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STUDY ON DETECTION METHOD OF DEFECTS IN COVERED CONCRETE USING ELECTRICAL RESISTIVITY MEASUREMENT

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This study reports on a fundamental study on the investigation of electrical resistivity measurements for detecting internal defects or damages, which aims at developing Electrical Resistance Tomography techniques based on electrical resistivity distribution measured via Wenner method. In particular, 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.

Keywords: Electrical resistance tomography, Non-destructive measurement, Wenner method, Internal damage, Current flow.

1 INTRODUCTION

A four-probe method (Wenner method) has been investigated as a simple and rapid method for measuring the electrical resistivity of cover concrete for existing concrete structures (Sengul and Gjørv 2008). It has been reported that the electric resistivity of concrete is influenced by mix proportion of concrete, moisture content and/or salt content in concrete and so on, and as the water cement ratio becomes smaller, the electric resistivity becomes larger (Minagawa *et al*. 2009). Furthermore, it is considered that the presence or absence of defects inside the concrete also affects the electric resistivity measured by Wenner method.

This study reports on a fundamental study on the investigation of electrical resistivity measurements for detecting internal defects or damages, which aims at developing Electrical Resistance Tomography techniques based on electrical resistivity distribution measured via Wenner method. 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. For the experimental investigation, ten electrodes comprising stainless steel and electric conductive epoxy were partially embedded on the surface of prism concrete specimen.

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2 EXPERIMENTAL INVESTIGATION

2.1 Specimens

Concrete and mortar were used for specimens. The cement used was high-early-strength Portland cement with a density of 3.14 g/cm^3. The fine aggregate was crushed limestone with a density in saturated surface-dry of 2.66 g/cm^3 and water absorption of 0.55%. The coarse aggregate was crashed sandstone with a density in saturated surface-dry of 2.61 g/cm^3 and water absorption of 0.80%. Specimens were cast with water-to- cement ratio of 50% and sand-total aggregate ratio of 48.5%. In the mortar, the ratio of water, cement and fine aggregate was 1:2:4 by weight.

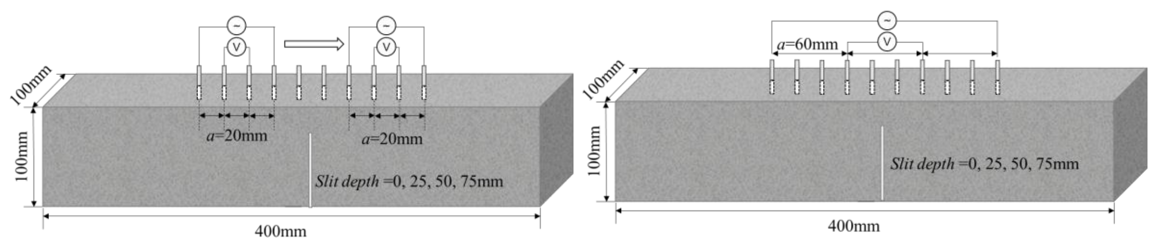

Figure 1. Schematic diagram of specimen and measurement (electrode interval *a* = 20 and 60 mm).

Figure 1 shows a schematic diagram of prism specimen and placement of electrodes. A slit simulating internal defects was introduced into the specimen from the bottom of the center part by a dry diamond cutter. The slit with a width of 1 mm were gradually deepened to 25, 50, 75 mm. The electrode was a stainless steel rod with ϕ3 mm. Holes with ϕ5 mm were dug up to 100 mm in the specimen and the electrodes were fixed with a conductive adhesive. Two specimens were made of concrete and mortar respectively.

