TUGAS AKHIR – ME234804

ANALISIS TRAFFIC BASED MODEL UNTUK KECELAKAAN KAPAL FERRY DI JALUR MERAK-BAKAUHENI

KELANA CAHAYA MUHAMMAD

NRP 5019201059

Dosen Pembimbing

Dr. Eng. M. Badrus Zaman, S.T., M.T.

Dr. Eng. Trika Pitana, S.T., M.Sc.

Undergraduate Program

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2024

APPROVAL SHEET

TRAFFIC BASED MODEL ANALYSIS FOR FERRY SHIP ACCIDENT IN MERAK-BAKAUHENI ROUTE

BACHELOR THESIS

Submitted to fulfil one of the requirements

For obtaining a bachelor's degree in engineering at

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Department of Marine Engineering

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

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STATEMENT OF ORIGINALITY

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Hereby declare that the Final Project with the title of "TRAFFIC BASED MODEL ANALYSIS FOR FERRY SHIP ACCIDENT IN MERAK-BAKAUHENI ROUTE" is the result of my own work, is original, and is written by the following the rules of scientific writing.

If in the future there is a discrepancy with this statement, then I am willing to accept sanctions in accordance with the provisions that apply at Institut Teknologi Sepuluh Nopember.

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ABSTRAK

ANALISIS TRAFFIC BASED MODEL UNTUK KECELAKAAN KAPAL FERRY DI JALUR MERAK-BAKAUHENI

Nama Mahasiswa / NRP	**:**	**Kelana Cahaya Muhamamd / 5019201059**
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Abstrak

Merak-bakauheni merupakan salah satu jalur pelayaran tersibuk di Indonesia. Jalur ini sering dilalui oleh kapal, terutama kapal Ferry dan Ro-Ro sebagai akses penyeberangan dari Jawa ke Sumatera. Jalur ini berada pada Selat Sunda yang memiliki tingkat kepadatan kapal yang tinggi. Selain itu, jalur merak-bakauheni ini mempunyai probabilitas tubrukan kapal yang cukup tinggi ditinjau dari kepadatan kapal yang ada serta rekam historis yang menunjukkan cukup sering terjadi tubrukan kapal pada area tersebut. Oleh karena itu, akan dilakukan analisis probabilitas dan konsekuensi pada penelitian ini, dengan tujuan mengetahui estimasi tingkat frekuensi tubrukan kapal yang terjadi selama satu tahun, beserta dengan dampak yang terjadi pada tubrukan tersebut. Analisis probabilitas akan dilakukan dengan menggunakan Traffic Based Model, sedangkan analisis konsekuensi akan dilakukan dengan menggunakan software ANSY sebagai media untuk simulasi 3D kapal. Hasil menunjukkan probabilitas head-on, overtaking, dan crossing secara berturut-turut adalah 0,0652827, 0,0168664, dan 0,106833 untuk skenario 1, sedangkan untuk skenario 2 adalah 0,0656066, 0,020929, dan 0,10147 ships/year. Untuk hasil perhitungan energi terdisipasi akibat tubrukan kapal dengan menggunakan skenario crossing 2, didapatkan hasil sebesar 29,100549 MJ. Untuk analisis konsekuensi kapal menghasilkan hasil berupa total deformasi, directional deformasi, dan equivalent stress sebesar 37,481 x 10^{-3} m, 12,906 x 10^{-3} m, dan 1,1143 x 10^{9} Pa. Dengan semua hasil yang diperoleh, dapat disimpulkan menggunakan risk matrix bahwa jalur merak-bakauheni termasuk kedalam area high risk level. Rekomendasi untuk mitigasi, adalah dengan menerapkan regulasi oleh VTS, batas kecepatan kapal pada area tertentu dengan tidak lebih dari 12 knots, dan juga program kesehatan untuk awak kapal.

Kata kunci: ***analisis probabilitas, ANSYS, Selat Sunda, tubrukan kapal***

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ABSTRACT

TRAFFIC BASED MODEL ANALYSIS FOR FERRY SHIP ACCIDENT IN MERAK-BAKAUHENI ROUTE

Student Name / NRP	**:**	**Kelana Cahaya Muhammad / 5019201059**
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Abstract

Merak-Bakauheni is one of the busiest shipping lanes in Indonesia. This route is often traveled by ships, especially Ferry and Ro-Ro ships as access to crossings from Java to Sumatra. This route is located in the Sunda Strait which has a high level of ship density. In addition, the Merak-Bakauheni route has a fairly high probability of ship collision in terms of the existing ship density and historical records that show quite frequent ship collisions in the area. Therefore, a probability and consequence analysis will be conducted in this study, with the aim of knowing the estimated frequency level of ship collisions that occur during one year, along with the impacts that occur in the collision. The probability analysis will be carried out using the Traffic Based Model, while the consequence analysis will be carried out using ANSYS software as a medium for 3D simulation of ships. The results show the probability of head-on, overtaking, and crossing are 0.0652827, 0.0168664, and 0.106833 for scenario 1, while for scenario 2 are 0.065607, 0.020929, and 0.10147 ships/year, respectively. For the calculation of dissipated energy due to ship collision using crossing scenario 2, the result was 29.100549 MJ. The consequence analysis of the ship produced results in the form of total deformation, directional deformation, and equivalent stress of 37.481 x 10-3 m, 12.906 x 10-3 m, and 1.1143 x 109 Pa, respectively. With all the results obtained, it can be concluded using the risk matrix that the Merak-Bakauheni route is included in the high risk level area. Recommendations for mitigation are to implement a regulation according to Vessel Traffic Service (VTS), ship speed limits in certain areas with the limit of 12 knots, and also a health program for ship crews.

Keywords: ***probability analysis, ANSYS, Sunda Strait, Ship Collision***

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In the process of preparing this thesis, the author received a lot of help, guidance, and support from various parties. Therefore, the author would like to express her deepest gratitude to :

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The author hopes that this research can be useful in the Indonesian maritime world. The author realizes that this research is far from perfect. Therefore, any reasonable input and criticism is welcome with the aim of future research progress.

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CHAPTER 1

INTRODUCTION

1.1 Background

Sunda Strait is known as water area of Indonesia which located between the islands of Sumatra and Java. Specifically, Sunda Strait located in the southern part of Lampung Province and the western part of Banten Province. This strait become one of the most busy and important strait in Indonesia. This happened because this strait connects two main island in Indonesia and become a route for various type of vessel to take passengers from one island to another. The routes that usually passed by ferry ship is Merak-Bakauheni route. From an economic perspective, this strait is very strategic for shipping companies. There are many companies in there that deliver passenger, cargo, and goods. Seeing that this route is the most effective for transporting passengers from Java to Sumatra, it is also possible that the number of passengers will increase every year.

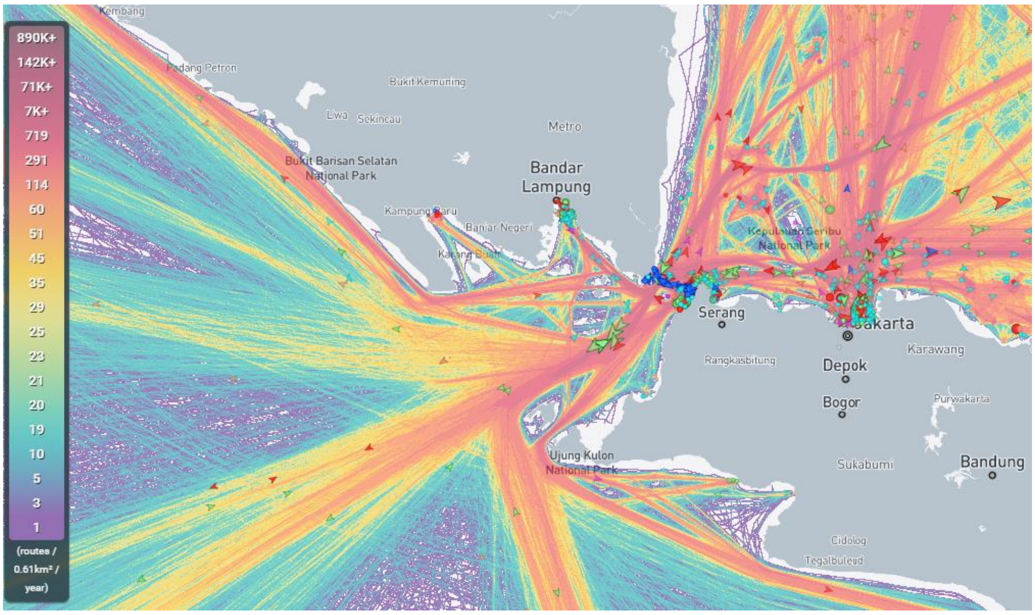

Figure 1. 1 Sunda Strait from MarineTraffic

The increase in the number of passengers indicates that the number of ships will also increase, especially for ferry and ro-ro ship. An increase number of ships in this strait certainly not unreasonable thing, because the economic status continues to improve so that ship companies, especially ferry and ro-ro, will continue to keep up with the number of passengers each year. Based on ASDP data, the number of passenger, two-wheeled vehicles, four-wheeled vehicles and large bus that using Ro-Ro ship services is increasing in the year of 2023. In 2023, passenger who used ferry ship increase 57%, two-wheeled vehicle that used ro-ro ship increase 73%, while four-wheeled vehicle and minibus increase sequentially 32% and 14%. This number of increases is also supported by data from Badan Pusat Statistik (BPS) Lampung that passenger departure from Bakauheni Lampung to Merak Banten is also increasing.

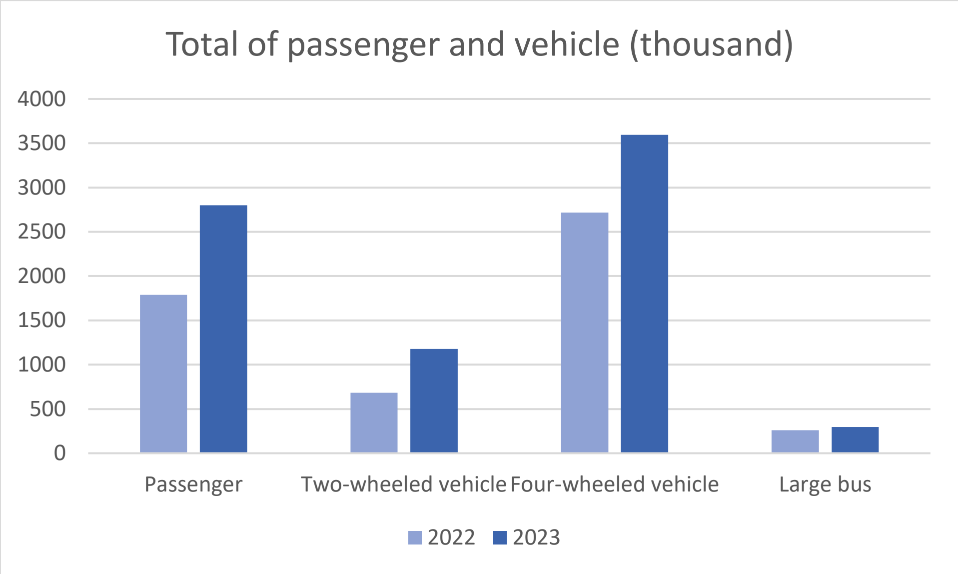

Figure 1. 2 Total of passenger and vehicle used Ro-Ro ship from Bakauheni to Merak

Source : ASDP Bakauheni

Table 1. 1 Total passenger monthly from Bakauheni to Merak

Source : BPS Lampung

Month	Total passenger		
	2022	2023	Percentage (%)
January	19.501	47.652	144,35
February	11.599	33.046	184,9
March	21.482	34.027	58,4
April	17.529	92.740	429,06
May	60.521	104.047	71,91
June	42.632	49.315	15,67
July	56.718	68.760	21,23
August	31.489	40.853	29,73
September	28.938	40.181	38,85
October	36.359	-	-
November	34.868	-	-
December	49.001	-	-

From the data above, it can be concluded that every year the number of passengers from Bakauheni to Merak tends to increase, as well as the ship. An increasingly dense ship traffic can certainly increase the possibility of accidents occuring. Congested routes, poor ship traffic monitoring, outdated regulations, and improper safety equipment can trigger ship accidents, especially collision. According to KNKT data, collision type ship accidents are one of the most frequent accidents in the Sunda Strait that occurred in the past 5-10 years. The collected data from KNKT can be seen in the table below.

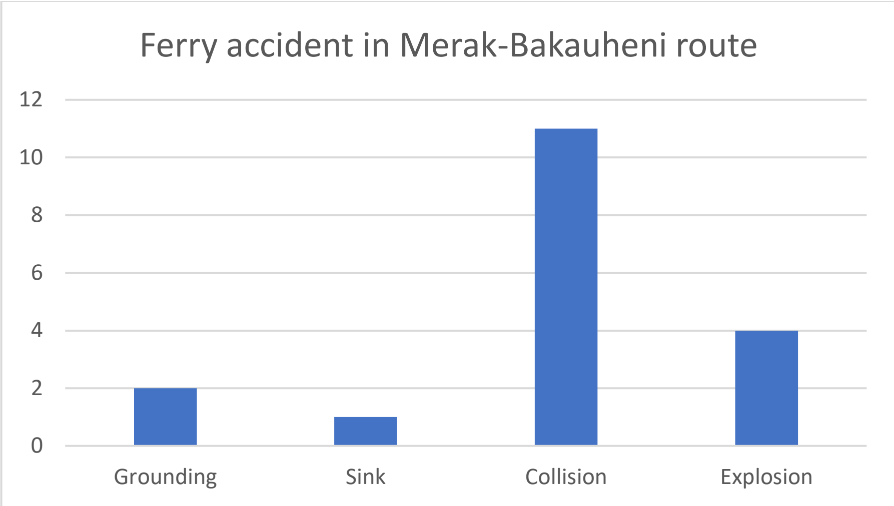

Figure 1. 3 Type of ferry ship accident in Sunda Strait

Source : KNKT

From the graph above, it can be concluded that the type of collision accident is the one that occurs most frequently on ferry ship in the Sunda Strait on the Merak-Bakauheni route. For that reason, this research aims to analyze specific types of accidents which is ferry collisions in the Sunda Strait. This research only focuses on ferry ship, for the reason that ferries are the dominant ships in the Sunda Strait area, and also with the aim of continuing previous research.

In previous research, it does not contain a proper method to determine the probability of ship collision. Consequently, previous research did not produce a collision probability data and scenario that corresponding to the dimension of ship and Sunda Strait. Hence, this research will complement previous research, namely by using the Traffic Based Model method. This method will produce probabilities from scenarios using ship data, technical standards, surrounding conditions, and also the level of traffic density on the route. As for the consequence of the collision, this research will use a software that able to simulate the collision and estimate of how much the damaged caused by that. Later this method will be included in a risk assessment.

1.2 Problem Statement

Regarding the background and problems that were encountered in this research, there are several problem statement point that will be analyzed, specifically:

1. What are the probability of ferry ship collision in Merak-Bakauheni route?
2. What are the consequences of damage from ferry ship collision in Merak-Bakauheni route?

3. What are the recommendation of safeguard to mitigates a future ferry ship collision in Merak-Bakauheni route?

1.3 Research Objectives

Based on mentioned problem statement, the research objectives for this paper are:

1. Get the probability of ferry ship collision in Merak-Bakauheni route
2. Get the consequences of damage from ferry ship collision in Merak-Bakuheni route
3. Get the recommendation of safeguard to mitigates a future ferry ship collision in Merak-Bakauheni route

1.4 Scope of Research

Because this research paper only focus on a specific area, therefore there is limitations that consists of:

1. The object of this research is passenger vessel, which is ferry/Ro-Ro ship
2. The area of analysis is Merak-Bakauheni route
3. Probability or frequence analysis calculated using Traffic Based Model
4. Consequence analysis simulated using ANSYS software

1.5 Research Benefit

The benefit that are resulting from this research paper are:

1. Can be use for additional safeguard to mitigates future ship accident, especially ship collision
2. Open up opportunities for related class or institution to improve maritime regulations.

CHAPTER 2

LITERATURE REVIEW

2.1 Related Studies

Risk assessment has been used many times on research paper that related to maritime safety. One of the example of risk assessment is Formal Safety Assessment (FSA). A study based on (Purba et al., 2020) were using FSA as an application to analyze risk from ship collision in Surabaya West Access Channel (APBS). By following IMO's guideline, the stage taken in their research are; First stage, Hazard Identification to identify the list of hazard based on available data. The first stage was carried out by using Event Tree Analysis method. Second stage, the Risk Analysis was carried out to determine variation of scenarios that affected by two main things, probability/frequence and consequences. In calculating the frequency, they used Traffic Based Model, while the consequences were calculated by ANSYS software in modelling the hull's structural damage that resulted from accident. Third stage, Risk Control Option (RCO) carried out in order to acquire the best possible solution for the most frequent accident. It is also being use to get several options for the purpose of preventing accident. Fourth stage, the Cost Benefit Assessment is being use to compare the benefit and cost from RCO by using Net Cost of Averting a Fatality (NCAF) and Gross Cost of Averting a Fatality (GCAF). Fifth stage, the Recommendation for Decision Making is the last stage in FSA that used to get some option available in order to mitigates accident. This research was very influential in the study that the author will conduct.

Hartoyo (2022) conducting a research about ferry ship accident in Sunda Strait by using FSA. This research was not focusing on collision, but comprises all accident types that occurred on ferry ship. This research use FSA as its basis of the structure. Based on the conclusion from this research, ship collision or ship bumping was the most type of ship accident that often occurred in Sunda Strait. However, this research only use basic calculation for its probability analysis and consequence analysis. It does not used a concrete method to determine the frequence and consequence of the accident. The probability analysis only using a single formula from KNKT data, as well as the consequence analysis.

Görçün & Burak, 2015, in their research were conducting a risk assessment for ship traffic in Istanbul Strait, located at Bosphorus. In hazard identification, the data of hazard that were obtained are to be listed to associated scenarios, prioritize with risk level, and describing the causes and effects of it (Görçün & Burak, 2015). In risk assessment, the author made an index of frequency and severity of an accident. With previous two index, the author made a risk index based on that. For risk analysis, different factors are selected which consists of vessel specification, accident location, time, type of accident and related causes. According to author, a total of 391 ship accidents happened in Istanbul Strait from 2001 until 2010. In this study however, the selected scenarios is only the the most high risk value, which is 40 accident that were determined for risk analysis. For RCO, is to be determined and selected based on risk analysis result. For cost benefit analysis, is to evaluates the cost and benefit of risk reduction measures (Görçün & Burak, 2015). Finally, the last stage which is recommendations for decision makers were made.

