Effects of Collision with a Self-Propeller Oil Barge Ship on a Navigational Buoy

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(Received: 02 March 2023 / Revised: 24 March 2023 /Accepted: 24 March 2023)

***Abstract*. A navigation buoy is a navigational aid tool that is very important in supporting the safety of shipping lanes. However, navigation buoys are often lost and damaged, caused by several factors, one of which is being hit by a ship. Therefore, it is essential to conduct this research to determine the damaging effect on the navigation buoy after being hit by a vessel and to determine the effectiveness of using medium-density polyethylene material in the navigation buoy structure. This study uses a finite element numerical simulation method by making three variations of speed, as well as two variations of the angle of impact, namely 0° and 45°, which lasted for 0.1 seconds and was assisted by FEA software. The simulation results indicate that the largest maximum deformation occurs when the ship strikes the buoy with a speed of 7 m/s at an angle of 0° of 0.6 m. In this scenario, there is also a significant damage condition that results in tearing the buoy shell's surface by as many as 413 elements, or 1.24 m. The most extraordinary kinetic and internal energy produced occurred at a speed of 7 m/s with an angle of 45° of 147.15 kJ and 45.70 kJ. Therefore, it can be stated that the amount of buoy damage caused by a ship collision is dictated or impacted by the starting speed of the ship and the angle of impact State the most important part of your findings and achievements**

***Keywords* : Navigation buoy, Numerical Simulation, Ship Collision, Self Propelling Oil Barge**

I. INTRODUCTION

Navigational Aids are equipment or systems outside the ship designed and operated to improve the safety and efficiency of navigating ships or ship traffic [1]. There are several types of navigational aids, one of which is a navigation buoy. The existence of a navigation buoy is crucial to the safety of shipping lanes, as it serves as a lighting source that emits a specific light and is moored along the shipping lane to alert ships to the presence of hazards or shallow areas. The manufacture of navigation buoys in Indonesia refers to the standards issued by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA).

There are 1,396 navigation buoys scattered throughout Indonesian waters, divided into 25 navigation districts [2]. This number is recorded until December 2021; this number indicates that navigation buoys have an essential role in the world of navigation in shipping lanes so that ships sailing at night safely arrive at their destination ports.

However, the navigation buoy is often lost and damaged due to several factors, such as bad weather in the form of strong winds and large waves, which can cause the navigation buoy to be lost and dragged by the waves. And also another factor is being hit by a ship which can cause damage to the navigation buoy. The collision will significantly affect the structure and construction of the navigation buoy.

Using numerical computing, a previous study investigated and evaluated the collision between 10000 tonnes of a ship and a buoy u. They determined that the stress-strain caused by the collision between ships and the bottom of buoys is more significant than the collision between ships and the top. [3]. Bela et al. researched ship collisions with offshore turbines and concluded that the impact velocity and direction of the wind concerning the ship direction greatly influence offshore wind turbine structural behavior [4]. Jia et al. studied operation ships that collided with wind turbines during berthing. They discovered that the collision of the operation and maintenance vessels increases the bending moments at the foot of the tower and the roots of the blades. [5]

Damage to navigation buoys caused by ship collisions has happened in many sites around Indonesia. In 2016, a barge operated by PT Timur Jaya Lestari collided with a navigation buoy near the Merauke port, causing it to be damaged and rendered inoperable [6]. Another navigation buoy was damaged at the entrance to the port of Merak, which was thought to have been struck by a ship [7]. In 2021, two navigation buoys in the Class II Navigation District Semarang operational area were destroyed again, purportedly due toeing struck by a passing ship [8].

Based on previous research and the cases above, it's crucial to research damage analysis on navigation

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buoys made from materials such as Medium Density Polyethylene (MDPE). This study aimed to determine the effect of ship collision damage on a navigation buoy body plate and the effectiveness of using Medium Density Polyethylene in the structure. This study uses explicit dynamic Finite Element Method software to simulate 0.1-second collisions between SPOB ships and navigation buoys. This research can help design and select strong materials for navigation buoy structures.

II. MATERIALS AND METHODS

The initial stage of the research began with a literature study on previous studies and conducted interviews about the damage to the navigation buoy in the work area of the Class II Navigation District Semarang, as well as requests for data on navigation buoys and self-propeller oil barge ships. The data obtained were converted into 3D form with the help of CAD software and for Finite Element Analysis (FEA). The output taken in this study is the damage condition and the value of kinetic energy on the navigation buoy body that occurs after the collision.

