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Numerical Analysis Of The Function Of Galvanostatic Pulse Technique With The Current Confinement Guard Ring In Cracked Concrete

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Abstract

Uncertainty of the polarized area of reinforcing steel is one of the major sources of error when measuring corrosion rate of steel in concrete. To overcome this problem, instruments equipped with the guard ring, aimed at limiting the polarized area, have been introduced and are available commercially. However, some limitations and disadvantages of the guard ring equipment have been reported. The function of this system on measuring the corrosion in sound concrete was analyzed experimentally and mathematically. This paper explains the function the guard ring equipment in cracked concrete by using finite element analysis (FEA).

Keywords: polarization; modelling; galvanostatic pulse; guard ring, steel reinforced concrete

1. Introduction

In the galvanostatic pulse technique, a short-time anodic current pulse is applied galvanostatically between a counter electrode placed on the concrete surface and the steel rebar. The applied current is usually in the range of 5 to 100µA and the typical pulse duration is between 5 to 30 seconds. The reinforcement is anodically polarized and the resulting change in the electrochemical potential of the reinforcement is measured with a reference electrode, which is usually positioned in the centre of the counter electrode [1, 2]. The major sources of error when measuring the corrosion rate of steel in concrete are the uncertainty of the area of the steel bar affected by the electrical signal from the counter electrode and non-uniform current distribution on the steel rebar [3, 4] and it has been studied by many researchers [5-13]. One of the approaches to overcome the aforementioned difficulties is using second electrode to confine the polarized area and is employed by most commercially available instruments for on-site measurements. In this approach, the extra electrode, a “guard ring” (usually ring-shape) in used to confine the signal applied from the counter electrode to a known length at the working electrode (steel bar) [14-17]. A secondary current is applied between the guard ring and the rebar while the rebar is polarized by the counter electrode. The objective is for the current applied from the guard ring to repel the lines of current from the central counter electrode and confine them to an area of the structure located approximately under the counter electrode Schematic illustration of the mentioned system is shown in Figure 1.

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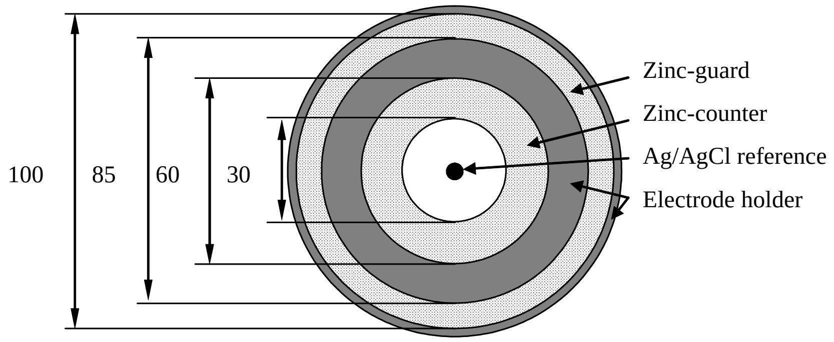

Figure 1. Schematic illustration of the instrument (i.e. GalvaPulse ™) using guard ring to limit the polarized area while performing the corrosion measurement.

In spite of using the same principles for determination the corrosion rate, data obtained using the guard ring show differences from those obtained from other electrochemical techniques and gravimetry test [11, 15-17]. These inconsistencies have been already discussed by the author and his colleague for sound concrete [18]. However, concrete structures are seldom un-cracked and little work has quantitatively described how performance changes when cracks are present. The objective of this paper is to explain discrepancies in the results obtained from galvanostatic pulse technique using the guard ring, by analyzing its function using finite element analysis in cracked concrete.

2. Materials and Methods

The GalvaPulse™ system, which was developed by FORCE Technology in Denmark, works based on the galvanostatic pulse measurements and its function was evaluated by Poursaee and Hansson [18] and the results from that evaluation are used to develop the model for the current study.

Accessing the inside of the concrete is not an easy task. Therefore, current distribution, potential distribution and the effect of a localized corrosion on the current and potential distributions have been analyzed, by finite element technique using ANSYS 11.0 [19]. In this study, a two dimensional reinforce concrete sample with the dimension of 1000mmX110mm (50mm as cover depth) with a 10M steel bar at the centre has been considered and modeled. In the model, several cracks were considered at the specimen, as shown in Figure 2, and it was assumed that the steel is locally corroded under the cracked area. All corroded areas have the length of 35mm except the one, designated as 0.65m in Figure 2, with the length of 70mm. The temperature was considered constant (25^{o}C) through all analyses.

