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Checking Concrete by Quantitative Ultrasonics

Contrôle du béton par la méthode quantitative par ultrasons

Betonüberprüfung durch quantitativen Ultraschall

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SUMMARY

Echo detection and tracking of deterioration in concrete is shown using quantitative ultrasonics. The method and analysis is described, and the difference from conventional ultrasonic testing is explained. The randomly scattered ultrasonic waves resulting from the composite are used for material characterisation purposes, and their influence is reduced by signal processing for echo detection. Several possible applications for checking concrete structures are indicated. Characterisation of micro-cracking can be performed using direct transmission. Voids and inclusions can be detected with direct transmission, and also in single-sided measurements if they cause echoes with other frequency characteristics than the material noise.

RÉSUMÉ

La méthode quantitative par ultrasons est appliquée pour la détection de la détérioration du béton. La méthode et l'analyse sont décrites et la différence, par rapport aux méthodes ultrasoniques conventionnelles d'essai, clarifiée. Les vagues ultrasoniques sont utilisées pour déterminer les caractéristiques du matériau. Plusieurs domaines d'application possibles pour l'emploi de la méthode quantitative par ultrasons dans le contrôle de structures en béton sont indiqués. La définition des micro-craquelures peut être effectuée en utilisant une transmission directe. Vides et inclusions peuvent être détectés par transmission directe et par mesures individuelles.

ZUSAMMENFASSUNG

Echoortung und die Verfolgung von Alterungen im Beton werden durch die Verwendung von quantitativem Ultraschall gezeigt. Verfahren und Analyse werden beschrieben und der Unterschied zur herkömmlichen Ultraschallprüfung wird erklärt. Die beliebig zerstreuten Ultraschallwellen, die vom Verbundmaterial stammen, werden für die Materialkennzeichnung verwendet und ihr Einfluss wird durch Signalverarbeitung für Echoortung reduziert. Mehrere mögliche Anwendungen für den Gebrauch von QU bei der Prüfung von Betonstrukturen werden aufgezeigt. Die Kennzeichnung der Mikrorissbildung kann durch Direktübertragung ausgeführt werden. Hohlräume und Einschlüsse können bei Direktübertragung wie auch bei einseitigen Massnahmen entdeckt werden.

1. BACKGROUND

To assess the condition of an existing concrete structure, defects must be detected and the state of the material must be determined. Concrete exposed to deteriorating processes will change its properties, and these changes need to be characterised prior to determining the state of health. Evaluation techniques are needed for the detection of distinct defects such as cracks and delaminations as well as for tracking the distributed damage caused by deterioration.

Methods based on ultrasonic wave propagation are interesting for these purposes. New measurement technique is developed and new methods for analysing ultrasonic data is used in concrete testing. Some of the more recent advances include ultrasonic pulse-echo measurement equipment [1][4], and data processing adopted to handle the composite nature of concrete [5]. Other new applications are in the field of material characterisation using spectroscopy [2][3][5].

2. QUANTITATIVE ULTRASONICS - METHOD AND ANALYSIS

Ultrasonic waves propagating in concrete are likely to be affected by the composite structure of the material, at least at high frequencies. These are random effects which might lead to misinterpretations as false echoes or reproducibility problems in conventional ultrasonics, viewing the signal as coming from a homogeneous medium. However, if such effects of the material character are present in a captured wave form, it carries an imprint of the state of the material. NDT using pulsed ultrasonic waves is expected to give a total measured response which contains both direct specular waves and randomly scattered waves since the pulses include a broad band of frequencies. The specular waves which arrive coherently in frequency can be modelled. The randomly scattered waves which appear incoherently in space and frequency are difficult to model.

