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Planning of Gosong Pasir Beacon Buoy with Flush-Mounted Aluminum Anode as a Corrosion Solution for SBNP

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ABSTRACT

Based on Law No.43 of 2008, guarding and monitoring the coastline of Indonesia is very important, because it is closely related to the boundaries of the sea area that needs to be regulated for national defense. In the sea area, Navigational Aids (SBNP) type of beacon signs are used as a sign of state boundaries which have been regulated in Permenhub No.25 of 2011. In Indonesia, the beacon building in the waters of Gosong Pasir, Riau Province, experienced two collapses within 12 years. Therefore, this study examines more deeply and provides solutions to structural strength, cathodic protection, and mechanical electrical structures. The data used in this study are bathymetry data, underwater image data, sub bottom profile data, tide data, current data, and sediment sample data. Hydrodynamic modeling is carried out to obtain platform elevation and cycle time results. Furthermore, for corrosion problems, ASTM A252 Grade B and ASTM A53 Grade B steel pipes are proposed with Flush-Mounted Aluminum Anode cathodic protection with a trapezoidal cross section and coating process.

KEYWORDS *Beacon Sign, Collapse, Cathodic Protection, Coating*

INTRODUCTION

Indonesia is a country with a coastline stretching 99,083 km (61,567 miles). This makes Indonesia the second country with the longest coastline in the world, after Canada (WorldAtlas, 2025). One of the utilizations of Indonesia's extensive coastline is for the determination of maritime boundaries and administrative regions, which must be protected as they are part of the country's funding for national defense (BIG, 2023). According to the Minister of Transportation Regulation No. PM.25 of 2011, Aids to Navigation (SBNP) in the form of lighthouses can be used as markers for national territorial boundaries in maritime areas. Therefore, the construction of lighthouses needs to be carefully considered to support various maritime activities in Indonesia, ensuring safety, security, and order to facilitate smooth maritime traffic.

The Indonesian Notices to Mariners Nr.51 (2020), in Section III, recorded numerous incidents related to lighthouse structures in Indonesia, including damage, outages, disappearances, and collapses occurring from 1992 to 2020. One example is the Gosong Pasir Lighthouse in the Malacca Strait, which was built in 1994 but disappeared in 2006. After being rebuilt on November 21, 2013, another incident occurred—its structural collapse on January 12, 2018. Figure 1 shows the condition of the Gosong Pasir Lighthouse before its collapse in 2018. Prior to the 2018 collapse, the lighthouse suffered from severe structural damage, including concrete deterioration and collapse due to ship collisions. Additionally, corrosion occurred on the piling and the steel baseplate joints. Figure 2 illustrates the damage to the Gosong Pasir Lighthouse before its collapse in 2018.

This indicates that further in-depth analysis is necessary for lighthouse construction in Indonesia, as *Aids to Navigation* (*SBNP*) play a crucial role in ensuring maritime safety.

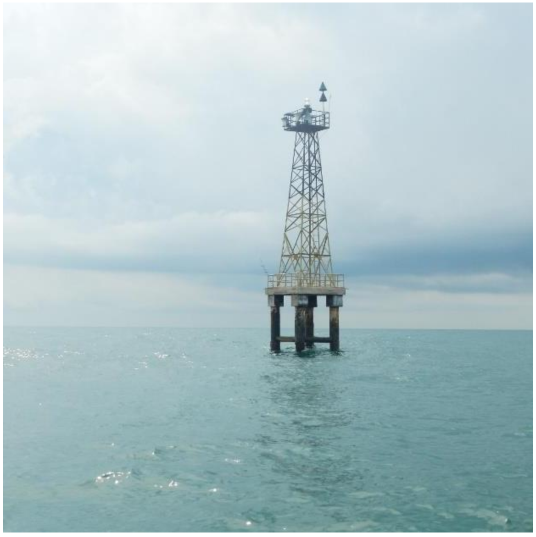

Figure 1. Condition of Gosong Pasir Lighthouse Before Collapse

Figure 2. Damage to Gosong Pasir Lighthouse Before Collapse

It is evident that the main factor contributing to the collapse of the *Gosong Pasir* Lighthouse was corrosion. However, further analysis is required regarding the strength of both the upper and lower structures, as well as the load-bearing capacity of the *Gosong Pasir* Lighthouse during its operational period. This would help determine the exact cause of the collapse of the existing structure and identify the best solution to ensure that the lighthouse is built effectively according to its intended role and function (PM, *The IALA Maritime Buoyage System for Region A*, 2019). Based on the above discussion, this study aims to conduct an in-depth analysis of solutions for the collapse of the *Gosong Pasir* Lighthouse from the perspective of structural strength and cathodic protection.

RESEARCH METHOD

The data analysis method in this planning process employs a quantitative approach to determine the best solution for the construction of the *Gosong Pasir* Lighthouse. The collected data include:

1. Bathymetric data to obtain a seabed surface model using NavEdit software.
2. Underwater imagery data to capture details of existing seabed features.
3. Sub-bottom profile data to obtain sedimentary layering beneath the seabed using SonarWiz 7 software.

4. Tidal data to determine the type of tide using the Admiralty method.
5. Current data to measure current velocity using a JFE Advantech current meter, along with current modeling using Naotide Tidal Prediction software.
6. Sediment sample data to analyze the type of seabed material around the *Gosong Pasir* Lighthouse.
7. Oceanographic data, including wind and wave data, to determine the planned platform elevation and project execution timing.

Additionally, soil investigation data and technical data of the *Gosong Pasir* Lighthouse were also collected. Geotechnical analysis was conducted to assess the structural strength of the lighthouse, particularly its foundation. Data processing was performed using Allpile and SAP 2000 software. In the structural analysis of the lighthouse, the soil was modeled as an elastic spring pile system, which depends on the modulus of subgrade reaction (k_s) of the soil. The embedded piles were modeled using nonlinear spring forces.

Based on the above analysis and data collection, several solutions for the construction of the *Gosong Pasir* Lighthouse were identified, particularly in terms of cathodic protection. Since the design utilizes ASTM A252 Grade B steel pipes for the pile structure and ASTM A53 Grade B steel pipes for the upper structure, welding must follow the *Welding Procedure Specification* (WPS) document. To maintain material quality, particularly in welding processes, *Sacrificial Anode Cathodic Protection* (SACP) is implemented in accordance with the NACE Standard RP0176, using Flush-Mounted Aluminum Anodes with Flat Bar Insert (YUXI).

RESULT AND DISCUSSION

The Gosong Pasir North Cardinal Light Beacon ILL.NR 574 is located at coordinates 02°6’47.48”N / 101°53’35.46”E within the jurisdiction of the Class I Navigation District of Dumai, Riau Province. Figure 3 presents the location of the Gosong Pasir Light Beacon project.

