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Monitoring of Substructure Building of Suramadu Bridge Causeway Segment on Surabaya Side Based on Corrosion Level

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A B S T R A C T

The structure of the steel pile foundation for the Suramadu Bridge crossroad is located in a corrosive marine area. Air humidity, rainwater, mud, or friction with other objects that cause the protective layer to peel off. Corrosion monitoring is carried out to determine the corrosion rate as one of the steps to prevent corrosion. This study aims to evaluate and monitor the bridge's structure Suramadu Causeway. The evaluation carried out includes observing the damage caused by corrosion. So that it will be known the cause of corrosion and the handling of corrosion protection in the building under the bridge, this study used primary and secondary data collection methods and visual observation of damage from routine inspections carried out. The observations show that the condition of the piles is filled with marine life in the tidal area, while for areas that have never been submerged the condition is quite good. The value of the condition of the structural elements at level 3 - 5, which requires protection on steel pillars that have suffered a lot of damage—handling that needs to be done in the Atmospheric zone and Splash zone / Tidal zone is recommended Recoating, Wrapping, HDPE Jacketing, Epoxy Grouting. In the Submerged zone and the Embedded zone, it is recommended that the Cathodic Protection be replaced (120 kg for 600 mm). So from the results of the research that has been done, it can be used as a study for the maintenance of the Suramadu bridge in preventing corrosion.

1. Introduction

Suramadu Bridge is the longest Cable Stay bridge in Indonesia which currently spans the Madura Strait and connects Java Island (Surabaya City) with Madura Island (Bangkalan Regency). This bridge was built at a great cost, so it is worth a high investment with a design life of 100 years [1][2]. The Suramadu Bridge consists of 3 (three) parts of the bridge structure, namely the Causeway (Surabaya side and Madura side), Approach Bridge (Surabaya side and

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Madura side), and the Main Bridge, with a total bridge length of 5,438 meters and a bridge width of 30 meters [3][4]. Causeway Suramadu Bridge was built to connect the bridge construction with land access roads through shallow water on both sides, namely the Surabaya and Madura sides. The Causeway on the Surabaya side consists of 36 spans of 1,457.5 m, and the Causeway on the Madura side consists of 45 spans of 1,818.5 m. The Causeway Upper Structure Building is a Pre-stressed Concrete I Girder (PCI Girder) with a length of ± 40 m each for each beam, and the Substructure Building is a steel pile foundation with a diameter of 600 mm and 1000 mm.

The steel pile foundation structure of the Suramadu Causeway Bridge on the Surabaya side and the Madura side is in a corrosive marine area. The environmental conditions around the foundation pile structure require special attention, particularly the prevention and control of corrosion. In an environment that has a high pH, the corrosion rate will generally be faster for corrosion [5][6]. Factors causing corrosion, among others, are caused by; humidity, rain, mud, or friction with other objects that cause the protective layer of steel to be damaged and peeled off [7][8][9]. Corrosion arises due to an oxidation reaction between metal materials and oxygen, one of which can accelerate the corrosion process, namely seawater which contains salt levels [10][11]. Corrosion occurs because the metal surface is in direct contact with acid-containing water so that it undergoes a process of air oxidation [12]. The more dirty water allowed to stick to the steel pile, the more acid reacts to the iron, causing corrosion. The occurrence of corrosion in a building can affect the service life of the building because the performance of the building's structural components decreases [13][14].

Therefore, so that this bridge can maintain its service until the age of the plan mentioned above, routine maintenance activities are carried out on the Suramadu Bridge. This study aims to analyze and monitor the structure under the causeway piles of the Suramadu bridge, which is affected by corrosion. So that by doing this analysis, the factors that cause corrosion, the level of corrosion, and proper handling are obtained.

2. Research Method

This research is located at the Suramadu Bridge, East Java, focusing on the causeway section piles on the Surabaya and Madura sides. Some of the scopes of problems raised are the causes of corrosion on the Surabaya side of the Suramadu Bridge Causeway, the level of corrosion that occurs, the analysis and strategy for handling the structural reliability of the Surabaya side Suramadu Bridge Causeway. The data from this study were obtained by conducting a visual survey in the field directly on the Suramadu Bridge and collecting data on the construction of the Suramadu bridge from the relevant agencies.

