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Evaluation of cover concrete and assessment of chloride ingress by Non Destructive Testing.

Part II – Comparison of NDT measurements and correlations.

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Abstract

During the European research program MEDACHS, four Non Destructive Testing methods (NDT) have been carried out for the study of the evolution of the physical properties of concrete samples stored in tidal zone. The main objective was the application of these NDT methods to the forecast of the maintenance actions of works according to exposure time in tidal zone.

Two electromagnetic methods: Ground Penetrated Radar technique (GPR), capacitive method with an array of three different of electrodes, an electric method (resistivity measurement – see part I) and a sonic technique (sonic testing with laser interferometer) have been used.

The testing methods have been developed to tend to correlate the physical properties of the concrete, like apparent complex dielectric permittivity, apparent resistivity and mechanical properties (Young modulus, Lamé coefficients), with the intrinsic ones like porosity, chloride and water content or mechanical strength.

The results obtained with electric and electromagnetic methods corroborate the trend of a moisture gradient in the material. These techniques, coupled with the acoustic measurements allow the detection of local heterogeneities (empty zones, granular distributions) or anisotropies (electric, electromagnetic properties). The localization of these heterogeneities is easy with NDT without extracting many cores samples.

Keywords: Chloride, Concrete, Capacitive technique, GPR, Resistivity, Seismic.

1. Introduction

In most countries, the weight of new civil engineering constructions is constantly decreasing to the benefit of structure maintenance, basically for economical reasons. In the meantime, owners are concerned about a precise knowledge of the health of the existing infrastructures, their preservation and safe-keeping evolution.

Hence, monitoring and non destructive testing (NDT) become a great part of the operational systems that are being developed and are placed at engineers's disposal for diagnosis (Malhotra and Carino 1991; Bungey and Millard 1996; Breyse and Abraham 2006). The implemented techniques are related to physics fields (as seismic, electric, electromagnetism, etc.) providing information relevant to the characteristics of the structures and constitutive materials.

In this context, ultra-sonic, electrical and electromagnetic (EM) techniques offer several interests. The first one is their sensibility to porosity and mechanical behaviour of the concrete, and the

second one for their sensitivity to water content, which is one of the major causes of the civil engineering structures pathologies. On the other hand, the electrical resistivity method is a technique allowing to assess water content, salinity of interstitial fluids of concrete, and porosity. The empirical Archie law describes the influence of these parameters variations on electrical resistivity (Lataste *et al.* 2006).

2. Experimental program

Four concrete mixes were designed by the LEPTAB Laboratory (Loche *et al.* 2008). For all concretes, the maximal diameter of aggregates is equal to 12.5 mm to limit the mechanical wave diffraction on the aggregates. Parallelepiped slabs (45x45x12 cm³) were casted vertically, demolded at the age of 24 hours and then placed in a chamber whose relative humidity (RH) remains superior to 90%. At the age of 90 days, several tests for mechanical and micro-structural characterisations were performed. The concrete composition, averaged mechanical strength and bulk water porosity are reported in Table 1. The micro-structure of concrete C15 is very different from the others: its pores are larger due to the higher water-to-cement ratio (see Part I). This leads to a different mechanical behaviour. Concrete C4 has the same aggregate skeleton as concrete C22 and the same water-to-cement ratio as C30. These mixes properties are intended to make easier analysis of the ND seismic data results. Moreover, for concrete C22 and C30, several batches were prepared with different salt water solutions (NaCl) in order to obtain different chloride contents for each concrete: 0 and roughly 0.25, 0.37 and 0.45 mol/L in the internal concrete pore solutions.

Five faces of all the slabs were covered with four layers of epoxy coating to water-tight them. After 6 months in the humid chamber, the first ND measurements were performed in June 2006. For each concrete without sodium chloride, one slab has been stored in the humid chamber whereas another one has been stored in the tidal zone of La Rochelle harbour, the June 23rd, 2006. The faces exposed to chloride ingress were oriented on site vertically toward the south to improve drying, and the slabs were spaced to eliminate shadow influence.

