SIMULATION OF ULTRASONIC FLAW-DETECTION IN CONCRETE WITH VARYING PERCENTAGE OF AIR INCLUSIONS

SIMULATION VON US-RISSDETEKTION IN BETON MIT UNTERSCHIEDLICHEM LUFTGEHALT

SIMULATION DES EXPERIMENTS ULTRASONIQUE DANS BETON ARME AVEC DES INCLUSION D'AIR A DES POURCENTAGES DIFFERENTS

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SUMMARY

The elastic wave-propagation of ultrasonic signals in concrete with varying percentage of air inclusions is simulated in two dimensions using finite-difference-methods. Snapshots of the waves explain their different behaviour in several kinds of inhomogenous models with varying contrasts in their elastic parameters. The received A- and B-Scans show the negative influence of size-effects and air inclusions on the data and the induced problem to detect a flaw inside the concrete.

ZUSAMMENFASSUNG

Die aktive Durchschallung von Beton wird an zweidimensionalen Betonmodellen mit unterschiedlichem Luftgehalt mit Hilfe einer Finiten-Differenzen-Methode simuliert. Momentaufnahmen der Wellenausbreitung im Medium ergeben Aufschluß über das unterschiedliche Verhalten der Welle in dem inhomogenen Medium mit verschieden großen Kontrasten der elastischen Parameter. Die empfangenen A- und B-Scans werden daraufhin untersucht, inwieweit die Lufteinschlüsse und Randeffekte die Ultraschallsignale negativ beeinflussen bzw. die Detektion eines Risses erschweren.

RESUME

Nous avons simulé la propagation des ondes élastiques en béton armé avec des inclusions d'air à des pourcentages différents en deux dimensions avec des méthodes à différences finies. Instantanés des ondes nous donnent des explications de leur conduire dans des matériaux avec des inhomogenités différents. Les données reçu nous montrent les influences négatives des inclusions d'air et celles du bord du modèle. Nous avons la possibilité d' évaluer les problèmes qui resultent pour l´inversion et qui resultent pour la détection d' une rupture dans le béton.

KEYWORDS: finite-difference simulation, elastic wave-propagation, scattering, air inclusions, ultrasound, non-destructive testing

1. INTRODUCTION

The motivation for this simulation are the difficulties occurring during the interpretation of ultrasonic data obtained in the non-destructive testing of concrete. The main problems arise because of air inclusions and size-effects. The wave-propagation depending on these parameters is to be investigated with this simulation.

This simulation is one of the first with the new finite-difference-grid investigated at the Geophysical Institute of the University of Karlsruhe [Karrenbach, 1995] [Gold, 1997] which can cope with the problems that arise when FD-schemes solve the elastic wave equation for big contrasts in elastic parameters (like air inclusions). The wave-propagation is computed up to eighth order. Because of that the FD-algorithm is more suitable than the finite-integration-algorithm that only can cope with second order [Fellinger, 1995].

