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A comparative Analysis of Surface electrical resistivity in Concrete with different compositions

NESIB REŠIDBEGOVIĆ, AMIR DŽANANOVIĆ

CIVIL ENGINEERING INSTITUTE (GIT) TUZLA, KOJŠINO 29, 75000 TUZLA, BIH

ABSTRACT

Research on the application of electrical resistivity for concrete condition assessment started during the 1970s by adopting this method from the area of geophysical soil research, but the application for the purpose of assessing the condition of concrete constructions was intensified in the last twenty years. Experimental research on concrete samples of different compositions are presented in this paper. During the research, the samples were exposed to various environmental conditions. The paper presents electrical resistivity development curves for the tested samples. Based upon previous experience from the studied materials and experimental research results, the paper presents possibilities and limitations regarding the application of this approach for concrete condition assessment.

Keywords: Electrical resistivity, concrete, porosity, durability.

Introduction

Market availability and an acceptable price in relation to other materials contributed to the fact that concrete is the most applicable material in construction today. Engineering AB constructions is founded on the concept of safety where questions regarding the object's stability and functionality have been fairly defined and conceptually determined. Solving the problem of concrete constructions' durability still presents a challenge for researchers and engineers in the construction practice. The complexity of this problem is particularly shown in highly aggressive environments such as industrial zones.

Research implemented so far in the area of measuring concrete electrical resistivity, as a non-destructive method, shows that certain responses can be gained in terms of concrete pore structure, thus serving as an indirect assessment of concrete properties in the sense of a possibility for aggressive substances to penetrate through the concrete structure. Experimental research shown in this paper are conducted on concrete samples made by different formulations and with diverse raw material inputs. In order to establish an appropriate correlation and perform an analysis of the possibility for applying this procedure in concrete condition and exploitation period assessment, the samples have been exposed to various environmental conditions. All research have been conducted in laboratory conditions. The measurements were carried out by applying a device, with a commercial name “Resipod” produced by the company “Proceq”, which operates on the principle of a Wenner Probe. The stated instrument serves for measuring concrete electrical resistivity of the surface layer up to 50mm in depth, which is enough to assess electrical resistivity in the concrete protective layer. During preparations for this experiment, previous research have been studied and the most significant ones are hereafter presented, We subsequently presented the results of our research, on the basis of which we made conclusions about the possibilities and limitations for measuring electrical resistivity in assessing the exploitation period for concrete constructions, considering the previously studied research.

An overview of previous research

Paper [1] presents some of the first research, on the basis of which the connection between electrical conductivity and porosity of concrete was proposed. Since concrete diffusivity also depends on its porosity, it is clear that there is a possibility of establishing a connection between conductivity and diffusivity. Based upon the stated experimental research, the paper [2] presents a formula:

$$\frac{D}{D_0} - \frac{\sigma}{\sigma_0} - \Phi\beta \qquad (1)$$

where:

σ - conductivity of the electrolyte-saturated sample or a porous medium (concrete) (mS/cm)

σ_0 - electrolyte or porous solution conductivity (mS/cm)

D - porous medium diffusion coefficient

D_0 - porous solution diffusion coefficient

Φ - porosity

β - pore structure parameter

Concrete electrical resistivity depends on the quality of concrete and exposure conditions, which is reflected through relative humidity and the degree of pore saturation. Image 1. shows concrete electrical resistivity dependence on the environmental exposure conditions.

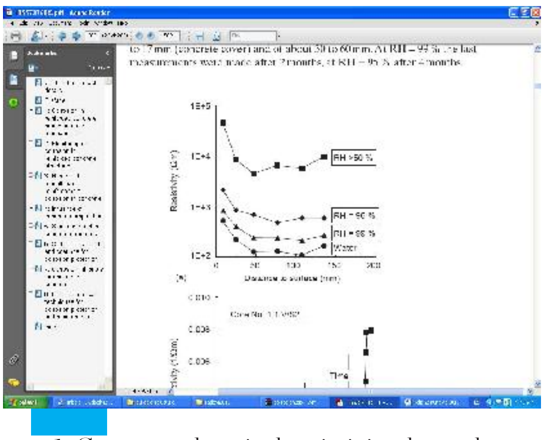

Image 1: Concrete electrical resistivity dependence on environmental exposure conditions (relative humidity RH)

Concrete electrical resistivity is altered by changing the degree of saturation in the pores. There is even a multiple size gradation. Typical and saturated concrete electrical resistivity amounts to 50 Ωm, while dry concrete resistivity goes up to 10^9 Ωm [4]. Image 2. shows the research conducted in dissertation [4], in the sense of quantifying concrete electrical resistivity for concrete formulations with water-cement factors 0.4, 0.5 and 0.6, as well as different degrees of saturation in the concrete pore structure.