The six slabs made with water containing chlorides for batches were kept in the humid chamber.

Table 1 Concrete characteristics

Samples	C15	C22	C4	C30
Gravel (kg)	1085	1099	1099	1205
Sand (kg)	729	709	709	593
Cement (kg)	275	330	380	380
Water (L)	222	208	190	190
W/C	0.8	0.63	0.5	0.5
Rc (MPa)	15.4	32.0	39.0	51.0
Bulk porosity (%)	15	14	12	10

3. Non-destructive testing techniques

Four different types of ND techniques have been tested at the same time on the slabs stored in the humid chamber and on the slabs stored in the tidal zone. These ND techniques were a sonic technique, using surface waves, an electrical technique using a quadripole device, and two EM techniques: a capacitive approach at about 35 MHz and a GPR approach with centered waves at 1.5 GHz respectively.

3.1 Sonic technique

One of the advantages of NDT methods that rely on mechanical waves propagation is that the physical parameters measured are directly linked to the material mechanical properties. The surface waves used can be characterised by an investigation depth approximately equal to half their wavelength so that a variation of the concrete mechanical properties with depth will result in a variation of their phase velocity with frequency, a close link with the shear wave propagation velocity in concrete (which is equal to the square root of the shear modulus – under very small strain – divided by the density).

Thus, by looking to the variation of the surface wave phase velocity, we may expect to be able to discriminate concrete mixes and to verify if the slabs are homogeneous with depth or not.

The surface waves are generated by a piezo-electric transducer coupled to the concrete surface with water (Fig. 1). The centre frequency of the source is equal to 120 kHz and the wavelengths used are smaller than 6cm. The scattering of ultrasonic waves in concrete at these frequencies has been treated elsewhere (Chekroun *et al.* 2006, 2007). The receiver is a laser interferometer that is moved away from the source along a line with a dedicated robot. The distance between two measurement points is 0,005m while the most distant sensor is located 0,39m away from the source. The phase velocity dispersion curves are obtained with a p-w transform (Mokhtar *et al.* 1988).

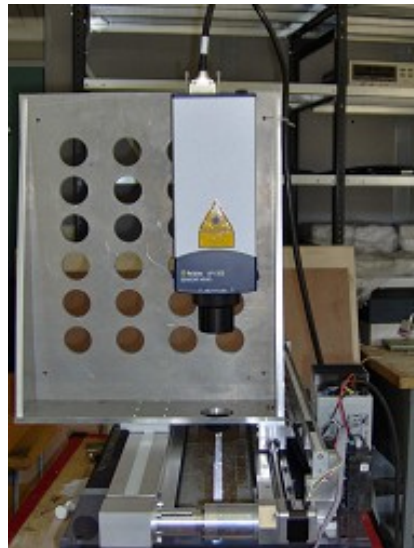


Fig. 1 Robot designed to carry out surface waves measurement with a laser interferometer as a contactless receiver. The source is a piezoelectric transducer (central frequency 120kHz)

The results obtained for the 4 mixes are shown on Figure 2. The phase velocity is represented as a function of frequency or as a function of wavelength. In order to check the performances of the sonic technique, several identical measurements were performed on 4 different lines on the same C4 concrete slab. The C4 narrow green curve beam shows the reproducibility of the technique though the heterogeneity of the material. It can be seen also that: concrete C15 (blue) has the lowest velocity as expected because its dynamic shear modulus is the lowest of all the slabs. Indeed as the shear modulus increases the phase velocity increases as well: C22 (magenta) has a velocity higher than the C15 one but lower than the C30 or C4. We can notice that for C22 the batches show differences that cannot be explained by the salt content.

The magenta curves (C22) are clearly separated in two beams. Thus it means that the C22 batches have different mechanical properties. This is less visible for C (red): the 4 C30 batches have similar shear moduli. As expected also C30 and C4 give similar results as their E/C ratio is similar. To be able to discriminate C30 and C4 and eventually differences due to varying aggregate proportions or batching for C30, it would be necessary to proceed to averaging of the recorded seismograms in order to get a proper evaluation of the coherent field that is propagating in the

medium (Chekroun *et al.*, 2006, 2007). This will be done in a near future in the new LCPC non contacting ultrasonic measurement lab (MUSC lab).

