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Enhancing Crashworthiness of Aluminum Fishing Boats with Stiffener Plate Configurations

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ABSTRACT

Collisions involving fishing vessels pose a significant threat to maritime safety, often resulting in structural damage, loss of life, and environmental harm. This study investigates the crashworthiness of aluminum fishing boat hulls with the integration of stiffener plates to enhance structural resistance during collisions. Crashworthiness, defined as the ability of a structure to absorb impact energy, was analyzed through finite element simulations using ANSYS software. This study investigates the crashworthiness of aluminum fishing boat hulls with stiffeners to enhance structural resistance during collisions. The simulations modeled collision scenarios at different speeds (20 and 30 knots), with various stiffener configurations. The results showed that the inclusion of stiffeners increased energy absorption (EA) by up to 83%, underscoring the importance of stiffener design. These findings highlight a potential reduction in collision damage and improvements in maritime safety, offering practical guidelines for safer fishing vessel construction. Nonlinear structural responses were observed under high-speed impacts, underscoring the importance of optimized stiffener design. This research provides critical insights into the design of safer fishing vessels, offering practical recommendations for improving maritime safety and minimizing collision-related risks. Future work will include experimental validation of the simulation results to ensure the reliability of these findings for real-world applications.

1. INTRODUCTION

Collisions of fishing vessels are frequent and pose a serious threat to the safety of seafarers and the marine environment. Fishing vessels are often more vulnerable to damage and sinking than larger ships due to their smaller size, lower stability, and weaker structural design [1-4]. Fishing vessel collisions remain a persistent problem globally, accounting for a substantial portion of maritime incidents. According to the FAO, fishing vessel accidents can lead to death rates that are significantly higher than national averages in countries like the US and Australia. Several studies have explored the causes of these collisions and proposed preventive measures. However, a concise gap exists regarding how specific stiffener types and configurations can improve collision outcomes. Therefore, the objective of this research is to bridge that gap by assessing the crashworthiness of aluminum fishing boats using detailed FEA simulations, thus providing targeted solutions for safer maritime operations.

The cause of the fishing boat accident is the occurrence of a collision at sea in Indonesia from 2018-2020 as shown in Table 1 [5].

The frequency of fishing boat accidents in Indonesia highlights an urgent safety concern. Over the period from 2018 to 2020, these accidents claimed the lives of 342 individuals, with fishing vessels accounting for the majority of maritime mishaps [6, 7]. This alarming trend underscores the critical need for enhanced safety measures and stricter regulations for fishing vessels in Indonesia [8]. To address this issue, Sunardi et al. [9] developed computational models to simulate fishing boat collisions under extreme weather conditions, offering insights into structural vulnerabilities.

Table 1. Fishing boat accident types in Indonesia (2018-2020) [5]

Accident Types	Total	Percentage
Collision	56	27.05
Sinking	55	26.57
Occupational Accident	39	18.84
Grounding	26	12.56
Man Overboard	26	12.56
Fire-Explosion	2	0.97
Others	3	1.45

A key strategy to mitigate these risks is the redesign of wooden fishing vessels into aluminum boats, which offer superior strength and durability. This study aims to further improve the structural integrity of aluminum ship hulls by integrating stiffener plates. Stiffeners are essential structural components that enhance the rigidity and strength of hull plates, minimizing deformation under impact loads [10, 11]. Despite their potential, the effects of stiffeners on the crashworthiness of fishing boats under varying collision conditions—such as speed, angle, and impact location—remain insufficiently explored. Furthermore, the optimal stiffener configuration to maximize energy absorption (EA) during collisions is yet to be determined. Crashworthiness, defined as the ability of a ship structure to withstand impact loads and prevent catastrophic failure, is evaluated through EA, which quantifies the kinetic energy dissipated by the ship structure during a collision. A higher EA value indicates improved structural resistance and protection [12-14].

