



RCON™

CONCRETE ELECTRICAL RESISTIVITY METER

OVERVIEW

Giatic RCON™ is an advanced tool for the electrical resistivity measurement of concrete using uniaxial method. RCON™ employs AC impedance technique for the accurate and fast readings that can be continuously obtained using its customizable and user-friendly operating software for various concrete materials. The electrical resistivity of concrete can be simply related to their pore network characteristics such as pore size and their connectivity, moisture content in the pores and pore solution chemistry. In concrete materials, the electrical resistivity has been correlated well with important durability parameters such as permeability and diffusivity.

In addition, this non-destructive test can be easily conducted on fresh or hardened concrete specimens at different ages or various stages of hydration in order to study workability, setting and durability performance of

concrete. The electrical resistivity method has also been applied to investigate corrosion of rebar in concrete, creep, aggregate segregation and freeze and thaw of concrete since they affect the pore network properties.

FEATURES

- Fast (<5 Second)
- Accurate ($\pm 2\%$)
- AC measurement (Galvanostatic)
- Wide range of measurement frequencies (1Hz to 30kHz)
- Phase detection (0-180 degree)
- Stand alone operation
- Continuous measurement
- User-friendly PC software
- Flexible sample holders
- Customizable setup
- USB connection to computer

MEASUREMENT CONCEPT

Giatic RCON™ applies a small alternating current at intended frequencies without causing any disruption and measures the voltage between the two ends of the concrete specimen. The impedance (Z [Ω]) can then be calculated from measured voltage and applied current values. In order to apply the current, two conductive plates are used as shown in Fig. 1. Concrete resistivity is then determined using the impedance value as follows:

$$\rho = \frac{A}{L} Z \quad \text{Eq. 1}$$

where ρ [$\Omega \cdot \text{cm}$] is the resistivity, A [cm^2] is the cross-sectional area of the specimen, L [cm] is the length of the specimen, and Z [Ω] is the impedance (resistance) measured by the device.

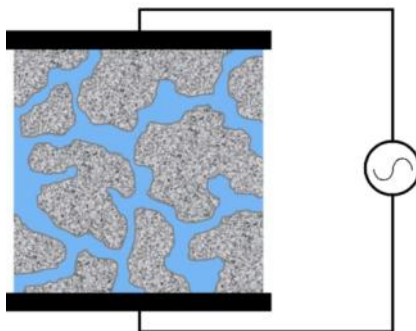


Figure 1: Concrete specimen placed between two plates

The current signal generated by the device is sinusoidal. The voltage measured across the specimen is divided by the imposed current to obtain the impedance (See Fig. 2-a). Based on the value of the impedance, the current scale may vary from 10 μ A to 1 mA.

The phase of the impedance is calculated by determining the difference between the phase of the voltage and current (See Fig. 2-b).

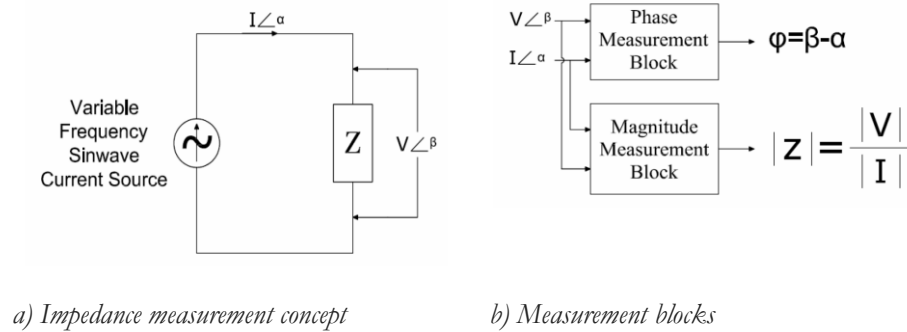


Figure 2: Impedance measurement concept

APPLICATION

RCOTM is a unique tool to investigate the micro-structural properties of concrete including:

A) PERFORMANCE-BASED QUALITY CONTROL OF CONCRETE

Concrete electrical resistivity techniques is a suitable replacement for the Rapid Chloride Permeability Test of concrete (as per ASTM C1202 or AASHTO 277) since there is a good correlation between the bulk electrical resistivity and durability performance of concrete (See Table 1). Therefore, this technique can be used for the performance-based quality control of concrete.

