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# DISCUSSIONS

## A Discussion of the Paper "ELECTRODE POTENTIAL MEASUREMENTS OF CONCRETE REINFORCEMENT FOR CORROSION EVALUATION"
by R. Francois, G. Arliguie and D. Bardy*

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In a recent paper[1] by R. FRANCOIS et al., a method involving the movement of both reference electrodes simultaneously was reported. These bi-electrode methods do not require any electrical connection with the reinforcing steel and the problem of local destruction of concrete cover during the evaluation of reinforcing steel corrosion can be avoided. However, some caution should be taken before applying the bi-electrode method to the practical diagnosis of the reinforcing steel corrosion in concrete. Uncertainties exist in the measurement and interpretation of the potential data based on electrochemical concepts and principles applied to the bi-electrode measurement. Care is required in the evaluation of reinforcing steel surface corrosion using this method.

Consider the measurement of the potential difference of a metal-solution interface. A single potential difference cannot be determined; a second electrode must be introduced to complete an electrical circuit as illustrated in Figure 1a. This system can be simulated by the electric circuit depicted in Figure 1b where metal-solution interface elements are in series with the electrolytic resistance. The measured potential difference, ΔV, between the metal electrodes $M_1$ and $M_2$ is actually the algebraic sum of at least two potential differences, i.e., $PD_{M1/s}$, $PD_{s/M2}$ and as many extra potential differences as there are new phase boundaries involved in the measurement[2]. The potential difference, ΔV, indicated by the measuring instrument can be expressed as:

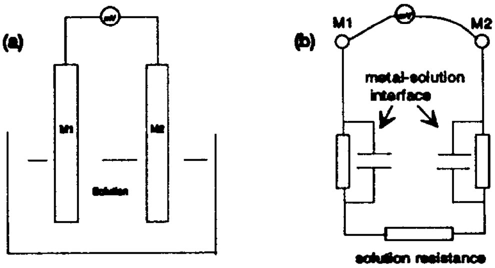

Figure 1: Schematic presentation of: (a) metal-solution-metal cell system, (b) corresponding electric equivalent circuit.

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* Cem. Conc. Res., 24(3) 401-412, 1994.

$$\begin{aligned}\Delta V &= PD_{M1/s} + PD_{s/M2} + PD_j \\ &= (P_{M1}-P_{sol}) + (P_{sol}-P_{M2}) + PD_j \\ &= P_{M1} - P_{M2} + PD_j \qquad (1)\end{aligned}$$

where $P_{M1}$, $P_{M2}$, $P_{sol}$ and $PD_j$ are potential of metal $M_1$, $M_2$, solution and other junction potentials involved respectively.

For a half-cell potential measurement in a reinforced concrete system (Figure 2a), the concrete (containing a certain amount of moisture) acts as the electrolyte. The electrical circuit (Figure 2b) then contains a very high "electrolyte resistance". The $PD_{M1/s}$ and $PD_{s/M2}$ terms are represented by $PD_{ref/conc}$ and $PD_{conc/steel}$. Equation (1) then becomes:

$$\begin{aligned}\Delta V &= PD_{ref/conc} + PD_{conc/steel} + PD_j \\ &= (P_{ref}-P_c) + (P_c-P_s) + PD_j \\ &= P_{ref} - P_s + PD_j \qquad (2)\end{aligned}$$

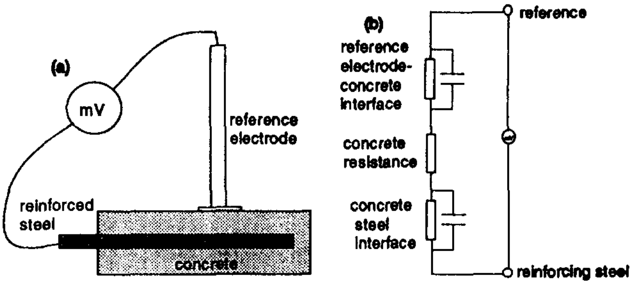

Figure 2: (a) Experimental set-up for half cell potential method,
(b) corresponding electric equivalent circuit.

where $P_{ref}$, $P_s$, $P_c$ and $PD_j$ are the potentials of the reference electrode, reinforcing steel, concrete and other junction potentials involved respectively. It is apparent from equation (2) that throughout the measurement of the potential difference across the reinforcing steel bar-concrete interface, the corrosion of steel surface can be evaluated in accordance with the fundamental electrochemical principles behind ASTM C876-91[3].

The electrical cell for a bi-electrode system where two reference electrodes are used is constructed between the two reference electrodes. The elements include $R_o$, the concrete resistance between two electrodes, and $R_c$, the concrete resistance between the reference electrode and reinforcing steel. In addition elements are required for electrode-concrete and concrete-steel interfaces depending on moisture conditions (Figure 3a). The following situations merit consideration:

i) The concrete is dry, e.g., $R_o$ and $R_c$ are extremely large. The electrical circuit cannot be completed.

ii) The concrete is wet (the surface especially is wet). $R_o \ll R_c$. In this case, there will be a short circuit through $R_o$, (Figure 3b). The actual measured $\Delta V$ is the potential difference between the two reference electrodes.

