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THE EFFECT OF IMPACT LOADS ON THE SUBSTRUCTURE OF THE MAHAKAM-1 SAMARINDA BRIDGE

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ABSTRACT
As the number of coal-carrying ships passing under the Mahakam-1 Bridge increases, the risk of collisions between ships or barges into bridge's substructure also rises. The most recent incident occurred in December 2022, when the bridge was struck again by a coal barge, causing the concrete on pillar P3 become erode and chip away due to the collision. Besides that, the hard impact can affect the reliability of the Mahakam Bridge's substructure Given the critical role of the Mahakam-1 Bridge, it is necessary to analyze the impact energy and impact forces resulting from the collisions on bridge's substructure, as well as the probability of bridge failure caused by passing ships or barges. Then, using the finite element method with Plaxis 3D software, a model of the actual conditions was created to determine the deflection occurring and the serviceability of bridge's substructure, particularly on pillar P3. Furthermore, appropriate handling recommendations are provided to mitigate damage caused by future collisions by ships or barges.
The results of the research and data processing using Plaxis 3D software indicate that the actual impact force is 968.95 kN, with a deflection of approximately 0.005026 meters. Therefore, the collision condition caused by ships or barges does not affect the service condition of pillar P3, with the resulting deflection being smaller than the allowable deflection value of 0.025 meters.

Keywords:
Bridge, Pillar, Collision, Plaxis 3D, Deflection.

INTRODUCTION

Mahakam-1 Bridge as a means of crossing vehicles passing towards Samarinda and shipping traffic of cargo ships. Mahakam-1 Bridge is a class II bridge with a truss construction, and a total bridge length of 400 meters. This bridge is divided into six sections with seven pillars, five sections with a length of 60 meters and one section with a length of 100 meters, with each pillar using a steel pipe pile foundation. Incidents that often occur are collisions by coal carrier ships on the Mahakam-1 Bridge which cause damage to the bridge's substructure. Most recently, the bridge was hit again by a coal-laden ship in December 2022 which caused the concrete on the P3 pillar to erode and peel off due to the collision. In addition, the hard impact that occurred can also affect the reliability of the Mahakam Bridge's substructure. Therefore, it is necessary to conduct an analysis of the forces that occur due to ship impacts on the substructure of the bridge using the finite element method, from the modeling of the existing conditions to find out how much deflection occurs and how much serviceability of the

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substructure of the bridge, especially on the pillars, and the proper handling of elements that are damaged due to collisions that occur due to collisions by ships or barges. So, the results of this study can answer problems and doubts regarding the existing condition of the bridge's substructure against collisions caused by ships/barges, to the proper handling of the pillars in the bridge's substructure.

METHODOLOGY

This research was conducted on the Mahakam-1 Bridge which crosses the Mahakam River and is located in Samarinda City, East Kalimantan Province, which has been standing since 1986 and until now there have been no significant structural changes, besides that the function of this bridge is to connect land transportation from Samarinda Seberang to Samarinda City. According to the regulations, tugboats pulling barges are only permitted to pass under the bridge and can only be passed by one ship.

Figure 1. Research Location

Figure 2. Mahakam Bridge-1

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Figure 3. Pillars and fenders of Mahakam Bridge-1

Figure 4. post-collision situation on Mahakam-1 Bridge

The research stages required include literature studies, primary data collection, secondary data collection, determining the force and energy of ship/barge impacts, analysis of the sub-bridge structure with the help of Plaxis 3D software, reinforcement of bridge pilecaps or fenders. The begins by collecting literature studies related to collisions that occur on the substructure of bridges caused by passing ships/barges, and conducting gap analysis on the literature adapted to the research to be conducted. Then, primary data and secondary data are collected as needed according to existing conditions and the latest data that can be used in the research. From the data collection, a numerical analysis is then carried out according to the calculation method used in determining the force and impact energy that occurs and determining the load acting on the substructure of the bridge, which will later be used in the input process of load modeling in Plaxis 3D software.

Furthermore, in the process of input modeling and input of loads acting on the substructure of the bridge, it is carried out with several variations of horizontal loading due to the impact force by the ship/barge, including the actual conditions of the impact force and the conditions of gradual increase in impact force, this aims to obtain deflection at the time of actual conditions and the lateral resistance capacity of the piles in the substructure of the bridge, especially in the condition of the P3 pillar.

