RESISTIVITY MAPPING

Introduction

- Concrete resistivity is a geometry-independent material property that describes the electrical resistance, which is the ratio between applied voltage and resulting current in a unit cell.
- The dimension of resistivity is resistance multiplied by length, its unit usually is in Ω-m.
- Resistivity of concrete may vary over a wide range, from 10^1 to 10^5 Ω-m, depending on the moisture content of the concrete (environment) and its composition (material).
- In concrete, the current is carried by ions dissolved in the pore liquid.
- More pore water (wet concrete) as well as more and wider pores (high water to cement ratio) cause a lower resistivity.

RESISTIVITY MAPPING

Introduction---continued

- Resistivity mapping does not show whether steel in concrete is actively corroding. This information must be obtained using other methods, such as chloride profile analysis, carbonation depth, potential mapping, etc.
- Resistivity of concrete is related to the following two principal stages in the service life of a structure:
  - the initiation period (low resistivity fast chloride penetration)
  - the propagation period (low resistivity high corrosion rate)
- Thus, locations within a structure having low electrical resistivity possess high chloride penetration and high corrosion rate
- The choice between local and more general repair measures can be based on the distribution of the expected corrosion rates.
- If maintenance actions are taken, resistivity and its distribution are important for electrochemical repair methods.

RESISTIVITY MAPPING

Principle of Resistivity Measurement

- **Resistivity of the near-surface concrete of a given concrete structure can be measured non-destructively using electrodes placed on the concrete surface**
- **This requires at least two electrodes, one of which may be a reinforcing bar.**
- **A voltage is applied between the electrodes, and the resulting current is measured (or vice-versa).**
- **The ratio of voltage to current gives a resistance (in Ω)**
- **The resistivity is obtained by multiplying the measured resistance by a conversion factor, called the cell constant (in m)**
- **Temperature changes affects concrete resistivity because temperature influences ion mobility, ion-ion and ion-solid interactions**
- **Overall, a temperature increase causes a decrease of electrical resistivity and vice-versa.**

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RESISTIVITY MAPPING

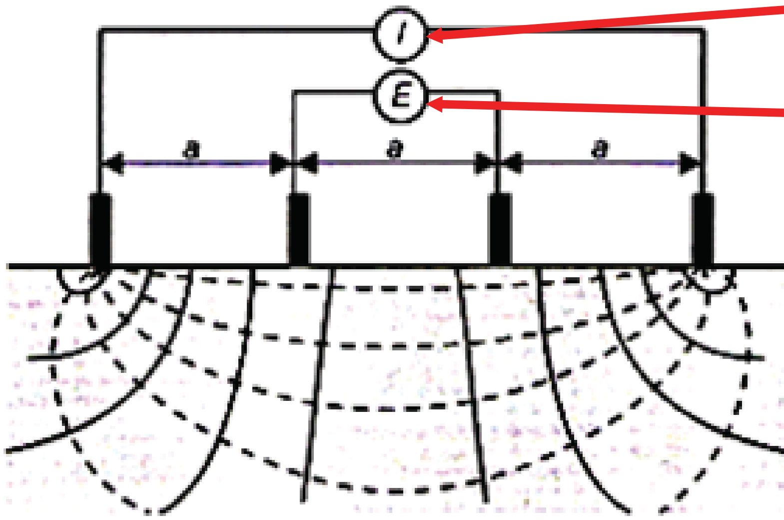
Methods of Resistivity Measurement

- **Resistivity of concrete can be determined using the following methods:**
  - **Wenner four-probe method**
  - **Two-probe method**
  - **Disc method**
  - **Core-clamping method**

RESISTIVITY MAPPING

Wenner Four-Probe Method of Resistivity Measurement

Resistivity of concrete is measured non-destructively using Wenner's probe electrodes placed on the concrete surface, as shown in Figure below:



Current *I* is applied through the two outer electrodes

Potential drop *E* between the two inner electrodes is measured

Resistivity is calculated as:

$$\rho = 2\pi . a . R$$

$$R = E / I$$

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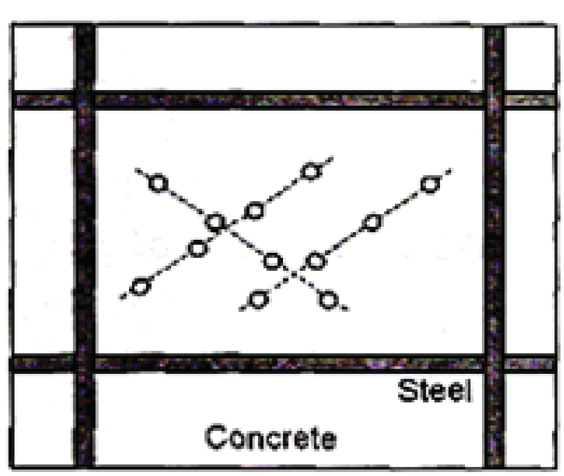
Wenner Four-Probe Method -----continued

