# ADVANCED MEASURES ON MONITORING OF REINFORCEMENT CORROSION BY HALF-CELL POTENTIAL TECHNIQUE

Ahmet GOKCE*, Hitoshi TAKEDA, Kenichi HORIGUCHI, and Tsuyoshi MARUYA
Member of JSCE,
Taisei Corporation, Civil Engineering Research Institute

## Introduction

Half-cell potential measurements have been widely used in monitoring of uncoated steel corrosion in concrete. Determination of the potential map of an existing structure by this electrochemical technique allows to get a simple understanding about the corrosion activity of the element under inspection. Prediction of the electrochemical weight loss of the reinforcement has been already done in the earlier studies taking into account the half-cell potential measurements [1]. This study introduces a further approach in evaluation of the corrosion state of the reinforcement that is capable of estimating the cross-section loss of the steel bar subjected to chloride attack.

## Experimental

A number of reinforced concrete specimens with the dimensions of 100×100×1200-mm were produced in different design characteristics. The discussion of the present study was based on the state of rebar corrosion for the concrete specimen designed with a W/C of 0.60 and a cover thickness of 20 mm and kept in marine splash zone where the chloride has been transported into the test specimen through wind spray containing salt mist or contact with sea water carried by the wave for an exposure period of 32 months. The mixture proportions and some important properties of the concrete were summarized in Table 1.

The details of the test specimen are shown in Fig. 1. The edge portions of the specimen were completely coated with acrylic rubber. The half-cell potentials were measured with a Pb electrode along uncoated bottom exposure surface. The spacing between two measurements was 25 mm. The measurements were terminated, when severe cracks following to the steel bar were observed in visual inspections at 32 months of exposure. After extracting the crack images from the exposure surface, the specimen was split to determine the residual cross-section of the corroded parts of the steel bar.

**Table 1 Concrete properties and mixture proportions**

| W/C (%) | Slump (cm) | air (%) | mixture proportions (kg/m$^3$) | | | | |
|---|---|---|---|---|---|---|---|
| | | | water | cement* | sand | gravel | chemical admixture |
| 60 | 10 | 4.5 | 162 | 270 | 858 | 991 | 0.675 |

*ordinary portland cement

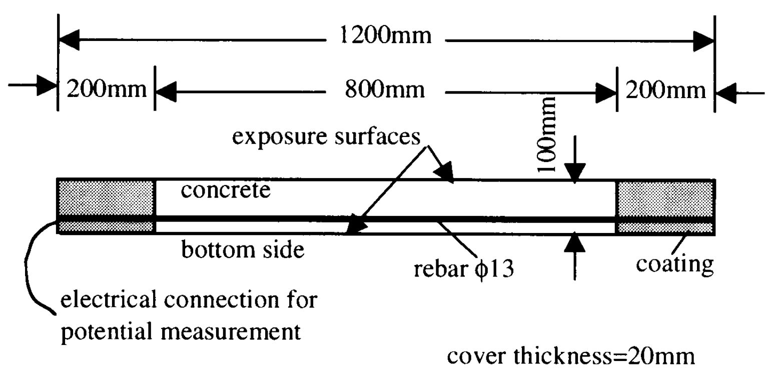


**Fig. 1 Specimen details**

## Results and Discussion

Half-cell potential distributions between acrylic rubber coated edge portions for pre-exposure stage and after 32 months of exposure were illustrated in Fig. 2. The potential values are in the range of Pb electrode (PRE). The results indicate a significant corrosion activity especially in the middle portion of the specimen. The separation of the anodic and cathodic areas can be judged by employing the model for macrocell current density [2]. In determination of the current density distribution along the rebar, the half-cell potentials obtained at each measurement point and resistivity of concrete should be added into calculation. Due to the lack of the resistivity data for this study, the preliminary calculations were performed with a typical concrete resistivity value of 10 kΩ-cm [3]. After determining the macrocell current density along the rebar (Fig. 3), electrochemical weight loss could be easily calculated for each potential measurement point by applying Faraday's law. Assuming a uniform corrosion depth on the steel surface, the thickness of the corroded layer can be calculated by using the following expression:

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*Taisei Corporation, Civil Engineering Research Institute, 344-1 Nase-cho, Totsuka-ku, Yokohama 245-0051, Japan

$$h\{Fe\} = (T.\ W\{Fe\})/\rho \qquad (1)$$

where, $h\{Fe\}$ : the corrosion depth of the rebar (cm)
T: duration of the corrosive exposure (day)
$W\{Fe\}$: weight loss in the corroded area ($mg/cm^2/day$)
$\rho$: density of Fe (7860 $mg/cm^3$)

