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Combined effect of Cracks and Rebar on Electrical Resistivity of Concrete: A Review

Diana Varghese
PG Student, Department of Civil Engineering,
Sree Narayana Gurukulam College of Engineering
Ernakulam, Kerala, India

Jeena Mathew
Department of Civil Engineering
Sree Narayana Gurukulam College of Engineering
Ernakulam, Kerala, India

Abstract
Structural reliability is a yardstick of the capability of the structure to operate without failure when put into service, which has become a more important task when it comes to existing structures for engineers along with the age of structure. To ensure the structural reliability of existing structures, identifying the presence of crack and rebar is essential. Early prediction of crack and rebar presence will help us to reduce the cost in terms of rehabilitation works. Most commonly used Non-destructive tests to detect crack and rebar are very much costly. Electrical resistivity of concrete can be used to detect the presence of cracks and rebar, which may help to predict the reliability of concrete structure in terms of reinforcement cover, quantity, quality etc. The Four-point Wenner probe technique is used to measure the resistivity of concrete from the surface in seconds without the need for coring. In this paper effect of rebar and crack in terms of electrical resistivity under varying parameters is discussed.

Keywords: *Electrical resistivity, rebar presence, crack parameters*

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I. INTRODUCTION

As per the records 6 billion tons of concrete are used around the world each year which is increasing along the time, which makes concrete an inevitable building material for modern construction. Concrete is a building material that gains strength over time. Concrete's 100-year service life conserves resources by reducing the need for reconstruction. Concrete is durable and it resists weathering, erosion and natural disasters, needs few repairs and little maintenance, adding up to a solid investment. Concrete is used for many applications, including basic foundations, superstructures, wastewater treatment facilities, water treatment facilities, parking structures, floor construction, and exterior surfaces. Concrete is so integral to our communities because it is the only building material that cost-effectively delivers: the lowest carbon footprint for a structure or pavement over its lifecycle, unparalleled strength, durability, longevity and resilience. Early prediction of crack presence will help as to reduce the cost in terms of rehabilitation works. Non Destructive test is a method of testing existing concrete structures to assess the strength and durability of concrete structure. Active infrared thermography with microwave excitation and the eddy current technique are some of them. But the instrument used for Non Destructive test is costly and difficult to handle. So we usually don't prefer this kind of instruments in India. Therefore in order to overcome this problem, electricity resistivity of concrete is used.

Electrical Resistivity is an inherent characteristic of a material, and is independent of the geometry of the sample. On-site electrical resistivity of concrete is commonly measured using four probes in a Wenner array.

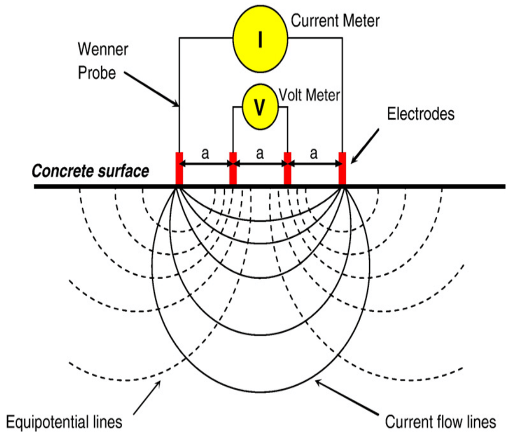

Fig1. Wenner Array Probe Method

The reason for using four probes is the same as in the laboratory method is to overcome contact errors. In this method four equally spaced probes are applied to the specimen in a line. The two outer probes induce the current to the specimen and the two inner electrodes measure the resulting potential drop. The probes are all applied to the same surface of the specimen and the method is consequently suitable for measuring the resistivity of bulk concrete in situ.

The resistivity is given by:

$$\rho = 2\pi a\ (V/I)$$

where, V is the voltage measured between the inner two probes (measured in volts, V)
I is the current injected in the two outer probes (measured in amps, A)
a is the equal distance of the probes (measured in meters, m).