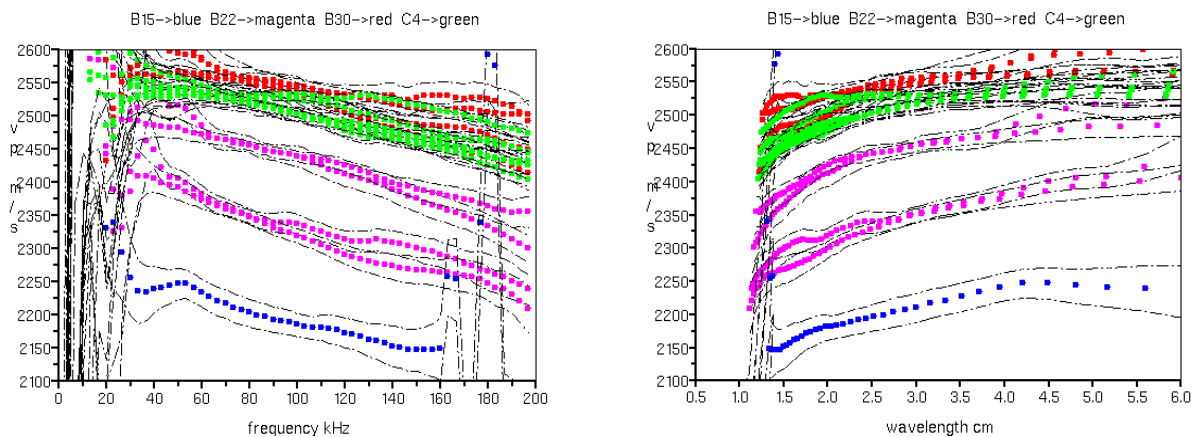


Fig. 2 Phase velocity dispersion curves for the 4 concretes. Left – as a function of frequency Right – as a function of wavelength.

Other information can be found from the phase velocity dispersion curves: the velocity is not constant with frequency because of a gradient of mechanical properties with depth at least in the first centimetres. Indeed, the velocity is higher when depth increases. This can be due to the influence of the first centimetre inside which the aggregates are not positioned as at deeper depth (skin effect). The information which are important to keep in mind when dealing with other non destructive methods results: for some concrete (C22) batches are not mechanically the same which certainly implies that their porosity is varying, and the concrete slab cannot be considered as homogeneous with depth as expected.

3.2 Electrical technique

Electrical resistivity of concrete is mainly conditioned by the electrolytic conductivity through material porosity, which is related to reinforcement corrosion (humidity and ionic ingress which promotes rebar alteration). The principle of the technique has been already presented in Part I.

Electrical resistivity measurements have been done with the two sizes of set of quadripoles (5 and 10 cm between probes) to study the electrical contrast in depth; and with different directions of electrical current injection to assess electrical anisotropy of concrete: the first time in July 2006 (few weeks after the layout of slabs in the harbour), then in April 2007, to see any evolution between these two dates.

The apparent resistivity deduced is a composition of the electrical resistivities of each component and also of their arrangement, in a volume roughly defined by the set size. Generally it is considered that the investigation depth is about 0.5 to 1 the set size. Figure 3 indicates a gradient between the Q5 and the Q10 sensors results, the concrete been more conductive in surface. This fact seems to confirm the observations done by the sonic technique, which both show a higher porosity in surface (under the hypothesis of a saturated medium).

Moreover, the slabs been in the tidal zone show after only 15 days a slight increase of the conductivity, point which has been developed in the Part I.

Concerning the sensibility of resistive measurements related to chloride content, the two series C22 and C30 do not present a clear general tendency. Indeed, for the C22 the red curves show a logical decrease related to the increase of chloride content. Nevertheless, the last slab containing 0.45 mol/L appears to be surprisingly more resistive. For the C30 series, the general tendency is less visible.

