

# Multi-sensor investigation of concrete moisture using ultrasound, radar and microwave

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## Abstract

Moisture and salt loads of concrete can significantly change its microstructure and consequently lead to chemical and mechanical degradation. However, the non-destructive investigation of moisture and salt present in concrete is still difficult. In order to address and compare the sensitivity of different methods concrete samples with different pore systems realized by varying the w/z ratios have been fabricated. The focus of this study was put on the analysis of ultrasonic long and trans waves measured on the surface and in transmission mode.

The results show clear dependencies of all applied methods. With the radar and microwave methods predominantly changes in the concrete moisture could be detected, whereas the different pore systems were not observed to alter the signals. In contrast for the ultrasound method also the ongoing hydration as well as the nature of the pore system strongly influenced the signals. As a consequence in a subsequent drying experiment it was also tried to delineate the effects of moisture and hydration. All specimens have been re-saturated under pressure and the drying experiment was repeated using the same multi-sensor approach.

**Keywords:** concrete, moisture, ultrasound, radar, microwave, multi-sensor approach

## 1. Introduction

New technologies and ways of data analysis are needed in order to monitor also small microstructural changes like chemical or physical degradation occurring in concrete and affecting our built infrastructure. Almost all processes are triggered or only made possible when water is present. But, we are still lacking reliable ways of measuring moisture or salt distributions non-destructively. Repeatedly even destructive testing fails to deliver useful information when sampling is not carried out carefully.

Also the use of embedded ultrasound sensors for bridge deck monitoring is getting more and more attention today. In order to evaluate the signals the influences of moisture and temperature changes must be known. In this study concrete samples with different pore structures (realized by different w/z-ratios) were investigated during hydration and after 160 days looking at changes in the propagation properties of ultrasonic long and trans waves. The results are compared to the observations made with radar and microwave sensors.

## 2. Experimental

A series of nine standard concrete cubes with 15 cm length of the edges has been casted, three of them having a w/z ratio of 0.55, three having a w/z ratio of 0.65 and three having a w/z value of 0.75 respectively. Moreover three plate shaped samples of 30 cm\*30 cm\*15 cm size were casted for ultrasonic trans wave investigations. All samples were cured for 28 days under water after casting. Afterwards the specimen were stored in a climate chamber at 23°C and rH 50% and measurements were taken daily during the first week of drying and then at longer time intervals. At the end of the experiment the samples were oven dried at 105°C until

constant weight. The moisture contents during the experiment were then calculated based on the final dry mass of the samples.

The focus of this work was on studying the effect of moisture on the propagation properties of ultrasonic long and trans waves. Different types of sensors (PunditLab from *Proceq*, UK1401 from *Acsys*, and a time of flight equipment from BAM in combination with A1220 from *Acsys*) were used to study the signals measured at the surface as well as in transmission mode. The ultrasonic pulse velocities and amplitude changes have been analyzed for long and trans waves as a function of concrete moisture. Moreover microwave probes and Ground Penetrating Radar (GPR) were used as these methods are well known to strongly depend on varying moisture contents. The applied microwave sensors types were MOIST R1 and PM from *Hf-Sensor* [1,2] and the GPR system a SIR 3000 with a 2.0 GHz palm antenna from *GSSI* [3]. The first part of this work has been carried out in the frame of the MSc thesis of Eik Bischof from HTW Berlin [4].

In the second part of the experiment we intended to discriminate the effect of hydration (which could not be regarded as fully completed after the 28 days of curing under water) from the mere influence of moisture change. To this end the specimen were re-saturated in a desiccator when they were about 160 days old. Subsequently they were dried again in the climate chamber and all ndt measurements were repeated at regular intervals. The results of the two experiment cycles (1: hydration or “hydr.,” 2: saturation or “sat.”) are compared and discussed.



Figure 1. Photo of the cubic concrete samples during measurements with the UK1401 (left) for ultrasonic surface velocity measurements; with the A1220 (center) for the ultrasonic bulk velocity measurement and with the microwave R1 sensor (right) for the measurement of changing electromagnetic properties.

### 3. Results

With the UK1401 the moisture induced change in velocity of ultrasonic long and trans waves has been investigated. As can be seen in Fig. 2 (top and center) both wave modes showed significant dependencies during the hydration and saturation experiments. The influence of hydration can be traced for about 21 days (about 5 M% moisture content) shifting the velocity towards higher values. In the transmission measurements we observed (Fig. 2 bottom) a similar phenomenon, in this case however, the hardening of the concrete even masked the velocity drop due to moisture completely within the first three weeks and even caused it to rise. We assume that the strong dependencies we observe for long and trans wave velocities are caused by the stiffness change (or elasticity change) of the matrix with reducing water content. It seems likely that the stiffness of the matrix reduces as the pores get gradually filled with compressible air instead of incompressible pore water. The results were also compared with literature values

published in [5, 6], but these authors only worked with long waves. Up to our knowledge these experiments have not yet been carried out systematically for trans waves.

The results obtained with GPR and microwave are in very good agreement with each other as both methods basically indicate changes in the effective permittivity of the samples. The reducing water content leads on the one hand to a velocity drop and on the other hand to an amplitude increase of the electromagnetic waves. Fig. 3 shows the results obtained with the microwave R1 sensor during hydration and saturation experiments. The so called moisture index (at the frequency minimum of the wobble curves) was used to observe the changes in moisture content of the samples.