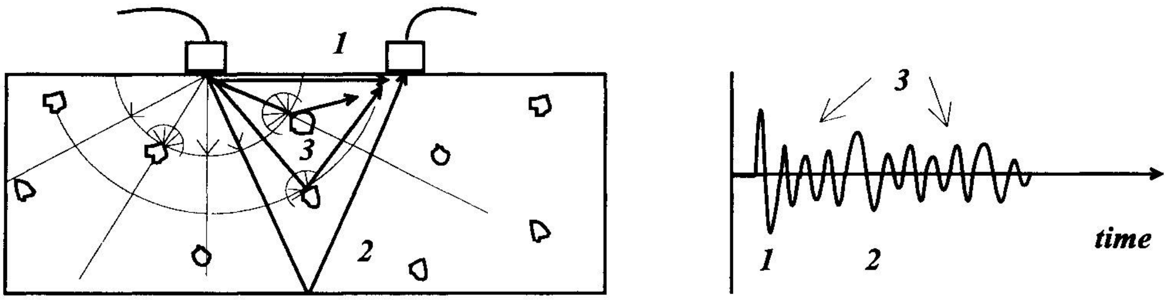

Fig. 1 Schematic representation of waves propagating in a heterogeneous solid

Methods to either analyse the scattered part of the wave form for material characterisation, or to reduce this influence to be able to identify echoes can be useful as true ultrasonic waves are likely to be scattered in concrete. Flaws large enough to cause specular echoes might be detected from the total wave form if the coherent waves are enhanced so that they are distinguished from the scattered waves. This could be achieved by substantial spatial averaging to reduce the random parts of the wave form, or by simply low pass filtering to reduce high frequency scattering. The first of these procedures requires many signals from comparable measurement locations and is thus not suitable for field applications. The other one uses a single record, but is likely to leave some of the scatter and will produce longer echoes thus reducing the resolution of echoes. Another possibility is to use the frequency dependence of the scattered waves to average them out. For the purpose of enhancing specular waves a split spectrum processing technique was tried which preserves or even improves the resolution.

The scattered waves are expected to carry information about the concrete composition, state of deterioration and defects cutting off direct specular waves. The material through which the wave is propagated acts as a frequency filter on the wave form. The material character was investigated using spectral measures reflecting the frequency shift in the received signal due to scattering.

Estimation of filtering characteristics can be done with fourier methods, or as was done in this investigation with parametric modelling using auto regressive low order models from which resonating frequencies can be estimated. The effect of scattering in a measured wave form can be examined by averaging the power of signals. Coarse grains and long transmission paths increase the scattering effect possibly making it a dominating feature in the measured wave form. The diffused behaviour of scattered waves can be analysed by forming the average power called the pulse shape.

3. MATERIAL CHARACTERISATION AND TRACKING OF INTRINSIC DAMAGE

Quantitative ultrasonics was used in this investigation to verify the presence of scattered waves in concrete, and for determining the extent of material deterioration. The results from measurements in deteriorated concrete showed that the additional attenuation, due to deterioration can be used to characterise the degree of deterioration.

3.1 Scattering in sound concrete

The effect of grain noise was investigated by measurements on two concrete slabs with different maximal grain sizes. Echo measurements with a two transducer arrangement were made on two slabs with thicknesses 0.10 m, one with fine grains (< 0.5mm) and the other with coarser grains (<18mm). The measurements were made with a transducer spacing of twice the slab thickness. The echo signal clearly shows substantial grain noise in the coarse grained concrete (fig.2). The bottom echo at 114 μs can be identified only in the fine grained material.

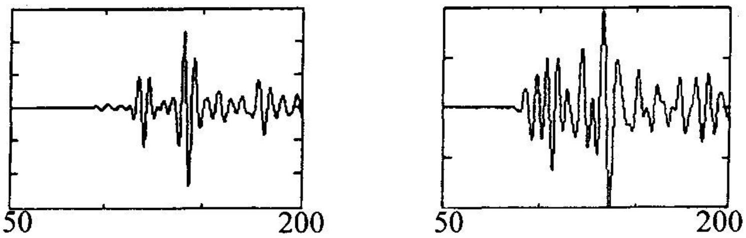

Fig. 2. Measured echo signals from a fine and a coarse grained concrete versus time [μs]

Frequency dependent attenuation of broad band pulses in concrete was shown, and the scattering effect was shown to increase with increasing travel paths in direct transmission measurements. The frequency filtering of measured signals due to the material causes power spectral changes. Spectral estimates of the first few oscillations of signals transmitted over path lengths 0.10, 0.35 and 0.50 m shifts towards lower frequencies for longer transmission paths (fig.3). A similar effect was shown comparing fourier spectra from slabs with fine and coarse grains.

