The Effect of Stray Current from Sacrificial Anode Cathodic Protection (SACP) System on the Adjacent Unprotected Reinforcing Steel

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Abstract. Concrete protects reinforcing steel from corrosion, but the steel may be corroded if exposed to coastal environment. Cathodic protection is a popular method to protect steel structures from corrosion. Previous researchers have conducted studies on sacrificial anode cathodic protection (SACP). However, the effect of stray current on the unprotected reinforcing steel in concrete was not reported. This study aims to analyze the effect of the stray current phenomenon on reinforcing steel which are not protected by SACP. Three types of specimens were used in the study: (1) unconnected anode-cathode, (2) connected anode-cathode, and (3) partially connected anode-cathode. The specimens were treated with 30 weeks of wet-dry cycle. Half-cell potential technique was used to measure corrosion potential. The results show that the first specimen had an average potential value of -505.44 mV, meanwhile the second specimen had average potential value -883.66 mV. According to ASTM C876 criteria, the first specimen is categorized into high corrosion risk. While, the second specimen was protected from corrosion based on NACE standard. However, the result on the third specimen shows that only the first reinforcing steel was protected from corrosion, while the other steels were categorized as severe corrosion risk level. The result on third specimen indicates that the stray current produced by SACP system could cause negative effect on the reinforcing steel by increasing susceptibility to corrosion, instead of protecting them.

Keywords: Corrosion, Reinforced Concrete, Cathodic Protection, Zn Anode

1. Introduction
Steel and concrete are the most common building materials over the past hundred years along composite materials. Reinforced concrete with rebar steel is the staple of civil construction. Standards for concrete and steel were determined by the limits of their strength and compositions [1].

Banda Aceh is an aggressive area for corrosion because it is located on the coast. The air in the coastal area contains evaporated salt from sea. When the wind blew from the sea, it brings salt vapor that penetrates into the buildings. Banda Aceh is also an area that has been affected by tsunami in

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2004. The tsunami washed and immersed the buildings with seawater and the reinforcing steel in concrete have become more corrosive [2]

In addition to aggressive environment, stray current is also the cause of corrosion. Stray current is an electric current that flows through another path into reinforced concrete. The current will move from one metal conductor to another metal conductor through ionic medium when the metals are not connected. Stray current generally occurs in pipes. This is due to a number of external DC currents. Pipes with stray current get cathodic protection from stray current at the point of entry, but the effect of amends will appear at the point of exit. Stray current on a structure is generally marked with a rapid corrosion rate [3].

Research related to reinforced concrete with cathodic protection systems has been widely carried out by researchers. However, the effect of stray current from sacrificial anode cathodic protection on reinforced concrete has not been reported. This study analyses the impact of the stray current phenomenon on reinforced steel which are not protected by cathodic protection.

2. Materials and Methods

2.1 Material

The sacrificial anode used in this study was Zn alloy anode which was manufactured according to ASTM B418 [4]. The Zn alloy sacrificial anode was 25 mm in length and 50 mm in width. The Zn alloy used in this study can be seen in figure 1.

![Sacrificial anode Zn alloy](image)

**Figure 1.** Sacrificial anode Zn alloy

Reinforcing steel that acts as a cathode material was carbon steel, according to SNI 07-02-2052-2002 [5]. The reinforcing steel was 13 mm in diameter, with stirrup rebar steel 140 mm in length and longitudinal rebar steel 800 mm in length. The reinforced steel can be seen in figure 2.

![Dimensions](image)

**Figure 2.** Dimensions (a) stirrup rebar steel (b) longitudinal rebar steel

2.2 Specimen preparation

2.2.1 Mix proportion. The concrete specimens for this study were prepared with mix proportions K-250, this is due to ACI 211.1-91 [6]. The mix proportions of concrete are shown in Table 1.
Table 1. The proportion of mixed concrete in 1 m³

| No. | Material             | Unit (Kg) | Information               |
|-----|----------------------|-----------|--------------------------|
| 1   | Portland cement      | 373.8     |                          |
| 2   | Coarse Aggregate     | 923       | Passes 9.52 and Detained 2.38 |
| 3   | Fine Aggregate I     | 335.6     | Passes 4.76 - Remain     |
| 4   | Fine Aggregate II    | 419.6     | Passes 1.20 - Remain     |
| 5   | Water                | 228       |                          |

2.2.2 Specimen size. Three types of specimens were used: connected anode-cathode, non-connected anode, and anode-cathode connected on first reinforcement. The geometry of the specimen is based on previous study [7]. The specimens were 100 cm in length, 10 cm in width, and 10 cm in height as shown in figure 4.

