Identification of Delamination in Concrete Slabs by SIBIE Procedure

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Abstract. The Impact-Echo method is known as a non-destructive testing for concrete structures. The technique is based on the use of low-frequency elastic waves that propagate in concrete to determine the thickness and to detect internal flaws in concrete. The presence and locations of defects in concrete are estimated from identifying peak frequencies in the frequency spectra, which are responsible for the resonance due to time-of-flight from the defects. In practical applications, however, obtained spectra include so many peak frequencies that it is fairly difficult to identify the defects correctly. In order to improve the Impact-Echo method, Stack Imaging of spectral amplitudes Based on Impact-Echo (SIBIE) procedure is developed as an imaging technique applied to the Impact-Echo data, where defects in concrete are identified visually at the cross-section. In this study, the SIBIE procedure is applied to identify the delamination in a concrete slab. It is demonstrated that the delamination can be identified with reasonable accuracy.

1. Introduction

The Impact-Echo method is well known as a non-destructive testing for concrete structures [1]. The method has been applied to thickness measurement of a slab, grouting performance and void detection in a post-tensioning tendon duct, identification of surface-opening crack depth, location of delamination and determination of material properties.

The Impact-Echo method has been widely applied to identification of shallow delamination [1, 2]. In principle, the location of delamination is estimated by identifying peak frequencies in the frequency spectrum. However, the frequency spectrum cannot always be interpreted successfully, because many peaks are often observed in the spectrum. In order to circumvent this fact, Stack Imaging of spectral amplitudes Based on Impact-Echo (SIBIE) procedure is developed [3, 4]. In this study, the SIBIE procedure is applied to identify the delamination in concrete slab.

2. Principle

2.1. Impact-Echo method

The principle of void detection in the Impact-Echo is shown in Figure 1. When the elastic wave is driven, the paths of the elastic wave are shown. Frequency spectrum is analyzed by Fast Fourier transform (FFT), applying to an obtained waveform detected at the output point. As shown in the figure, peak frequencies could appear at f_T and f_{void}, which correspond to resonant frequencies due to the thickness of a plate and the depth of a void, and are calculated as,

$$f_T = C_p / 2T, \tag{1}$$
$$f_{void} = C_p / 2d, \tag{2}$$

where C_p = velocity of P-wave, T = plate thickness, and d = covered depth. The plate thickness and the cover depth are obtained by substituting f_T or f_{void} with C_p into these equations.
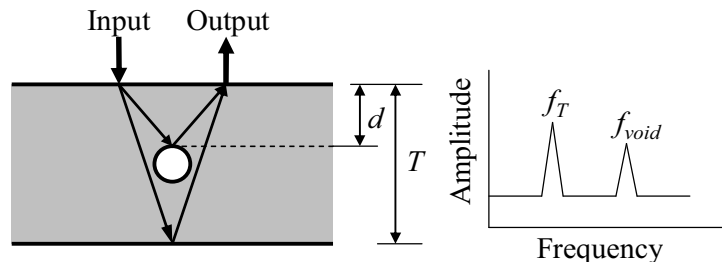

Figure 1. Principle of void detection.

2.2. SIBIE procedure

SIBIE procedure is a post-processing technique to Impact-Echo data. This is an imaging technique for detected waveforms in the frequency domain. In the procedure, first, a cross-section of concrete is divided into square elements as shown in Figure 2[5]. Then, resonance frequencies due to reflections at the elements are computed. The travel distance from the input location to the output via the element is calculated as,

$$R = r_1 + r_2. \tag{3}$$

The resonance frequency due to reflection at each element is calculated from,

$$f_R = C_p / R, \tag{4}$$

Spectral amplitudes corresponding to the resonance frequencies in the frequency spectra are summed at the elements. Thus, reflection intensity at each element is estimated as a stacking image as shown in Figure 3[5]. The minimum size of the square element, Δx, for the SIBIE analysis is approximately equal to $C_p \Delta t / 2$.
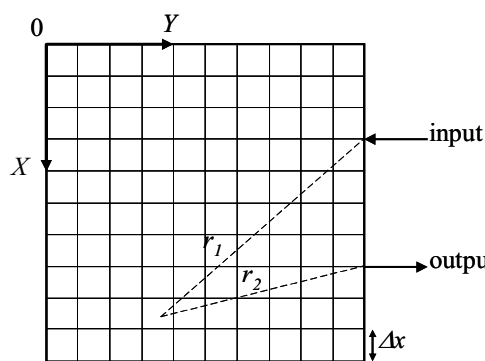