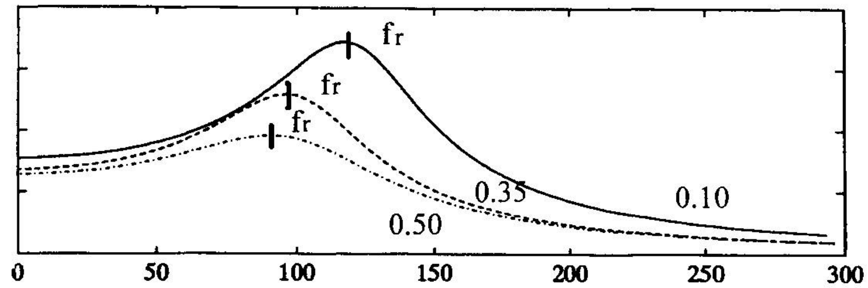

Fig. 3. Spectral estimates versus frequency [kHz] from path lengths 0.10, 0.35 and 0.50 m

3.2 Crack detection

The ultrasonic signal was shown to be sensitive to deterioration causing cracking, and thus quantitative measures from the signal can be used to track deterioration.

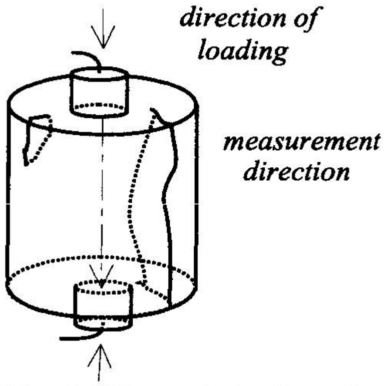

Fig. 4. Ultrasonic testing of a cracked concrete cylinder

A total of 18 cored concrete cylinders with height and diameter 0.10m were exposed to cyclic loads in the axial direction. The load was introduced as a sinusoidal pressure varying from almost zero to a maximum value specific for each specimen as described in [5]. The stage of deterioration was characterised by investigation of the development of cracks. All cracks visible on the surfaces of the cylinders were registered. A normalised amount of cracks λ was defined as the summed crack length divided by the cylinder height. The closeness to failure expressed as the ratio between the number of applied load cycles and the number of cycles at failure N/Nf was also used to characterise the deterioration for six specimens that were loaded to failure.

The degree of deterioration was investigated using various quantitative ultrasonic spectral measures such as resonating frequency *fr* estimated by parametric modelling of the first few cycles of the pulse (fig. 5). It was shown that the frequency dependent attenuation tracked crack growth rather than closeness to failure.

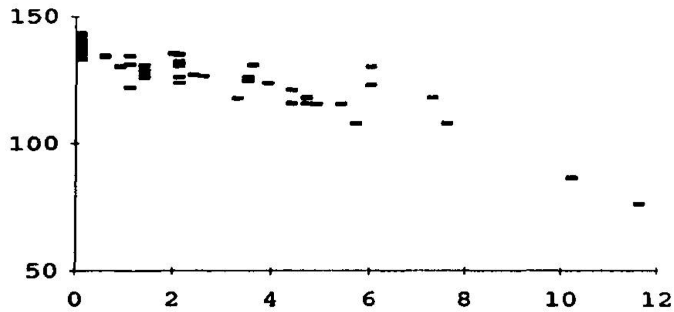

Fig. 5. Resonating frequency *fr* [kHz] versus normalised amount of cracks λ

3.3 Detection of freeze-thaw deterioration

Quantitative ultrasonics was shown to track internal crack growth due to freezing and thawing.

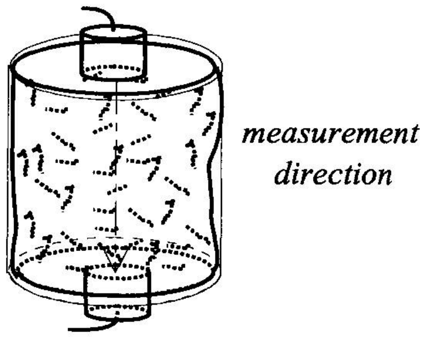

Fig. 6. Ultrasonic testing of a freeze-thaw deteriorated cylinder

Nine groups of concrete cylinders with three specimens in each group were exposed to 0, 1, 7, 14 or 28 cycles of freezing and thawing; half of them in contact with chlorides. Scaling reduced the cross sections and heights of the specimens especially for specimens frozen with chlorides. For the ultrasonic investigation the top and bottom surfaces of the specimens were therefore ground resulting in heights varying between 0.08 and 0.10 m. The effect of deterioration was evaluated from changing material properties characterised by strength and stiffness of the central parts of the cylinders. Internal cracking and surface scaling were also evaluated [5].