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2.1 Data Collection

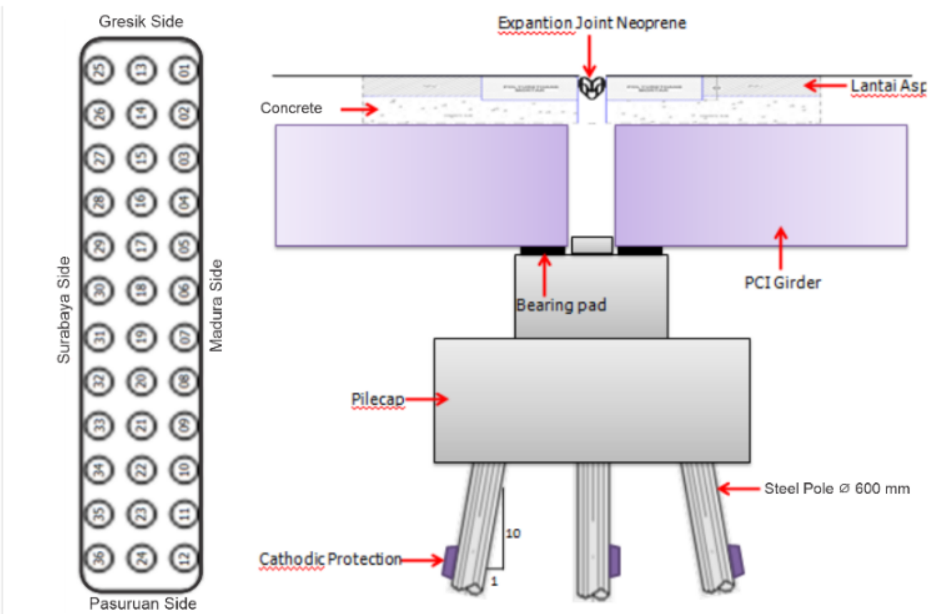
The data used include primary and secondary data with the following description:

1. Primary Data

   Data were taken from the condition of the Suramadu Bridge and observations of visual damage to the Suramadu Bridge, especially the Causeway sections on the Surabaya and Madura sides. Observations were made on 2951 causeway piles of the Suramadu Bridge.

2. Secondary Data

   The data taken include the length and cross-section of the Suramadu Bridge and routine inspection data of the Suramadu Causeway Bridge on the Surabaya side. Technical Study of Causway Pile Foundations for the substructure of the Causeway segment of the Suramadu Bridge in construction with steel piles 600 mm thick 12 mm and 1000 mm thick 16 mm, where the steel piles are driven to a depth of -26 m to -30 m for the Causeway on the Surabaya side and -28 m to -40 m for the Causeway on the Madura side. The following are the parts or elements of the Suramadu Bridge and the causeway segment:



Sources: Project Data

Figure 1. Long Section Segmen Causeway

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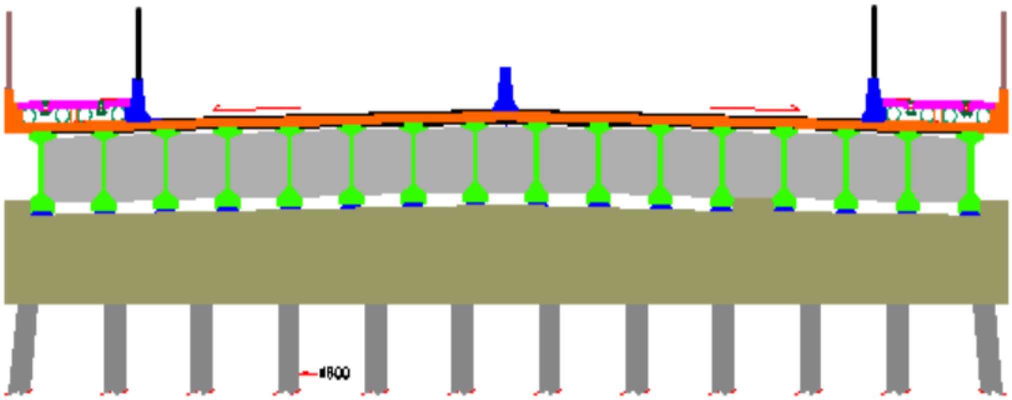

