

Ultrasonic Signal Evaluation Used to Analyse Changes in a Concrete Specimen Caused by Weather-Related Temperature Changes

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Abstract

Ultrasonic measurement evaluation methods have been proven to be effective for detection of subtle changes, caused by temperature, load or moisture. However, for its application outdoors it is necessary to analyse unavoidable influences, such as weather. Therefore an ultrasonic monitoring system with 40 ultrasonic sensors (20 transmitters, 20 receivers; 25 kHz central frequency) has been implemented on a concrete specimen ($4 \times 5 \times 0.8 \text{ m}^3$), that is exposed to weather conditions. Data from 400 sensor combinations was collected over a period of six months with an interval of two hours. The data was evaluated by both qualitative (correlation techniques) and quantitative (ultrasonic velocity changes via Coda Wave Interferometry and time of flight method) evaluation methods and compared to the temperature changes caused by weather.

Keywords: Ultrasound, Monitoring, Concrete, Time of Flight Method, Coda Wave Interferometry, Temperature

1. Introduction

Detection of subtle changes in concrete structures is an important subject to evaluate damages over time (e.g. freeze-thaw attacks, alkali silica reaction). By means of ultrasonic signals it is possible to detect not only the direct way, but also the area around, due to signal reflections in the concrete structure. This makes it possible to monitor structures in larger areas.

In laboratory setups exterior influences, such as load, temperature, moisture or other means were analysed already (e.g. [1, 2]). For the usage of ultrasonic systems in practice a monitoring system was implemented on a specimen outside of a laboratory environment that is exposed to weather conditions to observe especially the influence of consistent temperature changes towards the velocity of ultrasonic signals. Furthermore the sensor distances were chosen very large (up to 6.5 m) to guarantee a resource-efficient observation even on larger structures.

2. Experiment

The used specimen is a $4 \times 5 \times 0.8 \text{ m}^3$ concrete block, that has been cast at *BAM Test Site Technical Safety* for various experiments with ultrasonic sensors outside of laboratory environments. A total of 40 ultrasonic sensors have been attached around the specimen (10 sensors on each side of the specimen: north and west side contain transmitting sensors, south and east side contain receiving sensors). One multiplexer connects all transmitting sensors to a rectangular transmitter (25 kHz), the second multiplexer connects all the receiving sensors to an analog to digital converter for storage of the collected data on the PC. Additionally, the receiving signals were preamplified by factor 60 to ensure a good signal quality on the high distance between transmitting and receiving sensors. The measurement setup is shown schematically in Figure 1.

This setup makes it possible to track 400 transmitter-receiver combinations within only a few minutes, regarding to the number of repetitions. Data was collected in two hours intervals within a period of six months. Approximately five meters away from the specimen a weather station got installed, that provided accurate air temperature and moisture data in an interval of ten minutes to ensure the comparison between changes in measured data and changes of temperature.

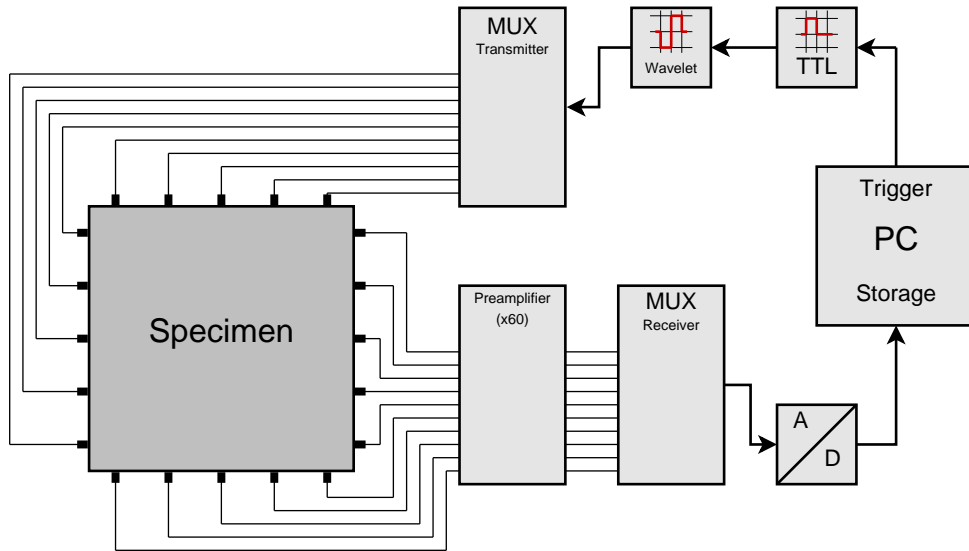


Figure 1: Measurement setup (just half of the sensors is shown for clarity)

