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DEVELOPMENT OF FISHING BOAT COLLISION MODELS IN EXTREME WEATHER USING COMPUTER SIMULATION

Sunardi
Department of Mechanical Engineering[1]

Moch. Agus Choiron✉
Department of Mechanical Engineering[1]
agus_choiron@ub.ac.id

Sugiarto
Department of Mechanical Engineering[1]

Putu Hadi Setyarini
Department of Mechanical Engineering[1]

[1]Brawijaya University
167 Jl. M.T. Haryono, Malang, Indonesia, 65145

✉**Corresponding author**

Abstract

The incidence of fishing boat accidents in Indonesia is very worrying, with 342 people dying during 2018–2020. Based on this, it is crucial to investigate the construction strength of fishing vessels against the possibility of a collision. In this study, the fishing boat due to the impact load was investigated in extreme weather conditions using Finite Element Method (FEM) analysis. Traditional fishing boat was constructed by measuring the thickness of the hull, deck, keel, frames, and longitudinal structure of the fishing boat. The collision model is carried out with an impactor in the form of a mooring pole during extreme weather with a wave height of 6 meters and wind speeds 30 knots. Variations in velocity and frame spacing as in actual conditions are modeled to obtain differences in deformation, absorption energy values, and plasticity of boat construction due to collisions. The collision speed of 30 and 20 knots are set on the extreme weather conditions, while the collision speed of 7 knots is set on operating speed. Frame spacing of 0.5 and 0.6 meters is built according to the boat's frame spacing in the field. Computer simulation is carried out using application software ANSYS Research License. The fishing boat material used is mahogany wood with tested by using impact test with a toughness value of 39.1 kJ/m^2. Based on the simulations results, the impact velocity has an effect deformation wider crash area and hull stress value. The speed of the ship collision was 7 knots, the collision did not damage the hull, but the construction failed at speeds of 20 and 30 knots. The closer of frame spacing, the higher collision performance of structure to withstand impact are indicated by the higher energy absorption. At a ship collision speed of 30 knots, the absorption energy of the construction at 0.5-meter frame spacing is 49.8 kJ, greater than 0.6-meter frame spacing with a value of 29.6 kJ.

Keywords: fishing boat, wood material, collision, deformation, finite element, extreme weather.

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1. Introduction

Fishing boats in Indonesia are made for generations without adequate construction calculations. Under normal conditions, most accidents are caused by small boats that capsize due to operating in waters with high waves [1]. The National Transportation Safety Committee noted that as many as 31 percent of the total ship accidents during 2018–2020 were dominated and experienced by fishing boats. In accumulation, the number reached 342 dead and missing in 2018–2020. About 100 people per year die in fishing boat accidents [2]. Other data states that 38 % of ship accidents are due to natural factors that cause collisions [3]. Previous research on modern ship design has now been able to consider several accidents after a collision or develop designs to reduce the impact of a collision. Prediction of the possibility of ship collisions in offshore construction was investigated by using computer simulations [4]. Several studies investigated shipbuilding double-hull designs to increase collision safety by using granular materials [5]. The next study of granular materials as crash absorbing material is carried out and modeled with the Discrete Element Method, while the structure of the ship was modeled with the Finite Element Method [6]. Computer simulation by using the LS-DYNA code is validated by using available test results of a subassembly which are failing weight impact test of a steel box module [7]. For the next challenge, the ship collision model can be predicted by mathematical models and computer simulations. Characteristics of the ship construction strength against collisions can be evaluated with deformation combined by hydrodynamic factors on the extreme weather. The purpose of this study was to determine the model of the collision of fishing boats with traditional ship structures in Indonesia and the condition of the waters with high waves. Collision simulation is carried out to predict the damage of ship collision when operating in extreme weather.