2.2 Measurement of Electrical Resistivity

The distribution of electric resistivity was measured by the four probe method as shown in Figure1. In the case with the electrode spacing of 20 mm, four electrodes were used from ten electrodes arranged on the concrete surface. Then, the measurement position was moved and the measurements at 7 positions were carried out. In the case with the electrode spacing of 60 mm, the electrodes at the both ends were used as electrodes for energization and the inner electrodes arranged at intervals of 60 mm were used as electrodes for measuring the potential difference. An alternating current (AC) stabilized power supply with a voltage of 30 V and a frequency of 100 Hz was used for energization. Since the AC current value is not constant, the current value was estimated by measuring the voltage with a multimeter using a shunt resistance of 10 kΩ. The range of the applied current value is about 0.5 to 2.6 mA for the mortar specimen and 0.1 to 1.5 mA for the concrete specimen. The electrical resistivity (ρ) was calculated from Eq. (1).

$$\rho = 2\pi \cdot a \cdot \frac{V}{I} \tag{1}$$

where, a : electrode interval, V : voltage between the electrodes for potential difference, I : applied current. Eq. (1) is a theoretical solution derived from Ohm's law that the current density in concrete energized from the electrodes at both ends is isotropic.

3 ANALYTICAL INVESTIGATION

In this study, an analytical investigation was conducted on the influence of the presence / absence and the depth of the slit added from the bottom of the concrete on the current path and potential distribution. For the numerical analysis, an analytical model in the electrostatic field of COMSOL Multiphysics ver. 5.0 AC / DC Module which is a general-purpose FEM software was used. The following Poisson equation, Eq. (2), is used as a governing equation, and a finite element model to calculate current density and potential distribution in the target region discretizes the region of concrete having local defects.

$$-\nabla \cdot (\sigma \nabla V - J^{e}) = Q_{j} \tag{2}$$

where, σ : dielectric constant (=1/ρ), V : electric potential, J^e : externally generated current density, Q_j : applied current.

For numerical analysis condition, the electrical resistivity of concrete was set to 100 Ωm. The boundary condition was set as the insulation for the concrete surface. As the applied current value, 1 A/m^2 was given to one of the electrodes arranged at the end portion and the other electrode was grounded. Then, the voltage between the inner electrodes was calculated, and the electrical resistivity was calculated by Eq. (1) in the same manner as the four probe method.

4 RESULTS AND DISCUSSION

4.1 Effect of Internal Defect on Measurement of Electrical Resistivity

Figure 2 and Figure 3 show the effect of slit depth on electrical resistivity of concrete. Figure 2 shows the results of measurements with the electrode interval of 60 mm. Regardless of the presence or absence of a slit, the electric resistance of concrete is larger than the electric resistance of mortar. This increase is due to the detouring of the current path by the coarse aggregate in concrete. In both mortar and concrete, remarkably, the electrical resistance increases with the progress of the slit, especially when the slit depth increases from 50 mm to 75 mm.

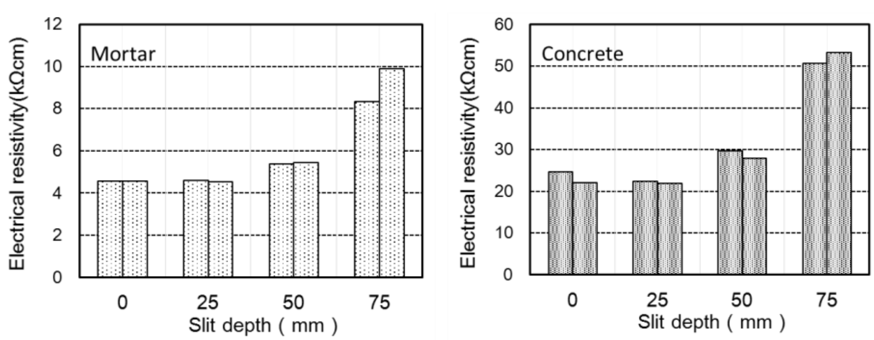

Figure 2. Effect of slit depth on electrical resistivity (electrode interval a = 60 mm).

Figure 3 shows the results of measurements with the electrode interval of 20 mm. For the specimen of mortar 1, the electric resistance measured at position (4) remarkably increases when the slit depth of 75 mm is provided. The slit is provided just under the position (4). On the other hand, at the position where the slit is not provided directly below, there is no clear increase in electrical resistivity due to the increase in the slit depth.