If the deflection that occurs exceeds the permitted limit, it is necessary to strengthen the pilecap structure or strengthen the fender system. Furthermore, a re-modeling analysis is carried out to obtain deflection or lateral resistance after reinforcement. However, if the deflection that occurs is still within the permitted limits, the research is declared complete, from all the stages that have been explained, a flowchart is made which is used as

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a technique in the research sequence so that it can help researchers know the relationship between the steps and the research process carried out.

RESULTS AND DISCUSSION

Visual Inspection of Bridge Substructure

In Figure 5.1 there is damage to the rubber fender on the upstream side of the river at pillar 4 of the bridge which is torn on the rubber part caused by a collision by a ship/barge. Figure 5.2 there is damage to the concrete on the pilecap at pillar 3 on the upstream side of the river which has rompal due to collisions by passing ships/barges, this is due to the absence of fenders protecting the pilecap concrete. Figure 5.3, visual observations were made on the piles on the bridge pillars, notation 41 was obtained, which concluded that the total length of the piles was around 42 meters to the pillar pilecap structure. Figure 5.4, visual observations were made of the rubber fenders on pillar 3 which were only installed on part of the side in the downstream position of the river. Figure 5.5 a visual observation is made of the rubber fender at pillar 4 which is only installed on the side of the pillar in the direction of the shipping channel.

Figure 5. Condition of rubber fenders on pillar P4

Figure 6. Concrete condition of pilecap at P3 pillar

Figure 7. Notation of total pole length

Figure 8. Fender installation condition on P3 pillar at downstream river position

Figure 9. Fender installation condition on pillar P4

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Existing Concrete Quality Measurement

Concrete rebound testing (hammer test) is carried out by taking random points

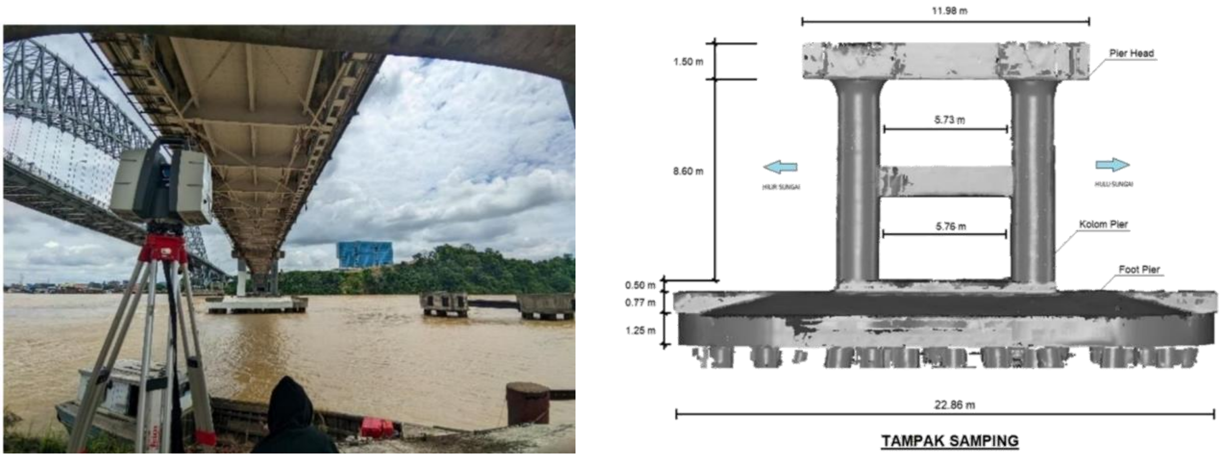
Table 1. Recapitulation of compressive strength values from concrete rebound testing

No	Point	Compressive Strength (kg/cm^2)
1	*Pilecap point 1 - Pillar 3*	**265**
2	*Pilecap point 2 - Pillar 3*	**425**
3	*Pilecap point 3 - Pillar 3*	**350**
4	Body - Pillar 3	**490**
Average		**382,5**

Figure 10. Concrete insitu test points taken at P3 pillar

Geometry Measurement of Bridge Under Structure

Measurement survey activities on the existing condition of the lower structure of the Mahakam-1 Bridge using Terrestrial Laser Scanner survey tools, but due to the limited coverage area of the tool station, the data collection is quite complete only at Pillar 3.



