LAYER THICKNESS DETERMINATION OF POLYMER CONCRETE

SCHICHTDICKENBESTIMMUNG AN POLYMER BETON

DETERMINER LA GROSSEUR D'UNE COUCHE DE BETON POLYMERE

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SUMMARY

The intention of the work described in this article is to determine the thickness of a layer of 4 cm polymer concrete which covers a concrete cube of 15 cm edgelength. For this purpose electromagnetical (Ground Penetrating Radar) and acoustic echo techniques were used. The results show that only the Impulse-Echo technique was able to identify the thickness of the polymer concrete layer. If the target thickness of the layer is known, the Impulse-Echo technique can be adjusted to that thickness. This is also shown here.

ZUSAMMENFASSUNG

Ziel der in diesem Artikel beschriebenen Untersuchungen war die Schichtdickenbestimmung einer 4 cm dicken Lage aus Polymer Beton, die auf einen Betonwürfel (15 cm Kantenlänge) aufgebracht wurde. Hierfür kam Bodenradar als elektromagnetisches Verfahren sowie akustische Echo Verfahren zum Einsatz. Die Ergebnisse zeigten, dass nur mit dem Impuls-Echo Verfahren die Dicke der Schicht aus Polymer Beton bestimmt werden konnte. Bei vorheriger Kenntnis der Soll-Dicke einer solchen Lage, kann das Impuls Echo Verfahren auf diese Dicke „geeicht" werden. Dieser Ansatz wird ebenfalls vorgestellt.

RESUME

L'objectif des investigations qui ont décrient dans ce article était la détermination de la grosseur d'une couche de béton polymère. Cette couche de béton polymère a une grosseur de 4 cm et est situé sur un cube de béton avec un longueur des arêtes de 15 cm. Les méthodes utiliser était le Ground Penetrating Radar, la méthode Impact-Echo et la méthode Impulse-Echo. Seulement avec la méthode Impulse-Echo il était possible de déterminer la grosseur de la couche de béton polymère. Une approche est présenter pour déterminer la grosseur d'une couche quand on connaît une grosseur a valeur de référence.

KEYWORDS: Polymer Concrete, Impulse Echo, Impact Echo, Georadar, Layer Thickness

1. INTRODUCTION

Layer thickness determination in solid bodies is a challenge in different scientific areas. Example applications range from the macro scale e.g. in exploration geophysics to the micro-scale e.g. in construction materials. However, the physical principle of layer thickness determination is similar at all scales. Using electromagnetic or elastic waves, it is possible to determine the thickness of a layer by the reflected waves from the boundary between two layers.

Here, the investigated test specimen consists of a concrete cube (15 cm edge length) with a 4 cm thick polymer concrete layer on top. A detailed description of the specimen will be given in the next section. Different methods were applied for layer thickness determination. These techniques will be discussed in the next but one paragraph.

2. TEST SPECIMEN

The test specimen is a concrete cube of 15 cm edge length covered by a layer of polymer concrete which has a thickness of 4 cm. A photo and a schematic diagram are shown in Fig. 1. The sound velocities of the two materials were estimated using the traveltime of ultrasonic waves through each layer. The concrete has a velocity of approximately 4000 m/s and the polymer concrete a velocity of 3500 m/s.

