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Carbonation Effect on Measurements of Electrical Resistivity Tomography

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Abstract **-** The electrical resistivity of concrete, measurable in various ways by lab cell or multi probes surfaces device, is a technique used on soil and can be implemented in the analysis of saturation. The concrete under natural conditions where it is exposed to air, undergo the carbonation phenomenon due to the presence of atmospheric carbon dioxide CO_2. The air contains CO_2 which, in the presence of moisture, reacts with the hydrated cement. This is reflected by a set of physical and chemical mechanisms which result from the instability phases portlandite and CSH of the cement matrix. This paper presents the experimental results of measurements of electrical resistivity tomography performed on slabs of concrete and cement paste non carbonated and carbonated, saturated or with a saturation gradient. These results show that the electrical resistivity of carbonated material remains lower than a saturation gradient, but the moisture gradient will increase the effect of the carbonate layer during measurement.

Keywords**:** Concrete, cement paste, non destructive technique (NDT), electrical resistivity tomography, carbonation.

1. Introduction

Electrical methods are non-destructive methods that rely on measuring the electrical resistivity, generally used in the field of geophysics [1] [2] [3] [4] for the exploration and characterization of the basement, where its knowledge allows us to understand the land and lithology of the subsoil. The principle is based on the injection of an electrical current of known intensity and then the estimation of the apparent resistivity of the basement will be given by the electric potential distribution of the current. In civil engineering, electrical methods are used for measuring the electrical resistivity, assessment of corrosion potential and associated to the polarization resistance. These methods are intended to characterize the state of corrosion of the reinforcements [5] [6] [7] and the concrete by determining the degree of saturation and characterizing the microstructure of the cement matrix to describe variations in porosity or cracking. These methods are interesting because they are sensitive to parameters related to materials, such as porosity, the nature and the resistivity of the interstitial fluid. The knowledge of these parameters allows to detect a gradient of saturation or a carbonation front which itself also depends on these factors. The present study was conducted to evaluate the sensitivity of the electrical resistivity tomography detecting a carbonation front and its effect on the saturation of gradient measurements. This study was conducted in the laboratory and in a controlled environment, testing of packaged slabs.

2. Materials and Methods

The cement used was a common CEM I 99% Clinker (origin: Lafarge, Val-d'Azergue, France). Two types of materials were used: an ordinary concrete with W/C ratio = 0.5 (Table 1) and cement paste with W/C = 0.7. The formulation of concrete are summarized in Table 1.

The concrete slabs are made in wooden molds 40x25x10 cm. For the mixing, the components are introduced from the largest to smallest in a mixer with a total capacity of 160 liters. Mixing lasts 1 minute to dry and extends to 1 minute and 30 seconds during which the addition of water takes place progressively and a scraping by hand for 30 seconds to ensure homogeneity of the mixture and finally a last kneading for 30 seconds. The molds are filled in two successive layers, using a vibration needle. In order to prevent desiccation, plastic sheets were placed to cover the upper side of the slabs before demoulding. The slabs were kept for 48 hours in a room (temperature: 20 ° C, relative humidity: about 65%). After two days, all the slabs were demoulded then cured in lime-saturated water at 20 °C for 7 months to ensure a sufficient maturation and saturation of the samples.

Table 1: Concrete compositions.

Component	Nature	Quantity (Kg/m^3)
Cement	CEM I 52.5 N	380
Sand	Siliceous [0-5 mm]	769
Gravel	Siliceous [6-14 mm]	1013
Water	-	193
W/C ratio	-	0.5
G/C ratio	-	4.69
Porosity (%) at 105°C	-	15.3

During this study, a resistivity Syscal R1 + (manufactured by IRIS Instrument) and a multi probe system consisting of a 16 electrodes, 2 cm spaced were used. This devise was developed at I2M laboratory, and it can make different combinations between these electrodes to increase the volume investigated. The true resistivity data were obtained from RES2DIV inversion software Loke & Barker [8] based on an optimization method by generalized least squares. The pseudo-section obtained is divided into a number of rectangular blocks, the size of the blocks increases with depth, with a bulk resistivity value associated with each block. In performing operations, the inversion software attempts to minimize a cost function based on the difference between the calculated and measured values of apparent resistivity. The error RMS (Root-Mean-Square) provides an estimate of this difference, ultimately to converge eventually to the true resistivity model that best fits the experimental observations. Prior knowledge of the geometry of the test samples to calculate a true accurately measured resistivity.

After 7 months of saturation period, the slabs were removed for testing begins. A first measurement is made on those slabs that are in a state considered saturated. The measurement is performed successively on the upper face and bottom of the slab. At the end of these steps, the slabs are covered with aluminum paper by 3 adhesive layers except the upper face, to ensure a one dimensional drying gradient or a carbonation front for the remainder of the study. Then, a slab of each material is placed in a warehouse for drying by the ambient air and the other slab was carbonated.