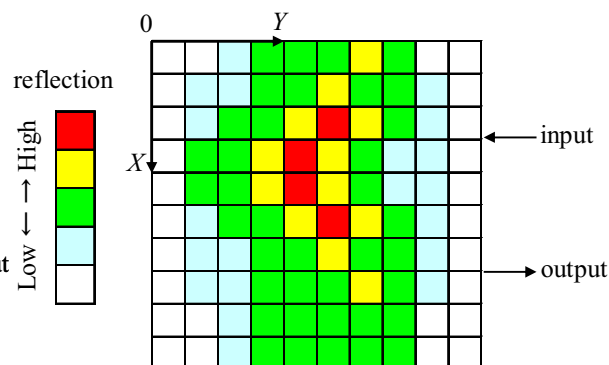**Figure 2.** SIBIE imaging model.   **Figure 3.** Example of SIBIE result.

3. Experiments

3.1. Test site

Piture1 shows a deck slab, which was removed from a bridge. In this deck slab, delaminated areas were found at some locations. One delamination was located at 160 mm depth from the top of the slab. Tests were conducted at three area of the slab which are selected as shown in Picture 2, 3, and 4. Picture 2 shows the normal area of the deck which has the pavement of 70 mm depth and an existing slab of 250 mm thickness. Picture 3 and Picture 4 show the overlaid areas of the deck with slabs of 250 mm thickness. The former has the pavement of 70 mm depth and the overlaid slab of 90 mm thickness

without a delamination below.   In the latter, a delaminated area is observed between the overlaid slab 90 mm thick and the existing slab 160 mm thick.

Picture1. Deck slab

Picture 2. Normal area (unit: mm)

(mm)

(mm)

Picture 3. Overlaid area (no delamination)   **Picture 4.** Overlaid area (delamination)

3.2. Impact test

Picture 5 shows the impactor, which is equipped with accelerometers. It is confirmed that the upper-bound frequency due to the impact could cover up to 30 kHz, by using an accelerometer system. Fourier spectra of accelerations were analyzed by Fast Fourier Transform (FFT).

Impact test was done once at each point, normal area, overlaid area, delaminated area, respectively. The impactor was shot by spring with 100 N to generate elastic waves. Sampling time of the wave recorded in Picture 6 was 4μsec and the number of digitized data for each waveform was 2048.
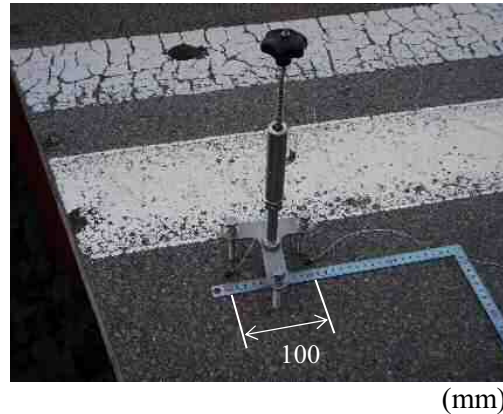

Picture 5. Impactor

Picture 6. Waveform recorder   .

The locations of impact and two detection points are also shown in Picture 7. Two accelerometers were placed at the detection points to record surface motions caused by reflections of the elastic waves. Here, the interval between the impact point and the detection point is 50mm. P-wave velocity is a very important parameter in using SIBIE procedure. P-wave velocity of the test deck slab was obtained as 4500 m/s by the Impact-Echo method [6].

(mm)

Picture 7. Impact point

4. Results and Discussion

4.1. Normal area

The result of Impact-Echo method is given in Figure 4. Figures 4 is the spectrum of the impact test at the Normal area. Calculated values of the resonance frequencies due to thickness, $f_T = C_p/2T$ is indicated with a block line. It can be seen from the frequency spectrum that there is the peak at f_T, however, it is difficult to identify the peak only from the specrum.

