NDT FOR DETECTING VOIDS IN POST-TENSIONING TENDON DUCT BY SIBIE

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ABSTRACT

Impact-echo technique is an advanced nondestructive evaluation (NDE) for identifying defects in concrete structures. Analyzing elastic waves due to a mechanical impact, resonance frequencies responsible for the locations of reflectors are extracted and the presence and depth of defects are estimated.

In order to improve the impact-echo method, a new procedure to evaluate defects in concrete is investigated, applying a scanning procedure. Thus, stack imaging of spectral amplitudes based on impact-echo (SIBIE) is developed. The procedure is applied to prestressed concrete to detect voids in tendon ducts. Effects of arrangement of an impact and a sensor are investigated by changing locations of the sensor and the impactor. It is confirmed that the location of the impactor is closely related with the results of SIBIE, and the presence of the voids is visually identified.

1 INTRODUCTION

Stack imaging of spectral amplitudes based on the impact-echo (SIBIE) is developed for improvement of impact-echo method [1]. This new procedure based on applying a scanning procedure can visually evaluate defects in concrete. Applicability of SIBIE was investigated to detect ungrouted ducts of prestressed concrete specimens and artificial voids in reinforced concrete slabs [2][3]. It was clarified that defects can be visually detected by SIBIE. In these papers, effects of frequency range of an impact were explained. However, effects of locations of an impactor and a sensor were not investigated.

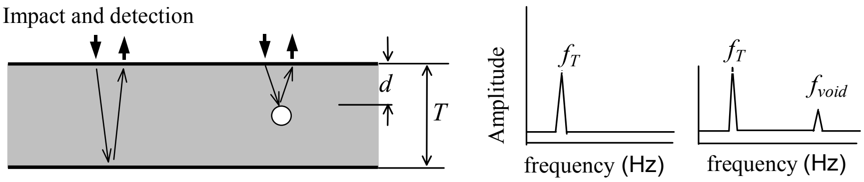
The main objective of this study is to investigate the effects of arrangement of an impact and a sensor. This paper is intended to repot results of impact tests and SIBIE for detecting voids in tendon ducts of prestressed concrete specimens.

2 IMPACT-ECHO TECHNIQUES AND CHARACTERISTIC RESONANCE

Theoretically, frequency responses of a concrete slab depend on size of a member, location of voids, and P-wave velocity. This is because material properties, incident waves and the characteristic lengths characterize wave motions in concrete structures. Concerning the frequency responses of a prestressed concrete slab, following relationships between the wavelength and the depth of the void are known [4][5],

$$f_T = 0.96\frac{C_p}{2T} \quad (1) \qquad f_{void} = 0.96\frac{C_p}{2d} \quad (2) \qquad f'_{void} = \frac{C_p}{d} \quad (3)$$

Where f_T is the resonance frequency of the plate thickness T, f_{void} and f'_{void} are the resonance frequencies of the void in the depth d. C_p is P-wave velocity. 0.96 is a shape factor determined by



f_T : Resonance frequency of the plate thickness
f_{void} : Resonance frequency of the void

Figure 1: Frequency responses of a prestressed concrete.

the geometry. f'_{void} implies the existence of higher resonance frequency than f_{void}.

According to Herz's theory, a mechanical impact due to a steel-ball drop has a particular contact time T_c that depends on diameter D of a steel ball [4]. A simplified equation is given as Eqn. (4), and the upper-bound frequency, f_c, covered by the impact is determined as Eqn (5).

$$T_c = 0.0043D \quad (4) \qquad f_c = \frac{1.25}{T_c} \quad (5)$$

In order to be able to identify all resonance frequencies f_T, f_{void}, and f'_{void} in the spectrum, the upper-bound frequency of the mechanical impact f_c should cover them.

3 SCANNING PROCEDURE OF SIBIE

Based on inverse scattering theory in elastodynamics [6], one scanning procedure is developed as SIBIE (Stack Imaging of spectral amplitudes Base on Impact-Echo) [1]. The peak (resonance) frequencies could consist of reflections from boundary surfaces of concrete and from a void.