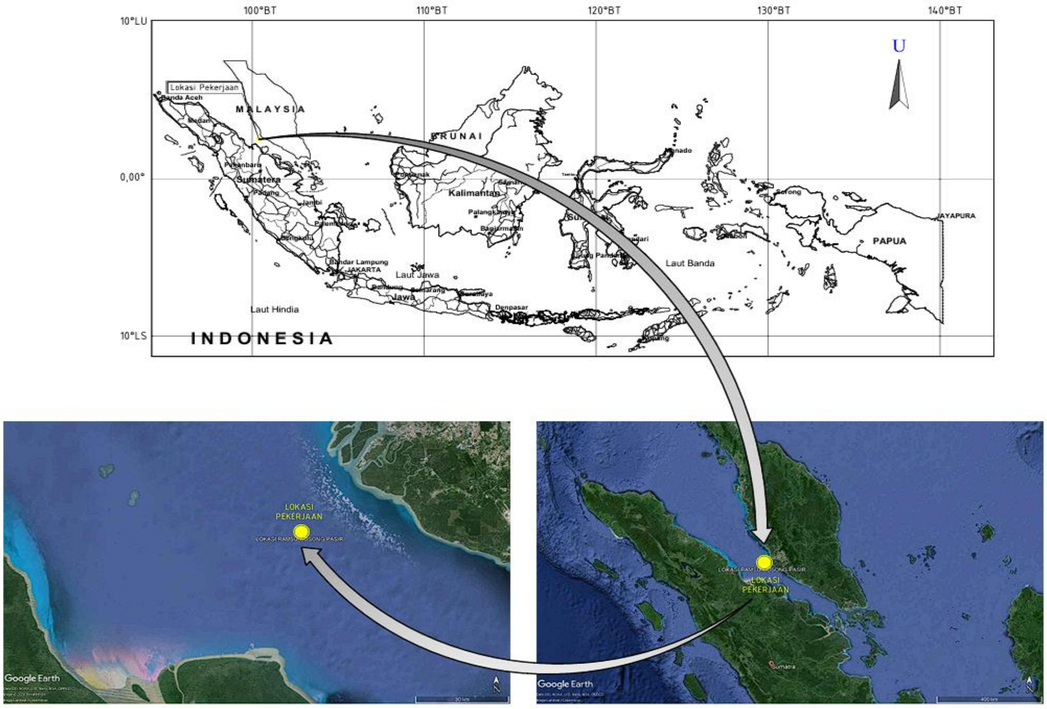

Figure 3. Orientation Map of the Gosong Pasir Light Beacon Work Location

1. Survey Analysis

The planning of the Gosong Pasir Light Beacon requires bathymetric data to obtain a model of the seabed surface. The analysis is conducted based on geodetic parameters, as shown in Table 1. The bathymetric survey covers an area of 1000 m x 1000 m with a primary track spacing of 10 meters. The data is processed using NavEdit software and plotted onto a single map. The results indicate that the seabed depth in the Gosong Pasir Light Beacon area ranges from -0.777 m LWS to -20.483 m, as depicted in Figure 4.

Table 1. Geodetic Parameters

Spheroid	WGS 84
Projection	UTM
Centre Meridian	100° E
Zone	47 North
False Easting	500000 m
False Northing	10000000 m
Scale Factor	0.9996

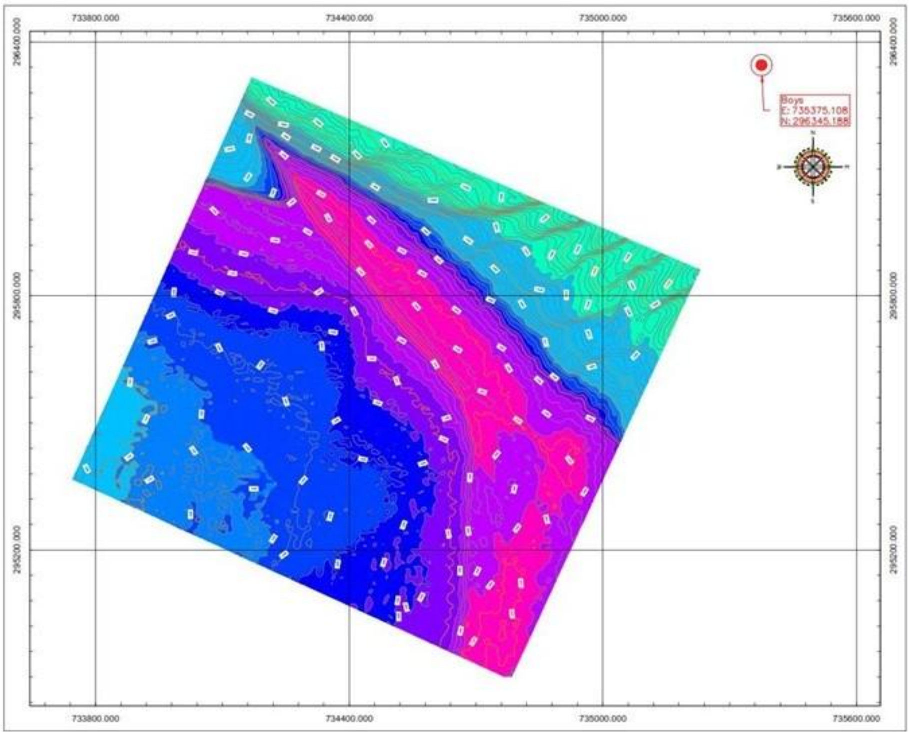

Figure 4. Bathymetry Map

Additionally, side-scan sonar data reveals the seabed conditions in the Gosong Pasir Light Beacon area, which consist of high reflectivity sediment and low to moderate reflectivity sediment. The analysis concludes that most of the seabed in the area exhibits low reflectivity, corresponding to sand sediment across the region. The seabed image displays sediment gradation and the presence of sand ripples, as shown in Figure 5.

