NON-DESTRUCTIVE DIAGNOSTICS OF CONCRETE CANTILEVER BEAM AND SLAB BY IMPACT ECHO METHOD

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Summary
This paper focuses on the application of the impact-echo method for the full scale tests conducted on concrete bridge cantilever beams and a floor slab. The method uses the phenomenon of propagating waves induced by an impact and registered by one or two accelerometers. Experimental studies proved the applicability of the impact-echo method for damage detection in the considered concrete structural elements.

Keywords: ultrasonic testing, impact echo, concrete structures.

NIENISZCZĄCA DIAGNOSTYKA KONSTRUKCJI BETONOWYCH BELEK WSPORNIKOWYCH I PŁYTY STROPOWEJ ZA POMOCĄ METODY IMPACT ECHO

Streszczenie
Praca poświęcona jest zastosowaniu fal sprężystych na przykładzie w metody impact-echo. Metoda ta wykorzystuje zjawisko propagacji fal wzbudzanych przez mechaniczne uderzenie i ich pomiar za pomocą jednego lub dwóch akcelerometrów. Przeprowadzone testy eksperymentalne dla betonowych wsporników oraz stropu potwierdziły skuteczność metody w wykrywaniu uszkodzeń.

Słowa kluczowe: diagnostyka ultradźwiękowa, metoda impact-echo, konstrukcje betonowe.

1. INTRODUCTION

The so called destructive methods [1] are widely used for diagnostics of concrete structures. They require to extract a concrete sample from a structure and laboratory tests to evaluate material properties. They are considered to be very reliable. The non-destructive diagnostic methods, like ultrasonic techniques, can be performed on the structure under operation, providing quick estimation of concrete quality [2], [3], [4].

The impact-echo technique was developed in the 1980s. This method belongs to sonic/ultrasonic methods. The method is performed by impacting a structural element by a special hammer to generate elastic waves. Acceleration signals are recorded in the selected points on the element. Then the spectral analysis of the registered time-domain waveforms is carried out. The technique enables to determine the presence of the damage, its localization or it can be used for measurement of the element thickness.

In this paper, two applications of the impact-echo method are presented. In situ experimental studies were carried out on cantilever beams of a bridge and a concrete floor slab of the petrochemical machinery supporting structure.

2. PRINCIPLE OF IMPACT ECHO METHOD

Impact-echo is a method for non-destructive testing of concrete structures based on stress waves propagating through the structure and reflecting by potential flaws or structural boundaries. The stress wave is generated by a mechanical impact. Free concrete surface is stroke by a steel ball and the time signals (acceleration signals in this study) are registered at selected points.

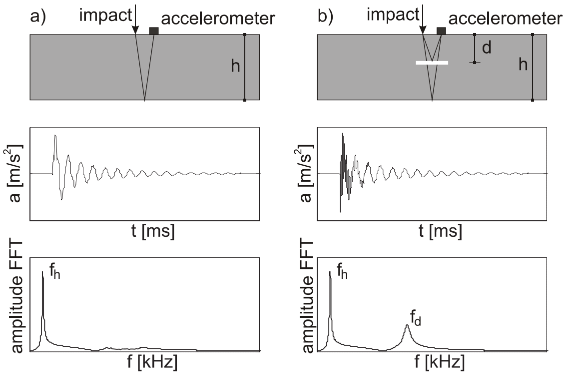


Fig. 1. Sketch showing principle of the impact echo method: a) intact structure; b) damaged structure

The principle of the impact-echo method is presented in Fig. 1. Due to the impact, a longitudinal wave (P-wave) and transverse wave (S-wave) propagate into the interior of the structure and a surface wave (R-wave) propagates along the surface. Damage detection procedure is based on the spectral analysis of registered time-domain waveforms. If an intact structure is considered (Fig. 1a), the waveform is dominated by sine wave of frequency f_h, called the thickness frequency:

$$f_h = \beta c_P / (2h)\,, \qquad (1)$$

where c_P is a P-wave speed, h is a plate thickness and β is a correction coefficient equals 0.96 for plates [1]. Considering the plate with an internal flaw (Fig. 1b), the low-amplitude, high-frequency oscillations appears in the time signal. In this case, the spectrum exhibits two amplitude peaks of thickness frequency f_h and frequency f_d connected with the reflection from damage:

$$f_d = \beta c_P / (2d)\,, \qquad (2)$$

where d is a defect depth.

