Strength Analysis on Redesign of Penajam Paser Utara Ferry Port Jetty Fenders

Achmad Dwi Risqi[1]
[1]Teknik Kelautan, Fakultas Pembangunan Berkelanjutan, Jurusan Teknologi Kemaritiman, Institut Teknologi Kalimantan,
Balikpapan 76127 Indonesia
Corresponding Author: achmaddwirisqi@gmail.com

ABSTRACT

Fenders are bumper devices that absorb impact when a ship docks at a pier or when a moored ship moves due to currents or waves in the harbor. The existing fenders at Penajam Ferry Port are currently damaged. This study aims to redesign the existing fender system at Penajam Ferry Port. The selection of fender size is based on calculations of berthing energy generated when the ship comes into contact with the fender, taking into account variations in conditions during the berthing process. Modeling and analysis of deformation and stress on the fender were conducted using ANSYS Workbench software. The calculation results show a berthing energy of 274.68 kNm at a berthing velocity of 0.26 m/s and a distance of 9.4 m between each of the six fenders. The total deformation obtained for the existing fender is 0.009 m, while for the alternative fender it is 0.006 m. Greater deformation occurs on the existing fender due to its inverted position. Meanwhile, the highest maximum equivalent stress occurs in the bolt hole area, which is 0.519 MPa on the existing fender and 0.681 MPa on the alternative fender, influenced by the difference in surface area due to the fender size. Based on the deformation and stress results, both are still within safe limits regarding structural failure. By conducting a Monte Carlo simulation on both fenders, a failure probability of 0% and a reliability value of 100% were obtained.

Keywords: Berthing Energy, Fender, Ferry, Deformation, Equivalent Stress

1. INTRODUCTION

Penajam Paser Utara (PPU) Ferry Port is an important facility serving the crossing between Balikpapan and Penajam in Penajam Paser Utara Regency, East Kalimantan. Operating for 24 hours, the port is crucial for loading and unloading of vehicles and passengers. Therefore, the port must have the capacity to anticipate and adapt to changing service needs, and be managed with careful planning to optimize its function and role.

The pier structure consists of two main components: the superstructure, which includes slabs, beams, and poers connected to the foundation in the substructure, as well as additional elements such as bollards and fenders. Bollards serve as a means of anchoring ships to prevent them from shifting while docked. Meanwhile, fenders are pads installed at the front of the pier to absorb the impact energy between the ship and the pier, while passing the resulting force to the pier structure. The amount of force passed on depends largely on the type of fender and the level of deflection allowed. Fenders also play an important role in preventing damage to the ship's paint layer due to friction generated by the movement of the ship against the pier due to currents, waves or wind. This research is motivated by the urgent need to optimize the infrastructure of Penajam Ferry Port. Penajam Ferry Port infrastructure, given its role as one of the alternative transportation routes to the Archipelago's National Capital. In this context, a reliable and appropriate In this context, a reliable and appropriate fender system is fundamental to ensuring safety, operational efficiency, and sustainability of marine transportation mobility. The condition of The existing fenders at Penajam Paser Utara Ferry Port are currently damaged and even installed upside down, requiring comprehensive repair or redesign.

Regarding fenders, several previous researchers have conducted studies on different issues. Research has been conducted by (Putri, 2023) and (Pranata, 2019) on the design of cone-type fenders, where the size is determined after obtaining the value from the berthing energy calculation. Other studies have used V-type fenders, such as those by (Abidin, 2018), (Fitriyanti, 2020), (Bambang S, 2016), and (Pangkey, 2022). In another study by (Fauzan, 2018), research was conducted but supplemented with calculations of the maximum contact force using the finite element method and calculating the loads acting on the fender. Several studies (Putra, 2017), (Alfarizi, 2022), and (Tarigan, 2023) performed fender modeling, where after modeling, an analysis was conducted regarding the deformation and stress occurring on the fender to conclude that the structure is safe from structural failure.