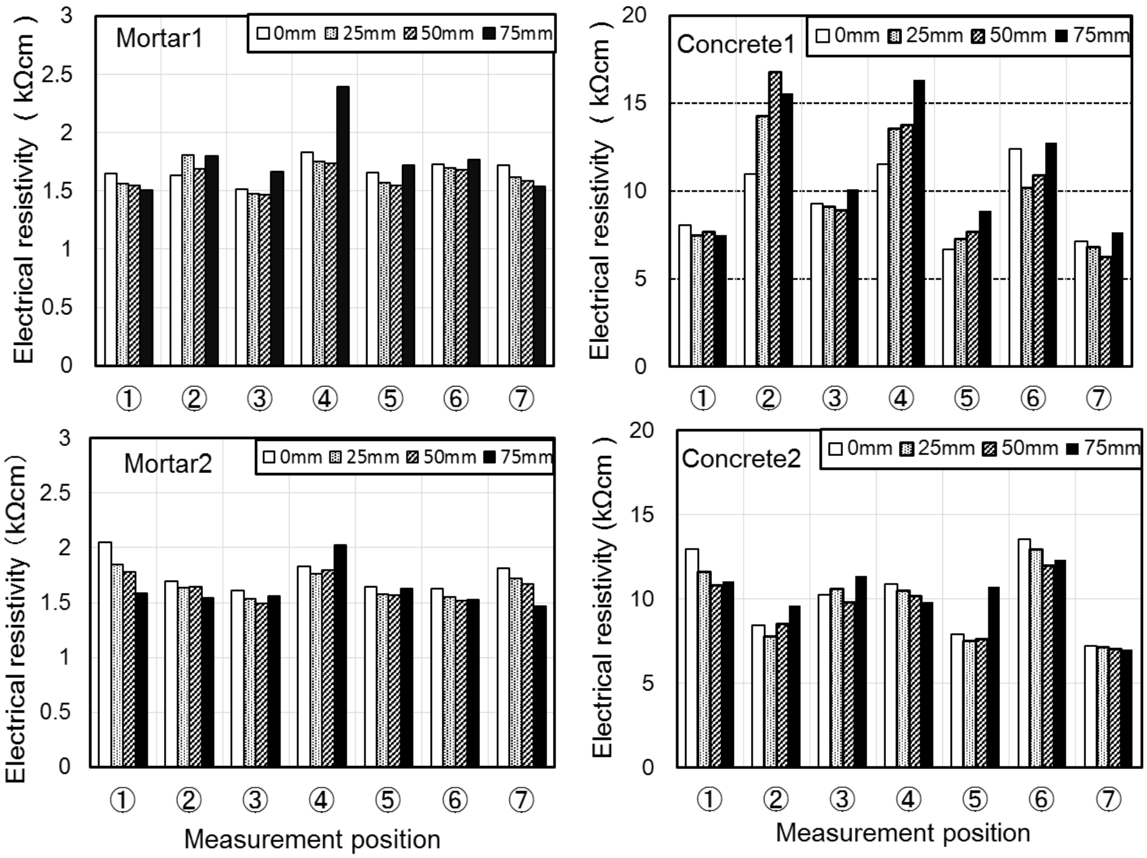

Figure 3. Effect of slit depth on electrical resistivity (electrode interval *a* = 20 mm).