Before the process of carbonation, the slabs were dried for 14 days in a climatic chamber at 45 °C and then they are placed for 2 days in the atmosphere air with a relative humidity close to 65%. Because of the large volume of slabs, a specific device that is made, it consists of a PVC tray with a volume of 165 L, a bottle of carbon dioxide and nitrogen bottle for a CO_2 and N_2 supply, whose flow rate is controlled from a pressure gauge, a valve which allows to vent the gas and the excess CO_2 and to maintain a pressure equal to atmospheric pressure when the injection of gas and avoid overpressure in the enclosure for the transfer of CO_2 gas in the samples is done by diffusion. The concentration of CO_2 is maintained at 50 %.

3. Results

3.1. Saturated materials

The graphs of fig. 1 show the results obtained by electrical resistivity tomography of saturated materials. These results show the repeatability of measurements especially for cement paste (uniform material). We can highlight also the influence of the quality of the facing on the measurements performed on concrete slabs: the bottom face which was in contact with the wooden molds, has an electrical resistivity slightly higher than that of the upper face, this is probably due to the timber interacts with the concrete formwork upon shrinkage of the drying and promotes better surface condition (in terms of transfer properties). This effect is neglected on a larger scale.

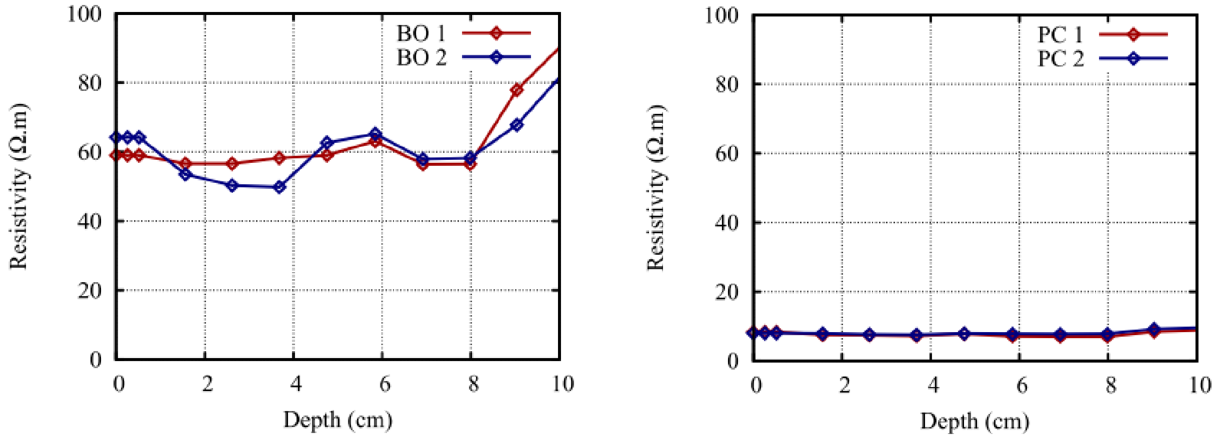

Fig. 1: Electrical resistivity of saturated materials.

3.1. Materials with saturation gradient

After the first set of measures, the tiles are placed in a room at ambient temperature and humidity for 8 months in order to create a natural saturation dimensional gradient. After this period of conditioning, the injection of current is done using wet sponges (to limit the effects of contact resistance). Graphs of figure 2 show the results obtained.

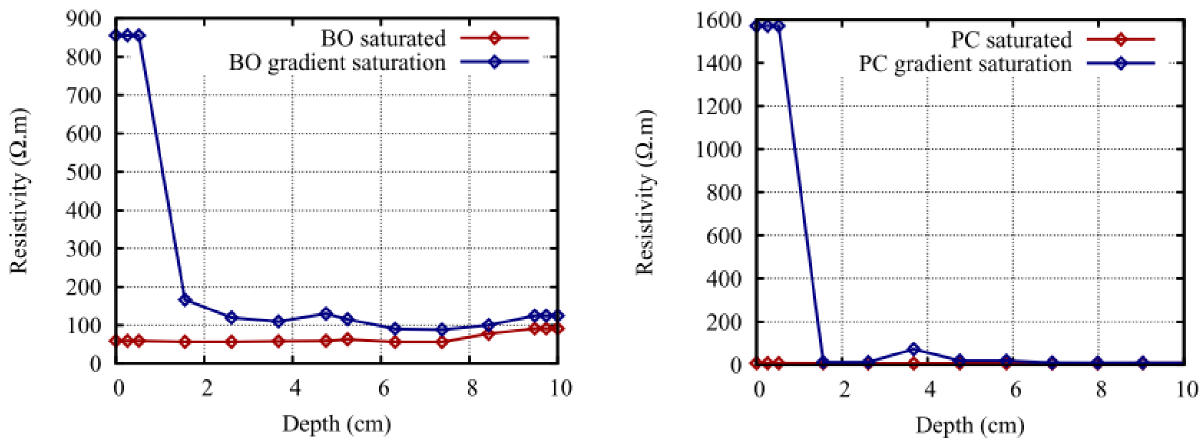

Fig. 2: Comparison between the electrical resistivity of saturated and dried materials.