Aluminum is a highly versatile material that offers numerous advantages for boat construction, particularly when compared to traditional wooden designs. Its key benefits include superior strength, reduced weight, enhanced durability, and improved safety, making it an ideal choice for modern fishing vessels [15]. Aluminum is 30-40% lighter than fiberglass and 45-55% lighter than steel, which contributes to better fuel efficiency, higher speeds, and overall improved vessel performance [16]. Additionally, its corrosion resistance enables aluminum boats to endure harsh marine environments, including prolonged exposure to saltwater and UV radiation, with minimal maintenance requirements [17]. Aluminum's flexibility allows it to be molded into various designs and profiles, supporting a wide range of applications in boat construction. The material is available in semi-finished forms, such as castings, rolled sheets, extrusions, and specialized products, enabling tailored construction solutions [18]. Importantly, aluminum is environmentally friendly, with a low environmental footprint due to its recyclability, which reduces greenhouse gas emissions and waste generation compared to primary production [19].

Numerous studies have analyzed ship collisions and the structural performance of vessels under impact conditions. These investigations explored existing procedures for ship grounding and collision analysis, focusing on the structural response and damage assessment of ships and offshore structures. Methods such as analytical models, empirical formulas, numerical simulations, and experimental approaches were evaluated for their accuracy and limitations [20, 21]. For example, stochastic finite element methods have been applied to model hull responses in random damage scenarios, while Monte Carlo simulations have been used to estimate failure probabilities [22]. Coupled Eulerian-Lagrangian (CEL) methods have been employed to simulate fluid-structure interactions, accurately predicting deformation and motion during ship collisions [22]. Experimental validation remains essential, as real-world scenarios often deviate from theoretical models [23, 24].

The design and configuration of stiffeners significantly influence the structural performance of ship hulls under various loading conditions. Previous research has examined how different stiffener layouts and load locations affect the deformation and strength of ship hulls, particularly for tankers [25]. Advances in topology optimization methods have enabled the simultaneous optimization of stiffener layout and cross-sectional shape, enhancing the efficiency of thin-walled structures [26]. Other studies have investigated factors such as the thickness ratio of stiffener legs to web plates and rivet placement, which impact the effectiveness of single-sided stiffeners in resisting shear loads [27]. These findings underscore the importance of optimizing stiffener design to improve the crashworthiness of ship structures.

2. METHOD

This study aims to investigate the effect of stiffener plates on the crashworthiness of aluminum fishing boats under various collision scenarios using finite element analysis (FEA). Simulations were conducted with ANSYS software, modeling collisions at speeds of 20 and 30 knots and incorporating different stiffener configurations in the impact area. The energy absorption (EA) values of the fishing boat hulls, both with and without stiffeners, were compared to evaluate structural performance under impact conditions.

The FEA simulations were performed using the ANSYS Research License, which supports detailed modeling and analysis of complex engineering problems [28]. Finite element analyses were conducted using ANSYS. The aluminum fishing boat model was based on typical small vessel dimensions: 15 meters in length, 4.8 meters in width, and 2 meters in height [29, 30]. The hull plate material was assumed to be aluminum alloy 5083-H116, a widely used marine-grade material known for its high strength and corrosion resistance [31]. Material properties for the hull plate and steel object were sourced from existing literature [32].

Collision scenarios were simulated at two speeds (20 and 30 knots) and two angles of impact (0° and 55°) relative to the longitudinal axis of the boat. The collision point was set at the midpoint of the vessel (Figure 1). To enhance structural performance, stiffener plates were incorporated into the hull design, tested in two configurations: T-shaped and bar-shaped (Figure 2). These variations were selected to analyze the effect of stiffener geometry on crashworthiness. To simplify the analysis, the configuration of the stiffener model on the hull with short naming refers to the combination of positions, profile sections of side beam impact and speed of crash as shown in Table 2.