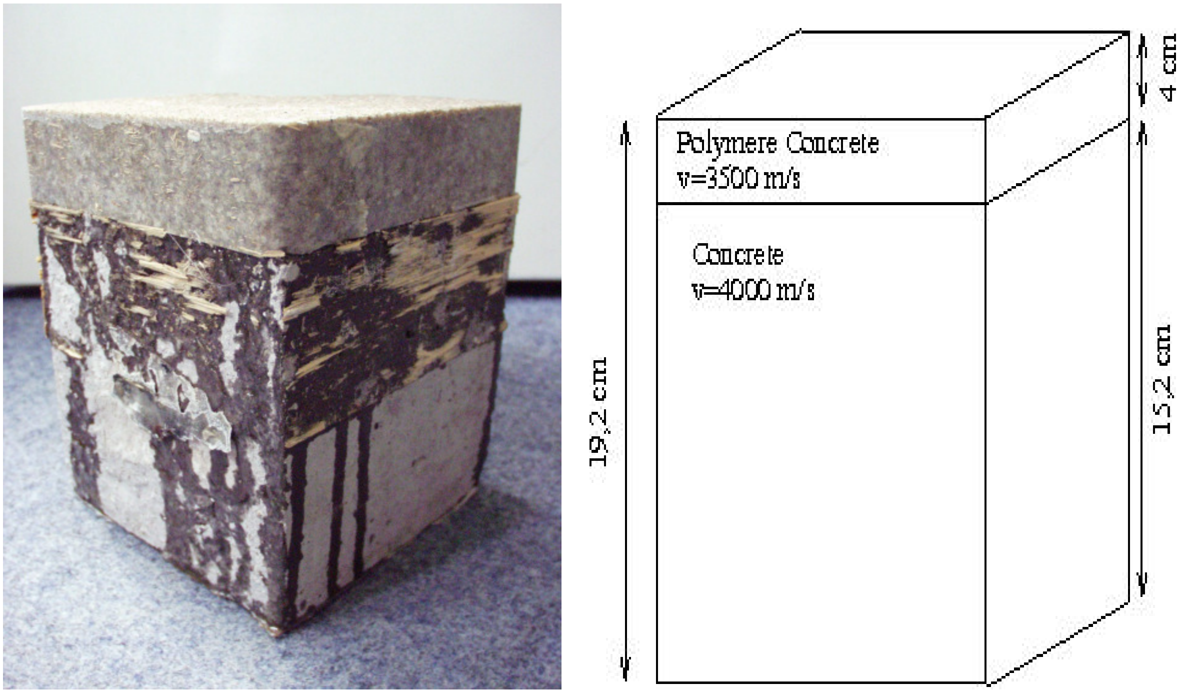

Fig. 1: Picture and scheme of the test specimen

The densities of the two materials do not differ significantly since only the matrix material is different. The determined velocities are also relatively close to each other. Therefore, the impedance contrast between the layers is expected to be small.

The task regarding this test specimen is if it is possible to determine the thickness of the polymer concrete layer despite the low impedance contrast of the two materials. Several methods which will be described in the following were tested.

3. APPLIED METHODS

The velocity measurements showed that the impedance contrast of the two materials of the specimen (concrete and polymer concrete) is not very high. This is not surprising, since only the matrix material of the two materials is different. However, the low impedance contrast is a problem for the non-destructive evaluation of the thickness of the polymere concrete layer. Several methods were applied because it was not clear in advance which one might be successful.

3.1 Ground Penetrating Radar

Finck [1] and Beutel et al. [2] showed that this electromagnetic method is able to detect structures within concrete and it is also often used for geophysical near surface investigation e.g. for groundwater aquifer detection. However, the georadar principle only works if the relative dielectricities of the investigated materials are significantly different from each other. The results showed that this is obviously not the case and therefore, the layer boundary could not be detected.

3.2 Impact-Echo

The principle of the Impact-Echo technique is to generate elastic waves by a mechanical impact. This generates ultrasonic waves and audible sound waves. The generated P- and S-Waves travel through the medium and are reflected back and forth between the layers or inhomogenities in the material. The broad frequency spectrum generated by the impact generally activates resonance frequencies of the structure or specimen. Recording the elastic waves e.g. with accelerometers and transforming the digitized signal in the frequency domain, the resonance frequencies of the structure or specimen can be identified. With the velocity of the material v and the determined resonance frequency f the thickness d of the specimen can be calculated by:

$$d = \frac{v}{2f} \qquad (1)$$

A detailed description of the Impact-Echo method and technical details about the usable impacts can be found in [3] and [4].

Concering the polymer concrete – concrete specimen described in the last section the resonance frequencies corresponding to the layer thickness are expected. Several measurements using different impactors and sensors were made.

3.3 Impulse-Echo

The principle of the Impulse-Echo technique is identical to Impact-Echo. However, the source is different. As the name already indicates the source is an ultrasonic impulse. Herefore, an ultrasonic transmitter and a receiver are placed on the same side of the test sample (on top or at bottom). The layer boundaries or inhomogenities reflect the ultrasonic signal and an additional signal is generated.

In our application several measurements from the top and the bottom of the test specimen were made.

