WATER CONTENT EFFECT ON CONCRETE RESPONSE IN UPV TESTS

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Abstract

One main feature of previous literature results on Ultrasonic Pulse Velocity (UPV) tests is that direct to indirect UPV test results could be very different. Differences depend strongly on in situ concrete conditions (stress, cracking, rebar arrangement, ...) and humidity level while depend lesser on apparatus and operator.

The Authors studied in the past the in situ conditions influence on UPV, now they are studying the influence on laboratory specimens.

Test results show that if the water content is disregarded the usual survey techniques (like SonReb approach) could fail dramatically.

In particular, it is possible to point out that the ratio of direct to indirect UPV test results is pseudo-linear with humidity.

UPV test results strongly depend on humidity content for higher humidity level: in dry specimens, UPV values of indirect tests are lower than direct ones while in wet specimens UPV values of indirect tests are quite the same than the direct ones.

A correlation between in situ to laboratory humidity level is of paramount importance for a correct use of the UPV test results and a control of in-situ humidity level has to be considered as mandatory for a correct approach to this kind of NDT test.

1. INTRODUCTION

The Ultrasonic Pulse Velocity (UPV) method is presently well grounded and largely applied (e.g. European Standard EN 12504-4 2004,), yet it continues to receive considerable attention in the literature in the attempt to improve the method efficiency, (Breysse (2012)).

Ultrasonic Pulse Velocity tests are used in structural engineering to detect r.c. structures with the aim to determine material properties. The UPV test is one of the non-destructive testing techniques largely used to evaluate the quality of concrete (in terms of strength, generally via stiffness evaluation).

The assessment of concrete properties in buildings is a very popular subject nowadays. The real in situ strength of a structural concrete is a fundamental datum for the capacity assessment of existing structures. In previous papers (Biondi et al. (2014) and Biondi et al. (2016)) the Authors discussed the state-of-the-art of this matter.

So the dependence of UPV on chemical-physical characteristics of concrete, e.g. quality and hydration of cement, different size of aggregates in concrete was discussed (Panzera et al. (2011)) and a significant correlation between the UPV and porosity and permeability of concrete was pointed out.

The central topic is the relation between ultrasonic pulse velocity and concrete compression strength (Qixian and Bungey (1996), Lawson et al. (2011), Mahure et al. (2011), etc.). A lot of experimental campaigns based on direct, semi-direct or indirect measurements to estimate strength have been carried out and the predicted strengths were compared with the compression strength obtained with destructive tests. In reality, the dynamic modulus of elasticity (E_d) is the parameter that, according to elastic theory, UPV test detects on concrete. Some correlation between the dynamic modulus and the concrete strength obtained from compression tests are discussed. Generally, direct UPV tests provide more reliable results for the estimation of the concrete strength, while indirect UPV tests can underestimate in-situ concrete strength.

When there is no access to the opposite surface of the structural element under test, it is necessary to carry out indirect measurements. Generally, it is observed a smaller pulse velocity in case of indirect tests. The results depend on concrete composition and humidity distribution between concrete cover and nucleus. Some Authors tried to overpass this problem. So a procedure for measuring the indirect UPV in concrete slabs and for estimate the similarity between direct and indirect UPV was carried out (Yaman et al. (2001)) and an experimental study was conducted to compare direct, indirect and semi-direct UPV measurements on concrete specimens (Turgut & Kucuk (2006)). The focus, in this case, was the concrete casting direction: the average direct UPV is 9% higher than the average indirect UPV in the casting direction, while the average direct UPV is 4% higher than the indirect UPV in the orthogonal direction.