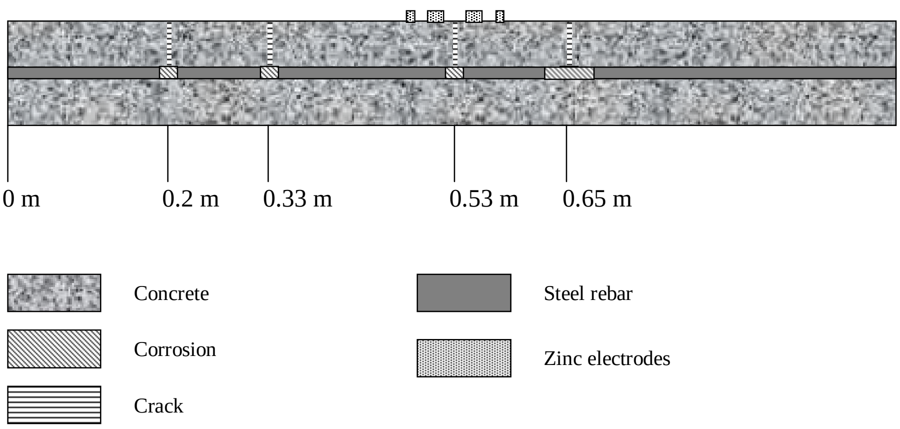

Figure 2. Concrete model, used for FEA with the crack locations

For the analyses, four different materials were considered: concrete, steel with passive layer, actively corroding steel and zinc. To characterize these materials for ANSYS, different resistivities at a constant temperature were used. The resistivity of the ordinary portland cement concrete has been reported between 50 to 500Ω.m, based on the exposure conditions [20]. In this paper, 100Ω.m is used as the concrete resistivity. For passive steel, actively corroding steel and zinc oxide, the resistivities used were ~1000Ω.m [21], ~ 2×10^{-7}Ω.m and ~2×10^{3}Ω.m [22], respectively. It was assumed that the cracks were filled with water with the conductivity of 200Ω.m [23]. A 100μA anodic current pulse was used in all analysis. In this analysis capacitative currents are not being taken account due the duration of the test [18].

3. Results and Discussion

In previous work, it was shown that the counter and guard electrodes apply approximately the same current to the surface with the same polarity and consequently, the guard ring doubles the applied current under the counter electrode. In addition, it was concluded that when the guard ring is "on", the steel bar is polarized significantly more compare to the time that the guard ring is off [18].

The current distribution at the embedded rebar surface in cracked concrete (Figure 2) was analyzed and the results for the current are shown in Figure 3a. It is clear that the current distribution is not only dependent on the surface condition of the steel, but also on the positioning of the electrode assembly with respect to areas of localized corrosion and the extension of the corroded area. It was shown before that in sound concrete and for the fully passive steel, the current is more uniformly distributed on the surface of the steel [18]. However, when the steel is locally corroded in cracked concrete, most of the applied current goes to that corroded spot which is, therefore, polarized more than the rest of the steel bar. Nevertheless, even with use of guard ring, the electrical signal applied from the counter and guard ring electrodes tend to concentrate on the corroded spots. As can be seen, when the corroded spot with larger area is not under the guard ring but close to it, most of the current goes to that area instead of the spot immediately under the measuring unit.

The corresponding polarization distributions (Figure 3b) show that the polarization at the surface of concrete is generally higher than that on the surface of steel due to concrete ohmic resistance. Due to the presence of more corroded area close to (but not under) the guard ring, the peaks of the potential distributions are also shifted toward that area.

In order to determine how effective the guard ring is in confining the signal to a central area with 70 mm diameter, the proportion of the current reaching the steel in the 70 mm diameter area immediately under the electrodes (designated by the vertical lines in Figure 3) has been calculated and the values are given in Table 1.

As can be seen from Figure 3, much of the current concentrated in the corroded region adjacent to the guard ring and it would not contribute to the information detected by the instrument. The corresponding rates of corrosion are included in Table 1, making the assumption that the applied current with the guard ring off is 100μA and that with the guard ring on is 200μA.

It can be also seen when there is active corrosion at the presence of crack; the polarization at the rebar is greater than 20mV which is outside the linear polarization range, invalidating the use of the Stern-Geary technique.

The current applied by the guard ring is supposed to confine the current from the counter electrode to within the 70mm diameter area under the electrode. It was shown that the current is so confined, with or without the guard ring, only when there is a small area of active corrosion directly under the electrodes [18]. However, as illustrated in Figure 3, it is not the case at the presence of cracks and localized corrosion on the steel rebar.

Based on the experimental results from the previous study [18] and the results from finite element analysis, it is clear that direct use of the values of corrosion current densities obtained by the GalvaPulse™ may cause errors in the predictions and structural evaluations especially when cracks exist.