Based on previous research analysis, it was identified that there has never been a method for analyzing fenders using both Monte Carlo simulation and finite element methods. To fill this gap, this study will contribute new insights into analyzing fender failure using the Monte Carlo method. Most current research focuses on redesigning V-type fenders at ferry ports and analyzing their deformation and stress. V-type fenders were chosen for several reasons. One of them is that fenders are designed to absorb energy well and restore elasticity, making them more resistant to frequent collisions at ports. In this final project, a redesign of the fender at Penajam Ferry Port will be carried out. This will be done by modeling the current V-type fender and then analyzing the deformation and stress results between the two fenders.

A fender is a structure installed on the side of a pier to protect it from ship collisions. Its main function is to absorb the impact energy when a ship docks and transmit the force to the pier structure. The amount of force passed on is influenced by the type of fender and the allowable deflection. Fenders also prevent damage to the ship's paint finish due to friction. Fenders must have high reliability and be designed to function optimally for many years under extreme conditions with minimal maintenance. Rubber fenders are often used due to their good impact energy absorption capability and availability of various types and sizes.

2. METHOD

Penajam Paser Utara Ferry Port is a Balikpapan-Penajam ferry port located in Penajam, Penajam Paser Utara Regency, East Kalimantan.

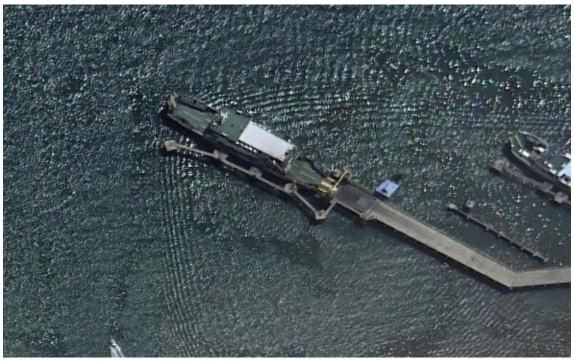

Figure 1. PPU Port Pier Layout

The ship data used for fender redesign is using the largest and smallest ship data that has ever docked at the dock. The ship data is used to calculate the force value, distance between fenders and create a berthing scenario. The ship data used are Tranship II (the largest ship) and Madura Strait II (the smallest ship).

Table 1. Tranship II ship data

Jenis Kapal	RoRo
Gross Tonnage	1058 GT
Lenght Overall (LOA)	63,2 m
Length Between Perpendiculars (LBP)	58,2 m
Breadth	11,8 m
Draught	3,6 m
Deadweight tonnage	641,4 DWT
Displacement	2063,89 Ton
C_B	0,75

Table 2. Selat Madura II ship data

Jenis Kapal	RoRo
Gross Tonnage	209 GT
Lenght Overall (LOA)	37,6 m
Length Between Perpendiculars (LBP)	27,79 m
Breadth	10,02 m
Draught	1,98 m
Deadweight tonnage	183 DWT

Displacement	573,75 Ton
C_B	0,75

Table 3. Dimensions Fender

Dimensions Fender	Units	Size
H	mm	235
W	mm	570
w	mm	176
C	mm	180
FL	mm	1.270

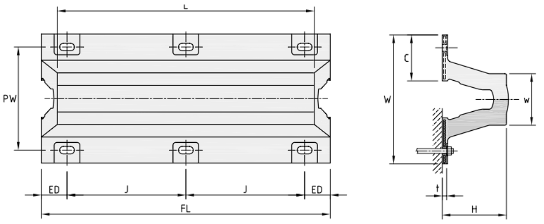

Figure 2. Dimension Size of Existing Fender Type V

The complete procedure of this study as table 1 and table 2 data analysis carried out to calculate the variables sought on the type of Ferries ship, using the calculation formula used internationally (PIANC, 2002) as follows

1. Berthing Energy
   a. Normal Energy (EN)

   Calculation of Normal Energy in accordance with the equations found in PIANC (2002) can be calculated with the equation:

   $EN = 0{,}5 \times MD \times VB^2 \times CM \times CE \times CC \times CS$ (1)

   Description: En is the normal energy, MD is the mass displacement, VB is the anchored velocity, CM is the mass coefficient, CE is the eccentricity coefficient, CC is the anchored configuration coefficient, CS is the softness coefficient.

   b. Abnormal Energy (EA)

   $EA = En \times Sf$ (2)

   Description: EA is abnormal energy, En is normal energy, SF is safety factor.