Finally, Lencis et al. (2013) investigated how various degrees of moisture saturation influence the UPV in concrete. The UPV is influenced by some variables like water/cement ratio, aggregate type and size, humidity level and cement type. It is observed that when specimens are tested after water immersion, at a relatively small loss of mass corresponds a most significant decrease in the UPV values. Biondi et al. (2014) pointed out a relation between direct and indirect UPV for different natural humidity levels and for different test directions (direct and indirect). A linear model can be assumed as efficient for indirect to direct dependence on humidity. Correlation coefficients are quite similar for both the so-called "summer" (natural dry) and "winter" (natural wet) conditions. Biondi et al. (2016) discussed artificial (laboratory) humidity levels. For this purpose, each specimen is immersed in water at (20 ± 2) °C until its mass variation is less than 0,20% in 24 h. Each level of humidity is then determined on the basis of stabilization of mass. Some intermediate humidity levels are obtained according to Standards (BS EN 12390-7: 2009), i.e. by drying the specimens in a ventilated oven at (105 ± 5) °C until the variations of mass is less than 0,20% in 24 h.

2. PREVIOUS TESTS WITH NATURAL WATER CONTENT CONDITION

The experimental activity reported in Biondi et al. (2014) was carried out with the aim to contribute to the in-situ tests on existing r.c. structures. Ultrasonic pulse velocities were measured, using direct and indirect tests, on ten concrete specimens. Test results showed that it is possible to obtain a good correlation between direct and indirect UPV tests but that this correlation is strongly dependent on the humidity rate.

Three different natural conditions were studied: the so-called "dry", "intermediate" and "full wet". The reference condition for minimum humidity content was assumed to be the "dry" condition in summer season. On the contrary, the reference condition for maximum humidity content was assumed to be the "full wet" condition in winter season. The "full wet" conditions are obtained, in each season, via water immersion of specimens. This condition is really a "full wet" condition while the "dry" is not the real driest condition.

Direct, semi-direct and indirect UPV tests were performed and replicated in two opposite seasonal conditions (summer and winter) according to an average temperature range of about 20 °C. For these specimens the concrete casting direction showed to be quite irrelevant.

Ratios between direct and indirect UPV tests were determined for both summer and winter conditions and for both wet and dry conditions. A first relation between direct and indirect UPV for different humidity level was pointed out using a simple linear regression. Correlation coefficients are quite similar for both summer and winter condition and a linear model can be assumed as efficient for indirect to direct velocity dependence on humidity.

3. ACTUAL TESTS WITH ARTIFICIAL WATER CONTENT CONDITION

In Biondi et al. (2016) a wider test campaign was carried out on the same concrete specimen set by means of two different ultrasonic pulse velocity apparatus. In order to limit the number of tests, only direct and indirect measures were considered. While previously those specimens were used for different test series at different natural humidity level (the so-called summer [dry] and winter [wet] condition), in this case, a ventilated oven was used to calibrate the concrete humidity level.

The fundamental hypothesis is to assume, according to the literature, that the maximum water content in concrete corresponds to 6% of the concrete weight. Basing on this hypothesis, intermediate humidity levels are defined and the full dry condition is obtained by means the oven. Density, casting direction, operator, UPV apparatus, test type and humidity level dependence were investigated. It was found that test results are independent regarding concrete density, casting direction and measurement apparatus whereas a small dependence was evidenced regarding to the operator if different values of surface humidity were caused.

A stronger influence on humidity level was detected: only for wet (saturated) specimens both direct and indirect tests shown the same UPV results. In the other cases (intermediate or dry conditions) a strong dependence on humidity level was pointed out, this dependence is quite linear for each type of test and it is higher for the indirect tests. It was noted that the maximum humidity level is generally lower than 6%, for this reason, the minimum (full dry) weight as to be assumed as a basic parameter for this kind of approach.

4. HUMIDITY INFLUENCE AND IN-SITU HUMIDITY LEVEL CONTROL

The parameter that allows to take into account the water content in the i^{th} specimen is absolute partial percentage of weight, H_{Wi} (1), that depends on the actual specimen weight, W_i, and the minimum (full dry) specimen weight, $\min\{W_i\}$.

$$H_{Wi} = \frac{W_i - \min\{W_i\}}{\min\{W_i\}} \qquad (1)$$

Assuming, as in the literature, that maximum (full wet) condition is $H_{Wi} = 6\%$ the target minimum (full dry) specimen weight, $\min\{W_i\}$ i.e. $H_{Wi} = 0\%$, is estimated according to (1); similarly every intermediate condition, $H_{Wi} = 1\% \div 5\%$, is defined.

