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Identification of ungrouted tendon duct in prestressed concrete by SIBIE

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Abstract

In the impact-echo method, the presence and the 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, spectra obtained include so many peak frequencies that it is fairly difficult to identify the defects correctly. SIBIE (Stack Imaging of spectral amplitudes Based on Impact Echo) procedure is developed as an imaging technique applied to the impact-echo, where defects in concrete are identified visually at the cross-section. In this study, the SIBIE procedure is applied to identify ungrouted post-tensioning ducts in prestressed concrete. Concrete slabs containing an ungrouted duct, a partially-grouted duct, and a fully-grouted duct of metal and polyethylene sheaths were tested. It is demonstrated that the defect can be identified with reasonable accuracy by SIBIE in all the cases tested.

Résumé

Dans la méthode impact-écho, la présence et les emplacements des défauts dans le béton sont évalués à partir de l'identification des fréquences maximales dans les spectres fréquentiels, qui sont responsables de la résonance induite par le temps de vol jusqu'aux défauts. Dans des applications pratiques, cependant, les spectres obtenus incluent tant de fréquences maximales qu'il est assez difficile d'identifier les défauts correctement. La procédure SIBIE (sommation d'images des amplitudes spectrales de type impact-écho) est développée comme une technique d'image appliquée à l'impact-écho, où les défauts dans le béton sont identifiés visuellement à l'intersection. Dans cette étude, la procédure SIBIE est appliquée pour identifier des vides dans des gaines de béton précontraint. Des dalles en béton contenant une gaine vide, une gaine partiellement vide et une gaine entièrement pleine de métal et des gaines de polyéthylène ont été évaluées. Il est démontré que le défaut peut être identifié avec une précision raisonnable par SIBIE dans tous les cas évalués.

Keywords

Impact-echo, prestressed concrete, ungrouted tendon duct, metal and polyethylene sheaths.

1 Introduction

As one of nondestructive evaluation (NDE) techniques, the impact-echo method has been successfully applied to locate defects, flaws, inclusions and voids in concrete structures [1]. Since the attenuation of high-frequency components in elastic waves is dominant in concrete, a high-energy impact and the detection of elastic waves in the low-frequency range are recommended [2]. The impact is usually generated by dropping or hitting a steel-ball, and a displacement sensor is placed next to an impacted location to detect elastic waves. By identifying the resonant frequency in a frequency spectrum, which is obtained through the

Fourier transform (FFT) of the detected waveform, the location of a defect is estimated from a relation between the wavelength of resonance and the travel distance via the defect. In actual cases, however, many peak frequencies are usually observed in the spectrum and the peak frequency responsible only for the location of the defect is not easily identified.

In order to compensate this drawback, SIBIE (Stack Imaging of spectral amplitudes Based on Impact-Echo) has been developed, as an imaging procedure applied to the impact-echo data in the frequency domain [3]. Applying the procedure, depths of voids in reinforced concrete were successfully determined [4]. The presence of ungrouted tendon ducts in pre-stressed concrete was also evaluated by the improved procedure [5]. The impact was driven right over the duct hole between two locations on the surface where elastic waves were detected by accelerometers. To generate a high-energy and reproducible impact, a device for shooting an aluminum projectile by air-pressure was developed.

In the present paper, an applicability of the improved SIBIE procedure to the cases of steel sheath, polyethylene sheath and imperfectly grouted ducts are examined.

2 SIBIE Procedure

In order to generate an impact of high-energy with wide-frequency coverage, a device for shooting a projectile with tapered head by air-pressure was developed. An aluminum bullet of 8 mm diameter and 17 mm length in Fig. 1 (a) is shot at the impact point by compressed air (0.05 MPa) via a compressor in Fig. 1 (b). Elastic waves generated are detected at the surface by an accelerometer.