Sources: Project Data

Figure 2. Cross Section Segmen Causeway.

2.2 Observation of the Cause of Corrosion

Corrosion in a wet environment is usually accompanied by a cessation of direct current caused by the difference in electric potential in certain corrosion cells. Seawater corrosion is influenced by factors related to metals [15][16]. By conducting a site inspection and inspection, how much damage has occurred to the steel pile substructure of the Causeway Suramadu Bridge on the Surabaya side will be known. To identify the cause of pile corrosion in the marine area, a survey and inspection of the condition of the pile were carried out [17][18]. From the results of observations, identification of the cause of damage from each finding of defects is carried out, which is then assessed according to the format and type of code that has been determined so that the conclusion is obtained from the damage condition of each pile [19].

2.3 Corrosion Level

Corrosion level inspection is carried out using a supporting tool for checking the level of corrosion [20]. The conductivity of the dissolved electrolyte is generally determined by the conductivity of the corrosion rate factor or the severity of the metal in a corrosive environment [21][22]. One of them is the environment that contains chloride ions or the marine environment. The Testing / Measurement Equipment used is a Multimeter + Ag/AgCl electrode which is used to measure the cathodic potential value [23][24][25].

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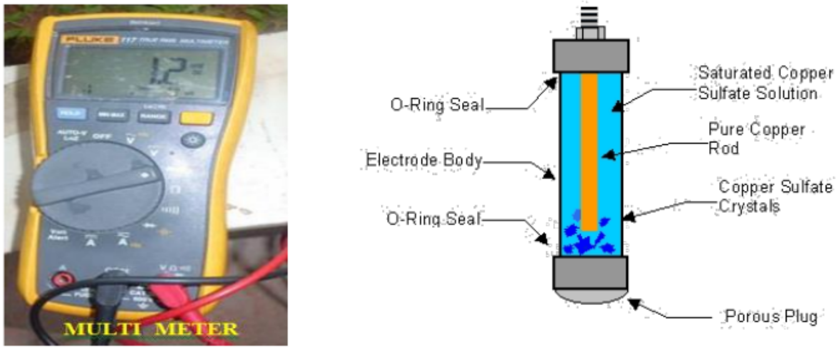

Sources: Electric Power System Research

Figure 3. Multimeter + Electrode Ag/AgCl

2.4 Repair Strategy

During a detailed inspection, it was found that the main components of the bridge were damaged by type 3 (bad condition) and type 4 (dangerous condition). A special inspection must be scheduled immediately if serious problems are discovered during the inspection.

Table 1. Value of Bridge Specific Conditions and Types of Maintenance

Condition Value	Description	Maintenance Type
0	Bridges/main components/elements are in good condition, and no damage only needs regular maintenance.	Routine Maintenance
1	The main bridge/component/element has minor damage and requires routine maintenance, may affect traffic conditions, and require immediate, routine maintenance.	Routine Maintenance
2	The main bridge/component/element is damaged, requiring regular monitoring or repair/maintenance.	Periodic Maintenance
3	The main bridge/component/element is damaged, which requires immediate action and has already affected the load capacity, requiring special inspection and repair or retrofitting.	Rehabilitation or strengthening
4	The main bridge/component/element is in critical condition, and maybe the bridge can still be functioned again by doing reinforcement.	Rehabilitation or strengthening
5	The main bridge/component/element is not working or collapsing.	Rehabilitation

Sources: Bridge Routine Maintenance Guidelines [26].