Table 1: Rapid chloride permeability and bulk electrical resistivity values¹

Chloride Penetration	56-Day Rapid Chloride Permeability Charge Passed as per ASTM C1202 (Coulombs)	28-Day Bulk Electrical Resistivity of Saturated Concrete (k Ω .cm)
High	>4,000	<5
Moderate	2,000-4,000	5-10
Low	1,000-2,000	10-20
Very Low	100-1,000	20-200
Negligible	<100	>200

B) DIFFUSION OF CHLORIDE IN CONCRETE

An almost linear correlation between chloride diffusion coefficient determined through ponding test and conductivity ($1/\rho$, where ρ was measured using uniaxial technique with AC current at 1 kHz frequency) was reported by Ghods et al. (see Fig. 3)². Similar findings have been reported by Sengul and Gjorv³.

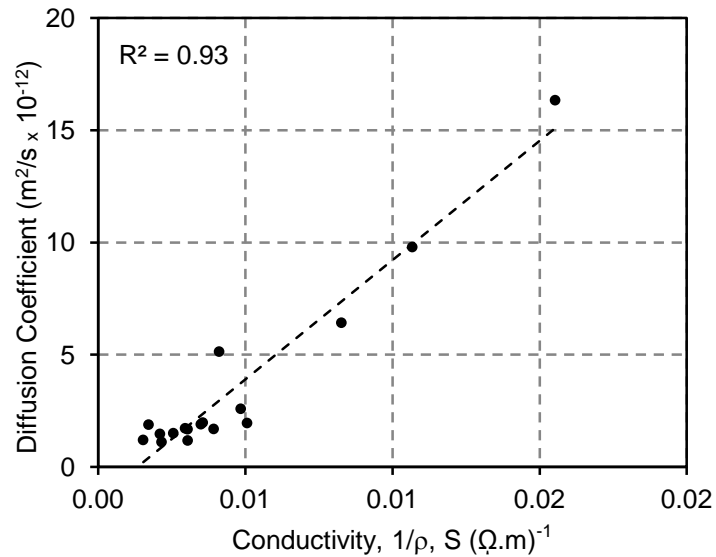


Figure 3- Relation between electrical conductivity and chloride diffusion coefficient of concrete for twenty mixture proportions²

C) CORROSION OF REBAR IN CONCRETE

Investigations have found correlations between concrete resistivity and both, the corrosion initiation and the propagation period. The corrosion rate often has an inverse correlation to the electrical resistivity. Hornbostel et al.⁴ have gathered a comprehensive literature review on the relation of corrosion rate and electrical resistivity and the contributing factors. In general, higher electrical resistivity of concrete lowers the risk and the rate of corrosion (Table 2).

Table 2: Relation between concrete resistivity and severity of corrosion⁵

Resistivity ($k\Omega.cm$)	Severity of corrosion
>20	Low corrosion rate
10-20	Low to moderate corrosion rate
5-10	High corrosion rate
<5	Very high corrosion rate

D) SETTING TIME OF FRESH CONCRETE

The concept of electrical resistivity has been used to develop test methods for determining the setting time of cement, mortars and concrete. Li et al.⁶ have investigated the hydration process and setting times of fresh concrete using electrical resistivity (Figure 4). Gu et al.⁷ also investigated the microstructural characteristics of hydrating cement-silica fume system using A.C. impedance spectroscopy.

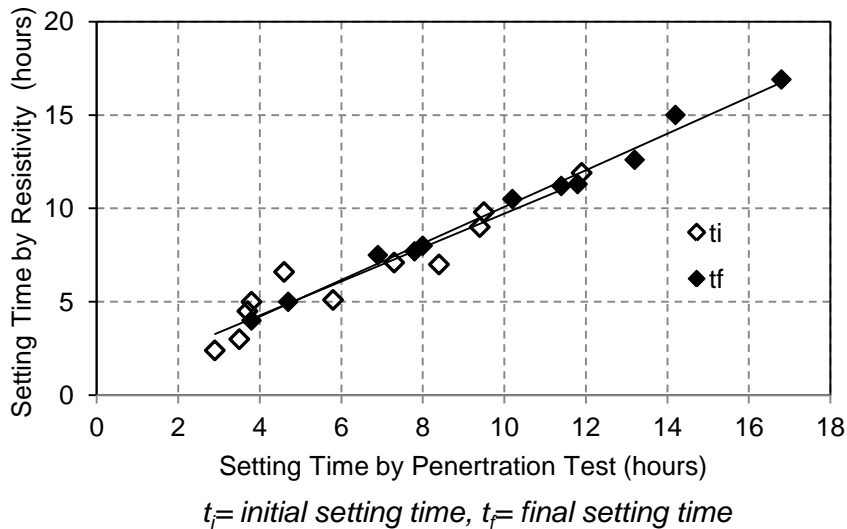


Figure 4- Comparison between setting times of fresh concrete using ASTM C403 and electrical resistivity method⁶

E) MOISTURE TRANSFER IN CONCRETE

One potential application of electrical resistivity method is to determine the moisture content of concrete. Several research have shown that the electrical resistivity is significantly affected by moisture content^{8,9}; however, the application and reliability of the method to determine the moisture content is yet to be studied. Shekarchi et al. used electrical resistivity technique to monitor the water content of concrete in large elements (Figure 5)⁸.