Study on the strength of ship construction was carried out to find out stress and deformation due to collisions on steel ships. The hull without stiffener produces much more significant deformation than the hull with stiffeners for the simulation of steel ship collisions with computer simulations [8]. The objectives of this study are to review the existing structure of traditional fishing boats made of wood, and the speed of collisions of fishing boats in computer simulations. This analysis is essential for selecting materials to fulfill stronger constructions to withstand impact loads by optimizing frame spacing on fishing boat hull.

2. Method and materials

The fishing boat model sampled in this study is a traditional fishing boat in Prigi, East Java. The fishing boat hull is quite dominant in Indonesia with a length of about 15–20 meters; the sample size of the boat taken is 15 meters long, 5 meters wide and 2 meters high deck as shown in the **Fig. 1**.

Fig. 1. 15-meter Fishing Boat

The impact test was carried out to obtain the toughness value of the boat material simulated in this study. The test was carried out with a impact test machine with 3 specimens as shown in **Fig. 2.** The test result is enlarged with a microscope photo to obtain the characteristics of the mahogany wood material in cross-section (**Fig. 3**).

Fig. 2. The impact toughness test machine

Fig. 3. Observation of the cross-section of the wood impact specimen

The construction of fishing boats against collision in the hull is observed by using computer simulation with application software based on the Finite Element method, which is the ANSYS Research License. The deformation is observed due to collisions in that part of the hull. The mooring pole as the object of the collision is in the form of a beam with a side size of 10 cm, which collides on the skin of the hull between the two supporting frames.

The design parameter in this study is collision speeds and frame spacing. The three variations of collision speed include ship service speed (7 knots), collision speed with high waves (20 knots) and very extreme weather speeds (30 knots). The variation of the distance between frame of 50 cm and 60 is the range of the frame spacing on the existing Prigi traditional fishing boat. The variation of the frame spacing is carried out to obtain the effect of the frames spacing on the construction damage due to collision. A fish hold between the two bulkheads is modeled for a fishing boat collision analysis. This is done to reduce cost time in the running process. Collision modeling of the hull construction assuming a flexible hull and the impactor assuming a rigid hull. The impactor setting is assumed to be positioned at the weakest part of the boat's hull. The collision model is applied to the middle position of the boat with the collision to the side of the boat - below the deck as shown in **Fig. 4**. The deformation in the variation of the frames spacing and the velocity is observed on front view, side view, and crash zone view.

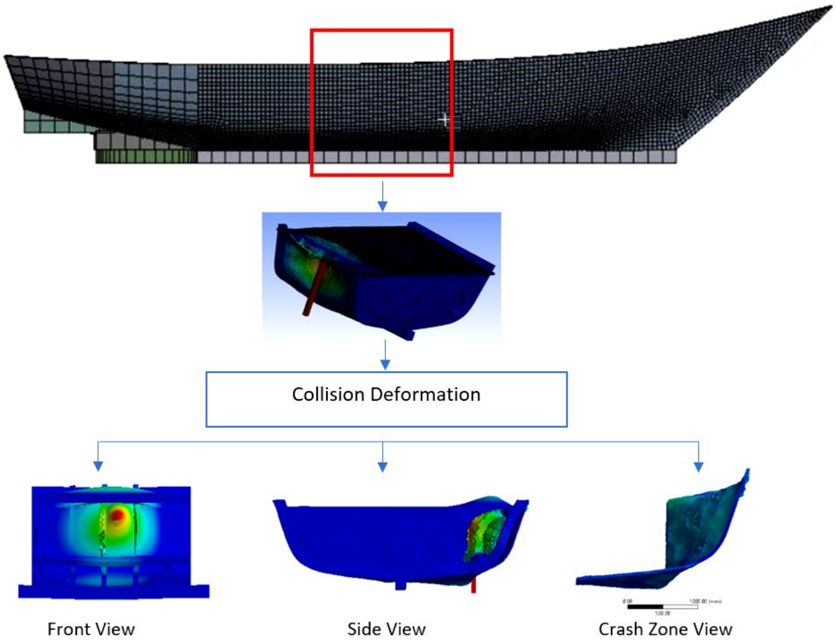


Fig. 4. Model of the fishing boat collision

Traditional fishing boat in Prigi is made of mahogany wood and the model is constructing based on field measurements. Midship section construction of fishing boat is design by using frame spacing 0.5 and 0.6 meters as shown in **Fig. 5**.