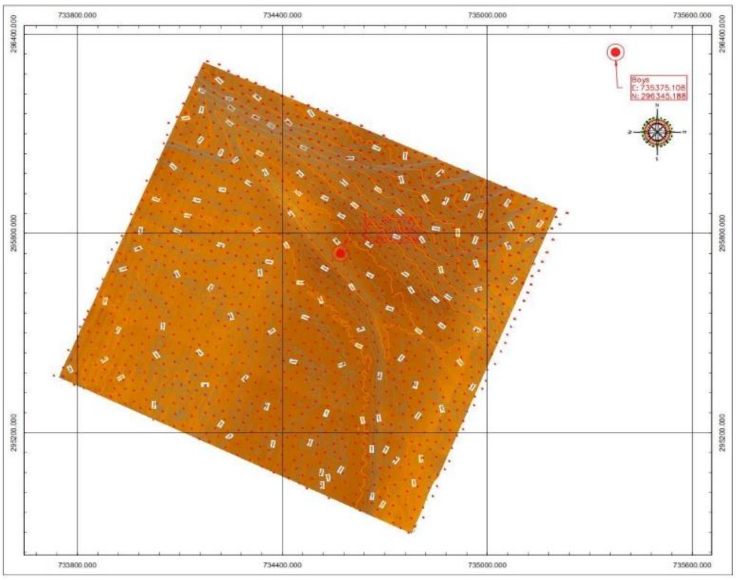

Figure 5. Underwater Imagery and Bathymetry Map

Sub-bottom profiling is conducted to obtain information on sedimentary layering beneath the seabed and verify the positions of subsurface objects. The data is processed using SonarWiz 7 software, following the bathymetric tracks and adjusting to current and wave conditions with a primary track interval of 50 meters and cross-track spacing of 200 meters. Interpretation is based on seismic signal analysis and sediment sample references, with the results displayed in Figure 6.

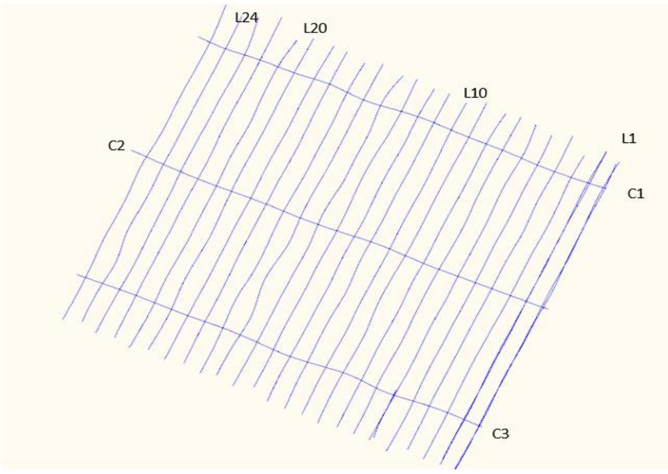

Figure 6. Sub-Bottom Profile Interpretation Line

Hydro-oceanographic data includes tidal, current, and wave data. A 30-day tidal observation with readings taken every 5 minutes categorizes the tides as a mixed semi-diurnal type. A comparison between the Admiralty and Least Squares methods for determining tidal range in the Gosong Pasir Light Beacon planning confirms that the Admiralty method provides the most accurate field representation. Current measurements are taken at two points with depth-layered readings, revealing a maximum current velocity of 1.733 m/s, as shown in Figure 7. Wave analysis estimates a deep-sea wave height with a 50-year return period at 571.60 cm from the northwest. Due to wave propagation effects, wave heights at the planned site differ from those in deep water, as summarized in Table 2.

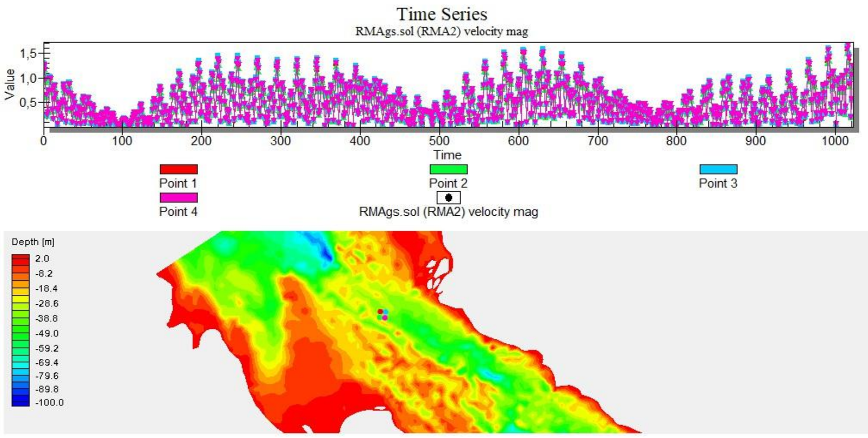

Figure 7. Current Velocity Graph During Simulation in the Area Around Gosong Pasir Beacon

Table 2. Wave Heights in the Gosong Pasir Light Beacon Area

Wave Direction	Deep Sea Wave Height Return Period 50 (Years)	Simulated Wave Height at the Planned Location of the Light Beacon
	H (cm)	H (cm)
North	109.00	58.00 – 84.00
Northeast	75.60	41.00 – 53.00
East	71.90	39.00 – 52.00
Southeast	143.10	58.00 – 111.00
South	76.30	35.00 – 55.00
Southwest	105.50	44.00 – 69.00
West	102.20	52.00 – 78.00
Northwest	571.60	195.00 – 380.00

Sediment sampling and water quality analysis are conducted both in situ and ex situ to determine seabed material composition. Laboratory results indicate that sand sediment is dominant, accounting for 99% of samples, while water sediment concentrations range from 2.5 mg/L to 19.9 mg/L.

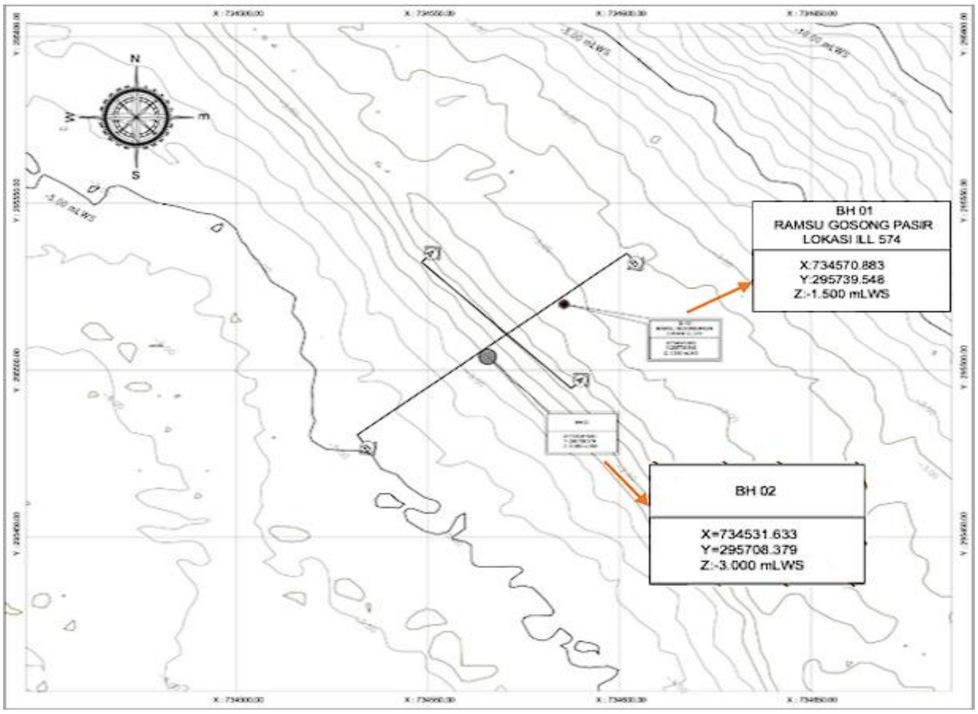

Figure 8. Location of Soil Investigation Points

2. Geotechnical Analysis

Soil data is obtained from core drilling at two locations. Figure 8 shows the borehole locations, and Table 3 provides a summary of soil investigation results.