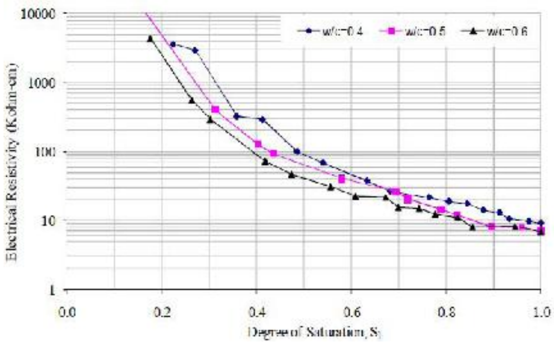

Image 2: Concrete electrical resistivity depending on the water-cement factor and the pore saturation degree of concrete

The electrical resistivity of concrete primarily depends on the cement paste microstructure, i.e. capillary pore size, the complexity of the pore system and moisture content. Changes in the type of aggregate can affect concrete electrical resistivity. Therefore, according to [5], concrete resistivity with a sandstone aggregate amounts to 18 000 Ωcm, while concrete resistivity with a granite aggregate amounts to 880 000 Ωcm. Also, some research have shown that alongside an increase in aggregate contents, there is an increase in the electrical resistivity of concrete. Throughout the hydration process development, during the process of solidifying a concrete mixture, electrical resistivity changes. In paper [6], the formula for changing electrical resistivity in time is proposed in the form of:

$$\rho_t = \rho_0 \left(\frac{t}{t_0} \right)^q \qquad (2)$$

where:

q - aging factor, with proposed values of 0.22 to 0.57.

The report [7] and paper [8] show research in the possibility of applying electrical resistivity as an alternative to rapid chloride permeability tests. Within the research, certain parameters affecting the intensity of electrical resistivity and measurement precision were analysed. Research have shown that electrical resistivity increases with an increase in drying days. Within the research analysis, there is an emphasis on the importance of balancing the measurements, i.e. equalising the samples' saturation conditions by performing measurements immediately after the sample is removed from the humid environment where it was tended to. Image 3. shows the dependence of electrical resistivity in relation to the age of concrete.

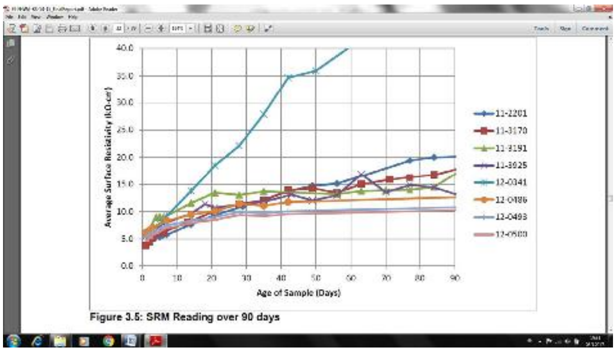

Image 3: Dependence of electrical resistivity and the age of concrete samples

An overview of the value attributed to electrical resistivity for different concrete formulations and the age of concrete samples is given in papers [9] and [10]. Research have shown that the highest increase in electrical resistivity happens until the 15th day when the values range from 40 to 80 Ωm.

Paper [11] researches the effect of fly ash addition to PC, as well as slag addition in the sense of concrete resistance to chloride ion penetration. The measured electrical resistivity of concrete varies from 10^1 to 10^5 Ωm, depending on the moisture content in concrete and the composition of materials.

The fly ash and slag additions increase concrete density thereby increasing its electrical resistivity. The methods used for measuring electrical resistivity are the Wenner Probe, a Two-Electrode Method and a Multi-Ring-Electrode Method.

The Wenner Probe, initially developed for soil testing and later modified for concrete constructions, is the most intensive method applied for measuring concrete electrical resistivity of the surface layer [12].