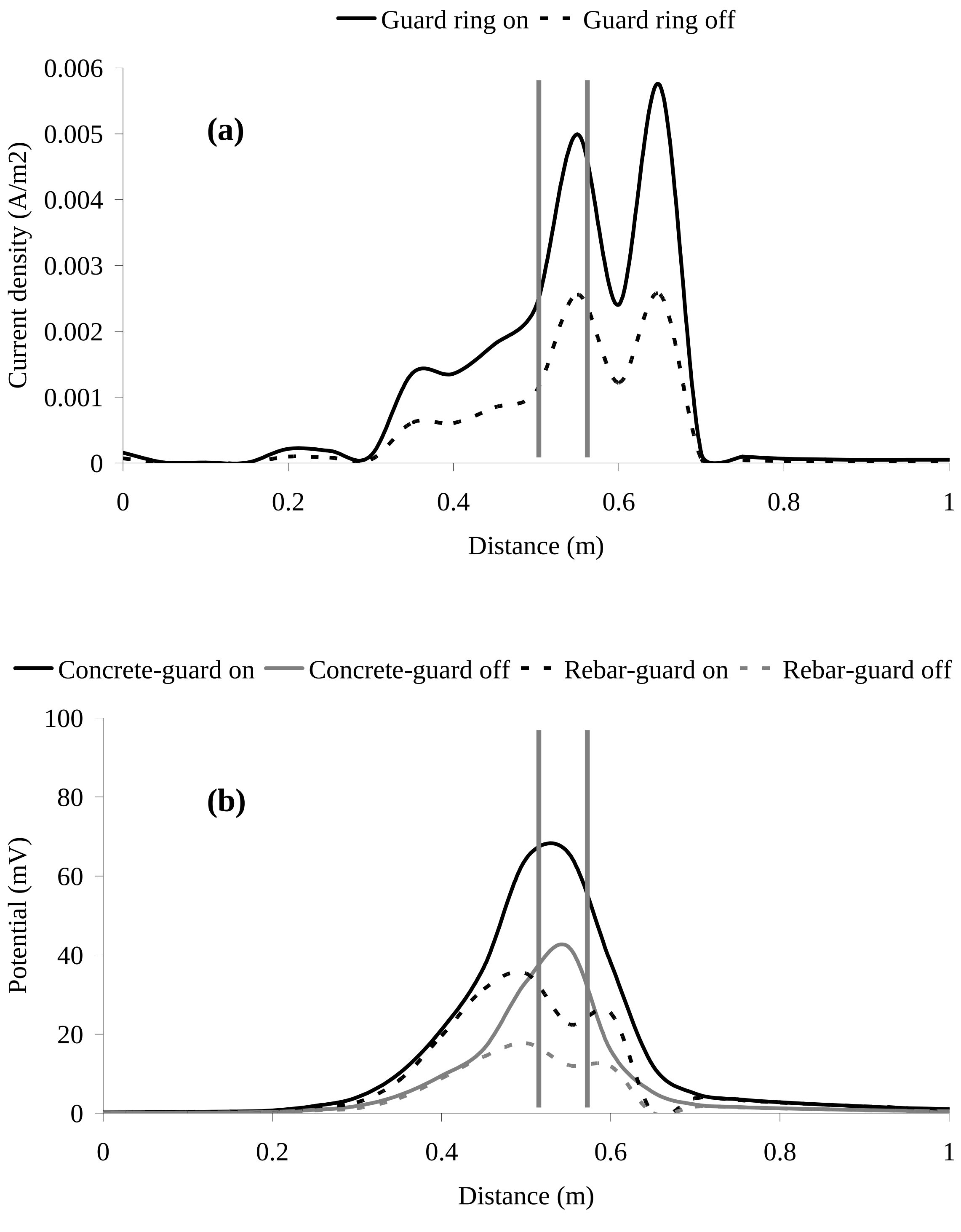

Figure 3. The current density distribution on the steel rebar and the polarization potential distribution on the steel rebar and concrete: (a) rings are on top of the crack location and (b) rings are not on top of the crack location. The vertical grey lines represent the position of the assumed measured area (70 mm)

TABLE 1. SUMMARY OF THE CALCULATIONS, BASED ON THE RESULTS OBTAINED FROM FIGURE 3

Proportion of current under the electrode	Guard ring On	35%
	Guard ring Off	60%
Corrosion rate assuming 100% current, including guard ring current	Guard ring On	0.051
	Guard ring Off	0.041
Corrosion rate based on actual proportion of current in area used for calculation	Guard ring On	0.018
	Guard ring Off	0.025

4. Conclusions

1. When the multiple cracks exist in the concrete, the current from the counter electrode is not confined to the area of rebar under the electrode and if another corrosion area locates out of but close to the guard ring, most of the current goes to that area.
2. When there is active corrosion at the presence of crack, the polarization at the rebar is greater than 20mV which is outside the linear polarization range, invalidating the use of the Stern-Geary technique.
3. Uncertainty of the area of the steel bar affected by the electrical signal from the counter and guard electrodes and non-uniform current and potential distribution on the steel rebar can cause errors when calculating the corrosion rate of steel in concrete.

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