Table 3. Summary of Soil Investigation at Gosong Pasir Light Beacon

No	Bore Hole	Coordinate		Depth (m)
		X	Y	
1	BH-01	734570.883	295739.548	32.45
2	BH-02	734531.633	295708.379	28.00

The borehole data shows that the upper soil layers (4–5 meters deep) consist of loose to very loose coarse sand (NSPT < 4 blows/30 cm). At depths of 28–32 meters, the core drilling results indicate dense coarse sandstone layers. Figure 9 presents the core drilling results integrated with sub-bottom profile analysis. Using the Touma & Reese method, pile bearing capacity is determined for a 30-meter depth using a 609 mm diameter steel pipe pile with a 14 mm thickness.

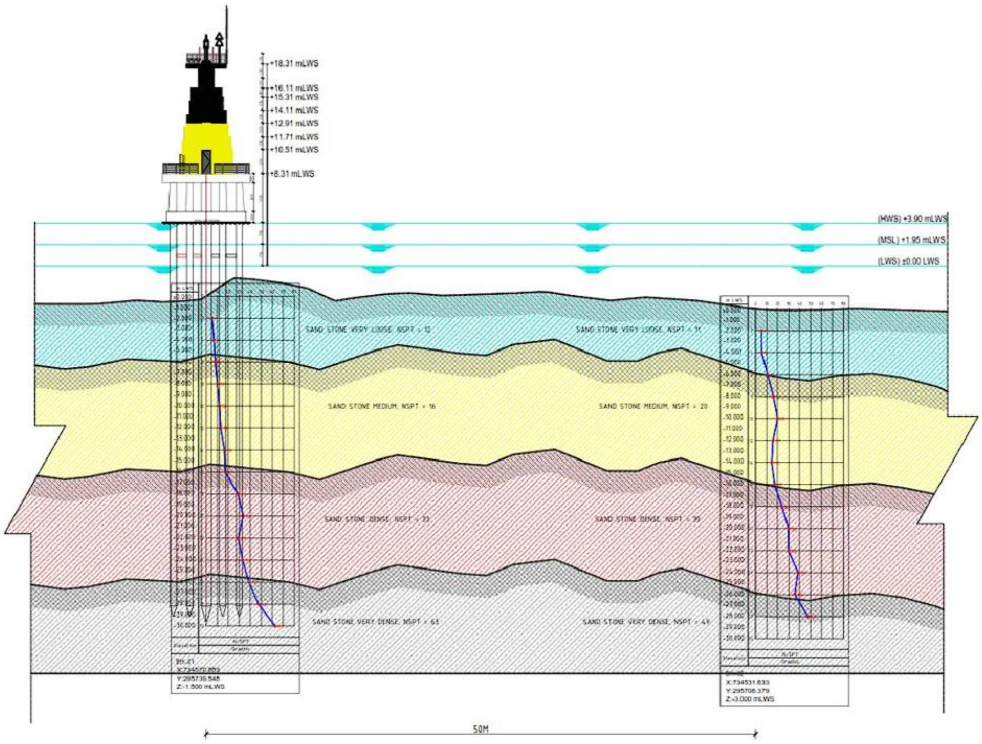

Figure 9. Stratigraphy of the Soil at the Work Site

3. Structural Analysis

Material properties and structural dimensions for the Gosong Pasir Light Beacon are listed in Table 4.

Table 4. Structural Material Strength and Dimensions

Structural Material		
Concrete	f'c = 31 MPa	
Steel (piles)	ASTM A53 grade B (UpperStruktur) ASTM A252 grade B (Tiang Pancang) Fy = 240 MPa, Fu = 415 Mpa Dia 609 mm t= 14 mm	
Reinforced Steel (BJTS 420A)	Fy = 420 MPa, Fu = 525 MPa	
Plain Reinforcing Steel (BJTP 280)	Fy = 280 Mpa, Fu = 405 MPa	
Dimension Material Structure		
Element	**Dimension (mm)**	**Material**
Beam	Pipe 304,8 mm	Steel
Platform Deck	Tower Beacon DP1 150 x 100 x 80 Tower Beacon DP2 300 x 300 x 12	Concrete
Pile	ø=609 t=14	Steel

The analysis considers the largest vessel that will use the Gosong Pasir Light Beacon. Maximum vessel characteristics are provided in Table 5.

Table 5. Maximum Vessel Characteristics

Vessel Characteristics Docking at Gosong Pasir Light Beacon	
Ship Type	Passenger Ship /Patrol Boat
Weight	30 GT (maximum)
Full Draft	1,2 m
Length (LOA)	18,5 m
Beam	4,60 m
Berthing Velocity	0,2 m/det
Maximum Berthing Angle	25°

Structural modeling is conducted using SAP2000, resulting in a 3D representation shown in Figure 10. The beacon's diameter is 7.20 meters (Figure 11), with deck elevations as follows:

- Deck 1: +3.9 m LWS
- Deck 2: +8.31 m LWS
- Seabed: -1.50 m LWS

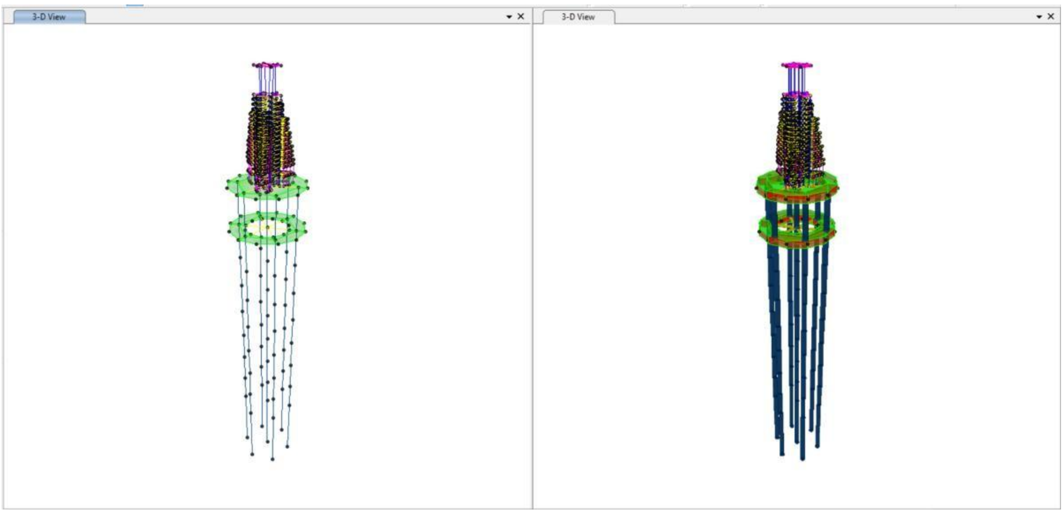

Figure 10. 3D Modeling of the Gosong Pasir Beacon

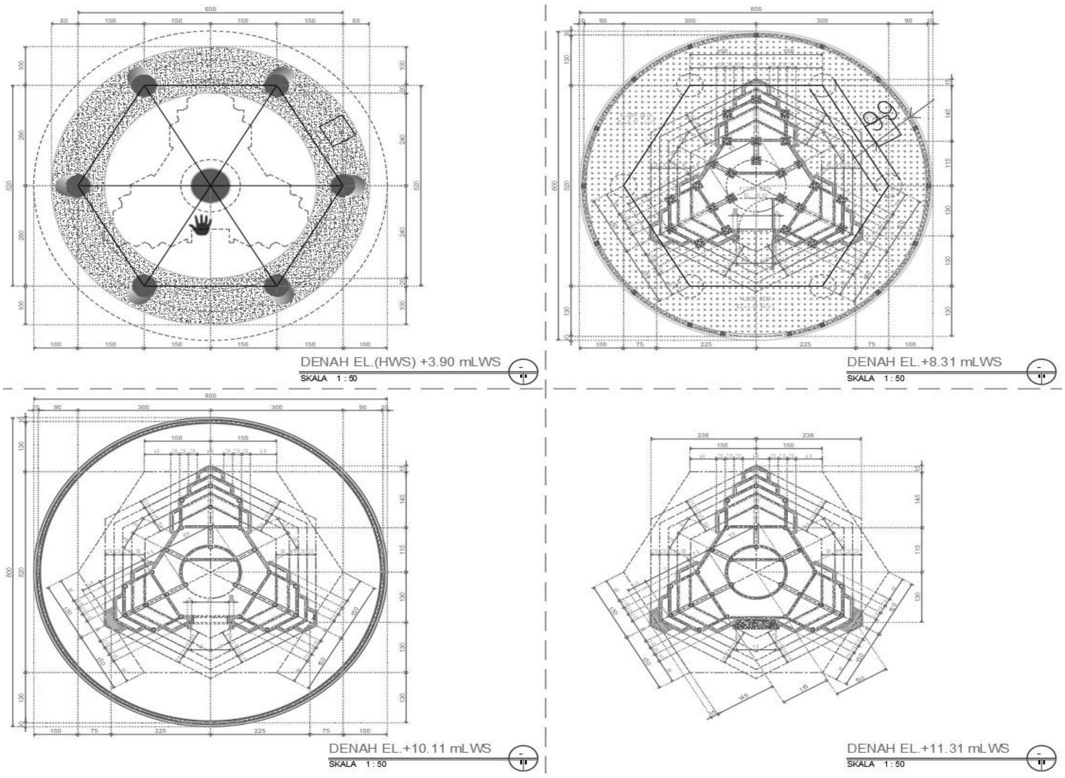

Figure 11. Layout of the Gosong Pasir Beacon

With advancements in construction and material technology, various alternative methodologies have been introduced to enhance reliability under different conditions. The Gosong Pasir Light Beacon is designed with a modern aesthetic while incorporating local cultural elements. This design makes it the first of its kind in Indonesia, as shown in Figure 12.

Figure 12. Perspective of the Gosong Pasir Beacon

Structural analysis is performed using SAP2000, modeling pile foundations with elastic spring supports. Load combinations are applied according to SNI 1725-2019, with a summary of applied loads in Table 6 and load combinations in Table 7.

Table 6. Load Summary

Vertical Load	Dead Load	Selfweight = 1
	Live Load	0.2 ton/m^2
	Uplift Load	15.96 kN
Horizontal Load	Berthing Load	193 kN
	Mooring Load	30 kN
	Wave and Current Load	Wave Height = 3.80 m Wave Period = 10.6 s Current Speed = 1.733 m/s
	Seismic Earthquake	Structure R = 3.0 Pile R = 2.0

Table 7. Load Combination

Boundary State	D	L	T	AG	U	Ex	Ey	B	M
Strong 1	1.3	1.8	1.8	1	-	-	-	-	-
Strong 2	1.3	1.4	1.4	1	-	-	-	-	-
Strong 3	1.3	-	-	1	-	-	-	-	-
Extreme 1-1	1.3	0.5	0.5	1	-	1	0.3	-	-
Extreme 1-2	1.3	0.5	0.5	1	-	0.3	1	-	-
Extreme 1-3	1.3	0.5	0.5	1	-	-1	-0.3	-	-
Extreme 1-4	1.3	0.5	0.5	1	-	-0.3	-1	-	-
Extreme 2-1	1.3	0.5	0.5	1	-	-	-	1*)	-
Extreme 2-2	1.3	0.5	0.5	1	-	-	-	-	1*)
Service Life 1	1	1	1	1	-	-	-	-	-
Service Life 2	1	1.3	1.3	1	-	-	-	-	-
Service Life 3	1	0.8	0.8	1	-	-	-	-	-
Service Life 4	1	-	-	1	1	-	-	-	-
Earthquake 1	1	0.5	0.5	-	-	1	0.3	-	-
Earthquake 2	1	0.5	0.5	-	-	0.3	1	-	-
Earthquake 3	1	0.5	0.5	-	-	-1	-0.3	-	-
Earthquake 4	1	0.5	0.5	-	-	-0.3	-1	-	-

The structural analysis results with various load combinations yield internal forces and reactions from the structure's foundation. The strength of the steel structural elements, particularly the pile elements, shows a color range indicating the load-to-capacity ratio. This ratio can be seen in Figure 13. The detailed results of the pile capacity ratio are shown in Table 8 below.