The SIBIE result at the normal area is given in Figure 5, which shows a cross-section of the deck (Picture 2). The size of cross-section is 320 mm × 500 mm. The red color regions indicate the highest reflection of the elastic wave. The impact point and the detection points are indicated by a downward arrow and upward arrows, respectively.

It is clearly seen that there exists high reflection zone only at the bottom of the deck. There are no other high reflections observed at the cross-section
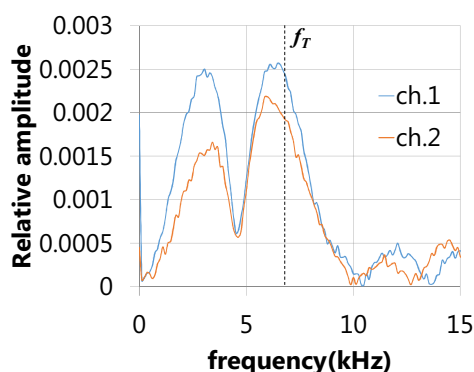.

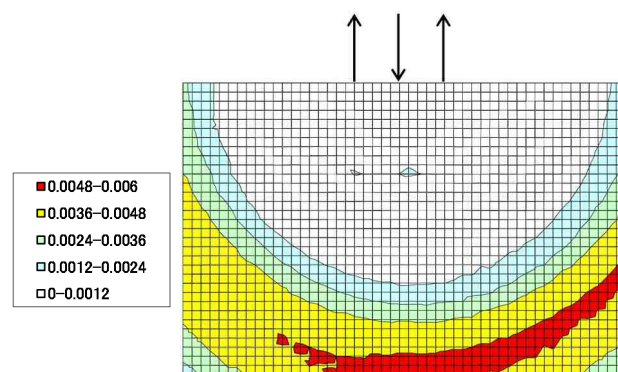**Figure4.** Impact-Echo result at normal area

Figure5. SIBIE result at normal area

4.2. Overlaid area (no delamination)

In Figure 6, frequency spectrum obtained by the impact-test is shown. The resonance frequency f_T is observed at 7.03 kHz, although it is not a strong peak.

SIBIE result of the impact test for the case at the overlaid area (Picture 3) is shown in Figure 7. Red and yellow color of high reflection are clearly observed at the bottom of the deck again. There are no other high reflections observed at the cross-section. Thus, no differences are observed between the SIBIE result at the normal area and that of the overlaid area.
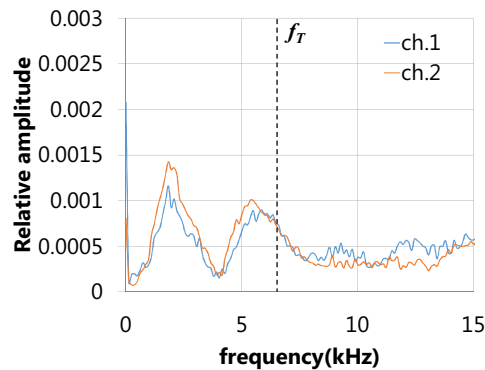

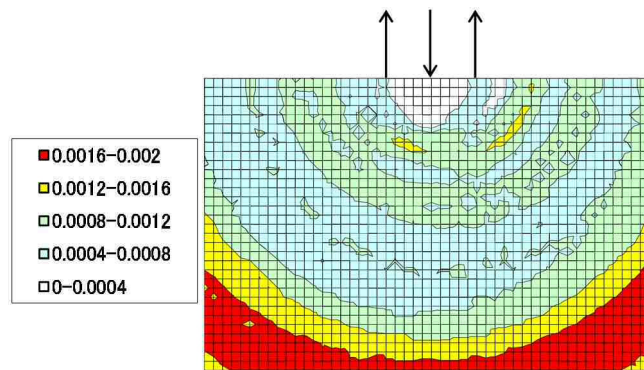**Figure6.** Impact-Echo result at overlaid area

Figure7. SIBIE result at overlaid area

4.3. Overlaid area (delamination)

Figure 8 shows the result of Impact-Echo method at the delaminated area. The resonance frequency of delamination at 160 mm depth is calculated as 14.1 kHz is observed, and it's amplitude is higher than the resonance frequency f_T at 7.03 kHz.