First, at a cross-section of a specimen, meshes are arranged evenly. Then, resonance frequencies due to reflections from elements are computed. In this case, the travel distance from the input to the output via the element is calculated as indicated in Figure 2, and the total distance, R is obtained as Eqn (6).

$$R=r_1+r_2 \qquad (6)$$

At each element, the distance R of reflected path is calculated. Then, resonance frequencies are computed.

$$f_1=C_p/(R/2)\,, \quad f_2=C_p/R \qquad (7)$$

The spectral amplitudes corresponding to these resonance frequencies are summed, and the intensity of reflections at each element is determined.

4 EXPERIMENTS

4.1 Specimens

Plain and prestressed concrete specimens containing ungrouted tendon duct were prepared.

Dimensions of the specimens are 600*900*200mm, in Figure 1. P-wave velocity was measured by pulse velocity test, and it was 3160m/s. From Eqns. (2) and (3), the resonance frequencies of a duct at 60mm depth, f_{void} and f'_{void}, were calculated as 25.3kHz and 50.6kHz. In the same way, the resonance frequencies of the void at 90mm depth, f_{void} and f'_{void}, were calculated as 16.9kHz and 33.8kHz From Eqn. (1), the resonance frequency of the plate thickness f_T was calculated as 7.6kHz.

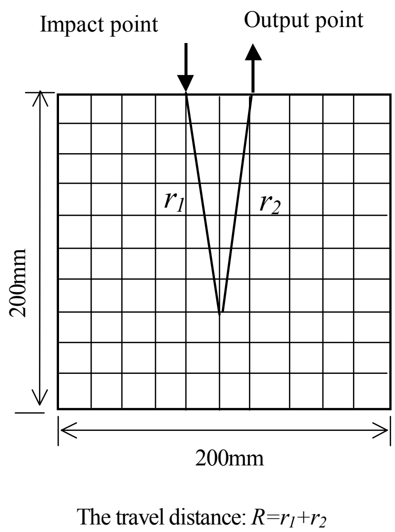


Figure 2: Spectral imaging model.

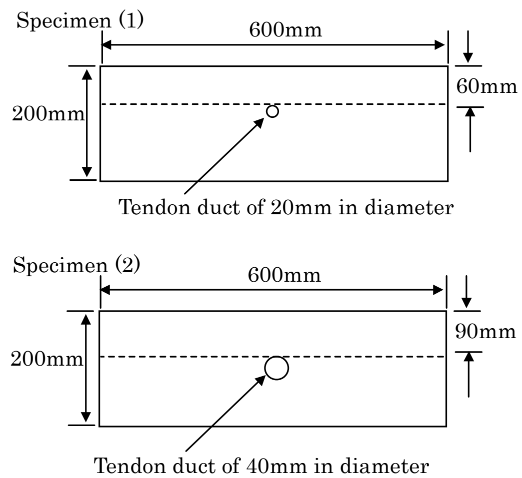


Figure 3: Concrete specimens.

4.2 Impact tests

The impact tests using a steel ball conducted. Elastic waves due to the steel balls were detected by an accelerometer. The waveforms were analyzed by FFT. Sampling rate of frequencies is 100Hz. The steel ball of 9.5mm diameter was dropped at 200mm height over the top surface of the specimen. Eqns (4) and (5) give the upper bound frequencies of the steel ball as 30.6kHz. By comparing the upper-bound frequency and resonance frequencies of void, it is found that the upper-

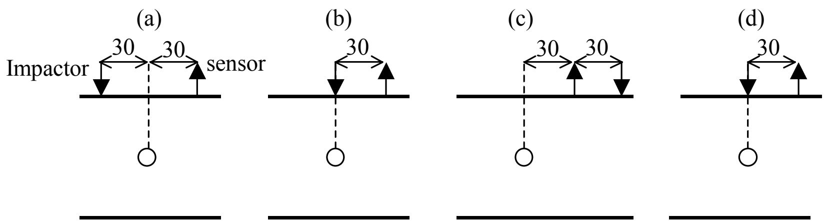


Figure 4: Arrangement of Impactor and sensor.

bound frequency covers resonance frequencies of f_{void} at 60 and 90mm in depth.

In the impact tests, the location of the impactor and the sensor were changed as Figure 4. In (a), the impactor and the sensor were symmetrically placed above the duct. In (b), sensor was located as (a) and impactor was placed over duct. In (c), sensor was located as (a) and impactor was placed 30mm side of sensor. In (d), sensor was placed over duct.

