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Application of Four-electrode Method to Analysis Resistance Characteristics of Conductive Concrete

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***Abstract*—**The purpose of this paper is to discuss the influence of resistance characteristic on the high conductive concrete considering the various voltage and environment. The four-electrode method is applied to the tailor-made high conductive concrete with appropriate proportion. The curve of resistivity with the changes of voltage and environment is plotted and the changes of resistivity are explored. The result based on the methods reveals that resistivity is less affected by the temperature factor, and the four-electrode method would be an applicable measurement method on a site inspection.

***Keywords*—**Conductive concrete, Resistivity.

I. INTRODUCTION

CONCRETE is widely used around the world with unique physical property. The conductive concrete is commonly to be applied to pave on the roadway to ensure the road smooth, transportation safety and the airports operation efficiency. The conductive concrete applied to the road surface with snow is particularly effective because the road surface can be cleaned rapidly and efficiently. For road maintenance in the area with snow in winter, this project becomes significant [1]-[3]. In addition, the soil resistivity is the critical concern for a grounding system to an electrical grounding system. The conductive concrete with low resistivity characteristics can increase the promotion of the grounding characteristic. For example, the grounding resistance of the transmission tower can be decreased if the concrete with conductive property combined with the original grounding grid is applied as the foundation of tower. The grounding characteristic will be greatly promoted. In the example, lightning power can be dissipated to the earth rapidly, and the transmission reliability can be enhanced. For this reason, many researches have discussed the characteristic of conductive concrete in recent years [4], [5]. The conductive concrete with conductive and magnetic capacity applied to grounding system would moderately reduce the damage caused by lightning and surge. Therefore, the purpose of this paper is to discuss the resistance characteristics of the conductive concrete using four-electrode method and also discusses the influences of voltage and environment corresponding to the resistance characteristics of the high conductive concrete.

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II. CONDUCTIVE CONCRETE AND MODELS

A. Introduction of conductive concrete

The conductive concrete known as a compound concrete for special purpose not only maintains its basic mechanical property, but also makes it constitute a conductive network. The conductive concrete is mixed with a certain amount of conductive material in the cement. Some part of the aggregate in the concrete is replaced by adding metal fibers and metal substances. With the same function as the resistance reducing agent with a lower resistivity, the conductive concrete is particularly employed to the reinforced concrete and road surface. Moreover, the conductive capacity of conductive concrete is different according to the conductive materials and doping concentration. In this paper, materials, proportion and production procedures applied to the conductive concrete is adopted from the reference [5]. The main concrete materials are cement, coarse aggregate, and fine aggregate, and the proportions for each material are 20%-30%, 15%-20%, and 15%-20%, respectively. The conductive material (30%) is further divided to steel fiber (5%), and steel grit (25%). The value of water-cement ratio is between 0.3 and 0.4 approximately. The detailed specification is shown in Table I.

B. The models

The four-electrode method is applied to measure the resistivity of conductive concrete in this paper. Then, the resistivity related to time, temperature and voltage are obtained. The measurement method is depicted as follows.

TABLE I
MATERIAL AND PROPORTION OF THE CONDUCTIVE CONCRETE

Material	Proportion	Annotation
Cement	25%	The cement of type I
Coarse aggregates	20%	Maximum diameter is 30mm
Fine aggregates	15%	Maximum diameter is 2mm
Steel fiber	5%	Maximum length is 40mm
Steel grit	25%	Maximum diameter is 1.42mm
Water-cement ratio	0.4	The weight ratio of water and cement
※ The proportion of water is about 15%		

B-II The four-electrode method

The four-electrode method refers to the four electrodes applied to conductive concrete. The four electrodes are embedded in the conductive concrete in equidistant mode. The two electrodes inside is connected to voltmeter and the two electrodes outside are connected to ammeter, as shown in Fig. 1. This method makes voltage and current of measuring electrodes separate. Besides, the outside electrodes are supplied by the DC source and the value of voltage and current are recorded [6], [7].

B-III The formula

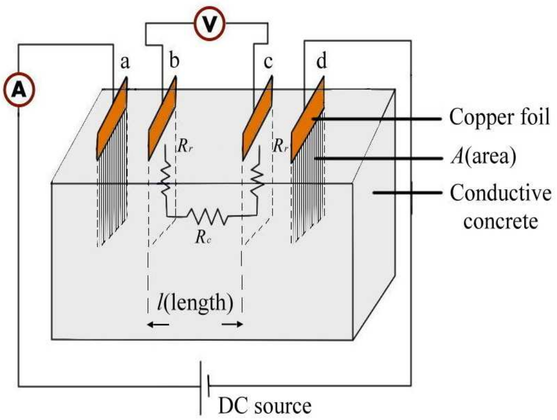

Fig. 1. Structure of the four-electrode method.

