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LPR METER FOR CONCRETE CORROSION STUDIES

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ABSTRACT

The design and development of a LPR (Linear Polarisation Resistance) Meter for Concrete Corrosion Studies has been reported. Two different measurement techniques are used to obtain the actual polarization resistance of the reinforcing steel embedded in concrete. The DC technique determines the total resistance including concrete resistances as well as polarization resistance. AC technique is used to measure the concrete resistance alone. The difference between the DC and AC measurement is the true polarization resistance. The typical results obtained using the Meter are reported.

1. INTRODUCTION

Corrosion of the reinforcing steel in a concrete and its monitoring is an active area of research. The reinforcement in all structures provides a constructional security. Concerning the load carrying capacity or for the necessary rehabilitation measures, information about the actual state of the corrosion of the metallic inside the concrete is of great importance. This assumes greater significance because of its safety as well as the economic importance of it. Commonly used inspection techniques usually identify the corrosion, only after the concrete damage has become visible at the surface, posing lot of difficulties in further rehabilitation. Corrosion testing by weight loss methods is generally a long, tedious affair, which often does not produce completely satisfactorily results. This is particularly true when the corrosion rate changes with time. Thus an early stage detection of the corrosion damage or the health check up of the existing structures in a non-destructive way is most urgently needed. The most popular electrochemical technique utilized for corrosion monitoring is the LPR technique. The LPR meter already reported in literature is not suitable for use in reinforcement concrete structures because the DC linear polarization resistance measurement includes concrete resistance also. Hence a LPR Meter that eliminates the concrete resistance by applying AC technique has been developed and reported in this paper.

2. OPERATING PRINCIPLE

The Meter employs two different techniques namely the DC technique and the AC technique to determine the actual polarization resistance [1]. The probe consists of a wetted sponge of 100 x 40 x 30 mm size in which a counter electrode (a stainless steel electrode 10 x 60 mm) and a reference electrode (saturated calomel electrode) are fixed. As described in ASTM G59, it utilizes a measurement of the slope of the potential versus current plot ±20mV around the corrosion potential to define a parameter defined as the polarization resistance [2].

Linear Polarisation Resistance Measurement: (DC Technique)

Using Stern Geary equation [3] the polarization resistance (including the concrete and charge transfer resistances) is estimated as follows.

Linear Polarisation Resistance (LPR) $R_p = B/i_{corr}$

$= \Delta E / \Delta I$

$= Rc + R_{ct}$ ....(i)

Where,

Stern Geary Constant, $B = (b_a \times b_c) / 2.3(b_a + b_c)$

$= 0.026V$

b_a = anodic tafel slope

b_c = cathodic tafel slope

i_{corr} = corrosion current density ($\mu A/cm^2$)

AC Polarisation Resistance Measurement : (AC Technique)

The electrochemical equivalent circuit of corroding rebars embedded in concrete is shown in Fig.1. The equivalent impedance of Fig. 1 is given as

$Z = R_c + R_{ct} / (1 + j\omega C_{dl} R_{ct})$ ....(ii)

Where,

R_c = Concrete Resistance

R_{ct} = Charge transfer resistance or True Polarisation Resistance

$j = -1^{1/2}$

$\omega = 2\pi f$

C_{dl} = Double Layer Capacitance

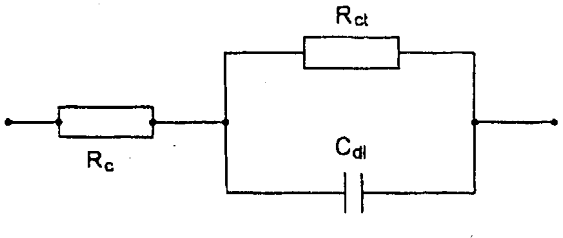

Fig.1 : Electrochemical equivalent circuit of a corroding rebar embedded in concrete

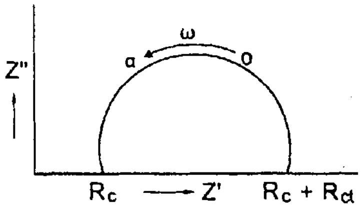

Fig.2 : Nyquist plot for corroding rebar embedded in concrete

The Nyquist plot for steel in concrete is shown in Fig.2. At the AC measurement frequency utilized, the double layer capacitance (C_{dl}) in parallel with the polarization resistance (R_{ct}), is extremely low impedance and nullifies the polarization resistance's effect in the measurement.