5 RESULTS AND DISCUSSION

Results of SIBIE are shown in Fig.5 and Fig.6. The results are parts of cross-section view of specimen. The size of cross-section is 200×200mm as the imaging model shown in Fig.2, and

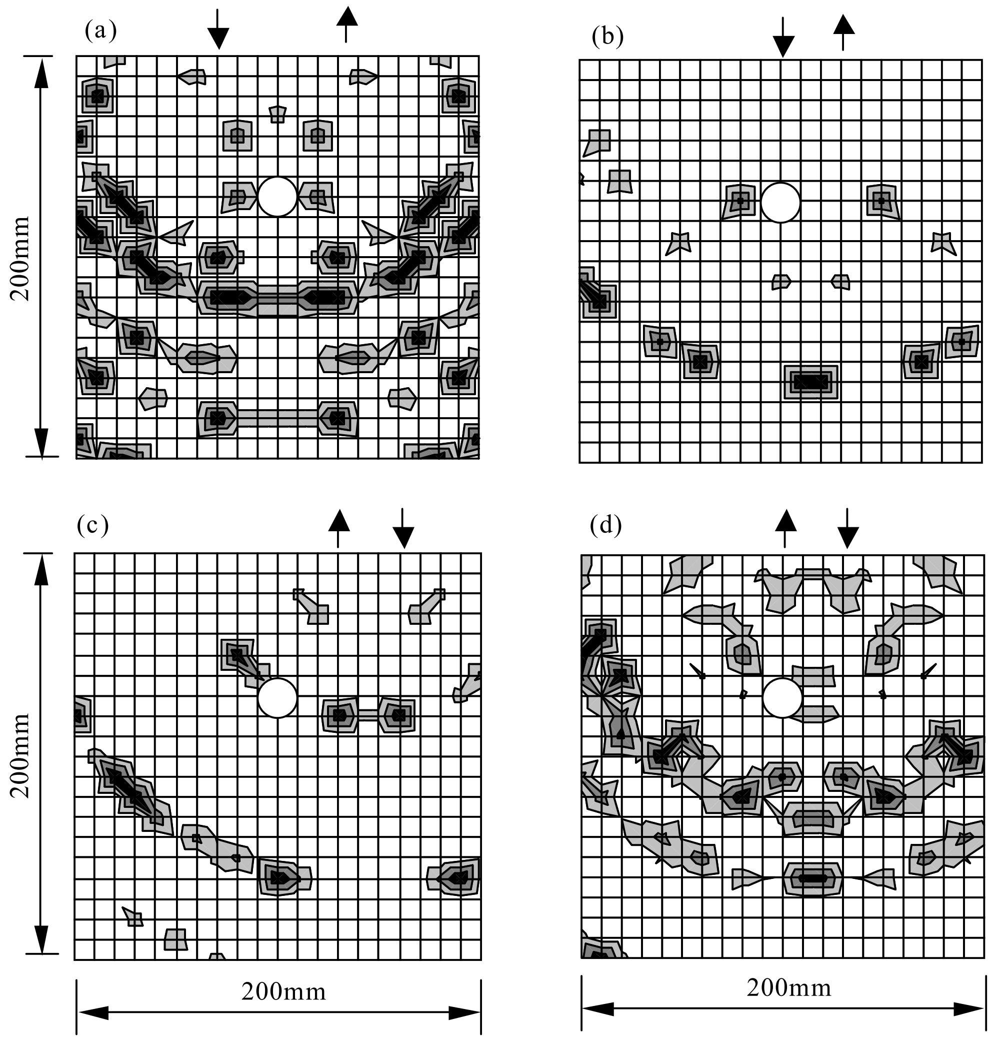


Figure 5: Results of SIBIE due to the specimen (1).

meshes are arranged 10mm pitch evenly. In the figures, darker color regions indicate degree of high intensity regions due to presence of reflectors. White circles mean location of duct and arrows show location of impact point and sensor.

The results of SIBIE due to the specimen (1) are shown in Figure 5. At cross-section (b), the high intense regions due to void of duct are observed side of the duct. Other cross-section, high intense regions are observed, however not clearly relate with location of duct.

In Figure 6, the results of SIBIE due to the specimen (2) are shown. At cross-section (b), the high intense regions due to void of duct are observed around the duct. At cross section (a), the high intense regions due to void of duct are observed around the duct of void as (b).