The objects used in the collision simulation are the self-propeller oil barge ship as the pounder and the polyethylene navigation buoy as the pounder. The following data from the research object used are based on Tables 1 and 2.

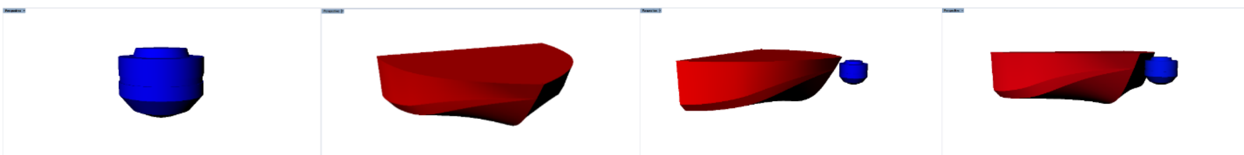
TABLE 1.
SHIP PRINCIPAL DIMENSION

NO	ITEM	UNIT
1	Length Over All (LOA)	71.40 m
2	Breadth (B)	16.80 m
3	Depth (H)	4.40 m
4	Draft (T)	3.40 m
5	Displacement (Δ)	3749 ton

TABLE 2.
NAVIGATION BUOY DIMENSION

NO	ITEM	UNIT
1	Buoy Body Diameter	2.6 m
2	Buoy Body Height	2.04 m
3	Draft	1.24 m
4	Freeboard	0.797 m
5	Buoy Body Weight	2.4 ton

Data processing in the simulation is carried out by performing three stages, namely the creation of a 3D model, where the 3D modeling stage is carried out with the help of CAD software based on the data that has been obtained. The step of making 3D models is done with Rhinoceros software based on the information that has been received. However, because the size comparison of the ship's length is not comparable to the body buoy, according to research(Chang et al., 2012), a simple model can be used in this study. The 3D model is illustrated in Figures 1(a) and (b). Then merge the models according to the collision scenario, where the angle of contact, namely 0° and 45°, and the ship's speed as the impactor, 0.1, 0.2, and 0.27, will vary. Merging the 3D models is done by giving a distance between the two objects of 0.05 m which will be shown in Figures 1(c) and 1(d). The next step is to analyze using the finite element method. In the finite element method, three phases must be carried out, including the pre-processing phase, the processing phase, the analysis phase, and the post-processing phase [7].



(a) (b) (c) (d)

Figure 1. Illustration of a 3D image of the buoy model (a) and the bow of the SPOB ship (b) and Illustration of the scenario that occurs between SPOB and Buoy with a collision angle of 0° (c) and 45° (d).

Meshing is a process by which the geometric space of an object is divided into thousands or more to determine the exact physical shape of the object. Meshing is done on Ansys Ls-Prepost software using auto mesher tools. The cell type selected for both parts is a triangle cell because this cell type can form a complex model [8]. In this study, the element size used is 0.05 m on the buoy and 0.1 m on the ship. Figure 5 shows the meshing settings on the model.

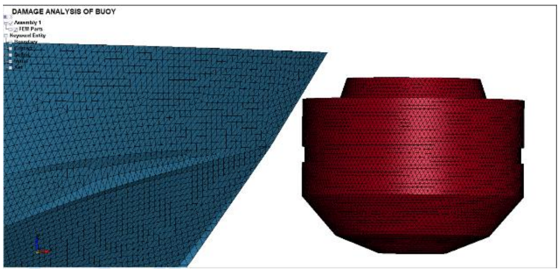


Figure 2. Meshing Model

The process of defining the material model is carried out in the Ansys LS-PrePost software individually for each model. The selection of the suitable model material constitutive relationship is critical to ensure that the collision simulation process is close to the truth [9]. In this study, the Plasticity With Damage model material was chosen as the model material for the buoy because this model material can take into account the effects of the damage and failure criteria on plastic materials [10]. Meanwhile, Rigid material was chosen as the model material for the SPOB ship so that all of the buoys could absorb all of the energy that occurs. This is done to focus the investigation on the buoy body [11]. The material definition will be explained in Tables 3 and 4

TABLE 3.
NAVIGATION BUOY DIMENSION

ρ − Density (Kg/m3)	940
E − Young modulus (GPa)	0.2
υ − Poisson ratio	0.4
σ_y − Yield stress (MPa)	19.3
Strain rate C	104
Strain rate P	4.26

TABLE 4.
NAVIGATION BUOY DIMENSION

ρ − Density (Kg/m3)	7800
E − Young modulus (GPa)	200
υ − Poisson ratio	0.32

The defining section defines each model's element formulation, integration point rules, and element thickness. The type of element and the thickness used for the Shell Buoy polyethylene element is 0.013m thick, while the shell element on the hull uses 0.01m thickness.