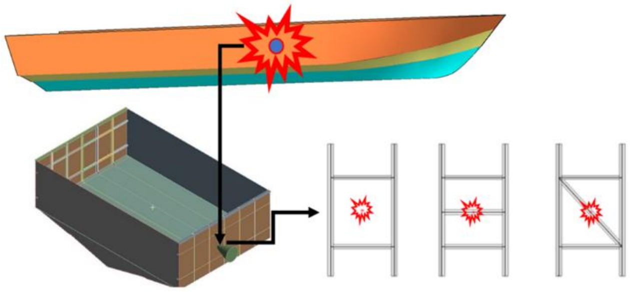


Figure 1. The collision of side hull to the sharp object and side beam positions (existing, transverse and longitudinal)

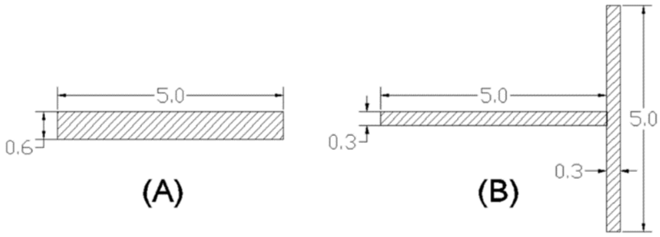


Figure 2. The Profile Bar 6×50 (mm) and T Profile 3×50+50×3 (mm) for side beam impacts shapes

Table 2. The combination of positions, profile sections of side beam impact and speed of crash

Position Side Beam	Profile Type	Speed (Knot)	Stiffener ID
Existing	-	20	E-20
Existing	-	30	E-30
Longitudinal	T	20	Long-T-20
Longitudinal	T	30	Long-T-30
Longitudinal	Bar	20	Long-B-20
Longitudinal	Bar	30	Long-B-30
Transversal	T	20	Trns-T-20
Transversal	T	30	Trns-T-30
Transversal	Bar	20	Trns-B-20
Transversal	Bar	30	Trns-B-30

Key parameters analyzed in the simulations included maximum stress, deformation, and energy absorption of the hull during collisions. These metrics were used to assess the effectiveness of the stiffener designs in enhancing the crashworthiness of aluminum fishing boats. Comparisons were made between scenarios with added stiffeners and the baseline (unstiffened) conditions.

In this research, the method chosen is computer simulation using ANSYS LS-DYNA, which is a nonlinear explicit finite element code that can simulate the response of materials to short periods of severe loading [33]. The fishing boat hull was modeled with aluminum alloy and the impactor with steel with detail properties as shown in Table 3. To clarify the modeling assumptions, a mesh convergence study was performed by gradually refining the mesh until changes in stress and deformation fell below 5%. Additionally, boundary conditions were configured to replicate real-life constraints, including fixed supports at the keel and free surfaces along the hull (Figure 3). Collision speeds ranged from 20 to 30 knots. and the energy absorption (EA) was calculated explicitly as the function of reaction force and the deformation. Assumptions include linear material behavior up to yield, followed by bilinear isotropic hardening in the plastic region. This approach assumes that the material undergoes elastic deformation under an applied load, transitioning to plastic deformation as the load increases beyond the elastic limit. The impactor was modeled using structural steel, treated as a rigid body to simplify the calculations and focus on the response of the hull structure [34].

The load modeling employed the crash test method, a widely utilized approach in engineering for simulating drop and impact scenarios. This method is instrumental in evaluating product integrity and identifying critical regions within an assembly that are most susceptible to failure under impact conditions [35].

Table 3. Mechanical properties of alloy and steel

Properties Material	Fishing Boat	Impactor
Density (kg/m^3)	2770	7850
Modulus elastisitas (GPa)	71	200
Poisson ratio	0,33	0,3
Yield strength (MPa)	280	450
Tangent modulus (MPa)	500	1450

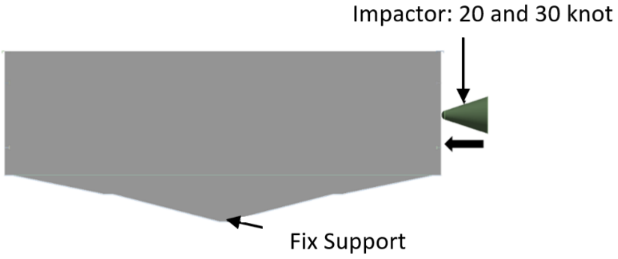
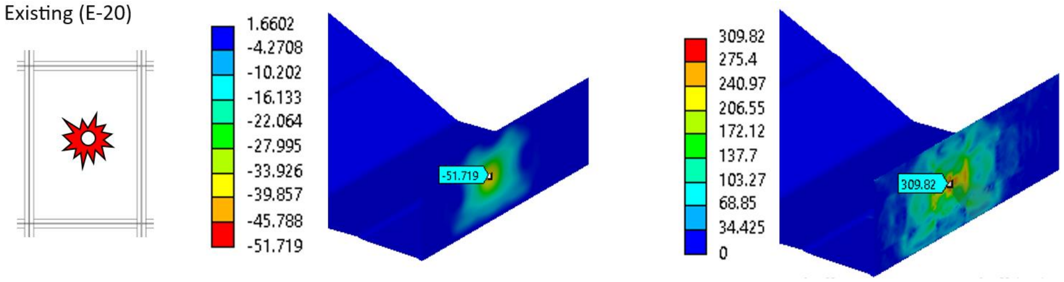