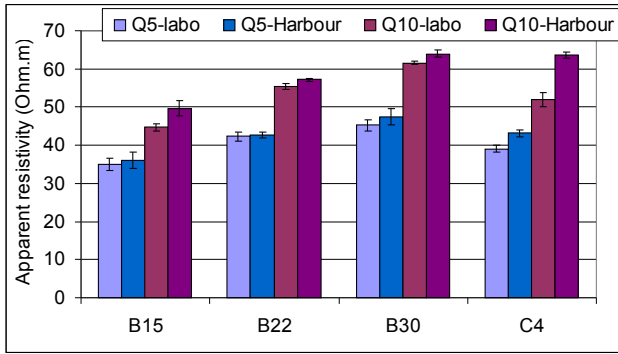


Fig. 3a Apparent resistivity of the four concretes (July 2006), concrete without initial chloride

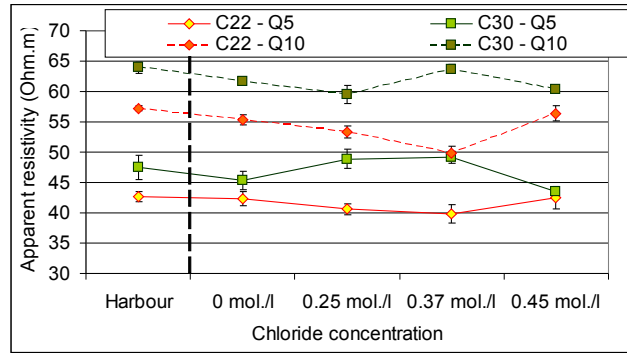


Fig. 3b Apparent resistivity of C22 (B22) and C30 (B30) for various initial chlorides concentration

3.3 Capacitive technique

An original method has been studied during over 30 years in the French network of Public Works Laboratories, related to the assessment of the water content in soils (Baron and Tran 1977 ; Blaszczyk and Blaszczyk 1993), and afterwards on reinforced concrete before being adapted to post-tensioned structures (Iaquinta 2004), or to cover concretes (Dérobert *et al.* 2007).

The guiding principle consists in placing two electrodes or more on the outer plane surface of the samples, and applying an alternative electric current between them at a 35 MHz frequency. This system forms a capacitor, which capacitance is proportional to the permittivity of the medium, and changes are indicative of internal constituents (like the nature of the materials or their moisture content).

The geometry of the sensor itself plays a very important role on the possibility of employing different configurations of electrodes in order to reach various depths of penetration, from few millimetres to above 8 centimetres, as illustrated in the Figure 4 hereafter:

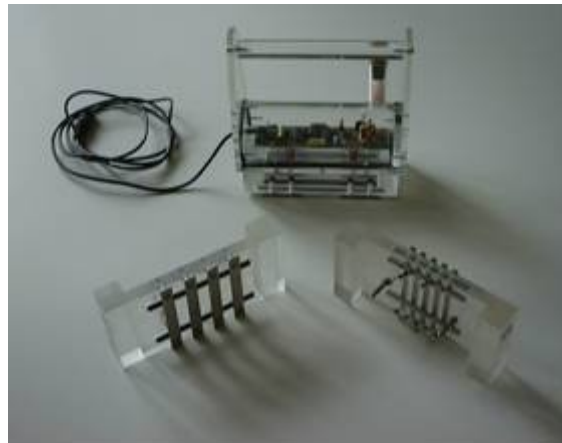


Fig. 4 Prototype of a capacitance probe for measuring the water content of flat concrete structures, with its connector and the resonant circuit (at the background).

Figure 5 presents some results which indicate points. The results of the C22 series appear more dispersive than the C30, which can be due to the mixing itself and its variability. Indeed, variations could be due to a water gradient content or to a variation of concrete mixing in the very near surface.