At low frequency (0Hz, DC) ($\omega \rightarrow 0$) ⇨ C_{dl} is high;

$$\mathbf{Z = R_c + R_{ct}} \quad \text{.........................(iii)}$$

At intermediate frequency ($\omega \rightarrow 2\Pi f$) ⇨ $C_{dl} \parallel R_{ct}$:

$$Z = R_c + R_{ct} \,/\, (1 + j\omega\, C_{dl}\, R_{ct}) \quad \text{................(iv)}$$

At high frequency (1000Hz, AC) ($\omega \rightarrow \infty$) ⇨ C_{dl} is low

$$\mathbf{Z = R_c} \text{......................................(v)}$$

Therefore, $\mathbf{R_c} = \Delta \mathbf{E_{ac}} \,/\, \Delta\, \mathbf{I_{ac}}$

Hence the difference between the DC and AC measurement is the true polarization resistance. i.e.,

True Polarization Resistance = $R_p - R_c$ ....(vi)

= $(R_c + R_{ct})$ - Rc

= Rct

= Charge Transfer Resistance

The corrosion current obtained from LPR measurements is given by the relationship,

$$I_{corr} = [0.026 \times 10^6] \,/\, [R_{ct} \times \text{Area (cm}^2)]\ \mu\text{A/cm}^2 \quad \text{..........................(vii)}$$

It is inversely proportional to the polarization resistance. Therefore, high values of polarization resistance generally yield low corrosion rates. The corrosion rate in millimeter per year is estimated by the relationship,

Corrosion Rate (mmpy) = 0.012 x corrosion current ....(vii)

3. DESCRIPTION OF THE INSTRUMENT

Fig.3 shows the complete schematic blgck diagram of the LPR Meter. It mainly consists of a dc source, an ac source, voltage follower, control amplifier, ZRA, an active filter and a unipolar generator. The voltage follower, control amplifier, and ZRA form the basic potentiostat circuit. An active filter is included to allow only the predetermined frequencies. To convert ac into dc the unipolar generator circuit is added. The polarization resistance is measured using the steel rebar working electrode (WE), a stainless steel counter electrode (CE) and Saturated Calomel reference electrode (RE) [2]. The instrument first initiates the measurement of OCP between the working and reference electrodes [4] in the potentiostat circuit and apply the appropriate potentiostat dc over potential. The over potential is applied between the counter and working electrodes. The over potential is within 10 mV over and above the OCP, in either anodic or cathodic direction. A zero resistance ammeter in the potentiostat circuit measures the cell current. By using Stern Geary equation as above, the linear polarization resistance (R_p) is estimated. The same is repeated for a small amplitude ac over potential at a predetermined frequency and the corresponding ac component of the current is measured. This current is