(a) (b)

(a) Figure 11. Measurement of the geometry of the structure under the bridge

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(b) Figure 12. Layout of measurement results of the side view of P3 pillar

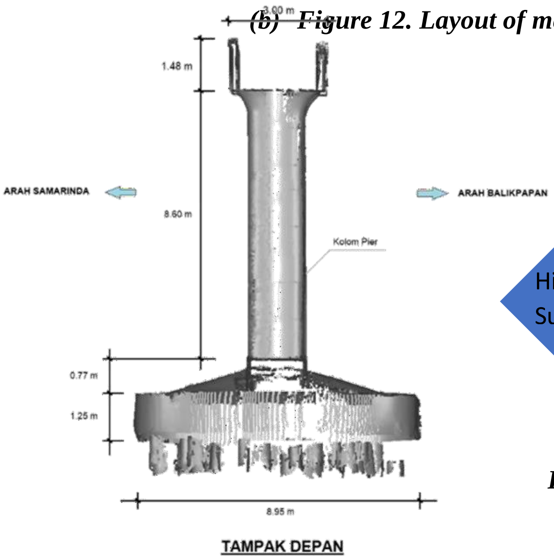

Figure 13. Layout of measurement results of the front view of P3 pillar

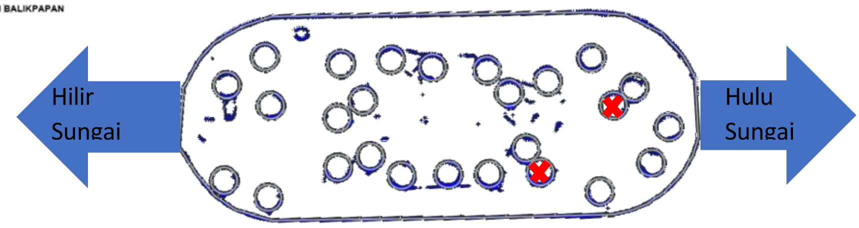

Figure 14. Layout top view of pile distribution at P3 pillar

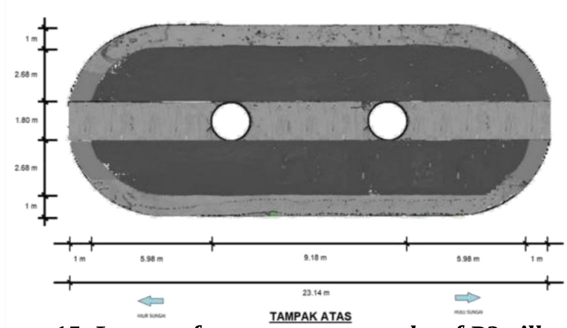

Figure 15. Layout of measurement results of P3 pillar top view

The results of geometry measurements are two piles that are close to each other, which is assumed that the two piles have been deformed (red cross), also reinforced in the research of Efendi A.W. (2022) in his journal entitled Behaviour Analysis of Forensic Audit Results at Pier 3 Mahakam Bridge, where it is stated that two foundation piles are damaged, so that in Plaxis 3D modelling later the two piles will be ignored.

Table 2. Measurement data of the geometry of the structure under the bridge at pillar P3

Description	Length (meters)	Width (meters)	Height (meters)	Diameter (meters)	Total
Pier Head	11,98	3,00	1,50	-	-
Kolom *Pier*	-	-	8,60	1,80	2
Distance between columns	-	5,70	-	-	-
Foot Pier	23,14	8,95	1,25	-	-
Steel Pipe	42,00	-	-	1,10	24

Riverbed Contour Measurement

Survey activities measuring the contours of the Mahakam riverbed using an echosounder tool.