The part stage is the process of combining material information and section properties. This stage is done by inputting the SECID and MID for each part made in the previous location, aiming to identify the section and material in the correct detail. During the simulation, two types of contact will be allowed by applying static and dynamic friction coefficients of 0.2 and 0.17 to both [12] [13]. The two types of communication include; Contact between the buoy and ship, Set Automatic Surface to Surface with the buoy as master and the ship as an enslaved person, then Self contact on the buoy body using Automatic Single Surface. The boundary condition given to the buoy body is a single point constraint (SPC) while yet enabling the buoy to move with three degrees of freedom (DOF), namely translation on the x-axis (surge), translation on the y-axis (sway), and rotation on the z-axis (yaw). The water around the buoy will constrain the buoy's motion when the ship strikes it; mass will be added due to the interaction with the surrounding water. [14]. The coefficient of mass addition used for ship collisions with buoys is 0.03 for ships and 0.4 for buoys [15].

II. RESULTS AND DISCUSSION

A. Maximum Deformation.

The maximum deformation that occurs after the collision on the navigation buoy with the 0° angle scenario is 0.20 m; 0.40m; 0.60 m, while the 45° angle scenario is 0.14 m; 0.32m; 0.51m. According to the deformation results obtained, the most significant maximum deformation in each angle scenario is caused by the ship's collision with a speed of 7 m/s. The following is the result of the most significant maximum deformation in each scenario of the collision angle shown in Figure 4.

The zero-degree comparison of deformation values is shown in Figure 5 & 6. The graph shows that the deformation value is higher for the collision at an angle of 0 degrees than it is for an angle of 45 degrees.

Analysis of a ship colliding with a buoy at an angle of 0 degrees revealed that the impact caused deformation and ripping of the buoy body surface at 3 meters per second, 5 meters per second, and 7 meters per second. As can be seen in Figure 5, the most excellent deformation value in this simulation scenario is -0.6m.

B. Kinetic and Internal Energy

When the ship and buoy collision occurs, the ship's initial kinetic energy will be transformed into various other fuels, mainly internal energy. Following are the results of the kinetic energy obtained after the collision on the navigation buoy with a scenario of 0° angle is 8.04 kJ; 25.86 kJ; 62.95 kJ and internal energy of 5.59 kJ; 21.18 kJ; 39.60 kJ. At the same time, the results of the kinetic energy obtained after the collision on the navigation buoy with a 45° angle scenario are 6.21 kJ; 51.46 kJ; 147.15 kJ, and internal energy of 10.33 kJ; 29.70 kJ; 45.70 kJ. Like the maximum deformation, the most outstanding energy value obtained by the navigation buoy after the collision occurred at a speed of 7 m/s. The following energy graphs obtained from the simulation results are shown in Figures 7.

C. Navigation Buoy Damage Condition

The condition of the buoy body after the collision simulation according to 3 damage criteria will be described in Table 6. The amount of damage is based on the number of elements in the buoy body, which amount to 22028 elements. The criteria for damage to the buoy body element are determined based on the value of the effective stress, or von mises stress encountered on the buoy body element. This is also related to the material used in the buoy. In this study, a medium-density polyethylene type of polyethylene material was used, which has a yield strength value, so elements that have a von mises stress value exceeding the yield strength value will be categorized as plastic deformation damage.

Then, the failure damage criteria are determined because the element has a von mises stress value that is close to or equal to the ultimate strength value of the material, which causes a decrease in the stiffness value and has not yet broken. Meanwhile, the criteria for rupture damage are determined based on elements with a von mises stress value that exceeds the ultimate strength value and has failed.

In a collision scenario with an angle of 0 degrees, significant damage conditions and even the rupture of the navigation buoy body plate occurred. This information is shown in Table 6. and may be seen in full. The body plate of the navigation buoy experienced fractures at each of the three speeds of 0.61 meters, 0.96 meters, and 1.24 meters per second.