Figure 3. Setting model in ANSYS analysis

3. RESULTS AND DISCUSSIONS

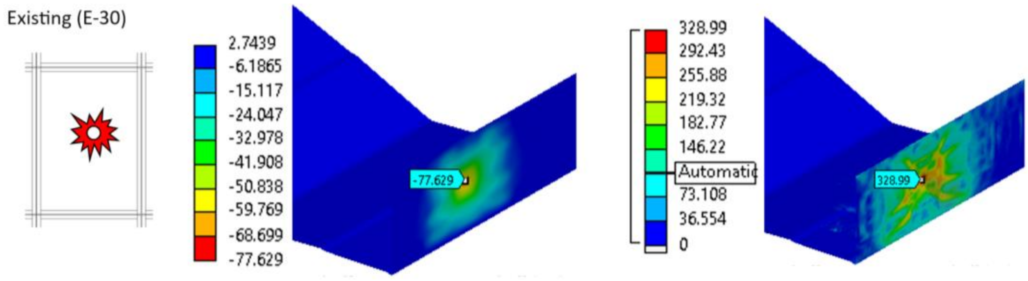
The deformation, stress, and energy absorption of stiffener plates are important factors that affect the crashworthiness of ship structures. In this study, we compared the existing design of the side hull of an aluminum fishing boat with four different models of stiffener plates. The finite element analysis to simulate the collision conditions and obtain the deformation, stress, and energy absorption distributions of each model [36, 37]. The results showed that the stiffener plate models had different effects on the crashworthiness of the side hull. The influence of collision speed on the deformation of the ship's hull was analyzed by comparing the results presented in Figures 4 to 11 and Table 4.

As anticipated, the deformation increased with higher collision speeds. At a speed of 20 knots, the hull deformation was approximately 51.5 mm, whereas at 30 knots, it increased to about 77 mm. Interestingly, the profile and angle of inclination of the side beam impact did not significantly affect the deformation (Figure 12). This suggests that collision speed is the primary factor influencing the extent of structural damage during ship collisions [38, 39].



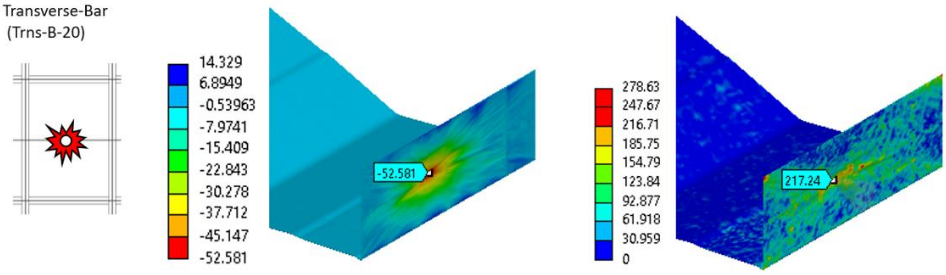
(a) (b) (c)

Figure 4. E-20 Stiffener ID: (a) crash area, (b) deformation in mm, (c) stress in MPa