3. DIAGNOSTICS ON CONCRETE CANTILEVER BEAMS OF THE BRIDGE

3.1. Research object and motivation

The object of the study is the road bridge (Fig. 2) in Nowy Dwór Gdański over the road no. 7 Gdańsk-Warsaw. During construction process the cantilevers of transverse beams were prestressed according to the plan (this state is referred here as 'state 0'). After prestressing process, cracks and cavities appeared on the cantilever surfaces (Fig. 3). Therefore repair operation was undertaken in the form of additional reinforcement and new gunite parts, but the cracks were not injected before gunite process. The aim of performed diagnostics was assessment of technical condition of cantilevers after repair (this state is referred here as 'state 1'). The impact-echo method was applied to non-destructive testing of the considered structure.

3.2. Field tests and results

The photo of data acquisition setup is presented in Fig. 4. The elastic waves were induced by a mechanical impactor in the form of a steel ball with a handle. The diameter of the impactor was 5 mm, what enables excitation of waves of frequency up to 58.2 kHz. The propagating signal was registered by two accelerometers (a_1 and a_2 in Fig. 4b) connected to the oscilloscope.

a)

b)

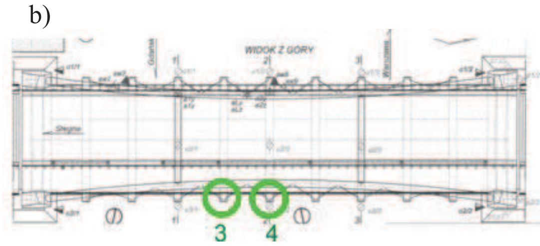


Fig. 2. The road bridge in Nowy Dwór Gdański: a) the photo ; b) top view

Fig. 3. Damaged cantilever no. 4 after prestresing

a)

b)

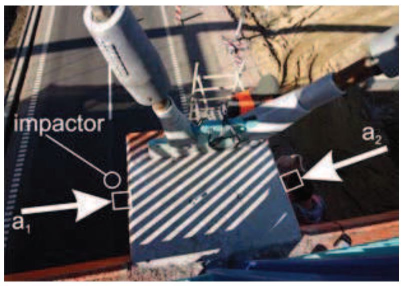


Fig. 4. Field tests: a) instrumentation setup; b) cantilever under examination

Measurements have been made on two cantilevers, no. 3 and no. 4, as indicated in Fig. 2b. Waves were generated on the left side of the cantilever, while the accelerations were measured on the left side as well as the right side (Fig. 4b). Measurements were performed at selected 59 points distributed on the cantilever surfaces. Location of measurement point is illustrated in Fig. 5. The distance of the wave travelling was constant for each point and equal to 0.986 m.

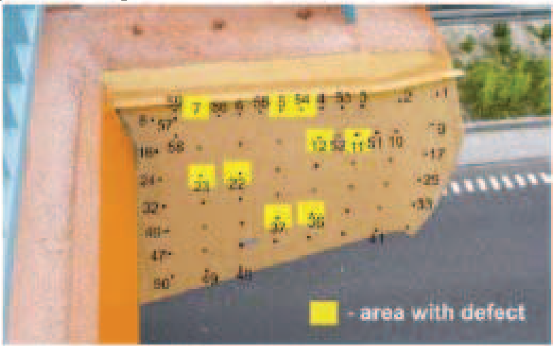


Fig. 5. Measurement points for cantilever no. 4 with marked damaged areas

To damage assessment of considered structure, velocities of propagating waves were applied. This can be done, because a wave in homogeneous material propagates faster and any flaws inside causes reduction in the wave speed. This approach was chosen, because the shape of the cantilever resembles a cube, therefore in spectrum domain reflections from the element boundaries could masks reflections form defects.

Fig. 6 shows signals registered in point no. 6 for the cantilever no. 3. The a_1 signal is the acceleration measured on the left side of the cantilever, while the a_2 is the acceleration measured on the right side, after passing through the structure. The time-of-flight t_h was 217.8 μs what enabled to calculate velocity of the P-wave as 4527.09 m/s. This procedure was repeated in all selected points.