![Figure 3. Dimensions of specimen connected anode-cathode (mm)](image1)

![Figure 4. Dimensions of specimen unconnected anode-cathode (mm)](image2)
2.3 Testing

2.3.1 *Determine the location of rebar* steel. In this study, Profometer5+ was used to locate the reinforced steel without damaging the surface reinforced concrete. Figure 6 shows the profometer 5+ used in this study.

2.3.2 *Half-cell potential measurement.* The measurement of the corrosion potential value by using a Digital Half-Cell Potential Meter Scribe DHC (PC1018). This measurement process refers to ASTM C876 [8]. The measurement of half-cell potential on reinforced concrete can be seen in figure 7. To measure the potential values, the specimen was immersed and removed from soaking medium of 3.5% NaCl. Then the surface of specimen with exposed reinforced steel was cleaned from the remnants of corrosion products. This reinforced steel was used for electrical connection between specimens and half-cell potential meter.

The reference electrode was then connected to the cleaned reinforcing steel. Digital Half-Cell Meter was used to measure the corrosion potential and the measured number was taken at the point.
of stabilization (when the displayed number is close to zero). A thin foam was placed at the surface point of the specimen. This foam was used as a connector to the tip of the reference electrode (RE).

3. Results and Discussion
Corrosion potential value that measured on the surface of reinforced concrete was used to determine the level of corrosion risk which occurs in reinforced steel. ASTM C876 is a standard to interpret corrosion potential value data. An excerpt of ASTM C876 is shown in Table 2. Sacrificial anode cathodic protection acceptance criteria to protect reinforcing steel from corrosion standard refers to NACE RP-0169,2002 [9].

Table 2. The ASTM C876 criteria for corrosion risk of reinforced concrete.

| Reference Electrode (Cu/CuSO₄) | Reference Electrode (Ag/AgCl) | Corrosion Risk                  |
|--------------------------------|--------------------------------|---------------------------------|
| ≥ -200 mV                      | ≥ -106 mV                      | Low (10% risk of corrosion)     |
| -200 to -350 mV                | -106 to -256 mV                | Intermediate corrosion risk     |
| ≤ -350 mV                      | ≤ -256 mV                      | High (<90% risk of corrosion)   |
| ≤ -500 mV                      | ≤ -406 mV                      | Severe corrosion                |

The measurement results on all specimens starting from week 0 show that corrosion did not occur at all, this is due to the corrosion potential above -200 mV (ASTM C876-91 16). As the wet-dry cycle was carried out on all specimens for 30 weeks, the corrosion potential was getting negative slightly every week.

Figure 8 illustrates the line graph of the distribution of corrosion potential in unconnected anode-cathode specimens. The distribution of corrosion potential was getting negative every week of measurement. In week 24th, the corrosion potential value does not tend to increase. The results of measurements for 36 weeks on the unconnected anode-cathode specimens show that these specimens categorized into high-risk corrosion rates as can be seen in Table 2.1 ASTM C876-91 [8]. This happens because the specimen is not connected to the anode.

Figure 9 shows the line graph of the distribution of corrosion potential values in the connected anode-cathode specimen. Corrosion potential become more negative gradually every week. On the 30th week, the corrosion potential of all test points had entered the protected criteria according to NACE RP-0169, 2002 [9].
Figure 8. corrosion potential distribution (unconnected anode-cathode)

Figure 9. corrosion potential distribution (connected anode-cathode )

Figure 10 presents the line graph distribution of corrosion potential in anode-cathode connected on first reinforced steel. In this figure, the corrosion potential was uneven. This is due to partial connection where only the first test point (50mm from anode) is connected to the anode. Test point 1 of this specimen falls into the protected criteria. Test point 2 of this specimen (100 mm from anode)
also had corrosion potential in the protected criteria. However, this test point had corrosion caused by stray current.

Figure 10. corrosion potential distribution (connected anode-cathode on first reinforced steel)

Due to stray current on test point 2, the current from anode went to the third test point until ninth, but the current that originated from anode did not create a loop of current for sacrificial anode cathodic protection. As a result, third test point up to ninth test points had severe corrosion rates. The phenomenon of stray current causes corrosion potential of the specimen to be more negative than the unconnected anode-cathode specimens. The uneven distributions of corrosion potential at test point 2 to test point 9 is thought to be caused by permeability of the concrete.

4. Conclusion

The phenomenon of stray current occurred on reinforced concrete that was not connected to the anode. The stray current causes the unconnected steel anode to be at severe corrosion risk [8]. The steel with stray current has a more negative corrosion potential than unconnected anode-cathode. At the 30th week, the unconnected anode-cathode specimen already showed corrosion potential at a high level (< -500 mV), according to ASTM C876-91. On 30th week, the corrosion potential on connected anode-cathode specimen had reached the protection criteria value according to NACE RP-0169. The use of Zn anode connected to the cathode may protect reinforced concrete from corrosion as expected and prevents the stray current phenomenon.

References

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