A research conducted by Zaman et al., were carried out using FSA as a methodology to analyze ship collision using Automatic Identification System (AIS) data. This study chose Malacca Strait as the research object, because this strait were considered and known to be one of the busiest ship lane and traffic in the world. For that matter, the strait become a high risk area for ship navigation (Zaman et al., 2015). AIS is being used in this study as the source of hazard identification data, while FSA is used as the risk evaluation steps method. The steps of FSA in this study consists of: Hazard Identification, Risk Assessment/analysis, Establishes Safety Measure/Risk Control Option, Cost Benefit Assessment and Decision Making recommendation. In conclusion of this study, the risk analysis stage consists of two main activities, which is probability modeling and consequences modeling. The probability were established by using AIS data.

In a research by Nurmawati (2015), were conducting a risk analysis of ship collision at Buoy 12 in Madura Strait. The research using FSA to properly compile risk assessment that occurred in certain area of the strait. While the method itself, in order to find the probability or frequence of ship collision in Madura Strait, the author using Traffic Based Model. It was essential in order to complete the probability analysis step that were part of risk analysis. However, for the consequence analysis, the author only using statistical data from KNKT.

Another research by Alfanda (2015), were conducting an estimated probability of ship collision in APBS by using a method called Minimum Distance To Collision (MDTC). This research focus on APBS which was located in Madura Strait as it becomes a route for many ship and eventually become more denser. Many thing such as platform, pipes, and also underground cable in APBS also contributes in the difficulty of overcome Madura Strait density. This research use MDTC, but also use Traffic Based Model (TBM) as a comparison method.

2.2 Sunda Strait

The shipping route in the Sunda Strait is an important and strategic route because it provides access for domestic ships to cross between islands and also for international ships to pass from the Indian Ocean to Java Sea. According to the Ministry of Transportation statement, the narrowest point in Sunda Strait only reached around 30 km. With the limited width of the strait, the Sunda Strait becomes very congested, especially with the determination of this route as Alur Laut Kepulauan Indonesia (ALKI) I.

Figure 2. 1 Sunda Strait as ALKI I

Source : Kementerian Perhubungan

2.3 Ferry/Ro-Ro ship

Ferries and Ro-Ro are ships that usually being used to make crossings between islands over relatively short distances. This type of vessel can accommodate passengers, goods and vehicles. However, ferries and Ro-Ro usually specifically intended for passengers and vehicles. This sea transportation mode is essential to meet transportation needs in archipelagic regions, such as Indonesia. Ferries and Ro-Ro are not only effective means of transportation in connecting the outer islands, but also open up new opportunities for the development of economic sectors such as tourism and trade (Mas Akbar Suhar Dianto & Hilman Saputra, 2024).

Figure 2. 2 Ro-Ro ship

Source : NPR, 2017

In fact, a Ro-Ro and ferries ship have the same functions and similarities. Ro-Ro is an abbreaviation of Roll On and Roll Off. Ro-Ro ships are ships that used to transport cargo that have wheels such as two-wheeled motorcycle, four-wheeled like cars, bus, and even mini truck (Muzdalifah et al., 2016). The only difference between ferries and Ro-Ro, is that Ro-Ro has much easier access for vehicles from the port to the ship, because of the horizontal doors that installed on the Ro-Ro ship. In ferries, usually the loading and unloading of vehicles by using a support tools from the port. The advantages of ferries is that they usually have facilities that are more comfortable for the passengers to board.

2.4 Type of ship accident

A ship accident is a bad incident that occurs on ship which causing harm to property, environment, and also human. Ship accident itself generally have several types that most common occur, namely collision, explosion/fire, grounding, sink, and others.

2.4.1 Collision

Collision are one of the ship accidents type that often occur on sea routes that have heavy traffic. Collision occurs when there are two ship that come into contact to each other. The accident can happen because many things, such as system malfunction, poor traffic management, and others. In Indonesia, there are many water area that have heavy traffic, one of them is in Sunda Strait. For that reason, this research will focus on analyze this type of accident that occurs on ferry ship in Sunda Strait.

Figure 2. 3 Ship collision

Source : Gonzales, 2011

2.4.2 Explosion or Fire

Ship explosion or fire on ship is a type of accident when some part or whole ship is burned as a result from an uncontrolled fire source. This type of accident is considered dangerous because it has a high probability that can causing loss of life.

Figure 2. 4 Fire on ship

Source : WSJ, 2011

2.4.3 Grounding

A ship grounding is when the bottom part of ship hit the bottom of water. However, in this incident, the ship still had the ability to float with limited and disturbed movement. This type of accident occurs happen on the shallow waters. Indonesia has many shallow water, so the probability of ship grounding in Indonesia should be considered.

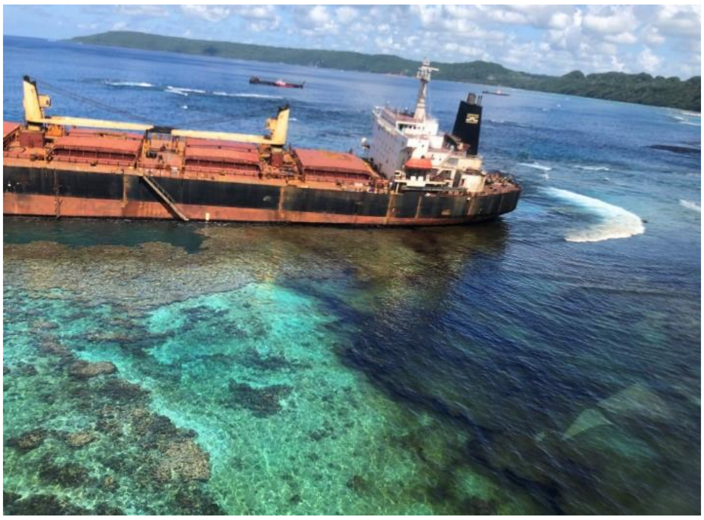

Figure 2. 5 Ship grounding

Source : Knowledgeofsea, 2019

2.4.4 Sink

Ship sinking is an accident when a ship loses its ability to float, resulting in the sinking of part or whole part of the ship. A common causes for this accident is a damage from the ship hull that causing water to enter the hull and disrupt the stability of the ship.

Figure 2. 6 Ship sinking

Source : Navytimes, 2017

2.5 Hazard Identification

To conduct a study with a risk assessment method, can start by identifying the hazards. In this step, we can know the existing and possible of hazard scenarios in the object of this research. The aim of this steps is to list all the existing hazards found in the scenarios and prioritized by using a risk level. In order to carry out hazard identification, it can be done with a standard techniques/method to identify the hazard that corresponding to the accident, and also by screening the hazard by using the available data. If all the possible hazard has been identified, then the hazard should be ranked based on priority. The ranking of hazard can be done by using available data information and support by judgement on each scenario.

There are several standard techniques or method that can be used to carry out hazard identification. The selection of method depends on the available data and should choose the most suitable one. The following are the hazard identification techniques described by IMO:

2.5.1 Fault Tree Analysis

In general, a Fault Tree Analysis is a technique to identify and analyze factors that contributes in the type of accident or unwanted event, which can also called as top event. In Fault Tree Analysis, in order to find out the unwanted event and causes, it can be done by using a top-down approach, where the unwanted events is at the top level and the causes at level below that. In application, Fault Tree Analysis requires logic gates. The “AND” gate is being used when there are two or more lower events need to occur to cause the next higher event. The “OR” gate is being used when there are any one of two or more lower event can cause next higher event.

2.5.2 Event Tree Analysis

Event tree analysis is a method that used to identify and analyze the effects from an accident or unwanted events. Basically, focus of event tree analysis is come from basic to top event, where the main focus is at the effects that possibly happen next if an accident or unwanted events occured. Event tree analysis diagram comprises probability of an accident connects to the safeguard action that necessary to prevent those accident.

2.5.3 Failure Mode and Effect Analysis

Failure Mode and Effect Analysis (FMEA) can be defined a technique which systematically identifying effects or consequences from a system failure or process, also reduce the chance of failure (Brigitta Devianti Cahyabuana, 2015). In FMEA, every component in the system must be identified at the necessary level of analysis. The effects from the component failure at specific level are analyze in order to decide their severity from the system. Therefore, a system failure mode may result from only a one failure.

2.5.4 Hazard and Operability Studies

Hazard and Operability Studies (HAZOP) is a technique or study that carry out to identify and analyze hazards in a complex system. It is expected that all hazards which can be identified are appropriately and in detail. In order to carry out HAZOP, the first step is to determine the node. The node is to separate process into some part. In conclusion, the aim of HAZOP is to minimize potential hazards (Siswantoro et al., 2022).

2.5.5 What If Analysis Technique

Next method mentioned by IMO is What If Analysis technqiue to identify hazard. This method carry out discussion of the system operation and function with consideration. All available data such as information and drawing, if needed, may be used. The progress starts with a question of "what if?". Then, the question followed with discussion of system failure, malfunction, maintenance, etc.

2.5.6 Risk Contribution Tree

Risk Contribution Tree (RCT) can be described as mechanism which displayed diagram of risk distribution among different accident categories or type. To start the tree, may be carried out using categories of accident, which if necessary can be further sub-divided into many categories.

2.5.7 Influence Diagram

Modeling the network of influences surrounding an event is the goal of Influence Diagram method. The influence are to be connected to failures of operational level with direct causes. This method requires expert judgement, which can determine the approach of decision analysis. This method is able to identify all influences which explain on the risk level profile, wheter it is high or low.

2.5.8 Bayesian Network

Based on IMO, in general Bayesian Network is a method that shows a causal dependencies from various variable in system by using a probabilistic graphical model. To see a general Bayesian Network graphical model, see the figure below.

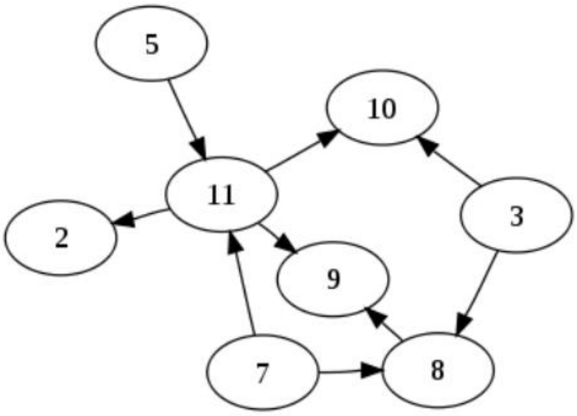

Figure 2. 7 Bayesian Network

2.5.9 Sensitivity and Uncertainty Analysis

Based on IMO, Sensitivity Analysis is a a process to know the model output of uncertainty that can be distributed to other sources in model input. On the other hand, Uncertainty Analysis is focusing to quantify the uncertainty from model output. Both sensitivity and uncertainty need to be run simultaneously.

2.6 Risk Assessment

The aim of this step is to obtain a more detailed results from event and causes accident that has been listed in hazard identification. In order to carry out risk analysis or risk assessment, can be achieved with a suitable techniques or method that can model the risk, in accordance to the related available data. There are several method that can be used in implementing a risk analysis. The type of method for this second step is similar to the method that has been described in Hazard Identification. All the information from the available data, report, and also type of hazard that has been identified from Hazard Identifiaction, will affect and influence the type of techniques or method that will be use in risk analysis. Then, the risk assessment will divided into two parts, which is probability and consequence analysis. Those two analysis will be carry out using different method or technique.

In describing the risk for each accident, different type of risk should be mentioned as appropriate consideration, such as risk to the human, environment, or property. The period of every accident could be described in a range of 10 to 20 years to make the calculation event more accurate in the matter of risk analysis. After the first step is done, all hazard from accident has been identified and prioritized by ranking the scenarios. Therefore, to faciliate the ranking and validation of ranking, it is recommended to define the probability and consequences on a logarithmic scale. IMO has provide several index that can be used to model the risk. Risk index could be used by adding probability/frequency and consequences indices.

The following below is severity index, that can be used to measures or scaled the maritime safety issues:

Table 2. 1 Severity Index according to IMO

Severity Index				
SI	SEVERITY	EFFECTS ON HUMAN SAFETY	EFFECTS ON SHIP	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

The following below is probability/frequency index, which provides a logarithmic model example:

Table 2. 2 Frequency Index according to IMO

Frequency Index			
FI	FREQUENCY	DEFINITION	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship's life	0.1
3	Remote	Likely to occur once per year in a fleet of 1,000 ships, i.e. likely to occur in the total life of several similar ships	10^{-3}
1	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5,000 ships	10^{-5}

The following below is risk index table that gives an example of risk matrix based on the previous frequency and severity index:

Table 2. 3 Risk Index according to IMO

Risk Index (RI)					
FI	FREQUENCY	SEVERITY (SI)			
		1	2	3	4
		Minor	Significant	Severe	Catastrophic
7	Frequent	**8**	**9**	**10**	**11**
6		**7**	**8**	**9**	**10**
5	Reasonably probable	**6**	**7**	**8**	**9**
4		**5**	**6**	**7**	**8**
3	Remote	**4**	**5**	**6**	**7**
2		**3**	**4**	**5**	**6**
1	Extremely remote	**2**	**3**	**4**	**5**

The following below is an example of risk matrix to model the risk analysis which provided by IMO:

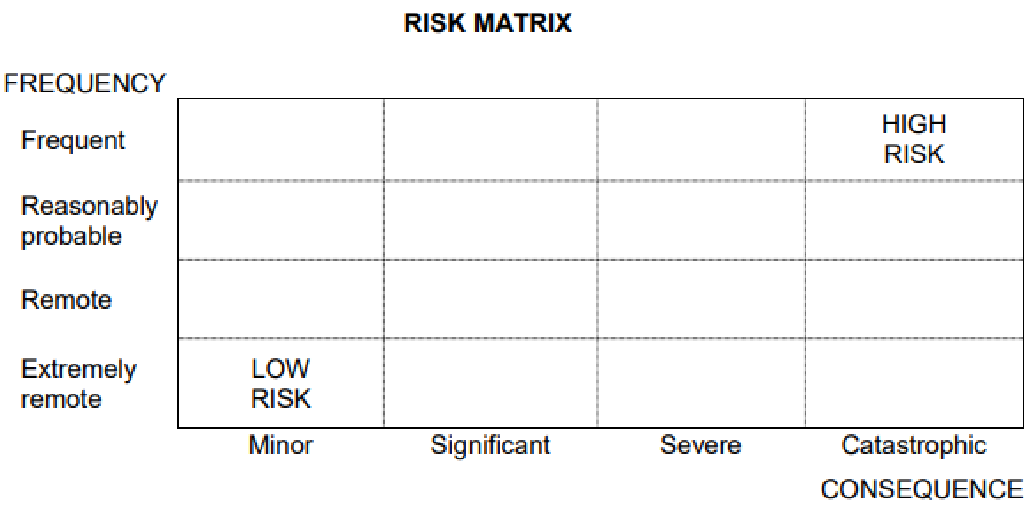

Figure 2. 8 Risk Matrix according to IMO

With the assisst of provided index table and risk matrix, we can model the risk analysis based on each level of hazard identified. In conclusion, the risk analysis step has two main output that need to be obtained, namely: list of high-risk areas that has been identified in order to be handled later, and risk model explanation.

In order to calculate the risk analysis, can use the equation that state risk is defined as combination of probability of occurrence (P) and possible consequence (C).

$$R = P \, x \, C \qquad (2.1)$$

2.7 Risk Mitigation and Control

Risk Mitigation and Control or safety measures has a purpose to consider in controlling the risk from hazard that has been identified with several option. According to IMO, Risk Control Measures (RCMs) is need to be identify first, then the results will be grouped to a limited number of RCO. Available information data of high-risk areas that has been identified from the Risk Analysis step will be used in RCO. Risk control measures can assist in reducing the occurrence likelihood of failures and/or mitigating their possible consequences (Zaman et al., 2015). Based on IMO, the RCO steps consists of the following stage:

1. Focus on risk areas that need control
2. Identify potential Risk Control Measures (RCMs)
3. Evaluating the effectiveness of the RCMs in reducing risk by re-evaluating Risk Analysis step
4. Grouping the RCMs intro practical regulatory options

A determination of areas needing control is important. The intention of focusing risk in certain areas is needed so that the effort is focused on the most highest-risk areas. In conducting this stage, several main aspects are expected to review:

1. **Risk levels**, consider the frequency of occurrence with severity of outcomes. Therefore, an accident with unacceptable risk level should become the primary focus.
2. **Probability**, identify areas of the risk model that have the highest probability of occurrence.
3. **Severity**, identify areas of the risk model that contribute to the highest severity outcome.
4. **Confidence**, identify areas where the risk model have considerable uncertainty, either in risk, severity or probability.

When the RCMs has been determined, it should be evaluated regarding the risk reduction effectiveness and also the consideration of any potential side effects. In general, RCMs should have the following aim, such as:

1. Reduce frequency of failures through better design, procedures, organizational polices, training, etc.
2. Mitigates the effect of failures, to prevent accident.
3. Reduce the circumtances which failure may occur.
4. Mitigates the consequences of accidents.

While the process is carried out, some new RCMs or RCO may initiate a new or additional hazards. In the end, the expected results or output of the RCO step should consists the following below:

1. List of RCOs with their effectiveness in reducing risk
2. List of interested entities affected by the identified RCOs
3. Table that stating the interdependencies between the identified RCOs
4. Results of analysis of side effects from RCOs

2.8 Traffic Based Model

In this research, Traffic Based Model is used as a method to determine probability analysis. Based on the book of Maritime Transportatio-Safety Management and Analysis, Traffic Based Models is an approach calculations of ship accidents frequency in accordance with technical standards, environmental conditions and ship traffic density on certain sea routes (Kristiansen, 2005). In this purpose, the accident that being used is collision. There are three scenarios that can be used ifirmann order to carry out this Traffic Based Models method, namely (a) head-on collision, (b) crossing collision, and (c) overtaking collision.

