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DETECTION OF VARIOUS TYPES OF CRACKS USING THE INNER ELECTRICAL RESISTIVITY MEASUREMENT IN REINFORCED CONCRETE MEMBERS: A REVIEW

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ABSTRACT

This research aims to detect any types of cracks whether flexural, shear, or torsional generated inside any RC members whether made of normal or heavy weight concrete using efficient non-destructive method such as linear inner electrical resistivity and square inner electrical resistivity measurements. The two efficient parameters used to detect the cracks inside the RC members in real time are the percentage change in inner electrical resistivity between uncracked and cracked members and the decimal logarithm resistivity anisotropy (DLRA) at different setups of measurements inside the cracked members to show the crack's presence and its direction instantaneously.

Keywords: Electrical Resistivity, Inner Electrical Resistivity Measurements, Square Inner Electrical Resistivity Measurement, Linear Inner Electrical Resistivity Measurement, Cracks, Decimal Logarithm Resistivity Anisotropy (DLRA), Heavy Weight Concrete.

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1. Introduction

Electrical resistivity is considered a non-destructive testing method for Reinforced Concrete (RC) elements, and it can be used in detecting cracks [1, 2]. Electrical resistivity measurements were proposed earlier by Lataste et al. [3] for measuring the existing damage in concrete. Moreover, the advantages of the electrical resistivity technique are low cost, simplicity, and efficiency. The electrical resistivity of concrete is related to the microstructure of the cement matrix, its pore structure, porosity, and pore size distribution. In concrete, the current flows through the pores in the cement paste [4]. Aggregates are considered essentially inert. Generally, concrete is not a homogeneous conductor, and the flow of electric current will be heterogeneous. Heavyweight concrete is used in the shield for nuclear power plants and radiotherapy rooms [5]. The aggregate component of heavy-weight concrete contains a mixture of many heavy elements that play an important role in improving concrete shielding properties [5]. The conduction of electricity through concrete may take place in two ways, electronic and electrolytic. Thus, concrete electrical resistivity is a geometry-independent material property that describes the electrical resistance [6].

Several methods for measuring electrical resistivity were studied by Gowers and Millard, [6]. One of the most common methods used for measuring electrical resistivity is the Wenner probe method which is considered a reliable method [6, 7]. One of the factors that control electrical resistivity features in concrete is the hydration degree of the cement paste which would result in an increase in electrical resistivity over time. Moreover, the other influential factors affecting electrical resistivity measurements include the relative humidity, the concrete temperature, the ions concentration, and their mobility inside the pore solution [8]. Furthermore, when the interconnectivity of the pore network in concrete is broken, the movements of ions are disrupted. Accordingly, the presence of cracks in the concrete acts as a barrier between the movements of these ions, and thereby the electrical conductance of concrete [6]. The electrical resistivity of concrete can be measured using several means [9]. Moreover, the resistivity is often related to corrosion and the durability performance of concrete [10]. In general, the most common methods for measuring the electrical resistivity of concrete are as follows:

a. Two-Plate Electrode Method:

During testing, a low-frequency electrical current passes between the two electrodes through the entire specimen while the voltage drop is measured [8,11]. The electrical resistivity for the two-plate electrode method is conducted using equation (1).

$$\rho = \frac{R\,A}{L} \quad (1)$$

b. Four-point electrode method (Wenner method):

The four-point electrode method is the most widely used technique for field concrete resistivity measurements. During testing, a low-frequency alternating current is applied between the two outer electrodes while the voltage drop is measured in the two inner electrodes [6]. The electrical resistivity for the Wenner method is calculated using equation (2).

$$\rho = 2\Pi \times \mathrm{a} \times \mathrm{R} \quad (2)$$

c. Four probes square configuration:

In this technique, the four probes are arranged in a square pattern on the outer surface of the concrete, and the electrical resistivity measurements can be calculated using equation (3) [1, 2, 4, 12, 13, 14, 15, 16, 17].