The Wenner Probe was chosen as the standard method for measuring electrical resistivity of concrete in Europe, due to its efficiency and simplicity of use [13]. Measuring resistivity is performed in such a way that an alternating current is released through the external electrodes, while measuring the difference in potentials on the internal electrodes. Resistivity is calculated according to the formula:

$$\rho = 2\pi a V / I \tag{3}$$

where:
p - resistivity
I - alternating current (A)
V - difference in potentials (V)

The application of "Resipod" instruments for measuring electrical resistivity is presented in paper [14]. All papers emphasise the importance of a proper contact with the surface so as to perform reliable measurements. That is why it is necessary to perform measurements as soon as the sample is removed from water, before the surface starts to dry. Humidity variance significantly affects the results.

Our experimental research

Within the experimental research, three sets of concrete samples were made according to different formulations bearing the marks CM1, CM2 and CM3. The concrete mixture compositions are shown in Table 1. In order to obtain as many results as possible and depending on the input components in the concrete mixture composition, the CM1 and CM2 formulations were made from the same type (origin) of aggregate and cement, while the CM3 formulation had a different type of concrete integral components.

Table 1: Concrete mixture composition

Formulation	Cement (kg)	Water (kg)	w/c	Aggregate (kg)				Total (kg/m3)
				0-4	4-8	8-16	16-32	
CM1	320	160	0.50	840	300	340	500	2,460
CM2	440	220	0.50	850	284	416	378	2,588
CM3	265	160	0.60	700	304	384	580	2,393

For each set, 87 samples of concrete shaped like a cube were made in dimensions of 15cm. All samples were treated in appropriate laboratory conditions until the age of 28 days, after which they were exposed to different environmental simulations and surface electrical resistivity tests. Testing the physical and mechanical properties of the created concrete samples was conducted on 15 samples, and the results are shown in Table 2.

Table 2: Test results of the applied formulations' physical and mechanical properties

Formulation	Subsidence consistency (cm)	Compressive strength	Porosity (%)	Fresh concrete density (kg/m³)	Hardened concrete density (kg/m³)
CM1	8.0	24.97	12.65	2,399	2,401
CM2	9.5	36.18	15.70	2,405	2,423
CM3	17.0	27.55	13.45	2,423	2,435

*Strength on the 28th day

The remaining samples were divided into three groups, with 24 samples each, and exposed to various environmental conditions during the testing period. The first group was exposed to air in laboratory conditions (samples marked SA). The second group was exposed to chloride injection under pressure, i.e. the samples were held in a special container under a 2 bar pressure in a solution of 16.5% NaCl, and afterwards left to age while exposed to air in laboratory conditions (samples marked PPT). The third group of samples was freely immersed in a 16.5% NaCl solution, with the solution height being above the contact surface of 20 mm (samples marked BDT). BDT group samples were continually held in the solution during the testing period that lasted 90 days. As illustrated in the previous description, the samples were subjected to different treatments so as to compare the electrical resistivity of concrete exposed to various environmental conditions.

The samples were simultaneously tested in the appropriate periodic intervals. 10 measurements were taken from each sample, five measurements for each diagonal, by moving the instrument for 5-6 mm (Image 4.).

Image 4: Measuring electrical resistivity with a Resipod instrument

The representative values of the measurement results, obtained after a statistical results analysis, are presented as diagrams on Images 5-7.