4. RESULTS

The time series of two Impulse-Echo measurements are shown in Fig. 2 and Fig. 3. In the first case (Fig. 2) the sensors were placed on top of the specimen (7 cm distance between the sensors) i.e., on the layer of polymer concrete. The second case (Fig. 3) shows the results with sensors placed on the underside of the specimen. The arrival times of the reflected signal from the layer boundary can easily be calculated from the layer thickness and the measured velocities. These calculated reflection times are marked as vertical lines in the time series.

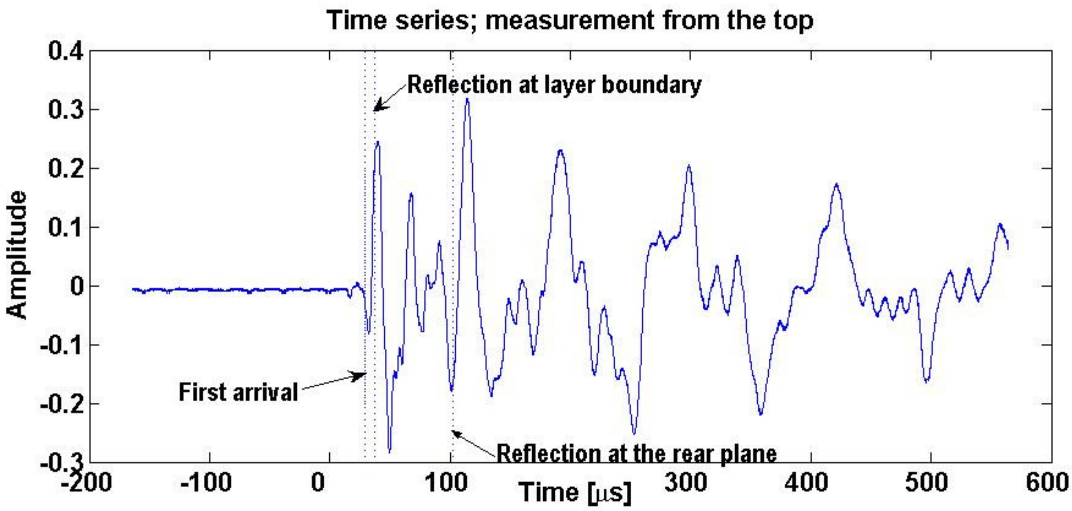

Fig. 2: Time series of a measurement done with transmitter and receiver placed on the top of the test sample.

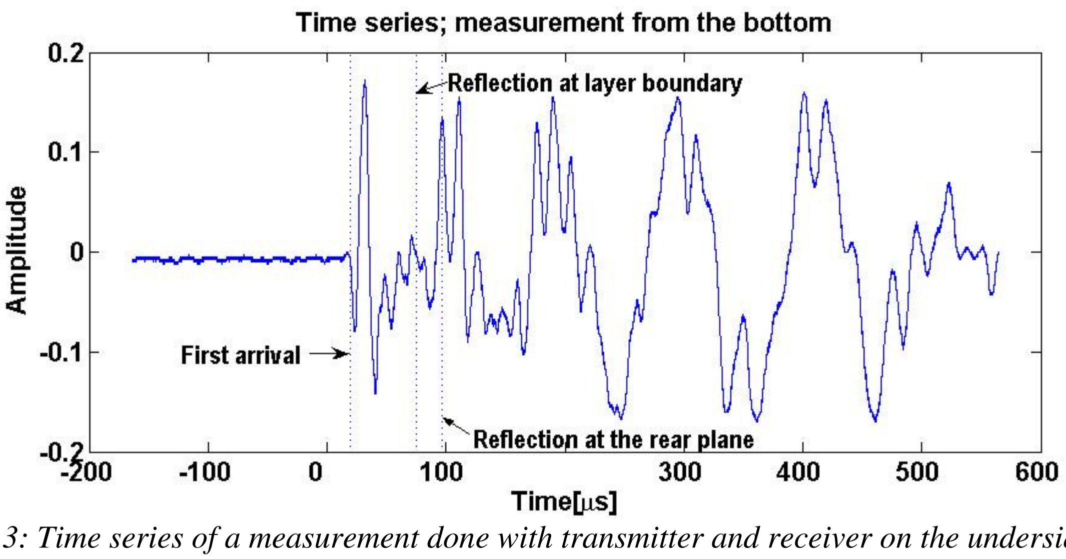

Fig. 3: Time series of a measurement done with transmitter and receiver on the underside of the test sample.