Notes:

- **Spacing of the probe electrodes *"a"* should be greater than the maximum size of aggregate.**
- **Positioning of Wenner's probe electrodes on the concrete surface should be in the way as shown in Fig. below, in order to stay as far as possible from the rebars.**



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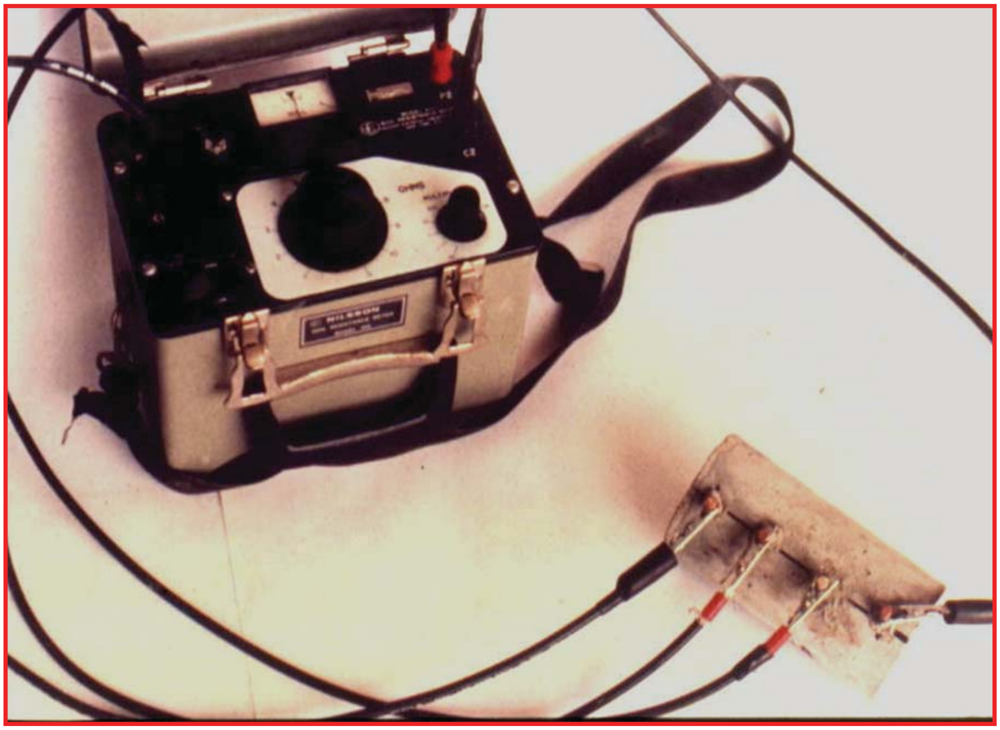
RESISTIVITY MAPPING

Wenner Four-Probe Method -----continued



Resistivity measurement using Wenner four-probe method

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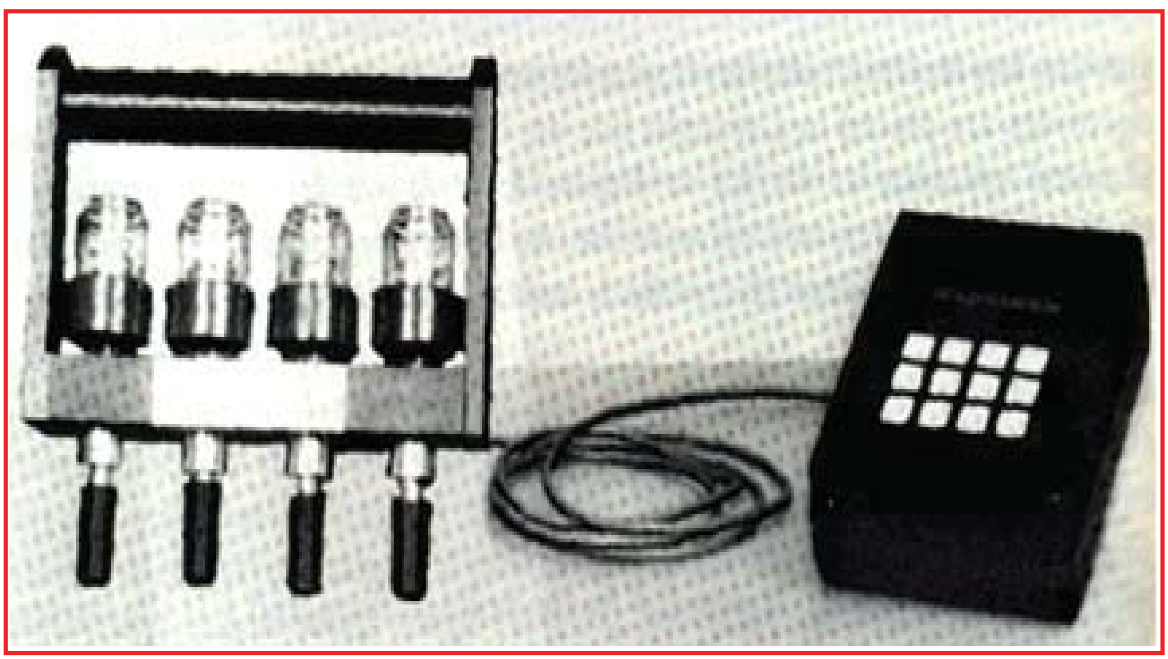
RESISTIVITY MAPPING