Furthermore, even in specimen of concrete 1, an increase in electrical resistivity is confirmed at measurement position (4). However, for specimen of concrete 1, though there is no slit just under position (2), the electrical resistivity measured at position (2) also increases like that at position (4). Furthermore, for specimen of concrete 2, the electrical resistivity measured at position (4) hardly changed, in spite of the fact that the electrical resistivity increases when the electrode interval is 60 mm as shown in Figure 2. This may be due to the effect of coarse aggregate existing near the electrode. In order to detect defects that are not apparent on the surface of concrete at an early stage, it is thought that it is desirable to jointly use measurements with wider electrode interval. Figure 4 shows electrical potential distribution and current path. It is known that the current path and the equipotential line cross at a right angle. Then as shown in the upper of Figure 4, stainless steel bars were placed in the mortar specimen and the electrical potential from the electrode was measured. The broken line in Figure 4 is an equipotential line extrapolated from the measured potential and the solid line indicates the current path obtained so as to be orthogonal to the equipotential line. When the electrode interval is 20 mm, a current is applied at the position (4). In both electrode interval of 60 and 20 mm, when there is no slit, the equipotential line is almost radial from the electrode to which current is applied, and the current curves toward the mortar, not reaching the slit at the center of the specimen, as slit depth deepens.

This increase in current path contributes to the increase in electric resistance. When the slit is 25mm, at the electrode interval of 60 mm, the current path near the surface of the specimen curves convex slightly upward. However, at electrode interval of 20 mm, such a change in electrode path does not occur.

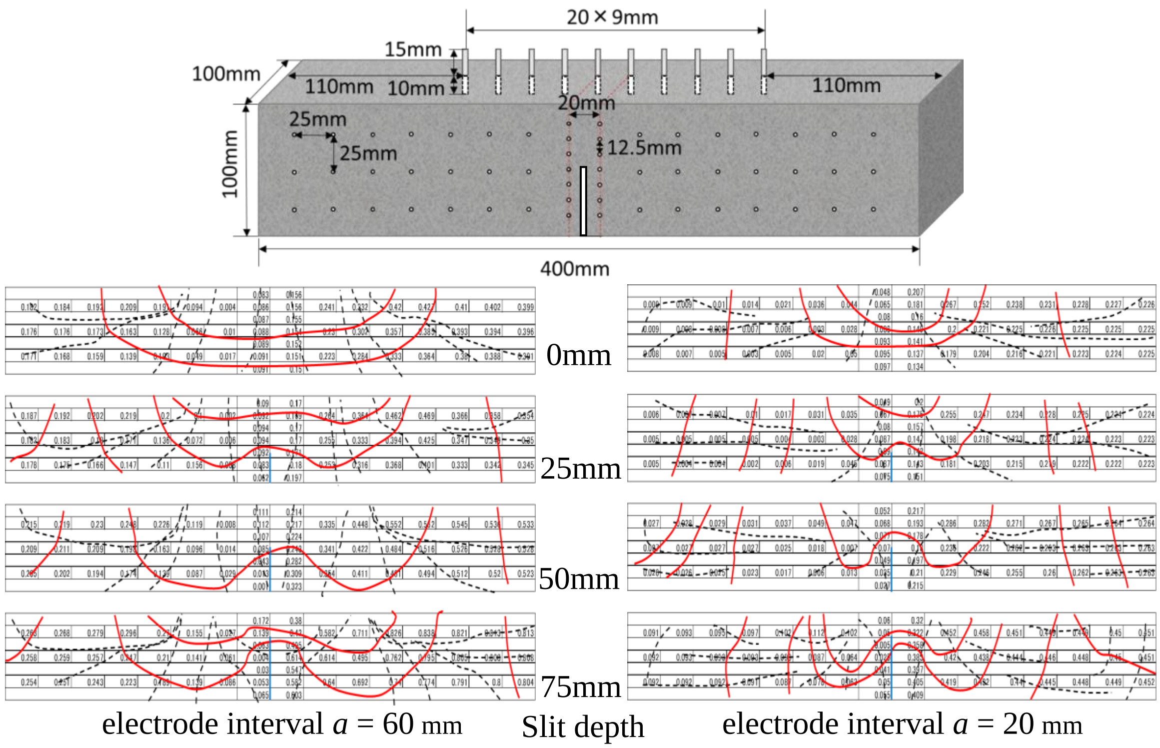

Figure 4. Electrical potential distribution in mortar specimen with/without slit.