Table 3. Voyage flow data

No	Information	Description
1	River Width	355 meters
2	River Depth	24 meters

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No	Information	Description
3	Width of shipping channel	80 meters
4	Distance between pillars	92,42 meters
5	Heavy Shipping Traffic	Solid and 1 lane
6	Bridge Position to River Flow Type Transitional area	Transitional area

Figure 16. Layout of riverbed contours on Mahakam-1 Bridge

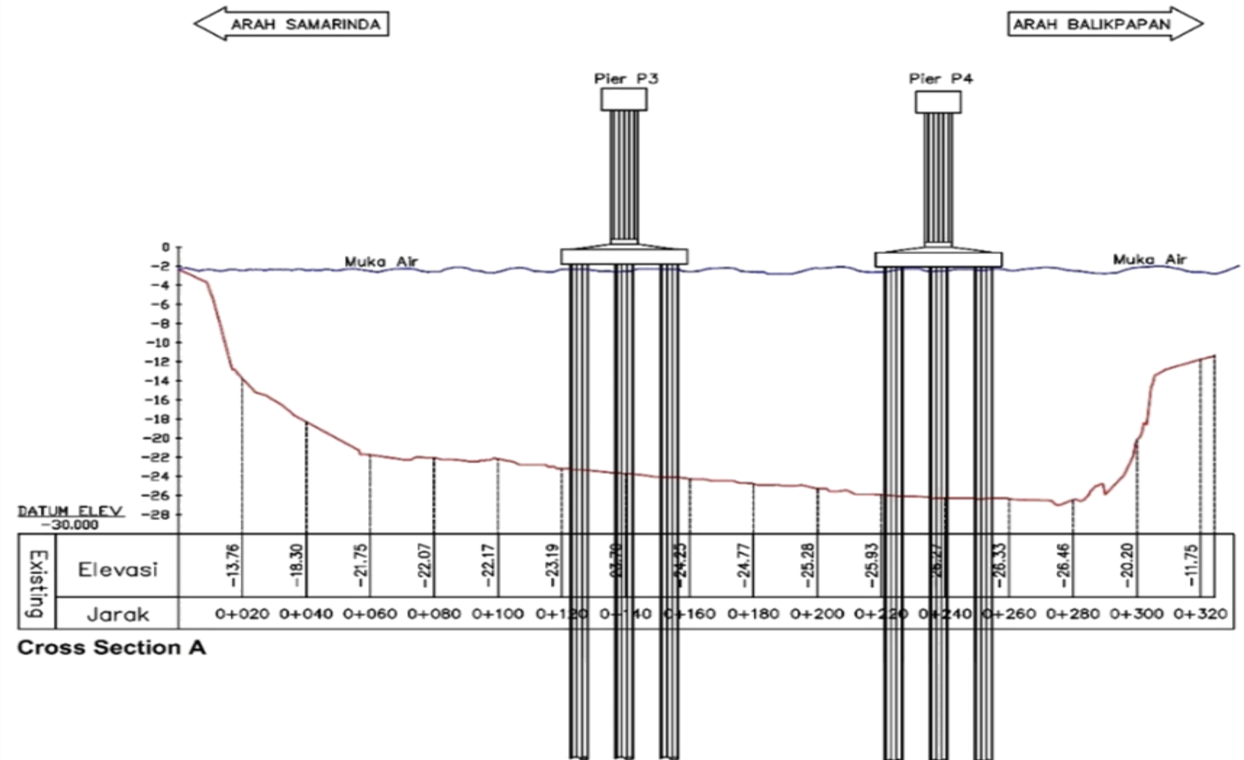

Figure 17. Cross section of riverbed cxontours in the bridge area

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River Water Flow Velocity Measurement

The Mahakam River is an area that is still influenced by tidal phenomena that occur twice a day, this phenomenon causes the movement of currents from upstream to downstream and vice versa.

Table 4. Mahakam River water flow data

No	Description	Rate
1	Tidal Height	1,0 metre – 2,5 metre
2	Water Current Speed	
	- Depth 1 metre	0,1 m/detik – 0,2 m/detik
	- 5 metre depth	0,1 m/detik – 0,3 m/detik

Soil Investigation Data

Based on information from the soil investigation data, it is concluded that the hard soil layer (N-SPT > 60) or bed-rock layer is at a depth of 21.55 meters from the bed-river. Furthermore, the correlation between field tests and laboratory test samples was carried out, which concluded the suitability of borlog data with laboratory test data, so that information was obtained that the soil layer at a depth of 0.00 - 11.30 meters with a type of poorly graded sand (SP), and the soil layer at a depth of 13.00 - 19.30 meters with a type of sandy silt (CL).