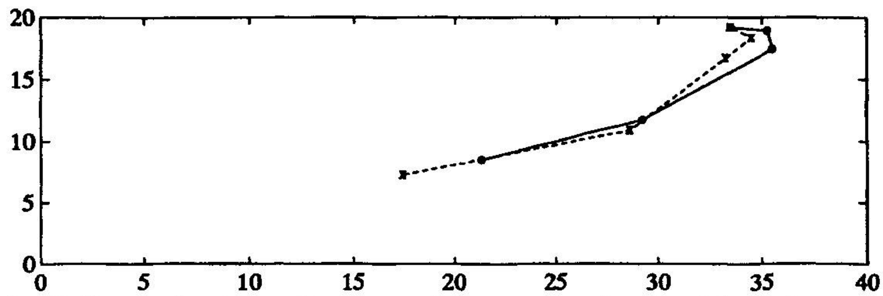

Fig. 7. Squared values of measured ultrasonic velocities [(km/s)] versus stiffness K [GPa]

Ultrasonic velocity as well as spectral changes were shown to mainly follow the number of freeze-thaw cycles, roughly reflecting internal crack growth. Quantitative ultrasonic measures to some extent also reflect changes in strength and stiffness. but not so that stiffness can be estimated from measured velocity (fig. 7), at least not without prior knowledge of the possible changes in Poisson's ratio due to deterioration. A comparison of relationships between strength and velocity, for deteriorated and undeteriorated concrete showed that the ultrasonic velocity decreased more rapidly with deterioration than was explained by the decrease in compressive strength.

4. DEFECT DETECTION IN STRUCTURES

Pulse-Echo measurements from concrete were shown to contain back scattered material noise with a clear frequency dependence. The frequency dependent character was used successfully to reduce the clutter, thus enhancing the coherently repeated specular echoes. The forward scattered energy was used in order to identify the presence of voids in a direct transmission measurement.

Echo measurements on concrete plates with thicknesses 0.10, 0.20, 0.30 m were made with broad band focused transducers. The measured signals were band pass filtered for evaluation of coherent specular signals and incoherent scattered waves. The measured response from the 0.30 m slab was the only one that showed a clear bottom echo in the low frequency part of the signal (fig.8).

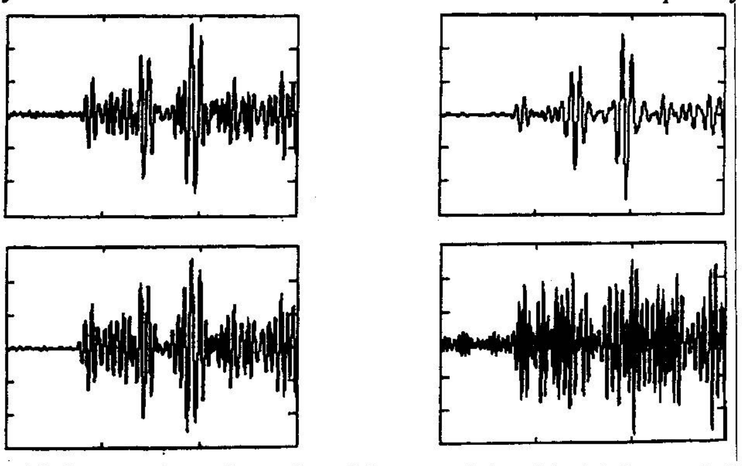

Fig. 8. a) Measured random signal from a slab with thickness 0.30 m. Band pass filtered signals with centre frequencies b) 75 kHz, c) 150 kHz and d) 225 kHz.

Split spectrum processing was used to reduce material noise from single sample records thus enabling identification of specular echoes with good resolution. The signal from the 0.30 m thick slab (fig 8a) showed a clear echo after split spectrum processing (fig 9) as did the signal from the 20 cm slab. The echo in the signal from the 0.10 m slab could not be clearly identified.