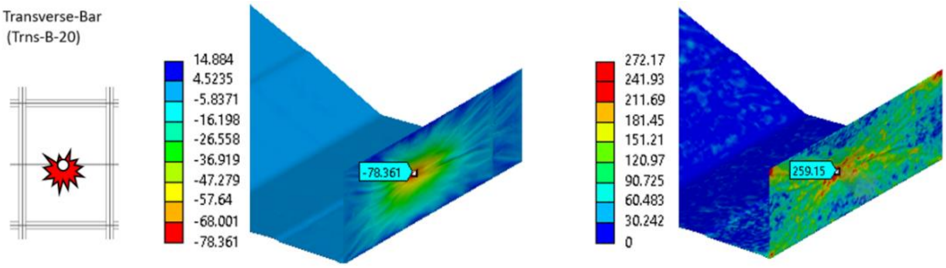
(a) (b) (c)

Figure 5. E-30 Stiffener ID: (a) crash area, (b) deformation in mm, (c) stress in MPa



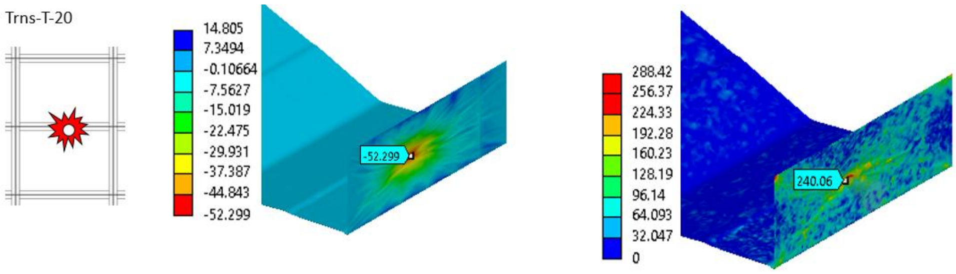
(a) (b) (c)

Figure 6. B-20 Stiffener ID: (a) crash area, (b) deformation in mm, (c) stress in MPa



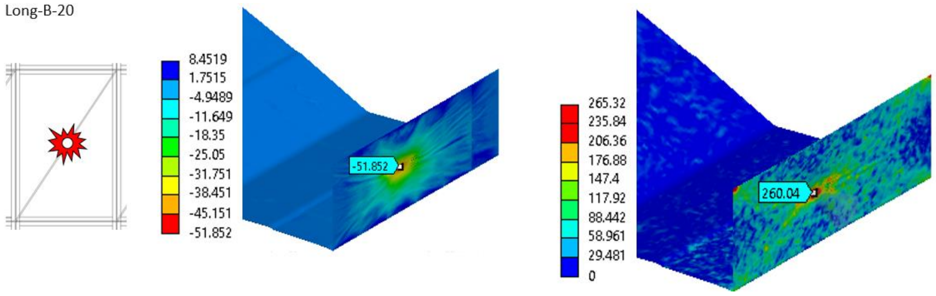
(a) (b) (c)

Figure 7. Trns-B-30 Stiffener ID: (a) crash area, (b) deformation in mm, (c) stress in MPa



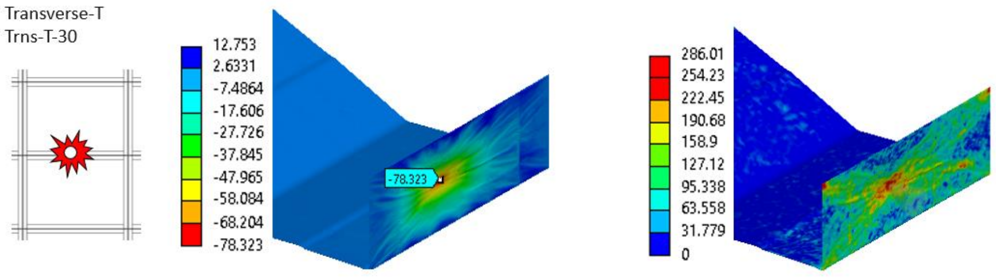
(a) (b) (c)

Figure 8. Trns-T-20 Stiffener ID: (a) crash area, (b) deformation in mm, (c) stress in MPa