VARIOUS PARAMETERS AFFECTING ELECTRICAL REISISTIVTY OF CONCRETE UNDER COMBINED EFFECT OF CRACK AND REBAR

Various researchers conducted the study to evaluate the effects of rebar in concrete specimen under varying covers and moisture conditions using Wenner probe method. Studies were also conducted on presence of cracks in concrete structure under varying parameters.

Garzon et al. [1], experimental study, small scaled cylindrical and prismatic specimens were casted. As polarization will happen due to double layer at the steel and concrete interface acting as a resistance capacitor, resistivity measurements taken directly above rebar will result in errors. Hence, a rebar factor was suggested to be applied to the obtained resistivity results. In addition, modified Wenner equations are recommended for various geometric parameters. Only reinforced cylindrical and prismatic specimens were included in the experimental setup without considering a reinforced slab. However, in a numerical study, a slab with embedded rebar was considered. The experimental investigation lacked in using concrete mixture instead of a mortar mixture which is not exactly representative of real world cases and may lead to more errors. Furthermore, the proposed rebar factor may not be applicable to a large concrete slab with multiple rebar because their experimental conclusions are based on laboratory testing.

Young-Chul Lim et. al. [2], study suggested a geometric effect (GE) rate for quantitatively analyzing the effect of reinforcing bars in the evaluation of concrete resistivity. This geometric effect (GE) was calculated using the resistivity estimation model (REM), which is a mathematical model that takes into consideration the geometric conditions of reinforcement, such as the concrete cover and bar diameter, and the electrode interval. The GE rate can be generalized as a function resulting from the relationship between A (a/r), the ratio between the electrode interval (a) and the reinforcing bar radius (r), and D (d/r), the ratio between the concrete cover depth (d) and the reinforcing bar radius (r). In the case of the geometric effect of the reinforcement, the value of the GE rate decreases with the concrete cover depth, while it increases as the bar diameters become larger and the electrode intervals are extended. The apparent resistivity (AR) rate can be used to quantitatively analyze the geometric effect of steel bar from measurement directly above the reinforcement.

F. Preseul Moreno et al. [3], Study confirms that the resistivity of concrete changes with the varying parameters like specimen geometry, specimen size, rebar presence including rebar number, cover depth using Wenner probe method and these variations and influence can be quantified using FEM model. Study reveals that this quantization is useful to obtain normalization parameters (i.e. cell constants) or to better interpret field resistivity measurements. Researchers also reveals the gap of no numerical modeling and experimental studies on the effects of rebar layers and rebar number on the measured resistivity have been studied. However the findings of present work confirm that they have a significantly influence on the resistivity of concrete. It is also demonstrated that such effects can be quantified by FEM and that cell constants can be obtained.

J. Pacheco et al. [4], Cracks represent fast routes for chloride ingress that lead to corrosion of reinforcement. In concrete, cracks can be considered as spatial discontinuities between aggregates and concrete hardened matrix. For concrete infrastructure, cracks are important for assessing the remaining service life. Tensile cracks in bending have a tapered geometry, i.e. the widest crack occurs at concrete's surface with a decreasing opening as crack propagates towards the reinforcement. This type of crack is critical for assessing the condition of a concrete structure. In this paper, real-time measurements of concrete resistance during cracking of reinforced concrete specimens were performed under laboratory conditions. A Modified Wedge Splitting Test (MWST) was used in order to create controlled cracks in the specimens. Reinforced and unreinforced concrete specimens were subject to loading in a Modified (MWST) and ordinary Wedge Splitting Tests (WST). Displacement and electrical resistance between two electrodes were monitored during loading. Results showed that resistance variations found in reinforced concrete were attributed to crack opening and propagation, independently. For unreinforced concrete, these two mechanisms were found to be acting at the same time, leading to smaller variations of resistance and loading during the experiment.

