Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 57/1/57/2 (1989)

Artikel: Ultrasonic testing of concrete
Autor: Wiberg, Ulrika
DOI: https://doi.org/10.5169/seals-44231

Ultrasonic Testing of Concrete
Contrôle du béton par ultrasons
Ultraschallprüfung von Beton

Ulrika WIBERG
Civil Engineer
Royal Inst. of Technology
Stockholm, Sweden

Ulrika Wiberg, born 1961, graduated with a Master of Science in Civil Engineering at the Royal Institute of Technology in Stockholm in 1985, since when she has been studying for a doctorate at the Department of Structural Engineering.

SUMMARY

A research project concerning the use of ultrasonic technology for detection of deterioration in concrete is reported. The development possibilities for the technology in detecting damage on the basis of excitation of broadband sound pulses and with evaluation based on digital signal analysis are discussed. Results are presented from a series of tests on concrete cylinders with fatigue-induced cracks.

RÉSUMÉ

Un projet de recherche concernant la détection de défauts dans le béton au moyen d'ultrasons est présenté. L'article expose les possibilités de développement de cette technique pour la détection d'anomalies, par la mise en oeuvre d'impulsions sonores à bande large et par l'évaluation des signaux au moyen d'analyse numérique. Il présente également les résultats d'une série d'essais réalisés avec des cylindres en béton présentant des fissures induites par fatigue.

ZUSAMMENFASSUNG

Es wird über die Forschung bezüglich der Schadensortung in Beton mit Ultraschalltechnik berichtet. Die Entwicklungsmöglichkeiten für diese Technik zur Kontrolle bei diffusen Schadentypen auf Grundlage der Erzeugung von breitbandigen Schallimpulsen und Auswertgung mit digitaler Signalanalyse werden diskutiert. Gleichzeitig werden die Ergebnisse einer Versuchsreihe an Betonzylindern mit Ermüdung ankündigenden Rissen untersucht.

1. INTRODUCTION

Ultrasonic measurements on concrete have in the past been used primarily for strength determinations. New opportunities for using ultrasonic technology are revealed when interest is expanded to include mapping of damage on the basis of relative assessments within a given structure. A completely new type of control is made possible through computerization of measurements and through digital storage and processing of measured ultrasonic signals.

Analysis of the transmitted sound enables not only detection of deterioration having an effect on the velocity of sound but also of deterioration that mainly affects the propagation and attenuation of the sound wave. Development of ultrasonic technology from this point of view is in progress at the Department of Structural Engineering at the Royal Institute of Technology in Stockholm.

The work is being carried out in cooperation with other research institutes in Sweden which are active in the field of non-destructive testing of concrete, see Ingvarsson [1].

2. ULTRASONIC DETECTION OF DETERIORATION

2.1 Measuring technique

Ultrasonic technology for detection of deteriorated concrete comprises a group of possible methods of measurement and analysis. The fundamental characteristic is that a ultrasonic pulse is introduced into the concrete, the signal subsequently being received after passing through the material.

Different parameters can be used to characterize investigated material of concrete. The most common is measurement of the ultrasonic velocity. The attenuation of the transmitted signal can also be used. As a measure of the attenuation of the material, it is customary to use the amplitude of the first wave in the received signal. Further studies of the received signal also make it possible to investigate those parts of the signal which have not been transmitted via the fastest route.

2.2 Deterioration criteria

The transmission of the ultrasonic signal is influenced by the changes to the acoustic properties which may be caused by deterioration. From these changes, it is therefore possible to establish criteria for the material in question. A frequently used damage criterion is low sound velocity in the concrete. A long measured transmission time, giving a corresponding low velocity, can originate from either the signal passing through a deteriorated area or from bypassing it. On transmission of a ultrasonic signal through a structure, the differences in impedance between sound and damaged concrete can cause a larger amount of energy to be reflected at the boundary surface of the damage and, in consequence, the attenuation of the transmitted signal is greater than in the case of homogeneous concrete.

Investigations of specimens with fictive damage that do not permit any transmission have for instance been carried out by Knab, Blessing and Clifton [2]. This investigation comprised velocity measurements in concrete specimens provided with fictive cracks. Moreover, Sansalone and Carino [3], have reported on work on impact-echo measurements of fictive cavities.

Measurements giving an estimate of the dispersion of the sound wave caused by a partially transmitting damage can also be of interest. In many cases, deterioration of a concrete structure occurs in the form of load- or frost-initiated cracking. Development of methods for attempting to measure and quantify this type of damage on the basis of transfer functions for concrete, will be carried out.