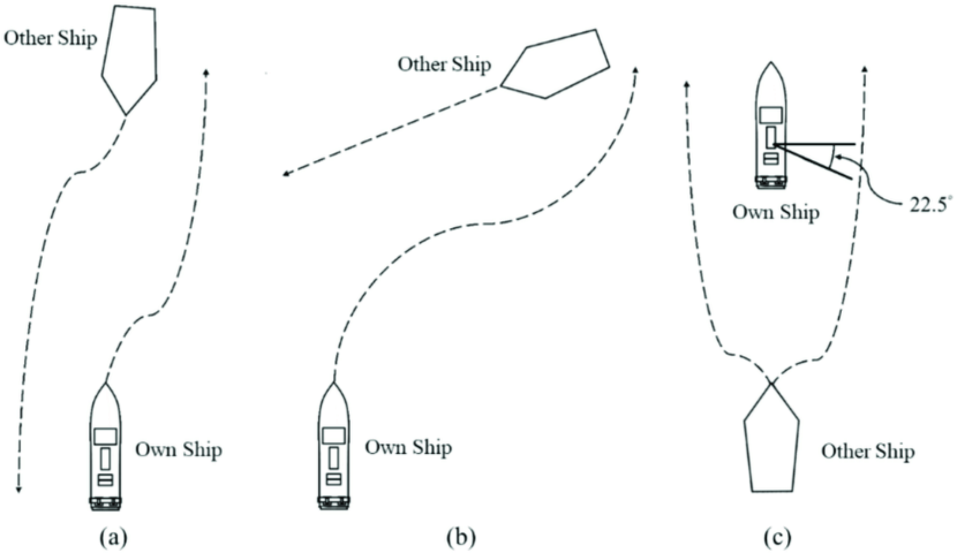

Figure 2. 9 Traffic Based Model scenarios

Source : (Ahn et al., 2017)

2.8.1 Head-On Collision

Head-on Collision is an accident where two ships are move and facing each other in opposite directions, with that there will be a collision between those two ship. The potential of head-on collision can be seen in the following figure.

Figure 2. 10 Head-on collision potential between two ship

Source : Mellhaoui, 2023

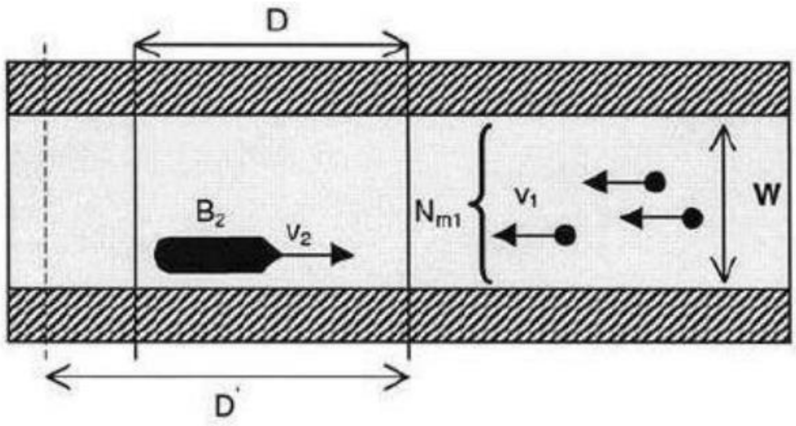

Figure 2. 11 Head-on collision model

Source : Maritime Transportation Safety Management and Analysis, Kristiansen

To determine the estimate ship traffic in a certain routes, can be calculated by using by the following formula :

$$\rho = \frac{N_m}{V_1 \ x \ W} \tag{2.4}$$

Where ;

ρ = level of ship traffic density (ship/nm2)

V_1 = average speed of ship 1 (Kn)

W = width of ship route (m)

To determine the probability of a collision that occurs on certain route, can be calculated using the formula as follow :

$$N_i = \frac{B_1 + B_2}{W} \ x \ \frac{(V_1 + V_2)}{V_1 \ x \ V_2} \ x \ D \ x \ N_m \tag{2.5}$$

Where;

N_i = estimated number of ships accident passing through restricted area

B_1 = breadth ship 1 (m)

B_2 = breadth ship 2 (m)

W = width of the water area route (m)

V_1 = average speed ship 1 (kn)

V_2 = average speed ship 2 (kn)

D = shipping distance relative to shipping lanes (m)

N_m = frequency of arrival of ships encountered (ship/unit of time)

To determine the causes factor of accident, can be calculated by using a formula as follow :

$$P_C = \frac{N_C}{N_T} \tag{2.6}$$

Where ;

P_C = causes factor of accident
N_C = total accident in the past 5 years
N_T = total of ship that passed certain route in the period of time

To determine the probability of accident, which in this case is head-on collision, can be calculated by using a formula as follow :

$$\boldsymbol{P_a = N_i \, x \, P_C} \qquad (2.7)$$

Where ;
P_a = probability of accident
N_i = estimated number of ships accident passing through restricted area
P_c = causes factor of accident

2.8.2 Overtaking Collision

An overtaking collision is a condition when two ships are moving in the same direction, but one of the ships has different speed. In the general scenario, one of the ship that has faster speed will try to overtake the slower ship, and that is when the probability of a collision occurs. To understand more clearly on overtaking collision, can be seen the following figure.

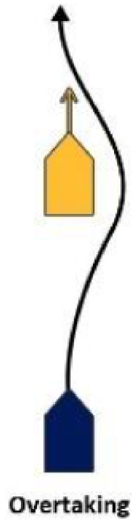

Figure 2. 12 Overtaking collision potential between two ships

Source : Mellhaoui, 2023

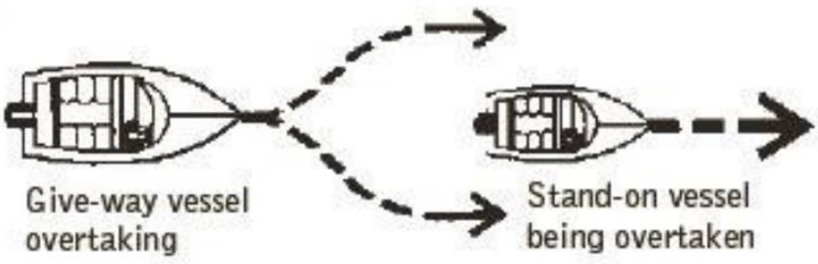

Figure 2. 13 Overtaking collision model

Source : Maritime Transportation Safety Management and Analysis, Kristiansen

To determine the estimate ship traffic in a certain routes, can be calculated by using by the following formula :

$$\boldsymbol{\rho = \frac{N_m}{V_1 \; x \; W}} \tag{2.11}$$

Where ;

ρ = level of ship traffic density (ship/nm2)

V_1 = average speed of ship 1 (Kn)

W = width of ship route (m)

To determine the probability of a collision that occurs on certain route, can be calculated using the formula as follow :

$$\boldsymbol{N_i = \frac{B_1 + B_2}{W} \; x \; \frac{(V_1 + V_2)}{V_1 \; x \; V_2} \; x \; D \; x \; N_m} \tag{2.12}$$

Where;

N_i = estimated number of ships accident passing through restricted area

B_1 = breadth ship 1 (m)

B_2 = breadth ship 2 (m)

W = width of the water area route (m)

V_1 = average speed ship 1 (kn)

V_2 = average speed ship 2 (kn)

D = shipping distance relative to shipping lanes (m)

N_m = frequency of arrival of ships encountered (ship/unit of time)

To determine the causes factor of accident, can be calculated by using a formula as follow :

$$\boldsymbol{P_C = \frac{N_C}{N_T}} \tag{2.13}$$

Where ;

P_C = causes factor of accident

N_C = total accident in the past 5 years

N_T = total of ship that passed certain route in the period of time

To determine the probability of accident, which in this case is overtaking collision, can be calculated by using a formula as follow:

$$\boldsymbol{P_a = N_i \; x \; P_C} \tag{2.14}$$

Where ;

P_a = probability of accident

N_i = estimated number of ships accident passing through restricted area

P_c = causes factor of accident

2.8.3 Crossing Collision

A crossing collision is an accident when two or more ships move towards a same crossing lane at the same time. At that time, the probability of collision may happen for those ships. To understand crossing collision more clearly, can be seen in the following figure.

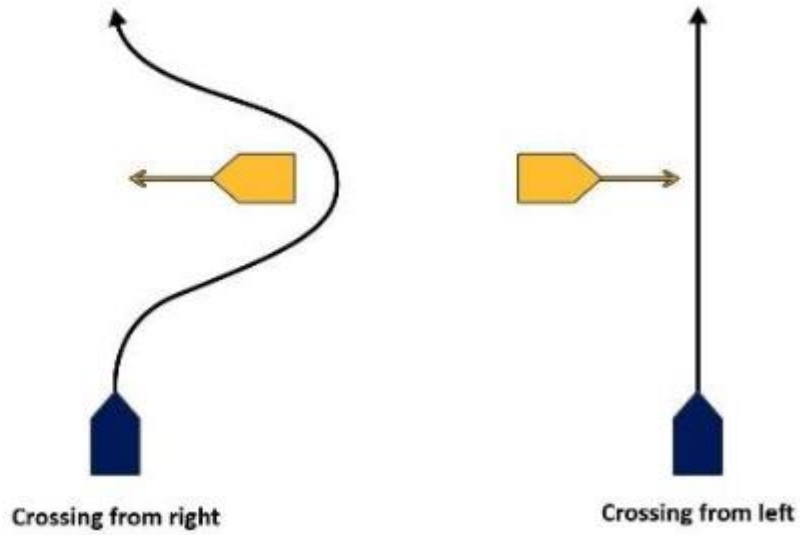

Figure 2. 14 Crossing collision potential between two or more ship

Source : Mellhaoui, 2023

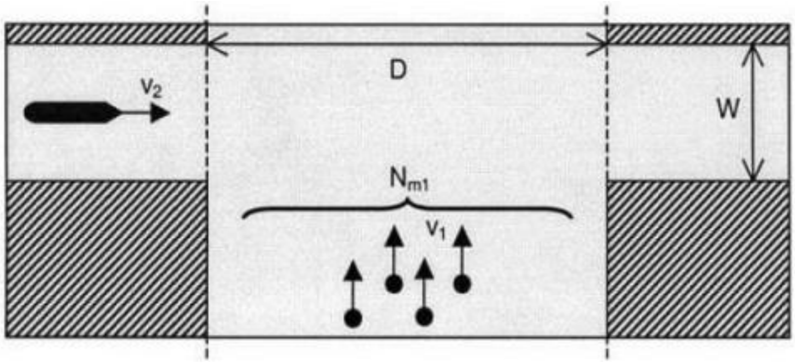

Figure 2. 15 Crossing collision model

Source : Maritime Transportation Safety Management and Analysis, Kristiansen

To determine the traffic density in a shipping lane, it can be calculated by using the formula as follow :

$$\boldsymbol{\rho = \frac{N_m}{V_1 \, x \, W}} \quad (2.8)$$

Where;

ρ = level of ship traffic density (ship/nm2)

V_1 = average speed of ship 1 (Kn)

W = width of ship route (m)

To determine the probability of a collision occurring on certain route, can be calculated by using the following formula :

$$\boldsymbol{P_i = \frac{N_m}{V_1\, x\, V_2} + [(B_1 + L_2)\, x\, V_1 + (B_2 + L_1)\, x\, V_2]} \qquad (2.9)$$

Where;

P_i = probability of collision

B_1 = breadth of ship 1 (m)

B_2 = breadth of ship 2 (m)

L_1 = length of ship 1 (m)

L_2 = length of ship 2 (m)

W = width of the water area route (m)

V_1 = average speed ship 1 (kn)

V_2 = average speed ship 2 (kn)

N_m = frequency of arrival of ships encountered (ship/unit of time)

To determine the probability of accident, in this case is crossing collision, can be calculated by using the following formula :

$$\boldsymbol{P_a = P_i\, x\, P_C} \qquad (2.10)$$

Where ;

P_a = probability of accident

P_i = estimated number of ships accident passing through restricted area

P_c = causes factor of accident

2.9 Consequence Analysis

In determining consequence analysis, an assessment can be carried out to know the causes and estimated value from the collision. In general, consequence analysis can be divided into three part, namely loss of life, damage to properties, and environmental damage (Iyuke et al., 2004). In this research, author intend to focus on damage to properties in order to determine for the consequence analysis. The resulted damage from ship collision can be modelled in a software named ANSYS. The software able to simulate a damaged properties of one object that getting hit from antoher object, in this case the object is ship.

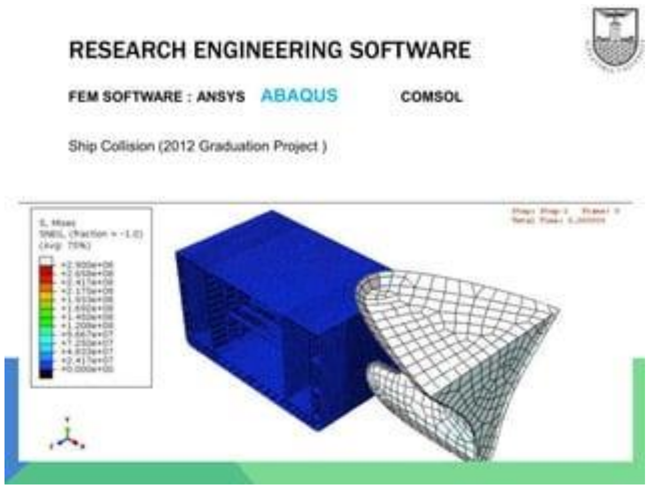

Figure 2. 16 Ship collision simulation on ANSYS software

Source : (Alexandria University, 2019)

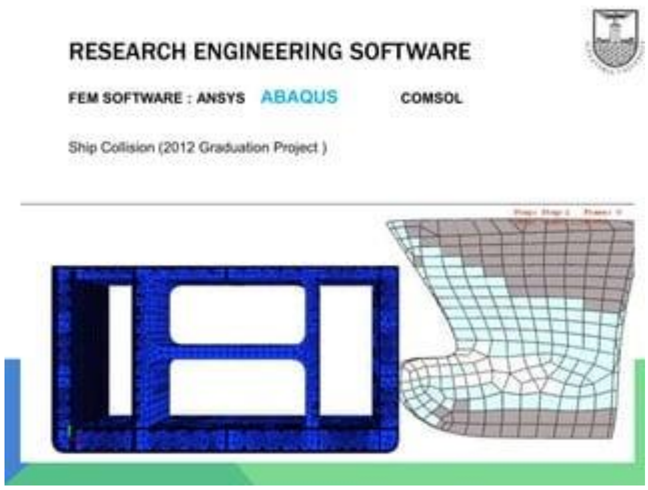

Figure 2. 17 Ship collide on ANSYS software

Source : (Alexandria University, 2019)

2.10 Transferred Energy Estimation

A ship damage from collision that will be assess in consequence analysis can be calculated with the data of transferred energy. Transferred energy is essential in determining the resulted value of how severe the collision is. To calculate the transferred energy, can be using by the following formula below :

$$\boldsymbol{E_{t2} = E_1 \ x \ (\frac{1}{1+\frac{m1}{m2}})} \quad (2.15)$$

$$\boldsymbol{E_1 = \frac{m1 \ x \ m2 \ (1+C_h)}{2(m1+m2(1+C_h))} \ x \ (V_1.sin\alpha)\hat{}2} \quad (2.16)$$

Where;

E_{t2} = Transferred energy

E_1 = Lost of kinetic energy

m1 = Striking ship mass

m2 = Struck ship mass

v1 = Striking ship speed

sin α = Angle of collision

Ch = Coefficient of mass

The needed data of transferred energy will be obtain from the ANSYS software. When the ship collision is being simulated, it will resulting of the following data such as loss of kinetic energy, etc.

CHAPTER 3

METHODOLOGY

3.1 Flowchart

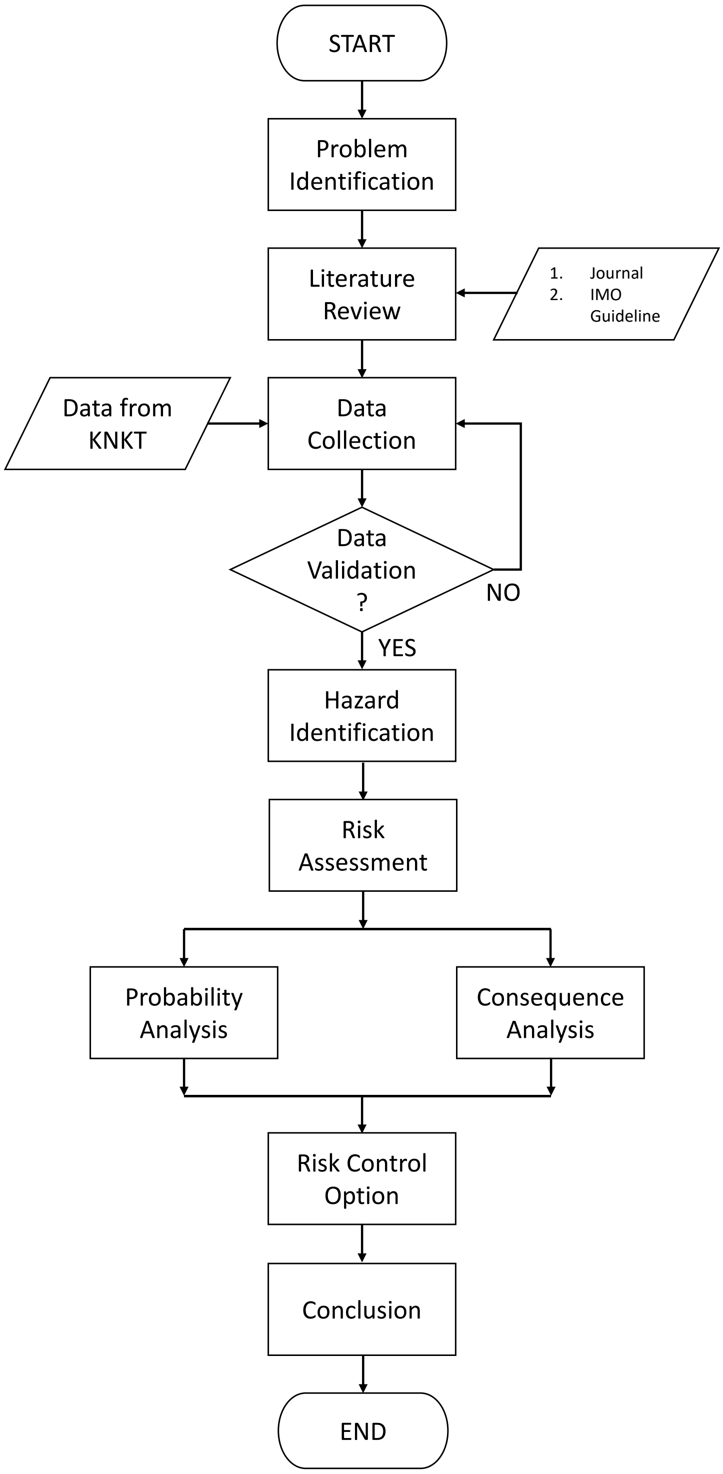

Figure 3. 1 Research flowchart

3.2 Problem Identification

Problem Identification is the first step to conduct this research. There are several way which can be done in order to carry out this step. Journal, research paper, books, news, and other sources can be used in order to determine related problems. When the problem has been determined, it should choose the proper method to conduct the research, in order to produce a good results.