Keiyu Kawaai et al. [5], this study examined the changes of resistivity upon the presence of damages in the bottom of concrete specimens which mirror internal cracking not visually observed on the concrete surface in typical reinforced concrete structure. For the experimental investigation, ten electrodes comprising stainless steel and electric conductive epoxy were partially embedded on the surface of prism concrete specimen. Then, electrical resistivity was measured via Wenner method using four electrodes selected among the electrodes placed 20 mm apart each other. In addition, analytical investigation simulating the influence of internal damages on current flow and measured voltage or potential was carried out by FEM analysis. As a result, electrical resistivity increased depending on the depth of slits with 1 mm width, which was sawed at the bottom of the specimen. This could be attributed to the influence of the damages on the current flow and equipotential planes, thus suggesting that there is a good possibility that internal damages can be detected based on the changes and the distributions of the electrical resistivity.

Mustafa Salehi et al. [6], investigated the effect of the presence of rebar mesh in concrete on electrical resistivity measurements conducted with a four-point Wenner probe. The effects of different concrete thicknesses, rebar diameter, rebar mesh densities and probe configurations with respect to the rebar mesh were studied. It was concluded that the smallest error will result while setting up the probe parallel to the top rebar within the rebar mesh and perpendicular to bottommost rebar during measurements taken as illustrated in Fig 2. It was also found that the observed resistivity decreased once the rebar mesh densities increased and the rebar diameter effect on concrete resistivity measurements can be neglected. There was no experimental investigation to confirm the conclusions based on the numerical study results, but it was one of the few investigations that includes rebar mesh and probe configuration with respect to rebar in its assessment of the effects of reinforcement to electrical resistivity measurements.

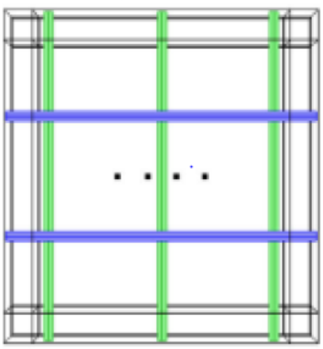

Fig2. Probe with respect to rebar mesh suggested to reduce electrical resistivity measurement error by Salehi et al.

Sengul and Gjorv [7], conducted an experimental investigation to understand the effects of cover thickness, electrode spacing, embedded rebar, probe measurement directions relative to the embedded rebar, and probe measurement distance away from the embedded rebar. Four point Wenner probes, each with different electrode spacing, were used to conduct the electrical resistivity testing for reinforced concrete test specimens as well as for field measurements on concrete structures. Five different probe configurations with respect to embedded rebar were considered, where four of the five configurations were parallel to rebar, and the fifth was perpendicular to rebar as seen in figure shown below.

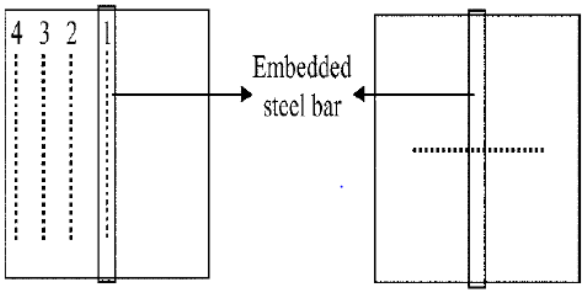

Fig3. Five Wenner probe with respect to embedded rebar tested by Sengul and Gjorv

It was concluded that embedded rebar and electrode spacing affect observed resistivity of concrete. For larger electrode spacing, parallel measurements with respect to embedded rebar significantly reduced observed resistivity, whereas when measurements were made perpendicular to rebar, there were no significant effects to observed resistivity.