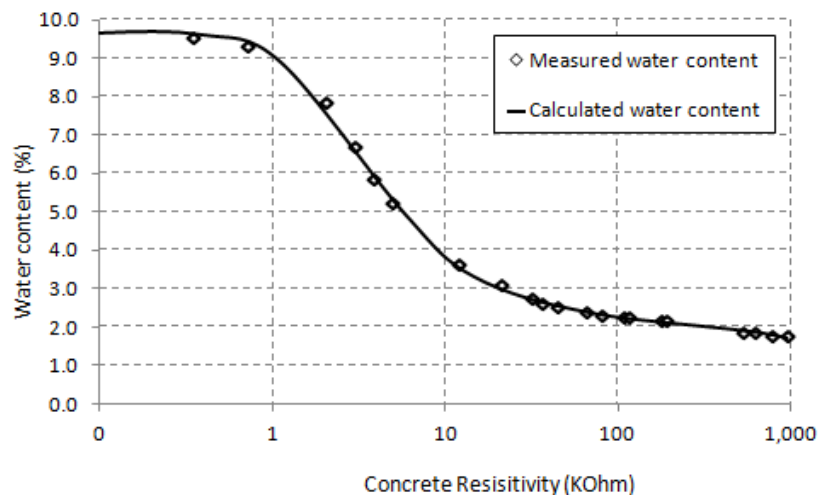


Figure 5- Comparison between water content of hardened concrete obtained directly by drying technique and indirectly by electrical resistivity technique⁸

F) MICRO-CRACK DEVELOPMENT IN CONCRETE

The electrical resistivity technique can also be used to detect cracks in concrete. However, it is noted that several parameters could affect the readings in this case. Salehi¹⁰ carried out a numerical study on the effect of cracks and presence of steel rebar on electrical resistivity of concrete. Wiwattanachang¹¹ also investigated the development of cracks in fiber concrete beams using electrical resistivity technique. Recently the relationship between electrical resistivity change and micro-cracks development in reinforced and unreinforced concrete was studied by a number of researchers^{12,13} (Figure 6).

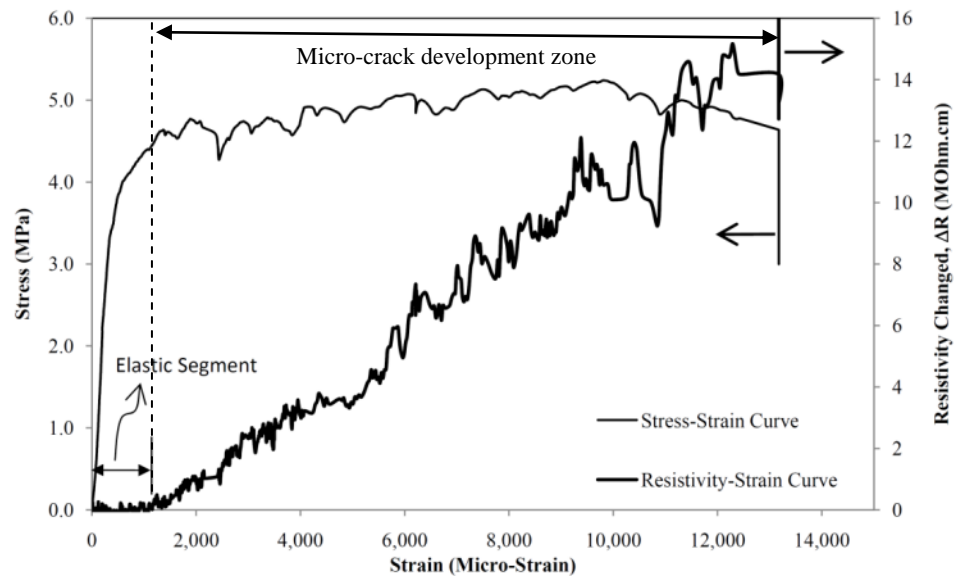


Figure 6- The change in electrical resistivity with the development of micro-cracks in concrete under tensile load¹³

