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Non-destructive evaluation of concrete properties in depth

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Abstract

Concrete can evolve over time due to internal swelling reactions as well as aging linked to mechanical and environmental stress conditions. These reactions depend on the transport of reactive elements (chlorine, water, and carbon) from the surface as well as the initial and local conditions when the concrete sets and after during the structure life. They therefore vary with depth and involve aging gradients. The evaluation of concrete according to depth is possible by Non-Destructive Testing. Usual NDT often leads to data either limited to a zone close to the surface or integrating properties over the entire depth tested. We propose two ultrasonic methods. Their objectives are, for one, the measurement of water content gradients as a function of depth, and the other, the localization of damage resulting from delayed reactions at the concrete core. For the first, sensor pairs are installed at different depths to measure the variations of the velocity of ultrasonic pressure waves linked to water content. These measurements are developed on a concrete plate 30 cm thick. For the second, measurements are done in the depth of the concrete block of 2*2*1 m³ to detect the concrete's nonlinear behaviour. That enables us to identify and even localize a zone of internal swelling reactions. We present the two principles and devices developed in these works. We detailed some measurement results of these NDTs. These different ways allow us to have perspective on the continuous control of the concrete. To conclude, we propose a strategy for the continuous monitoring of concrete in depth, based on these two approaches.

Mots-clefs NDT, Ultrasounds, Concrete, Gradient, Internal swelling reactions

I. Introduction

The inspection of a structure and its monitoring over time are two essential points for knowing the state of health of the concrete in a structure, either punctually at a defined date or continuously (Structural Health Monitoring). Non-Destructive Testing (NDT) plays a growing role in this, with an important role for ultrasounds due to its link with the mechanics and physics of the material [1], [2]. The inversion of measurement values from NDT is done using previously established conversion models [3] to deduce indicators of concrete durability. The main indicators are mechanical strength, modulus of elasticity, porosity, and water content.

Techniques requiring access to a single face are often used, but their inspection depths are limited and/or their accuracy decreases with the inspection depth. Other techniques may require or allow access to two sides of the structure, but in this case, the recorded data correspond to the accumulation of information over the entire wave path passing through the thickness of the material. Analysis based on the depth of the concrete property gradient or localized defect is complex.

In many cases, concrete durability indicators can change over time and depending on the depth within the structure. Real-time monitoring of these gradients with minimized uncertainty is a key element in lifespan prediction models. Furthermore, thermal gradients, water content gradients, and even micro-cracks associated with damage can modify the transfer phenomena of elements responsible for internal degradation (chlorine, water, carbon) or can even be a driving force in diffusion phenomena.



Embedded ultrasonic sensor solutions [4-5] have been implemented to locally study crack progression. We here present two methods for in-depth assessment of concrete properties and property gradients using ultrasonic techniques developed through two theses at LMA integrated into ANR and international projects. They are based on the integration of ultrasonic sensors embedded in the concrete for one and on the implementation of nonlinear acoustics as a function of depth for the other. We present them successively and then analyse their complementarity in a possible auscultation approach during on-site measurements.

II. Transducers embedded in concrete

This thesis work was carried out by Rouba Hariri as part of the French project SCAING, the objective of which is to make multi-technical non-destructive measurements with embedded probes. The various NDT measurements are subsequently merged [1] to improve the accuracy of the quantification of the desired indicators. We present here the measures of the pressure velocity of ultrasonic waves during a drying cycle. We produced sensors at the LMA in order to best meet the established specifications: a frequency of 100 kHz, a diameter of 12 mm for a wave path of 100 mm and optimized sealing and electromagnetic wave tightness. In order to monitor the properties of the concrete as a function of depth, we developed a support of two series of 8 pairs of probes (transmitter - receiver) positioned at 8 depths, from 2 to 22 cm as shown in Figure 1a. These transducers are implemented in a reinforced slab of 1 x 1 x 0.3 m³ subjected to drying cycles at different temperatures.