Weyder and Gehlen [8], studied the effects on Wenner probe electrical resistivity measurements on reinforced concrete blocks in which rebar was spaced parallel to one another. It was found that orienting the probe orthogonally with respect to the embedded rebar, errors on electrical resistivity measurements were reduced. This study lacked the investigation of the effect of rebar mesh and only studied where rebar segments were parallel. When Wenner probe was placed perpendicular to the rebar, the errors associated with the presence of reinforcement were reduced. However it is noted that, in practical cases reinforced concrete structures that rebar is in mesh form spanning both transversely and longitudinally within the concrete, which then may have different influences on measured electrical resistivity than the effect of parallel rebar spanning in only one direction.

Polder et al. [9], provided practical general guidelines for taking resistivity measurements on concrete by revisiting and summarizing existing literature. In the absence of research on resistivity measurements over rebar meshes, it was suggested that resistivity measurements should be taken in diagonal orientations from the mesh. Taking several measurements in this arrangement and averaging the results were also recommended. However, there are no experimental or theoretical studies to support this suggested scheme. Moreover, depending on the spacing between rebar and electrodes of the Wenner probe, it is not possible to have all four electrodes inside the rectangular unit created by the crossing rebar at all times. Thus, in some scenarios it is possible to have one or more of the electrodes located on top of the rebar and this arrangement might significantly affect resistivity measurements. And also state that the electrical current may travel through the concrete volume with approximately the same depth as that of electrode spacing. Hence, as the probe spacing increases, the current flows deeper inside the concrete volume and when the electrical current reaches the surface of the rebar, the current is transported through the reinforcement and, thus, results in lower resistivity observation.

Millard [10] and Gower and Millard [11], studied the effect of rebar diameter and spacing, as well as the effect of concrete cover thickness on electrical resistivity measurements using a four-point Wenner probe. Millard’s experimental investigation consisted of tanks filled with conductive solution and steel rebar placed parallel to the other within the solution. Probe measurements were taken in between rebar and parallel to rebar at different distances away from the rebar. The main influencing factor was found to be the distance taken away from the rebar, while rebar diameter was not found to be significant in its disturbance. Reduced rebar spacing was found to increase measurement errors. The experimental investigation lacked the use of actual concrete and did not investigate different probe configurations with respect to the rebar or rebar mesh.

Chen et al. [12], experimentally investigated the influences of specimen shape and size, electrode spacing, and cover thickness on electrical resistivity measurements made with a Four-point wenner probe. It was suggested that a correction factor should be applied to resistivity measurements corresponding with the ratio of specimen length to electrode spacing as well as the ratio of specimen diameter to electrode spacing for cylindrical concrete specimens. For prismatic specimens, that the effects by the probe spacing can be ignored when the spacing is larger than 40 mm. However, the resistivity values increased with less electrode spacing. For application of Wenner probe method, the important role of electrode spacing should be definitely considered during electrical resistivity measurements as it will affect the obtained results.

II. CONCLUSION

By the extensive evaluation of the above literature review, this paper identifies several factors which might have influence on the electrical resistivity of concrete. Effect of each parameter is briefly summarized below. In the most of studies, when there is an embedded rebar in the concrete, the electrical current field is distorted, and thus errors can result in the electrical resistivity measurements. To minimize this effect, it is suggested to place all electrodes perpendicular to the embedded rebar on the concrete surface and take at least five measurements, each a few millimeters in distance from one another. It also showed that using smaller electrode spacing would decrease measurement deviation from the actual resistivity of concrete when measurements are taken over rebar. As reported by Milliard, variation of rebar diameter was found to have some influence on measurements; however, this effect was negligible. As far as crack in reinforced concrete is considered as one of the most significant reason for the strength loss, resistivity measurements help us to understand the depth, orientation and position of these cracks and more field investigations are still needed in this area. Crack studies have been done in two ways, one is by insulating crack at the stage of setting and second one is creating cracks after the strength gaining by continuous loading. Either way cracks study on reinforced concrete experimentally has been an untouched area where a lot of potential conclusions could be invented.

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