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Detection of crack in a concrete element by impact-echo method

Z. Hlavač

Dept. of Building Testing, Faculty of Civil Engineering, Brno University of Technology,
Veveri 95, Brno 602 00, Czech Republic
Telephone: +420541147815
E-mail: hlavac.z@fce.vutbr.cz

Abstract

Demonstrative experiment was done to verify ability of the impact-echo method to detect discontinuity, honeycombing or any defect in a concrete structure. Two beams of the length 7.5 m were investigated, the first one with an evident shear crack, the second one without visible deterioration. Observation confirmed assumptions and in the depth 2,0 m a discontinuity was detected.
Key words: Impact-echo method, concrete structure, crack detection.

Usage of impact-echo method

There are many ways of testing by impact-echo method. Due to the mechanical impact various oscillations are excited. Shear torsion and longitudinal impulse waves are transmitted through the element. Its dynamic characteristics, as modulus of elasticity or the Poisson's coefficient, can be determined by their analyses. Longitudinal waves are commonly used [1 – 3].

To excite exactly longitudinal oscillation of a concrete element, dynamic impact should be applied to its forehead in the direction of longitudinal axis. The object will change its shape in sufficiently high and various frequencies, here just length shall be changing. In the same direction the echo can be read. Due to the dimensions of investigated element, impact and reading device can be put either on both opposite sides of the element or both, impactor and echo-reader, must be on the same side of the element. Compatibility of these two positions was verified before the experiment. For investigation of discontinuities the second case is applied.

As impactor a hammer or any object which has its centre of gravity on the very end can be used. The impacting part must be hard and relatively heavy comparing to the body which shall be long and soft. Very often just balls of different diameters on a wire are used [1].

The reader of echo signal is a device transforming the mechanical (acoustical) signal into the electrical. Simplest transducer of the signal is a microphone. Additionally noise filter and an amplifier are used to clear the signal. Finally the electrical signal, composed from many minor a noises, discontinuous dots, is approximated by the Fast Fourier Transformation of different frequencies and amplitudes. This approximation is done by audio-software and can be further analysed. The visualization is given as i) time-series, ii) spectrum or iii) spectrogram.

i) Time series show immediate amplitude of the signal (in dB or in percents of the maximum amplitude) and how is it changing in the time (Fig 1).

ii) Spectrum of frequencies provides the amplitudes (actual or the highest) representing different frequencies (Fig 2).

iii) Spectrogram shows amplitudes of the signal in degrees of grey scale or in colour. Each point has its position on the frequency- and time axis. Therefore the spectrogram shows actual intensities of the signal within different frequencies versus time (Fig 3).

For this experiment a special made transducer and SpectraLAB software were used.

Basic theorem which enables to detect any cavity, crack or even steel bar and define its depth is [1]

$$d = \frac{v}{2f}, \tag{1}$$

where d is the depth of a discontinuity or length of the element; v is the wave velocity and f its frequency. This theorem assumes that the first natural frequency of longitudinal oscillation has just a half wave shape. This says that the wave length $\lambda = 2d$ and the period of oscillation $T = 2t$, where the time t is given by

$$t = \frac{1}{2f}. \tag{2}$$

Placing assumption (2) into the relationship for velocity $v = \frac{d}{t}$ gives Eq.1. In the case of a steel bar detection in Eq.1 and 2 instead of the multiplier 2 the multiplier 4 should be used because just half wave in the first natural oscillation is exploited.

From Fig. 1 is clear how does the signal (echo) look like after one short impact by a small steel hammer.

Detection of the crack

The first step to detect the crack was to find expected velocity. Two prisms of different concrete quality were taken for estimation of the impulse-transmit velocity in the concrete. Longitudinal dimensions and natural oscillations of the prisms were measured (Fig 2 or 3 for the first prism) to determine higher and lower velocity by Eq.1 (see Table 1), the mean value was calculated afterwards.

