Concrete compressive strength determined by the ultrasonic pulse velocity method: accuracy and reliability

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1. Introduction

The ultrasonic pulse velocity method is by far the most widely accepted non destructive method for assessing the quality of concrete in a structure (e.g. Cannard et al., 1974; Blight et al., 1981; Hobbs, 1987; Blight and Alexander, 1981; Swamy and Al-Asali, 1988; 1989; Popovics, 1986; Popovics et al., 1990; 1991). However, the accuracy and reliability of this non destructive test method to estimate the concrete compressive strength is often criticized. This is likely why, the pulse velocity method is commonly used more as a relative measure of the concrete homogeneity rather than an absolute measure of its compressive strength. Indeed, concrete is a multi-phase composite material and there is no theoretical justified relationship between the elastic properties of a concrete, regulating the ultrasonic wave propagation, and its strength (Popovics, 1986). The ultrasonic velocity is indeed controlled primarily by the concrete Young modules. Moreover, a number of factors may introduce important variations (age of the concrete, moisture conditions, aggregate/cement ratios, type of aggregates, location of the reinforcement ...). When all these factors are kept constant an empirical relationship such a calibration curve or a formula can be developed for the strength estimation of each concrete. The relationship between the compressive strength and the pulse velocity has been studied by many authors and is usually represented by an exponential curve ($f = a \cdot e^{bv}$, where $f$ = concrete strength, $v$ = pulse velocity, and $a$ and $b$ = empirical constants depending on the type of strength, composition, air content, as well as curing of the concrete). However, even when all these conditions remain unchanged, such formula can predict the compressive strength of the concrete within only $\pm 20\%$ accuracy (Malhotra and Carette, 1980; Popovics, 1986).

It appears clearly that in order to improve such accuracy, the sampling of concrete cores is necessary. Such sampling will allow to settle calibration curves fitting perfectly to the studied concrete. Such procedure was followed in this study. Moreover, we have tried to determine the accuracy and reliability of compressive strength obtained by the ultrasonic pulse velocity technique by measuring afterwards the concrete compressive strength of concrete cores sampled in zones surveyed with ultrasounds.

2. Followed procedure

When a great number of similar structures have to be studied non destructive techniques are very useful. Such techniques are also necessary when the structures have a complicated form. Fifty structural elements as the one described in figure 1 had to be studied.

![Figure 1: Position of the ultrasonic pulse velocity measurements on one structural element (dashed lines).](image)
These structural elements were divided into five components. The ultrasonic velocities were measured on the structural elements along the dashed lines showed on figure 1. We obtained an ultrasonic velocity map for each structural element. Knowing the ultrasonic velocities, concrete cores were sampled in each of the five components, in parts showing a wide range of velocities. The concrete cores ultrasonic velocities were measured using the same equipment than the one used on the field. In order to establish precise calibration curves around 100 concrete cores were sampled: 40 of them were taken in the component number 1 which is underground and much more difficult to reach for ultrasonic velocity measurement. In the four other components (2, 3, 4 and 5), respectively 16, 18, 19 and 6 cores were sampled through all the building.

3. Results

As a first step toward the interpretation of the ultrasonic velocities of this building concrete, the cores ultrasonic velocities were correlated with the compressive strengths (Fig. 2 and 3).

Ultrasonic velocities versus compressive strength calibration curves were established for each of the five components.

A correlation coefficient superior than 0.9 was obtained allowing us to define for any ultrasonic velocity the compressive strength with an accuracy of ±10%.

Figure 3 enlighten the fact that it is necessary to study each component separately. Indeed, except for components 2 and 4 which present similar calibration curves, all the three other components exhibit rather different calibration curves.

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4. Discussion: accuracy and reliability

To verify the reliability of these results, 10 concrete cores were sampled afterwards in order to compare the measured compressive strengths with those estimated with the ultrasonic pulse velocities. These samples were taken in zones supposedly presenting compressive strengths ranging from 15 to 45 MPa.

The strength - pulse velocity relationship, being represented by an exponential curve, the best strength accuracy was supposed to be obtained for the slowest velocities. For example, a 5 MPa variation between 5 and 10 MPa is represented by a 500 m/s pulse velocity.
variation. As a difference, a similar variation between 45 and 50 MPa is represented by a 80 m/s pulse velocity variation. Between 60 and 65 MPa, this variation is represented only by a 40 m/s pulse velocity variation.

![Figure 4](image)

Figure 4: Concrete compressive strength map of one of the fifty structural units.

However, our observations are not in agreement with this assumption. Indeed, the following remarks regarding the reliability of this technique can be made (Figure 5):

- for compressive strengths greater than 25 MPa, the reliability of the ultrasonic pulse velocity technique is ± 2 MPa (= 5% uncertainty at 40 MPa).
- for compressive strengths lower than 25 MPa, the estimated compressive strength tend to be higher than the measured compressive strength. At 20 MPa the error is ± 5 MPa (25 %), and at 6 MPa the error is ± 9 MPa (150 %).

These large errors for low compressive strength values confirm that the relationship between the ultrasonic velocity and the concrete compressive strength is not regulated by a simple law. If an exponential curve may represent this relationship for high compressive strength values, it appears clearly that other factors must be introduce to the exponential relationship in order to obtain accurate and reliable values for low compressive strength concrete.

However, even if the analytical errors are quite large for low compressive strength values, the ultrasonic velocity method remains a good technique to give an internal image of a deteriorated concrete structure.

5. Conclusion

This study shows that it is possible under certain conditions to determine rather precisely the concrete compressive strength with the ultrasonic pulse velocity method: around 40 MPa the uncertainty is ± 5 %. However, for low compressive strength values some corrections are necessary. Indeed, the error between the measured and estimated compressive strengths is increasing toward lower compressive strength values: 25 % at 20 MPa and 150 % at 5 MPa.

![Figure 5](image)

Figure 5: Measured compressive strength versus estimated compressive strength.

6. References