The value of the electrical resistivity on the surface of the cement paste is higher than that of concrete, because during drying the cement paste loses a large part of the water present in the pore network in the first few millimeters from the upper surface (due to the high porosity of the cement paste). We then find in an area devoid of interstitial water with much of the condensed water voids pores due to the greater connectivity between the pores, the material becomes highly resistive. But in this case the high resistivity in upper surface is due to a combined effect of the desaturation and fine carbonate layer in the surface that amplifies the values of resistivity. We observe a saturation gradient stops at approximately 1.8 cm and then joined the measured values of the saturated material.

3.2. Materials with carbonation gradient

At the end of the accelerated carbonation period, the slabs were again resaturated with the same water used during the initial saturation period (water saturated with lime). At the end of the measurement session, carrots concrete and cement paste are recovered by coring water and carbonation front was measured by *phenolphthalein* on the side surface of the sawn cylinders.

Figure 3 show the results obtained by electrical resistivity tomography after 6 months of resaturation after carbonation. The obtained carbonation front is also presented on the curves.

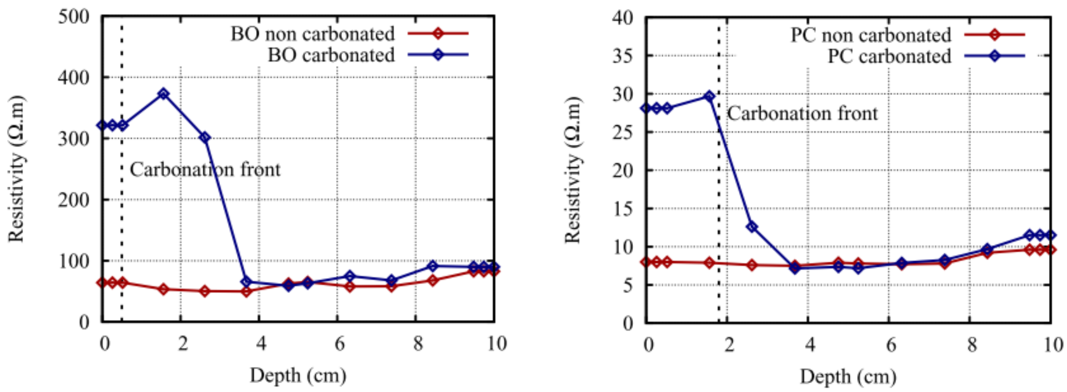

Fig. 3: Comparison between non carboneted and carbonated materials.

Electrical resistivity curves obtained are transferred to the position of the carbonation front in order to deduce the effect of a carbonate layer on the resistivity measurements. The resistivity from the upper surface is lower than that obtained in a saturation gradient and this is normal because in this case the materials were put into saturation after accelerated carbonation before the measurement period.

The carbonation front can be observed on the cement paste more than on the concrete, it is noted that resistivity front stops at the intersection with the carbonation front up to 1.8 cm, then a gradient was observed which is due to a slight gradient of saturation because the material has not been completely resaturated. Indeed, after carbonation, the porosity decreases with the formation of a layer of calcite and the intersection between the pores will be reduced, which explains that a resaturation period of 6 months, the cement paste is not completely saturated. The results on the concrete all the more valid this hypothesis, because the porosity of the concrete is much lower than that of the cement paste and therefore requires more time for a full resaturation.

4. Conclusion

Non-destructive methods such as electrical resistivity tomography, apply increasingly in the field of civil engineering inspection and auscultation in particular in very sensitive structures such as nuclear power plants where the core is not permitted. The importante of moisture and carbonation in the initiation phase for rebar corrosion is crucial. These results show that the electrical resistivity of a carbonated layer is higher than that of non carbonated material (for saturated materials), and the resistivity investigation shows the ability of this technique to detect the carbonation depth non destructively. The results obtained for the saturation gradient and those for the carbonation front, show that the electrical resistivity of carbonated material remains lower than a saturation gradient, which means that the moisture gradient will increase the effect of the carbonate layer during measurement, making them difficult to exploit.

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