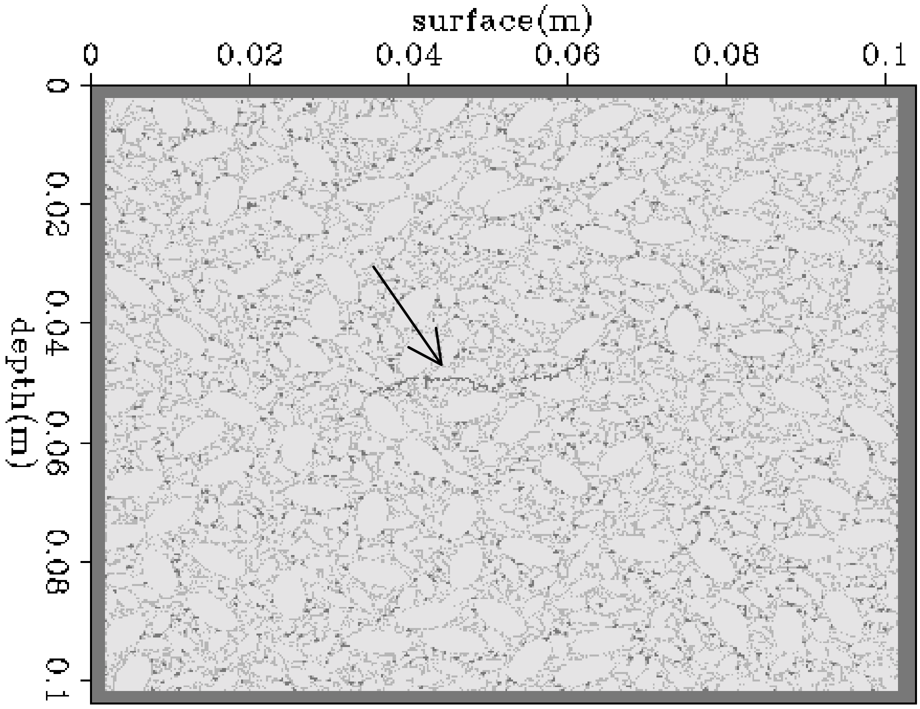

Fig. 1: *Twodimensional concrete model with elliptic inclusions and fractal flaw in 5 cm depth.*

2. SIMULATION

A special medium program has been developed for producing models of fibre-reinforced materials or concrete interactively, used as input for the FD-program. The chosen model exists of 500*500 gridpoints representing 0,1 m * 0,1 m concrete. Each gridpoint provides the three elastic parameters density, speed of P- and S-wave (compression and shear wave) for the finite difference simulation. The parameters are taken from the measurements of Weiler [Weiler, 1995]. The structure of the model is similar to specimen concreted according DIN 1045. Ellipses with different sizes are placed randomly into the matrix-material cement, representing the stuffing material: 22.54% aggregates with 4 -8 mm diameter, 24.05% aggregates with 2 - 4 mm diameter, 14.85% aggregates with 1 - 2 mm diameter and sand with 0.4 - 0.6 mm diameter.

The different models have 0%, 2% and 4% ellipses representing the air inclusions with the same diameter as the sand ellipses. So the smallest objects take at least six gridpoints in our model. A fractal flaw is placed horizontally in the middle of the model in a depth of 5 cm and with a length of approximately 3 cm and a diameter of 0.2 mm. Surrounding the model there is a frame of ten gridpoints including the parameters of air for getting total reflections on all sides and taking them into account as size-effects.

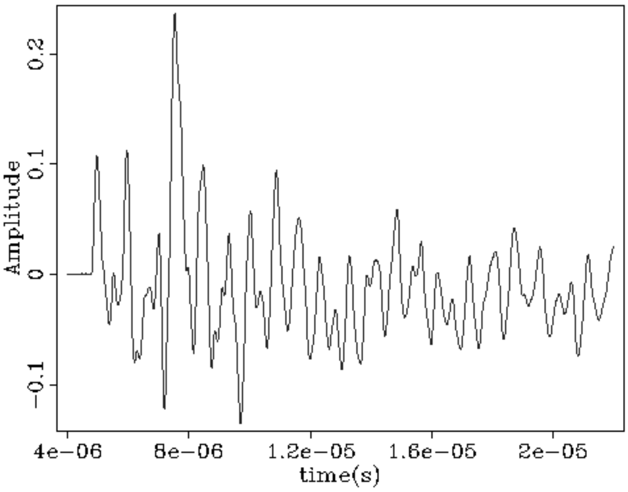

Fig. 2: *Input wavelet, convolved with the frequency response function of the ultrasonic receiver.*

The wavelet is produced by breaking a pencil on an ultrasonic receiver. There is also the possibility to use synthetic wavelets with given frequencies and shapes. The used method has the advantage, that the input signal is already convolved with the frequency response function of the receiver [Weiler, 1995]. The shape of the wavelet is very similar to the one given by a piezo-transducer. After converting the signal into the appropriate data format, it is send within a point source through the model.