3. Theory

To evaluate the velocity changes of ultrasonic signals two methods were used. Both methods used a reference time series and compared the velocity changes to the reference.

3.1 Time of Flight method

The Time of Flight method describes the time, that the pressure wave needs to travel from the transmitting sensor to the receiving sensor through the medium. Therefore the velocity of a reference time series v_{Ref} is calculated directly by knowing the distance between the two sensors s and the elapsed time between triggering and recording of the impulse t_{Ref} through:

$$v_{Ref} = \frac{s}{t_{Ref}} \quad (1)$$

By knowing the velocity of the reference signal it is possible to compare the relative velocity change Δv of a recorded time series towards the reference by using the first arrival time lag Δt between reference and recorded time series.

$$\Delta v = \frac{\Delta t \cdot v_{Ref}}{t_{Ref}} \quad (2)$$

The disadvantage of this technique is, that the limit of detection is limited to the resolution of the receiving signals and the distance between the sensors. A sampling frequency of 1 MHz and a sensor distance of 5 m is limited to detect velocity changes not smaller than approximately 0.08 % (in concrete).

3.2 Coda Wave Interferometry

For the detection of very small velocity changes Coda Wave Interferometry (CWI) is a suitable technique. Small velocity changes can cause a phase shift in the later stage of a time series (Coda). The CWI expands the cross-correlation, which is used to compare two time series $x(t), y(t)$, by a small factor ν , that compresses or stretches the reference time series to maxi-

mase the cross-correlation. This negates the phase lag and the relative velocity change can be calculated out of this. This technique was described in [3].

$$CC(\nu) := \frac{\int_{-\infty}^{\infty} x(t) \cdot y(t \cdot (1 - \nu)) dt}{\sqrt{\int_{-\infty}^{\infty} x(t)^2 dt} \cdot \sqrt{\int_{-\infty}^{\infty} y(t)^2 dt}} = \max \quad (3)$$

$$\nu = \frac{\Delta t}{t} = \frac{\Delta v}{v}$$

The disadvantage of this technique is, that larger velocity changes lead to larger phase shifts. This can cause multiple local maximums in the cross-correlation, so the time factor can't be allocated clearly anymore. But on the other hand the CWI can detect very small velocity changes up to approximately 10^{-3} %.

4. Results

4.1 Day and Night Temperature Cycles

First of all, the temperature changes between day and night were observed. Figure 2 shows the temperature graph on the right side and the velocity changes of the ultrasonic waves evaluated with the time of flight method and CWI on the left side. With the given measurement settings the resolution of the time of flight method is too low to see the temperature changes properly. Nonetheless the velocity changes evaluated with CWI follows the temperature changes with a slight delay. Heating up the specimen at daylight causes the ultrasonic velocity to drop down, cooling down the specimen at night causes the ultrasonic velocity to go up. The velocity between day and night evaluated with CWI differ by approximately 0.2 %.