Wenner Four-Probe Method -----continued



Portable four-probe resistivity equipment

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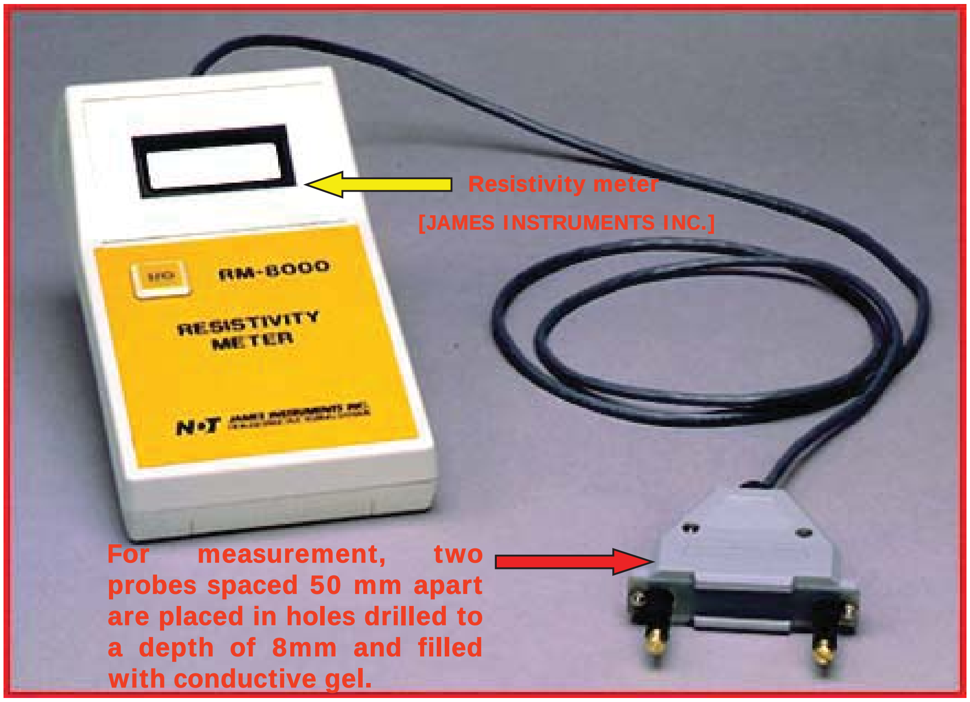
RESISTIVITY MAPPING

Two-Probe Method of Resistivity Measurement



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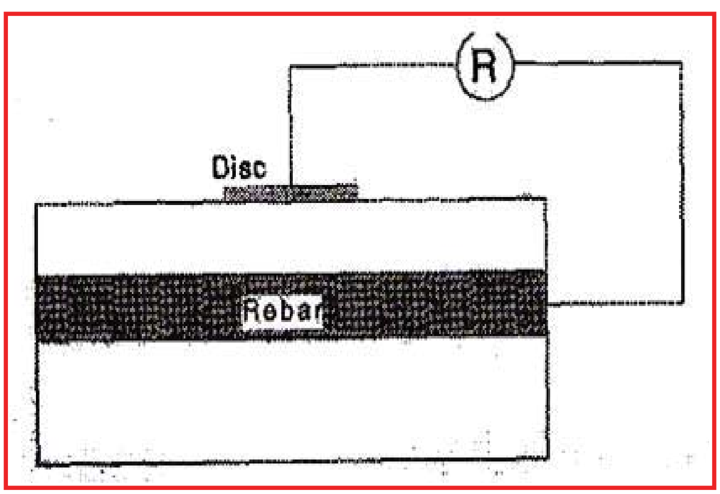
Disc Method of Resistivity Measurement