Because of its sampling rate in the dimension of Megahertz it takes about 10 000 timesteps to propagate the signal through the model. One simulation with the highly parallelized FD-program (written in High Performance Fortran) takes up to ten hours on 32 nodes of the Intel-Paragon parallel-computer of the University of Stuttgart.

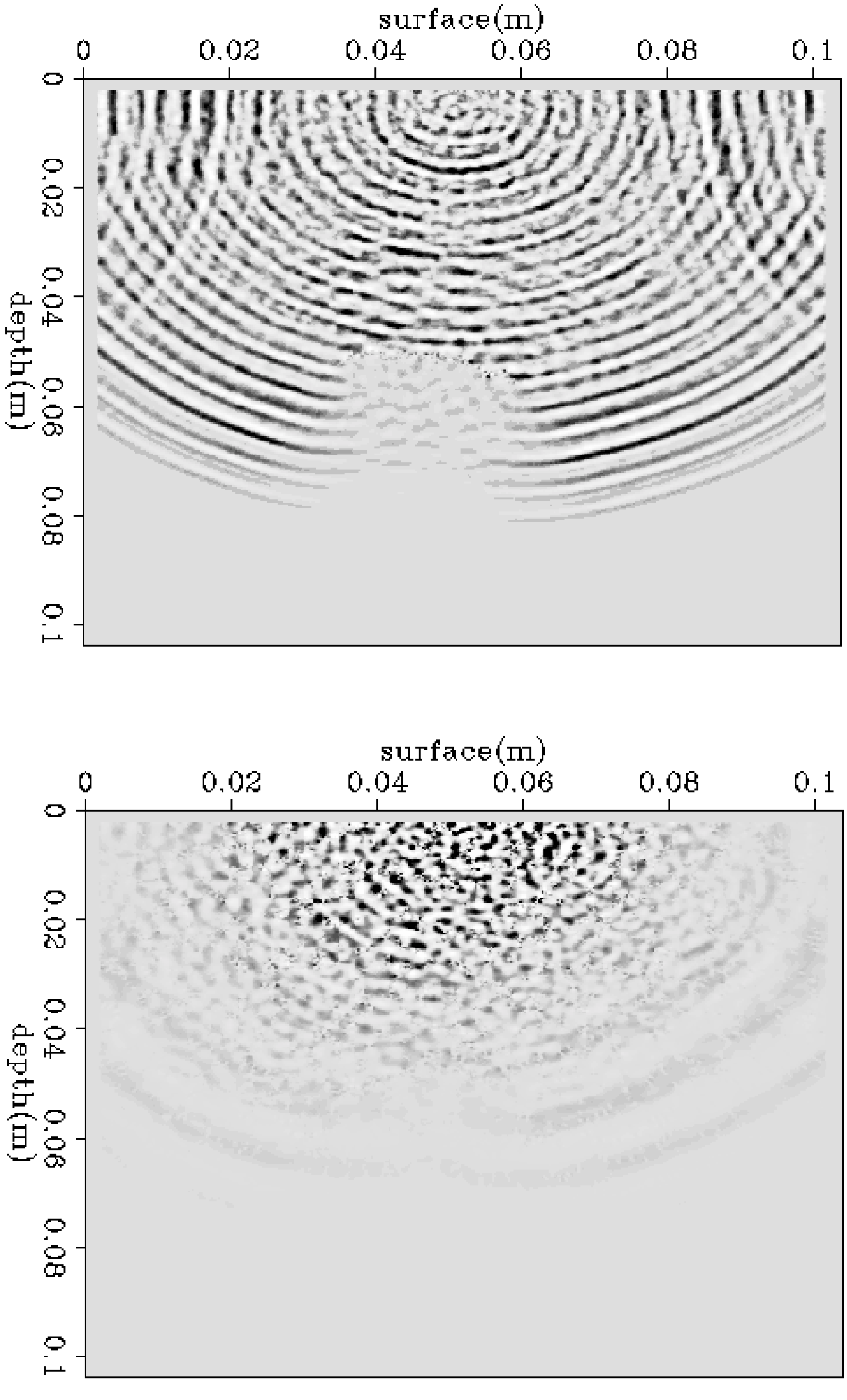

Fig. 3: *Top:* *Snapshot of the wave propagating through concrete without any air-inclusions.*