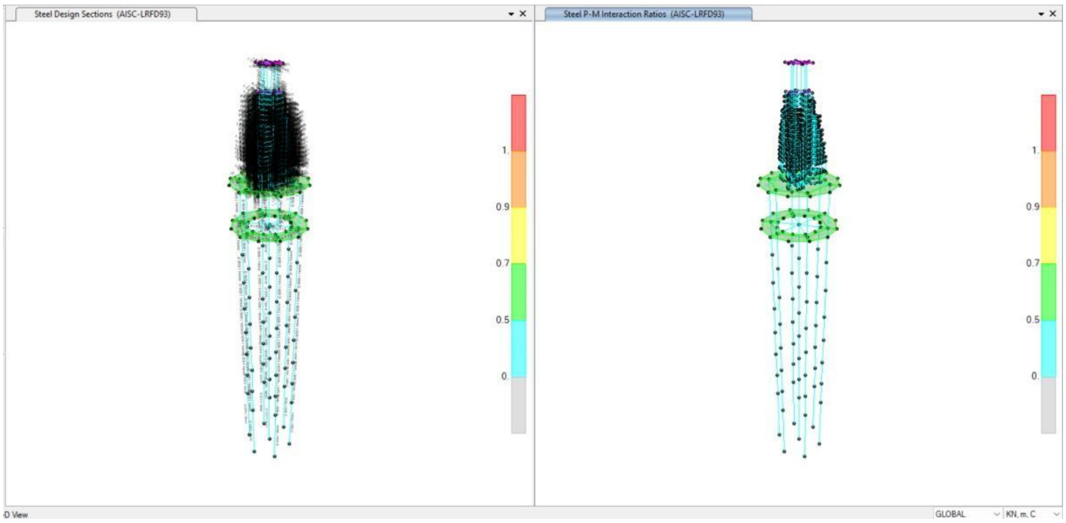

Figure 13. Pile Capacity Ratio

Table 8. Pile Capacity Ratio for Gosong Pasir Beacon

Frame Text	DesignSect Text	DesignType Text	Status Text	Ratio Unitless	RatioType Text	Combo Text	Location m	ErrMsg Text
20	D 609 t 14mm	Column	No Messages	0.493905	PMM	EKSTRIM 1-1= 1.3D...	0	No Messages
8	D 609 t 14mm	Column	No Messages	0.493299	PMM	EKSTRIM 1-1= 1.3D...	0	No Messages
16	D 609 t 14mm	Column	No Messages	0.479228	PMM	EKSTRIM 1-2 =1.3D...	0	No Messages
28	D 609 t 14mm	Column	No Messages	0.479061	PMM	EKSTRIM 1-2 =1.3D...	0	No Messages
12	D 609 t 14mm	Column	No Messages	0.478036	PMM	EKSTRIM 1-2 =1.3D...	0	No Messages
4	D 609 t 14mm	Column	No Messages	0.477884	PMM	EKSTIM 1- 4=1.3D+1...	0	No Messages
24	D 609 t 14mm	Column	No Messages	0.220629	PMM	EKSTRIM 1-2 =1.3D...	0	No Messages

The steel piles with a diameter of 609 mm and thickness of 14 mm show a maximum capacity ratio of 0.494, which does not exceed the allowable limit of 0.95, ensuring that the piles are safe to carry the ultimate load combination. The Gosong Pasir Beacon is designed for a pile thickness to last for 50 years. Considering a corrosion rate of 0.11525 mm/year, the total corrosion thickness is 8.2375 mm. This condition is calculated based on the corroded pile thickness. Figure 14 and Table 9 show the pile capacity ratio for the operational condition during the design lifetime.

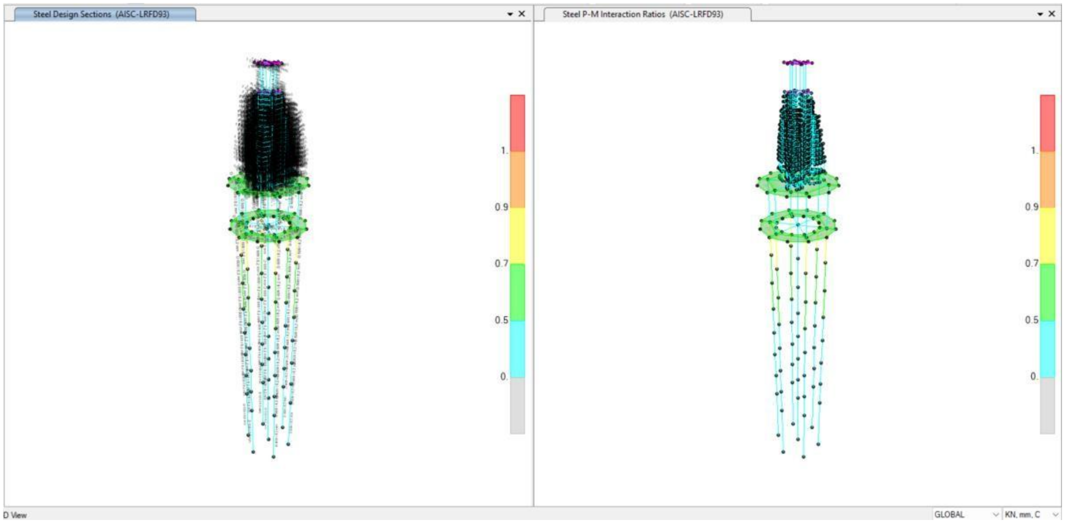

Figure 14. Pile Capacity Ratio under Operational Condition during Design Life

Table 9. Pile Capacity Ratio under Operational Condition during Design Life

Frame Text	DesignSect Text	DesignType Text	Status Text	Ratio Unitless	RatioType Text	Combo Text	Location mm	ErrMsg Text
20	D 609 t 8,2 mm	Column	No Messages	0.728447	PMM	EKSTRIM 1-1= 1.3D...	0	No Messages
8	D 609 t 8,2 mm	Column	No Messages	0.72756	PMM	EKSTRIM 1-1= 1.3D...	0	No Messages
16	D 609 t 8,2 mm	Column	No Messages	0.708417	PMM	EKSTIM 1- 4=1.3D+1...	0	No Messages
28	D 609 t 8,2 mm	Column	No Messages	0.708209	PMM	EKSTRIM 1-2 =1.3D...	0	No Messages
12	D 609 t 8,2 mm	Column	No Messages	0.706597	PMM	EKSTRIM 1-2 =1.3D...	0	No Messages
4	D 609 t 8,2 mm	Column	No Messages	0.706403	PMM	EKSTRIM 1-2 =1.3D...	0	No Messages
24	D 609 t 8,2 mm	Column	No Messages	0.361283	PMM	EKSTRIM 1-2 =1.3D...	0	No Messages

Based on the analysis of the capacity ratio, the steel piles with a diameter of 609 mm and a thickness of 8.2375 mm result in a maximum capacity ratio of 0.728, which still does not exceed the allowable limit of 0.95. Therefore, the piles are considered safe and meet the planned loading criteria.