$$\rho = \frac{2\times\Pi\times a\times R}{2-\sqrt{2}} \quad (3)$$

d. Embedded electrode configuration

d.1. Linear Inner Electrical Resistivity Measurement (LIERM)

In this technique, the four probes are arranged on the same line pattern inside the concrete, as shown in Fig.1. Inner electrical resistivity can be calculated using equation (4) [12,13, 14, 15, 16, 17].

$$\rho = 4\times\Pi\times a\times R \quad (4)$$

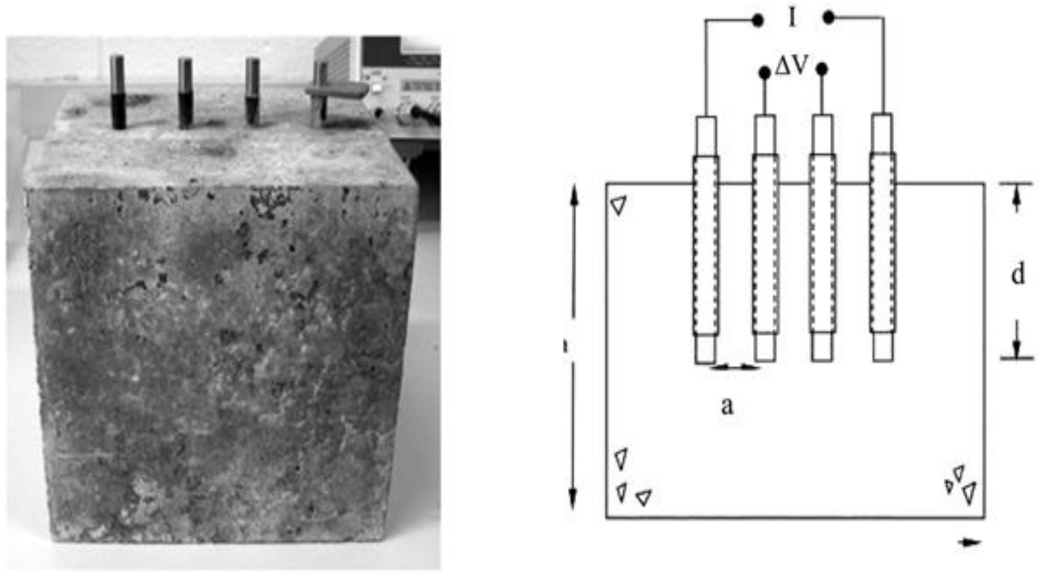

Fig.1. Linear inner electrical resistivity measurement for the concrete cube with embedded electrodes adapted from [12, 13, 14, 15, 16, 17].

d.2. Square Inner Electrical Resistivity Measurement (SIERM)

In this technique, the four probes are arranged on a square pattern inside the concrete, as shown in Fig.2, and the SIERM is calculated using equation (5) according to [2,13, 14, 15, 16, 17].

$$\rho = \frac{4 \times \Pi \times a \times R}{2-\sqrt{2}} \qquad (5)$$

where: ρ: electrical resistivity (Ohms.m), a: electrode spacing (m), and R: electrical current resistance (Ohm).

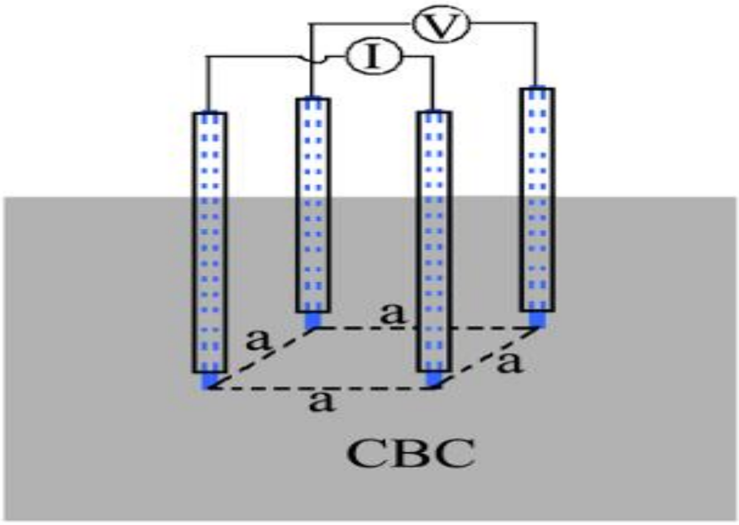

Fig. 2. Square inner electrical resistivity measurement configuration adapted from [2, 13, 14, 15, 16, 17].

