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Analysis of the Influence of Structural Profile Differences Between Tambak Lorok Traditional Fishing Vessels and BKI Standard Criteria

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***Abstract*— Traditional fishing vessels in Tambak Lorok are commonly constructed based on inherited craftsmanship and empirical experience, without adherence to any formal classification standard. Consequently, variations in the mechanical strength of wooden materials due to dimensional differences require further investigation. This study aims to examine the differences in destructive stress values that occur after the vessel experiences an impact, with reference to the Bureau of Classification Indonesia (BKI) criteria. The methodology involves recalculating the structural dimensions of wooden ship components following BKI standards and conducting localised impact tests at a standard berthing velocity of 0.25 m/s, with vessel speeds ranging from 1 knot to 2.5 knots. The analytical and experimental findings reveal a construction weight reduction of 258 kg, equivalent to approximately 42% lighter than the conventional design. The safe stress limits were determined to be 102.88 MPa on the frame and around 30 MPa on the hull plating under a 2-knot collision. These results demonstrate that applying BKI criteria enhances both structural efficiency and economic value while maintaining safety under standard berthing conditions.**

Keywords—Construction, traditional vessel, Tambak Lorok

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I. INTRODUCTION

The displacement of a vessel represents the combined weight of two primary components: the lightweight (LWT) and the deadweight (DWT). The LWT comprises the hull structure, main engine, and all associated fittings and equipment, while the DWT consists of the cargo load, provisions, and accommodation requirements. Vessels of identical principal dimensions—length (L), breadth (B), and depth (H)—may exhibit different displacement values depending on the material used for construction. Such variations arise due to differences in both material type and sectional size, as materials with higher density generally possess greater strength characteristics.

A vessel constructed using relatively heavier materials results in a greater draught (T), as a larger portion of the hull becomes submerged. Consequently, the displacement also increases, even when the vessel's principal dimensions—length (L), breadth (B), and height (H)—remain the same. Based on this observation, it can be explained that vessels built from lighter materials offer economic advantages, as they provide greater cargo capacity and lower construction costs. The increased capacity is indicated by a reduced draught (T), reflecting a lesser submersion of the hull. Another economic benefit derived from the efficient use of lighter wooden materials is the reduction in overall building expenses.

The Tambak Lorok fishing vessel is a type of traditional wooden boat constructed through craftsmanship and knowledge passed down across generations within local communities. This practice reflects a shipbuilding process carried out without reference to any formal classification rules. As a result, the dimensions of certain structural profiles may differ from those specified in the Bureau of Classification Indonesia (BKI) Construction Rules for Wooden Ships, including variations in the placement and number of specific components such as bilge stringers. These differences consequently affect the lightweight (LWT) of the hull. Therefore, it is necessary to conduct a study concerning the structural profile dimensions of such traditional vessels to evaluate their conformity with the BKI construction standards.

As wood serves as the primary material in the construction of traditional vessels, its quality and condition play a crucial role in determining the ship's technical performance. The strength of wood depends on several factors, including the species, the direction of applied loads relative to the grain, moisture content and density, anatomical structure, and the presence of defects. Various issues related to the use of wood as the main construction material for ships and other structural applications have therefore become important subjects of research and discussion.

It has been observed that exposure to acidic environments for 28 days of immersion significantly reduces the strength and increases the deformation characteristics of the tested wooden samples compared with those under standard moisture conditions. Under such circumstances, the tensile strength decreased by 42.4%, while the critical deformation and residual

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deformation increased by 18.5% and 24.8%, respectively [1]. The impregnation of silicon dioxide (SiO_2) nanoparticles has been shown to enhance both the strength and reliability of wooden materials [2]. Furthermore, extensive studies on compression, tension, torsion, and combined loading conditions have revealed that hardness, ageing, moisture content, grain orientation, and humidity are key factors influencing wood strength. Dynamic loading conditions are considerably more complex than static ones, as the strength under dynamic stress largely depends on the strain rate [3].

Several studies have been conducted concerning the structural profile dimensions of traditional wooden vessels. Research on the conformity of wooden fishing vessel construction in Gresik Regency revealed that certain sectional modulus dimensions in field measurements were greater than those specified by BKI standards—namely, the keel by 22.26%, the outer shell by 43.17%, and the deck by 50.36%. However, smaller modulus values were observed in the frames (53.685%) and floors (18.375%) [4]. Further findings indicated that the construction dimensions of wooden vessels in the field could be reduced by up to 30%, thereby decreasing the overall hull fabrication cost by approximately 30% compared with the original estimate [5]. In another study on KM. Putra Bimantara III, most structural components remained consistent with BKI regulations, while non-conforming elements included the frame spacing, floor height, deck plank thickness, deck side covers, collision bulkhead stiffeners, and deck planks within the fish hold area [6].

This study aims to evaluate the efficiency of wooden material utilization in relation to both the structural strength and economic value of traditional vessels. The economic aspect is associated with changes in cargo capacity resulting from variations in the ship's own weight. The structural implication lies in the fact that reducing the dimensions of the construction profiles leads to a corresponding decrease in the vessel's displacement and structural strength. The assessment of the techno-economic feasibility is determined based on the maximum local stress values observed during collisions at specific velocities. The reference threshold used corresponds to the stress level at which the wooden material begins to fail. The expected outcome of this research is to develop a more economical wooden ship design that retains sufficient structural strength within safe criteria.