(a) Aluminum bullet

(b) Compressor and projector

***Figure 1**. (a) Projectile and (b) an impacting system.*

A cross-section of a specimen measured is modeled and divided into square elements as shown in Fig. 2. Then, resonant frequencies due to reflection of P-wave at the element are only calculated. The travel distance from the input point to the output via the center of the element is obtained as denoted in the figure,

$$R = r_1 + r_2. \tag{1}$$

Resonant frequencies due to reflection at the element are calculated as,

$$f_2 = \frac{C_p}{r_2}, \quad \text{and} \quad f_R = \frac{C_p}{R}. \tag{2}$$

Here C_p is the velocity of P wave. In a frequency spectrum of a detected wave, spectral amplitudes corresponding to these two resonant frequencies are summed up at the element as reflection intensity. Thus, the reflection intensity is estimated as a stack image at each element. Assigning stack images at all elements, a contour map on the reflection intensity is eventually obtained at the cross-section.

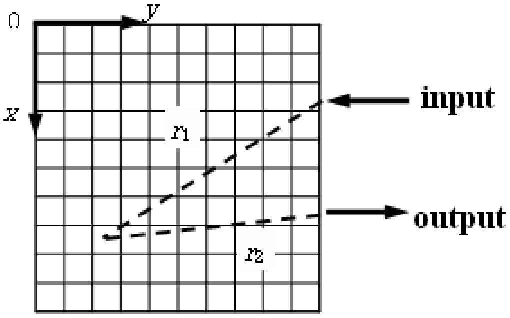


Figure 2. *A cross-section divided into meshes.*

As discussed in the previous paper [3], the minimum length of the square element, Δx, is determined from,

$$\Delta x = C_p \Delta t/2, \qquad (3)$$

where Δt is the sampling time of a recorded wave.

3 Experiments

A specimen tested is illustrated in Fig. 3. The compressive strength of concrete at 28-day standard curing was 32.9 MPa. A concrete block of dimensions 260 mm x 400 mm x 1000 mm contains two ribbed sheaths of steel (tin-galvanized: 60 mm outer diameter and 55 mm inner diameter) and polyethylene (65 mm outer diameter and 55 mm inner diameter).

In the latter case, it is reported that the peak frequency corresponding to an ungrouted duct is not readily identified because the acoustic impedance of the polyethylene sheath is comparable to that of concrete [1]. Thus, it is known that identification of particular peak in the spectrum is fairly difficult.

The impact tests were conducted as shown in Fig. 4. A downward arrow shows the impact point, and two upward arrows denote the locations of accelerometers. The distances (interval) between the accelerometer and the impact point, which is located right over the duct, are varied as 20 mm, 50 mm, and 90 mm.

Right before the test, P-wave velocity was determined by employing an ultrasonic tester (MIN-02, Marui). The time of flight was measured 10 times in the axis-direction of a cylindrical sample, and the averaged P-wave velocity at the test was obtained as 4025 m/s. A storage-type oscilloscope (TDS2014, Tektronix) was employed to store the waveform data in time domain. A waveform was digitized at 4 μsec sampling time (Δt) of 2048 recording words (N=2048).