Ohm's law is applied to the two methods and the resistance R_c of the conductive concrete between b and c, and the resistivity ρ are obtained, as shown (1) and (2), respectively.

$$2R_r + R_c = \frac{V}{I} \tag{1}$$

$$R = \rho \frac{l}{A} \tag{2}$$

which

R_r : electrode resistance (Ω)

R_c : resistance of the conductive concrete between b and c (Ω)

V : the voltage between b and c (V)

I : the current flowing through b and c

ρ : resistivity of the conductive concrete (Ω·m)

l : the length between b and c (m)

A : contact sectional area between the conductive concrete and electrode (m^2)

III. Practical Model and Measurement

A. The practical models

A-I The four-electrode method

To avoid fail to obtain the actual resistivity value of the conductive concrete. The four-electrode method is applied in this paper. In the measurement, a digital multimeter is connected to any of two electrodes, and the measured value is composed of the sum of the resistance of the conductive concrete itself, the electrode resistance, and contact resistance generated between copper electrode and specimens. Therefore, the four-electrode method is the major measurement in this experiment. In order to eliminate the influences of electrode and contact resistance, the four-electrode method with four pre-embedded electrodes is applied to measure the conductive concrete. The required instruments for four-electrode method are shown in Fig. 2.

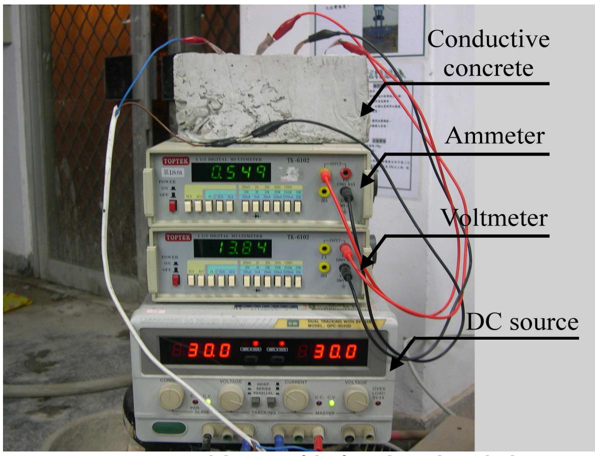

Fig. 2. Measured diagram of the four-electrode method.

B. Step of the measurement

To observe the stability and accuracy using the four-electrode method, a better measurement is chosen when the smaller resistivity without severe change as time varying. Meanwhile, the conductive concrete is placed outside, and the temperature and environmental conditions are recorded. The measurement flowchart is shown in Fig. 3, and the steps are briefly listed below.

a. The equipment is necessarily prepared for the

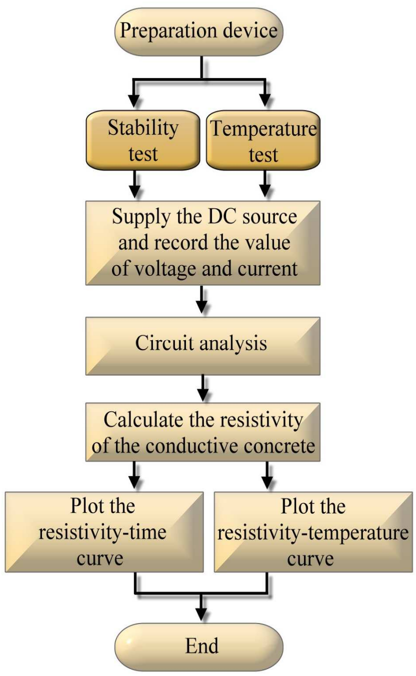

Fig. 3. Flowchart of the resistivity measurement.

four-electrode method.

b. The voltage and current of the conductive concrete are measured using two different methods, and the resistivity is calculated according to Ohm's law.
c. The stability test is recorded once per 60 seconds.
d. The conductive concrete is placed outdoors and it is measured at different temperature and climate conditions.
e. The resistivity-time and resistivity-temperature curves are drawn.
f. The results of two measurement methods are discussed and compared.

IV. THE DATA AND THE MEASURED RESULTS

For a better understanding of the influence on the resistivity of the high conductive concrete, temperature and humidity are considered, and the stability of the high conductive concrete is tested using the four-electrode method. The results have shown that using the four-electrode method, the generated polarization in process of connecting voltage source can be avoided and contact resistance between electrode and the conductive concrete is also reduced. Therefore, the resistivity measurement of the conductive concrete at different voltage is based on the four-electrode method.

A. Time

The conductive concrete is not a general dry solid material.