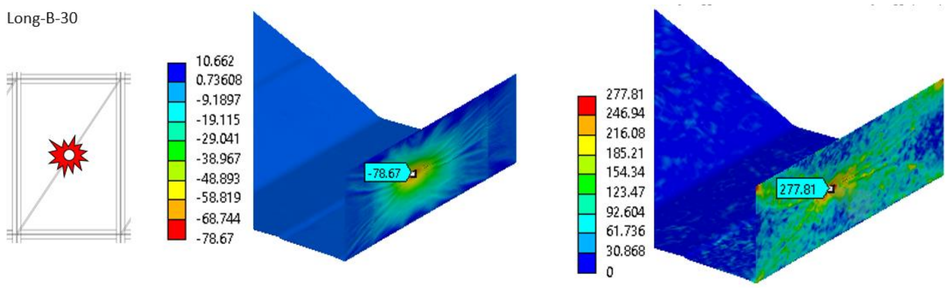
(a) (b) (c)

Figure 9. Long-B-20 Stiffener ID: (a) crash area, (b) deformation in mm, (c) stress in MPa



(a) (b) (c)

Figure 10. Trns-T-30 Stiffener ID: (a) crash area, (b) deformation in mm, (c) stress in MPa



(a) (b) (c)

Figure 11. Long-B-30 Stiffener ID: (a) crash area, (b) deformation in mm, (c) stress in MPa

Table 4. Values of deformation, stress, reaction force and energy absorption in collision with aluminum fishing vessel

Position Side Beam	Profil Type	Speed	Stiffener ID	Deformation _Max (mm)	Stress Max (MPa)	Energy Absorption (kJ)
Existing	-	20	E-20	51.441	309.82	7,942
Existing	-	30	E-30	77.161	328.99	13,942
Longitudinal	Bar	20	Long-B-20	51.443	288.42	80,773
Longitudinal	Bar	30	Long-B-30	77.161	277.81	**83,743**
Longitudinal	T	20	Long-T-20	51.443	286.01	75,474
Longitudinal	T	30	Long-T-30	77.164	278.63	83,468
Transversal	Bar	20	Trns-B-20	51.442	277.56	**86,169**
Transversal	Bar	30	Trns-B-30	77.166	265.32	**80,812**
Transversal	T	20	Trns-T-20	51.443	272.17	85,114
Transversal	T	30	Trns-T-30	77.161	279.29	76,376

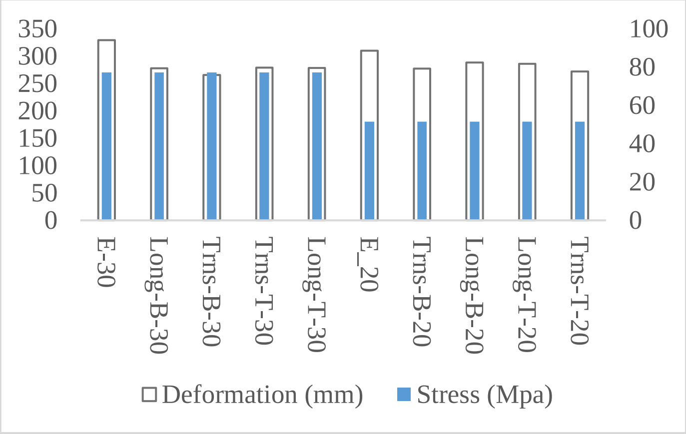


Figure 12. Deformations and stress in all configurations

One of the objectives of this study was to compare the effect of different types of additional stiffeners on the absorption energy (EA) of ship structures under impact loads. The EA value indicates the amount of energy that the ship structure can absorb before failure. The higher the EA value, the better the performance of the ship structure [40]. The EA value for each case using the formula.

$$EA = \int_0^d F(x)\,dx, \text{ or}$$
$$EA = \int_0^t F(t)\,dt$$

F is reaction Force and d is deformation.

F(t) represents the time-dependent impact force exerted on the ship's structure during the collision event. This formula fundamentally captures the work done by the impact force over the duration of deformation, representing the total energy absorbed by the structure as it undergoes elastic and plastic deformation. The philosophy behind this approach is grounded in the principle of energy conservation, where the kinetic energy of the impacting object is transferred to the ship's structure and dissipated through various deformation mechanisms. By integrating the force over the displacement during the collision, the formula quantifies the structure’s capacity to absorb energy, which directly correlates to its crashworthiness and ability to minimize damage during high-impact events.