3.3 Literature Review

The overall goal and reason in literature review step is to collect, discover, and study all information data related to the research object. This step can be accomplished by reading related topic research on previous research, journals, books, or even YouTube to deepen the knowledge of author before conducting research.

3.4 Data Collection

Data collection is the crucial part of the research. Because this data will later be used to analyze and calculate the needed certain value to obtain the purpose of research. In this research, data collection is being collected from :

1. KNKT
2. Badan Pusat Statistik (BPS) Lampung and Banten
3. KSOP/ASDP
4. AISITS
5. MarineTraffic

3.5 Data Validation

Data validation is a step to validate the data that has been taken before in data collection step. In this step, various data is being sorted, only the related data that will be later used in the analysis and calculation step.

3.6 Hazard Identification

In this step, all hazard are being identified from the ferry ship accident that have been collected. Hazard Identification can be conduct by using various method, such as FTA, ETA, and others. However, in this research the author will be using the manual hazard identification, because the data is not too much and can be identified manually, as it is more efficient and effective.

3.7 Risk Assessment

Risk assessment or risk analysis is conducted in order to know a more detailed cause from the hazard identification and also know the value of ship collision frequency in certain route area. In this research, risk analysis is being divided into two parts, that is probability analysis and consequence analysis.

1.1.1 Probability Analysis

In this research, the probability analysis is conducted with Traffic Based Models (TBM) method. By using this method, the research can obtain the value of ship collision probability/frequency in Sunda Strait. The Traffic Based Models method will be divided into three ways, that is head-on collision, crossing collision, and overtaking collision.

1.1.2 Consequence Analysis

For the consequence analysis, it will be carried out by using a software named ANSYS. The software is able to simulate a ship collision and provided the near estimated value of transferred energy that later will be used in the cost-benefit assessment process.

3.8 Risk Mitigation and Control

Risk Mitigation and Control is being conducted in order to know several option of risk that can be controlled. This step is based on the previous finding of probability analysis and consequence analysis. Those two analysis will results a risk matrix that later will be use in this step, which is Risk Mitigation and Control

3.9 Conclusion

All data results obtained from the previous step will be concluded in this step. The conclusion not only showing the main things or point about the research, but also giving the recommendation of safeguard to mitigates a future ferry ship collision, especially in Merak-Bakauheni route. Therefore, it can be concluded that this research aims to reduce the probability of existing ship collision accidents by using the results of founded data.

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CHAPTER 4

ANALYSIS AND DISCUSSION

4.1 Data Collection

In the working process of this final report, author will conduct a research of probability and consequence analysis on the ferry ship collision accident that occur in the Sunda Strait, especially in Merak-Bakauheni route. The required data for this research include the total number of ship accident in Merak-Bakauheni route, ferry ship principal dimension, potential ship collision scenario from AIS, and also area of the Sunda Strait. All data were obtained from various sources such as KNKT, ASDP, BPS and MarineTraffic and AISITS.

From all the available sources, the author uses two main data sources, namely :

1. Static data, which contains a list of the names passenger ships that most frequently pass through merak-bakauheni route from 2023 to 2024. And also from AISITS that limited to only two ship data that most frequently pass through merak-bakauheni route in June 2024.
2. Dynamic data, which includes data from MarineTraffic to create the ship collision scenarios.

Due to the limited data obtained, 1 scenario of collision will use the data from AISITS, while the other scenario will use directly from MarineTraffic in order to make the collision probability scenario.

The static data obtain from AISITS and ASDP to know the most frequent passenger ship in merak-bakauheni were combined with dynamic data from MarineTraffic to know the general information of the ship along with principal dimension.

Table 4. 1 List of ship data

No	Name	GRT	Year	Length (m)	Breadth (m)
1	TRIMAS KANAYA	6547	1990	117	18
2	KM.SANUS 28	1171	2011	58	12
3	PORT LINK III	15341	1986	151	25
4	KMP. RAPUTRA JAYA 888	5578	2018	103	18
5	SMS MULAWARMAN	5030	1988	83	15
6	KMP. SUKI 2	5008	1993	99	16
7	WIRA KENCANA	5648	2016	103	18
8	KMP MUFIDAH	5584	1973	102	18
9	TRIMAS FHADILA	6527	2017	106	20
10	KMP.TITIAN NUSANTARA	5532	1971	102	19
11	WINDU KARSA PRATAMA	5071	1985	90	17

Another static data obtained from KNKT is also used to determine and develop the ship accident data. The table below is the ship accident data with various type of accident that recorded by KNKT from month to month.

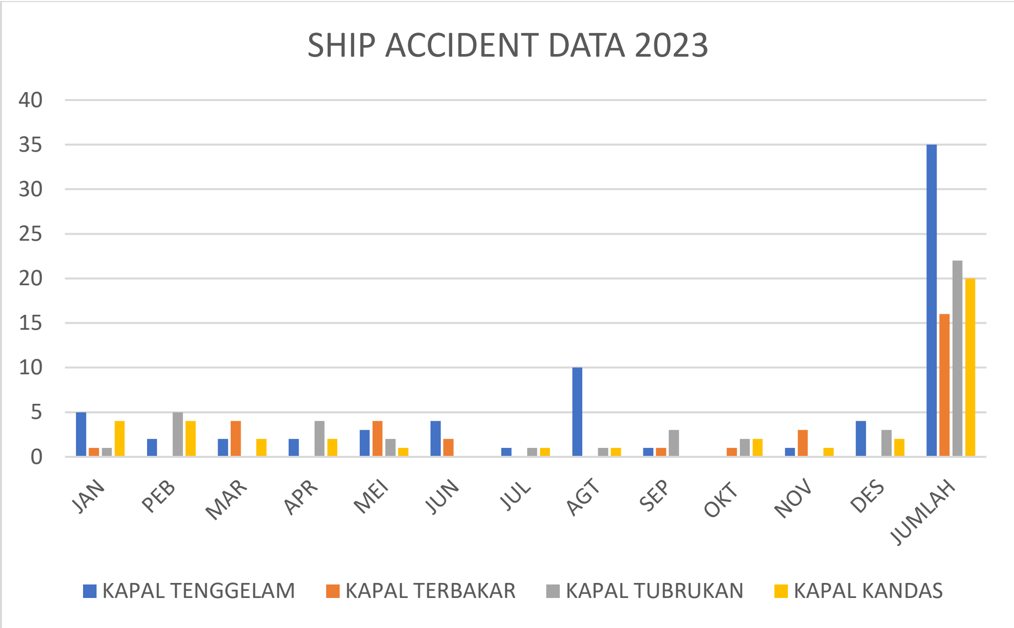

Figure 4. 1 Ship accident data in 2023

Source : KNKT database

Based on Direktorat Perhubungan Laut, the total of ship that crossed merak-bakauheni route or Sunda Strait is about 53.068 ship unit per year and 100-130 ship unit per day.

4.2 Hazard Identification

Risk or hazard identification aims to find out a list of all potential hazards at a certain location along with their scenarios. Every hazard has causes and effects that results from a different type of incident. For the hazard identification, this research will only focus on a particular event that being inspected in order to be more specific. This research study on a ship collision, so that the hazard identification will focus on collision which can be divided into three type of collision. The hazard identification of those three type collision will be describe in a table below.

Table 4. 2 Hazard Identification list

Number	Accident category	Sub type of accident	Scenario	Causes
1	Collision	Head-On	Head-On collision of ship occur when two ship met head to head in a traffic passing.	Technical failure in propeller, causing the propeller not operating as desired
				Currents, wind, and waves that dragged the ship towards other ship
2	Collision	Crossing	Crossing collision occur when two ship move toward the same lane at the	Human error by captain, could be due to the inexperience

Number	Accident category	Sub type of accident	Scenario	Causes
			same time. Usually this type of collision happen by error in determining ship's bow when maneuvering.	person in charge in this water area.
				Lost control of ship when the collision about to happen
3	Collision	Overtaking	Overtaking collision occur when a ship try to overtake other ship, but instead it hit other ship by accident.	Human error in determining speed and direction of ship when trying to overtake
				Failure of the navigation, causing miscommunication

4.3 Risk Assessment

In risk assessment, there will be two different analysis that will conducted in order to know the potential risk in the Merak-Bakauheni route, that is probability analysis and consequence analysis. The probability analysis will be carry out using Traffic Based Model that were introduced by Svein Kristiansen in 2005 through her book which called Maritime Transportation: Safety Management and Risk Analysis. On the other hand, the consequence analysis will be carry out by using a software called ANSYS explicit dynamic that can simulate a ship collision and generate a result of a damaged ship hull.

According to IMO guidelines of FSA, in the chapter 6 and appendix 4, it was stated that risk is a result of multiplication of probability and consequence. Hence, the equation become as the following below :

$$\text{Risk} = \text{Probability x Consequence} \qquad (5.1)$$

4.4 Probability Analysis

In carry out probability analysis, there are several formula that provided by the book of Maritime Transportation: Safety Management and Risk Analysis. The formula is part of the work on the Traffic Based Model method. The main and final variable to be searched for is frequency of total accident that could potentially happen. The equation is as follows :

$$\boldsymbol{N_a = N_m \, x \, P_a} \qquad (5.2)$$

Where,

N_a = number of accident (accident/year)

N_m = encountered ship frequence per unit time (ship/hour)

P_a = probability of accident

There are several data needed for the purpose of the calculation in Traffic Based Model method. Based on the total data of ferry ship encountered in Merak-Bakauheni from ASDP, it can be calculated that the value of Nm is 4,8 ship/hour. Furthermore, the data of surrounding area of Merak-Bakauheni route is also necessary, which is Sunda Strait area.

Sunda Strait has an average size compare to other strait in Indonesia, which is also seen in terms of ship density. The data of the surrounding strait is required in order to calculate the ship collision in the type of head on, crossing, and overtaking. Based on the journal from (Anwar, 2019), the relative sailing distance (D) of ferry ship in Sunda Strait is about 19,43 nautical miles or 36 kilometer. Moreover, the widest width of Sunda Strait is 52 nautical miles and the narrowest width (W) of sunda strait is around 2,2 nautical miles or 4,074 kilometer.

Besides relative sailing distance and width of sunda strait, there is also another parameter that will affect the probability calculation, which is causation factor (Pc). Causation factor will specifies probability of the ship navigator to fail to react. It is important because it acted as a reduction factor in the calculation of blind navigation. The causation factor selected in this calculation will use values that have been used in previous research in the same location, which is sunda strait. The uses value of Pc in the sunda strait is as follow (Firman Fahrirozan, 2018) :

1. Head-On = 0,00003
2. Overtaking = 0,000011
3. Crossing = 0,0000129

4.4.1 Head-On 1

Head-on is one of three type ship collision when there are two or more ship moving toward each other in the opposite direction. When the head-on collision happen, the part of ship that usually affected is the bow. Ships that have a possible chance to experience a head-on collision is ferry ship in Merak-Bakauheni route. In this research, the author will choose two ferry ship to be in a scenario of a head-on collision. The ships are Trimas Kanaya and KM. Sanus 28.

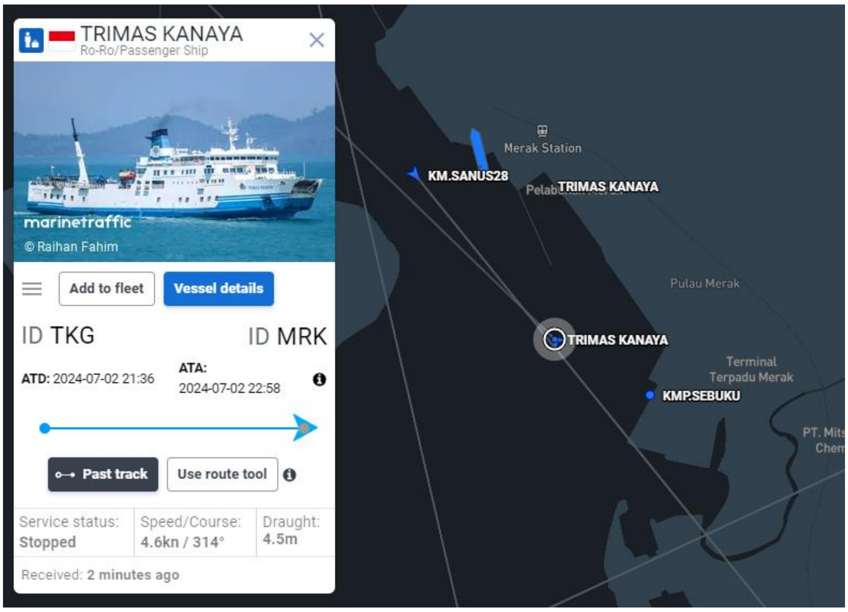

Figure 4. 2 First head-on scenario

Source : MarineTraffic

Table 4. 3 Data ship 1 for head-on 1

Source : VesselFinder

Ship 1			
Trimas Kanaya			
L	=	117	m
B	=	18	m
V	=	4,6	knot
Type	=	Ro-Ro	

Table 4. 4 Data ship 2 for head-on 2

Source : VesselFinder

Ship 2			
KM. Sanus 28			
L	=	58	m
B	=	12	m
V	=	7,2	knot
Type	=	Ro-Ro	

1. Collect and identify the data needed in analysis of head on collision scenario calculations :
   Ship length 1 (L1) = 117 m
   Ship breadth 1 (B1) = 18 m
   Ship length 2 (L2) = 58 m
   Ship breadth 2 (B2) = 12 m
   Ship speed 1 (V1) = 4,6 knot
   Ship speed 2 (V2) = 7,2 knot
   Relative sailing distance (D) = 19,43 nm = 36 km
   Width (W) = 2,2 nm = 4,074 km
2. Find the value of traffic density in a shipping lane (ρ) can be found using the equation:
   $$\rho = \frac{N_m}{V_1 \, x \, W}$$
   $$= 0{,}000256 \, ships/m2$$
3. Estimating the probability of a collision occurring on a lane can be calculated using the equation:
   $$N_i = \frac{B_1 + B_2}{W} \, x \, \frac{(V_1 + V_2)}{V_1 \, x \, V_2} x \, D \, x \, N_m$$
   $$= 453{,}3521$$
4. Find the probability of head on collision value can be calculated using the equation:

$$P_a = N_i \, x \, P_C$$
$$= 0{,}0136006 \text{ accident/passage}$$

5. Calculation of frequence in ship collision can be calculated using the equiaton:

$$N_a = N_m \, x \, P_a$$
= 0,0652827 ships/year

From the results of calculations using the traffic based model method, the frequency or probability of head on ship collision is obtained based on the scenarios that have been created, with the following results :

traffic density	=	0,000256
Expected number of collision per passage	=	453,3521
Probability	=	0,0136006
Estimate frequency of collision	=	0,0652827

4.4.2 Head-On 2

For the second scenario, the ship that are selected to have a possibility in head-on collision are Suki 2 and Port Link III. Both ships are passenger type.

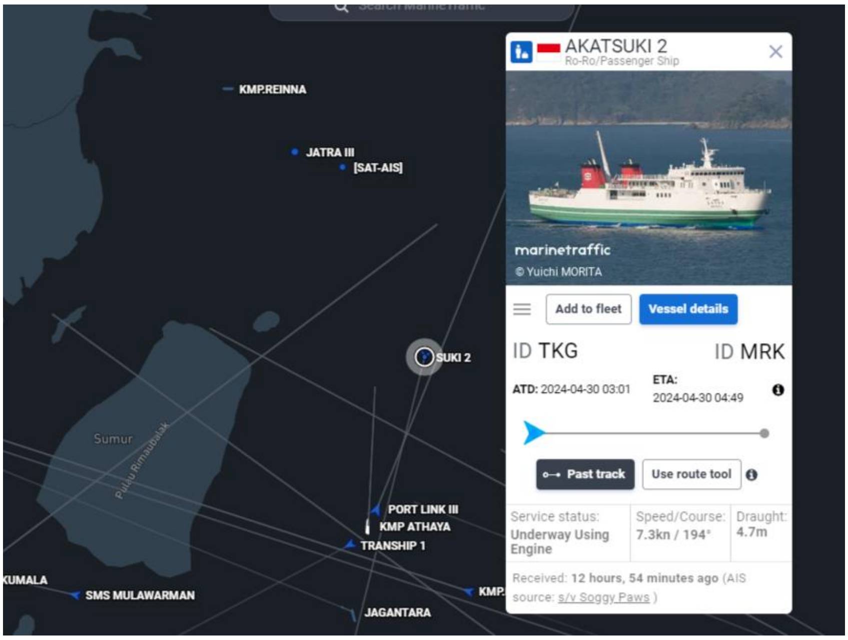

Figure 4. 3 Second head-on scenario

Source : MarineTraffic

Table 4. 5 Data ship 1 for head-on 2

Source : VesselFinder

Ship 1			
SUKI 2			
L	=	99	m
B	=	16	m

V	=	7,3	knot
Type	=	Ro-Ro	

Table 4. 6 Data ship 2 for head-on 2

Source : VesselFinder

Ship 2			
PORT LINK III			
L	=	151	m
B	=	25	m
V	=	8	knot
Type	=	Ro-Ro	

1. Collect and identify the data needed in analysis of head on collision scenario calculations :
   Ship length 1 (L1) = 99 m
   Ship breadth 1 (B1) = 16 m
   Ship length 2 (L2) = 151 m
   Ship breadth 2 (B2) = 25 m
   Ship speed 1 (V1) = 7,3 knot
   Ship speed 2 (V2) = 8 knot
   Relative sailing distance (D) = 19,43 nm = 36 km
   Width (W) = 2,2 nm = 4,074 km
2. Find the value of traffic density in a shipping lane (ρ) can be found using the equation:
   $$\rho = \frac{N_m}{V_1 \, x \, W}$$
   $$= 0{,}000161 \; ships/m2$$
3. Estimating the probability of a collision occurring on a lane can be calculated using the equation:
   $$N_i = \frac{B_1 + B_2}{W} \; x \; \frac{(V_1 + V_2)}{V_1 \, x \, V_2} x \; D \; x \; N_m$$
   $$= 455{,}6015$$
4. Find the probability of head on collision value can be calculated using the equation:
   $$P_a = N_i \; x \; P_C$$
   $$= 0{,}013668 \text{ accident/passage}$$
5. Calculation of frequence in ship collision can be calculated using the equiaton:
   $$N_a = N_m \; x \; P_a$$
   = 0,065607 ships/year

From the results of calculations using the traffic based model method, the frequency or probability of head on ship collision is obtained based on the scenarios that have been created, with the following results :

traffic density	=	0,000161
Expected number of collision per passage	=	455,601
Probability	=	0,013668
Estimate frequency of collision	=	0,065607

4.4.3 Overtaking 1

Overtaking collision occurred when two or more ship move in a same route and direction but with different velocity. The accident of collision happens when the ship with higher velocity try to overtake the other ship. For this scenario of overtaking collision in Merak-Bakauheni route, the author chose two ship, which is KMP Titian Nusantara and Windu Karsa Pratama. Both ships are passenger type.