II. Method

The methodology adopted in this study involves conducting field surveys and measurements to collect data on the principal dimensions and structural profiles of traditional fishing vessels in Tambak Lorok. Based on these measurements, a three-dimensional model of the vessel was developed to facilitate further analysis aimed at evaluating its structural strength. The criteria assessed include von Mises stress, internal energy, kinetic energy, and deformation values resulting from impact loads. The strength analysis was performed using the finite element method (FEM) through the simulation software.

Table 1 presents the data of a traditional fishing vessel from the Tambak Lorok area in Semarang, obtained through field measurements. The vessel in question is a type of sopek boat, which is commonly used by the local fishing community.

TABLE 1.
PRINCIPAL DIMENSIONS OF THE TAMBAK LOROK TRADITIONAL FISHING VESSEL

Principal Dimension	Value
Length overall (LOA)	5.98 m
Length between perpendiculars (LPP)	4.92 m
Breadth (B)	1.68 m
Depth (H)	0.77 m
Draft (T)	0.37 m
Service speed	5.00 knots
Gross tonnage	1.156 tons

The principal dimensions presented in Table 1 were subsequently used as the basis for calculating the structural profile dimensions in accordance with the BKI Rules for Wooden Ships. The determination of these structural profiles was carried out by first calculating the indicator coefficient [7], as expressed in Equations 1 – 3.

$$L \times \left(\frac{B}{3} + H\right) \tag{1}$$

$$\left(\frac{B}{3} + H\right) \tag{2}$$

$$\frac{L}{H} \tag{3}$$

Based on the structural calculations carried out in accordance with the BKI Rules for Wooden Ships, the required construction dimensions were obtained. These results were subsequently processed through a modeling approach using computer-aided design (CAD) software. This stage involved the development of both the vessel model and the jetty structure to support further simulation and analysis.

The three-dimensional modeling was performed using Computer-Aided Design (CAD) software. All components were created as closed-solid bodies to enable seamless import into the finite element analysis (FEA) application. The jetty was modeled as a beam with dimensions corresponding to those of the vessel. All body interactions of the ship components were defined as bounded contacts with a maximum offset of 1 mm. The jetty geometry was set to a rigid (non-deformable) condition. The 3D models of the existing vessel and jetty are presented in **Figure 1**, while the collision scenario is illustrated in **Figure 2.** In this simulation, the collision scheme assumes that the vessel moves towards the jetty along the Y-axis direction.

Meshing for the vessel model was carried out using the finite element method (FEM) by generating a network of interconnected elements linked through nodal points. The meshing process was conducted by defining specific element sizes (body size meshing) for different structural components. The mesh size applied to the hull and frames 2, 3, 4, and 5 was set at 15 mm, while other parts of the vessel were assigned a mesh size of 50 mm. The meshing result of the existing vessel model is shown in **Figure 3.**

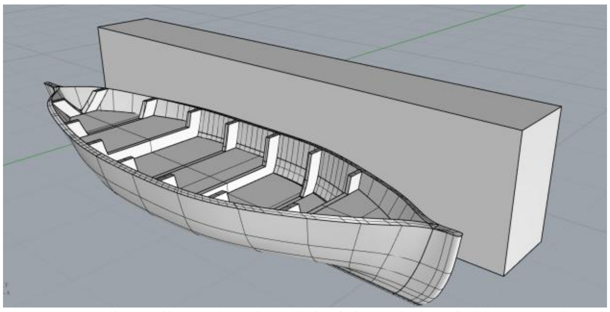


Figure. 1. Three-dimensional model of the existing fishing vessel and jetty used for collision analysis.

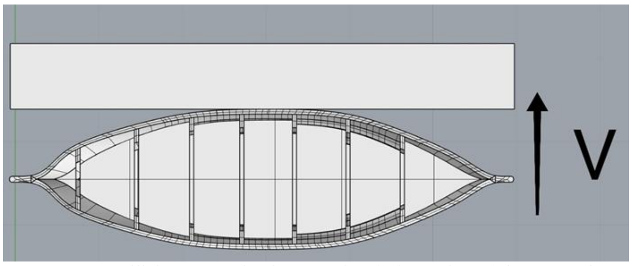


Figure. 2. Collision scenario (impact simulation scheme) between the vessel and the jetty.

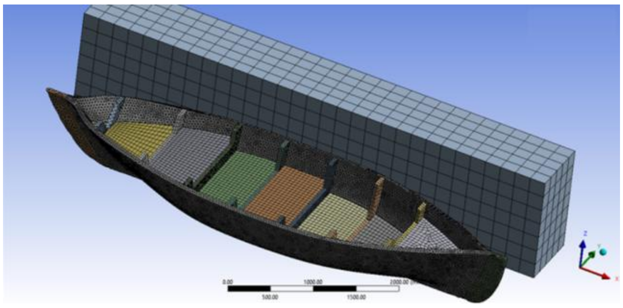


Figure.3. Finite element meshing of the existing vessel model.

The vessel's hull was simulated to move at a specified velocity along the Y-axis, directed towards the jetty. According to the BKI guidelines, the standard berthing speed for vessels of up to 500 DWT is 0.25 m/s [8]. For comparative purposes, additional simulations were conducted with vessel velocities of 1 knot, 1.5 knots, 2 knots, and 2.5 knots. The direction of the vessel's motion was defined in the Coordinate System settings, with the Y-component representing the axis of movement towards the jetty. The simulation was executed with an output control of 100 steps and a time limit of 0.02 seconds, representing the condition of the vessel immediately after impact with the jetty.