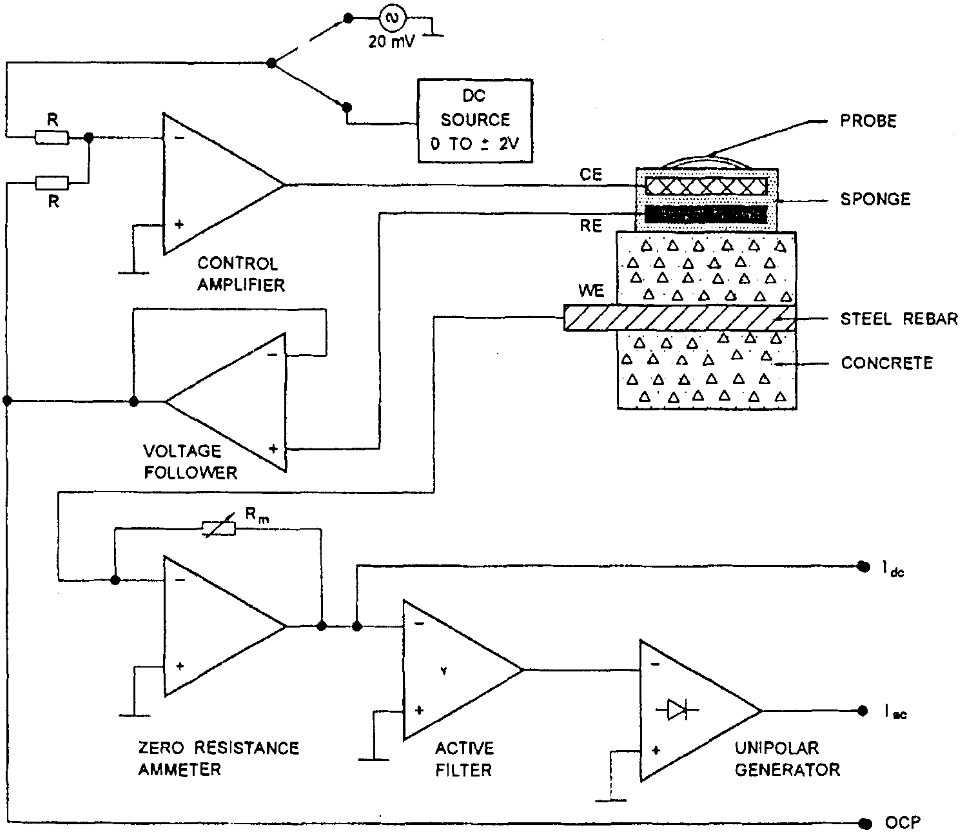

Fig.3 : Schematic block diagram of LPR meter

used to compute the concrete resistance (R_c)The True Polarization Resistance or Charge Transfer Resistance is calculated from the difference in values of R_p and R_c [5].

4. SPECIFICATIONS OF THE INSTRUMENT

LPR Measurement : (DC Techriique)

Control potential : ± 2000mV
DC current : ± 2mA
Resolution : 1 µA

Concrete Resistance Measurement: (AC Technique)

Control potential : 20mVr.m.s
Frequency : 1000Hz
Current : 200µA
Resolution : 0.1µA

Display : 31/2 digit LCD with 2V FSR

Accuracy : ±1%

Power : ±9V, Battery operated

5. RESULTS AND DISCUSSION

The following table gives the performance of the LPR meter.

Corrosion Rate (mmpy)	
By Weight Loss Method	By Developed Meter
0.040	0.036

Table 1 : Experimental Data by existing and Developed Methods

In the above experiment, mild steel specimen of 10 mm diameter and 50 mm length was embedded in 1:2:4 cement concrete containing 4% NaCl by weight. The mild steel specimen was initially weighed. After curing for 28 days, the concrete cube was subjected to alternate wetting using tap water and drying. This cycle of alternate wetting and drying was continued for 3.5 years. At the end of the exposure period, the dc polarization resistance and ac polarization resistance values were measured by the developed device. These values were 1000Ω and 476Ω respectively. From these values the charge transfer resistance was calculated. It was 524Ω and the corrosion current was $3.05\mu A/cm^2$. From this the corrosion rate is obtained and reported above. For weight loss measurements, the concrete specimen was broken open and the final weight of the steel specimen after de-rusting and cleaning was obtained. From the weight loss values, the corrosion rate in mmpy was obtained trom the relationship,

Corrosion Rate (mmpy) = [87.6 x Weight Loss (mg)]/[Area (cm^2) x time (hrs) x Density]

This value was compared with that obtained by the developed LPR meter and was found to be within 15%.

CONCLUSION

- An instrument was designed and fabricated for measurement of the True Polarization Resistance/Charge Transfer Resistance of steel in concrete. The instrument has been field tested and found to work satisfactorily.
- DC and AC technique are incorporated in a single instrument and thus concrete resistance is eliminated in the measurement.
- The corrosion rate of the reinforcement steel is inversely proportional to the polarization resistance. Using this true polarization resistance, it is possible to obtain the rate of corrosion.

- Quantification of corrosion of steel in concrete is possible by using this meter.
- As long as the polarization resistance remains high and the open circuit potential is small in magnitude the reinforcement steel is passive and corroding at a very small rate.
- As the steel begins to depassivate due to an increase in [CI-] or other corrosive environmental conditions the OCP will become more negative accompanied by a decrease in the polarization resistance.

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