Comparing results of tests with natural and artificial water content, humidity levels can be defined as in Table 1, assuming that natural conditions are in the range $1{,}00 \le H_{Wi} \le 5{,}00$.

The question is now: how to measure this parameter in situ? The goal of moisture detection in concrete structures could be carried out by means of different apparatus; a simple and cheap commercial concrete moisture meter was used in previous studies, Figure 1.

Table 1. Humidity levels

H_{Wi}	**Level**	**Description**
6	maximum	Maximum humidity content / full wet
5-4		Natural wet
3	intermediate	Natural dry
2-1		Natural dry
0	minimum	Artificial dry

Figure 1: Measurement of impedance humidity with moisture meter

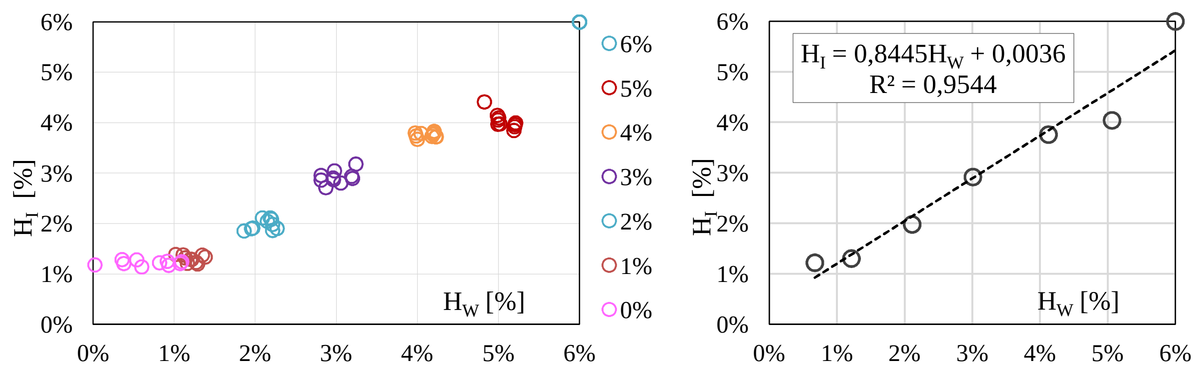

Figure 2: Comparison between partial percentage of weight, H_{Wi}, and impedance humidity H_{Ii} (left - for any humidity level) and correlation (right - for average ratios at any humidity level).

This apparatus detects and evaluates moisture conditions, impedance humidity H_{Ii}, both on the surface and deep by non-destructively measuring the electrical impedance within building material. A comparison between partial percentage of weight, H_{Wi} assuming H_{Wimax} = 6%, and impedance humidity H_{Ii} for any humidity level [i.e. for any pre-defined target (0%, 1%, 2% ...) level] and linear correlation of these average values are shown in Figure 2. It is possible to note that in the so-called “Natural wet - Natural dry” range a very good correlation between partial percentage of weight, H_{Wi}, and impedance humidity H_{Ii}, was pointed out. For this reason, it is possible to assume that a commercial concrete moisture meter can be usefully used for in situ humidity evaluation.

5. CONCLUSIONS

The most important result of previous studies was that a strong dependence on humidity level was pointed out and that for wet (saturated) specimens both direct and indirect tests shown the same UPV results. So it is necessary to control in-situ humidity level.

It is possible to note that a very good correlation between partial percentage of weight, H_{Wi}, and impedance humidity H_{Ii}, was pointed out even if a simple and cheap commercial concrete moisture meter was used.

For these reasons, the Authors propose that a control of in-situ humidity level has to be considered as mandatory for a correct approach to this kind of NDT test.

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