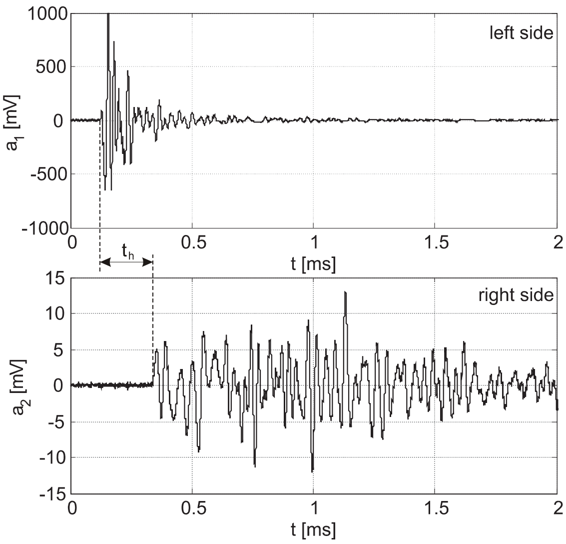


Fig. 6. Acceleration signals measured in point no. 6 for the cantilever no. 3

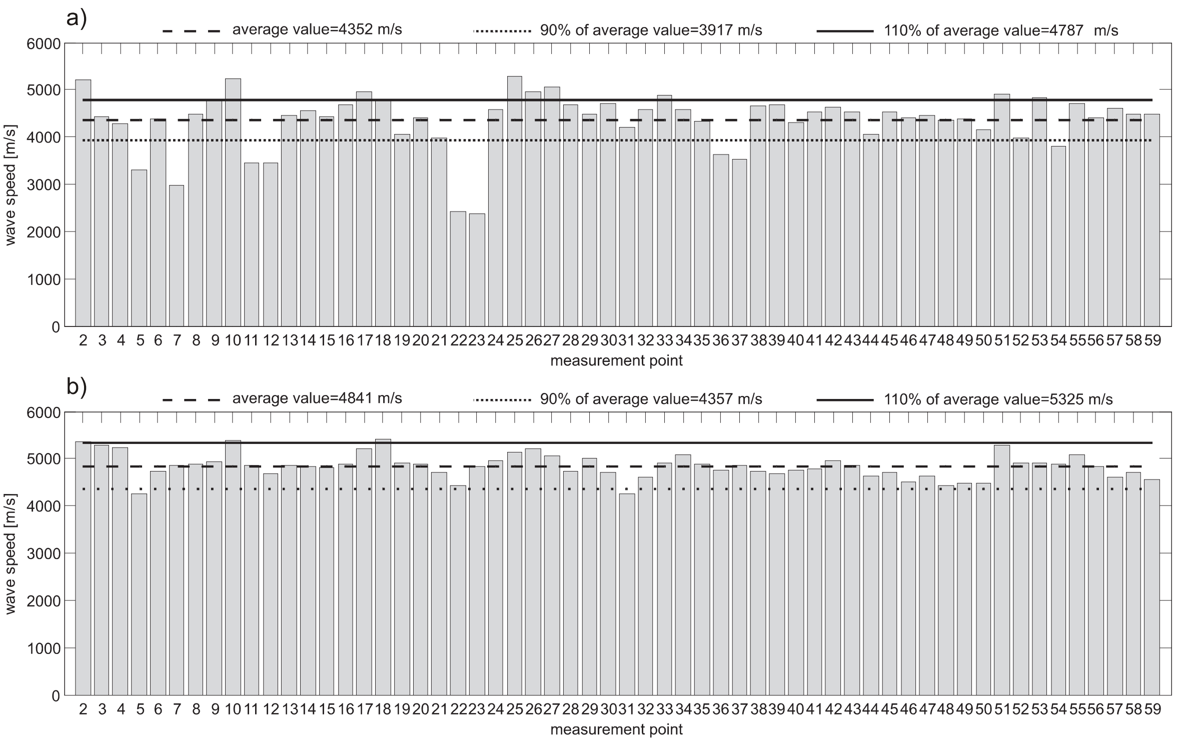


Fig. 7. Distribution of wave speeds in measurement points: a) cantilever at 'state 1'; b) cantilever after injection ('state 2')

As results, a map of distribution of wave speeds in 59 measurement points was plotted in Fig. 7a for the cantilever no. 4 at 'state 1'. The average value of P-wave speed in cantilever no. 4 was 4352 m/s. There are several points in which wave speeds are significantly smaller than average value. Points in which wave speed was smaller than 90% of average values were indicated as damaged areas (points 5, 7, 11, 12, 22, 23, 36, 37, 54). They are marked in Fig. 5 and they cover with localization of cracks observed at 'state 0' (c.f. Fig. 3).

In order to improve reliability and safety of the bridge, the injection of the epoxy resin was preformed. Both cantilevers were injected with about 5 liters of epoxy resin, and then ultrasonic testing was repeated. After injection the values of wave speeds considerably increased and the distribution of wave speeds became regular (Fig. 7b). In the cantilever no. 4 wave speeds hold in the range of 88% to 110% of the average values.