In Figure 9, SIBIE result of the impact test for the case at the delaminated area is observed. The high intense region due to the delaminaion is observed at 160 mm from the top of the deck, while the high intense red regions can not be observed at the bottom. From this result, it is confirmed that the SIBIE procedure is available for void detection .
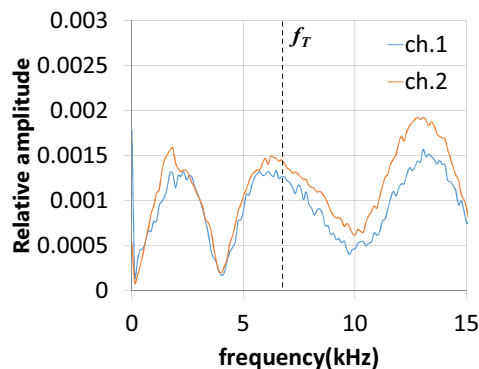

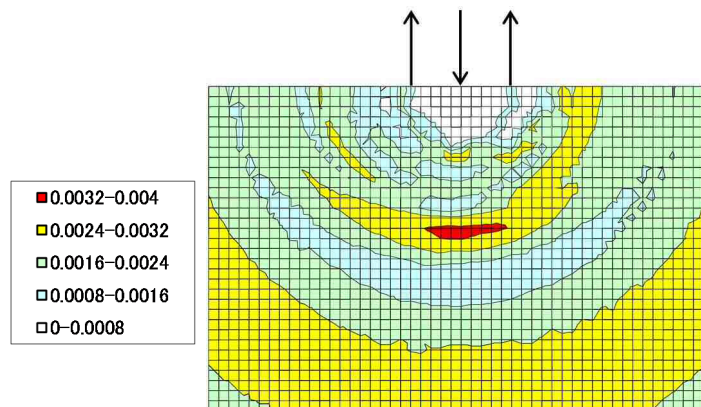**Figure8.** Impact-Echo result at delaminated area

Figure9. SIBIE result at delaminated area

5. Conclusions

Based on the study, conclusions can be drawn, as follows:

(1) In the concrete slab taken out of a bridge, it was found to be not easy to identify the resonant frequencies of delamination and thickness only from the spectra obtained by the Impact-Echo method.

(2) According to the SIBIE results of normal area and overlaid area, there exist high reflection zones only at the bottom of the deck.   On the SIBIE result of delaminated area, in contrast, the high intense region of reflection due to the delaminaion is observed clearly at 160 mm from the top of the deck. Therefore, it is confirmed that the location of the delamination can be clearly identified using the SIBIE procedure.

Thus, it is demonstrated that the delamination between an existing part and an overlaid part can be identified with the reasonable accuracy by the SIBIE procedure.

References

[1]   Sansalone M.J. & Streett W.B. 1997a. Impact-echo, Ithaca, NY Bullbrier Press.
[2]   Sansalone M. 1997b. Impact-echo: The complete story, ACI Structural Journal, 94(6), 777-786
[3]   Ohtsu M. & Watanabe T. 2002. Stack imaging of spectral amplitudes based on impact-echo for flaw detection, NDT&E International, 35, 189-196.
[4]   Ohtsu M. 2016. Innovative AE and NDT Techniques for On-Site Measurement of Concrete and Masonry Structures, RILEM State-of-the-Art Reports, Vol.20, 89-103
[5]   Yamada M., Ohtsu M. 2010. Case studies on ungrouted tendon-duct in prestressed concrete models by SIBIE, Construction and Building Materials, Vol.24, Isuue12, 2376–2380
[6]   Japanese Society for Non-Destructive Inspection Standard, NDIS 2426-2: Non-destructive testing of concrete : elastic wave method : Part 2: Impact elastic wave method