Specifically, two studied parameters are used based on electrical resistivity measurements in detecting damage as follows:

a- Percentage of change in electrical resistivity (% change in resistivity):

The Percentage change in electrical resistivity between any cracked specimen and the uncracked specimen in the same direction of measurement is calculated using equation (6) [1, 2, 13, 14, 15, 16, 17].

$$\%\, change\ in\ Resistivity = \frac{Rp-Rr}{Rr} \times 100 \qquad (6)$$

Where: R_p: resistivity for the cracked specimen, and R_r: resistivity for the uncracked specimen.

b- Decimal Logarithmic Resistivity Anisotropy (DLRA):

The Decimal Logarithmic Resistivity Anisotropy (DLRA) is calculated using equation (7) [1, 2, 13, 14, 15, 16, 17].

$$DLRA = \log_{10}\frac{R_v}{R_h} \quad \text{or} \quad DLRA = \log_{10}\frac{R_h}{R_v} \qquad (7)$$

Where: Rv: resistivity at the vertical current direction, R_h: resistivity at the horizontal current direction.

In practice, the change in electrical resistivity would indicate a crack. Thus, percentage change and DLRA are efficient parameters for detecting cracks [1, 2, 13, 14, 15, 16, 17].

2. Detecting Cracks Using Square Inner Electrical Resistivity at Different Embedded Sensors Inside RC Members

The measurements of the inner electrical resistivity were taken once perpendicular to the crack plane in the horizontal direction, and the other one parallel to the crack plane in the vertical direction according to the outer and inner square setup configuration over the time according to [2, 13, 14, 15, 16, 17]. The square inner electrical resistivity measurement technique as a nondestructive testing method inside the core of the RC walls detects the presence of cracks [2,13, 14, 15, 16, 17]. Two parameters detected the damage, especially the cracks. The first parameter used is the percentage change in electrical resistivity between different cracked specimens and the uncracked specimen according to [2,13, 14, 15, 16, 17]. The second parameter used is Decimal logarithm Resistivity Anisotropy (DLRA) which gives a good indication of the presence and the direction of the crack inside the RC members in real time [13, 14, 15, 16, 17].

2.1. Detecting The Crack Length Using the Decimal Logarithm Resistivity Anisotropy (DLRA)

The more efficient parameter used to detect the presence of the cracks is the Decimal Logarithm Resistivity Anisotropy (DLRA) for heavy weight concrete by dividing resistivity in the direction perpendicular to the crack plane to the other measurement parallel to the crack plane. DLRA detected efficiently the presence and direction of the crack inside the RC specimens in different setups [13, 14, 15, 16, 17].

3. Conclusions

The two parameters used in detecting the presence of cracks inside the RC members are the percentage of change in electrical resistivity between the cracked specimens and the uncracked specimen, the second parameter is Decimal Logarithm Resistivity Anisotropy (DLRA) according to [13, 14, 15, 16, 17] using inner electrical resistivity setup measurements.

- When the current cuts the crack plane which is perpendicular to the crack, the percentage change in electrical resistivity reached a maximum value, However, when the current moves in the direction parallel to the crack plane, the percentage change in electrical resistivity is decreased, and reached a negative value according to [13, 14, 15, 16, 17]. When the electrical current moves perpendicular to the crack plane, it gives a good indication of the presence of a crack, when using the percentage change in inner electrical resistivity measurement.
- DLRA detects the presence of a crack inside the RC members and gives the directions of the crack plane from its measurements according to [13, 14, 15, 16, 17].

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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