In establishing damage criteria which can be utilized to assess significant differences within a structure, it is also of great interest to study the magnitude of the changes in a measured signal that can be caused by deterioration in comparison with the variations arising on account of the natural inhomogeneity of the concrete. The problems caused by the test reproducibility must also be analyzed.

3. DETECTION OF CRACKS

3.1 Specimens

A series of concrete cylinders were tested with the ultrasonic technique in order to investigate the possibility of detecting cracks in concrete on account of fatigue .

Cylinders with a diameter of 100 mm were drilled out of a cast concrete slab with a height of 300 mm. These cylinders were sawn into specimens with an approximate height of 90 mm. The concrete mix consisted of Portland cement and natural aggregate with a maximum size of 16 mm. The mixing ratio by weight was: 1.00 part cement, 2.1 parts fine aggregate and 1.6parts of coarse aggregate. The water- cement ratio was 0.50 and the air content 8 %.

3.2 Performance of ultrasonic measurements

In the test series, ultrasonic measurements were carried out with direct transmission in the axial direction of the cylinders . Piezo-electrical transducers with a high frequency response in the band from 40- 160 kHz were used as sending and receiving probes. In all measurements the electric input, shown in Fig. 1, consisted of one cycle of a sinusoidal wave in 130 kHz with a voltage of 250 V. The received signal was stored in digital form with a sampling frequency of 2 MHz.

The transducers were applied to the concrete specimen in each separate ultrasonic measurement according to Fig. 1. In order to bring about a reproducible coupling the probes were mounted against a spring- loaded holder which produced a constant contact pressure. A coupling medium was applied between the probes and the concrete.

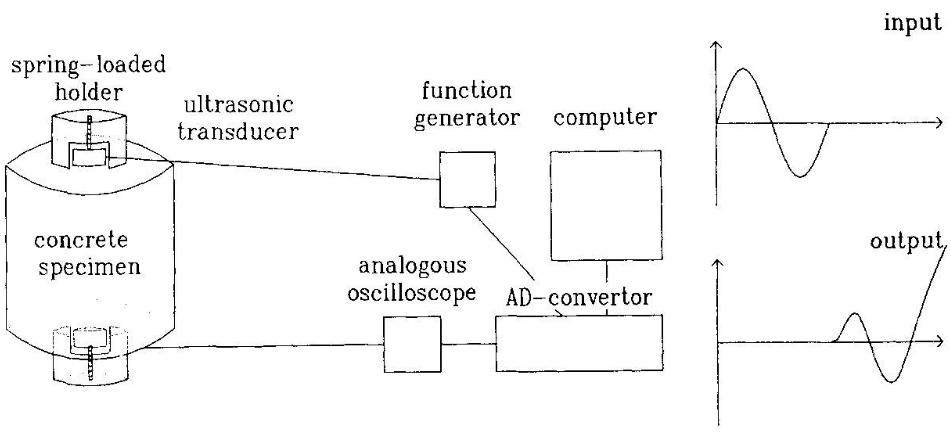

Fig. 1: Schematic diagram of test setup

The ultrasonic measurements were performed on unloaded specimens at roughly each 400,000th load cycle. The test was discontinued after 2 million load cycles if failure had not occurred. Each measurement was done with eight independent couplings of the transducers. All eight separately stored readings consisted of a time mean value of four transmitted impulses. On the occasions when ultrasonic measurements were performed, any cracks visible on the surface of the cylinder were registered.

3.3 Results from crack detection tests

In the study of concrete cylinders exposed to a uni-axial fatigue load, ultrasonic velocities and signal amplitudes were registered in order to study if these parameters can give an indication of crack development.

The changes in amplitude were studied by calculation of a coefficient of reduction, defined as

$$D_a = 1 - \frac{A}{A_0}$$

where A is the average of the amplitudes of the first received wave in eight registered signals from a specific specimen and test occasion and A_0 is the corresponding value prior to loading.

The reduction in velocity was determined in a corresponding manner.

A comparison between λ, the total length of visible cracks relative to cylinder height and calculated reductions in amplitude,D_a, and velocity,D_v, for the specimens is presented in Table 1.