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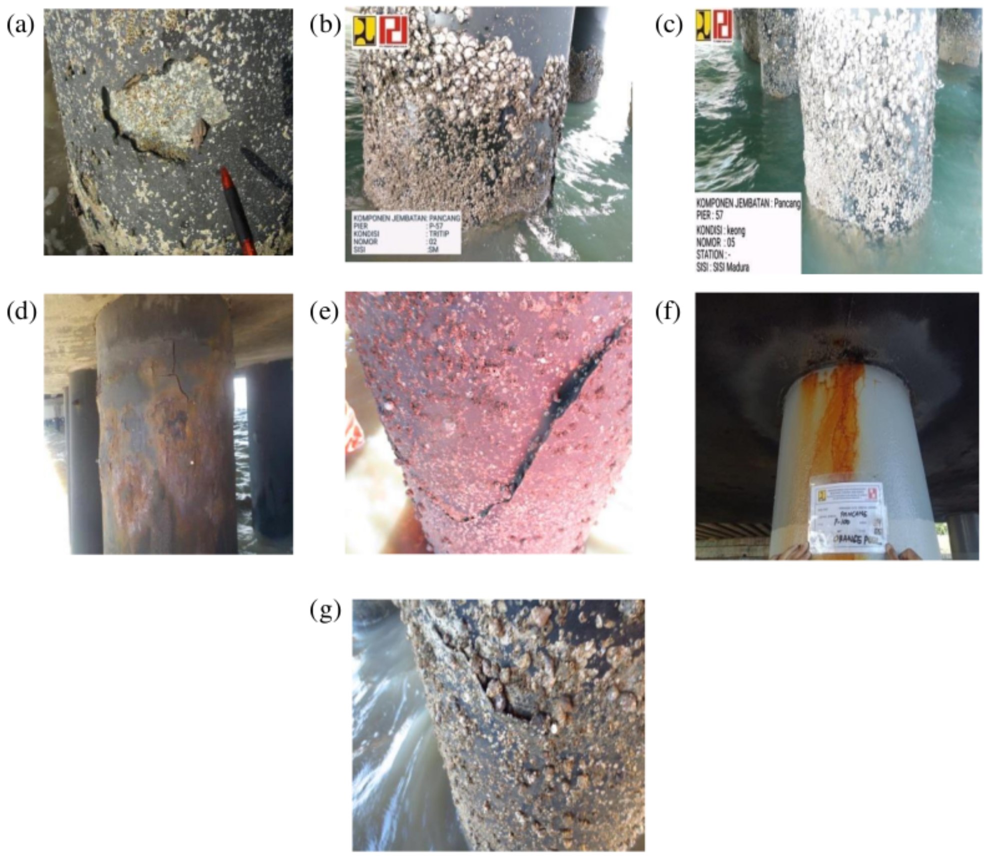
3. Results and Discussions

3.1 Pile Damage

After several years of piles being embedded in the waters of the Surabaya side, many piles have been damaged, including corrosion, peeling, porous, torn holes, bulging, tripping erosion, and snail erosion. During the inspection of the condition of the pile, visual observations and qualitative and subsequent assessments are carried out. The damage was caused by corrosion and several other factors so that the concrete blanket was damaged, with the observations presented in the following Figure:



Sources: Field Observation

Figure 4 (a) C-005 Metal Expose **(b)** C-008 Biofouling Tritip **(c)** C-009 Biofouling Keong **(d)** C-014 Blistering (e) C-016 Pin Holes (f) C-018 Orange Peel (g) C-020 Chalking Erosion

From **Figure 4(a),** it can be seen that the damage to the piles with the type of damage to hollow iron and concrete is visible. The damage occurred to 488 piles. **Figure 4(b)** pile damage with the type of damage: many tritip organisms are attached to the pile. The damage occurred in 1580 piles. **Figure 4(c)** damage to the pile with the type of damage, there are many snails attached to the pile, the damage occurred on 234 piles. **Figure 4(d)** pile damage with

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rust-type peeling/bubbling coating damage occurred on 150 piles. **Figure 4(e)** damage to piles with the type of damage to iron, torn piles the damage occurred to 72 piles. **Figure 4(f)** damage to piles with the type of damage to iron, corrosion, brownish-orange color, the damage occurred in 72 piles of 403 piles. **Figure 4(g)** damage to piles with the type of damage to the iron piles eroded due to tripping. The damage occurred to 24 piles. The above conditions mainly occur in the Splash Zone area (tidal area and areas affected by seawater splashes) at an elevation of -1.60 m to +1.90 m).