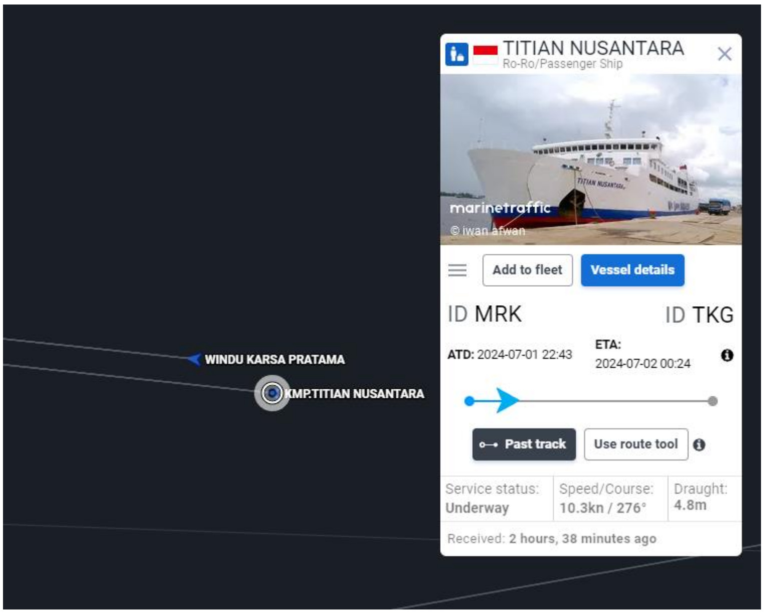

Figure 4. 4 First overtaking scenario

Source : MarineTraffic

Table 4. 7 Data ship 1 for overtaking 1

Source : VesselFinder

Ship 1			
KMP Titian Nusantara			
L	=	102	m
B	=	19	m
V	=	10,3	knot
Type	=	Ro-Ro	

Table 4. 8 Data ship 2 for overtaking 2

Source : VesselFinder

Ship 2			
Windu Karsa Pratama			
L	=	90	m
B	=	17	m
V	=	12,3	knot
Type	=	Ro-Ro	

1. Collect and identify the data needed in analysis of overtaking collision scenario calculations
   Ship length 1 (L1) = 102 m
   Ship breadth 1 (B1) = 19 m
   Ship length 2 (L2) = 90 m
   Ship breadth 2 (B2) = 17 m
   Ship speed 1 (V1) = 10,3 knot
   Ship speed 2 (V2) = 12,3 knot
   Relative sailing distance (D) = 19,43 nm = 36 km
   Width (W) = 2,2 nm = 4,074 km
2. Find the value of traffic density in a shipping lane (ρ) can be found using the equation:
   $$\rho = \frac{N_m}{V_1 \ x \ W}$$
   $$= 0{,}000114 \ ships/m2$$
3. Estimating the probability of a collision occurring on a lane can be calculated using the equation:
   $$N_i = \frac{B_1 + B_2}{W} \ x \ \frac{(V_1 + V_2)}{V_1 \ x \ V_2} \ x \ D \ x \ N_m$$
   $$= 272{,}3901$$
4. Find the probability of head on collision value can be calculated using the equation:
   $$P_a = N_i \ x \ P_C$$
   $$= 0{,}003514 \ \text{accident/passage}$$
5. Calculation of frequence in ship collision can be calculated using the equiaton:
   $$N_a = N_m \ x \ P_a$$
   = 0,016866 ships/year

From the results of calculations using the traffic based model method, the frequency or probability of overtaking ship collision is obtained based on the scenarios that have been created, with the following results :

traffic density	=	0,000114
Expected number of collision per passage	=	272,3901
Probability	=	0,003514
Estimate frequency of collision	=	0,016866

4.4.4 Overtaking 2

For the second scenario, the ship that are selected to have a possibility in overtaking collision are KMP Mufidah and Trimas Fhadila. Both ships are passenger type.

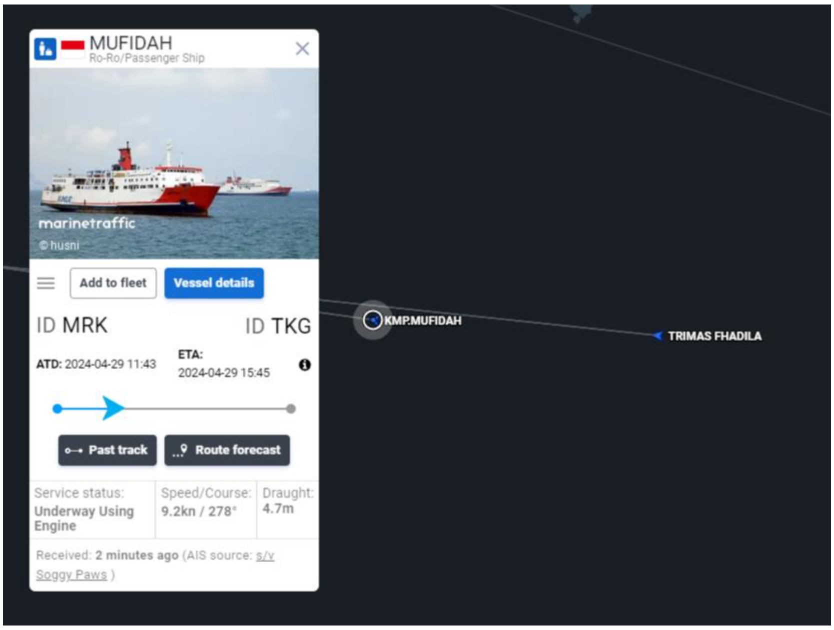

Figure 4. 5 Second overtaking scenario

Source : MarineTraffic

Table 4. 9 Data ship 1 for overtaking 2

Source : VesselFinder

Ship 1			
KMP MUFIDAH			
L	=	102	m
B	=	18	m
V	=	9,2	knot
Type	=	Ro-Ro	

Table 4. 10 Data ship 2 for overtaking 2

Source : VesselFinder

Ship 2			
TRIMAS FHADILA			
L	=	106	m
B	=	20	m
V	=	9,9	knot
Type	=	Ro-Ro	

1. Collect and identify the data needed in analysis of overtaking collision scenario calculations

Ship length 1	(L1)	= 102 m
Ship breadth 1	(B1)	= 18 m
Ship length 2	(L2)	= 106 m
Ship breadth 2	(B2)	= 20 m
Ship speed 1	(V1)	= 9,2 knot
Ship speed 2	(V2)	= 9,9 knot
Relative sailing distance	(D)	= 19,43 nm = 36 km
Width	(W)	= 2,2 nm = 4,074 km

2. Find the value of traffic density in a shipping lane (ρ) can be found using the equation:

   $$\rho = \frac{N_m}{V_1 \ x \ W}$$

   $$= 0{,}000128 \ ships/m2$$

3. Estimating the probability of a collision occurring on a lane can be calculated using the equation:

   $$N_i = \frac{B_1 + B_2}{W} \ x \ \frac{(V_1 + V_2)}{V_1 \ x \ V_2} x \ D \ x \ N_m$$

   $$= 338$$

4. Find the probability of head on collision value can be calculated using the equation:

   $$P_a = N_i \ x \ P_C$$

   $$= 0{,}00436 \text{ accident/passage}$$

5. Calculation of frequence in ship collision can be calculated using the equiaton:

   $$N_a = N_m \ x \ P_a$$

   = 0,020929 ships/year

From the results of calculations using the traffic based model method, the frequency or probability of overtaking ship collision is obtained based on the scenarios that have been created, with the following results :

traffic density	=	0,000128
Expected number of collision per passage	=	338
Probability	=	0,00436
Estimate frequency of collision	=	0,020929

4.4.5 Crossing 1

Crossing collision occurred when there are two ship that move to a same ship lane that crossed each other. For this scenario of crossing ship collision, the author will chose two ships, that is Raputra Jaya 2888 and Sms Mulawarman. Both ships are passengers type of vessel.

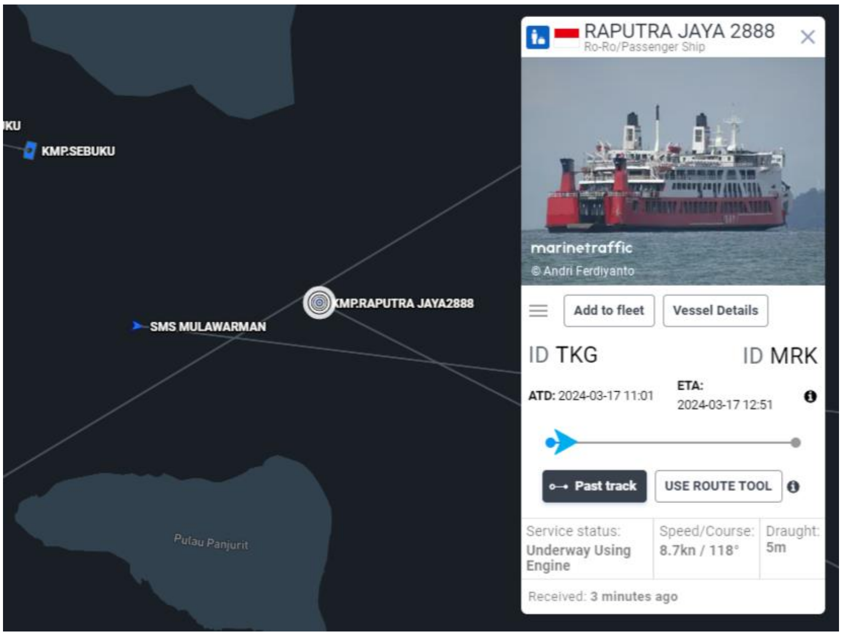

Figure 4. 6 First crossing scenario

Source : AISITS

Table 4. 11 Data ship 1 for crossing 1

Source : VesselFinder

Ship 1			
Raputra Jaya 2888			
L	=	103	m
B	=	18	m
V	=	8,7	knot
Type	=	Ro-Ro	

Table 4. 12 Data ship 2 for crossing 2

Source : VesselFinder

Ship 2			
Sms Mulawarman			
L	=	83	m
B	=	15	m
V	=	9,7	knot
Type	=	Ro-Ro	

1. Collect and identify the data needed in analysis of crossing collision scenario calculations

   Ship length 1 (L1) = 103 m
   Ship breadth 1 (B1) = 18 m
   Ship length 2 (L2) = 83 m
   Ship breadth 2 (B2) = 15 m

Ship speed 1	(V1)	= 8,7 knot
Ship speed 2	(V2)	= 9,7 knot
Relative sailing distance	(D)	= 19,43 nm = 36 km
Width	(W)	= 2,2 nm = 4,074 km

2. Find the value of traffic density in a shipping lane (ρ) can be found using the equation:

$$\rho = \frac{N_m}{V_1 \; x \; W}$$

$$= 0{,}000135 \; ships/m2$$

3. Estimating the probability of a collision occurring on a lane can be calculated using the equation:

$$P_i = \frac{N_m}{V_1 \; x \; V_2} + [(B_1 + L_2) \; x \; V_1 + (B_2 + L_1) \; x \; V_2]$$

$$= 2023{,}357$$

4. Find the probability of head on collision value can be calculated using the equation:

$$P_a = P_i \; x \; P_C$$

$$= 0{,}022257 \text{ accident/passage}$$

5. Calculation of frequence in ship collision can be calculated using the equiaton:

$$N_a = N_m \; x \; P_a$$

= 0,106833 ships/year

From the results of calculations using the traffic based model method, the frequency or probability of crossing ship collision is obtained based on the scenarios that have been created, with the following results :

traffic density	=	0,000135
Expected number of collision per passage	=	2023,357
Probability	=	0,022257
Estimate frequency of collision	=	0,106833

4.4.6 Crossing 2

For the second scenario, the ship that are selected to have a possibility in crossing collision are Suki 2 and Wira Kencana. Both ships are passenger type.

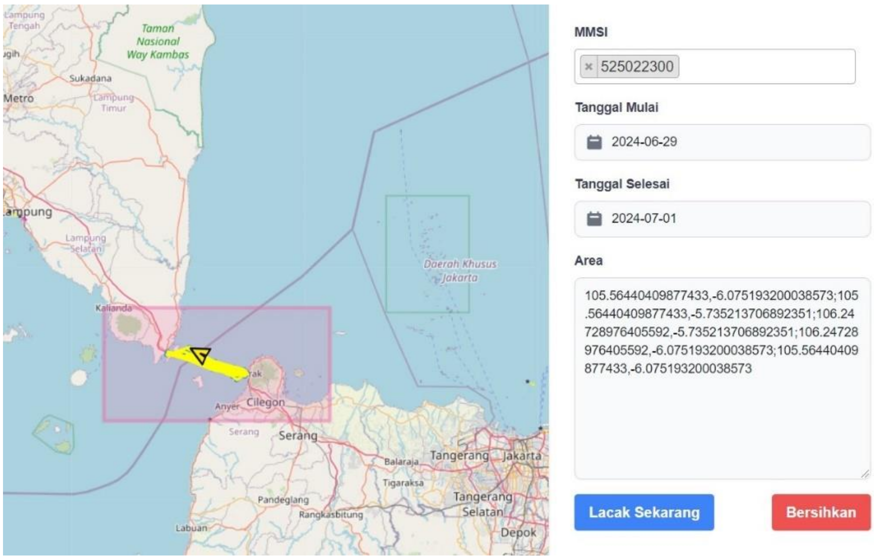

Figure 4. 7 Second crossing scenario

Source : MarineTraffic

Table 4. 13 Data ship 1 for crossing 2

Source : VesselFinder

Ship 1			
Suki 2			
L	=	99	m
B	=	16	m
V	=	7,3	knot
Type	=	Ro-Ro	

Table 4. 14 Data ship 2 for crossing 2

Source : VesselFinder

Ship 2			
Wira Kencana			
L	=	103	m
B	=	18	m
V	=	9	knot
Type	=	Ro-Ro	

1. Collect and identify the data needed in analysis of crossing collision scenario calculations

   Ship length 1 (L1) = 99 m
   Ship breadth 1 (B1) = 16 m
   Ship length 2 (L2) = 103 m
   Ship breadth 2 (B2) = 18 m
   Ship speed 1 (V1) = 7,3 knot

Ship speed 2 (V2) = 9 knot
Relative sailing distance (D) = 19,43 nm = 36 km
Width (W) = 2,2 nm = 4,074 km

2. Find the value of traffic density in a shipping lane (ρ) can be found using the equation:

$$\rho = \frac{N_m}{V_1\ x\ W}$$
$$= 0{,}000161\ ships/m2$$

3. Estimating the probability of a collision occurring on a lane can be calculated using the equation:

$$P_i = \frac{N_m}{V_1\ x\ V_2} + [(B_1 + L_2)\ x\ V_1 + (B_2 + L_1)\ x\ V_2]$$
$$= 1921{,}773$$

4. Find the probability of head on collision value can be calculated using the equation:

$$P_a = P_i\ x\ P_C$$
$$= 0{,}02114\ \text{accident/passage}$$

5. Calculation of frequence in ship collision can be calculated using the equiaton:

$$N_a = N_m\ x\ P_a$$

= 0,10147 ships/year

From the results of calculations using the traffic based model method, the frequency or probability of crossing ship collision is obtained based on the scenarios that have been created, with the following results :

traffic density	=	0,000161
Expected number of collision per passage	=	1921,773
Probability	=	0,02114
Estimate frequency of collision	=	0,10147

4.5 Total Frequence of Ship Collision

Table 4. 15 Scenario 1 of probability result

Scenario	Pa	Na
Head-on	0,0136006	0,0652827
Overtaking	0,003514	0,0168664
Crossing	0,022257	0,106833

Table 4. 16 Scenario 2 of probability result

Scenario	Pa	Na
Head-on	0,013668	0,0656066
Overtaking	0,00436	0,020929
Crossing	0,02114	0,10147

1. Total Na (Scenario 1) = Na head on 1 + Na overtaking 1 + Na crossing 1

   = 0,0652827 + 0,0168664 + 0,106833

   = 0,18898234 ships/year

2. Total Na (Scenario 2) = Na head on 2 + Na overtaking 2 + Na crossing 2

   = 0,0656066 + 0,020929 + 0,10147

   = 0,18800519 ships/year

Total = 0,37698754 ships/year

From the two scenario of ship collision that have been made, a results obtained of probability are 0, 18898234 for scenario 1 and 0,18800519 for scenario 2. Approximately, the total of frequence ship collision in a year is 0,4 ships/year.