Computer simulation of the boat model was carried out with a scale of 1:1, type of elements tetrahedrons, number of elements 134130 and mesh size is 0.04 meters. Boundary conditions of the boat collision model in FEM analysis is set as shown in **Fig. 6**. The impactor is set as a steel structure and hitting the boat hull area.

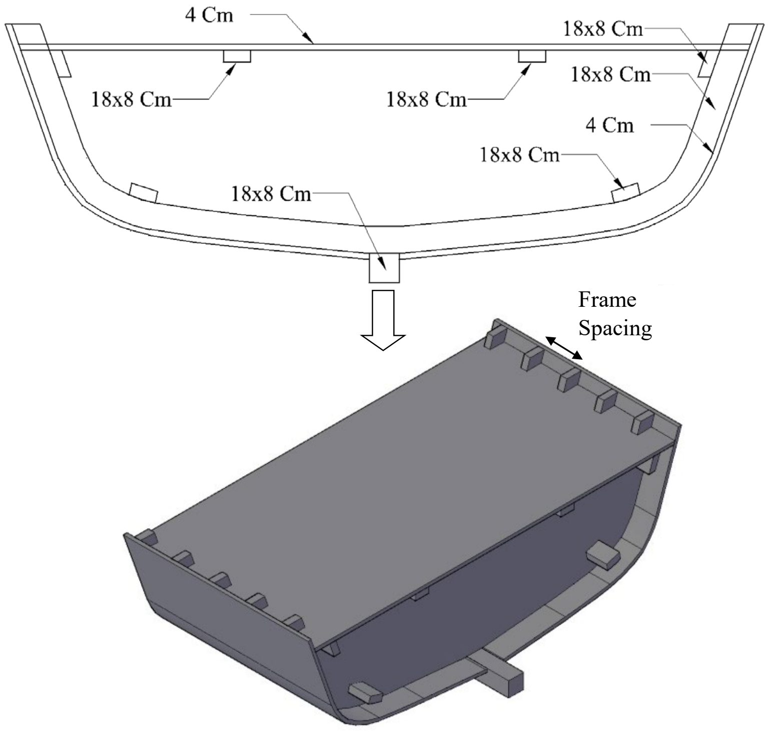


Fig. 5. Midship section construction of fishing boat

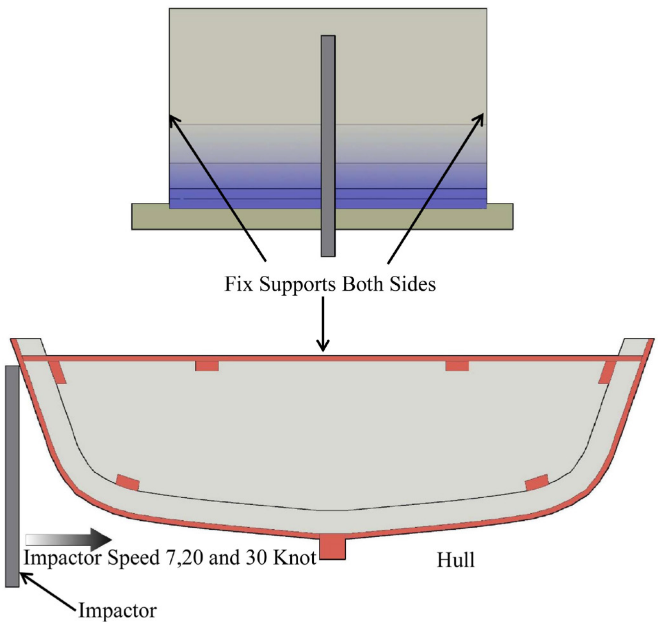


Fig. 6. Setting the boundary conditions of the fishing boat collision model

The material used for the construction of the fishing boat is mahogany and impactor used steel as shown in **Table 1**. Material model of Mahogany wood is assumed as porosity with crushable foam model.