Bottom: *Concrete with 4% air inclusions, causing scattering of the waves and attenuation of high frequencies.*

3. INTERPRETATION

The output of the finite-difference-program allows several possibilities of interpreting the simulations. First there is to mention the visualization of the wave propagating through the model with so called snapshots. Second there is the possibility to get the output of horizontal receiverlines. These datasets can be divided into B-Scans and A-Scans.

Snapshots of the propagating elastic wave inside the concrete are explaining the different behaviour of the wave in concrete with and without air inclusions. The higher the percentage of air inhomogenities, the more scattering and mode conversion of the wave leads to energy losses of the primary wave. The informations about air inclusions and flaws are shifted into the coda of the wave. This causes significant problems to extract and analyse them. The scattering of the stuffing material is of low order compared to the described effect, (Fig 3 and Fig. 4).

In the snapshots it can also be seen, that lower frequencies propagate through the concrete with air inclusions without getting scattered. Only wavelengths that have the size of the air inclusions are attenuated by scattering. Their energy concentrates in the upper part of the model. The lower frequencies can be used to detect the flaw. If a model with bigger sizes of air-ellipses would be used, these low frequencies would also be attenuated. The information about the flaw is hidden as soon as the size of the air ellipses tends to be of the size of the flaw.

In the following simulations one receiverline is placed on top of the model, which records the A-Scans and B-Scans of pointlike receivers. In order to get an A-Scan of a commercial transducer, all A-Scans in between the diameter of the receiver (2 cm), has to be averaged.

