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The effects of specimen parameters on the resistivity of concrete

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HIGHLIGHTS

- Resistivity varied with the water content.
- The resistivities were found related with the probe spacing and the specimen size.
- The cover thickness must be large enough to avoid interferences by the reinforcements.

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ABSTRACT

The nondestructive Wenner four-probe resistivity measurement is often used to evaluate the durability of concrete onsite owing to its merits of easy operation and instant results. However, the factors influencing the measurements are not clear. In this study, the influencing factors, including the specimen shape, size, measuring probe spacings, cover thickness, and moisture contents, are thus discussed. Results showed that a correction coefficient *K*, associated with the ratios of specimen length and diameter to the probe spacing should be applied to the resistivity measurements of the cylindrical specimens. Among all the factors, the moisture content had the highest impact on the measurement. When the specimen was oven-dried or air-dried at 40% RH, the measurements were unstable. On the other hand, the resistivities of the specimens at saturated surface dry (SSD) or wet were about the same. However, when the specimens were air-dried at 80% RH, the resistivities were increased by 6.9–8 times. In contrast, no correction was required for the resistivity measurements of the prismatic specimens as long as the applied currents did not pass through the reinforcements.

1. Introduction

In general, the resistivity of concrete can be used as an index for the water content and the connectivity of the mircopores inside concrete and thus it can be also used as an index for the quality and durability of concrete. Resistivity for concrete with looser microstructure is generally lower. That means the chloride ion may penetrate faster into a concrete with lower resistivity and consequently the corrosion may happen more easily [1–4]. Nowadays, the resistivity measurement has been recognized as one of the NDT method for in-situ monitoring of corrosion [5,6].

Resistivity of concrete is influenced by many factors, such as w/c, cement content, admixtures, curing conditions, moisture content and the ambient humidity. The resistivity can be increased by the low w/c, long curing time, and carbonation [7,8]. Among all the influencing factors, the moisture content highly influences the resistivity of concrete. At saturated state, the resistivity of concrete is decreased by the increased w/c. When the moisture content is reduced, the resistivity is increased significantly. As a result, the moisture of concrete specimens should be considered during the resistivity measurements [9]. In order to precisely compare the resistivities of different concrete specimens, the measurements should be conducted at the same moisture state. Most of the time, the saturated surface dry (SSD) condition is chosen as the standard moisture state.

Concrete is a multiple-phased material. Its microstructure contains many interconnected micropores, in which the applied external current can be transferred through the migrating ions. It is thus possible to explore the microstructure and the properties of ions in the micropores through the resistivity measurements. Chi [10] used resistivity to explore the effect of pozzolanic materials on the properties of concrete. Results showed that the resistivity was increased by the fly ash. The influences on the long-term resistivity were dominant. By mixing both fly ash and slag, the resistivity was even increased more. Such increased resistivities were

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attributed to the densified microstructure by C–S–H gel and modified ion species and concentrations. The slag hydrates and induces pozzolanic effect. The hydrating products of C–S–H and C–A–H gels fill the micropores, reducing the porosity and pore connectivity. The resistivity was thus increased. Smith et al. [11] reported the effect of supplementary materials on the concrete resistivity and corrosion monitoring techniques. They reported that fly ash, slag cement, and microsilica all proved to be highly effective in creating more durable concrete design mixtures. These materials have also shown success in substantially lowering chloride ingress, thus extending the initiation phase of corrosion. Saraswathy et al. [12] have studied the influence of activated fly ash on corrosion-resistance and strength of concrete. Sengul and Gjorv [13] suggested that the Wenner four probe resistivity is suitable for quality control during concrete construction if the relation between resistivity and the testing of chloride diffusivity, which is time consuming, is established beforehand. In addition, Yeih and Chang [14] used resistivity to explore the effect of realkalisation of carbonated concrete. They found that the resistivity was increased by the condensed microstructure induced by realkalisation. More and more applications of the resistivity measurements were discussed in recent studies. The resistivity was used to relate with the properties of fiber concrete, such as fiber volume fraction, fiber length, compressive strength, and conductivity [15–17]. Furthermore, the resistivity was used to monitor the health of carbon fiber-reinforced concrete [16,18]. Similar techniques were used to characterize the distribution of the steel fibers in concrete [19].

The most common way to determine the resistivity of concrete is the measurement using four-point Wenner array probe technique, developed by Frank Wenner in 1915 [20]. In this technique, the measurement is supposed to be conducted for a semi-infinite homogeneous material [21]. However, concrete is inhomogeneous. The size and the shape of the specimen influence the measured value. Therefore, a correction coefficient, K, is proposed by Morris et al. to correct the measured resistivity of concrete [22]. Gowers et al. [23] further proposed the influencing factors on the K in prismatic specimens to minimize the errors. They reported that the influencing factors for prismatic shape specimen included (refer to Fig. 1): (1) $a \leqslant \frac{b}{4}$, where a is the probe spacing and b is the specimen width; (2) $a \leqslant \frac{h}{4}$ where h is the thickness of the specimen; (3) $a \leqslant \frac{2c}{3}$ where c denotes the cover thickness; (4) $a \geqslant 8t$ where t is the thickness of the surface weak layer; (5) the influence of carbonation should be considered; (6) a should be greater than 1.5 times the maximum coarse aggregate size; (7) $x \geqslant 2a$ where x is the shorter distance between the probe and the edges of the specimen; (8) no limitation on Y where Y is the greater distance between the probe and the edges; (9) influence of temperature should be considered as the resistivity decreases 0.33 kΩ-cm while the temperature increases 1 °C.