Table 1
Mechanical Properties [9]

Material Parameter	Mahogany wood	Steel (Impactor)
Density (kg/m^3)	512.1	7850
Young's Modulus (MPa)	11.290	$2\cdot10^5$
Poisson's Ratio	0.3742	0.3
Bulk Modulus (MPa)	14.958	$1.6667\cdot10^5$
Shear Modulus (MPa)	41078	$7.6923\cdot10^4$
Tensile Ultimate Stress (MPa)	73.38	460
Tensile Yield Stress (MPa)	43.98	250

3. Results and Discussions

Computer modeling of ships require a transforming actual ships model into a computer model. Redrawing is done from the available technical drawings and surveys of existing fishing boats. Validation is carried out to provide similarities between the model and actual fishing boat. **Fig. 7** shows the results of modeling a sample of traditional fishing boats with a computer where the main size of the boat is the overall length = 15 meters, width = 5 meters, and deck height = 2 meters. Validation of the fishing boat model with the actual fishing boat can be seen in **Table 2**.

Fig. 7. Modeling of traditional fishing boat

Table 2
Validation fishing boat model with actual

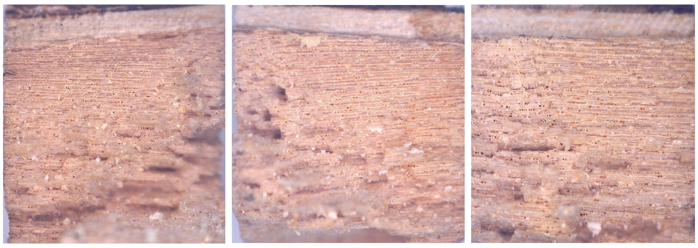
Parameter	Unit	Actual	Model	Difference (%)
Displacement	m^3	48.5	47.3	2.5
Draft Amidships	m	1.50	1.50	0.0
Immersed depth	m	1.50	1.50	0.0
WL Length	m	13.40	13.40	0.0
Beam (on WL)	m	4.80	4.80	0.0
LCG (horizontal)	m	6.10	6.07	0.5
LCG (Vertical)	m	0.98	0.98	0.0
Block coeff. (Cb)		0.50	0.49	2.4

The difference in measurement parameters of fishing boat data and modeling results for fishing boat weight and its coefficient of less than 5 % and Center of Gravity (LCG) of less than 1 % proves that the fishing boat model is very similar to the actual fishing boat (valid) to be used in the next calculation analysis. Impact test capacity of 250 Joules and an angle of 150 degrees are used to test 3 specimens of mahogany wood. The average energy value is 39.1 kJ/m^2. Referring to the impact value of mahogany = 39 kJ/m^2 [10]. There is a small difference due to the inhomogeneous structure of the woods, as shown in **Fig. 8.**

In operational speed conditions, this boat travels at a speed of 7 knots, but in extreme weather conditions, the fishing boat's speed can reach a speed of 30 knots. The calculation of the estimated wave speed is carried out by taking the location of the waters in the south of Java (Indian Ocean) when extreme conditions with a wave height of 6 meters and wind speeds 32 knots, the fishing boat speed follows the wave speed in deep waters of 30 knots with the following calculation [11, 12].