Calculation Analysis

Calculation of Impact Force and Energy

Based on the data already owned, an analysis of the calculation of force and energy when the collision occurs which will be taken at the maximum condition. Barge type 1 LOA = 100.58 meters, 10000 tons capacity, maximum kinertic energy of 80.35 kNm, and maximum impact force of 968.95 kN.

Loading of the Bridge Bottom Structure

The calculated loading data will later be input in the loading in Plaxis 3D software.

Table 5. Recapitulation of loads acting on the bridge

Description	Load (kN)
1. Self-Weight (MS)	
a. Upper structure (WMSA)	2412,71
b. Lower structure (WMSB)	12116,40
2. Additional Dead Load (MA)	1397,60
3. Traffic Load (PTD)	4047,30
4. Pedestrian Load (PTP)	1960,00
5. Brake Load (PTB)	372,40
6. Wind Load on Structure (EWS)	2184,55
7. Wind Load on Vehicle (EWL)	7,51
8. Earthquake Load (PEQ)	1694,18
a. Longitudinal earthquake horizontal force (HUX)	1084,276

Table 6. Mahakam-1 Bridge loading recapitulation

Description	Load (kN)
1. Total Vertical Load WMSA + MA + PTD + PTP	9817,61

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2. Total Horizontal Load in x direction PTB + PEQ	2066,58
3. Total Horizontal Load in y direction EWS + EWL + HUX	3276,33
4. Total Horizontal Load by ship/barge PB Maks	968,85

Plaxis 3D Modelling Software

After inputting the modelling analysis in Plaxis 3D software, the next step is the output analysis process. The results of the modelling analysis output include the deflection value of the working load and the forces that occur in the pile structure.

Table 7. Recapitulation of deflection against impact load

Tahapan Fase	Beban Tumbukan (kN)	Defleksi (m)
Kondisi Awal [*Initial Phase*]	0	0,0000
Beban Aktual [*Phase*_1]	968,95	0,005026
Beban Lateral 1000 kN [*Phase*_2]	1000	0,005206
Beban Lateral 2000 kN [*Phase*_3]	2000	0,01029
Beban Lateral 3000 kN [*Phase*_4]	3000	0,01543
Beban Lateral 4000 kN [*Phase*_5]	4000	0,02087
Beban Lateral 5000 kN [*Phase*_6]	5000	0,02572

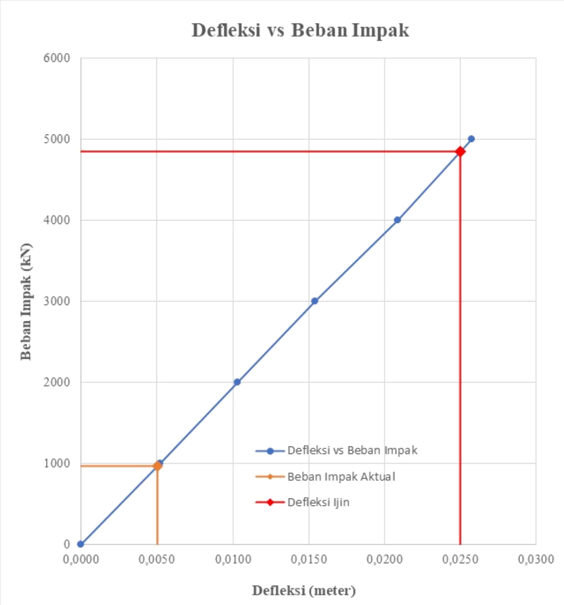

Figure 18. Deflection against impact load

From the impact load simulation, various deflection values were obtained (Table 5. 17), in the actual impact load condition of 968.95 kN a deflection of 0.005026 meters occurred; at an impact load of 1000 kN a deflection of 0.005206 meters occurred; at an impact load of 2000 kN a deflection of 0.01029 meters occurred; at an

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impact load of 3000 kN a deflection of 0.01543 meters occurred; at an impact load of 4000 kN a deflection of 0.02087 meters occurred; at an impact load of 5000 kN a deflection of 0.02572 meters occurred, then from the simulation a linear graph was made between deflection and impact load. In SNI 8460:2017, it is mentioned that the amount of allowable lateral deformation for strong earthquakes is 25 mm or 0.025 meters, so that in determining the value of the impact load in the allowable condition is obtained by drawing a line cutting against the linear line in the condition of the allowable deflection of 0.025 meters, which is 4850 kN. From these results it is conveyed that the actual impact load is still below the allowable deflection condition or can withstand loads due to collisions up to a capacity of 4850 kN, so it is concluded that the P3 pillar of the Mahakam-1 Bridge with existing conditions is able to withstand lateral loads due to collisions by ships/barges with a cargo carrying capacity of 10000 tons.