Neither in the measurements from the top (Fig. 2) nor from the bottom (Fig. 3), the echo from the layer boundary between concrete and polymer concrete is clearly identifiable. However, the reflection from the rear plane of the specimen is clearly detectable.

Analyzing the resonance frequencies of the specimen as described for the Impact-Echo method the recorded time series from the Impulse-Echo measurements were transformed to the frequency domain. Fig. 4 and Fig. 5 show the mean of all amplitude- and power-spectra calculated from the measurements. It is distinguished between the measurements from top (Fig. 4) and from the lower side (Fig. 5) of the specimen.

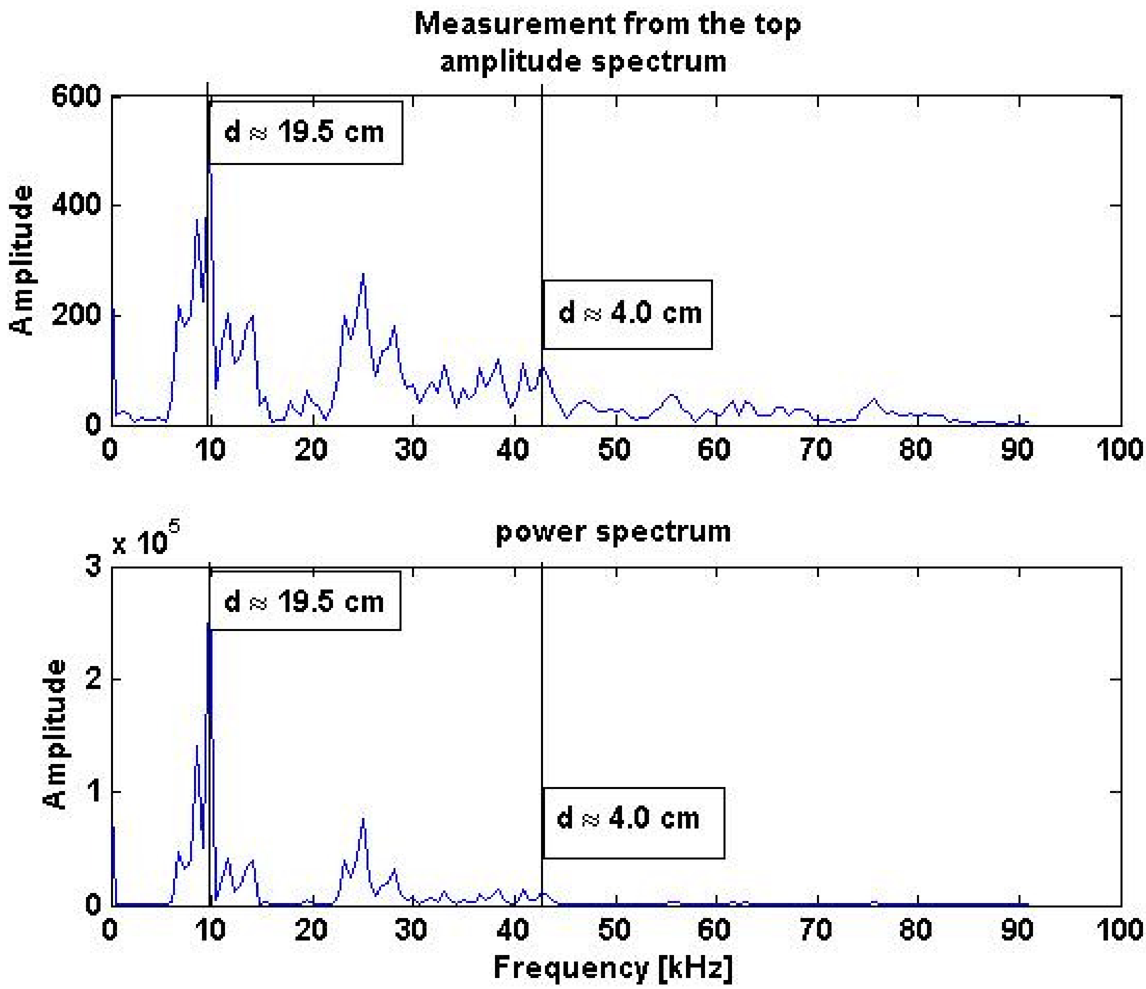

Fig. 4: Mean amplitude and power spectrum of the measurements done from the top of the test specimen. The resonance frequencies of the whole specimen and the polymer concrete layer are marked by vertical lines.