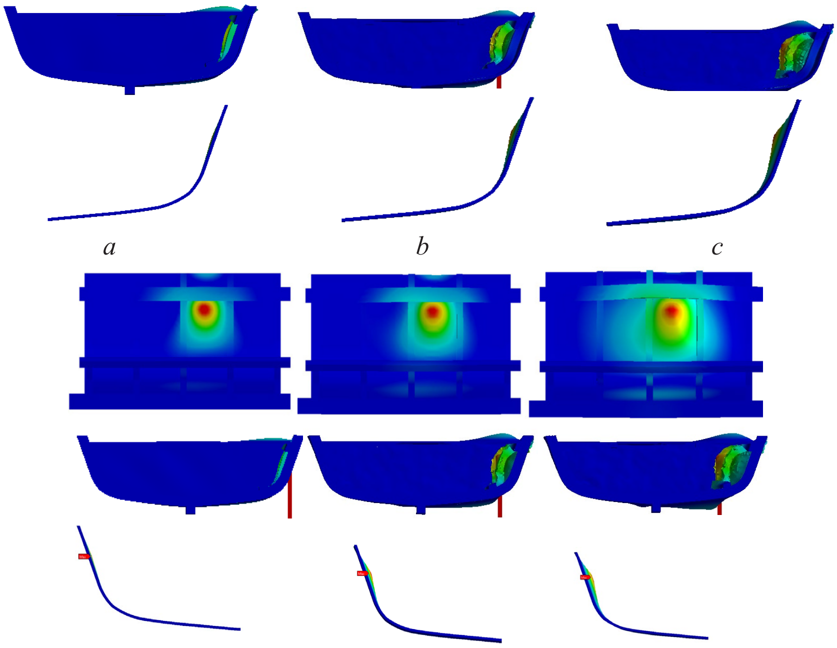
Based on the calculation, collision of fishing boat is occurred on maximum speed of 30 knots or 15.6 m/second. For comparison, fishing boat collision simulations were carried out for the speed of 7 knots and 20 knots.

The results of the computer simulation for the collision of traditional fishing vessels are visually shown in **Fig. 9**.



a *b* *c*

Fig. 8. Sections contour image of the specimen fracture in the impact test: *a* – specimen 1; *b* – specimen 2; *c* – specimen 3



a *b* *c* *d* *e* *f*

Fig. 9. The deformation pattern from various views: *a* – 0.5 m Frame Spacing on $V = 7$ knot; *b* – 0.5 m Frame Spacing on $V = 20$ knot; *c* – 0.5 m Frame Spacing on $V = 30$ knot; *d* – 0.6 m Frame Spacing on $V = 7$ knot; *e* – 0.6 m Frame Spacing on $V = 20$ knot; *f* – 0.6 m Frame Spacing on $V = 30$ knot

The crash zone is the area around the point of impact. Observations in this area are used to predict the area of the crash zone connected with frame spacing support effect. The hull shell made of mahogany is supported by side girders and frames as shown in **Fig. 10**. The magnitude of the deformation due to the collision can be determined by marking at several points to show the difference in deformation at various variations of the collision speed and the frame spacing as shown in **Fig. 11**.

From the deformation plot, it can be explained that the speed of the collision strong influences the magnitude of the deformation. The speed of 7 knots resulted in a small deformation (maximum = 18.85 mm) with a small crash zone area. The deformation and crash zone are bigger with increasing speed to 20 and 30 knots. This is proportional to the value of deformation, which increases, with the increasing speed of the fishing boat.