Table 3. Safety Factor (PIANC, 2002)

Ship Type	Size	Fs
Tanker, Bulk, Cargo	Largest Smallest	1,25 1,75
Container	Largest Smallest	1,5 2,0
General Cargo		1,75
RoRo, *Ferries*		≥ 2,0
Tugs, Workboat, dll		2,0

   c. Deformation

   In this case, the deformation analysis observed is the length of the fender. Calculations related to the failure of the fender structure are needed to ascertain whether it meets the material compression set criterion of 30%. This criterion refers to a catalog that is based on testing using the ASTM D395 standard, as described through equations including:

   Total Deformation ≤ 30% Fender Height (3)

   d. *Von – Mises Theory*

   The failure of a material occurs when the octahedral shear stress acting in the material reaches a value equivalent to the octahedral shear stress when the material experiences the yield limit in a uniaxial tensile test. Based on this principle, an equation is derived from the von mises equivalent stress equation to determine the failure condition. The equation used to determine the stress clearance limit is the von mises equation which has been

$$\tau_{oct} = \frac{1}{3}[(S_{yield} - 0)^2 + (0-0)^2 + (0 - S_{yield})^2]^{\frac{1}{2}}$$

$$= 2^{\frac{1}{2}} \times \frac{S_{yield}}{3}$$

   developed as follows:

   (4)

3. RESULT AND DISCUSSION

3.1 Results of Berthing Energy

Berthing energy is generally calculated using equations 1 and 3 which refer to the PIANC standard. The main purpose of the berthing energy calculation is to determine the amount of kinetic energy that must be absorbed by the mooring system, especially the fender structure, when the ship is leaning against the dock.

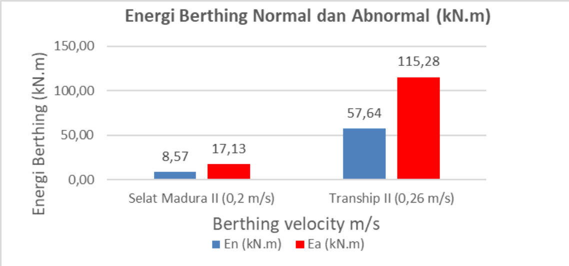

Figure 3. Energy Berthing Bar Chart

It can be seen in Figure 3 where in the graph there are results of berthing energy from 2 variations of berthing velocity and different ship sizes. For the Tranship II ship (the largest ship) the largest abnormal value is 115.28 kN.m and the Madura Strait II ship (the smallest ship) the largest abnormal value is 17.13 kN.m. The abnormal value sought will later be used as a loading on the fender and the permit limit on the type of material used. Previous research by Manan (2015) showed that the greater the berthing velocity, the greater the berthing energy generated.

3.2 Deformation and stress in existing fenders

The analysis carried out on the pier structure, especially the fender structure where the existing fender installation is not in accordance with the orientation direction of the fender installation. In this study, a change in the direction of fender orientation was made, the direction of fender orientation has an impact on the type of load that occurs such as centralized loads or evenly distributed loads that occur on the fender. In addition, the loading that occurs on the fender is influenced by the direction of the load that is parallel to the direction of the ship's arrival or the ship's berth.