4.6 Dissipated energy calculation

Dissipated energy is the energy that lost during the ship collision, primarily converted into deformation, heat, sound, and other forms of energy. In determining the dissipated energy, author will use reference from theory of external dynamic in *The Mechanics of Ship Collisions* published by Shengming Zhang in 1999. The purpose of external dynamic is to know the lost of kinetic energy that released resulting a deformation.

The scenario that will be used in the calculation of dissipated energy is the scenario of crossing 2, which is the collision between Suki 2 and Wira Kencana. Suki 2 will be the striking ship (a) and Wira Kencana will be the struck ship (b). Therefore, the mathematical calculation for consequence analysis of dissipated energy is as follow :

1. Known data
   Max = mb1 = 0,07
   May = mb2 = 1,3
   ja = jb = 0,21
   Ra = ¼ x Lpp a = 24,75 meter
   Rb = ¼ x Lpp b = 25,75 meter
   α = 90
   β = 0
   Sin α = 1
   Cos β = 1
   Vax = 7,3 knot = 3,75544 m/s
   Vay = 3 knot = 1,54333 m/s
   Vbx = 9 knot = 4,63 m/s
   Vby = 4,5 knot = 2,315 m/s
   Ma = 1064 ton
   Mb = 7000 ton

2. Relative of motion striking ship and struck ship

$D\alpha\xi = \frac{1}{1+max} . \sin^2 \alpha + \frac{1}{1+may} . \cos^2 \alpha + \frac{1}{1+ja} . \frac{[yc.sin\alpha-(xc-xa).cos\alpha]^2}{Ra^2}$

$D\alpha\xi = 19{,}37$

$D\alpha\eta = \frac{1}{1+max} . \sin \alpha .\cos \alpha + \frac{1}{1+may} . \sin \alpha . \cos \alpha + \frac{1}{1+ja} . \frac{[yc.\sin \alpha-(xc-xa)\cos \alpha] .[yc.\cos \alpha+(xc-xa)\sin \alpha]}{Ra^2}$

$D\alpha\eta = 13{,}049012$

$Db\xi = \frac{1}{1+mb1} . \sin^2 (\beta -\alpha) + \frac{1}{1+mb2} . \cos^2 (\beta -\alpha) + \frac{1}{1+jb} . \frac{[(yc-yb)\sin \alpha-(xc-xb).\cos \alpha]^2}{Rb^2}$

$Db\xi = 3{,}5524866$

$Db\eta = \frac{1}{1+mb1} . \sin(\beta -\alpha) . \cos(\beta -\alpha) + \frac{1}{1+mb2} . \sin(\beta -\alpha). \cos(\beta -\alpha) + \frac{1}{1+jb} . \frac{[(yc-yb)\sin \alpha-(xc-xa) \cos \alpha].[(yc-yb)\cos \alpha+(xc-xb)\sin \alpha]}{Rb}$

$Db\eta = 45{,}661262$

3. Constant Dξ and Dη determined by the following below

$D\xi = \frac{D\alpha\xi}{Ma} + \frac{Db\xi}{Mb}$

$D\xi = 0{,}0187124 = 18{,}7124 \times 10^{-3}$

$D\eta = \frac{D\alpha\eta}{Ma} + \frac{Db\eta}{Mb}$

$D\eta = 0{,}0187871 = 18{,}7871 \times 10^{-3}$

4. Relative velocities after collision

$\xi(0) = \xi a(0) - \xi b(0) = Vax. sin\alpha + Vay. cosa + Vb1 \sin(\beta - \alpha) - Vb2\cos (\beta - \alpha)$

$\xi(0) = 7{,}61377$

5. Dissipated energy

$E\xi = 0{,}5 \times \frac{1}{D\xi} \times D\eta \times \xi(0)^2$

$E\xi = 29{,}100549$ MJ

According to *The Mechanics of Ship Collision* (Zhang, 1999), the estimate dissipated energy are categorized as follow :

- Insignificant damage = < 10 MJ
- Minor damage = < 20 MJ
- Moderate damage = 20 MJ – 100 MJ
- Heavy/major damage = 100 MJ – 200 MJ
- Critical/catastrophic damage = > 200 MJ

Because of that, it can be concluded that the dissipated energy result is moderate damage with the value of 29,100549 MJ.

4.7 Consequence Analysis

Consequence analysis is part of the risk assessment along with probability analysis. In this research, the author will use ANSYS application as the software to simulate the impact causes by the collision. This method also known as finite element method (FEM). The ANSYS that will be used by the author is Explicit Dynamic that able to generate a result of impact value in a collision such as deformation in a ship hull. Scenario of crossing 2 will be use in the simulation. In this simulation, the author will review the ship impact on the following below :

1. Total deformation
2. Directional deformation
3. Equivalent stress

Before conducting the simulation, there are several initial assumption data needed to run the simulation in 3D model of ANSYS Explicit Dynamic, the following data are :

1. Velocity = 3,75544 m/s
2. Fluid density = 1,025 kg/m3
3. Hydrostatic acceleration = 9,81 m/s2
4. Material = Structural Steel
5. Angle = 90 degree

The velocity will be use from the known data. As for the fluid density and hydrostatic acceleration will use the general normal condition. The material chosen is Structural Steel as for the ship hull usually use a normal strength or super strength steel.

The 3D ship model was made in different application software, namely on SolidWorks. Once the 3D ship model is ready, it will be imported into ANSYS in .GIS or .SLDPRT file format. The following is the step of ANSYS explicit dynamic simulation :

1. By using ANSYS Workbench, choose the option with the system analysis with the type of Explicit Dynamic. Those type is used to simulate structural analysis. The following picture is the working window in ANSYS Workbench.

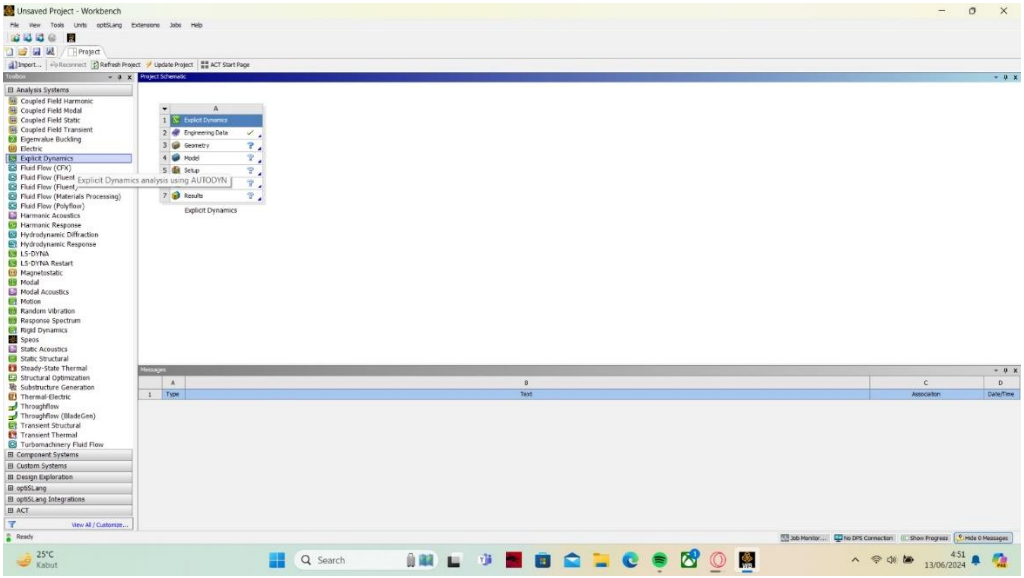

Figure 4. 8 ANSYS Workbench Explicit Dynamic window

2. Material selection, the type of material that will be used in this analysis is selected by using data engineering from ANSYS. In that option, it is done material selection in the form of Structural Steel used in the analysis.

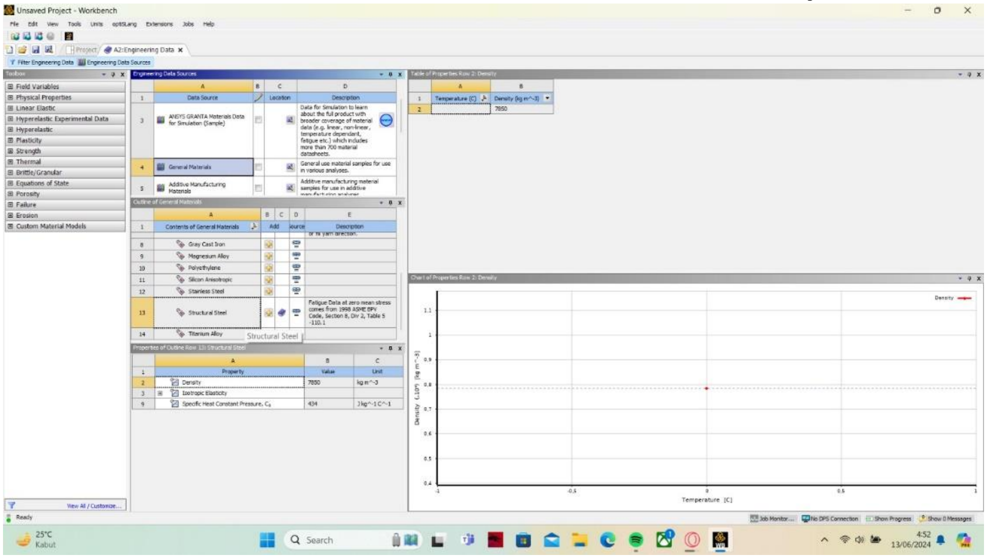

Figure 4. 9 Material selection of Structural Steel

For Structural Steel itself, the material has some specific characteristic as follow :

- Temperature = 22 degree celcius
- Material mass = 7,850 kg/m3
- Specific calor = 434 J/Kg.C

3. Import geometry. The 3D model that have been made in other software is imported to ANSYS Workbench.

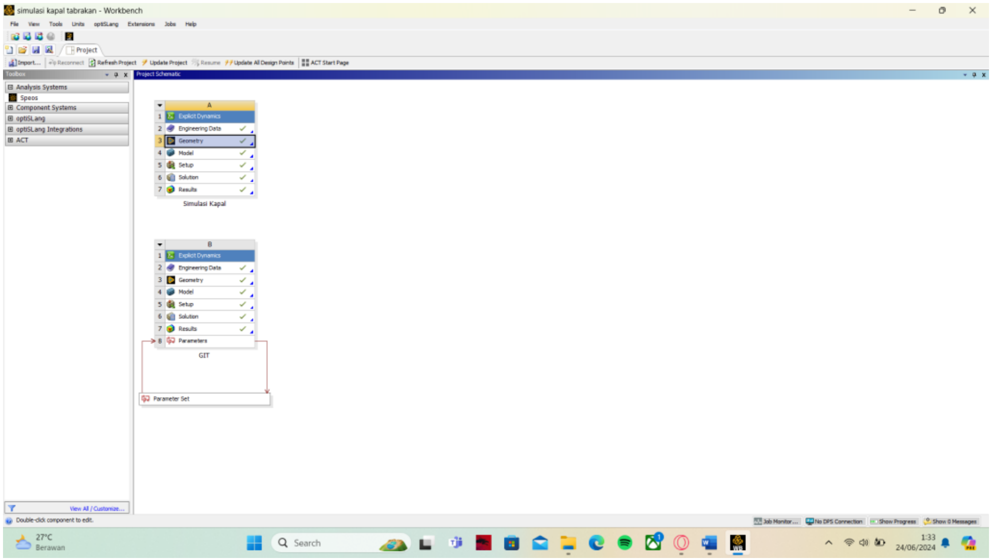

Figure 4. 10 Import geometry

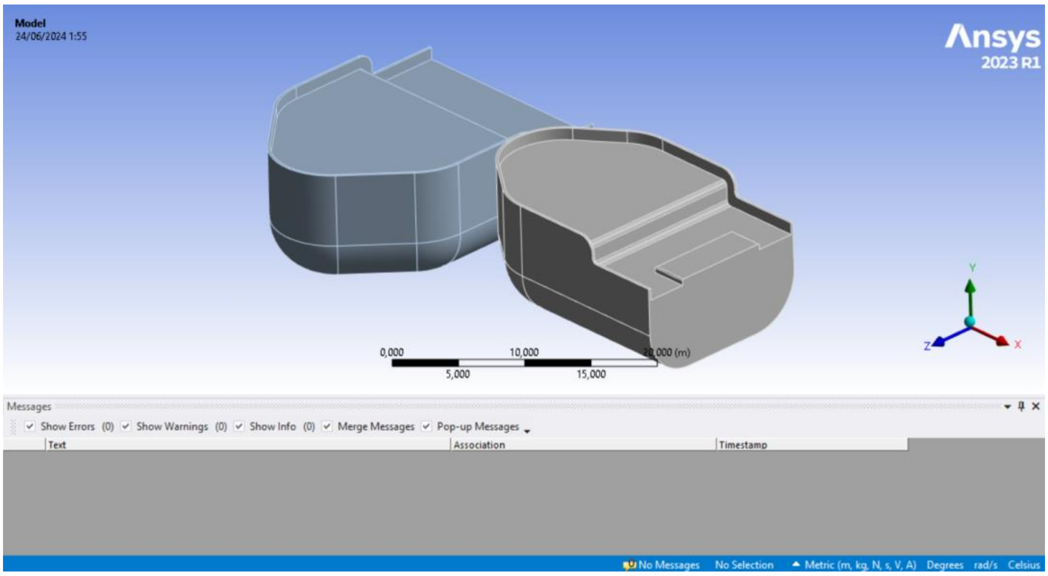

Figure 4. 11 Ship 3D model geometry

4. Meshing is the process of dividing geometric component into small elements. The smaller the mesh, the better the quality of the result.

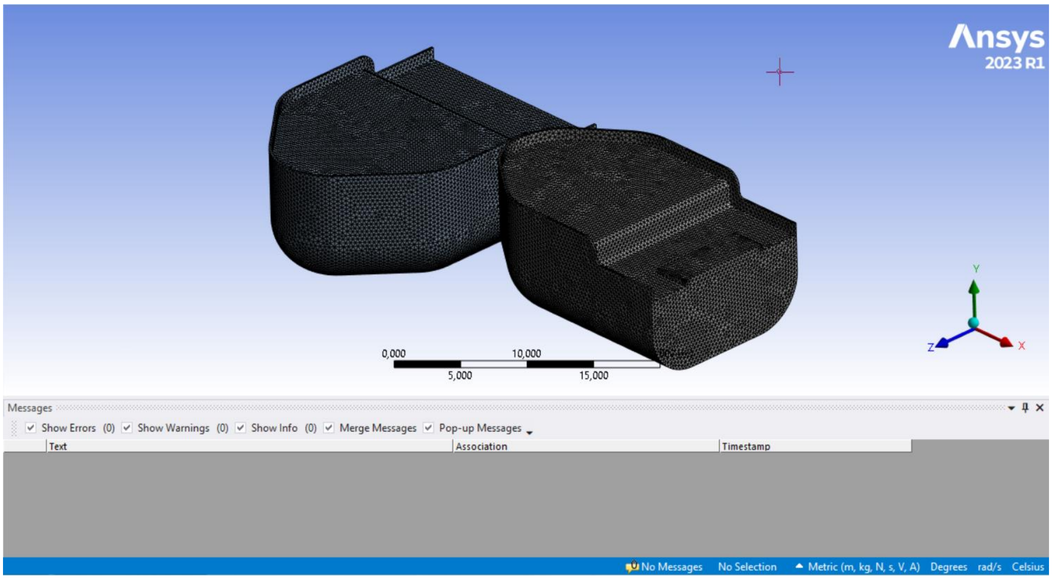

Figure 4. 12 Meshing result

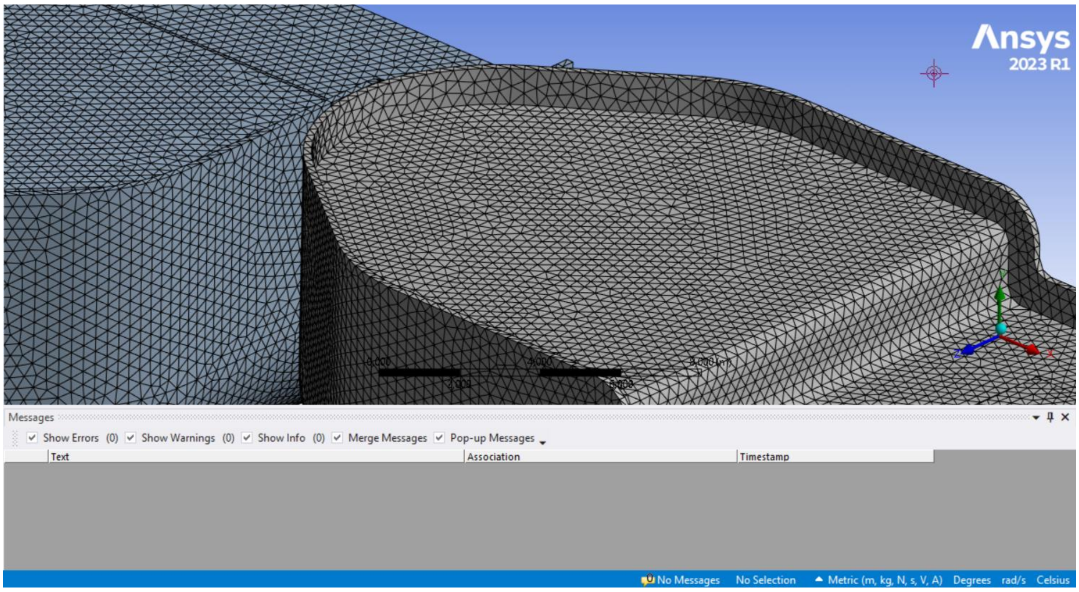

Figure 4. 13 Meshing detail

5. Input data. There are several important data that need to be insert to the simulation in order to get the best result. The initial data that getting applied are as follow :
   - Initial velocity : 7,3 knot = 3,75544 m/s
   - Hydrostatic pressure (fluid density) : 1,025 kg/m3
   - Displacement : to ensure the ship 1 is moving
   - Fixed support : to ensure the ship 2 is fixed
   - End time : 0,01 s

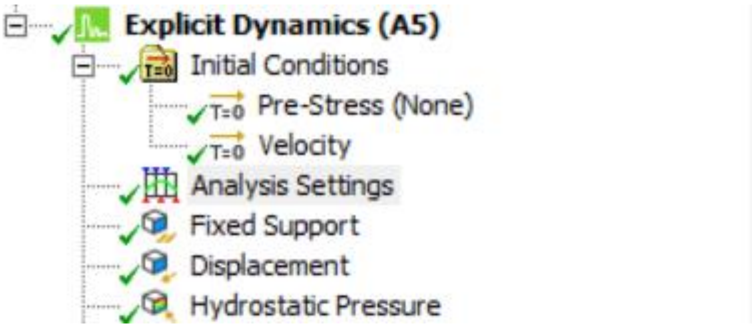

Figure 4. 14 Input initial data

6. Input analysis solution. For this specific simulation, the intended result value from the simulation are as follow :
    - Total deformation
    - Directional deformation
    - Equivalent stress

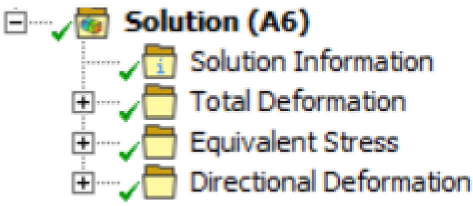

Figure 4. 15 Input solution option

After that, run the simulation by clicking on the solve solution option.