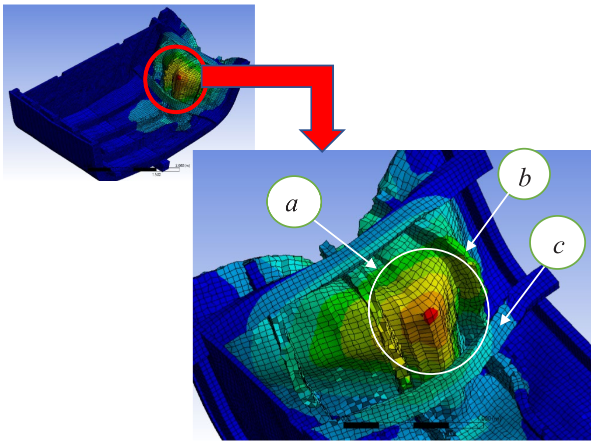
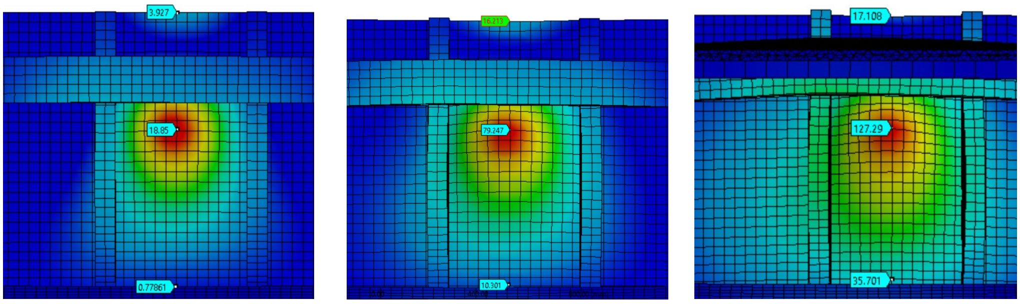


Fig. 10. Deformation mode at 30 knot speed: *a* – Crash Zone; *b* – frame; *c* – side girder



a *b* *c*

Fig. 11. Comparison of critical zone based on the maximum deformation at 0.5-meter frame spacing: *a* – v = 7 knot; *b* – v = 20 knot; *c* – v = 30 knot

To determine the construction's strength to withstand collision loads, the stress value by a fishing boat collision was not exceed the ultimate strength of the selected wood material. The results of collision plotting in 0.01 second intervals on construction with frame spacing of 0.6 meters as shown in **Fig. 12.**

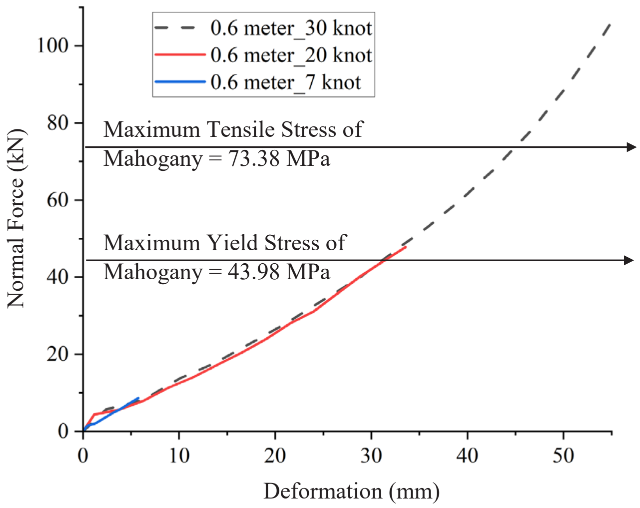


Fig. 12. Normal force-deformation graph

Based on **Fig. 12**, the collision of fishing boats at speeds of 20 and 30 knot produce the construction failure due to the stress value exceeding the maximum ultimate stress of mahogany wood as a fishing boat hull material. Meanwhile, the collision with a service speed of 7 knots did not cause any damage to the fishing vessels. These results can be used as a reference for further research to consider aluminum, fiberglass, or other metals as shipbuilding materials that are stronger in impact resistance. The relationship between frame spacing and reaction force on the collision speed of fishing boats in extreme weather conditions at 20 and 30 knots is explained in **Fig. 13, 14**.