All calculated spectra show the echo from the back side of the specimen at approx. 10 kHz. Using Equ. 1 the thickness of the whole specimen can be calculated. The measured thickness is 19.2 cm and the calculated 19.5 cm.

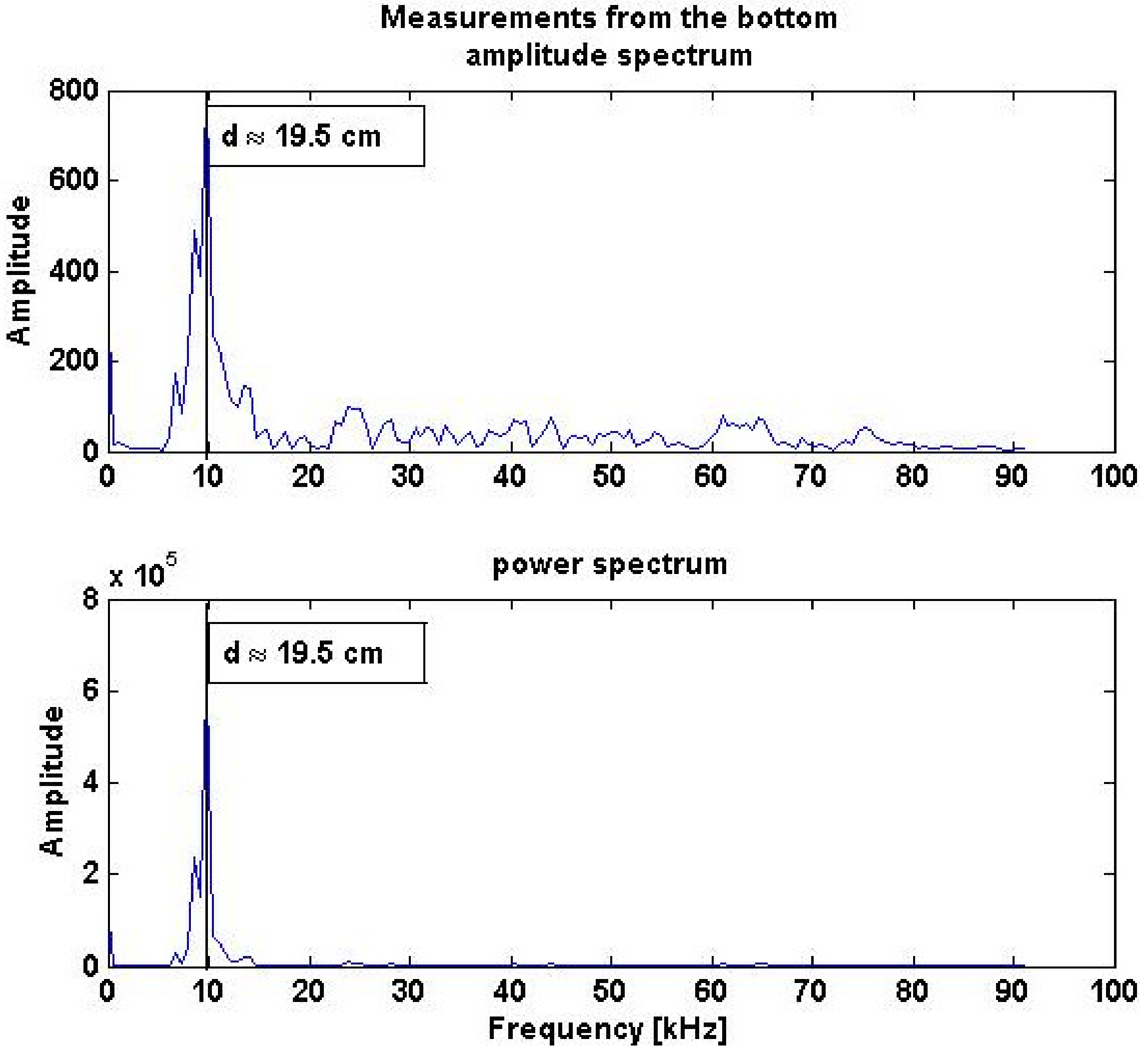

Fig. 5: Mean amplitude and power spectrum of the measurements done from the lower side of the test specimen. The resonance frequencies of the whole specimen is marked by a vertical line.