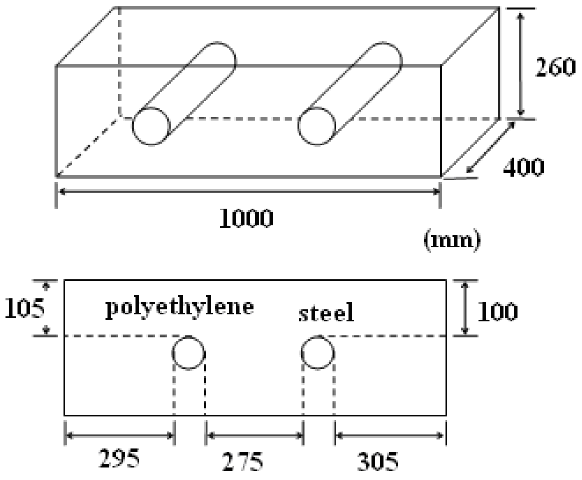


Figure 3. *A sketch of the test specimen.*

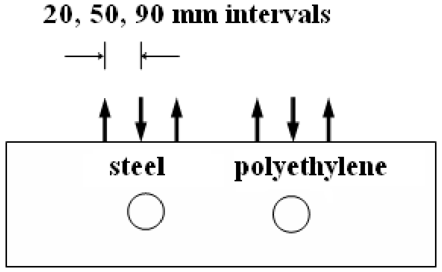


Figure 4. *Set-up for the impact test.*

The case that the sheath was imperfectly grouted was also tested. After the impact tests were conducted, two ducts in Fig. 3 were grouted by grouting cement as illustrated in Fig. 5. Keeping an inclined angle at grouting, one quarter, half and three quarters of the depth were filled with cement at the cross-sections (1), (2) and (3) in Fig. 5. The impact test was carried out one day after the sheaths were grouted.

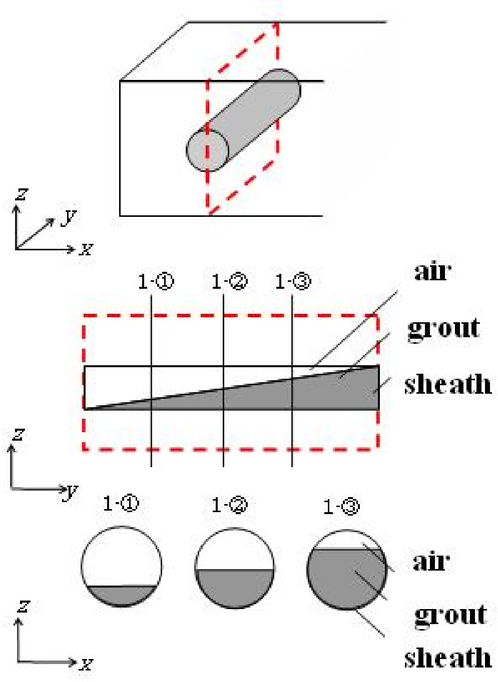


Figure 5. *Grouted cross-sections.*

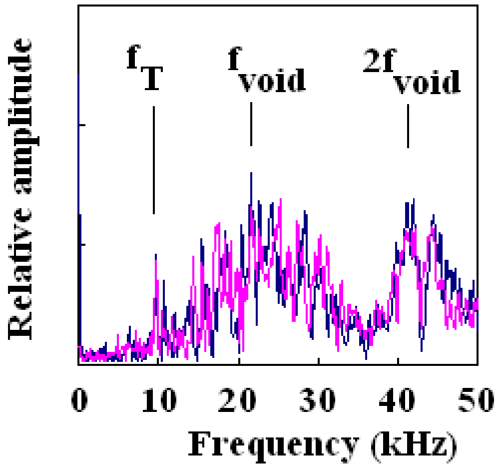


Figure 6. *Frequency spectra detected.*

4 Results

4.1 Ungrouted ducts

Frequency spectra obtained at two accelerometers in the case of 50 mm intervals in the metal sheath are shown in Fig. 6. Theoretical resonant frequencies f_T*(Cp/2T)*, *fvoid (Cp/2d)* and *f'void (Cp/d)* are denoted in the figure, where *T* is the thickness of the specimen and *d* is the depth of the duct.

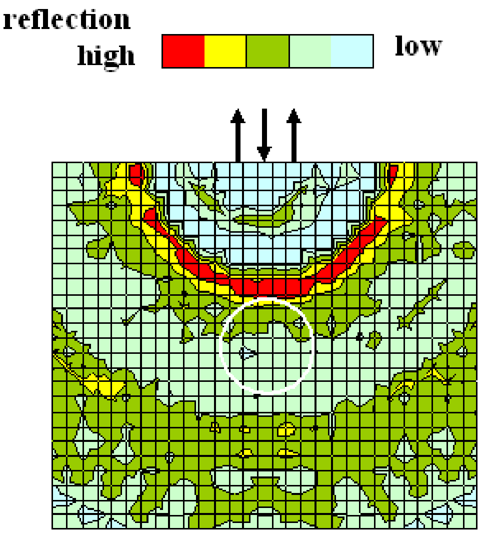
Although corresponding peak frequencies are observed, other peaks are also found. This implies that identification of peak frequencies only responsible for the location of the sheath is not always easy. By employing these spectra, the SIBIE analysis of two spectra was conducted and two images of reflection intensity are superimposed as one image. Typical results are given in Figs. 7 and 8.