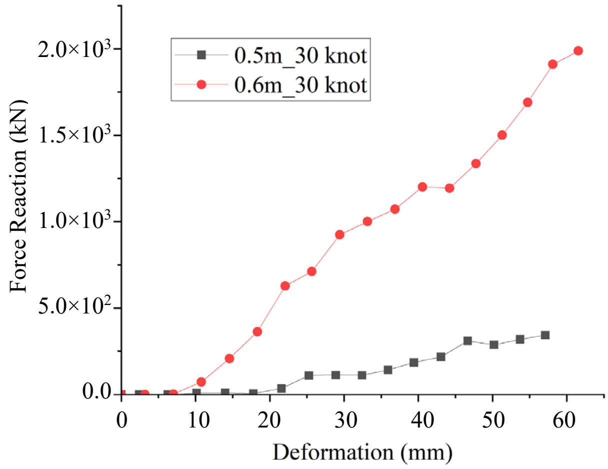


Fig. 13. Force-displacement graph at 30 knot speed

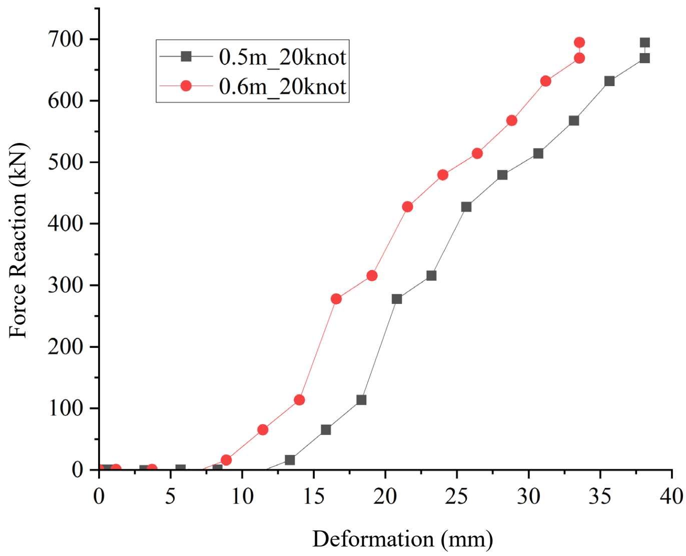


Fig. 14. Force-displacement graph at 20 knot speed

Absorption energy is calculated on the bottom area of Force-Displacement graph. It can be denoted that Frame spacing of 0.5-meter results in greater energy absorption than 0.6-meter are shown in **Fig. 13, 14.** Thus, 0.5 meter frame spacing has better energy absorption in resisting collisions indicated by a wider area under the curve than 0.6 meter spacing. The energy absorption for variations in speed and frame spacing are shown in **Table 3**.

The effect of the frame spacing between 0.5 and 0.6 meters shows that the 0.5-meter frame spacing produces more energy absorptions as shown in **Table 3** and **Fig. 13**. Frame spacing significantly affects the strength of ship construction, indicated by its energy absorption value. The energy absorption for 0.5-meter frame spacing is almost 2 times that of the energy absorption for 0.6-meter frame spacing at ship speeds of 20 and 30 knots (extreme weather). At a fishing boat collision speed of 7 knots, the absorption energy is low with a value of less than 1 kJ, therefore the hull of the fishing boat is safe from a collision at that speed. The trend data relates to the previous study [13].

Table 3
The energy absorption value

Speed (knot)	Frame spacing (meter)	Energy Absorbed (kJ)
7	0.5	$401.85 \cdot 10^{-3}$
	0.6	$20.063 \cdot 10^{-3}$
20	0.5	18.172
	0.6	9.712
30	0.5	49.811
	0.6	29.801

The characteristic of deformation-time graph on a ship collision with a speed of 7 knots is shown in **Fig. 15**. Initial Peak Force shows the beginning of the plastic deformation of a material shown in **Fig. 14, 15**. Based on the results of plotting the force-deformation curve, it shows that the initial peak force for various speed parameters and frame spacing produce at different deformation values.