The theoretical resonance frequency of the polymer concrete layer is about 43 kHz. Looking at the spectra measured from top of the specimen (Fig. 4) a weak resonance can be found at 43 kHz in the amplitude and power spectra. This resonance is not identifiable in the spectra calculated from the measurements from the lower side of the specimen.

The geometry of the specimen is definitely not ideal for detecting a thin layer with the Impact-Echo method which is created for analysing large specimen. The layered specimen used here, is relative small. Therefore, many reflections from the edges of the block disturb the analysis. Another problem is, that for the detection of the layer boundary in 4 cm depth an impact is required which generates high frequency signals. Three different impacts and two different sensors were used for the measurements. The spectra of the recorded signals are shown in Fig. 6. The lowermost graph presents a spectrum from the Impulse-Echo measurements for comparison.

It has to be stated at first, that there is not much energy transfered beyond 28 kHz in all shown impact echo measurements (Fig. 6). Therefore, the expected resonance of the layer of polymer concrete at about 43 kHz is not detectable.

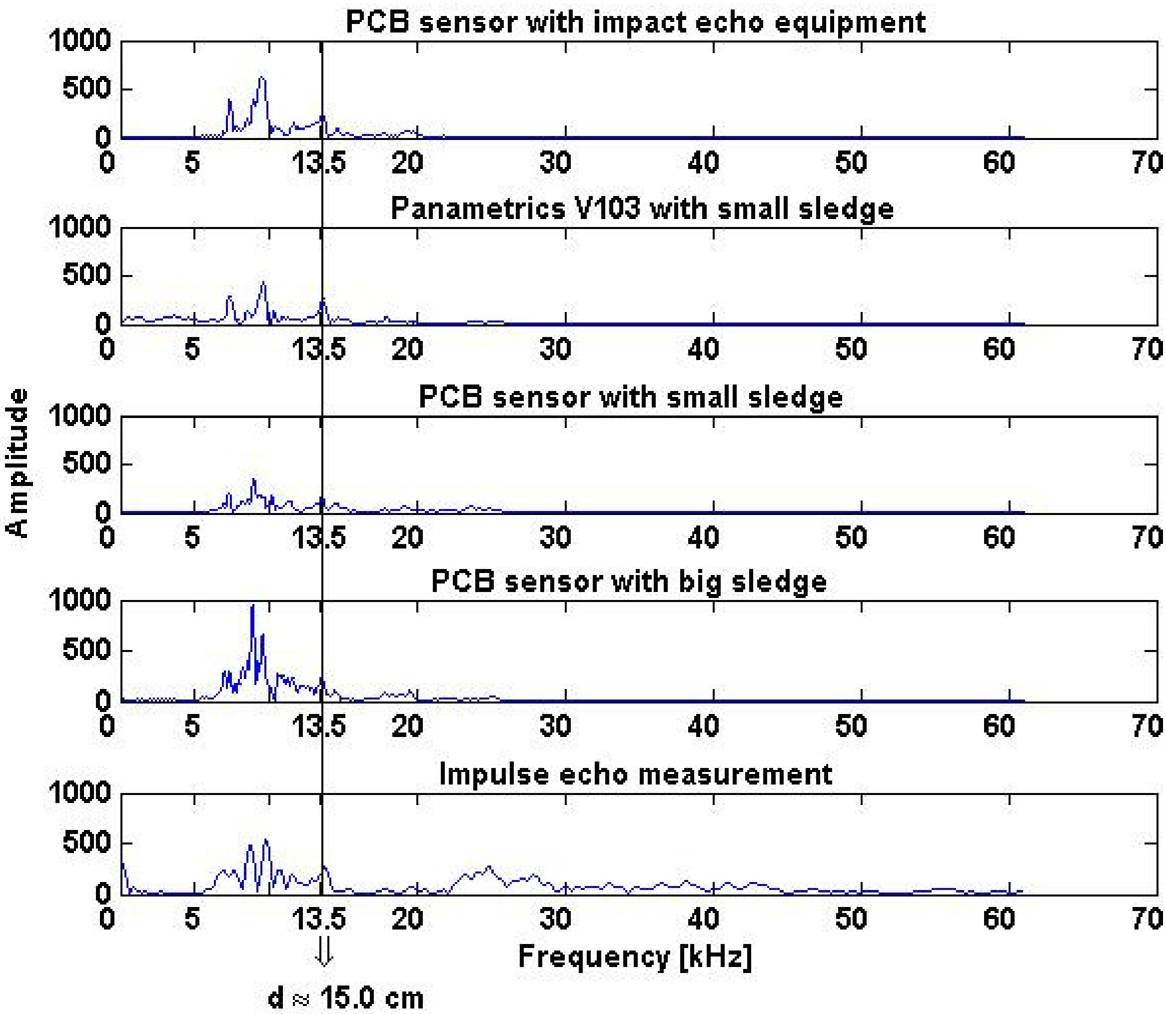

Fig. 6: Amplitude Spectra of the different impact echo measurements, using different impacts and sensors and for comparison one impulse echo measurement.

However, the consistent peak at about 10 kHz is the resonance from the back side of the specimen. The spectra of the Impact-Echo measurements show further resonance peaks. One is at about 13.5 kHz which corresponds to a thickness of 15 cm. This resonance frequency is also observable in the results of the Impulse-Echo measurements. The concrete cube of this compound specimen has a thickness of 15 cm.

Due to the question if the measured 13.5 kHz is a resonance frequency of the concrete cube, further investigations using a LMS PIMENTO MODAL ANALYSIS soft- and hardware were performed. These measurements showed that the 13.5 kHz correspond to the concrete cube. Furthermore, this resonance frequency was clearly identifiable and of equal strength on all components of the triaxial modal analysis sensor. This fact leads to the interpretation of these results that the 13.5 kHz resonace frequency belongs solely to the concrete cube and reflects the isotropic dilatation of the concrete layer. This behaviour is strongly related to the high symmetrical geometry and a spacious material isotropy.

DISCUSSION AND CONCLUSION

The relative dielectricities and the acoustic impedance between concrete and polymer concrete are very small. Most of the electromagnetical and acoustical energy is transmitted and only a small part is reflected. Therefore, the determination of the thickness of the relative small polymer concrete layer was difficult. The Ground Penetrating Radar measurements lead to no results.