Bridge Collapse Probability

Probability of ship diving

The probability value of ship straying (PA), the probability value due to geometric ship straying pillars (PG), the probability value of bridge collapse due to straying ship collision (PC), the annual number of ships passing through the shipping lane (N) are required to calculate the probability value of bridge collapse due to ship collision.

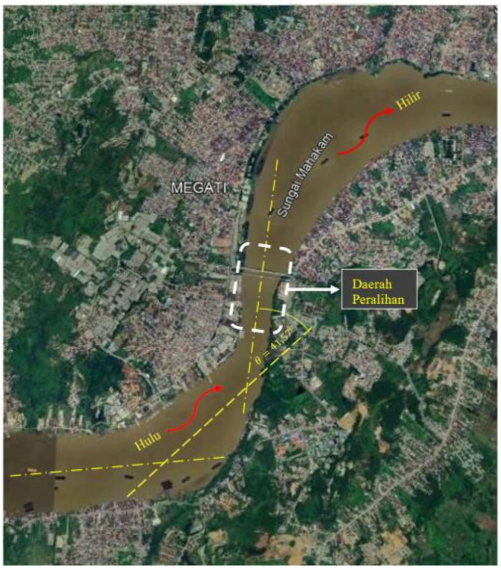

Figure 19. Shipping flow of ships/barges on the Mahakam River

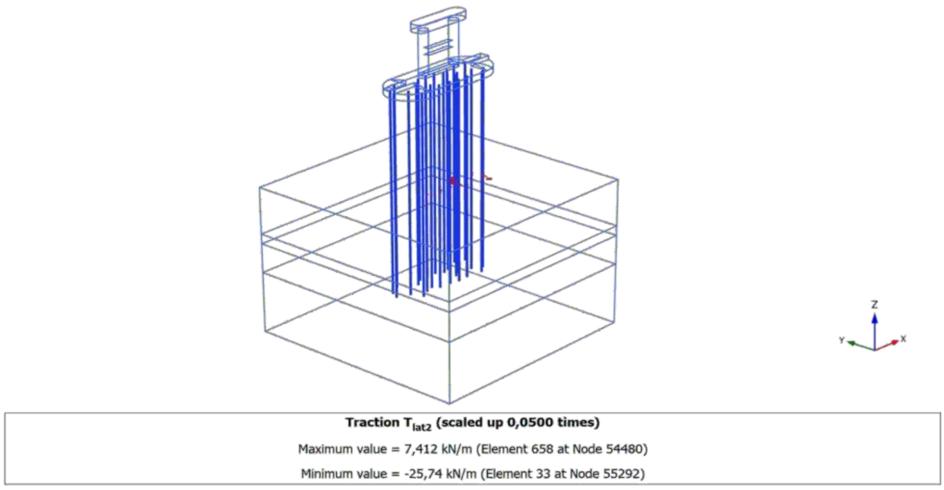

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Figure 20. Lateral force on pole perpendicular to loading (Q13)

Table 8. Bridge collapse frequency

Barge Type	N-ship (unit/year)	PA	PG	PC	AF
1	1406	0,000298	0,107	0,10	**0,0044**
2	16286	0,000298	0,116	0,09	**0,0524**
3	3157	0,000298	0,112	0,08	**0,0089**
4	1218	0,000298	0,138	0,06	**0,0031**
5	302	0,000298	0,153	0	**0,0000**
Total					**0,0688**

The calculation of the annual frequency of bridge collapse from Table 5.22 obtained a value of 0.0688 or a value smaller than 0.1 in 100 years (AF = 0.001).

Reinforcement of the Bridge Bottom Structure

From the previous calculation process, the maximum kinetic energy value that occurred was 80.35 kN.m, so that to reduce kinetic energy to the lower structure of the bridge on the Pillar 3 pilecap in accordance with the stages of the fender planning system. The type of fender that can be applied in accordance with the characteristics of the fender is selected. The types and types of fenders that can be applied to the maximum kinetic energy.