Absorption energy (EA) is a measure of the ability of a ship structure to withstand impact loads. It is defined as the area under the curve of reaction force versus deformation. EA is the relationship between deformation and reaction force in the Figure 13 and Figure 14.

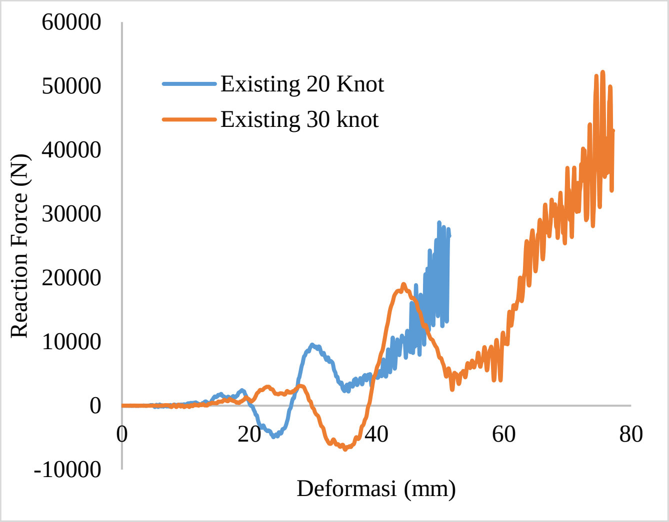


Figure 13. Force-deformation graph in 20 and 30 knot speed

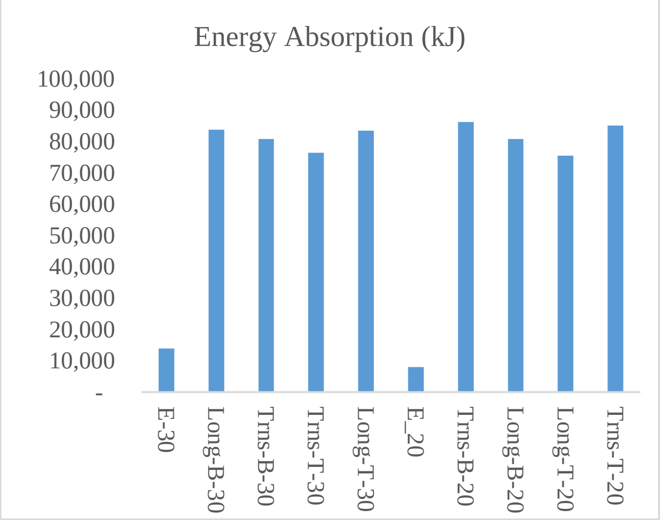


Figure 14. Energy absorption for all configurations

Finite element analysis (FEA) was conducted to evaluate various ship structures with different stiffener configurations using ANSYS software. Collision speeds ranged from 20 to 30 knots, and energy absorption (EA) values were calculated for each configuration. The results indicated a consistent increase in EA with higher impact speeds, demonstrating that the ship structures became more resistant to impact loads as speed increased (Figure 13). The simulations showed that adding stiffeners improved the hull's energy absorption as shown in Figure 14 and Table 5. The Table 5 indicate that the bar stiffener configuration achieved the highest EA at 30 knots, with approximately an 83% increase compared to the unstiffened model. Deformation and stress levels varied with speed but confirmed that stiffened models generally exhibited better performance. These results imply that improved stiffener design can effectively mitigate collision damage, supporting the development of more robust fishing vessels.

Addition of transverse stiffener profiles had a negative effect on EA at higher speeds (Figure 14). For instance, at a collision speed of 30 knots, the EA for the transverse profile was 85,114 kJ, compared to 76,376 kJ at 20 knots, as shown in Table 4. This reduction in efficiency at higher speeds can be attributed to the increased weight and complexity introduced by the transverse profile, which adversely impacted the ship's structural performance. This finding aligns with previous studies on transverse strength in ship structures [22].

Further analysis revealed that the bar profile with longitudinal installation achieved the highest EA value among all configurations tested at 30 knots. Specifically, the longitudinal bar profile recorded an EA of 83.743 kJ, highlighting its superior resistance and protective capability under impact loads. Conversely, the 6 mm bar profile with transverse installation demonstrated the lowest EA value at 30 knots, measuring 80.812 kJ. This suggests that this configuration was the least effective in enhancing the ship structure's crashworthiness. Table 5 summarizes the EA improvements achieved with the addition of stiffeners across different configurations and impact conditions.