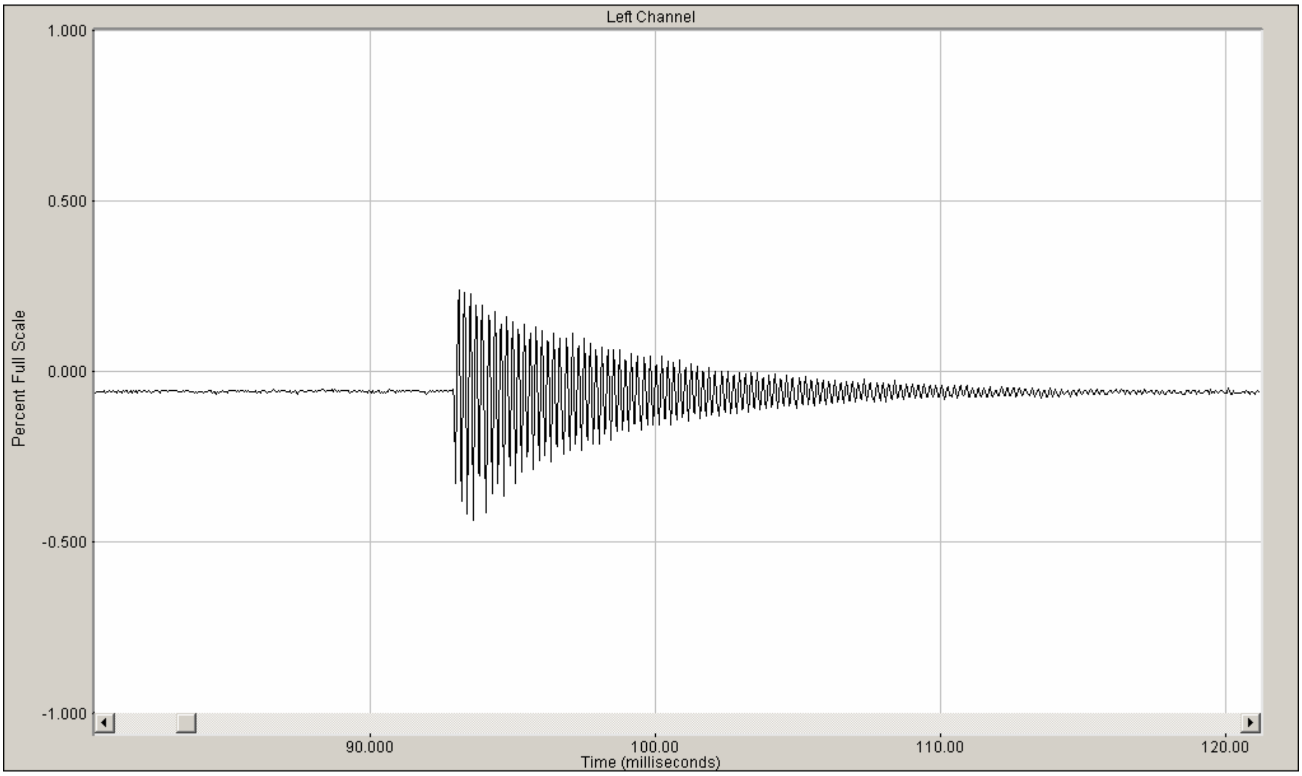

Fig 1. **Time series signal record during the whole duration of the echo after a short impact on the forehead of the first prism**