TECHNICAL SPECIFICATIONS

Reading Range and Accuracy

Reading Range	Frequency spectrum	Phase measurement	Impedance accuracy	Phase accuracy
1 -100 Ω				
0.1-1K Ω	1Hz - 30KHz	0-180°	$\pm 2\%$ ± 2 digit	5% ± 3 digit
1 -10K Ω				
10 - 100K Ω				
0.1 - 1M Ω	1Hz - 10KHz			

Measurement Time

Frequency	Sampling time	Reading time (minimum)
1Hz - 4Hz	5 seconds	10 seconds
5Hz - 30KHz	1 second	2 seconds

Operating Conditions

Type	Value
Operating temperature	15°C - 45°C
Operating humidity	30% - 80%
Storage temperature	0°C - 60°C
Storage humidity	5% - 90%
Operating voltage/current	100 - 240 V, 50/60 Hz
Dimensions	200 x 230 x 70 mm
Data acquisitions software (PC software)	Yes

Note: Specifications are subject to change without notice.



REFERENCES

1. Shane, J.D., Aldea, C.M., Bouxsein, N.F., Mason, T.O., Jennings, H.M., Shaw, S.P. (1999), "Microstructural and pore solution changes induced by rapid chloride permeability test measured by impedance spectroscopy", *Concrete Science and Engineering*, Vol. 1, pp. 110-119.
2. Ghods, P; Chini, M.; Hoseini, M., Alizadeh R. (2005), "Evaluating the chloride diffusion of concrete by measuring electrical resistivity", *Intl. Cong. on Global Construction: Ultimate Concrete Opportunities*, Proc. of the Intl Conf. on Young Researchers' Forum, Dundee, Scotland.
3. Sengul, O., Gjrv, O. E. (2008), "Electrical Resistivity Measurements for Quality Control during Concrete Construction". *ACI Materials Journal*, Vol. 105(6), pp. 541-547.
4. Hornbostel, K; Larsen, C. K., Geiker, M. R. (2013), "Relationship between concrete resistivity and corrosion rate – A literature review", *J of Cement and Concrete Composites*, Vol. 13, pp. 60-72.
5. ACI Committee 222R-01 (Reapproved 2010), "Protection of metals in concrete against corrosion", American Concrete Institute, Farmington Hills, Michigan.
6. Li, Z., Xiao, L., and Wei, X. (2007), "Determination of Concrete Setting Time Using Electrical Resistivity Measurement", *Journal of Materials in Civil Engineering*, Vol. 19, pp. 423-427.
7. Gu P., Xie, P., Beaudoin, J. J., and Brousseau, R. (1993), "A.C. Impedance Spectroscopy (II): Microstructural Characterization of Hydrating Cement-Silica Fume Systems". *Cement and Concrete Research*, Vol. 23(1), pp. 157–168.
8. Shekarchi, M., Debicki, G., Billard, Y., Briot, R. (2001), "Nondestructive Monitoring Technique Based on Electrical Resistivity for Moisture Condition in Containment Structures", *SMiRT 16*, Washington, DC USA, pp. 1409-1414.
9. Brameshuber, W., Raupach, M., (2003), "Non-destructive Determination of the Water-Content in the Concrete Cover using the Multi-ring-Electrode, PART I: ASPECTS OF CONCRETE TECHNOLOGY", *BB 85-CD International Symposium, Non-Destructive Testing in Civil Engineering (NDT-CE)*, Berlin, September 16-19.
10. Salehi, M. (2013) "Numerical investigation of the effects of cracking and embedded reinforcement on surface concrete resistivity measurements using Wenner Probe", M.Sc. Thesis, Carleton University.
11. Wiwattanachang, N., Giao, P. H., (2011), "Monitoring crack development in fiber concrete beam by using electrical resistivity imaging", *Journal of Applied Geophysics*, Vol. 75, pp. 294-304.
12. Pacheco, J., Šavija, B., Schlangen, E., Polder, R. B., (2012), "Relationship Between Cracking And Electrical Resistance In Reinforced And Unreinforced Concrete", *2nd Intl. Conf. on Microstructural-related Durability of Cementitious Composites*, Amsterdam, Netherlands.
13. Lin, V. W. J., Li, M., Lynch, J. P., Li, V. C., (2011), "Mechanical and electrical characterization of self-sensing carbon black ECC", *Proc. SPIE 7983, Nondestructive Characterization for Composite Materials, Aerospace Engineering, Civil Infrastructure, and Homeland Security 2011*, 798316 (April 18, 2011)

© Giatec Scientific Inc.

301 Moodie Dr., Suite 302
Ottawa, Ontario, K2H 9R4
Canada

Tel: +1 (613) 858-1895
Fax: +1 (613) 280-1544
<http://www.giatec.ca>

V14-01