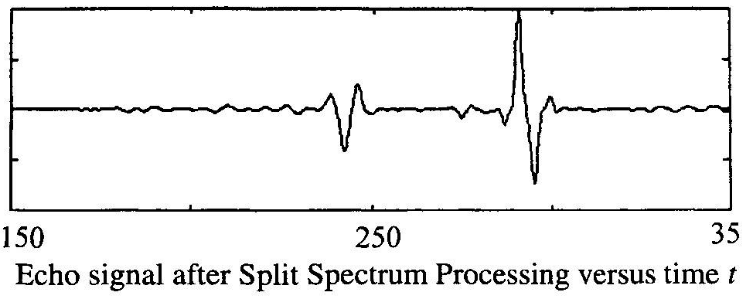

Fig. 9. Echo signal after Split Spectrum Processing versus time t [µs].

Total pulse shapes from direct transmission measurements were used to illustrate defect detection using forward scattered information. The absence of a distinct direct wave being replaced by a diffused arrival of waves indicates that a defect is cutting off the direct travel path. Total pulse shapes were formed by short time averaging of the power of measured signals and subsequent spatial averaging of the power signals from eight comparable locations. Measurements were made on a concrete slab with thickness 0.31 m with plastic tubes embedded in the concrete. Three tubes with diameter 0.11 m were placed at various depths in the concrete, and five tubes with diameter 0.04 m were placed the same way. The concrete had maximal aggregate size 0.032 m which is close to the size of the small tubes. Total pulse shapes from a solid section, from a 0.11m tube in the middle of the slab, and from a 0.04m tube in the middle of the slab showed that the larger tube causes a diffused arrival of waves whereas the small tube appears in a way similar to the solid section (fig 10). All three large tubes appeared in a similar way, and so did all the small tubes.

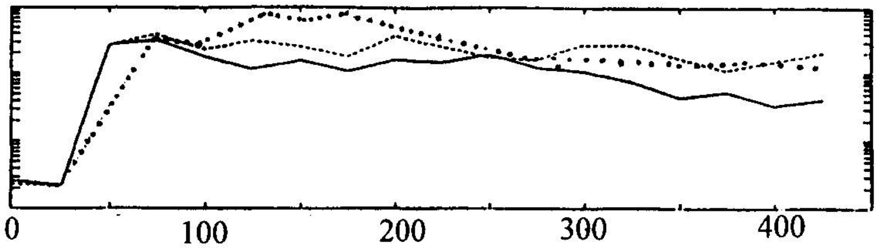

Fig 10. Total pulse shape versus time t [µs] for solid concrete (solid line), section with small tube (dashed line) and section with large tube (dotted line)

5. CONCLUSIONS

Ultrasonic waves in concrete were shown to contain incoherently scattered as well as coherent specular waves. It was shown that the frequency dependence of scattered waves can be used for material characterisation purposes, and that scattered waves can be used for defect detection.

Ultrasonic measurements on freeze-thaw deteriorated specimens, as well as measurements on specimens subjected to cyclic loads, showed that the quantitative ultrasonic measures mainly tracked crack growth. Strength, stiffness or closeness to failure were not significantly related to the ultrasonic measures in the cases presented here. The possible use of scattered waves for defect detection was verified. A total pulse shape with a diffused arrival of forward scattered waves was shown in a direct transmission measurement passing a 0.1 m tube. Echo detection in concrete using split spectrum processing to reduce material noise in measured signals was shown. Bottom echoes from slabs with thicknesses 0.20 and 0.30 m were identified with very good resolution.

ACKNOWLEDGEMENT

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REFERENCES

1. Alexander, A.M., Thornton, H.T., Developments in Ultrasonic Pitch-Catch and Pulse-Echo for measurements in Concrete, ACI Special Publication, SP-112, pp.21-40, 1988.

2. Berthaud, Y., Damage Measurements in Concrete via an Ultrasonic Technique, Cement and Concrete Research, Vol.21, pp. 73-82, 1991.

3. Daponte, P., Olivito, R., Frequency Analysis for Crack Detection in Concrete, Proc. 9th Int. Conf. on Exp. Mechanics, Copenhagen, pp.1355-1364, 1990.

4. Tasker, C.G., Milne, J.M., Smith, R.L., Recent work at the national NDT centre on Concrete Inspection, Br.J. of NDT, Vol.32, pp. 355-359, 1990.

5. Wiberg, U., Material Characterization and Defect Detection in Concrete by QU, TRITA-BKN. Bulletin 7, Royal Institute of Technology, Department of Structural Engineering, Stockholm, 1993.