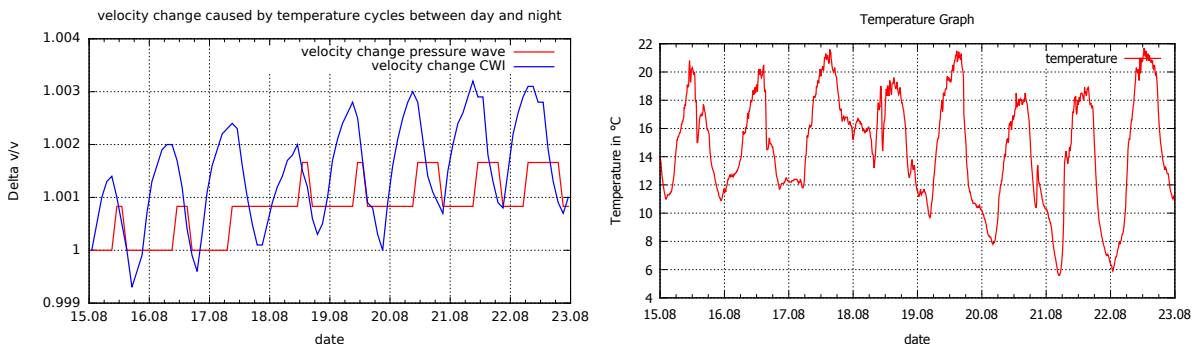


Figure 2: velocity changes caused by day and night temperature cycles evaluated with Time of Flight method and CWI (left) and temperature graph of the same time period (right)

4.2 Long-Term Observation of Temperature Influences

Figure 3 shows the velocity change evaluated with time of flight method and CWI over a period of 6 months on the left side and the temperature graph for the same time period on the right side. To ignore the day and night temperature cycles evaluated in section 4.1 only one set of data per day was used, measured at the same time of each day. First of all, both evaluation methods lead to similar results. Whereas the time of flight method could not provide a decent evaluation for the temperature day and night cycles, it provides nearly the same results like the CWI for bigger velocity changes even though both techniques analyse a different part of the ultrasonic signal.

The velocity changes follow the temperature here. Temperature peaks around 10th of June and 20th of July lead to local minimums in the ultrasonic velocity. Furthermore, the strong temperature between August and September, which marks the begin of fall, causes a strong velocity increase of the ultrasonic waves. Opposed to that, the temperature increase between spring and

summer causes a velocity decrease of the measured ultrasonic waves. The differences of the ultrasonic velocity maximum and minimum are approximately 1 %.

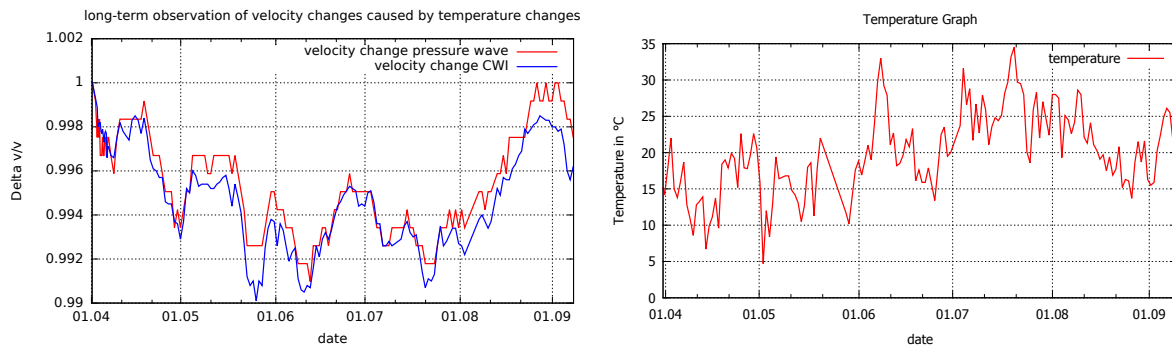


Figure 3: velocity changes over a period of six months evaluated with Time of Flight method and CWI (left) and temperature graph of the same time period (right)

5. Conclusion

The ultrasonic signal evaluation shows a large impact on the signals caused by temperature. Even day and night temperature cycles, which should not cause too much influence to the specimen led to a velocity change of approximately 0.2 %. Bigger temperature changes between the rotation of the seasons caused velocity changes even up to 1 %. Both evaluation methods provided similar data that can be compared to the results obtained in laboratory in [1]. Nevertheless, temperature changes play a huge role when monitoring damage influences and cannot be ignored when giving damage assessments, because the influence of temperature towards the ultrasonic velocity is too large. Compared to that, a specimen that was put under the load of 20 kN caused just a velocity change of 0.15 % [2]. It is therefore necessary to differ between changes caused by temperature and changes caused by other factors, when monitoring in a practical environment.

References

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