TABLE 2.
MECHANICAL PROPERTIES OF TEAK WOOD

Property	Value	Unit
Density	700	kg/m³
Young's modulus	12,523.09	MPa
Poisson's ratio	0.30	–
Bulk modulus	10,436	MPa
Shear modulus	4,816.60	MPa
Maximum tensile stress	101.11	MPa
Maximum shear stress	53.94	MPa

The material used for the vessel's hull and mass was teak wood, modeled with isotropic properties, while the jetty was defined as a rigid body, implying no deformation during impact with the vessel. **Table 2** presents the mechanical properties of the materials used in the simulation.

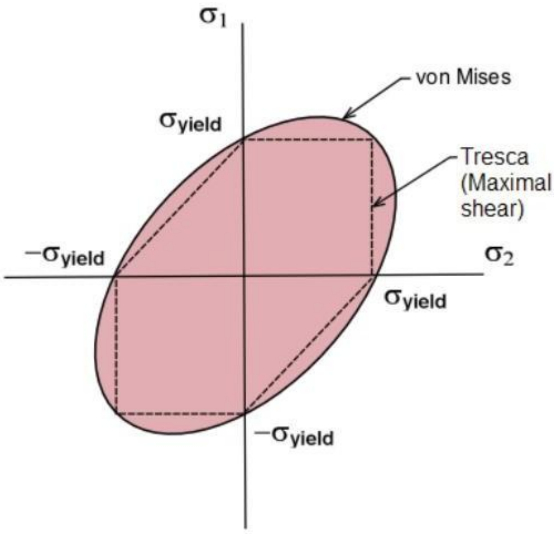


Figure 4. Comparison between the Von Mises circle and the Tresca hexagon representing material yield criteria.

The continuum failure criterion for wood was evaluated using a modified Von Mises criterion, as illustrated in Figure 4. The relationship can be expressed by the following equation, where X represents the tensile strength and other parameters denote material strength properties. The general failure criterion constant can be determined based on the compressive and tensile stresses of the material [3].

$$\frac{\sigma_{x,or}^2}{XX'} + \frac{\sigma_{x,or}}{X} - \frac{\sigma_{x,or}}{X'} - 2F_{12}\sigma_{x,or}\sigma_{y,or} + \frac{\sigma_{y,or}^2}{YY'} + \frac{\sigma_{y,or}}{Y} - \frac{\sigma_{y,or}}{Y'} + \frac{\tau_{or}^2}{S^2} \quad (4)$$

$$2F_{12} = \frac{1}{C'_{n_1}} = \frac{1}{\sqrt{XX'YY'}} \quad (5)$$

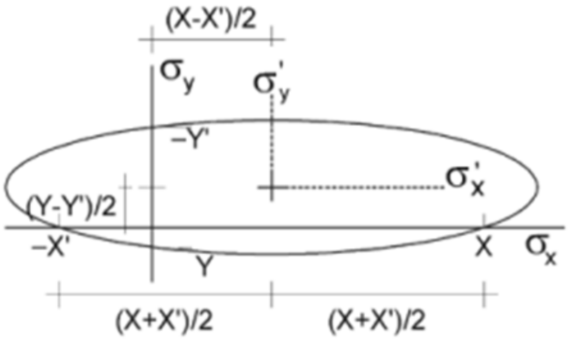


Figure.5. Von Mises criterion for wood [3].

The magnitude of impact energy used to assess damage to a vessel—or to other structures such as jetty fendering—can be determined by analysing the specific collision scenario experienced by the object under consideration. The energy generated when the vessel strikes the jetty is expressed in Equation 6.

$$E = \frac{WV^2}{2g} C_m C_e C_s C_c \quad (6)$$

In this equation, Erepresents the impact energy expressed in ton-meter units, while Vdenotes the vessel's velocity at the moment of collision when moving perpendicularly towards the jetty, measured in meters per second. Wrefers to the vessel's displacement in tonnes, and $g$is the gravitational acceleration in meters per second squared. The coefficient $C_m$indicates the mass coefficient, $C_e$represents the eccentricity coefficient, $C_s$corresponds to the stiffness coefficient (assumed to be 1), C_c denotes the mooring shape coefficient (also assumed to be 1), and $C_b$is the block coefficient of the vessel. Together, these parameters are used to evaluate the total energy generated during the impact between the vessel and the jetty.

Structural damage to a ship's hull due to impact may also occur when one vessel collides with another, or when a vessel strikes another at a certain velocity. Various collision conditions can generate different levels of impact energy, as illustrated in Figure 6, together with the corresponding equations [10].

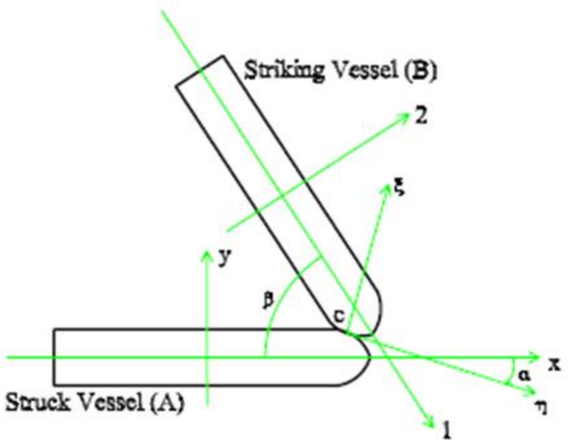


Figure. 6. Coordinate system applied in the numerical analysis of the vessel–jetty collision.