The calculation of the corrosion depth allows to determine the loss in cross-section of the rebar. In the preliminary calculations, the predicted loss of rebar cross-section was negligible compared with the actual values determined by experimentation for an exposure period of 32 months. This result can be explained considering the dependence of the predicted values to the concrete resistivity assumed for the calculations. It seems that the actual resistivity was much lower than 10 kΩ-cm at the end of the exposure. Severe cracking on the concrete cover, penetration of the chloride ions, relatively low quality of the concrete are the possible factors resulting low concrete resistivity. It is also generally accepted that concrete resistivity might be as low as 0.1 kΩ-cm [3]. Hence the calculations to predict the residual cross-section of the rebar were corrected assuming a new resistivity value of 2 kΩ-cm. The contribution of microcell corrosion on the cross-section loss of the rebar should be kept in mind as well, but the net effect of the microcell corrosion was not determined in the present study. The comparison of the actual residual cross-section measured by the experimental method and the residual cross-section calculated by using the model for macrocell current density is given in Fig. 4. It is clear that the corroded areas determined by both calculation and experimental method are well–matched. While the predicted residual cross-section in the middle portion of the rebar coincides with the values obtained by the experimentation, the calculations for the corroded areas within the side portions failed to predict the actual values. The most important reason causing this misleading result is the exclusion of the cathodic areas within the acrylic rubber coated end portions in the calculations. The results will be verified by taking into account the cathodic effect of the end portions in the future studies. Fig. 5 illustrates the crack paths along the rebar. Comparison of Fig. 4 and Fig. 5 also clearly shows that heavily cracked areas fit into the corroded regions with high cross-section loss determined by both calculation and experimentation.

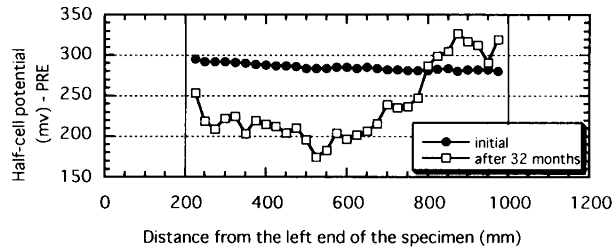


**Fig. 2 Distribution of half-cell potential**

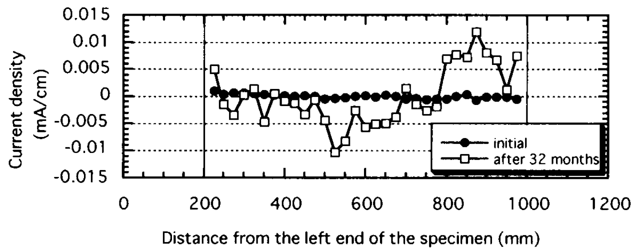


**Fig. 3 Distribution of the current density**

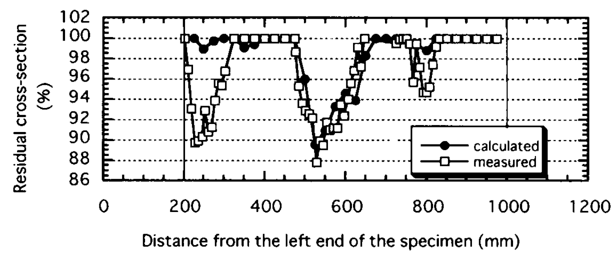


**Fig. 4 Residual rebar cross-section**

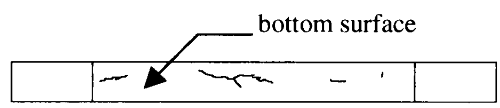


**Fig. 5 Crack paths on the exposure surface**

**Conclusions**

In the earlier researches, the corrosion state of the steel in concrete was experimentally evaluated in terms of the electrochemical weight loss of the rebar. This study demonstrates that the results of the half-cell potential measurements can be interpreted not only to determine the location of the corroded zone, but also to directly predict the loss of rebar cross-section by employing the model for macrocell current density. The results show a large dependence to the concrete resistivity accepted for the calculations. When the concrete resistivity was assumed as 2 kΩ-cm, the predicted and measured residual cross-section values in the middle portion of the specimen were well-matched except the side portions under the effect of both cathodic edges of the rebar (in fully coated parts) that were not taken into account in the calculations.

**References**

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