and bending moment distributions along the ship or boat stands as a cornerstone in ensuring not only the structural robustness but also the seaworthiness of the vessel. The determination of buoyancy, encapsulating the vessel's ability to stay afloat, is fundamental. It provides essential insights into the equilibrium between the weight of the vessel and the supporting buoyant force exerted by the water. This critical parameter forms the basis for subsequent analyses, guiding in design a vessel with optimal stability.

Simultaneously, the calculations of weight, encompassing the overall mass of the vessel, contribute to a comprehensive understanding of the load dynamics the vessel will undergo. Understanding the weight distribution is pivotal for not only balancing the vessel during operation but also for effective load management and stress distribution across the structure. The load analysis further refines this understanding, delving into the diverse forces acting on the vessel, aiding in designing a structure that can efficiently withstand these forces.

Moving to the shear force and bending moment distributions, these factors play a pivotal role in understanding how different sections of the vessel will bear the applied loads. Shear force, representing the internal forces trying to slide one part of the vessel past another, and bending moment, depicting the forces causing the vessel to bend, offer intricate insights into potential stress points. These distributions are critical for pinpointing areas of vulnerability and ensuring that the structure can resist deformation, guaranteeing the vessel's overall strength.

This research methodology provided a systematic approach to investigate the structure design and strength analysis of the GRP traditional Perahu Bedar boat. It facilitated accurate boat measurement, digital representation, structure design considerations, and comprehensive analysis. The findings from this study will contribute to enhancing the understanding of using GRP in the construction of the traditional Perahu Bedar, opening up new possibilities for sustainable and cost-effective boat building practices.

Results and Discussion

Weight, Buoyancy Force and Load

The weight and buoyancy forces of the Perahu Bedar vary along the different stations, indicating variations in the distribution of weight and buoyancy along the boat's length as shown in Figure 8. As the station number increases, there is a trend of increasing weight and buoyancy forces. This can be observed in the data where the weight gradually increases from 68.7583 N/m at station 0.5 to 981.0491 N/m at station 4.5. Similarly, the buoyancy force also increases from 46.54845 N/m at station 0.5 to 1024.1444 N/m at station 4.5.

From the weight and buoyancy force along the Perahu Bedar, the load along the Perahu Bedor has been obtained. The load as shown in Figure 9, which is calculated as the product of (buoyancy force - weight) and the station length (0.432 m), provides insights into the net force acting on the boat at each station. Negative load values indicate that the buoyancy force is less than the weight, resulting in a downward force. Conversely, positive load values indicate that the buoyancy force exceeds the weight, creating an upward force.

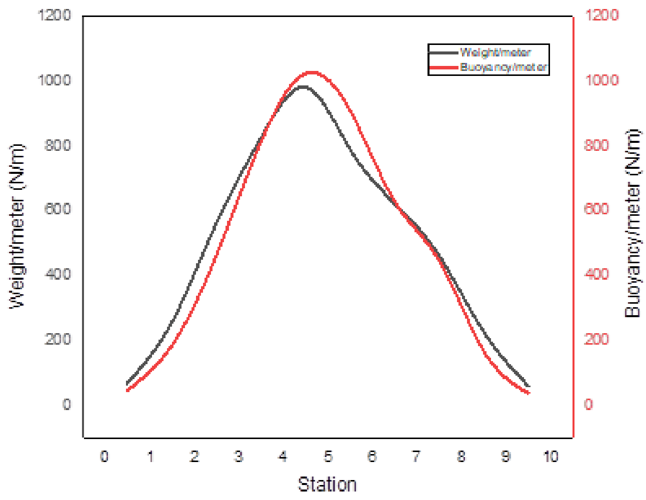

Figure 8. Weight and buoyancy force along the Perahu Bedar

Based on the load data, it can be observed a varying pattern along the stations. At some stations, such as station 4.5, the load is positive (18.6172 N), indicating an upward force that contributes to the boat's overall buoyancy. This suggests that the buoyancy force exceeds the weight, resulting in a net upward force at that particular station. On the other hand, at stations like 1.5 and 2.5, the load values are negative, indicating a net downward force. This suggests that the weight of the boat exceeds the buoyancy force at these stations.