D. Validation

According to Minorsky [9], collisions by ships can be assumed to be inelastic collisions. In inelastic collisions, there is only conservation of momentum, so the velocity after the collision on the navigation buoy can be found by the following formula.

Suppose it is known how fast the navigation buoy moved after the impact. In that case, one may use the following formula to determine the navigation buoy's kinetic energy, as shown in Table 7. According to Table 7, a comparison of the outcomes of human calculations with those produced by software shows that the difference is still less than 5%, which means that the numerical simulation may be considered to be accurate

From the results presented in the previous section, it can be seen that ship collision incidents can cause significant damage to the buoy. The increase in the value of deformation and energy in each collision scenario is due to the influencing factors, namely the speed and angle of collision. The faster the speed of the ship hitting the buoy, the greater the damage received by the buoy. This is in accordance with Zhang's theory in his research which says the speed of the ship can affect the results of the collision simulation [10].

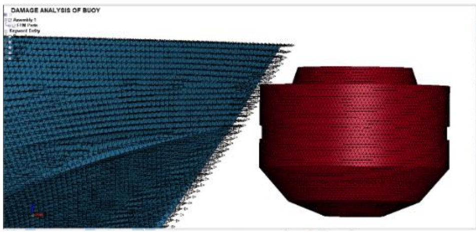
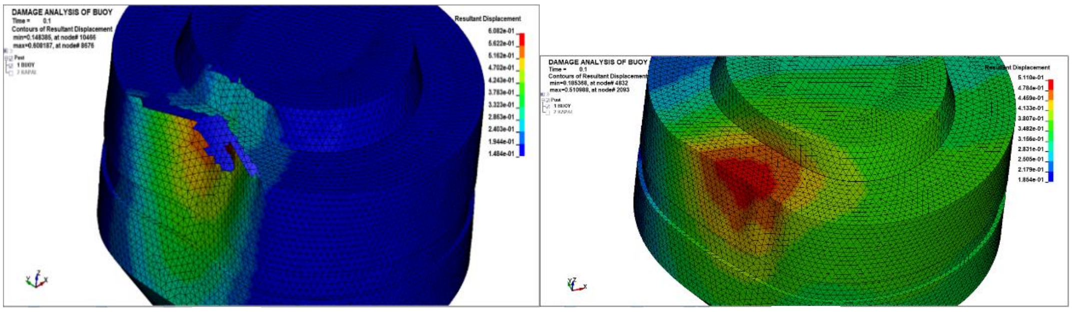


Figure 3. Initial Velocity Input on Boundary Layer



(a) (b)

Figure 4. Maximum Deformation at Speed 7 m/s with Position 0° (a) and Position 45° (b)

TABLE 5.
NAVIGATION BUOY DIMENSION

Speed (m/s)	Angle (°)	Plastic deformation (element)	Failure (element)	Rupture (element)
3	0	23	9	83
5	0	397	22	197
7	0	617	340	413
3	45	30	0	0
5	45	175	246	0
7	45	254	538	0

TABLE 6.
THE AMOUNT OF DAMAGE TO THE ELEMENT BODY BUOY

Ship speed (m/s)	calculation results (kJ)
3	8.36
5	26.36
7	63.27

TABLE 7.
THE AMOUNT OF DAMAGE TO THE ELEMENT BODY BUOY

Ship speed (m/s)	Analytic (kJ)	FEM (kJ)	Percentage Error
3	8.36	8.04	3.97 %
5	26.36	25.86	1.90 %
7	63.27	62.95	0.50 %

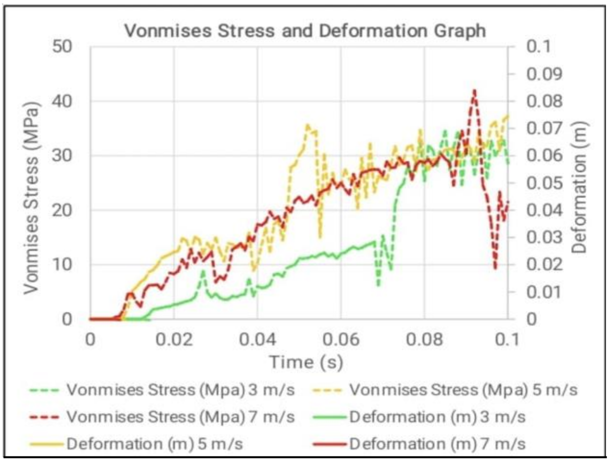


Figure 5. Graph of Vonmises Stress and Deformation Against Time at three different speeds for a collision angle of 0º.