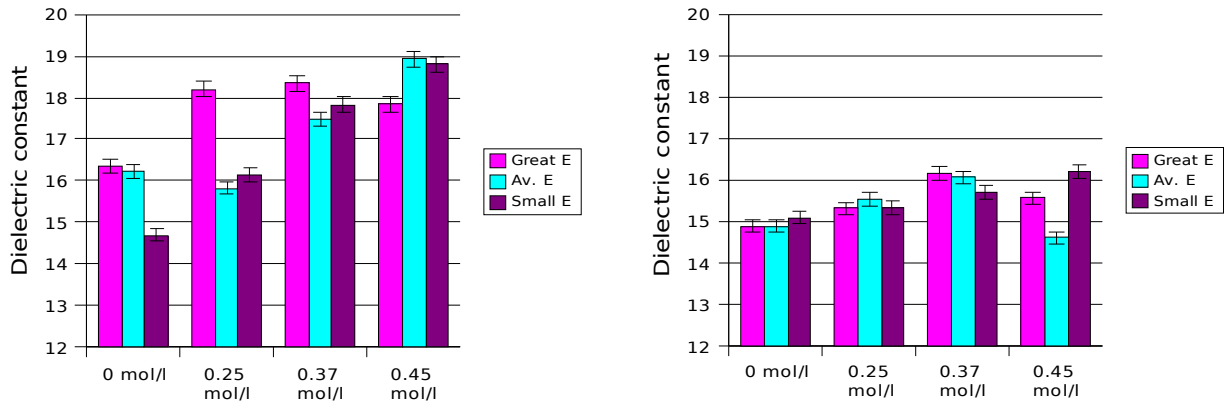


Fig. 5 Capacitive measures done with the set of electrodes, in July 2006. Left – on the C22 series. Right – on the C30 series.

The second point is related to a general tendency similar to the electrical results, showing a general increase of the results as the chloride content increase except the last slab (0.45 mol/l), if we consider only the capacitive electrode sock integrating the volume the most important. For a confirmation, or an explanation, of these results, chemical analysis are scheduled in the first semester 2008.

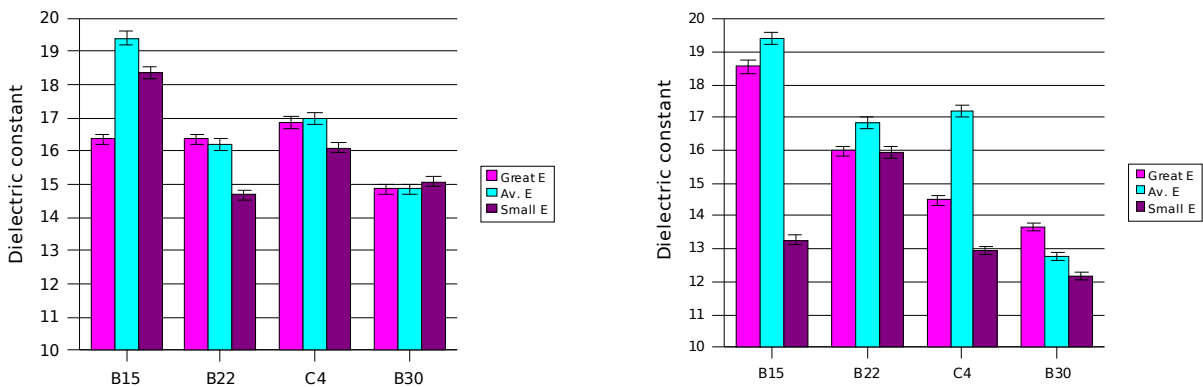


Fig. 6 Capacitive measures done with the set of electrodes, in July 2006. Left – in the moisture chamber. Right – in the harbour (port) of La Rochelle

Figure 6 is more related to any gradient of water content while comparing the results from the moisture chamber to the ones from the tidal zone. Except the C15 which present more dispersive values (the Great electrode gives surprising low value), one can see very small water gradient only in the very near surface (few millimetres) in the C22 and C4, perhaps due to the experimental design.

In the tidal zone, gradients of water content cannot be negligible. The concrete cover presents a lower content in surface and an apparent increase of the averaged electrode values. This is not only due to high water content but also due to an effect of the chloride ingress, which increase the capacitive measurements.