Furthermore, an analysis of deflection values is performed based on displacement analysis, focusing on the translational movement of the pile's tip, analyzed using U1 and U2 values. The largest values are used for displacement analysis on the structure. The allowable deflection for service condition is 50 mm, while for earthquake condition, the limit is 100 mm. Table 10 shows the joint displacement results for the service condition, while Table 11 shows the results for the earthquake condition. Table 12 provides a summary of the joint displacement analysis.

Table 10. Joint Displacement for Service Condition

Joint	OutputCase	CaseType	StepType	U1	U2
Text	Text	Text	Text	mm	mm
585	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.512	0.013
584	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.512	0.014
591	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.512	0.013
590	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.512	0.014
592	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.511	0.013
586	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.511	0.013
344	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.511	0.014
589	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.511	0.015
595	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.511	0.014
593	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.511	0.013
594	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.511	0.014
587	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.510	0.013
588	EKSTRIM 2-2=1.3D+1AG+0.5L+0.5T+1B	Combination		12.510	0.014

Table 11. Joint Displacement for Earthquake Condition

Joint	OutputCase	CaseType	StepType	U1	U2
Text	Text	Text	Text	mm	mm
585	EKSTRIM 1-1= 1.3D+1AG + 0.5L +0.5T+1Ex +0.3Ey	Combination	Max	81.620903	24.286668
585	EKSTRIM 1-3 =1.3D + 1AG+0.5L +0.5T-1Ex-0.3Ey	Combination	Max	81.620903	24.286668
584	EKSTRIM 1-1= 1.3D+1AG + 0.5L +0.5T+1Ex +0.3Ey	Combination	Max	81.620893	24.262833
584	EKSTRIM 1-3 =1.3D + 1AG+0.5L +0.5T-1Ex-0.3Ey	Combination	Max	81.620893	24.262833
585	GEMPA L1= 1D + 0.5L+0.5T+(1Ex+0.3Ey)	Combination	Max	81.612344	24.283774
585	GEMPA L3=1D +0.5L+0.5T-(1Ex+0.3Ey)	Combination	Max	81.612344	24.283774
584	GEMPA L1= 1D + 0.5L+0.5T+(1Ex+0.3Ey)	Combination	Max	81.612336	24.259688
584	GEMPA L3=1D +0.5L+0.5T-(1Ex+0.3Ey)	Combination	Max	81.612336	24.259688
591	EKSTRIM 1-1= 1.3D+1AG + 0.5L +0.5T+1Ex +0.3Ey	Combination	Max	81.606309	24.281539
591	EKSTRIM 1-3 =1.3D + 1AG+0.5L +0.5T-1Ex-0.3Ey	Combination	Max	81.606309	24.281539
590	EKSTRIM 1-1= 1.3D+1AG + 0.5L +0.5T+1Ex +0.3Ey	Combination	Max	81.6063	24.267804
590	EKSTRIM 1-3 =1.3D + 1AG+0.5L +0.5T-1Ex-0.3Ey	Combination	Max	81.6063	24.267804
591	GEMPA L1= 1D + 0.5L+0.5T+(1Ex+0.3Ey)	Combination	Max	81.597841	24.27859
591	GEMPA L3=1D +0.5L+0.5T-(1Ex+0.3Ey)	Combination	Max	81.597841	24.27859
590	GEMPA L1= 1D + 0.5L+0.5T+(1Ex+0.3Ey)	Combination	Max	81.597835	24.264711
590	GEMPA L3=1D +0.5L+0.5T-(1Ex+0.3Ey)	Combination	Max	81.597835	24.264711

Table 12. Joint Displacement Recap

Condition	Joint Displacement **(cm)**	Design Allowance **(cm)**	**Remarks**
Service	1,25	5	OK
Earthquake	8,16	10	OK

Based on the displacement analysis summarized in Table 12 above, both service and earthquake conditions do not exceed the allowable limits. Therefore, the structure is considered safe.

According to the Ministerial Regulation PM No.25 of 2011, SBNP refers to the equipment or system outside of ships designed and operated to enhance navigation safety and efficiency of ships and/or vessel traffic. After determining the maximum characteristics of the ship to dock, the analysis of the fender mounting at Gosong Pasir Beacon is modeled with the berthing load, considered as a live load of 193 kN. The fender is modeled using a WF 300, connected with a steel pipe of diameter 609 mm and thickness 14 mm.

The fender analysis uses a load combination of 1.2D + 1.6L. The result of the analysis shows the capacity ratio, as presented in Table 13 below. The maximum capacity ratio obtained is 0.246, which is within the allowable limit of 0.95, ensuring the fender mounting can safely bear the ultimate load. The deflection result for the fender mounting is 0.13 mm, well below the allowable limit of 50 mm. Therefore, the deflection is considered safe. The fender deflection analysis results are presented in Table 14.

Table 13. Fender Mounting Capacity Ratio

Frame Text	DesignSect Text	DesignType Text	Status Text	Ratio Unitless
3	WF 300	Beam	No Messages	0.24609
4	WF 300	Beam	No Messages	0.24609
5	WF 300	Beam	No Messages	0.24609
6	WF 300	Beam	No Messages	0.24609
7	WF 300	Beam	No Messages	0.24609

Table 14. Fender Mounting Deflection

Joint Text	OutputCase Text	CaseType Text	StepType Text	U1 mm
5	U2 = 1,2D +1,6L	Combination		1.354608
5	ENV	Combination	Max	1.354608
7	U2 = 1,2D +1,6L	Combination		1.034645
7	ENV	Combination	Max	1.034645
3	U2 = 1,2D +1,6L	Combination		1.034488
3	ENV	Combination	Max	1.034488

4. Cathodic Protection Analysis

The cathodic protection planning for Gosong Pasir Beacon in an aggressive marine environment involves selecting the appropriate steel material, applying suitable coatings, and adjusting the film thickness and drying time for optimal corrosion protection. One method applied is Sacrificial Anode Cathodic Protection (SACP), where active metals such as Zinc (Zn) and Aluminum (Al) are used to generate electrical currents. The metal with a more negative potential compared to steel will corrode first, protecting the steel (acting as the cathode) from corrosion. The SACP system links two metals with different potentials, where the anodic metal corrodes, and the steel remains safe (Callender & Thompson S., 2021; Chiu & Hsu J., 2019; Lee & Cho S., 2018; Shao & Tang J., 2020).