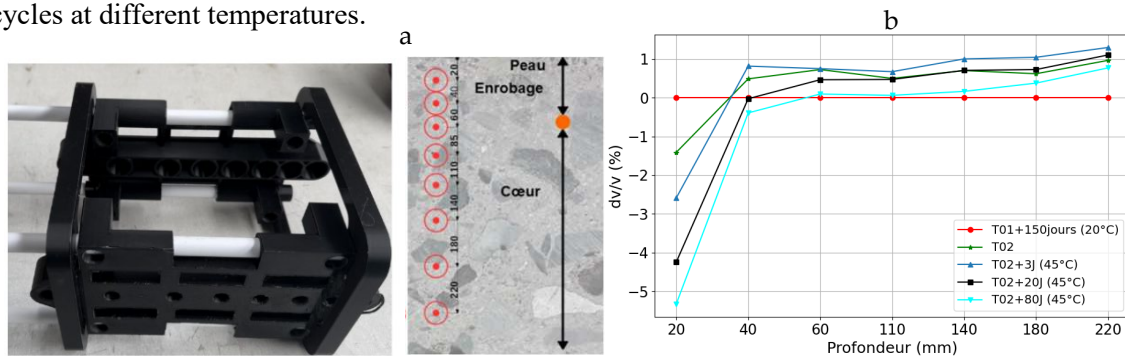


Figure 1: a) Transducers support and distribution b) Relative velocity evolution during drying

We monitor the relative variation of the velocity by cross-correlation between the signals recorded at each instant and the reference signal taken at the first instant of the tests. It is then possible to deduce ΔT then $\Delta V/V_0$ (Figure 1b). The relative variations during the drying time are around 5% (a drop of approximately 30% saturation) for the skin concrete to 0.5% for the deep concrete.

III. Non Linear In-Depth Acoustics

This thesis work is carried out by Klayne Da Silva within the framework of the Concrete consortium (2020-2024) and the international ODOBA (2016) project coordinated by ASNR. The project aims to detect early Internal Swelling Reactions in the containment walls of nuclear power plants which can lead to the degradation of the containment's tightness. Initial work has shown that the principle of orthogonal pump and probe waves is capable of detecting a damaged zone in the specimen of a 40x40x70 m³ specimen [6]. In order to be coherent with the possible access for in situ measurements, recent work has implemented the auscultation of this zone with collinear pump and probe waves (Figure 2a).

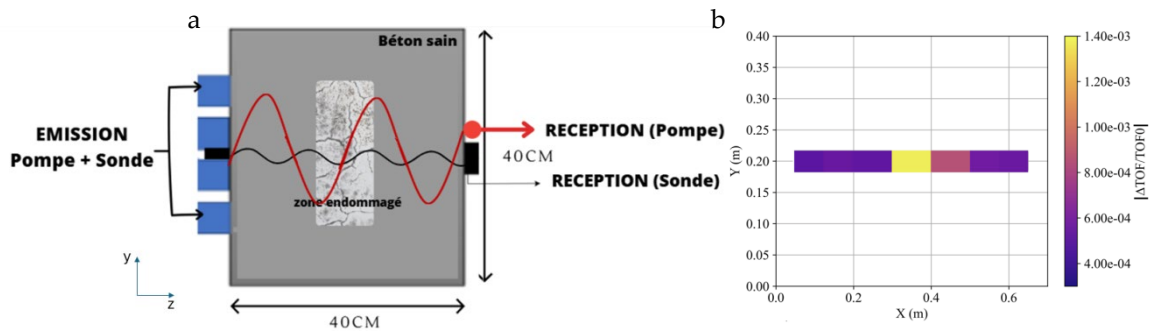


Figure 2: a) Principal of colinear pump and probe waves. b) Results for the relative time shift

Figure 2 shows the result of the relative time shift of the probe wave after solicitation by the pump wave. These measurements are realized for a horizontal line of points along the specimen obtained by moving the ultrasonic device. The variations in the velocity generated by the non-linearity of the concrete are significant (270%). It is also possible, by crossing the waves, to locate the affected area according to the depth. This work has already been carried out, as well as the transfer of RAG detection techniques on a large scale on 2x1x1m³ blocks. A 3D image of a large wall could be envisaged for the future using beam forming.

IV Conclusion

At this stage, the contributions of each of these techniques are different because they are linked to different behaviors of the concrete. The pressure velocity measurement technique is sensitive to changes in saturation, while nonlinear acoustics is mainly sensitive to changes in diffuse micro-cracking or ongoing macro-cracking. The complementarity between the two techniques is an asset for dissociating durability, saturation and damage indicators through data fusion processes. Detection or monitoring of damage represented by the modulus of elasticity and its evolution at the core may be an objective of future work.

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