- This method involves an electrode (disc) placed on the concrete surface over a rebar and measuring the resistance between the disc and the rebar.
- It requires a connection to the reinforcement cage and full steel continuity, as shown in Figure below:



- The resistance (R) measured can be converted to resistivity using a cell constant that depends on the cover depth and the rebar diameter
- For cover depths, disc and bar diameters being 10 to 50 mm, the cell constant is about 0.1 m
- So the resistivity measured using a disc electrode is about:

$$\rho = 0.1 \times R \ (\Omega\text{-m})$$

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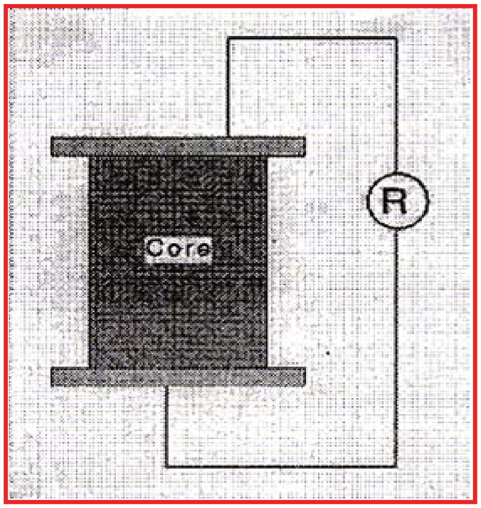
Core-Clamping Method of Resistivity Measurement

- It may be useful to take core samples from the structure and expose them in the laboratory in standardized conditions to determine the potential resistivity (i.e., the resistivity in saturated conditions)
- Core samples with two faces cut parallel are exposed in a fog room and potential resistivity is measured using metal plates , as shown in Figure below:



The resistivity is as follows:

$$\rho_{concrete} = R_{measured} \times A/L$$

Where:

$\rho_{concrete}$ = resistivity (in Ω-m)
$R_{measured}$ = R between the plates (in Ω)
A = area of the core face (in m^2)
L = length of the core (in m)

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RESISTIVITY MAPPING

Interpretation of Resistivity Test Results

- It may be useful to compare the resistivity measured on a structure to the data of similar concrete types.
- For this purpose, some reference values from laboratory studies are given in Table below, depending on the cement type and exposure:

Global reference values of resistivity for dense aggregate concrete at 20°C (age >10 years)

Environment	Concrete resistivity $\Omega_{concrete}$	
	Ordinary Portland cement	Blast furnace slag cement (>65% slag) or fly ash (25%) or silica fume (>5%)
Very wet, submerged, splash zone, [fog room]	50-200	300-1000
Outside, exposed	100-400	500-2000
Outside, sheltered, coated, hydrophobised (not carbonated) [20 °C/80% RH]	200-500	1000-4000
AS above but carbonated	100 and higher	2000-6000 and higher
Indoor climate (carbonated) [20 °C/50% RH]	3000 and higher	4000-10,000 and higher

RESISTIVITY MAPPING

Interpretation of Resistivity Test Results--continued

- The absolute value of the resistivity measured on a structure can be interpreted as follows:
  - If the cement type is known, the observed resistivity is compared to the reference value for that cement type in the relevant exposure conditions, as shown in previous Table
  - If, for example, a wet structure made with OPC has a mean measured resistivity of 50 Ω-m, it means that the water-to-cement ratio must be quite high.
  - The risk of corrosion is relatively high if, for example de-icing salts are present.

  Note:

  The resistivity data must be corrected for temperature effects. In general, one °K of temperature change causes a change of 3 to 5% (other factors remaining constant).

RESISTIVITY MAPPING

Interpretation of Resistivity Test Results--continued

- If the concrete composition is relatively homogeneous, mapping the resistivity may show wet and dry areas
- If an OPC structure has resistivity values between 100 and 500 Ω-m, the extreme values can be interpreted as indicating relatively wet and relatively dry areas
- If, on the other hand, the exposure (so the moisture content) is relatively uniform, variations in resistivity (say from 50 to 200 Ω-m) can be interpreted as caused by local variations in the water-to-cement ratio
- Areas with 50 Ω-m will be more susceptible to penetration of chloride from the environment than areas with 200 Ω-m.

RESISTIVITY MAPPING

Interpretation of Resistivity Test Results--continued

- The results of concrete resitivity measurements can be used for a quantitative or qualitative interpretation of reinforcement corrosion, as summarized in Table below:

Concrete resistivity, Ω.m	Risk of corrosion
<100	High
100-500	Moderate
500-1000	Low
>1000	negligible

- However, resitivity values are normally used to determine the corrosion risk only when the information on half-cell potential or chemical analysis is available