Table 9. Type of fender that can be applied

Kinetic energy (kN.m)	Fender type	Type	Energy absorbed by the fender (kN.m)	Force transmitted to the structure (kN)
80,35	*Super Cones*	SCN-700	130	355
	Arch Fenders	AN-500-E3	82,0	422
	Arch Fenders	ANP-500-E2	80,8	385
	Unit Element V-Fenders	UE-550-E1	88	348
	Cylindrical Fenders	875 x 500	81	406
	Wheel Fender	175-70W F	100	315

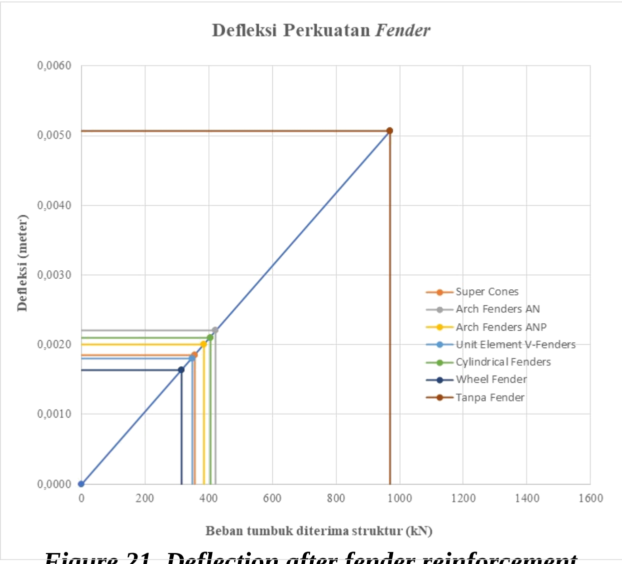

Figure 21. Deflection after fender reinforcement

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Based on the table above, it is concluded that the impact force received by the pillar structure after being reinforced with rubber fenders ranges from 315 kN to 422 kN.

Table 10. Deflection after fender reinforcement

Fender type	Type	Gaya diteruskan ke struktur (kN)	Defleksi yang terjadi (meter)
Super Cones	SCN-700	355	0,00185
Arch Fenders	AN-500-E3	422	0,00220
Arch Fenders	ANP-500-E2	385	0,00200
Unit Element V-Fenders	UE-550-E1	348	0,00180
Cylindrical Fenders	875 x 500	406	0,00210
Wheel Fender	175-70W F	315	0,00163

The results of deflection after fender reinforcement obtained fenders that are able to reduce the best reaction energy to the structure under the bridge, namely the wheel fender type with a deflection that occurs 0.00163 meters and a forwarded force of 315 kN..

CONCLUSION

Based on the calculation analysis that has been carried out on the existing conditions of the lower structure of the Mahakam-1 Bridge at the P3 pillar, as follows:

1. The probability that the ship/barge will hit the lower structure of the Mahakam-1 Bridge is 0.0688.
2. The amount of force and impact energy that occurs in accordance with the specifications of the barge that passes including, type of barge with a capacity of 10000 tons has a kinetic energy of 80353.63 Nm with an impact force of 968.85 kN; type of barge with a capacity of 7500 tons has a kinetic energy of 59949.03 Nm with an impact force of 723.38 kN; 5200 tons barge type has a kinetic energy of 41288.12 Nm with an impact force of 498.51 kN; 2790 tons barge type has a kinetic energy of 21881.77 Nm with an impact force of 264.36 kN; and 1000 tons barge type has a kinetic energy of 7643.30 Nm with an impact force of 92.38 kN.
3. The results of modelling analysis using Plaxis 3D software obtained a deflection value that occurred of 0.005026 meters with a lateral resistance capacity on the pole of 117.50 kN. The deflection value that occurs is smaller than the allowable deflection, it is concluded that the condition of the P3 pillar is able to withstand lateral loads due to ship/barge collisions.
4. Strengthening the lower structure of the P3 pillar bridge as an effort to reduce the impact force and kinetic energy that occurs is by strengthening the fender, in the form of a wheel fender type with the best ability to reduce the reaction force that is forwarded to the structure of 315 kN and the deflection that occurs in the structure of 0.00163 meters.

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