3.4 Radar technique

Concerning the radar technique (or ground penetrating radar – GPR), we have used a modified 1.5 Ghz antenna, which can propose a variable distance between the transmitter and the receiver (offset) from 7 cm to 14.4 cm. The objective herein is to study the radar surface wave propagating in the concrete and to give information either on the velocity and the attenuation of this kind of wave, while considering that the depth investigated could be about less than 10 cm.

Figures 7 shows that radar measurements remain stable in the moisture chamber, C4 being considered as an other kind of mixing. In the tidal zone, the results of radar velocities seem to indicate that some concretes have begun to dry: especially the C15 and surprisingly the C30 (due to problems of measurements?). When watching the normalized radar amplitudes, it seems that the C4 and C30 are not water saturated, point which is confirmed by the capacitive technique, and that the concretes more porous, such as C15 and C22, present lower amplitudes due to the chloride ingress effect.

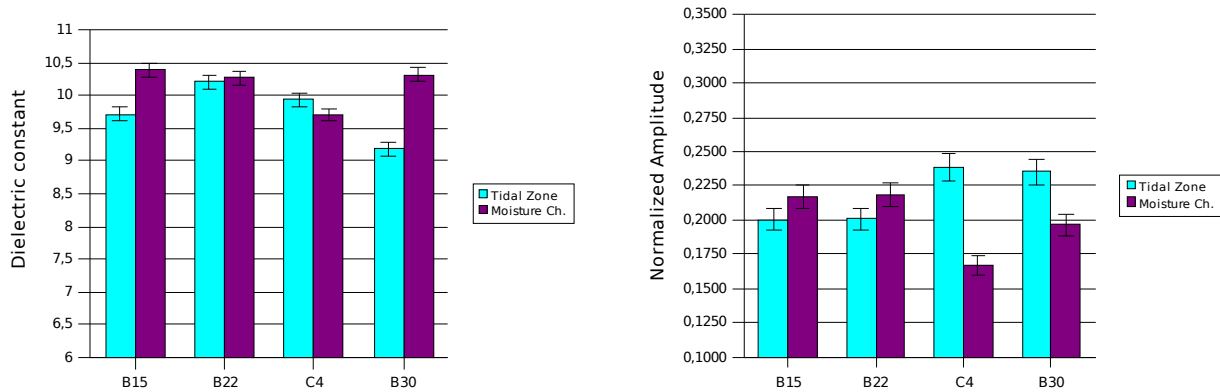


Fig. 7 Radar measurement on the four concretes (July 2006). Left – with the estimation of the velocity. Right – with the normalized amplitude of the surface wave (offset = 14.4 cm).

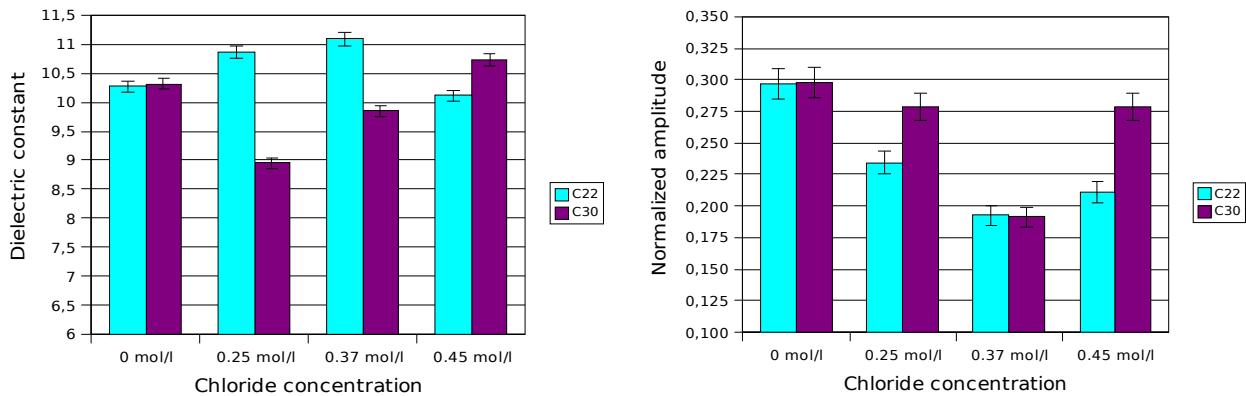


Fig. 8 Radar measurement on the C22 and C30 series (July 2006). Left – with the estimation of the velocity. Right – with the normalized amplitude of the surface wave (offset = 14.4 cm).