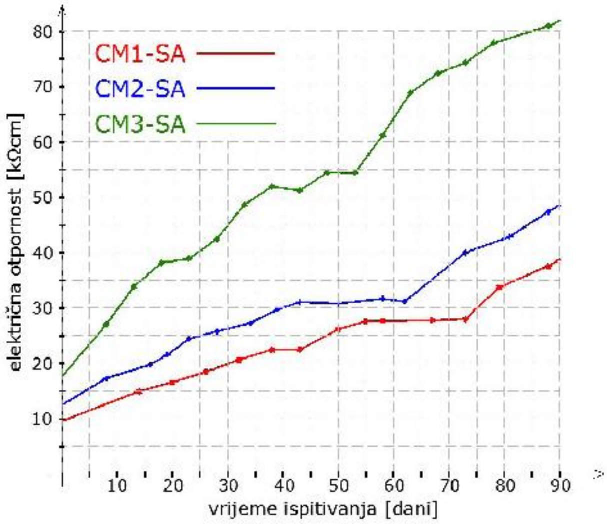

Image 5: The values of surface electrical resistivity for the sample set SA

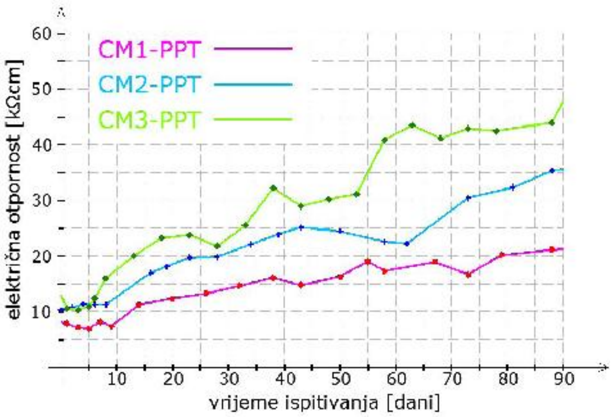

Image 6: The values of surface electrical resistivity for the sample set PPT

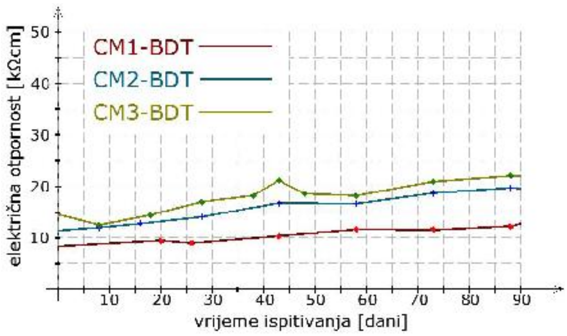

Image 7: The values of surface electrical resistivity for the sample set BDT

Conclusion

By analysing the obtained results, it can be stated that the samples with a CM3 formulation, in all three cases of environmental exposure, have greater values of surface electrical resistivity in relation to the other two formulations, during the entire testing period. The opposite goes for samples with a CM1 formulation. Since the CM1 and CM2 formulations were made of the same input components, it can be concluded that, by increasing the amount of cement in the formulation, there is an increase in electrical resistivity. However, it can be seen that, by changing the raw material inputs (CM3 formulation), we can obtain greater values of electrical resistivity with a significantly smaller amount of cement.

In the period of 90 days, during which measurements were taken, the obtained results show a smaller increase of electrical resistivity in PPT samples, that were, for 10 days, exposed to chloride under pressure and then to air, in relation to the SA samples that were exposed to air the whole time. Therefore, concrete exposure to an aggressive environment under pressure, even during short periods of time, causes a decrease in the electrical resistivity of concrete. Measurements have shown that there is a small increase of electrical resistivity in BDT samples that were continually immersed in the NaCl solution.

Research conducted so far can confirm that this method of assessing the concrete condition by measuring electrical resistivity can provide certain answers in view of the concrete pore structure, thus serving as an indirect qualitative assessment of concrete properties. The question of concrete resistivity measurement precision remains. Concrete is a highly inhomogeneous material, so its electricity, i.e. electrical potential is not uniform. There is an attempt to address this problem by multiple measurements.

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Uporedna analiza površinske električne otpornosti kod betona različitog sastava

SAŽETAK
Istraživanja u smislu primjene električne otpornosti za ocjenu stanja betona započela su sedamdesetih godina prošlog vijeka, preuzimanjem ove metode iz područja geofizičkih istraživanja tla, ali je primjena u svrhu ocjene stanja betonskih konstrukcija intenzivirana u zadnjih dvadesetak godina. U okviru ovog rada prezentirana su eksperimentalna istraživanja na uzorcima betona različitog sastava. Tokom ispitivanja uzorci su izlagani različitim uslovima okoliša. U radu su date uporedne krive razvoja električne otpornosti ispitanih uzoraka. Na osnovu dosadašnjih iskustava iz proučene literature i rezultata prikazanih eksperimentalnih istraživanja, date su mogućnosti i ograničenja primjene ovog postupka za ocjenu stanja betona.

Ključne riječi: Električna otpornost, beton, poroznost, trajnost.

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Correspondence to: Nesib Rešidbegović, Institut GIT Tuzla (Bosnia and Herzegovina)
E-mail: nesib7@hotmail.com