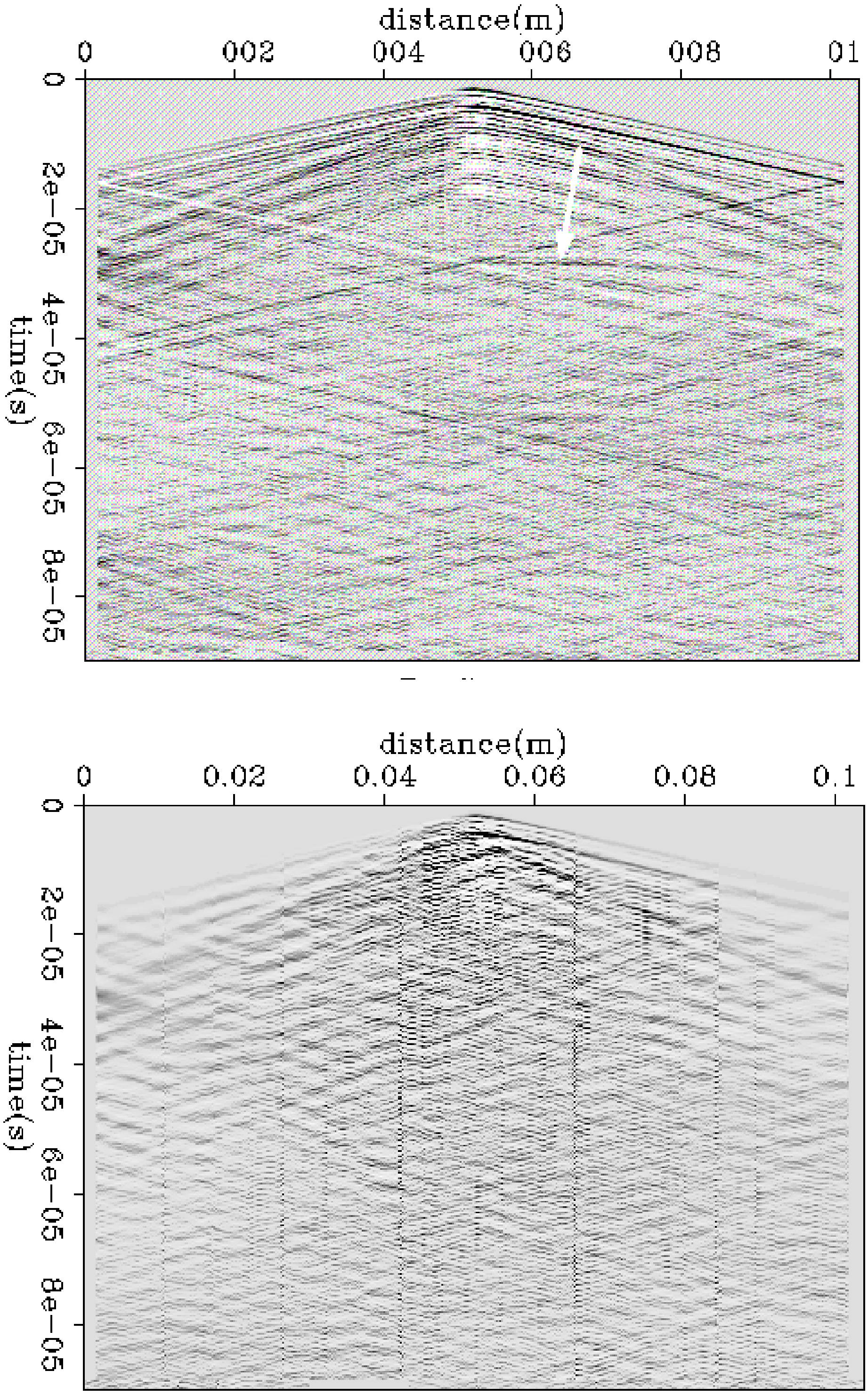

Fig. 4: *B-Scan's taken from a receiverline at the top of the model.*

Top: Concrete without any air inclusions. The reflection hyperbola is detected after 30µs, (white arrow).

Bottom: Concrete with 4% air inclusions, no reflection hyperbola can be seen.

This stack influences the quality of the data because the waves scattered at the air inclusions (<< 2 cm) are eliminated out of the data by this averaging procedure. Only the coherent wavefield is detected considering a receiver with a diameter bigger than the correlation length of the scattering objects [Ishimaru,1987]. In other words: A pointlike receiver doesn't detect the flaw as well as a receiver that has the length of the flaw (see Fig. 5).

Looking at the B-Scans it's obvious, that the influences of size-effects in simple shaped models (like the quadratic example) are also of low order. The reflection hyperbola of the flaw can be well seen in the concrete with 0% air inclusions. The waves propagating along the edges cross the hyperbola sometimes, but there is less noise than in the examples with air inclusions (Fig. 4).

Fig. 5 and Fig. 6 explain the possibility to detect a flaw in concrete with different percentages of air inclusions using only one A-Scan of a commercial receiver. With rising percentage of air inhomogenities, the energy of the transmitted signal decreases, it gets attenuated and the reflection of the flaw gets superimposed by the coherent noise of the scattering.