4. APPLICATION EXAMPLE ON CONCRETE FLOOR SLAB

4.1. Research object and motivation

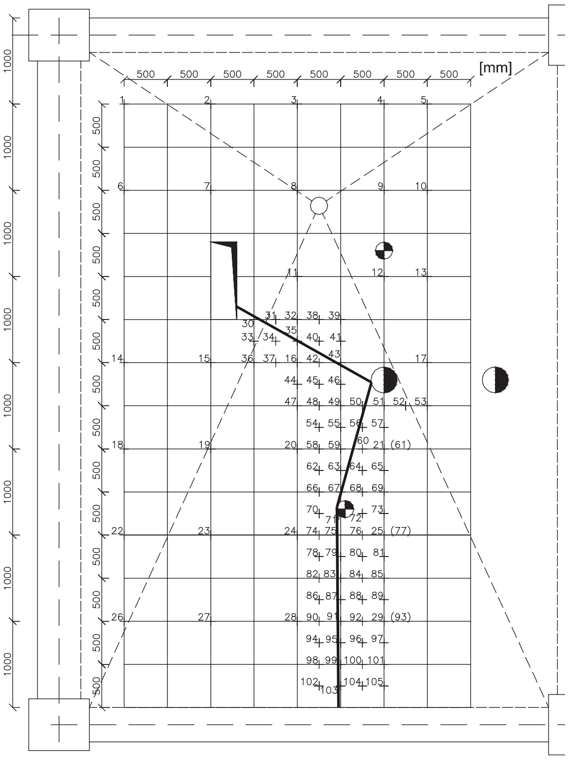
The object of the research was the concrete floor stab (Fig. 8). Due to disturbances in concrete delivery during the slab casting, the homogeneity of the concrete became in question. The non-destructive test was performed with the use of the impact-echo method to determine presence of discontinuities.

4.2. Field tests and results

The geometry of the slab is shown in Fig. 8a. The number of measurement points was 105. They were distributed along the line of potential discontinuity, depicted as thick solid line in Fig. 8a. The hardware equipment was the same, as in the case of bridge measurements (c.f. Section 3.2). In this experiment, one-side measurement was performed, i.e. both mechanical impact and acceleration measurements were realized on the upper side of the slab only. The slab height, varied from 17 to 19 cm, was calculated in the measurement points based in known slab slopes.

Data analysis was carried out in frequency domain by interpretation of spectra obtained from time domain signals. Fig. 9 shows example of signal registered in point no. 98. In the frequency domain, one distinct peak dominates of frequency 9.77 kHz, what is equivalent of the thickness frequency f_h. By knowing frequency and the slab height P-wave speed can be determined from Eq. (1). Distribution of wave speeds were relatively regular with all measured point and the average value was 4100 m/s.

a)



b)

Fig. 8. Concrete floor slab: a) geometry and measurement points; b) the photo

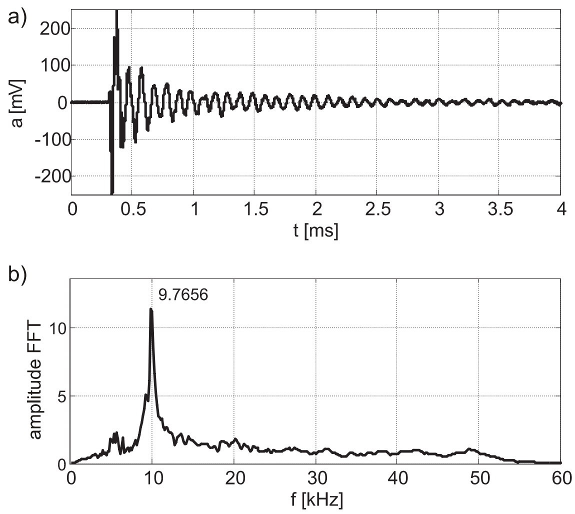


Fig. 9. Acceleration signals measured in point 98: a) in time domain; b) in frequency domain