In general, the results of observations of the condition of the piles on the pile are filled with marine life in the tidal area, while for areas that have never been submerged in seawater, the condition is quite good. The splash zone is the area with the highest corrosion level, which occurs because the splash zone area is exposed to alternating currents between wet and dry continuously. In addition, the level of abrasion in this zone is quite high, so a strong protective layer is needed. The existence of damage to the protective layer (coating), both light and heavy, has not disrupted the integrity of the pile. However, the risk of increasing disturbance acceleration is expected to be very fast if corrective action is not taken. For the splash zone, disturbances of marine biota, namely tritip and snails, are identified. The activity of taking tritip by fishers with tools and boat collisions can damage the coating. From the inspection results on the components of the steel pile foundation, it can be categorized as a top priority recommendation to immediately get treatment because the damage is already at level-3 (bad condition) and level-4 (dangerous condition).

3.2 Corrosion Level

The cathodic protection system on all piers shows that the potential protection is still within the range specified in the protection standard, namely -800 mV to -1200 mV against the Ag/AgCl reference. The potential value for each pile is almost the same. The difference in potential values for each pile is in the range of 10-30 mV. This is because each pile is electrically connected to one pier. The graph shows the potential value for the lowest (more positive) pile of a pier as a representative of that pier. As the value of the protection, limit is given a blue line, and according to the standard of NACE (The National Association of Corrosion Engineer) RP-0169, the minimum limit of the protection potential value is -800 mV against reference Ag/AgCl (or -850 mV versus CSE). So from the results of the research that has been done, it can be used as a study for the maintenance of the Suramadu bridge to prevent corrosion.

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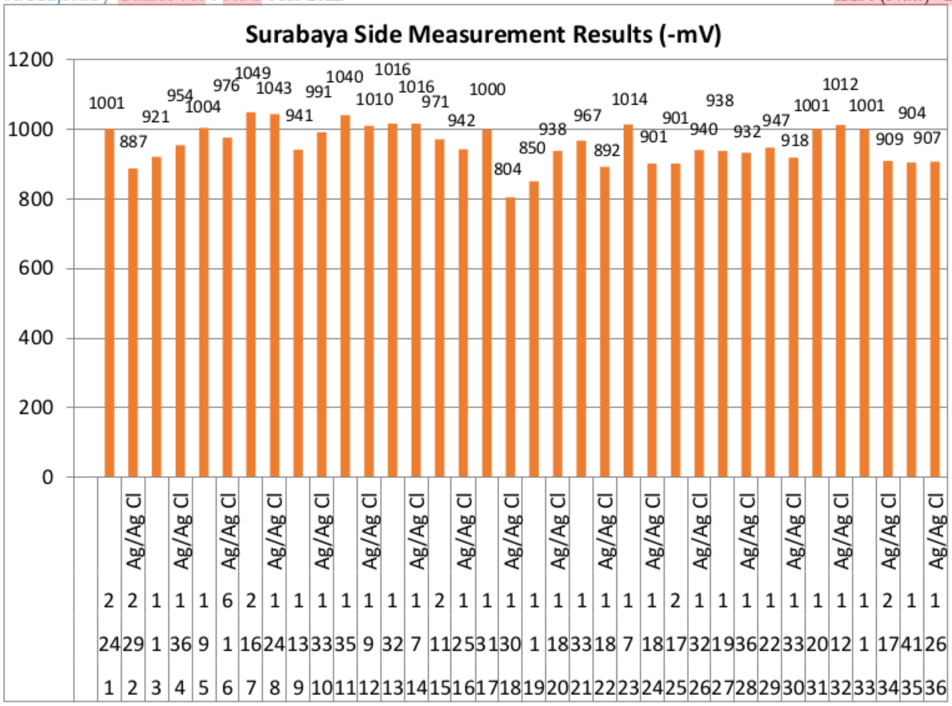