A hard collision (sticking condition) occurs when the friction coefficient $\mu_0$is greater than or equal to the impact impulse ratio μ. Conversely, a sliding collision takes place when the opposite condition is met. The magnitude of the impact energy for both cases can be determined using Equations (6) and (7), respectively.

$$\mu = \frac{I_{\eta 0}}{I_{\xi 0}} = \frac{D_\xi \dot{\eta}(0) - K_\xi[\xi(0) - \xi(T)]}{K_\eta[\xi(T) - \xi(0)] - D_\eta \dot{\eta}(0)} \quad (7)$$

Sticking collision case (hard impact condition).

$$E_\xi = \frac{1}{2} \frac{1}{D_\xi + \mu D_\eta} \dot{\xi}(0)^2 \quad (8)$$

$$E_\eta = \frac{1}{2} \frac{1}{\frac{1}{\mu} K_\xi + K_\eta} [\dot{\eta}(0)]^2 \quad (9)$$

Sliding collision case (frictional impact condition).

$$0_\xi = \frac{1}{2} \frac{1}{D_\xi + \mu_0 D_\eta} (1 - e^2) \left[\dot{\xi}(0)\right]^2 \quad (10)$$

$$E_\eta = \frac{1}{2} \frac{1}{\frac{1}{\mu} K_\xi + K_\eta} [([\dot{\eta}(0)]^2 - [\dot{\eta}(T)]^2)] \quad (11)$$

Where :

$$\dot{\eta}(T) = \dot{\eta}(0) - \frac{K_\xi + \mu_0 K_\eta}{D_\xi + \mu_0 D_\eta} \left[\dot{\xi}(0) - \dot{\xi}(T)\right] \quad (12)$$

The values of D_ξ, D_η, K_ξ, and $K_\eta$are constants determined as follows:

$$D_\xi = \frac{D_{a\xi}}{M_a} + \frac{D_{b\xi}}{M_b} \quad ; \; D_\eta = \frac{D_{a\eta}}{M_a} + \frac{D_{b\eta}}{M_b} \quad (13)$$

$$K_\xi = \frac{K_{a\xi}}{M_a} + \frac{K_{b\xi}}{M_b} \quad ; \; K_\eta = \frac{K_{a\eta}}{M_a} + \frac{K_{b\eta}}{M_b} \quad (14)$$

The expected outcome of this study is to determine the extent to which the reduction of wooden ship construction dimensions can produce a lighter structure while maintaining strength within safe limits. Under specific conditions, it is anticipated that the selected wooden material will not experience structural failure during impact or collision. For vessels with identical principal dimensions—length (L), breadth (B), and height (H)—a reduction in hull weight (lightweight) results in greater cargo capacity and lower construction costs, thereby enhancing the vessel's overall economic efficiency.

III. Results and Discussion

3.1 Main dimension ship

The construction dimensions of the existing vessel were obtained through direct measurements taken on the fishing boat selected for the study. The calculation of structural profile dimensions according to BKI criteria was carried out by determining the indicator coefficient in accordance with the provisions stated in the BKI Rules for Wooden Ships. This coefficient was derived from the principal dimensions of the traditional Tambak Lorok fishing vessel. A comparison between the existing vessel's construction dimensions and those calculated using BKI standards is presented in Table 3.

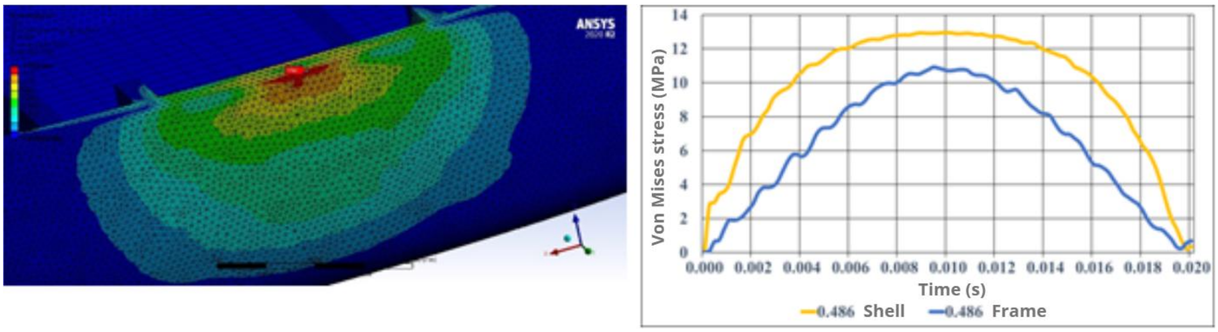
The difference in structural weight resulting from the variation in construction dimensions, as shown in Table 1, produced a total structural weight of 609.6 kg for the existing vessel and 351.4 kg for the vessel designed according to BKI criteria, yielding a difference of 258 kg, or approximately 42%. This reduction in hull weight provides additional advantages in the form of increased cargo capacity and lower construction costs, thereby improving the vessel's overall economic efficiency.