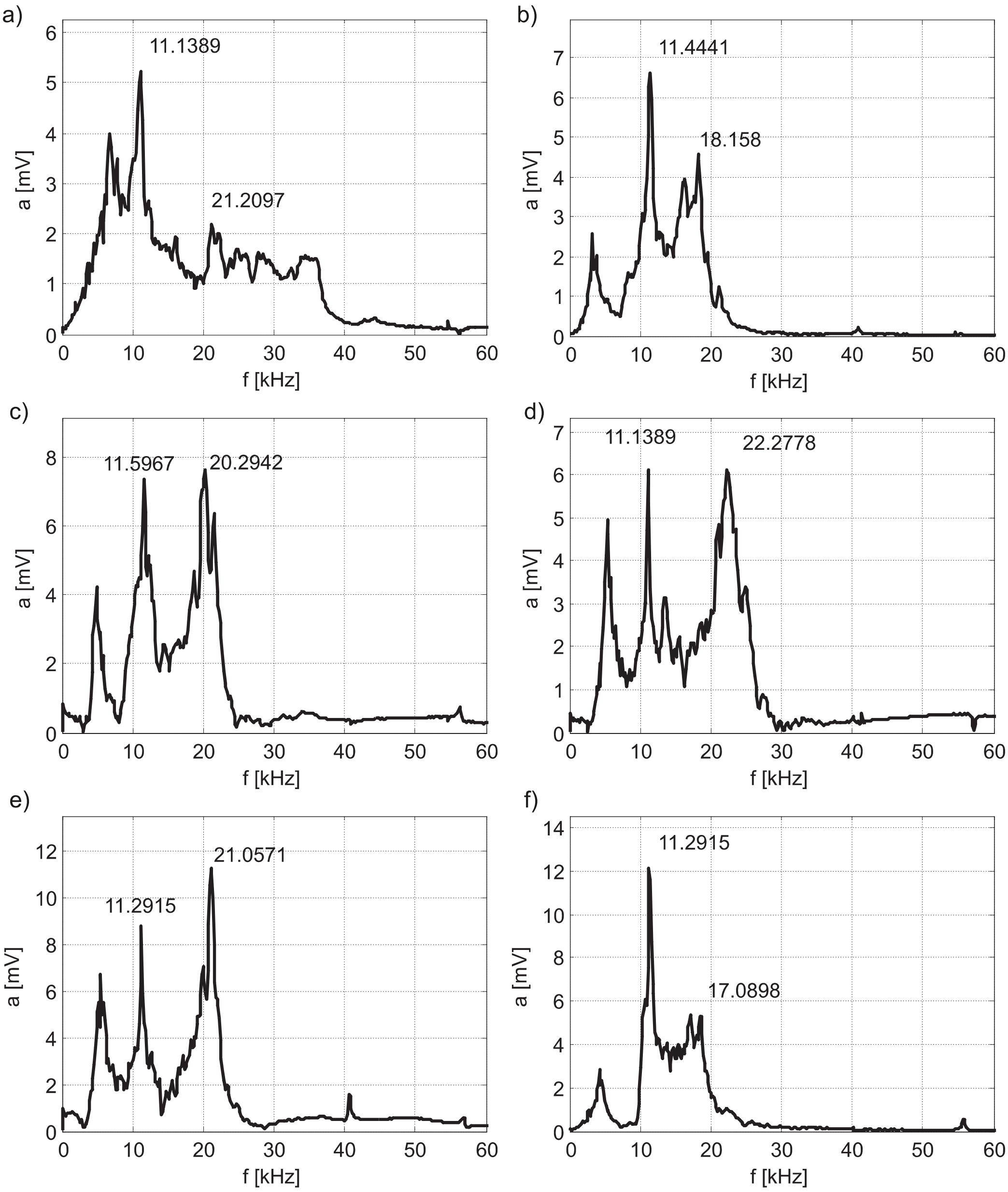


Fig. 10. Spectrums of signals measured at selected points: a) point 30; b) point 31; c) point 32; d) point 33; e) point 34; f) point 35

Spectral responses in majority points were similar to the spectrum shown in Fig. 9b. However, in points no. 30 to 35 additional peak appeared in the signal transformed to the frequency domain. Fig. 10 shows spectra for points 30 to 35. For all these points, additional peaks appeared of frequency 17.0898 kHz to 22.2779 kHz. The presence of higher frequencies indicates reflection of wave from internal defect at depth about 10 cm (from 8.96 cm to 11.84 cm). Points 30 to 35 were situated in the neighbourhood of the line of potential discontinuity.

5. CONCLUSIONS

In this paper, the impact-echo method was presented and applied in full scale tests on concrete bridge and floor slab structures. The method uses the phenomenon of propagating waves induced by a mechanical impact and spectral analysis of the recorded acceleration signals.

In this study, the impact-echo method was used in two different tests. In the first one, the measurements were made on both sides on the concrete cantilever element, and damage detection procedure was based on the analysis of P-wave speeds. This approach enabled identification of damage in the form of large internal flaws, in which substantial amount of epoxy resin was injected. The repeated ultrasonic tests on the injected structure revealed effectiveness of the applied repair method as well as the performance of the non-destructive testing.

In the second test, one-side measurements were conducted and for damage assessment of the slab floor structure. The data analysis was carried out in frequency domain by interpretation of spectra obtained from time domain signals. In the analyzed slab floor the defects were detected as additional peaks in spectral responses.

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