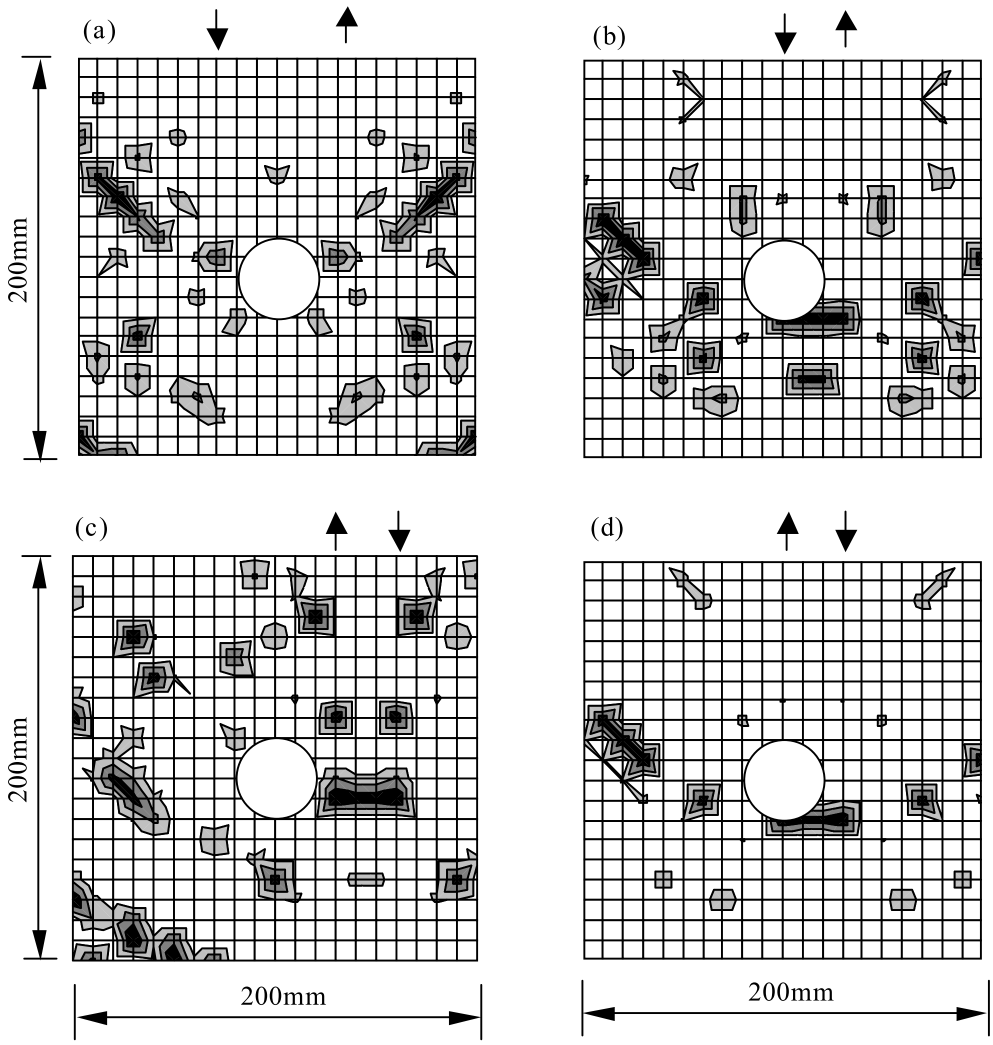


Figure 6: Results of SIBIE due to the specimen (2).

This result implies that arrangement of the location of the impactor and the sensor gives effects to results of SIBIE. In the case that the impactor and sensor is located over the void of the duct, the void is easily detected by SIBIE. In the case that the diameter of the duct becomes smaller, the condition of arrangement of the impactor and sensor become server to detect void.

6 CONCLUSION

A scanning procedure of SIBIE is applied to identification of a void in a tendon ducts. The effects of location of an impactor and a sensor are studied. Conclusions are summarized, as follows

(1) It is confirmed that location of an impactor and a sensor effects results of SIBIE.

(2) In the case of the imactor is located over duct, the void in the duct can be easily identified by SIBIE.

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