TABLE 3.
COMPARISON OF CONSTRUCTION DIMENSIONS BETWEEN THE EXISTING VESSEL AND BKI CALCULATION RESULTS

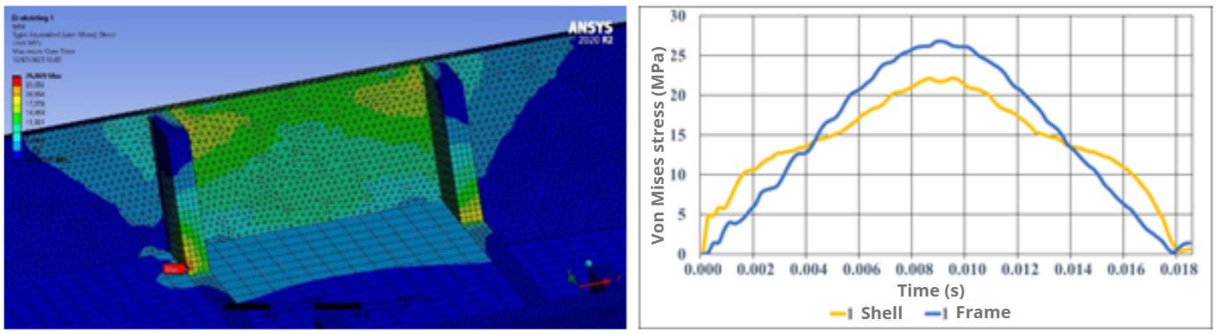
Structural Component	Construction Size (mm)					
	Width (mm)		Height (mm)		Thickness (mm)	
	Existing.	BKI	Existing.	Existing	Existing.	BKI
Keel	70	125.90	80	166.81	-	-
Stempost (Bow)	70	100.91	370	143.86	-	-
Sternpost (Stern)	70	100.91	370	151.05	-	-
Frame	-	-	160	44.15	50	39.61
Deck	-	-	-	-	20	28.77
Outer Plating (Hull)	-	-	-	-	60	25.18

3.2 Von Mises Stress Analysis

The frame construction of the existing vessel (as observed in the field) was analyzed under various collision velocities. At the standard berthing speed of V = 0.486 knots (0.25 m/s) [8], the Von Mises stress was found to be 12.960 MPa. For higher impact velocities of 1 knot, 1.5 knots, 2 knots, and 2.5 knots, the corresponding Von Mises stress values were 26.810 MPa, 46.630 MPa, 51.765 MPa, and 53.760 MPa, respectively. The Von Mises stress results for the existing vessel at each speed were further detailed by comparing the stress values between the hull plating and the frames. These variations are illustrated in the corresponding graphs. **Figures 5 and 6** present the calculated Von Mises stress distributions for the existing vessel structure.

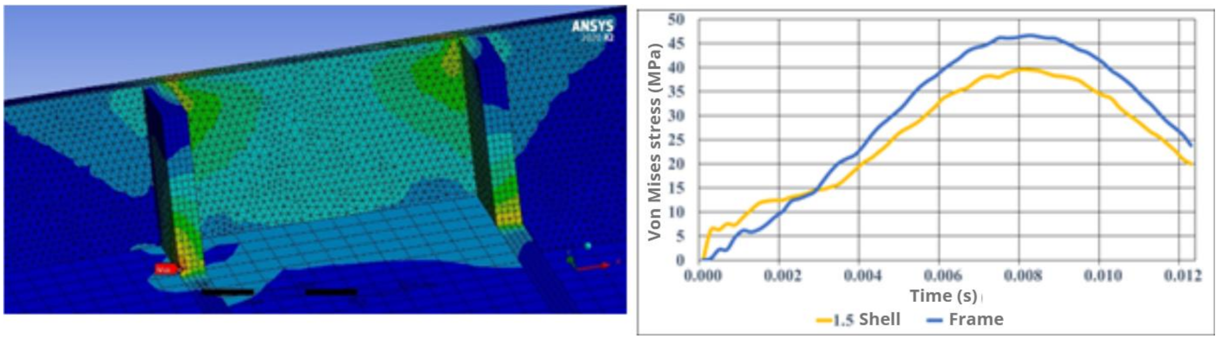


(a)

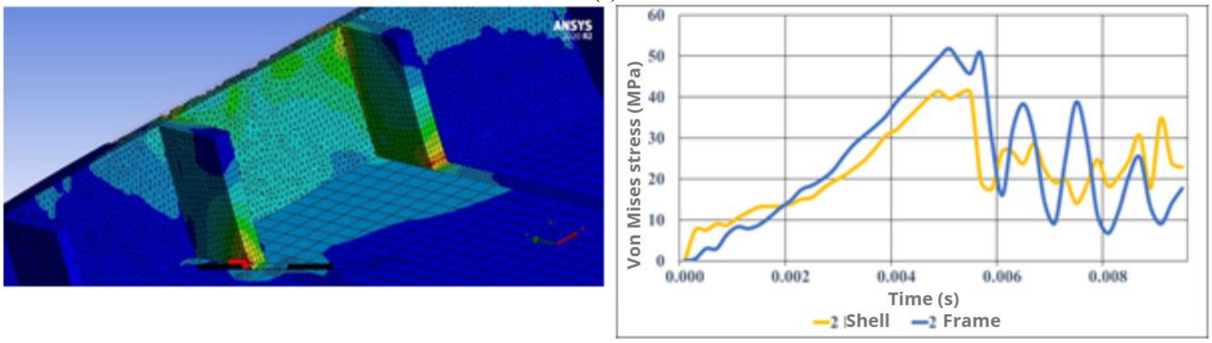


(b)