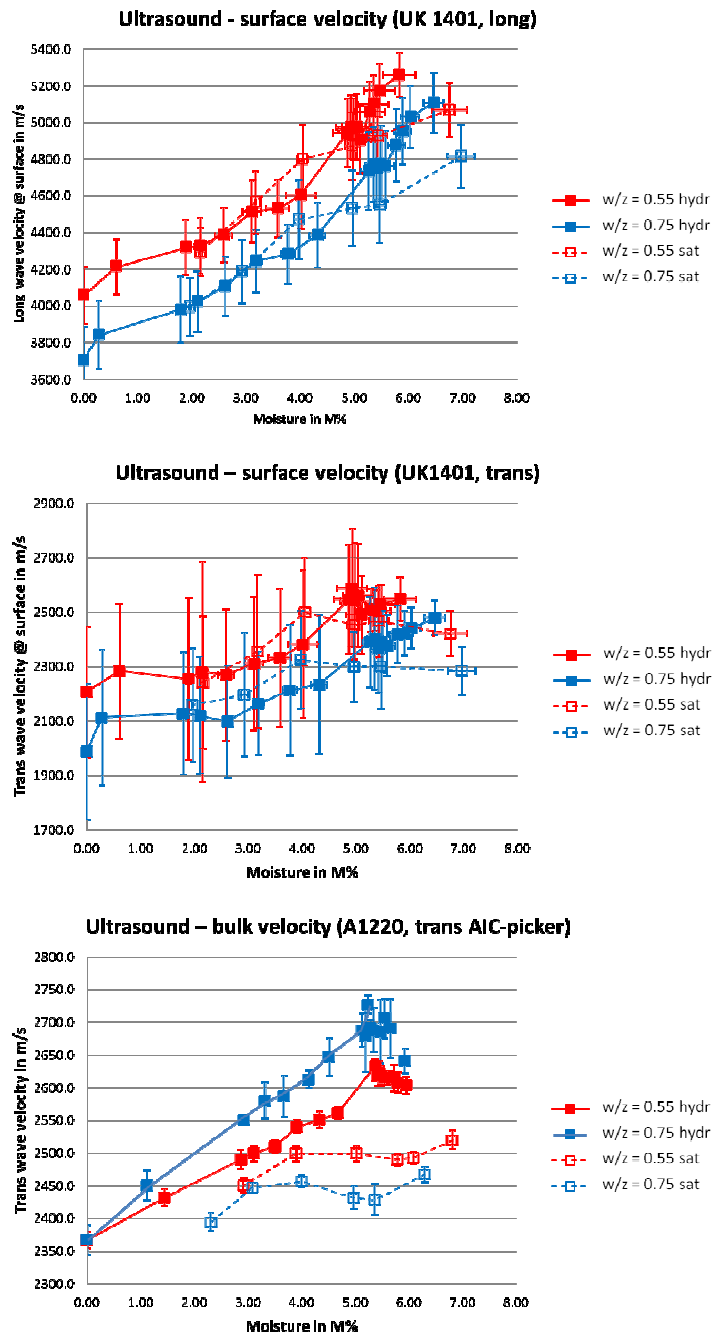


Figure 2: Comparison of the results obtained with the ultrasonic tests. Moisture dependent changes of the surface velocity measured with an UK1401 long probe (top), and with a trans probe (center) as well as measured in transmission with an A1220 trans probe (bottom).

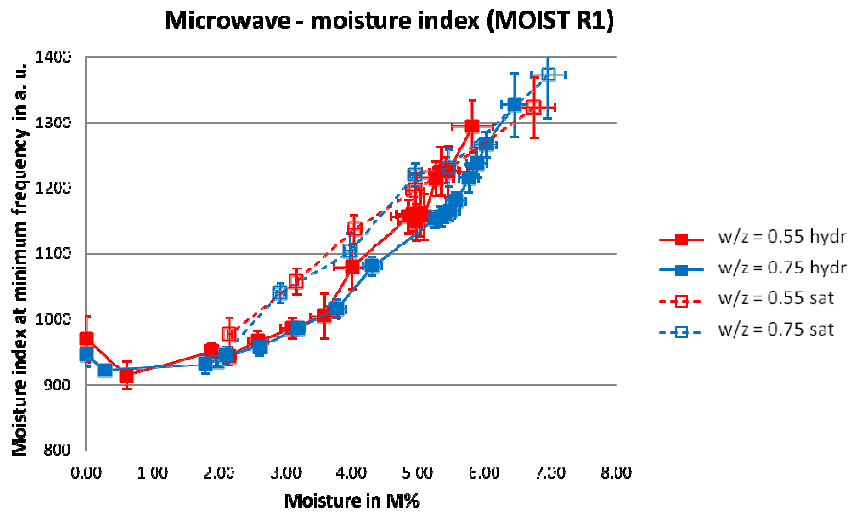


Figure 3: Moisture index measured with a handheld microwave sensor R1 from Hf-sensor. Data obtained on concrete cubes with w/z ratios 0.55 and 0.75 during the hydration and saturation experiments.

#### 4. Conclusions and Outlook

The effect of changing moisture content has been studied in a multi-sensory approach for concrete samples with significantly different pore systems. These were realized by working with different w/z ratios. The main focus was put on studying the changes in propagation characteristics of ultrasonic long and trans waves. Both wave modes showed clear velocity drops with decreasing moisture. These were detected with both surface probes and in transmission setup. In both surface and bulk velocity measurements the influence of hydration (causing a velocity increase) could be observed for about 20 days under these test conditions ( $T = 23^{\circ}\text{C}$ ,  $rH = 50\%$ ). Electromagnetic methods performed less sensitive for changes in hydration or the pore system (w/z ratio) though they proofed strong dependencies on the changing moisture content.

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