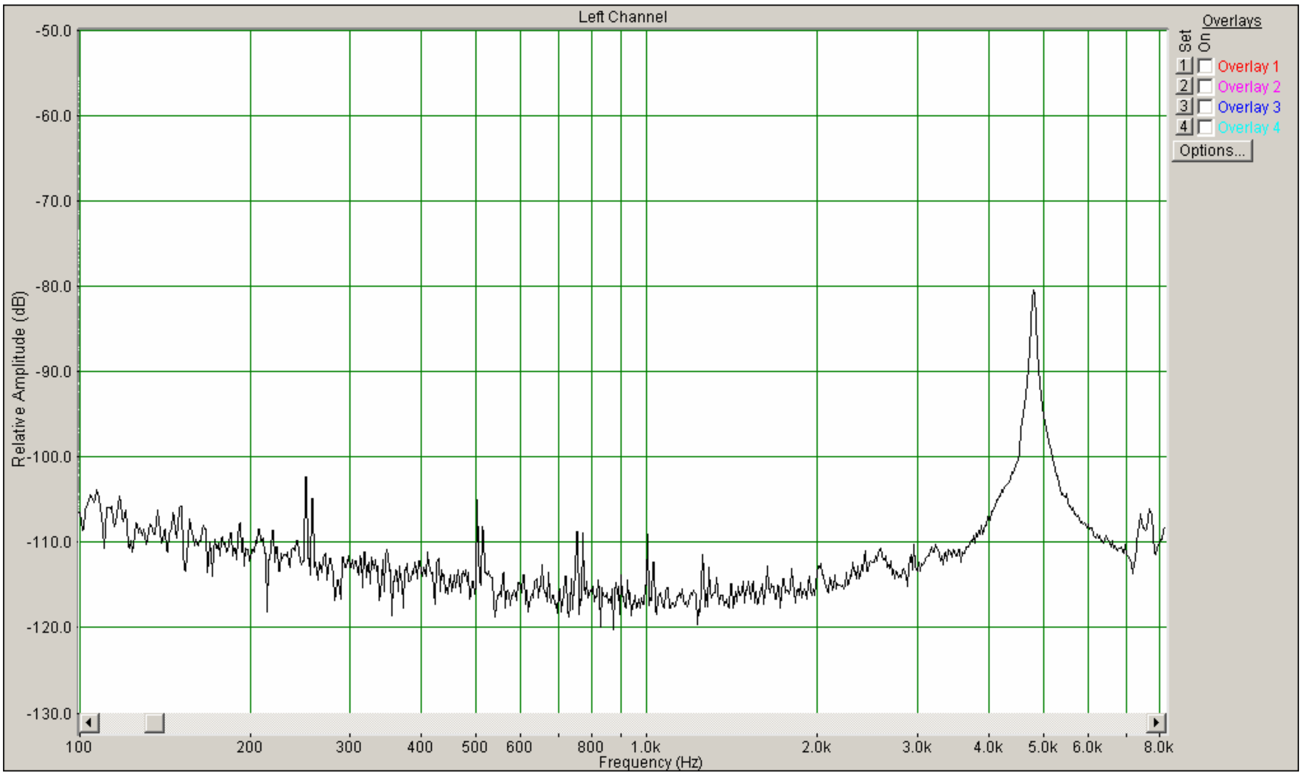

Fig 2. **Spectrum of the signal record of the highest echo imposed by a short impact on the forehead of the first prism**

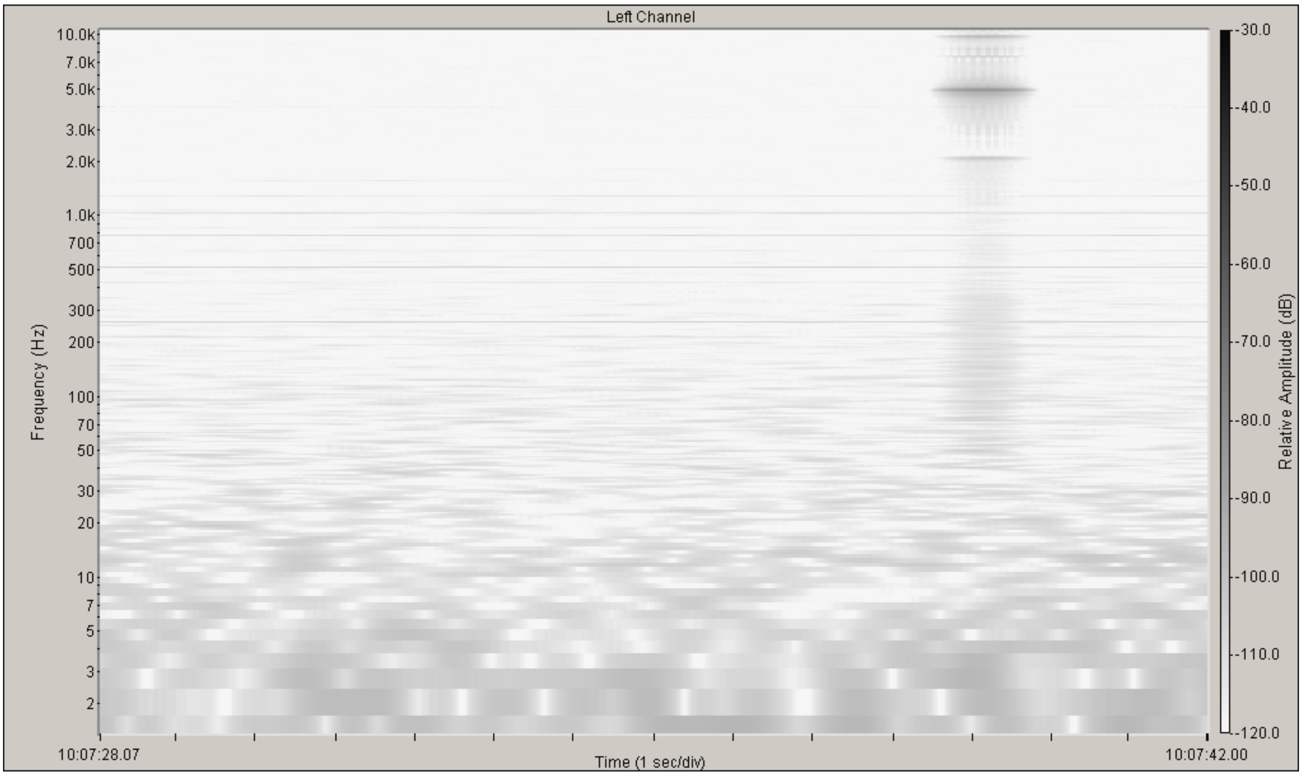

Fig 3. **Spectrogram signal record in wider circumstances with the echo of a short impact on the forehead of the first prism**

Second step was to measure the exact velocity in each element.