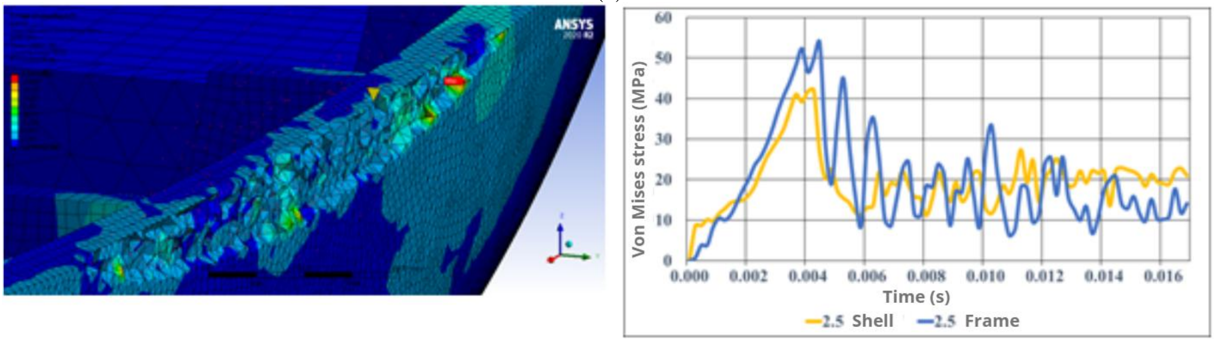
Figure 5. Von Mises stress on the frame during impact and comparison graph of stress between the frame and the hull at various vessel velocities: (a) V = 0.488 knot, (b) V = 1 knot



(c)

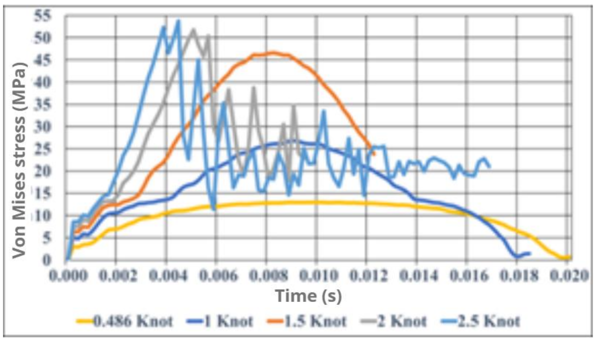


(d)

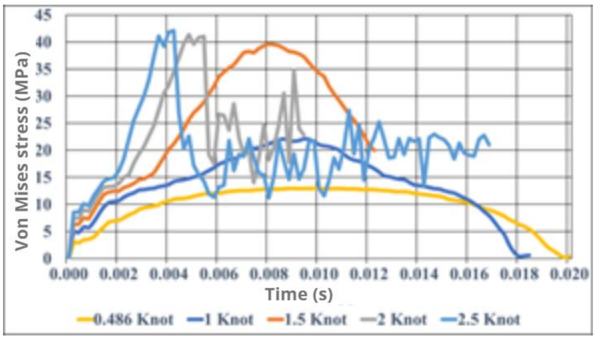


(e)

Continued - Figure 5. (c) V = 1.5 knots, (d) V = 2 knots, and (e) V = 2.5 knots.



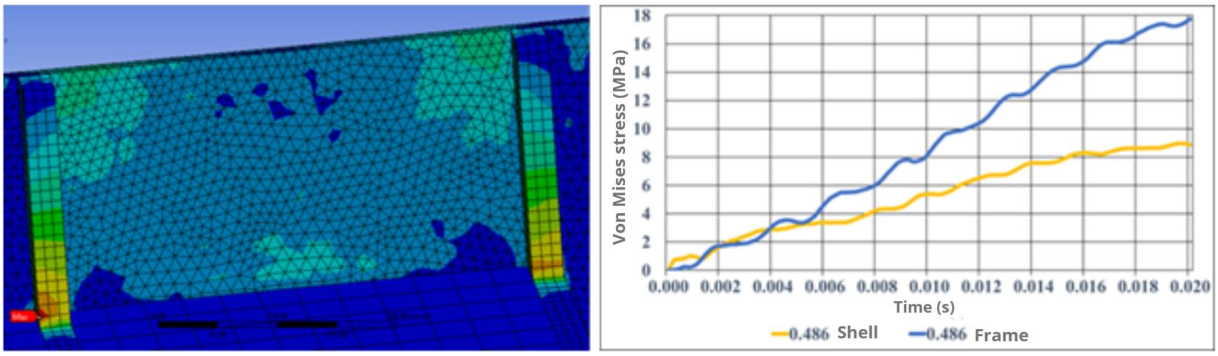
(a)



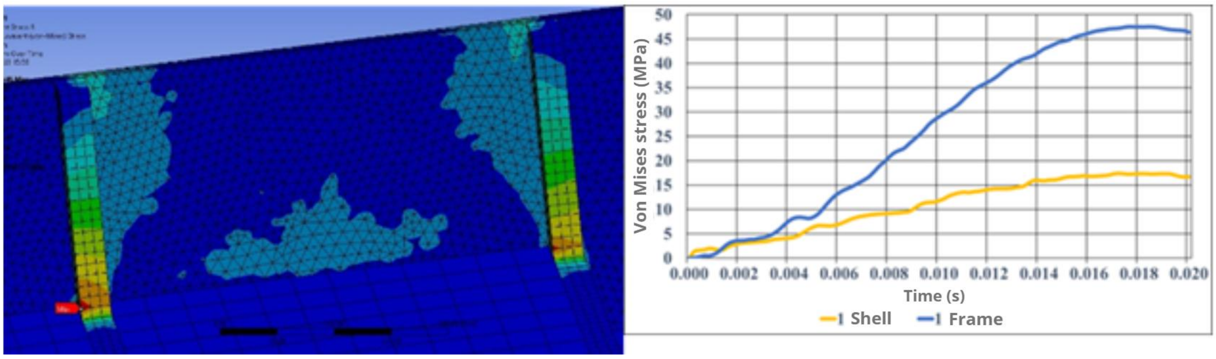
(b)

Figure. 6. Total Von Mises stress of the existing vessel on: (a) the frame structure, and (b) the hull plating.