TABLE II
DATA OF THE RESISTIVITY IN STABLE TEST

Date	Measurement	2 minute	4 minute	6 minute	8 minute
Day 1	Four-electrode	2.154	2.104	2.033	1.921
Day 2	Four-electrode	2.222	2.149	2.156	2.162
Day 3	Four-electrode	2.289	2.286	2.300	2.318
Day 4	Four-electrode	2.353	2.381	2.346	2.420
Day 5	Four-electrode	2.429	2.464	2.501	2.495
Day 6	Four-electrode	2.575	2.599	2.571	2.563
Day 7	Four-electrode	2.623	2.626	2.653	2.641

When connected to voltage source, the conductive particles inside of the conductive concrete are affected. This phenomenon displays the unstable data obtained from voltmeter and ammeter and results in measurement error every time. In order to understand the stability and accuracy of four-electrode method in the process of measurement, the stability of conductive concrete is firstly tested. The data in terms of the four-electrode method is recorded once 60 seconds, and 10 data are recorded in one day. Finally, these data are applied to calculate the resistivity in the unit of (Ω·m). The result of the 7-day measurement is shown in Table. II.

B. Temperature and moisture of the environment

The conductive concrete is placed outdoors. To observe the influence of conductive concrete on resistivity in different environments, including dry and wet conditions, the recorded data comprising the measurement values in sunny and rainy days are compared. The measurement data using four-electrode method is shown in Table III. Besides, these data is plotted to observe the curves related to resistivity, and outdoor temperature and climate as well, as shown in Fig. 4.

TABLE III
DATA OF THE RESISTIVITY IN ENVIRONMENT TEST
(FOUR-ELECTRODE METHOD)

Drying		Wetting	
Temperature (℃)	Resistivity (Ω·m)	Temperature (℃)	Resistivity (Ω·m)
18	4.513	11	2.841
19	4.455	12	2.675
20	4.289	13	2.168
22	4.033	13.5	2.096
23	4.213	14	2.057
24	3.511	16	2.097
26	3.222	17	1.895

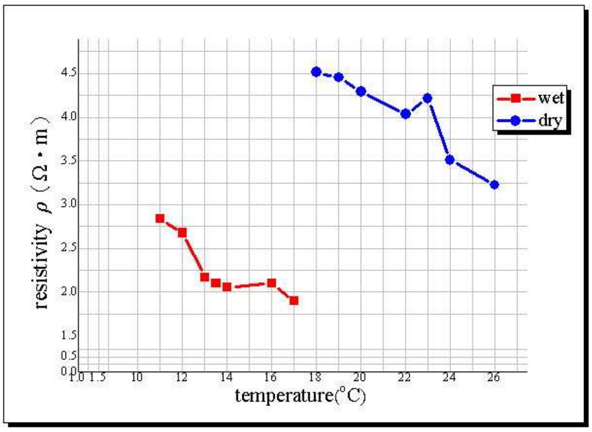

Fig. 4. Relation curve of resistivity and temperature in four-electrode method.

C. Voltage

The experimental results have shown that four-electrode method is considered a better measurement method compared with others. By using the four-electrode method, the measurement error caused by polarization can be eliminated indeed and the actual value of the resistivity of the conductive concrete can be calculated. In addition to considering the factors of time, temperature and humidity, the four-electrode method is also employed to measure the resistivity of the conductive concrete at different voltages (10V-60V). The values of the voltage and current are recorded for 25 days, and the resistivity curves with different voltage are plotted, as shown in Table IV and Fig. 5, respectively.

V. ANALYSIS AND DISCUSSION OF THE RESULTS

The resistivity of the high conductive concrete using the four-electrode methods is investigated. The resistance characteristics are observed and the diversity of the two methods is compared. Since the pore solution of the conductive concrete is gradually decreased in the dry environment, and steel fiber and steel grit would go rust slightly in the alkaline environment of cement, the conductive capacity is gradually decreased. For this, the two factors directly influence the current and make the resistivity increase. The result of the stability has shown that resistivity of the conductive concrete