Two reinforced concrete beams with dimensions (300/600 x 560 x 7500) mm were investigated to determine whether there is a crack or not (see Fig 4 and 5 – measurement points are marked by black arrows). The quality of the concrete was unknown and therefore the impulse velocity had to be verified. The range of velocities was taken from Table 1, the width of each beam was measured in situ (Table 2) and the expected frequencies were obtained again by from Eq. 1. After estimation of the expected values, the natural longitudinal oscillations measured in the transversal direction of the beam could be found easily and the real velocities of the transmitted impulse were computed by Eq. 1.

The third step was to find the position of the expected crack or what is the length of the element if it is measurable.

The same procedure as in the second step was employed to estimate the basic frequencies. Higher and lower limits of the distance between the crack and the forehead of the beam were estimated and put into Eq. 1 with the mean value of the real velocity. In this step it was not easy to determine which frequency is really the basic one (measured by Spectrogram), because more reflections from the sides were present. Finally only two of four measurements, each at different measurement points, were successful (Table 3). Any detection of the length of about 7,5 meters was not supposed.

Table 1**. Estimation of sound velocity for two different types of concrete**

Element	Length [m]	Frequency [Hz]	Velocity [m/s] by Eq.1	Density [kg/m^3]
Prism 1	0,400	4881	3905	2280
Prism 2	0,400	5342	4274	2370
Mean value of velocity			**4090**	-

Fig 4. **Foreheads of the two tested beams**

Fig 5. **Tested beams in a longitudinal direction**

Table 2. **Determination of the velocity of a mechanical impulse transmission in two tested beams**

Element	Testing place	Velocity range by Table 1 [m/s]	Observed width [m]	For calculation Eq.1 is used		
				Expected range of frequencies [Hz]	Observed frequency [Hz]	Determined velocity [m/s]
Beam 1	M1	4100±200	0,40	5100±250	4895	3916
	M2		0,40		4888	3910
	M3		0,40		4923	3938
	M4		0,60	3400±170	3234	3881
	Mean value of velocity					***) 3910**
Beam 2	M5	4100±200	0,40	5100±250	4956	3965
	M6		0,40		4943	3954
	M7		0,40		4928	3942
	M8		0,60	3400±170	3258	3910
	Mean value of velocity					***) 3940**
*) Because of the very near values of impulse velocity in both beams mean value will be considered						

Table 3**. Determination of the crack depth in the first beam and the length of the second beam**

Element	Testing place	Range of the depth visual estimation [m]	For calculation Eq.1 is used		
			Expected frequency [Hz]	Observed frequency [Hz]	Determined depth [m]
Beam 1	T1	1,8 ÷ 2,2	890 ÷ 1090	1509	1,30
	T2			991	**1,97**
	T3			1380	1,42
	T4			943	**2,07**
Beam 2	T5	7,0 ÷ 8,0	245 ÷ 280	316	6,23
	T6			-	not detected
	T7			260	7,58
	T8			-	not detected

Conclusion

After the whole testing procedure which was necessary to find the sensitive frequencies, the crack was detected on the depth of about two meters. The length of the beam No. 2 was not simply detectable but at the measuring point T7 the correct echo was received.

This paper confirmed the ability of the impact-echo method of detecting discontinuities in concrete and its structures. Sensitivity of this method seems to be good however the difficultness of the testing is rather in the understanding of the method but not in the material or financial costs. Anyway, in this case, the investigated crack would be detectable with any other non-destructive detecting method (radar, ultrasonic pulse-echo, visual method).

Acknowledgement

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Z. Hlavač

Konkretaus elemento įtrūkio suradimas aido metodu

Reziumė

Buvo atliktas demonstracinis eksperimentas, kad galima būtų patikrinti galimybę konkrečioje struktūroje surasti nevienalytiškumą arba konkretų defektą aido metodu. Buvo stebimi du spinduliai, kurių ilgis 7,5 m. Pradžioje pirmas spindulys parodė signalo pablogėjimą dėl struktūros pokyčio, o kitas buvo be matomo pablogėjimo. Stebėjimas patvirtino, kad kontroliuojamos vietos struktūra yra pablogėjusi. 2,0 m gylyje buvo nustatytas defektas. Tyrimas parodė, kad nustatytas betono struktūrų defektą galima nustatyti aido metodu. Tai vienas iš galimų neardomųjų bandymų metodų.

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