The frame construction of the new vessel, designed according to BKI criteria, was analysed under different collision velocities. At the standard berthing speed of V = 0.486 knots (0.25 m/s), the Von Mises stress was recorded at 17.758 MPa. For increased impact velocities of 1 knot, 1.5 knots, 2 knots, and 2.5 knots, the corresponding stress values were 47.546 MPa, 75.494 MPa, 102.880 MPa, and 113.910 MPa, respectively. The Von Mises stress results for the BKI-based vessel at each velocity were further analysed by comparing the stresses between the hull plating and the frames, as shown in the graphs. Figures 7 and 8 present the calculated Von Mises stress distributions for the vessel constructed in accordance with BKI criteria.



(a)



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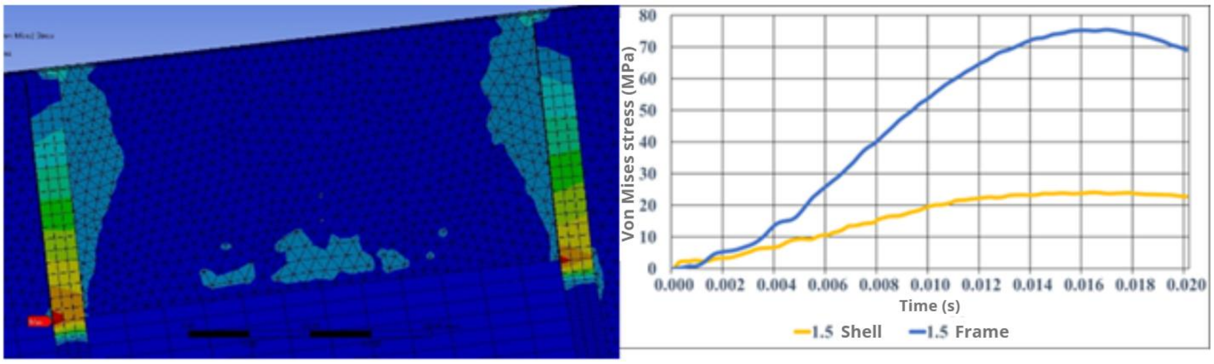

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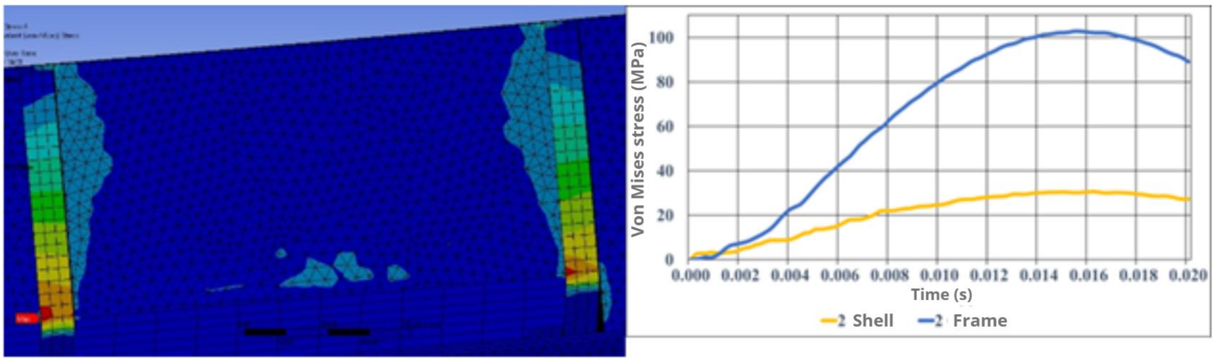
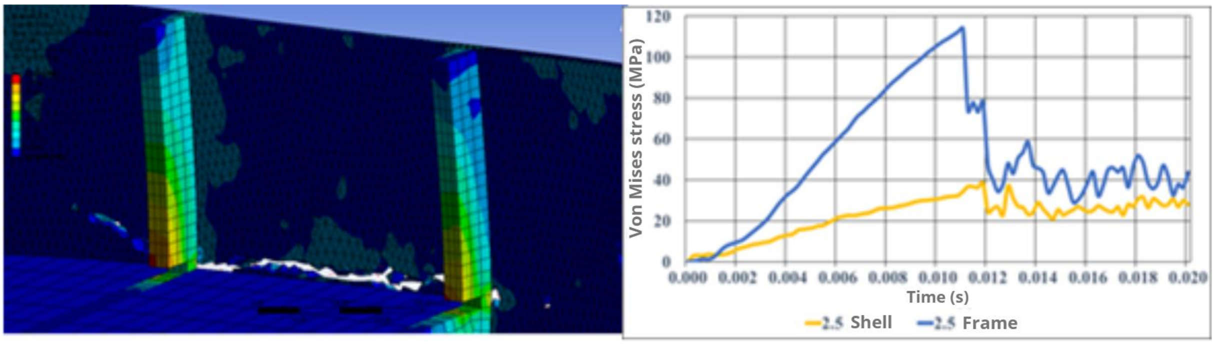


(d)

Figure. 7. Von Mises stress on the frame during impact and comparison graph of stress between the frame and the hull at various vessel velocities: (a) V = 0.488 knot, (b) V = 1 knot, (c) V = 1.5 knots (d) V = 2 knots.



(e)

Continued – Figure. 7. (e) V = 2.5 knots.