The four-point Wenner array probe technique has some advantages during the resistivity measurements of concrete. It is a non-destructive technique. The operation is simple and the data are obtained in a short time. Therefore, the technique is one of the common methods to explore the properties of concrete and widely used onsite. On the other hand, it has disadvantages. The moisture content of the specimen influences the resistivity measurements, but the moisture content is difficult to be controlled. In addition, the resistivity measurements of the cylindrical and prismatic specimens require correction, depending on the geometry and size.

In view of above issues, the scopes of this study include:

(1) The effects of the probe spacings and specimen sizes on the resistivities of the cylindrical specimens with different water–cement ratios and the corresponding corrections for the resistivity measurements.
(2) The effects of the moisture content and the ambient humidity on the resistivity of the cylindrical specimen.
(3) The effects of the probe spacings and reinforcement on the resistivities of the prismatic specimens.

2. Experimental

2.1. Principles of resistivity measurements

The principle of the resistivity measurement using four-probed Wenner meter is shown in Fig. 2. A current of I is applied on the electrodes I_1 and I_2, and the voltage of V between the electrodes V_1 and V_2 is measured. The resistivity R is determined by the ratio of V to I [24–26].

2.2. Specimens

This study explores the effects of specimen conditions and the mix proportions on the resistivity of concrete. Both cylindrical and prismatic specimens were prepared. The cylindrical specimens have sizes of ϕ 10 × 20 cm or ϕ 15 × 30 cm. They were used to explore the relationship between the probe spacing and the correction coefficient, K. The moisture content of the cylindrical specimens were varied and rested in air at various relative humidity to explore the changes in resistivity. On the other hand, the prismatic specimens have sizes of 20 × 20 × 17.5 cm, 16 × 16 × 14 cm, or 12 × 12 × 11 cm. For specimens with sizes of 20 × 20 × 17.5 cm and 16 × 16 × 14 cm, a #4 rebar (diameter of 1.3 cm) was placed in the middle of specimens. Therefore, when the Wenner probe array was placed on the top surface and parallel to the rebar the cover thickness was 9.35 cm and 7.35 cm for specimen of 20 × 20 × 17.5 cm and 16 × 16 × 14 cm, respectively. When the Wenner probe array was placed in the cross sectional plane with the rebar was in the middle of probe array, the cover thickness was considered as 0-cm. For The prismatic specimens of 12 × 12 × 11 cm, the locations of the #4 rebar were 5.35 cm (in the middle of the cross section), 6 cm, 8 cm and 10 cm measuring from the top surface to the rebar. Therefore, when the Wenner probe array was placed on the top surface and parallel to the rebar the cover thickness could be

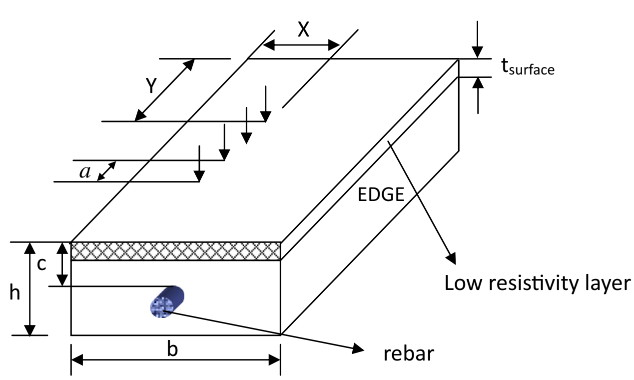

Fig. 1. Influencing factors for using Wenner four-probe test on prismatic specimen [23].

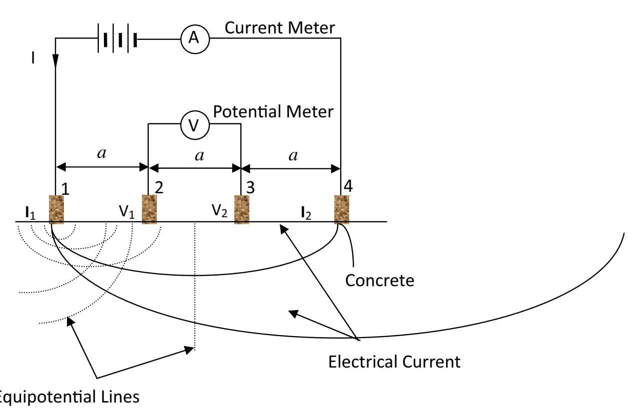

Fig. 2. Principles of resistivity measurements using four-probe Wenner technique [24–26].