Source : Analysis Data

Figure 5. *Bar chart of the potential measurement results for the Cathodic Protection Causeway area on the Surabaya side*

Based on the graph of the measurement results in the Causeway area on the Surabaya side, there is 1 (one) pier that is on the threshold of protection, namely pier-18. Several other piers approaching the protection threshold value and need to be considered more intensively include pier-19, pier-22, pier-24, and pier-25. With details of P-18 all piles no.1 to no.36, P-19 piles no. 1, 2, 3, 9, 10, 11, 12, 14, 16, 17, 18, 19, 20, 21, 23, 33, P-22 pile no. 20, P-24 pile no. 18 and P.25 pile no.1. So for the Causeway on the Surabaya side, there is a replacement of 120 Kg Cathodic Protection (poles 600 mm) = 55 pcs.

3.3 Damage Handling

Causeway steel piles for the Suramadu Bridge with a diameter of 600 mm and 1000 mm are staked in the waters of the Madura Strait with a depth varying between –26 m to -40 m and are protected in 2 ways, namely:

a. The Atmospheric Zone & Splash Zone area is protected with a 2000 micron thick "Chugoku" Glass Flake Coating.
b. Submerged Zone & Embedded Zone area protected with Cathodic Protection (Aluminum Alloy Sacrificial Anode) 120 Kg (Ø 600 mm) & 190 Kg (Ø 1000 mm).

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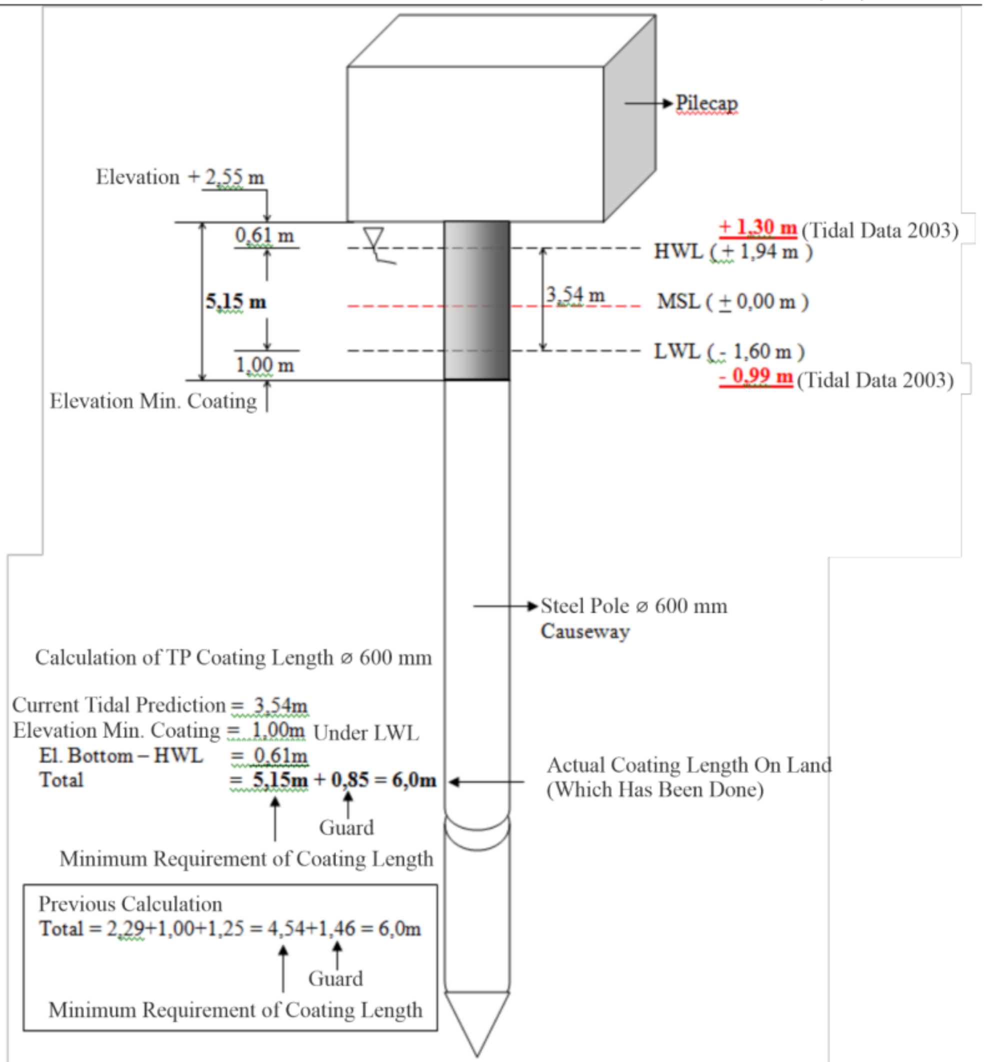