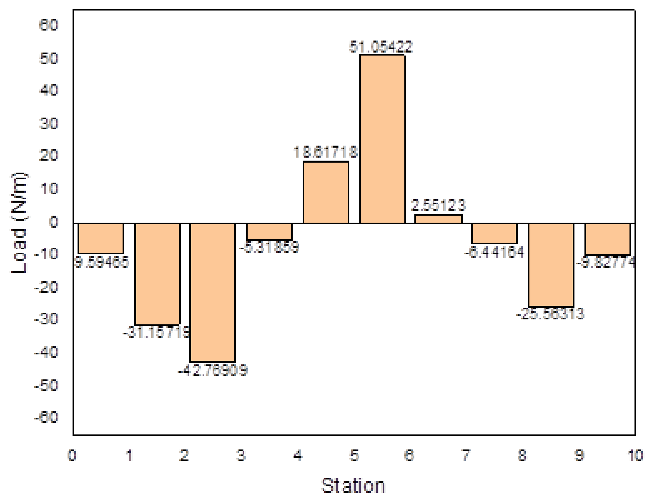

Figure 9. Load along the Perahu Bedar

The variation in load along the stations signifies the distribution of forces and the stability characteristics of the Perahu Bedar. Positive load values contribute to the boat's stability and the ability to remain afloat, while negative load values indicate a potential for instability and a tendency for the boat to sink. These scientific results highlight the significance of considering weight, buoyancy, and load distributions when assessing the stability and performance of the Perahu Bedar.

Sheer Force and Bending Moment

The sheer force is a measure of the internal force experienced by a structure in response to external loads. It indicates the intensity and direction of the force acting perpendicular to the longitudinal axis of the boat. From the Figure 10, it can be observed varying sheer force values at different stations along the Perahu Bedar. At stations 0 and 10, the sheer force is zero, indicating that there is no perpendicular force acting on the boat at these locations. This is expected as these stations represent the extreme ends of the boat. At intermediate stations, such as stations 1 to 9, the sheer force values are negative and gradually increase or decrease along the length of the boat. Negative sheer force indicates that the force is acting downward or in the negative direction along the longitudinal axis of the boat.

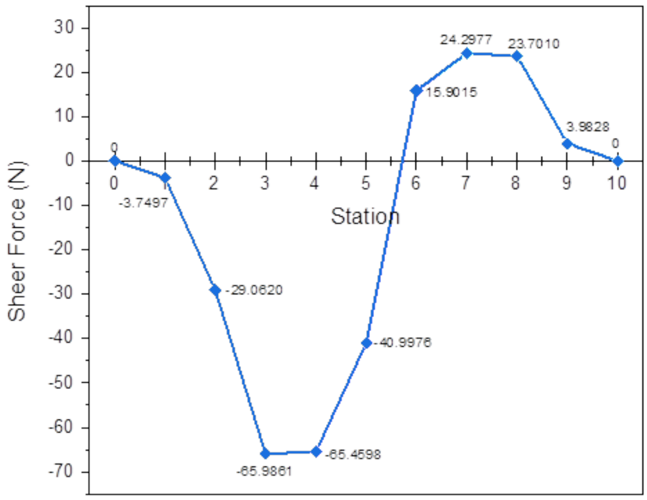

Figure 10. Sheer force along the Perahu Bedar

The bending moment, on the other hand, is a measure of the internal bending force experienced by a structure. It indicates the intensity and direction of the force causing the structure to bend. The bending moment values are influenced by both the sheer force and the distance from the point of measurement. From the Figure 11, it can be observed varying bending moment values along the stations of the Perahu Bedar. The bending moment is negative throughout the boat, indicating that the structure is subject to compression on the upper side and tension on the lower side. This is expected for the analyzed boat's configuration and the downward sheer force distribution. The bending moment values are highest at the midsection of the boat, represented by station 5, where the values reach -3482.1082 N. This indicates the maximum bending force experienced by the boat at this location. As it moves towards the ends of the boat, the bending moment decreases, reaching zero at stations 0 and 10.