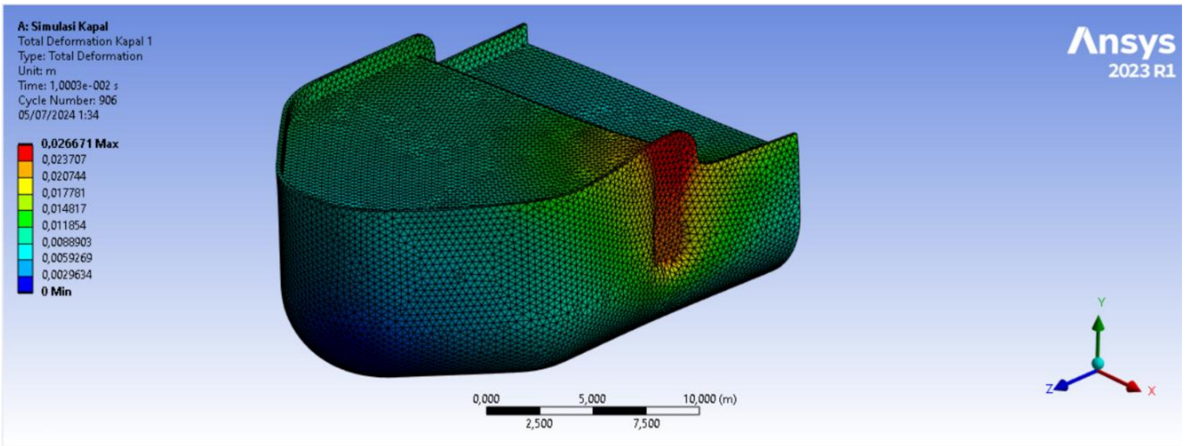

Figure 4. 16 Total deformation with 3D ship model

Above figure is the result of total deformation on a ship being struck that generate in an ANSYS simulation. The color gradation shows how much a part of the ship is deformed due to a collision with another ship. Red color indicates the largest deformation and blue color indicates the smallest deformation. From the total deformation solution, it shows that the largest deformation is 37,481 x 10^{-3} m and for the smallest deformation is 0 m. The detail result are as following below :

- Maximal deformation ship 1 = 26,671 x 10^{-3} m
- Minimum deformation ship 1 = 0 m
- Maximal deformation ship 2 = 37,481 x 10^{-3} m
- Minimum deformation ship 2 = 23,078 x 10^{-3} m

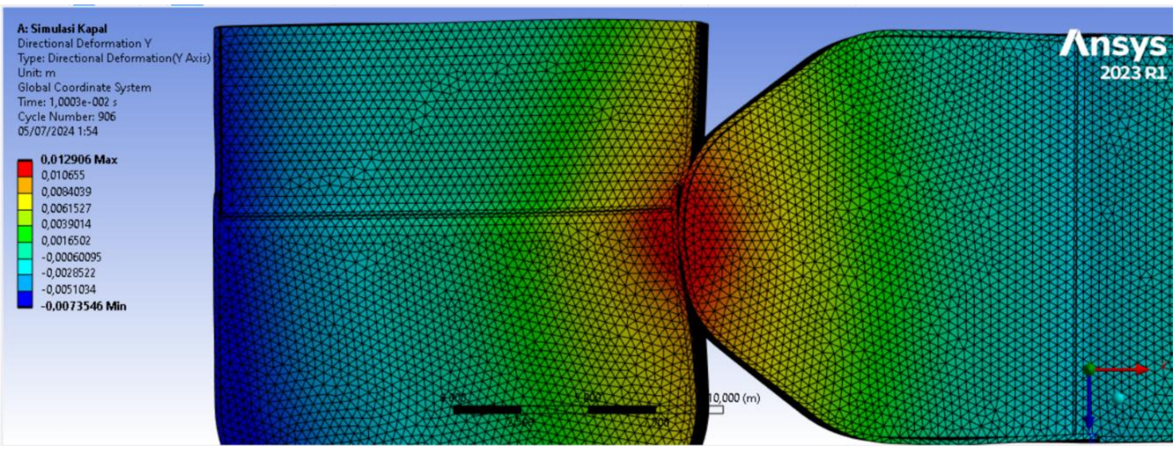

Figure 4. 17 Directional deformation with 3D ship model

Above figure is the result of directional deformation on a ship being struck that generate in an ANSYS simulation. The figure of simulation is seen from above. It can be seen that the ship hull is deformed slightly inside due to the collision from other ship bow. Directional deformation itself is divided into three, which is directional deformation x, y, and z. The largest deformation is 12,906 x 10^{-3} m and for the smallest deformation is -37,405 x 10^{-3} m with minus vector direction indicates that the direction is opposite. The detail result are as following below :

- Maximal deformation X ship 1 = 442,84 x 10^{-6} m
- Minimum deformation X ship 1 = -23,531 x 10^{-3} m
- Maximal deformation Y ship 1 = 12,669 x 10^{-3} m
- Minimum deformation Y ship 1 = -7,3546 x 10^{-3} m
- Maximal deformation Z ship 1 = 3,7034 x 10^{-3} m
- Minimum deformation Z ship 1 = -3,8579 x 10^{-3} m
- Maximal deformation X ship 2 = -19,68 x 10^{-3} m
- Minimum deformation X ship 2 = -37,405 x 10^{-3} m
- Maximal deformation Y ship 2 = 12,906 x 10^{-3} m
- Minimum deformation Y ship 2 = -3,635 x 10^{-3} m
- Maximal deformation Z ship 2 = 2,0148 x 10^{-3} m
- Minimum deformation Z ship 2 = -4,4215 x 10^{-3} m

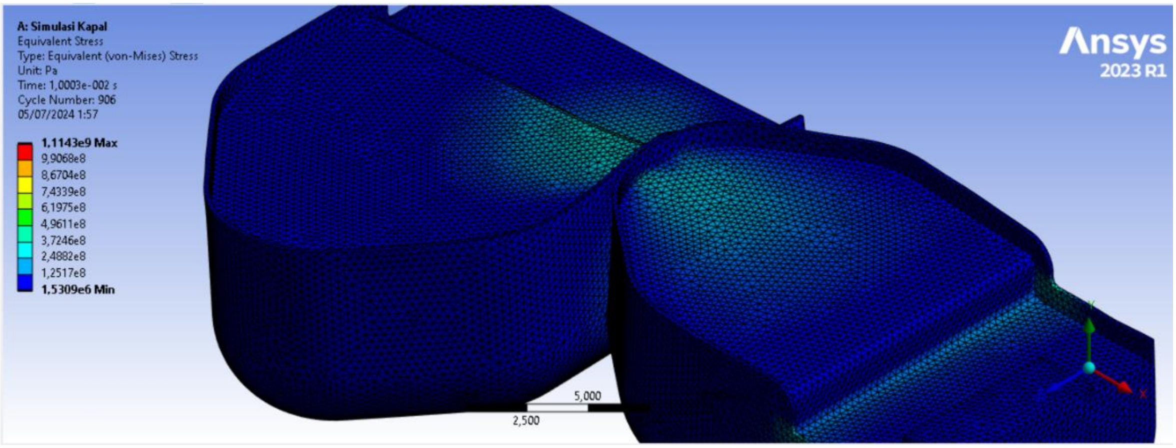

Figure 4. 18 Equivalent stress with 3D ship model

Above figure is the result of equivalent stress on a ship being struck that generate in an ANSYS simulation. The stress resulted in the simulation is indicates in a green color. The largest stress on a part of ship is 1,1143 x 10^9 Pascal and for the smallest stress generated is 1,5309 x 10^6 Pascal. The detailed result are as following below :

- Maximal equivalent stress ship 1 = 1,0049 x 10^9 Pa
- Minimum equivalent stress ship 1 = 1,5309 x 10^6 Pa
- Maximal equivalent stress ship 2 = 1,1143 x 10^9 Pa
- Minimum equivalent stress ship 2 = 1,9839 x 10^6 Pa

4.8 Risk Matrix

Based on the probability and consequence analysis which resulted a frequence number, next step is to make the risk matrix that can show the level of how dangerous the risk is. The risk matrix that will be use is according to ASDP risk matrix which associated with maritime safety. As for the probability/frequence index will use from IMO. The result of frequency from probability analysis is 0,37698754 per year and the impact or consequence is moderate damage based on the calculation of dissipated energy.

Table 4. 17 frequency index

Source : IMO MSC-MEPC Rev.2

RANK	FREQUENCY	DEFINITION	F (per ship year)
1	Frequent	Likely to occur once per month on one ship	10
2	Probable	Likely to occur once per year in a fleet of 10 ships	0.1
3	Occasional	Likely to occur once per year in a fleet of 100 ships	0.01
4	Remote	Likely to occur once per year in a fleet of 1,000 ships	10^{-3}
5	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5,000 ships	10^{-5}

Table 4. 18 Risk matrix

	Matrix ASDP	Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Frequency	Frequent	7	12	17	22	25
	Probable	4	9	**14**	19	24
	Occasional	3	8	13	18	23
	Remote	2	6	11	16	21
	Extremely remote	1	5	10	15	20

Table 4. 19 Risk matrix category

Risk category	Risk level score
Low	1-5
Low-medium	6-11
Medium	12-15
Medium-High	16-19
High	20-25

4.9 Risk Mitigation and Control

After getting the result of risk matrix, the next step is to make risk mitigation control measures. This steps aims to reduce the risk from ship collision in merak-bakauheni route. From the risk matrix, ship collision probability and consequence in merak-bakauheni route is categorized at high risk level area. Factors that influence in ship collision probability are waterway, the involved vessels, and human factors (Lützen, 2001). Therefore, the list of risk control measures are :

Table 4. 20 Risk control measures

Factors	Causes	Safety control to reduce risk
Waterway	High ship traffic density in merak-bakauheni route	Related parties in order to regulate the density of ship traffic on merak-bakauheni route such as VTS (Vessel Traffic Service)
Involved vessels	Ship speed too fast in narrow area	Apply speed limit at some area. Not more than 12 knots according to previous publication of 'Rules For Vessels Navigating

		Through the Straits of Malacca and Singapore' by IMO's Maritime Safety Committee in 1998.
Human factors	Fatigue, unhealthy condition, and lack of skills	Improve health programs and skills for crew

4.10 Recommendation for mitigation

Based on the probability and consequence analysis that result a frequence of ship collision, estimation of structural damage, and risk measure option, the final step is to make a recommendation of mitigation to reduce the risk in the upcoming future. The recommendation are as follow :

1. Improve sea transportation safety
   Improving sea transportation safety is an important things to achieve traffic safety in merak-bakauheni route. One of the suggestion is for Vessel Traffic Service (VTS) to control the ship traffic density in order to make merak-bakauheni route more safety and less dense than before.

2. Apply ship speed limit in narrow area.
   Merak-bakauheni route has some narrow area that has a chance for a ship to collide due to its environmental factor and ship density. Therefore, applying a ship speed limit may reduce those collision. To determine the speed limit of vessel in some area, may refer to the previous implementation in the Malacca Strait by GAC shpping. In the publication by GAC, it is stated that vessels passing through the Strait of Malacca must comply with the 'Rules for Vessels Navigating Through the Straits of Malacca and Singapore' made by the International Maritime Organization's Maritime Safety Committee in 1998. The port authority organizes and reminds all shipmasters who are onboard the vessel to be on the Traffic Separation Scheme if the vessel is about to pass through the channel. There are several points that need to be considered, one of which is ship speed. Ship speed through the strait must not exceed 12 knots over grounds at certain coordinates. Therefore, this regulation can also be applied to the Sunda Strait, namely the Merak-Bakauheni route, to limit ship speed to no more than 12 knots or according to expert agreement.

3. Initiate a healthy program for Ro-Ro ship crew
   In order to prevent fatigue, there must be a planning for appropriate replacement in ship crew shift to avoid overwork.

4. Improve ship crew skills and ability
   To increasing their experience in operating Ro-Ro ship at merak-bakauheni route.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the research that have been conducted in order to answer the problem statement about ship collision analysis in merak-bakauheni route, the following below are the conclusion :

1. The result of probability analysis in order to determine the frequency of ship collision which include head-on, overtaking, and crossing respectively produce a value of ,
   Head-on = 0,0652827 and 0,065607 ships/year
   Overtaking = 0,016866 and 0,020929 ships/year
   Crossing = 0,106833 and 0,10147 ships/year
   The analysis is using two scenarios as a comparison between two data for each ship collision scenario. From the result, it can be concluded that the total frequence of ship collision in merak-bakauheni is less than 1 accident within 1 year.

2. Based on the 3D simulation result of consequence analysis in order to know the structural damage from ship collision, the obtained results are as follows :

Table 5. 1 Structural damage result

Type of analysis	Maximal value	Minimum value	Unit
Total deformation ship 1	$26{,}671 \times 10^{-3}$	0	meter
Total deformation ship 2	$37{,}481 \times 10^{-3}$	$23{,}078 \times 10^{-3}$	meter
Directional deformation X ship 1	$442{,}84 \times 10^{-6}$	$-23{,}531 \times 10^{-3}$	meter
Directional deformation Y ship 1	$12{,}669 \times 10^{-3}$	$-7{,}3546 \times 10^{-3}$	meter
Directional deformation Z ship 1	$3{,}7034 \times 10^{-3}$	$-3{,}8579 \times 10^{-3}$	meter
Directional deformation X ship 2	$-19{,}68 \times 10^{-3}$	$-37{,}405 \times 10^{-3}$	meter
Directional deformation Y ship 2	$12{,}906 \times 10^{-3}$	$-3{,}635 \times 10^{-3}$	meter
Directional deformation Z ship 2	$2{,}0148 \times 10^{-3}$	$-4{,}4215 \times 10^{-3}$	meter
Equivalent stress ship 1	$1{,}0049 \times 10^{9}$	$1{,}5309 \times 10^{6}$	Pascal
Equivalent stress ship 2	$1{,}1143 \times 10^{9}$	$1{,}9839 \times 10^{6}$	Pascal

3. Based on the overall results of the analysis that has been carried out which includes frequency analysis, ship structural impacts, risk matrix, risk control measures, and recommendation for mitigation, it can be concluded that the risk of ship collision in merak-bakauheni route can still be tolerated because the frequency resulted is less than 1 accident for a year. However, mitigation to prevent ship collisions in the merak-bakauheni area still needs to be carried out, because the risk level in this area based on the risk matrix is in the medium risk level. Therefore, the author recommends that prevention to be carried out in the form of implementing a traffic separation scheme (TSS), implementing ship

speed limits in certain areas not more than 12 knots, and improving a health program for ship crew.

5.2 Recommendation

Based on the research that has been conducted by the author, there are several recommendation for further research with the similar topic. The things that need to be considered in for further research are :

1. Use different calculation method or use more than one method for probability analysis. This can deepen the research by comparing two different methods and produce more accurate validation
2. In the consequence analysis, the making of 3D ship model is still lacking. In further research using similar topic, it will be better if the author conduct the consequence analysis with a better 3D ship model that is more accurate in terms of the ship structural components.