Concerning the measurements related to the chloride content, the figure 8 shows that the normalized amplitude is more sensitive than the radar velocity for an evaluation of chloride ingress. The more the chloride concentration is important, the more the radar waves are attenuated, with a slight increase of the dielectric constant. Some particular measures are out these tendencies, and reveals similar results than those from the electric and capacitive techniques: some complementary analysis will be helpful for a more accurate interpretation.

4. Conclusion

The present experimental study has been realised in an European project (Interreg III B MEDACHS project) to follow the evolution of the concrete properties in tidal zone. Various ND techniques have been tested, such as sonic, electric, capacitive and radar techniques, on concretes presenting different water cement ratios. Although some measurements have been done periodically, only results of the first period have been shown and commented.

It has been observed that, on saturated concretes, when the water cement ratio increases, sonic and resistive measurements seem to decrease and the dielectric constant increases. Concerning the chloride ingress, when the chloride content increases, the radar amplitude and the resistivity seem to decrease, the dielectric constant increase and the sonic measurements is not sensitive. These general tendencies have to be confirmed as well as on other concrete slabs and on further analysis on cores taken from our test slabs.

5. References

- Baron J.P., Tran N.L., "Méthodes de mesure et de contrôle des teneurs en eau de matériaux dans les LPC", *Bull. des Ponts et Chaussées*, 1977, **87**, pp. 85-96.
- Blaszczyk F., Blaszczyk R., Trochet B., Bigorre M., Dupas A., Mesure de la teneur en eau en continu d'un matériau granulaire : TRITON II. Mesure à la jetée d'un transporteur, *Bull. des Ponts et Chaussées*, 1993, **186**, pp. 85-87.
- Breysse D., Abraham O., *Méthodologie d'évaluation non destructive de l'état d'altération des ouvrages en béton*, Presse des Ponts et Chaussées, 2006, 555 p.
- Bungey J.H., Millard S.G., *Testing of concrete in structures*, Blackie Acad. & Prof., 3rd edition, 1996, 286 p.
- M. Chekroun, et al., "Multiple scattering of ultra-sonic propagation for non destructive evaluation of concrete; first experiment". Proceedings of NDT-CE Conference (St Louis, USA), 2006, pp. 365-370.
- Chekroun, L. Le Marrec, B. Lombard, J. Piraux, O. Abraham, Numerical methods for multiple scattering of ultrasounds in random media. Proceedings of Waves 2007 conference, Reading (UK), pp 492-494 (2007).
- Dérobert X., Iaquina J., Klysz G., Balayssac J.P., Use of capacitive and GPR techniques for non-destructive evaluation of cover concrete, *NDT&E Int.*, In Press (2007).
- Iaquina J., Contribution of capacitance probes for the inspection of external prestressing ducts, *Proceedings of the 16th World Conference on Non-destructive Testing*, Montréal (Canada), 2004.
- Lataste J.F., Breysse D., Sirieix C., Naar S., Electrical resistivity measurements on various concretes submitted to marine environment : first draft for assessing porosity with CND, Proceedings of the conference Structural Faults and Repair, Edimburgh (Scotland) 13-15th June 2006,, 7p.
- Loche J-M., Lataste J-F., Amiri O., Larget M., Tahlaiti M., Aït-Mokhtar A., Evaluation of cover concrete and assessment of chloride ingress into cover concrete by Non Destructive Testing - Part.I - Samples preparation - Porosity and resistivity measurements, *Proceedings of the MEDACHS Conference*, Lisbon (Portugal), 2008.
- Malhotra V.M., Carino N.J., *Handbook on nondestructive testing of concrete*, CRC Press, 1991, 341 p.