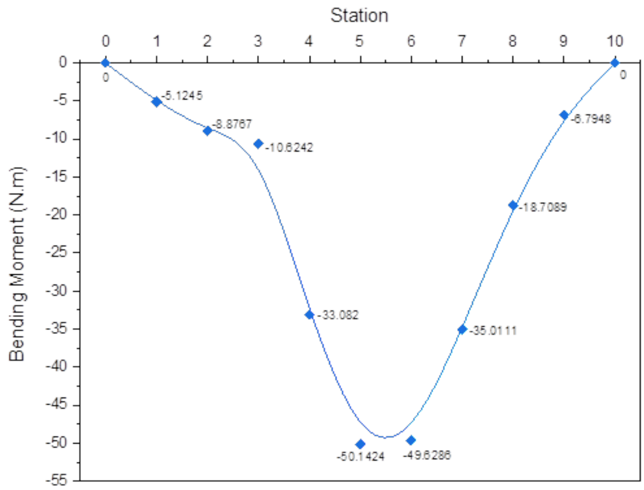

Figure 11. Bending moment along the Perahu Bedar

These scientific results highlight the distribution of sheer force and bending moment along the Perahu Bedar. The negative sheer force values indicate that the structure experiences downward forces, while the negative bending moment values suggest compression on the upper side and tension on the lower side of the boat's structure. Understanding the distribution of sheer force and bending moment is crucial for assessing the structural integrity and stability of the Perahu Bedar. It provides insights into the areas of maximum stress and deformation, allowing for further analysis and optimization of the boat's design to ensure adequate strength and safety. It is important to note that these results should be interpreted in the context of the specific Perahu Bedar under study and the assumptions made during the analysis.

Factor of Safety (FoS) Analysis

The FoS is a measure of the structural safety margin, indicating the ratio of the applied stress to the allowable stress. A higher FoS value indicates a greater safety margin, while a lower value suggests a reduced margin and potential for failure. In this analysis, the FoS is determined based on various parameters, including the maximum bending moment, area of midship scantling, neutral axis position, second moment of area, vertical distances from the keel and deck to the neutral axis, section moduli at the keel and deck, longitudinal bending stress at the keel and deck, yield stress for the material, and the calculated FoS value. The FoS is calculated using the Equation (1):

$$FoS = \frac{\sigma_y}{\sigma_{keel}\, or\, \sigma_{deck}} \quad (1)$$

In Equation (1);

σ_y: yield stress for the material;

σ_{keel} : longitudinal bending stress at keel

σ_{deck}: longitudinal bending stress at deck

The maximum longitudinal bending stress at the keel, σ_{keel} and deck, σ_{deck} has been determined by using the Equation (2) and Equation (3):

$$\sigma_{keel} = \frac{MI}{Y_{keel}} \quad (2)$$

In Equation (2);

M: Maximum bending moment at midship;

I: Second moment of area at natural axis (N.A);

Y_{keel}: Vertical distance from keel.

$$\sigma_{deck} = \frac{MI}{Y_{deck}} \quad (3)$$

In Equation (3);

M: Maximum bending moment at midship;

I: Second moment of area at natural axis (N.A);

Y_{deck}: Vertical distance from deck.

The section modulus at keel, Z_{keel} and deck, Z_{deck} has been determined by using the Equation (4) and Equation (5):

$$FoS = \frac{\sigma_y}{\sigma_{keel}\, or\, \sigma_{deck}} \quad (4)$$

In Equation (4);

I: Second moment of area at natural axis (N.A);

Y_{keel}: Vertical distance from keel.

$$FoS = \frac{\sigma_y}{\sigma_{keel}\, or\, \sigma_{deck}} \quad (5)$$

In Equation (5);

I: Second moment of area at natural axis (N.A);

Y_{deck}: Vertical distance from deck.

From the Table 2, it can be observed that the maximum bending moment, M is 50.1424 N.m, and the total area of midship scantling is 0.119 m². The neutral axis, $N.A$ is positioned at 0.145 m from the base line, and the second moment of area, I is calculated as 1.798 m⁴. The vertical distance from the keel, Y_{keel} to the neutral axis is 0.1556 m, while the vertical distance from the deck, Y_{deck} to the neutral axis, N.A is 0.1344 m. The section modulus at the keel, Z_{keel} and deck, Z_{deck} are determined as 11.5553 m³ and 13.3780 m³, respectively. The longitudinal bending stress at the keel, σ_{keel} is calculated as 579.4089 N/m², while the longitudinal bending stress at the deck, σ_{deck} is 670.8083 N/m². The yield stress, σ_y for the material is given as 1500 N/m². Based on these values, the Factor of Safety (FoS) is calculated as 2.2361.