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ATTACHMENT

1. Probability analysis calculation

TRAFFIC BASED MODEL ANALYSIS

(ρ) Traffic density in shipping lane

$$\rho = \frac{N_m}{V_1 \, x \, W}$$

(NI) Estimation of probability of a collision occuring on lane

for head-on and overtaking

$$N_i = \frac{B_1 + B_2}{W} \, x \, \frac{(V_1 + V_2)}{V_1 \, x \, V_2} \, x \, D \, x \, N_m$$

for crossing

$$P_i = \frac{N_m}{V_1 \, x \, V_2} + [(B_1 + L_2) \, x \, V_1 + (B_2 + L_1) \, x \, V_2]$$

(Pa) Probability of collision

$$P_a = N_i \, x \, P_C$$

(Na) Frequence of collision

$$N_a = N_m \, x \, P_a$$

Table of result

	Head-on 1	Head-on 2	Overtaking 1	Overtaking 2	Crossing 1	Crossing 2
ρ	0,00025613	0,000161	0,0001144	0,0001281	0,000135	0,000161
Ni/Pi	453,352116	455,6015	272,3901	337,99997	2023,357	1921,773
Pa	0,01360056	0,013668	0,0035138	0,0043602	0,022257	0,02114
Na	0,0652827	0,065607	0,0168664	0,020929	0,106833	0,10147

Total Na 1	0,18898234
Total Na 2	0,18800519
Total	0,37698754

Head-On 1	
	Ship data
V1 (kn)	4,6
V2 (kn)	7,2
B1 (m)	18
B2 (m	12
L1 (m)	117
L2 (m)	58

Head-On 2	
	Ship data
V1 (kn)	7,3
V2 (kn)	8
B1 (m)	16
B2 (m)	25
L1 (m)	99
L2 (m)	151

Initial Data	
Nm	4,8
W	4074
D	36000
Pc head-on	0,00003
Pc overtaking	0,0000129
Pc crossing	0,000011

Overtaking 1	
	Ship data
V1 (kn)	10,3
V2 (kn)	12,3
B1 (m)	19
B2 (m)	17
L1 (m)	102
L2 (m)	90

Overtaking 2	
	Ship data
V1 (kn)	9,2
V2 (kn)	9,9
B1 (m)	18
B2 (m)	20
L1 (m)	102
L2 (m)	106

Crossing 1	
	Ship data
V1 (kn)	8,7
V2 (kn)	9,7
B1 (m)	18
B2 (m)	15
L1 (m)	103
L2 (m)	83

Crossing 2	
	Ship data
V1 (kn)	7,3
V2 (kn)	9
B1 (m)	16
B2 (m)	18
L1 (m)	99
L2 (m)	103

2. Dissipated energy calculation

PERHITUNGAN ENERGI TERDISIPASI

Known data			
max =	mb1 =	0,07	
may =	mb2 =	1,3	
ja =	jb =	0,21	
Ra =	1/4 Lpp a =	24,75	m
Rb =	1/4 Lpp b =	25,75	m
(Xa, Ya) =	(100, 90)		
(Xb, Yb) =	(20, 0)		
(Xc, Yc) =	(20, 10)		
Sudut α =	90		
Sudut β =	0		
Sin 90 =	1		
Cos 0 =	1		
Vax =	7,3 knot =	3,75544	m/s
Vay =	3 knot =	1,54333	m/s
Vbx =	9 knot =	4,63	m/s
Vby =	4,5 knot =	2,315	m/s
Ma =	1064		ton
Mb =	7000		ton

Data Kapal		
Nama Kapal	Suki 2 (a)	Wira Kencana (b)
Panjang	99	103
Lebar	16	18
Massa	1064	7000

Relative of motion striking

$$D\alpha\xi = \frac{1}{1+may}.\sin^2\alpha + \frac{1}{1+may}.\cos^2\alpha + \frac{1}{1+ja}.\frac{[yc.sin\alpha-(xc-xa).cos\alpha]^2}{Ra^2}$$

***Dαξ* =** 19,37

$$D\alpha\eta = \frac{1}{1+max}.\sin\alpha.cos\alpha + \frac{1}{1+may}.sin\,\alpha.cos\alpha + \frac{1}{1+ja}.\frac{[yc.sin\alpha-(xc-xa)cos\alpha][yc.cos\alpha+(xc-xa)sin\alpha\,]}{Ra^2}$$

Dαη = 13,04901235

$$Db\xi = \frac{1}{1+mb1}.\sin^2(\beta-\alpha) + \frac{1}{1+mb2}.\cos^2(\beta-\alpha) + \frac{1}{1+jb}.\frac{[(yc-yb)sin\alpha-(xc-xb).cos\alpha]^2}{Rb^2}$$

Dbξ = 3,552486568

$$Db\eta = \frac{1}{1+mb1}.\sin(\beta-\alpha).\cos(\beta-\alpha) + \frac{1}{1+mb2}.sin(\beta-\alpha)\cos(\beta-\alpha) + \frac{1}{1+jb}.\frac{[(yc-yb)sin\alpha-(xc-xa)cos\alpha][(yc-yb)cos\alpha+(xc-xb)sin\alpha\,]}{Rb}$$

Dbη = 45,66126214

Constant Dξ and Dη determined by

$$D_\xi = \frac{D\alpha\xi}{Ma} + \frac{Db\xi}{Mb},\ D_\eta = \frac{D\alpha\eta}{Ma} + \frac{Db\eta}{Mb}$$

Dξ = 0,018712385

Dη = 0,018787147

Relative velocities after collision

$$\xi(0) = \xi a(0) - \xi b(0) = Vax.sin\alpha + Vay.cos\alpha + Vb1\sin(\beta-\alpha) - Vb2\cos(\beta-\alpha)$$

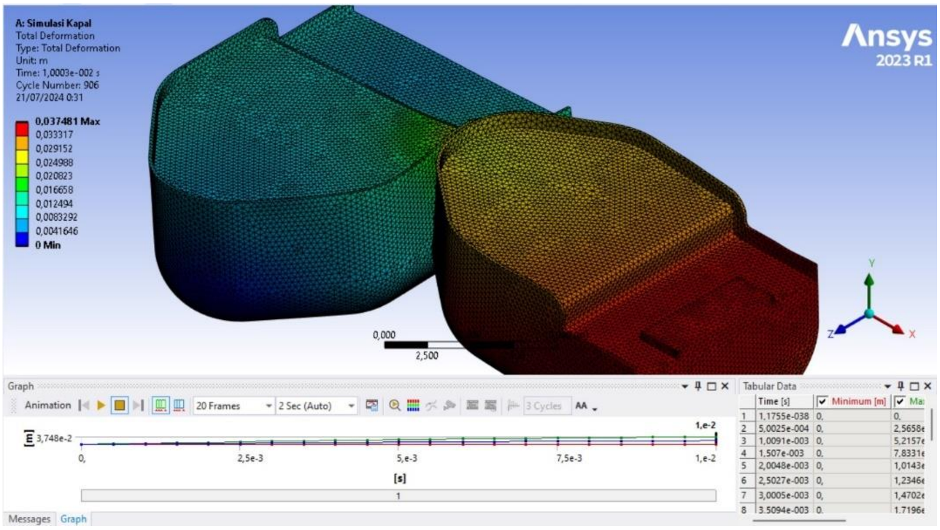
ξ(0) = 7,61377

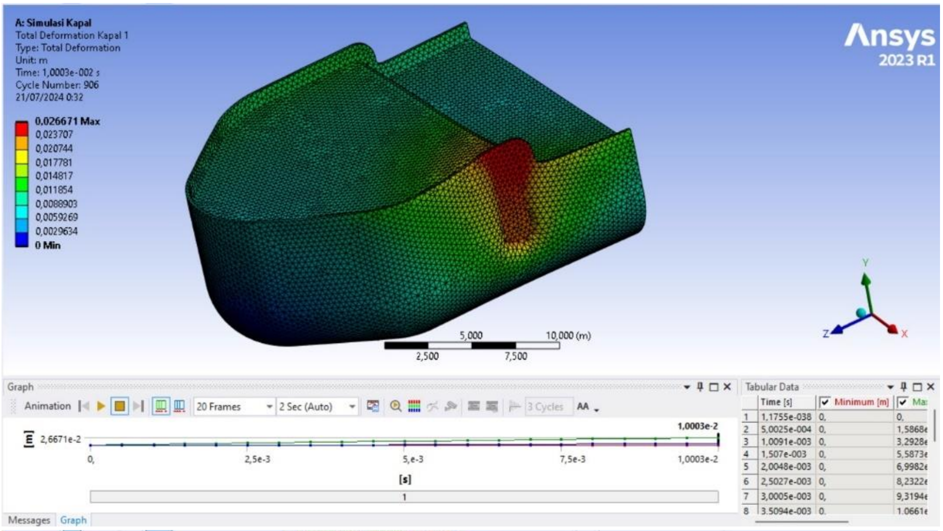
Energi terdisipasi adalah

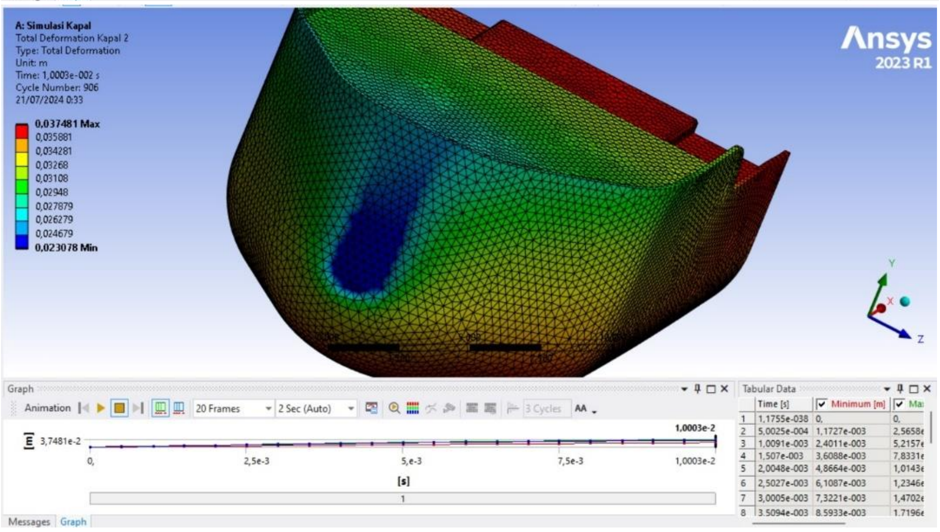
$$E\xi = 0{,}5 \text{ x } \frac{1}{D\xi} \text{ x } D\eta \text{ x } \xi(0)^2$$

Eξ = 29,10054942 MJ

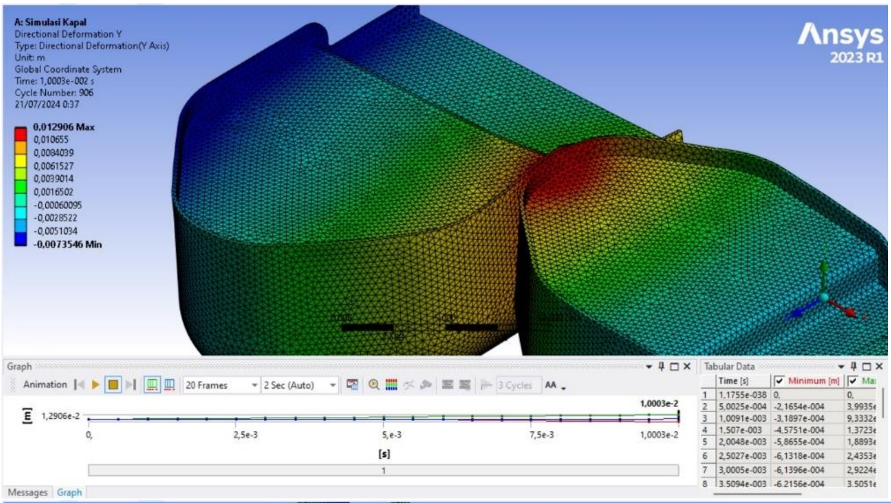
3. Total deformation

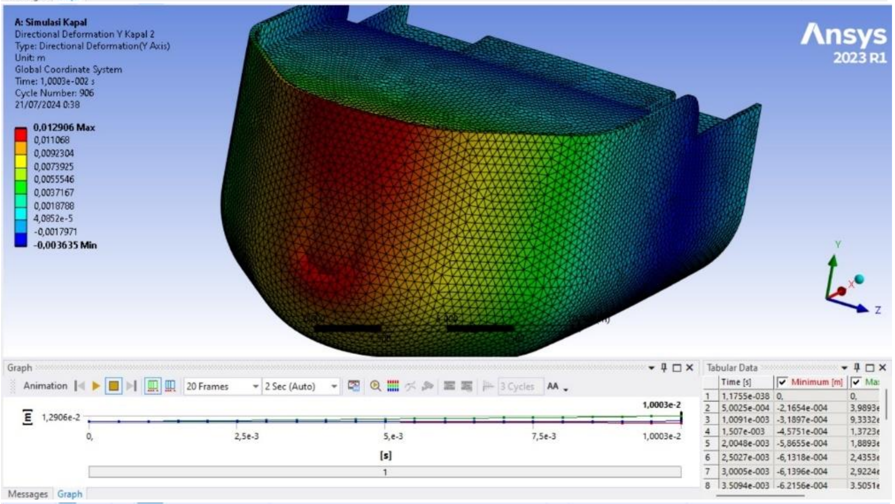


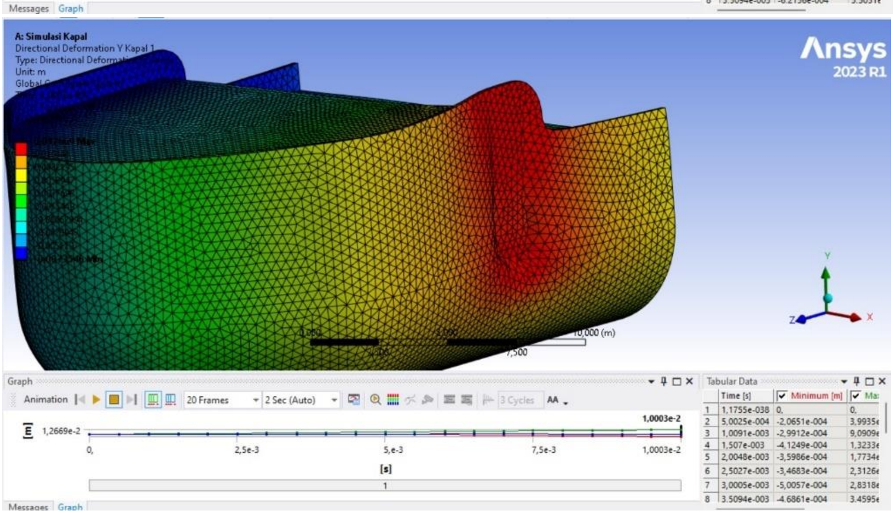




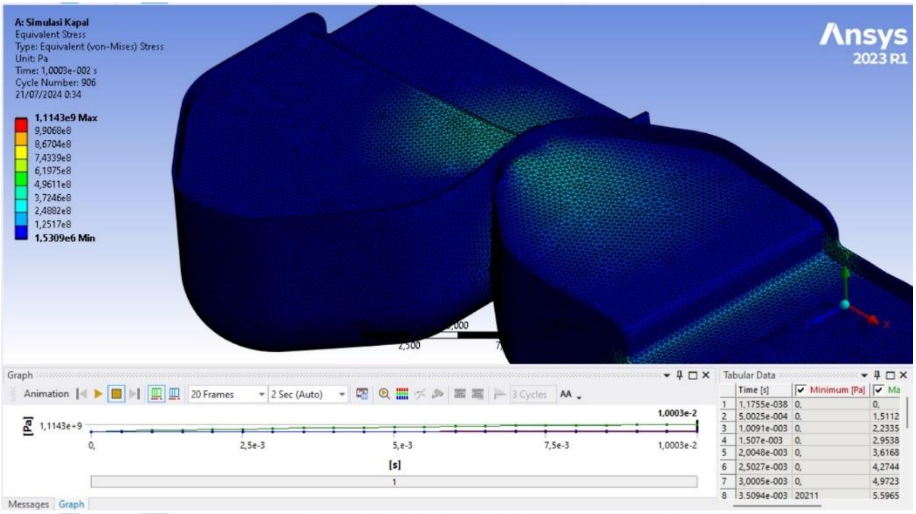
4. Directional deformation

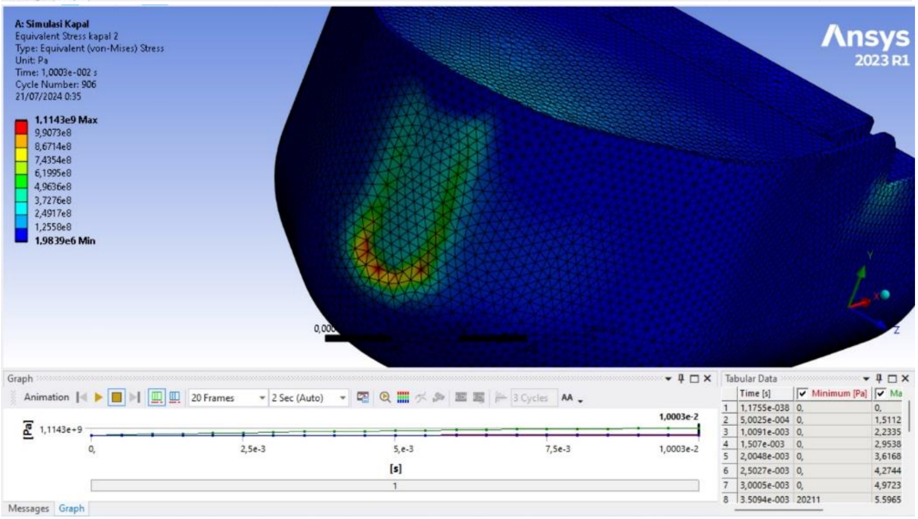


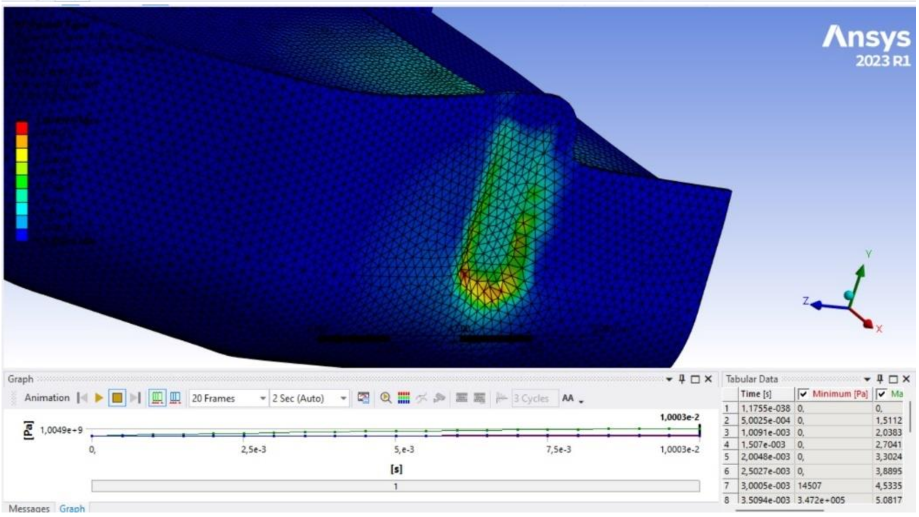




5. Equivalent stress







AUTHOR BIODATA

The author, Kelana Cahaya Muhammad, was born in Bandung on December 2, 2001. The author studied high school at SMAN 19 Bandung and graduated in 2019. In 2020, the author was enrolled in the double degree program of the Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember and Hoschule Wismar with NRP 5019201059.

During his education at Department of Marine Engineering, the author was active in campus activities, namely BEM FTK ITS, as staff of Strategic Review and Action. In addition, the author also conducts Practical Work activities as a form of adding experience to the company PT. Orela Shipyard and PT. Indonesian Classification Bureau.

The author has a strong and deep desire for a career in the maritime industry, such as logistics, shipping, and surveyor companies. The author hopes that after graduating from the Department of Marine Engineering, he can have a career in one of the companies mentioned above.

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