4.2 Analyzed Current and Potential Distribution

Figure 5 shows an example of analysis results of equipotential surfaces and current paths in concrete specimen with electrode interval of 60 mm. Analysis A is the result of the specimen without the slit, and analysis D is that with the slit depth of 75 mm.

The analysis results well reproduce the current path obtained from the measured potential shown in Figure 4. These analytical results theoretically explain the fact that the increase in the measured electrical resistivity is caused by the increase in the voltage between the potentiometric electrodes by paying attention to the variation of the current path.

Figure 6 shows the measured and analyzed increase ratio of electrical resistivity. The increase ratio of the electrical resistivity obtained from the measurement agrees well with that obtained from the analysis and it seems that the effectiveness of this method could be demonstrated. From the analysis results, internal defects such as cracks come closer to the surface, so it is considered that more remarkable increase in electrical resistivity can be caught in this method. In the future, the measurement of electrical resistivity distribution in concrete having cracks will be carried out with the ratio between the defects area and the sound area as a parameter, then, it is a subject to investigate a method of identifying the crack position and its depth (or depth of sound area) by statistical or inverse analysis.

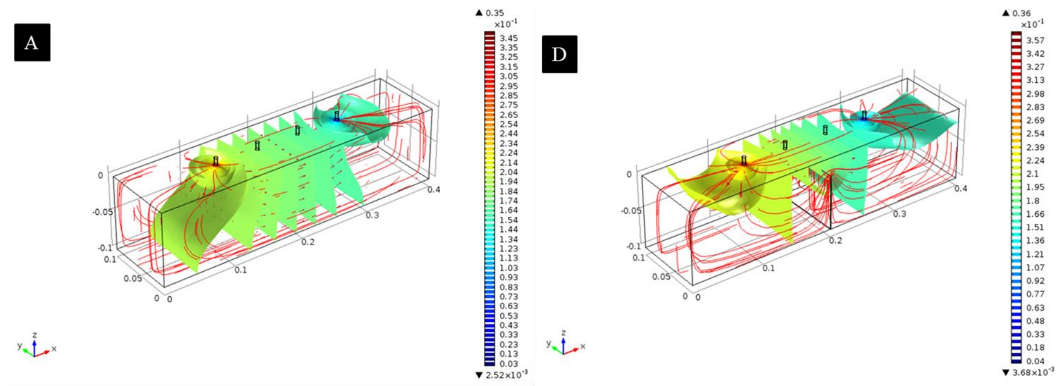

Figure 5. Example of FEM analysis results (electrode interval a = 60 mm).

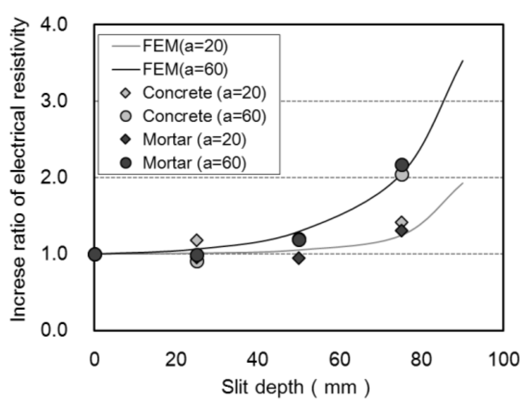

Figure 6. Comparison of measured and analyzed increase ratio of electrical resistivity.

5 CONCLUSIONS

The conclusions derived from this study are summarized as follows: 1) As the depth of the slit formed by simulating internal cracks at the bottom of the specimen increases, the electrical resistivity increases irrespective of the interval between the electrodes; 2) The increase in the electrical resistivity between the electrodes is caused by the fact that the current path is bent due to the presence of the slit and the voltage between the potential difference electrodes is increased; and 3) The possibility of detecting internal damage based on the change in electrical resistivity is demonstrated by appropriately combining the electrode interval of the four probe method.

References

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