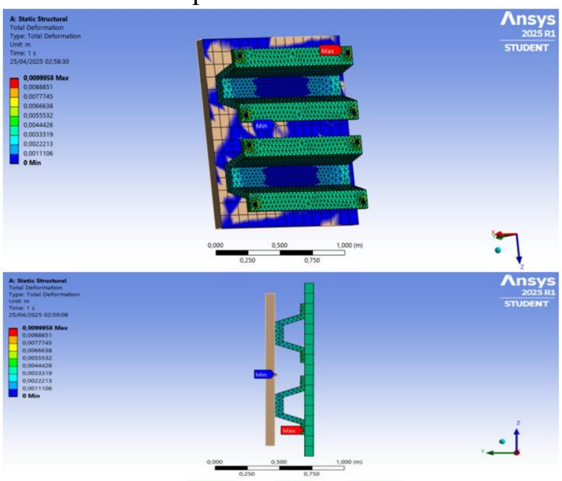

Figure 4. Deformation in fenders existing

Based on the total deformation simulation results shown in Figure 4, the maximum total deformation value is 0.01 meters.

$$0{,}01\ \text{m} < \left(\frac{30}{100} \times 0{,}7\ \text{m}\right) = 0{,}01\ \text{m} < 0{,}21\ \text{m}$$

The results of the calculation of equation 3 that the value of fender deformation meets the criteria of the compression set material from rubber that the value is less than 30%.

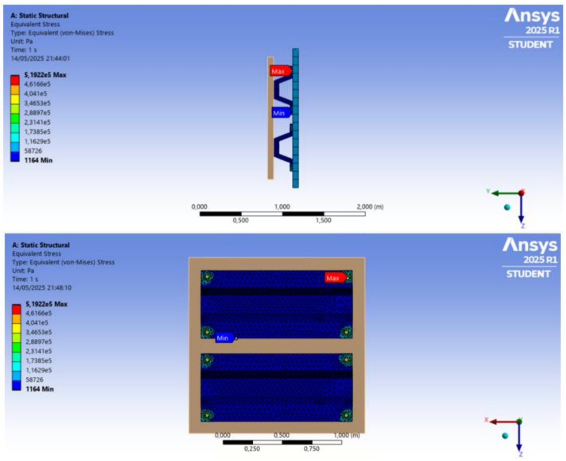

Figure 5. Equivalent stress in fenders existing

After simulating, the maximum equivalent stress value is 0.51922 MPa. The largest equivalent stress value occurs in the bolt hole area as shown in Figure 5 because if the bolt is subjected to a tensile or shear force, this force will be transferred to the plate through the contact between the bolt and the side of the hole. In the simulation using Tranship II ship data with berthing velocity of 0.26 m / s, the berthing value used is 274,688.38 N. After getting the equivalent stress value, then calculate the failure theory with equation 4. The results of the equation are as follows:

$$0{,}51922\ \text{MPa} \leq 7{,}54\ \text{MPa}$$

This is also the same as in the research of Manan (2015) where the largest stress value is taken because that is the last value where elastic deformation occurs. This value shows that the equivalent stress that occurs to the fender does not exceed the permit limit. After analyzing the existing fenders, the deformation and equivalent stress that occur are still acceptable or still below the permit limit. In this case, no alternative fenders are required, only the installation of the fenders in an inverted state.

3.3 Deformation and stress in Alternative fenders

It should be noted that the data used for the alternative fender simulation is the same as the existing fender simulation as it is based on the standard (PIANC, 2002). This guideline emphasizes the importance of correct installation orientation to ensure the fenders function optimally in absorbing ship impact energy and protecting the dock structure. In this case, the analysis of the alternative fenders carried out is to reverse the position of the fenders.