Number of load cycles		Specimen 1	2	3	4	5	6	7	8	9	10	11
	Da	0	0	0	0	0	0	0	0	0	0	0
0	Dv	0	0	0	06 0	0	0	0	0	0	0	
	λ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Da	23	34	1	22	5	5	90	23	-	16	52
400000	Dv	9	13	6	9	7	10	15	9	-	10	19
	λ	-	1.0	0.5	2.0	0.8	1.0	4.3	2.0	-	1.3	5.6
	Da	30	42	20	30	7	15	96	30	-	28	78
800000	Dv	10	13	7	11	9	13	22	11	-	11	24
	λ	-	4.3	0.5	2.0	1.3	2.0	10.1	2.0	-	2.3	7.5
	Da	35	37	83	36	9	16	-	61	-	31	97
1200000	Dv	10	14	13	12	9	13	-	11	-	14	31
	λ	-	4.6	5.9	3.2	1.3	2.5	-	2.0	-	3.4	11.5
	Da	33	36	88	36	3	59	-	39	-	30	-
1600000	Dv	11	14	14	12	9	18	-	12	-	13	-
	λ	-	4.6	5.9	4.6	1.3	7.2	-	2.0	-	3.4	-
	Da	31	40	-	37	3	-	-	35	-	32	-
2000000	Dv	10	14	-	12	9	-	-	12	-	13	-
	λ	3.5	5.3	-	4.8	1.3	-	-	2.0	-	4.0	-

Table 1: Coefficients of Amplitude Reduction, D_a (%), Coefficients of Velocity Reduction, D_v (%), and total lengths of visible cracks relative to cylinders heights,λ for specimens 1-11.

Mean values of velocities and amplitudes from signals measured with renewed coupling are presented in Fig. 2 together with the corresponding standard deviations.

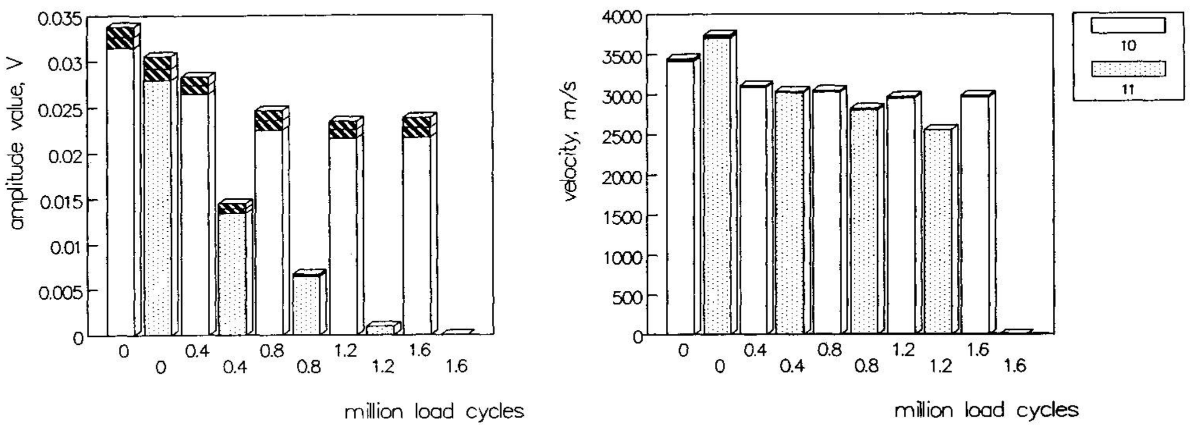

Fig. 2: Mean values with standard deviations of eight repeated measurements from specimens 10 and 11, at different stages of loading. Amplitude of first received sound wave, left and Velocity, right.

Apart from the deviations that can be calculated for selected analysis parameters, the reproducibility can be studied by calculation of the averaged coherence function between input and output signals. By this means a picture is obtained of how well the included frequencies are reproduced in all of the received signal. The coherence of the repeated measurements was therefore registered in each measurement stage. Calculated coherence functions for one of the cylinders are shown in Fig. 3 referring to two different occasions.