The Impulse-Echo measurements lead to better results than the GPR application. However, it was not easy to determine the thickness of the polymer concrete. The polymer concrete layer is thin compared to the concrete cube. The reflection from the boundary of the two layers is hidden in the direct arrival of the elastic wave (measuring from top of the specimen) or in the reflections from the edges of the block (measuring from the underside). Therefore, it is impossible to identify the layer thickness in the time domain.

In the frequency domain the resonance frequencies are used for calculating the thickness of a layer or the whole specimen. The resonance frequency of the whole block can be clearly identified at approx. 10 kHz. This corresponds to a thickness of 19.5 cm. Considering the coarse values for the velocities the assumed thickness of 19.2 cm is well hit.

A layer of 4 cm thickness would create a resonance at approx. 43 kHz. In the measurements from top of the specimen a small peak at 43 kHz is observable. This peak can not be seen in the spectra from the measurements from the lower side of the specimen. The reflected energy is too small and the signals vanishe within the noise due to scattering and attenuation on the way back through the concrete. The weak resonance peak at 43 kHz gained from the measurements from top of the specimen can be amplified. Herefore, the signal can be filterd with a narrowband filter. However, it might not always be possible to get a stable filter. If the expected thickness of the investigated layer is known, the frequency coefficients outside the narrow band of interest can be set to zero. Then the measurements along several lines on a plate can be compared and areas with no resonance peak easily identified.

With the Impact-Echo measurements it was not possible to find the layer of 4 cm. Only the resonance frequency of the whole specimen could be clearly identified.

With the Impact-Echo measurements it was not possible to find the layer of 4 cm. Only the resonance frequency of the whole specimen could be identified. The detected 13.5 kHz resonance frequency of the concrete cube measured as well as with Impact-Echo and the modal analysis is a pure geometric effect. This resonance occurs only due to the cubic geometry (highly symmetric) and the isotropic material behaviour of the concrete. This effect cannot be used in general for any thickness determination.

If the layer thickness is unknown, it is not easy to find it with the methods described here. But if we know a reference thickness it should be possible to develop a technique to find out if the layer has the expected thickness.

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