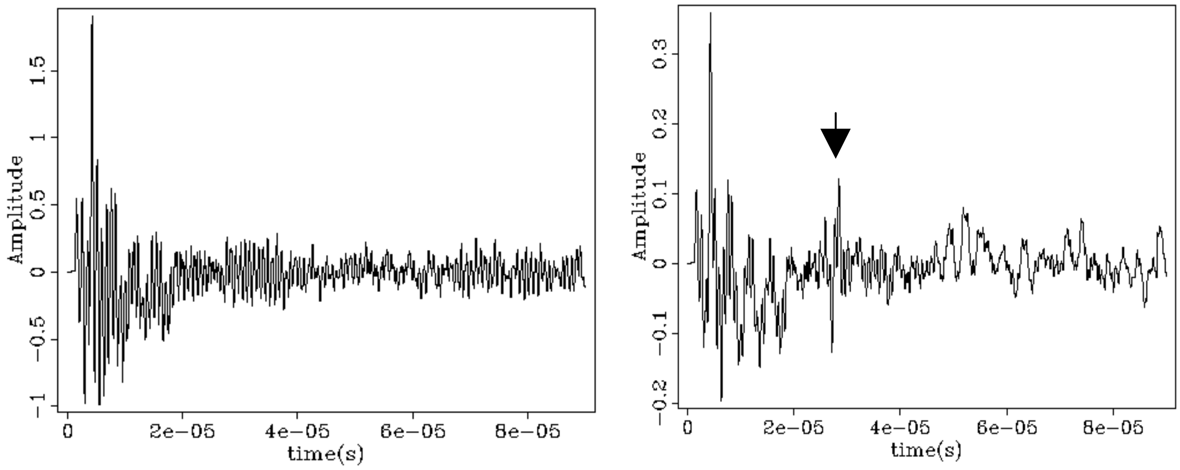

Fig. 5: *Both A-Scans were taken from the simulations investigating concrete without air inclusions. Left: A-Scan of a pointlike receiver. Right: Several pointlike receivers in-between the diameter of 2 cm were averaged. The reflection of the flaw can be detected after 30 μs.*

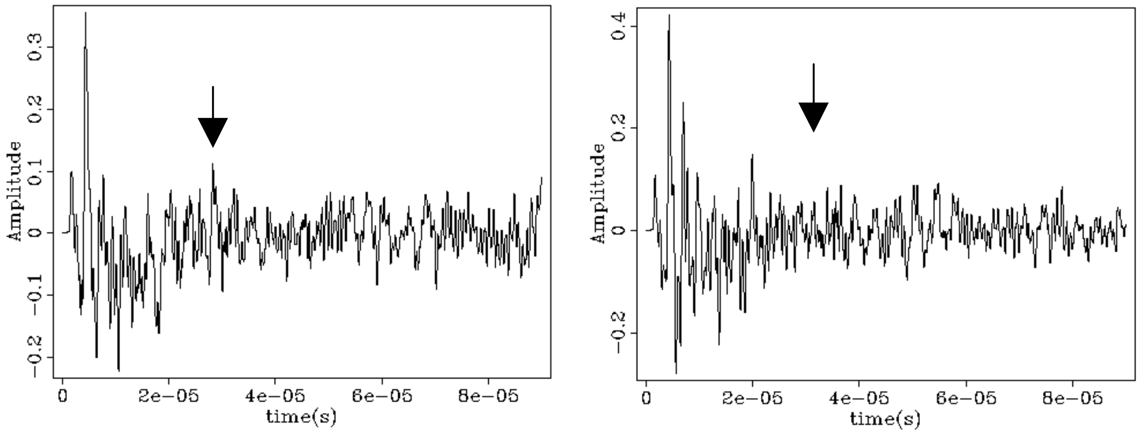

Fig. 6: *Left: A-Scan of a receiver with 2 cm diameter, obtained on the top of a concrete model with 2% air inclusions. Right: 4% air inclusions. Thereflection of the flaw at 30μs gets superimposed by scattering effects of the smaller air inclusions.*

4. CONCLUSIONS

The finite-difference-program and the medium program are two powerful tools to simulate the elastic wave-propagation in concrete. So there is the possibility to get more information about the behaviour of the wave inside different kind of concrete and with various kind of source wavelets. Additionally there is the ability to estimate the different influences on the wave. Those influences are for instance due to size effects when using other kind of surfaces and shapes of the concrete block.

The investigated B-Scans can be used to invert the data. With the help of this method informations are extracted out of the data about the structure of the examined model, (see also the article "Application of a modified SAFT-algorithm on synthetic B-scans of coarse grained materials" in this journal). The described algorithms are also implemented to test inversion-algorithms. Their applicability in coarse grained materials and the imaging quality of the programs using data with different signal to noise ratio can be tested comparing the output "image" with the input medium of the FD-program presented in this paper.

Future enhancements are the compilation of the FD-program on the new supercomputers CRAY T3E/512 and NEC SX-4/32 of the University of Stuttgart in order to cope with bigger 2D-models and to perform 3D-simulations.

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