Figure 6. *Details of the calculation of the need for coating on the pile*

Sources: Analysis Data

From the Figure above, the length of the steel pile coating with a thickness of 2000 microns is 6.0 meters long for the topmost connection (below the bottom pile cap) for the Causeway on the Surabaya side 600 mm (ABT-0 s/d P-36), for the Causeway side Madura 1000 mm (P-57 to P-68) and 600 mm (P-69 to ABT-102). To increase the coating thickness from 500 ~ 700 microns to 2000 microns, it is carried out at the stockyard on land before the steel piles are delivered to the piling location. For steel piles, the handling method is as follows:

a. Under the Atmospheric Zone pile cap area with a length of 0.65 m from an elevation of +2.55 m to an elevation of +1.90 m, a 2000 micron thick glass flake coating is applied.

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b. Meanwhile, for the Splash Zone area, Jacketing HDPE (Sea Shield Series 200 DM) is carried out with a length of 3.50 m from an elevation of +1.90 m to an elevation of – 1.60 m,
c. And for the Embedded Zone area, installation/replacement of the Sacrificial Anode is still carried out below the elevation – 1.60 m for 120 Kg (pole 600 mm) and 190 Kg (pole 1000 mm).

In detail, the results of observations made on the piles of the Suramadu Bridge can be seen in **Table 2.** below:

Table 2. Types of Protection on Piles in The Seawater Zone

NO.	Steel Pole Protection	Number of Poles	Volume	Zone
1.	Coating Glass Flake 0,65 m	2951	3906 m2	Atmospheric
2.	Jacketing HDPE 3,5 m Ø 600	2596	17127 m2	Splash
3.	Jacketing HDPE 3,5 m Ø 1000	355	3904 m2	Splash
4.	Sacrificial Anode 120 Kg	57	6840 Kg	Embedded
5.	Sacrificial Anode 190 Kg	66	12540 Kg	Embedded

Sources: Data Observation

4. Conclusion

For the results of research carried out on steel piles on Causeway Suramadu Bridge on the Surabaya side, the value of the corrosion condition is at level 3-5. Steel Pole 600 mm Causeway segment Surabaya side needs to be repaired/replaced the protection in the Atmospheric zone, and Splash zone / Tidal zone is recommended Recoating, Wrapping, Jacketing HDPE, Epoxy Grouting. In the Submerged and Embedded zones, the Cathodic Protection is recommended to replace (120 kg for 600 mm). Damage to the piles is grouped into low, medium, and extreme risk damage. From the total damage, it is still in the low category with a percentage of 70%, so technically for, the steel pile foundation of the Causeway Suramadu Bridge on the Surabaya side is "very safe from dangerous conditions" even though protection (protection) of the steel pillars have suffered a lot of damage (level-4).

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