Table 2. Factor of Safety (FoS) Analysis of Perahu Bedar

Maximum Bending Moment, M	50.1424 N.m
Total Area of Midship Scantling	0.119 m^2
Neutral Axis (N.A)	0.145 m from Base Line
Second Moment of Area, I at N.A	1.798 m^4
Vertical distance from Keel to N.A, Y_{keel}	0.1556 m
Vertical distance from Deck to N.A, Y_{deck}	0.1344 m
Section Modulus at keel, Z_{keel}	11.5553 m^3
Section Modulus at Deck, Z_{deck}	13.3780 m^3
Longitudinal Bending Stress at Keel, σ_{keel}	579.4089 N/m^2
Longitudinal Bending Stress at Deck, σ_{deck}	670.8038 N/m^2
Yield Stress for the Material, σ_y	1500 N/m^2
Factor of Safety, FoS	2.2361

The result can emphasize that the calculated FoS value of 2.2361 indicates a safety margin greater than 1, which suggests that the structural design of the Perahu Bedar meets the safety requirements and exhibits a satisfactory level of structural integrity. The FoS value above 1 indicates that the structure can withstand the applied stresses and loads without exceeding the material's yield strength. A FoS greater than 1 provides a safety margin, ensuring that the Perahu Bedar can safely operate under normal operating conditions, accounting for uncertainties and variations in loading.

Conclusion

The scientific analysis conducted on the GRP Malay traditional Perahu Bedar reveals promising potential for the use of GRP as a substitute material for the traditional Cengal wood in boat construction. The accurate boat measurement and digitization phases provided precise dimensions and a virtual model of the Perahu Bedar, enabling reliable structural evaluations. The structure design phase, encompassing considerations of weight, laminate properties, and reinforcement, ensured the strength and integrity of the GRP structure. The structure analysis phase, including stress distribution, load diagrams, and section moduli calculations, offered insights into the boat's structural behavior and stability. The factor of safety analysis demonstrated a satisfactory safety margin, indicating that the GRP Perahu Bedar can withstand applied stresses and loads without exceeding yield strength. Overall, the utilization of GRP presents a viable solution for preserving the Malay region's maritime heritage, addressing wood scarcity, and maintaining the performance and safety of the Traditional Bedar boat. Further research and validation can refine the design and construction techniques, ensuring the continued sustainability and success of the Perahu Bedar in modern contexts.

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Compliance With Ethical Standards

Author's Contribution

NMKNI: Conducted precise measurements of the Perahu Bedar on dry land, capturing stem profiles, stern profiles, and cross-sections and also contributed to the structure design phase, estimating weights, determining laminate weights, and calculating additional reinforcement;

MAJ: Utilized 3-D modeling software to create an accurate digital representation of the Perahu Bedar hull;

NAAR: Contributed to assisted the structure design phase, estimating weights, determining laminate weights, and calculating additional reinforcement;

ANR: Reviewed and edited the research findings, ensuring accuracy and clarity in the structure analysis phase;

SA: Oversaw the project, coordinating efforts, and supervising the research process;

MSM: Provided valuable insights into the historical and cultural significance of the Perahu Bedar as a representative from the museum.

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

The research conducted on the Perahu Bedar in this study has received official ethical approval and permissions from the Museum Negeri Terengganu, State of Terengganu, Malaysia. The authors like to express the gratitude to the Museum for their invaluable support and cooperation, which has allowed to access the Perahu Bedar and conduct the measurements and analyses. Their commitment to preserving and promoting the maritime heritage of the Terengganu region has been integral to the success of the research, and the authors have ensured that all activities involving the Perahu Bedar align with the ethical standards and guidelines established by the Museum.

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Data Availability Statement

All datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request. The authors are committed to promoting transparency and scientific collaboration.

Therefore, the authors encourage researchers and interested parties to reach out to the corresponding author to access the datasets, ensuring that the findings of this research can be further examined, validated, and utilized for future studies and advancements in the field of boat design and construction.

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