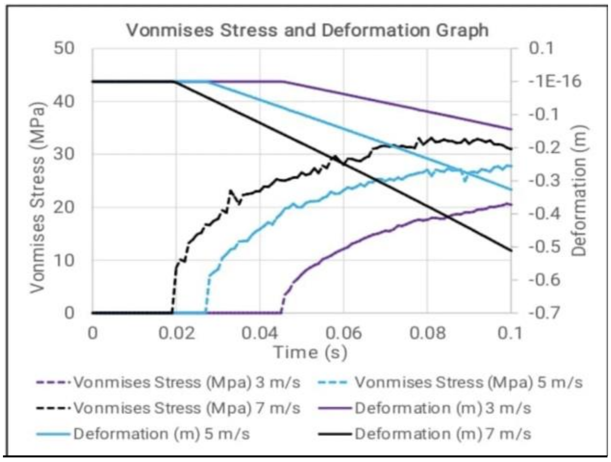


Figure 6. Graph of Vonmises Stress and Deformation Against Time at three different speeds for a collision angle of 45º

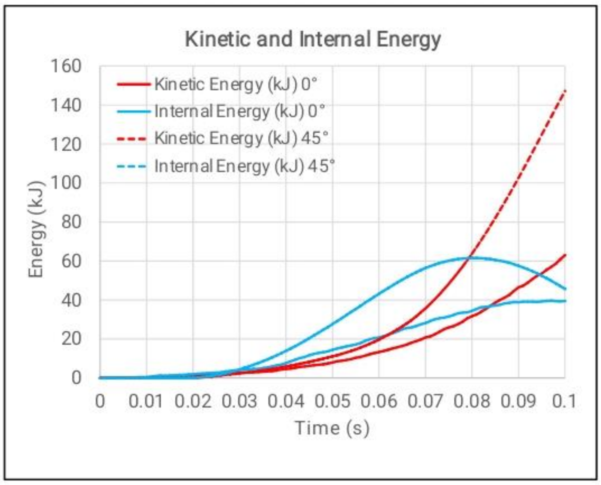


Figure 7. Energy graph at a speed of 7m/s with a collision angle of 0° and 45°

A collision at 45° gives a superior energy value than an angle of 0°. This arises because the cross-sectional area of the contact area at a collision of 45° is more significant than the cross-sectional area at a collision of 0°. However, as a smaller cross-sectional contact area will result in more considerable contact pressure, the 0° collision causes more severe damage than the 45° collision [11]. Furthermore, the simulation results in this study differ from previous studies in that plastic deformation occurred at a pressure of 16.53 MPa [12], which is due to differences in analytical treatment in the collision simulation, including differences in the thickness of the plates used on the buoy, namely 0.018 m and 0.013 m, as well as the material used, namely low-density polyethylene (LDPE) and medium density polyethylene (MDPE). Not only are the velocity and angle of the collision important in determining the outcome of the collision, but they are also crucial in collision analysis. The results of this study are consistent with those of Tabri et al. (Tabri et al., 2008). They found that the mass ratio is the essential factor in determining the proportion of total energy absorbed by ship structures in symmetric collisions.

IV.CONCLUSION

The numerical simulation of a collision study between a self-propelled oil barge ship and a navigational buoy has been successfully carried out with numerous variables, notably speed, collision angle, and material buoy. The following are the results that may be taken from the simulation of the navigation buoy damage study caused by the SPOB ship accident. After being hit by a ship traveling at a speed of 7 meters per second with a collision angle of 0° (collision head) of 0.6 meters, the buoy is deformed the most. This results in the most considerable possible deformation. The ship collided with the buoy at a speed of 7 meters per second and an angle of 0°, causing 413 elements and 1.24 meters of the buoy shell surface to rip. This resulted in significant damage to the buoy. The initial speed of the ship when it impacted the buoy and the angle of contact both have a role in determining or influencing the amount of damage caused to the buoy as a result of the ship's collision with the buoy.

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