$$\begin{aligned}\Delta V &= PD_{ref1/conc} + PD_{conc/ref2} + PD_j \\ &= (P_{ref1} - P_c) + (P_c - P_{ref2}) + PD_j \\ &= P_{ref1} - P_{ref2} + PD_j \qquad (3)\end{aligned}$$

where $P_{ref1}$, $P_{ref2}$, $P_c$ and $PD_j$ are the potentials of the two reference electrodes, concrete and other junction potentials respectively. It is apparent from equation (3) that the potential difference of the reinforcing steel-concrete interfaces has not been measured. The bi-electrode devices (with one or two moving electrodes) therefore do not provide information related to surface corrosion of the reinforcing steel.

iii) The two electrodes are far apart from each other and the concrete contains a certain amount of moisture. $R_o \gg R_c$, but has a finite value. The measuring circuit in Figure 3c simulates the concrete-reinforcing steel corrosion. The measured ΔV includes the potential differences of all the interfaces in the electrical circuit. They are $PD_{ref1/conc1}$, $PD_{conc1/s1}$, $PD_{s2/conc2}$, $PD_{conc2/ref2}$ and $PD_j$.

$$\begin{aligned}\Delta V &= PD_{ref1/conc1} + PD_{conc1/s1} + PD_{s2/conc2} + PD_{conc2/ref2} + PD_j \\ &= (P_{ref1} - P_{c1}) + (P_{c1} - P_{s1}) + (P_{s2} - P_{c2}) + (P_{c2} - P_{ref2}) + PD_j \\ &= (P_{ref1} - P_{ref2}) + (P_{s2} - P_{s1}) + PD_j \qquad (4)\end{aligned}$$

If $P_{ref1} = P_{ref2}$, then : $\Delta V = (P_{s2} - P_{s1}) + PD_j$ (5)

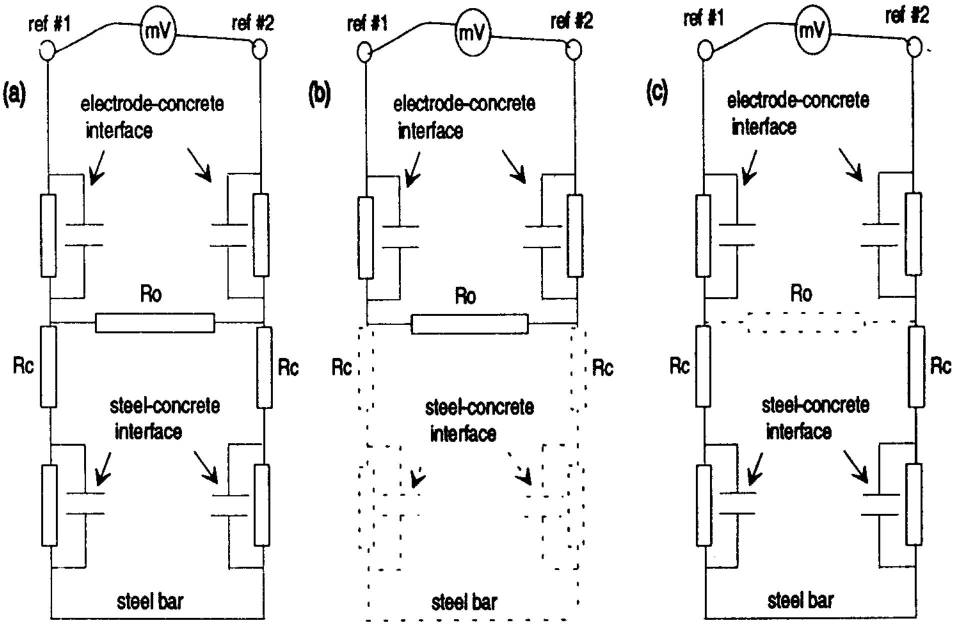

Figure 3: Schematic presentation of cell circuits for bi-electrode systems . (a) for Ro and Rc are close in magnitude; (b) electric equivalent circuitry for Ro<<Rc; and (c) for Ro>>Rc.

Examination of equations (4) and (5) indicates that the potential difference between two conducting steel surfaces is measured. Therefore, the bi-electrode potential measurement does give some indication of the surface corrosion of the reinforcing steel in concrete.

iv) The distance between the two reference electrodes is close to the distance to the reinforcing steel. $R_o$ and $R_c$ are close in magnitude. The electrical circuit involved in the potential measurement is more complicated as indicated in Figure 3a. The question is how much of the measured signal is related to reinforcing steel surface corrosion. The measured potential difference, $\Delta V$, ideally, can be expressed by the following inequality.

$$|P_{ref1} - P_{ref2}| + |P_{s2} - P_{s1}| + |PD_j| < \Delta V < |P_{ref1} - P_{ref2}| + |Pd_j|$$

It follows from the above discussion that the bi-electrode method can only detect relative potential differences of the reinforcing steel surfaces. Since many factors may affect the measured potential readings, especial caution should be taken when: (a) the moisture content and distance between the electrodes etc., affects the values of $R_o$ and $R_c$; (b) selection of a location as a reference point is critical. Otherwise procedures may lead to an over or under-estimate of the extent of reinforcing steel corrosion in concrete.

Data reported by R. FRANCOIS et al. exhibit excellent correlation with corroded areas of rebars. A bi-electrode device appears to be a useful tool for non-destructive determination of the extent of reinforced concrete corrosion provided certain precautions are taken.

## REFERENCES

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