The vessel collided with the jetty along its centreline, resulting in stress and deformation occurring primarily on the hull plating and frame structures. The Von Mises stress analysis due to this impact is illustrated in Figures 5–8. The magnitude of the induced stress is represented by red shading for maximum stress regions and light blue shading for minimum stress regions. The analysis results indicate that the frame construction, both in the existing vessel and the BKI-standard design, demonstrates sufficient strength to withstand the collision impact at the standard berthing velocity of 0.486 knots (0.25 m/s). The corresponding Von Mises stress values were 12.960 MPa for the existing vessel and 17.758 MPa for the BKI-standard vessel. This conclusion is supported by reference to the mechanical strength of teak wood, which, at a minimum density of ρ = 0.56 ton/m³, has a tensile strength of approximately 425 kg/cm² (42 MPa) [7].

The results of the dimensional modification, which rendered the vessel designed under BKI criteria lighter than the field-observed (existing) vessel, indicate that the BKI-standard vessel exhibits greater structural strength. Structural failure—specifically in the hull plating and frame components—was observed to occur at an impact velocity of 2.5 knots for the BKI-standard vessel, whereas failure in the existing vessel occurred at 2 knots. This finding demonstrates that the reduction in the vessel's overall weight or mass has a dominant influence on the extent of structural damage, particularly in the hull plating and frames that come into direct contact with the jetty structure during impact.

The technical and economic advantages resulting from the reduction in construction profile dimensions demonstrate that the vessel designed in accordance with BKI criteria is able to withstand structural damage when berthing and colliding with the jetty at a velocity of 2 knots, whereas the existing vessel experiences failure at the same velocity and can only remain intact up to 1.5 knots. From this perspective, the BKI-standard vessel performs better technically than the existing one. The reduction in structural weight effectively increases the vessel's cargo capacity by an amount equivalent to the weight difference between the two vessels—approximately 258 kg. Furthermore, the economic benefit extends to the reduction in construction cost, owing to the more efficient use of wooden materials. A related study reported that the difference in displacement weight between wooden hulls and HDPE hulls accounted for 25% of the total structural weight, which could potentially provide an additional passenger capacity of up to 50% [11].

Research findings on structural damage caused by ship collisions or impacts indicate that the extent of damage depends on several factors, among which velocity plays a significant role. Previous studies have shown that a critical velocity occurs when an LNG carrier collides at a point located 20% of the ship's length from the stern, with a critical speed of 5.2 knots [12]. Another study reported that a hull damage area of approximately 287.1 m² resulted from a collision at a velocity of 10.2 knots [13]. Furthermore, a vessel with a mass of 1,400 tonnes striking another ship at a speed of 12 knots was found to cause damage extending to the inner hull structure [14]. Statistical data from various ship types also indicate that significant structural damage is primarily associated with high kinetic energy impacts, particularly among passenger vessels [15], as illustrated in **Figure 9.**

Any change in the vessel's weight can influence its overall performance. This effect arises from variations in the forces acting on the ship's hull due to changes in loading conditions. Such variations can affect the vessel's structural strength, primarily because of the resulting changes in bending moments, as well as its stability characteristics. Additional hull weight and geometric differences in the bow and stern regions can alter the longitudinal bending moment, thereby influencing the vessel's overall longitudinal strength. Furthermore, changes in the vessel's total weight also affect the magnitude of kinetic energy generated during a collision. This kinetic energy is determined not only by the vessel's mass but also by its velocity at the moment of impact.

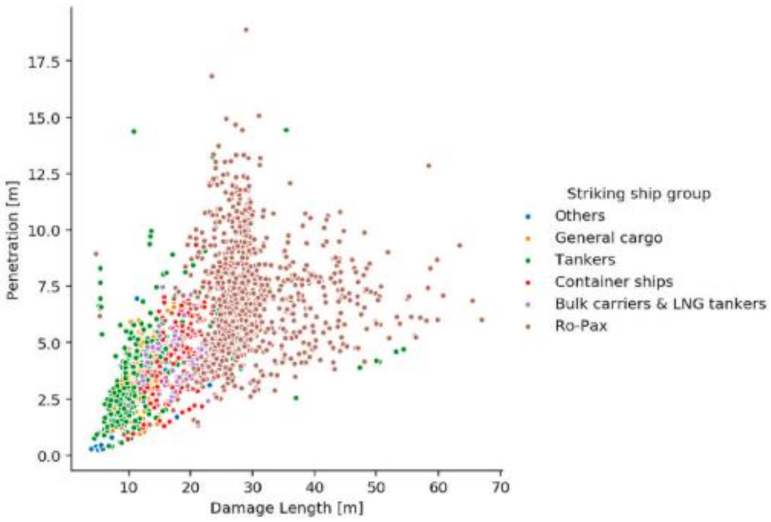


Figure. 9. Penetration versus damage length by vessel type based on collision damage simulation [4].

IV. Conclusion

Based on the analysis results, the following conclusions can be drawn: the difference in structural weight according to the BKI construction profile criteria amounts to 258 kg, or approximately 42% lighter than the existing vessel. Under this weight reduction, the vessel designed in accordance with BKI standards was found to withstand collision impacts at a speed of 2 knots without structural failure, whereas the existing vessel experienced damage at the same velocity, particularly on the hull plating and frame structures. These findings demonstrate that vessels built under BKI criteria are more advantageous both technically and economically. The lighter hull weight provides an economic benefit in the form of increased cargo capacity equivalent to the weight difference between the two vessels—258 kg, or 42%—thereby improving overall operational efficiency.

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