TABLE IV
RESISTIVITY TABLE AT DIFFERENT VOLTAGE IN FOUR-ELECTRODE METHOD

Date	10V	20V	30V	40V	50V	60V
Day 1	4.83	3.91	3.28	2.82	2.61	2.41
Day 2	4.94	3.95	3.31	2.90	2.63	2.44
Day 3	5.29	4.28	3.58	3.13	2.84	2.62
Day 4	5.59	4.46	3.73	3.25	2.94	2.74
Day 5	5.87	4.76	3.99	3.50	3.17	2.93
Day 6	6.15	4.89	4.10	3.54	3.22	2.97
Day 7	6.26	4.97	4.12	3.60	3.26	3.02
Day 8	6.35	5.04	4.20	3.67	3.33	3.07
Day 9	6.79	5.38	4.42	3.89	3.52	3.25
Day 10	6.47	5.22	4.35	3.79	3.43	3.17
Day 11	6.42	5.22	4.35	3.78	3.42	3.15
Day 12	7.06	5.58	4.82	4.08	3.70	3.42
Day 13	7.36	5.82	4.87	4.24	3.84	3.55
Day 14	7.71	6.01	5.04	4.39	3.97	3.68
Day 15	8.16	6.36	5.32	4.63	4.06	3.87
Day 16	7.69	6.15	5.17	4.55	4.13	3.82
Day 17	7.79	6.16	5.16	4.50	4.08	3.79
Day 18	8.25	6.42	5.36	4.72	4.29	3.99
Day 19	8.77	6.85	5.73	5.01	4.54	4.20
Day 20	8.80	7.00	5.85	5.10	4.62	4.27
Day 21	9.20	7.25	6.05	5.28	4.78	4.40
Day 22	9.24	7.32	6.09	5.35	4.88	4.53
Day 23	9.71	7.67	6.40	5.59	5.06	4.67
Day 24	8.96	7.07	5.90	5.17	4.68	4.32
Day 25	9.05	7.15	5.93	5.18	4.69	4.31

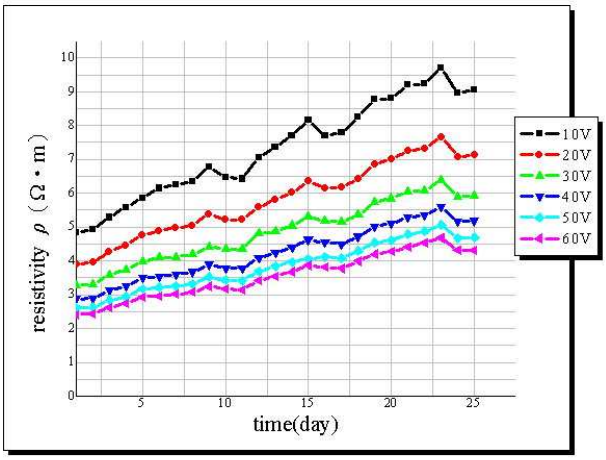

Fig. 5. Relation curve of the resistivity and day with different voltage four-electrode method.

significantly increases and the resistivity curve also rise.

On the other hand, the conductive concrete with pore solution is capable of either absorbing or evaporating water depending on the moisture change, for this reason, the resistivity of the conductive concrete is varied as the environment change. By observing Fig. 4, when the conductive concrete is placed outdoors, the resistivity of the conductive concrete is influenced by temperature and humidity. The higher the temperature and humidity are, the lower resistivity is, as shown in Table III. Considering the influencing factor of the internal water, after the concrete hydration, many ionic substances, electrolytes, is dissolved in the water and interconnected by capillary. Therefore, as the water increases, the conductive concrete of conductivity is increased and the tightness of the concrete structures is maintained. Comparing the factors between temperature and moisture, the resistivity of conductive concrete is evidently to be affected by water content. In this way, the warm and humid environment results in a lower resistivity for conductive concrete.

According to Table IV, the resistivity changes as the power source is supplied to conductive concrete at different voltage levels. The larger the connected voltage source is, the larger the power inputted to internal concrete is. Due to the obvious warming phenomenon, the resistivity is gradually decreased. Moreover, the environment temperature is less influenced on the resistivity of the conductive concrete. If the power source is supplied to the conductive concrete by higher voltage source, the conductive concrete inside brings warming reaction directly which makes internal temperature of the conductive concrete increase, and the resistivity of conductive concrete decrease.

VI. CONCLUSION

The resistivity of the high conductive concrete is computed in this paper using Ohm's law, and the four-electrode method is applied to measure and record in different conditions, including time, temperature and voltage. The results have shown that either the higher temperature or the higher humidity results in a smaller the resistivity. In addition, the voltage change also affects internal temperature and the structure of the conductive concrete. The greater the voltage is, the smaller the resistivity is. In sum, the resistivity of the high conductive concrete is not a constant value. The resistivity is not only slightly changed day by day, but also affected by external environment. The four-electrode method can be applied to eliminate the error caused by polarization and obtain approximate value of resistivity of the high conductive concrete. The measured average of the resistivity of the conductive concrete is 6.76(Ω·m). Both the applications of four-electrode method can be considered a reference for measuring the resistivity related to specific material in the future.

Generally, the conductive concrete is widely used for deicing; however, this paper focuses on the application of conductive concrete to grounding system. The important parameter, resistivity, is an indicator in terms of grounding system. The resistance characteristics of the conductive concrete are obtained based on the proposed method and measured data in this paper. The characteristics of the high conductive concrete corresponding to the grounding standard completely can be applied to grounding effectively.

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