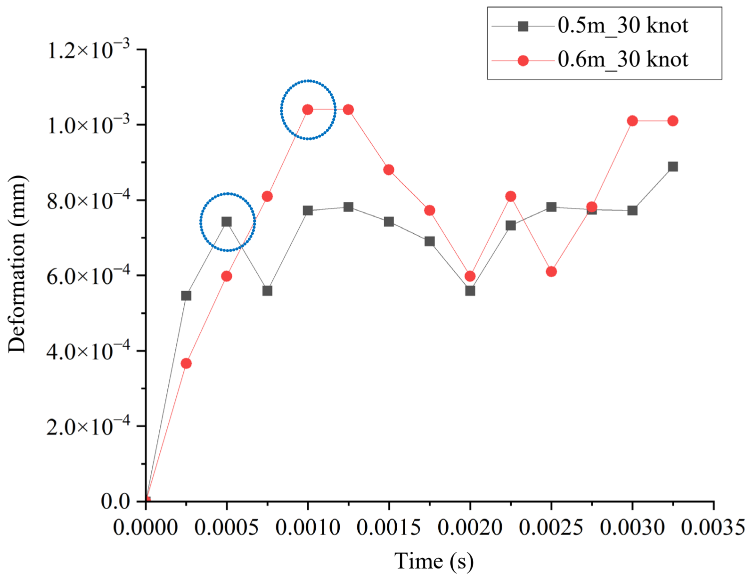


Fig. 15. Deformation-time graph of mahogany wood hull material

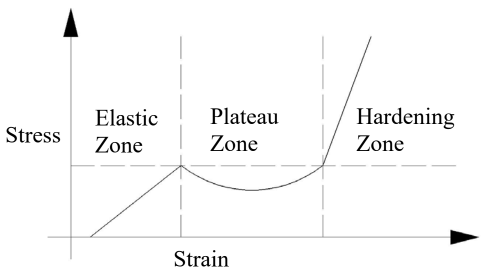


Fig. 16. Stress-Strain Diagram on wood [14]

Comparing the plot results of the simulation results in **Fig. 15** with the stress-strain diagram on the wood in **Fig. 16**, wider the frame spacing (0.6 meters) produce deformation rate compared to 0.5 meter before entering the Plateau Zone area.

Modelling the material nonlinearities are determined by the behavior of structures. The response up to necking and fracture initiation on indentation of a rigid sphere into a thin, ductile metal plate was predicted by using finite element analysis [15]. In experiment observation, structural failure mechanisms in ships subjected to stranding was studied [16]. To develop numerical simulation, the performance of two failure criteria with BWH instability criterion and the RTCL damage criterion was investigated [17]. The limitation of this study is wood material model did not fulfill the failure criterion due to lack of fit the wood material data. In the future study, to predict of the extent of damage in collision structures, the modelling of wood ship is required using the material nonlinearities, plastic strain hardening and critical fracture strain. Another challenge to predict failure mechanism, failure strain is approximated due to highly dependent on the finite elements size.

4. Conclusions

Traditional fishing boat construction analysis due to impact loads can be developed by computer modeling. Increasing the impact velocity resulted on deformation, wider crash area, and the magnitude of the stress on the fishing boat hull. With the collision speed of 7 knots, the construction of the ship was still able to survive the collision, but with the speed of 20 and 30 knots in extreme weather conditions, the constructions are failed. The closer of frame spacing resulted in the higher the collision performance of the structure to withstand impact, as indicated by the higher energy absorption. Wider frame spacing affects larger crash areas and stress on the collision construction. The effect of frame spacing between 0.5 and 0.6 meters shows that a frame spacing of 0.5 meters produce results two times greater energy absorption than 0.6 meters at a simulated speed of 20 and 30 knots (extreme weather). It is very significant to increase the strength of the ship's construction in withstanding the impact load. Frame spacing also affects the deformation rate; it can be seen at 0.6-meter frame spacing, it produces a significant strain rate compared to 0.5 meters. The collision modeling of fishing boats with actual sizes is predicted in extreme weather with 30 and 20 knots collision speeds, indicating structural failure.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining, and using its results, as well as any nonfinancial personal relationships.

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Data availability

Data will be made available on reasonable request.

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