The design and calculation stages of the SACP system should be performed systematically and thoroughly, considering the interrelationships between parameters. For the Gosong Pasir Beacon, the proposed SACP system follows the methodology of the NACE Standard RP0176. The product used is Flush-Mounted Aluminum Anodes with Flat Bar Insert (brand Yuxi), chosen for their light weight, ease of installation, and availability in various sizes (Blamey & Wilson A., 2017; International, 2018; Zhao & Zhang X., 2020). The anodes are equipped with steel rod terminals welded to the structure submerged in seawater, as shown in Figure 15 below.

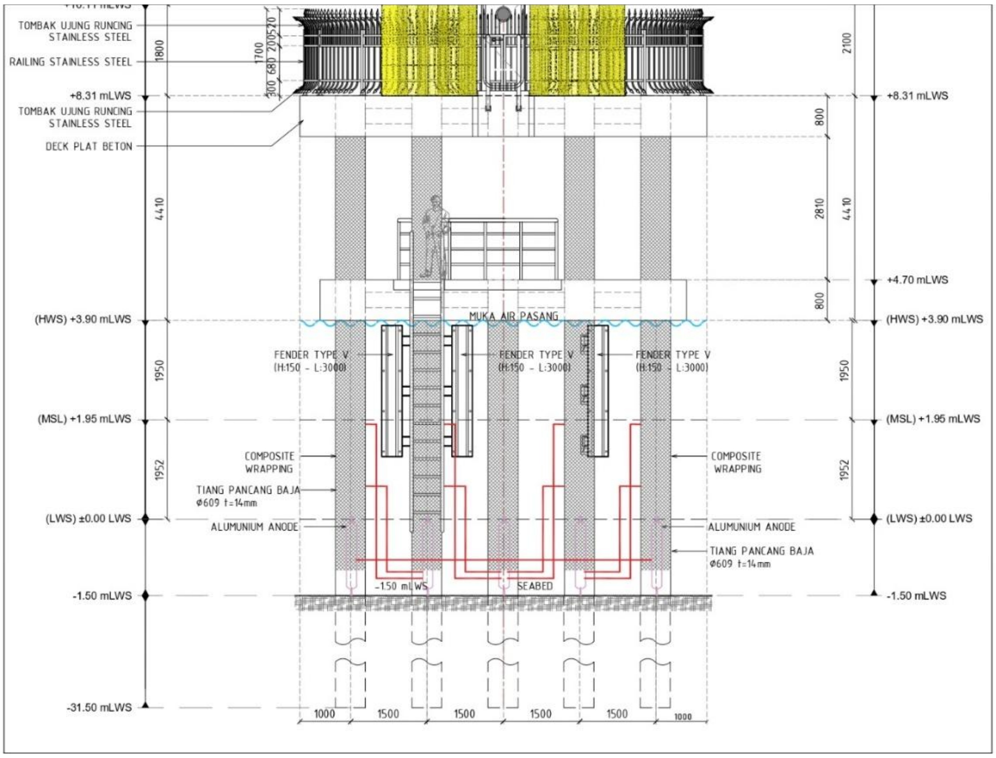

Figure 15. Anode Installation Position

In addition to cathodic protection, corrosion at Gosong Pasir Beacon is also triggered by seawater containing chloride ions that accelerate metal degradation. To address this, an effective coating system is required. The coating protection heavily depends on the base layer that provides good adhesion between the paint and the steel material.

The painting process for Gosong Pasir Beacon involves several layers: primer, anti-corrosion layer (intermediate), and anti-fouling topcoat. Each layer serves to control corrosion rates and protect the steel structure from the aggressive marine environment. Successful painting depends on the cleanliness of the base metal surface. Surface preparation is done using sandblasting, which uses high-pressure sprays with abrasive particles such as silica sand, olivine aluminum oxide, and iron sand. The goal is to remove rust, mill scale, and old paint while creating a rough surface to serve as an anchor pattern for paint adhesion. Sandblasting success should refer to the SSPC Sa No.3 or SSPC SP No.5 cleanliness standards.

A sufficient film thickness is essential for effective corrosion protection. The Dry Film Thickness (DFT) according to SSPC-PA 2 must be verified and recorded in the inspection document. Wet Film Thickness (WFT), based on ASTM D1212-

91, can be calculated from the nominal DFT value and solids by volume percentage. Based on the standards, the recommended coating specification for Gosong Pasir Beacon is a Zinc-rich base with added epoxy, polyurethane, acrylic, alkyd, and zinc silicate, with three layers of painting and a final thickness of 320-360 µm for maximum corrosion protection.

CONCLUSION

The *Gosong Pasir* Beacon's design has experienced two structural failures. This highlights the need for a more in-depth analysis for future construction. Considering the beacon's condition before the collapse on January 12, 2018, issues such as corrosion and concrete damage are critical factors to address in this design. Surveys and studies regarding the surrounding area for construction must be conducted to ensure the solution is suitable, making the *Gosong Pasir* Beacon a functional and effective beacon in line with the Minister of Transportation's Decree No. PM 25 of 2011 concerning *Navigation Safety Aids*.

Based on the geotechnical and structural analysis, it is concluded that the *Gosong Pasir* Beacon's structure uses steel and concrete materials. Steel materials include ASTM A53 Grade B for the superstructure and ASTM A252 Grade B for the piles with a diameter of 609 mm, thickness of 14 mm, and depth of 30 meters. Concrete strength used is 33.2 MPa (K-400 kg/cm²) with exposure class S2. For the superstructure, the pipes used are A36 with 4” pipes for the upper structure and 1.5” pipes for the bracing. To enhance the strength of the lower structure, the number of piles was increased from 4 to 7, and the previous open-frame structure will be enclosed with weather-resistant material to avoid corrosion. Thus, the pile arrangement forms a hexagonal pattern with one pile at the center.

Additionally, based on the analysis to protect the structure from corrosion, *Sacrificial Anode Cathodic Protection* (SACP) is applied, where anodic metals corrode first, protecting the steel. This process complies with NACE Standard RP0176 for Corrosion Control of Steel Fixed Offshore Structures Associated with Petroleum Production. Flush-Mounted Aluminum Anodes with Bar Inserts (brand Yuxi) are used for the cathodic protection, chosen for their slow consumption rate, making them ideal for marine applications.

As seawater contains chloride ions that accelerate metal damage, the *Gosong Pasir* Beacon design uses a coating system based on ISO 12944 corrosion protection standards for steel structures. Proper film thickness ensures effective corrosion protection, with the Dry Film Thickness (DFT) and Wet Film Thickness (WFT) measured and verified as per the standards. The recommended coating for the *Gosong Pasir* Beacon includes zinc-rich paint with added epoxy, polyurethane, acrylic, alkyd, and zinc silicate, with three paint layers and a final thickness of 320–360 µm for optimal corrosion protection. Therefore, the planned design of the *Gosong Pasir* Beacon, with these solutions, results in a safe and reliable maritime safety facility that supports navigation safety.

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