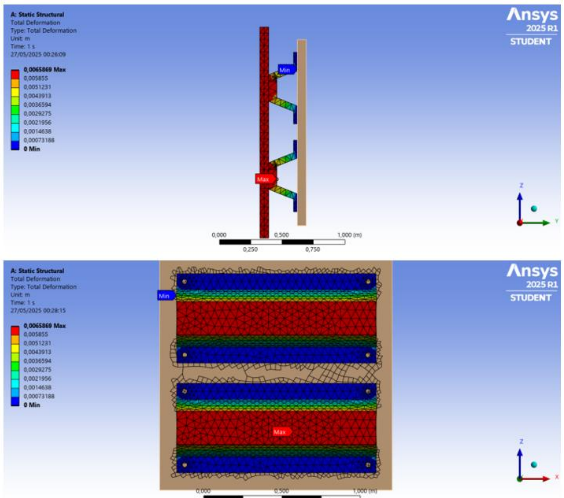

Figure 6. Deformation in alternative fenders

This result shows that the connection is a critical point in the fender structure and needs special attention in the design process and material selection. Based on this, the equation of the total deformation structural failure of the fender can be calculated using equation 3 The calculation of the equation is as follows:

$$0{,}006 \text{ m} < (\frac{30}{100} \times 0{,}7 \text{ m}) = 0{,}006 \text{ m} < 0{,}21 \text{ m}$$

Based on the above results, it is known that the total deformation that occurs is smaller than Total Deformation ≤ 30% Fender Height, so the alternative fender is still within normal limits.

The equivalent von-mises stress is an important parameter in material strength analysis because it is used to predict the likelihood of material failure due to the combined stresses that occur. If the value of this stress exceeds the elastic limit (yield strength) of the material used, the structure has the potential for plastic deformation or even failure. Therefore, the maximum value of this stress needs to be compared with the mechanical properties of the material to ascertain whether the structure remains in a safe condition or whether reinforcement or design changes need to be made to these critical areas.

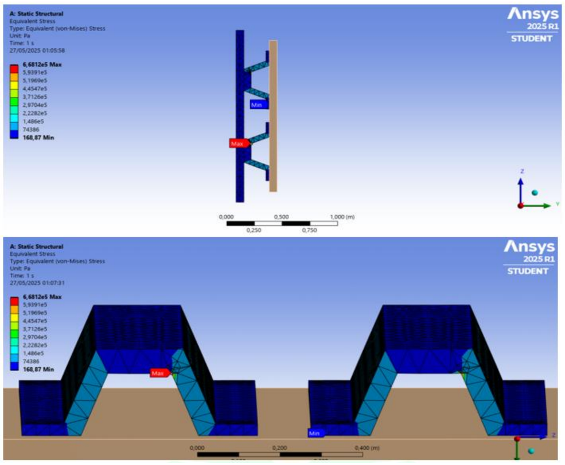

Figure 7. Equivalent stress in alternative fenders

In the simulation using Tranship II ship data with berthing velocity of 0.26 m / s, the berthing value used is 274.688,37 N. After getting the equivalent stress value, then calculate the failure theory with equation 4 The results of the equation are as follows:

$$0{,}6812 \text{ MPa} \leq 7{,}54 \text{ MPa}$$

This value shows that the equivalent stress that occurs to the fender does not exceed the permit limit. After analyzing the existing fenders, the deformation and equivalent stress that occur are still acceptable or still below the permit limit.

4. CONCLUSION

1. Based on the results of calculations that refer to the PIANC standard for berthing energy, the normal berthing and abnormal berthing values for 2 ship sizes are obtained as follows:

- **Tranship II (0,26 m/s)**

  Normal *berthing* : 57,64 kNm

  Abnormal *berthing* : 115,28 kNm

- **Selat Madura II (0,2 m/s)**

  Normal *berthing* : 8,57 kNm

  Abnormal *berthing* : 17,13 kNm

2. From the analysis that has been carried out using Ansys Workbench software, the total deformation and equivalent stress values are obtained as follows:

- **Tranship II (0,26 m/s)**

Normal *berthing* : 57,64 kNm

Abnormal *berthing* : 115,28 kNm

- **Selat Madura II (0,2 m/s)**

Normal *berthing* : 8,57 kNm

Abnormal *berthing* : 17,13 kNm

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