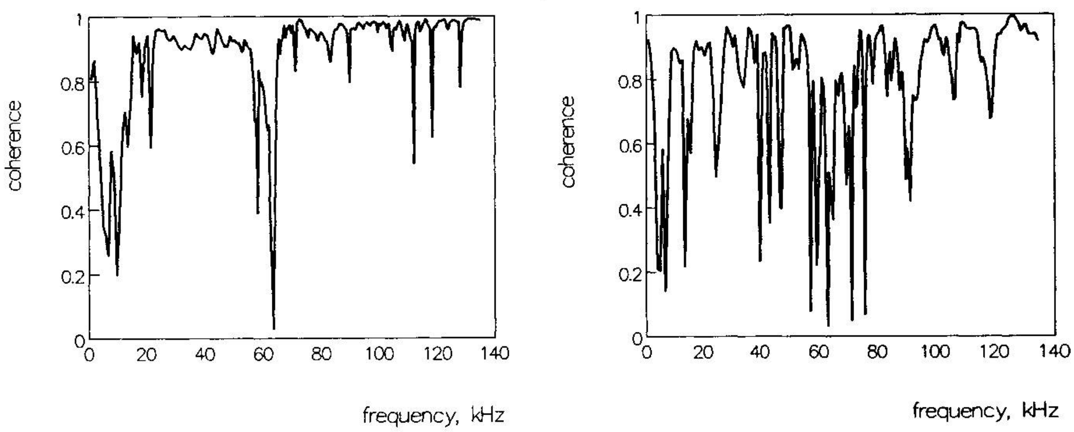

Fig. 3: Coherence functions for measurements on specimen number 11 at the initial stage, left, and after 0.8 million load cycles, right.

The duration of the first received wave was shown to be changed due to cracks. The appearance of this wave is shown in Fig. 4 for one of the specimens at different degrees of cracking.

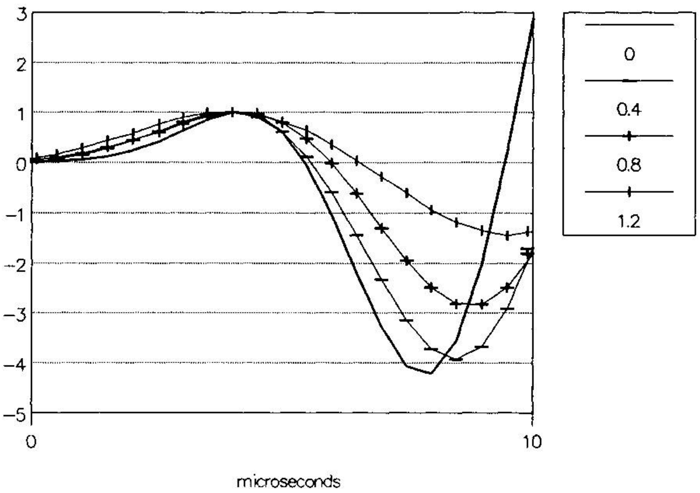

Fig. 4: First parts of received waveforms from specimen 11 at 0, 0.4, 0.8 and 1.2 million cycles. Amplitude values are normalized with respect to the first received peak.

4. CONCLUSIONS

This investigation shows that determination of ultrasonic parameters can be a meaningful way to analyse deterioration. Severe cracking is shown to give significantly greater effects in the values recorded than those related to the natural lack of homogeneity of the material.

The changes upon deterioration will be greater for amplitude measurements than for velocity measurements. The variation in values recorded with repeated measurements is however greater for amplitude than for velocity measurements. Several repeated measurements are therefore required to obtain a reproducible amplitude parameter. It is also shown that there are increasing difficulties to reproduce the entire signal when the concrete is deteriorated. A lack in coherence can in itself be an indication of an increased number of cracks in the concrete specimen.

The duration of the first wave of the received signal will also be longer and thus contain lower frequencies with increased damage. The changes in the frequency contents of the received signal due to deterioration is therefore interesting.

Signal analytic studies of the concrete frequency response due to ultrasonic stress wave exitation combined with control of the coherence of the measurement are thus very interesting to carry out for deteriorated concrete. Further research on detection of internal cracking due to fatigue and frost-cycles, using ultrasonic signals and digital signal analytic evaluation, is thus considered to be of considerable interest and will be further studied.

REFERENCES

1. INGVARSSON H., Non-Destructive Condition Assessment of Concrete. IABSE Report, Volume 56, Colloquium Bergamo 1987.
2. KNAB L.I., BLESSING G.V., CLIFTON J.R., Laboratory Evaluation of Ultrasonics for Crack Detection in Concrete. Journal of the American Concrete Institute, January-February 1983.
3. SANSALONE M., CARINO N.J., Impact-Echo: A Method for Flaw Detection in Concrete Using Transient Stress Waves. U.S. Departement of Commerce, National Bureau of Standards, NBSIR 86-3452.