This study investigated the effect of adding a side beam impact to the ship structure, with the primary objective of enhancing the energy absorption (EA) capacity under impact loads. As shown in Table 5, the inclusion of side beams increased EA values by 82–91% compared to the baseline condition (without side beams). This significant improvement demonstrates that side beam impacts effectively enhance the resistance and protective capability of ship structures during collisions. However, the results also revealed that different side beam configurations yielded varying EA performance, highlighting the importance of configuration design.

Table 5. Improvement of Energy Absorption (EA) with side beam impact

Position Side Beam Impact	Profil Type	Speed	Stiff ID	Energy Absorption (kJ)	Existing	Increase EA
Existing	-	30	E-30	13,942	13,942	0%
Existing	-	20	E_20	7,942	7,942	0%
Transversal	Bar	20	Trns-B-20	86,169	7,942	91%
Longitudinal	Bar	20	Long-B-20	80,773	7,942	90%
Longitudinal	T	20	Long-T-20	75,474	7,942	89%
Transversal	T	20	Trns-T-20	85,114	7,942	91%
Longitudinal	Bar	30	Long-B-30	83,743	13,942	83%
Transversal	Bar	30	Trns-B-30	80,812	13,942	83%
Transversal	T	30	Trns-T-30	76,376	13,942	82%
Longitudinal	T	30	Long-T-30	83,468	13,942	83%

The most extreme collision scenario in this study involved a collision speed of 30 knots. Among the tested configurations, the L-30-B (longitudinal bar) configuration achieved the highest EA value. Despite its superior performance, practical considerations, such as installation complexity and feasibility in field applications, may limit its adoption. Notably, the difference in EA values between the L-30-B and Trns-30-B (transverse bar) configurations was approximately 3 kJ, which is relatively insignificant. Considering its simpler installation and shorter profile, the transverse stiffener (T-30-B) emerges as a practical alternative, offering a balance between performance and ease of implementation.

The findings suggest that stiffener plates can substantially enhance the crashworthiness of aluminum fishing boats by absorbing impact energy. This has significant implications for real-world applications, where fishing vessels often operate under high collision-risk scenarios. By aligning with existing maritime safety regulations, such as SOLAS guidelines, the optimized stiffener designs presented here could inform policy updates or new regulatory measures. In practice, this design approach offers a cost-effective route to reduce hull damage, prolong vessel life, and potentially lower insurance and repair costs.

4. CONCLUSIONS

This study investigated the effect of adding stiffeners on the ship crashworthiness in ship collision events. Crashworthiness is the ability of a ship structure to withstand impact loads and prevent catastrophic failure. One of the parameters that measures the crashworthiness is the absorption energy (EA), which is the amount of energy that the ship structure can absorb before failure. The higher the EA value, the better the crashworthiness performance. In this study, finite element analysis using ANSYS software was performed to simulate ship collisions at a speed of 30 knots with different configurations of stiffeners in the impact area. The results showed that the addition of stiffeners could increase the EA value of the ship's hull significantly, up to 81%. This means that the stiffeners enhanced the resistance and protection of the ship structure under impact loads. The effect of stiffeners also depended on the collision speed. In general, as the collision speed increased, the EA and stress values also increased. However, there were some exceptions where higher collision speed led to lower EA and stress values. These phenomena could be explained by the nonlinear behavior of the ship structure under large deformation and dynamic loading conditions. The future work will focus on conducting experimental validation to complement the simulation results. A drop test will be performed on hull panel configurations with stiffeners to directly assess their energy absorption capacity and structural response under impact loads. Additionally, a ship collision test using a scaled vessel model on water will be conducted to evaluate the damping effects caused by the surrounding fluid, providing a more comprehensive understanding of real-world collision dynamics. These experimental approaches will help validate the finite element analysis findings and offer deeper insights into the influence of fluid-structure interactions on the crashworthiness of aluminum fishing boats.

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