In the case of 20 mm intervals, high reflection zones of red colored are clearly observed at the top of the sheath, while both reflection zones at the top and the bottom are realized in the case of 50 mm intervals. This suggests that the diameter of the duct could be identified in the case that the interval is comparable to the diameter of the sheath. This is because the reflected waves are generated due to deformation at the bottom and they are readily detected at the accelerometers located at the surface with comparable-interval distances.

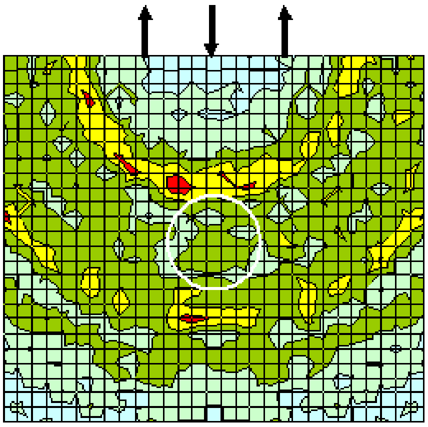
In the case that the interval is shorter than the diameter of the sheath, in contrast, reflected waves are hardly detected by the accelerometers. It is also note that results in the cases of polyethylene sheath are similar to those of metal sheath, suggesting the effect of the acoustic impedance is minor in the SIBIE analysis. This implies that the SIBIE procedure is also available for the case of polyethylene and plastic sheaths to identify ungrouted ducts.

4.2 Imperfectly ungrouted ducts

SIBIE results of imperfectly grouted ducts are given in Figs. 9 and 10. In the cases of imperfectly grouted ducts, high reflection zones of red are only observed at the top of the sheath in the both cases of metal and polyethylene. In the case of fully grouted, no high reflection zones are observed as found in Fig. 10 (b). Thus, an applicability of the SIBIE procedure to identify imperfectly grouted ducts is confirmed.

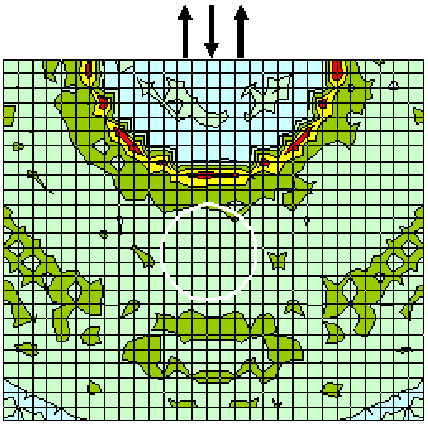


(a) 20 mm intervals

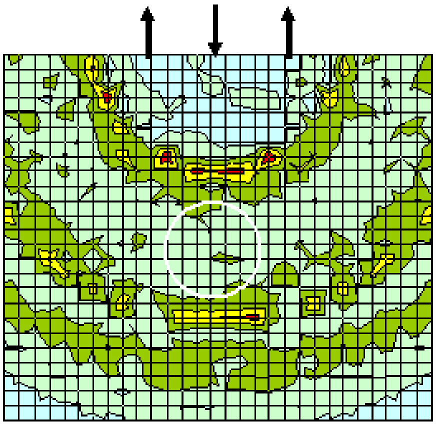


(b) 50 mm intervals

Figure 7. *SIBIE results in metal sheath.*



(a) 20 mm intervals



(b) 50 mm intervals

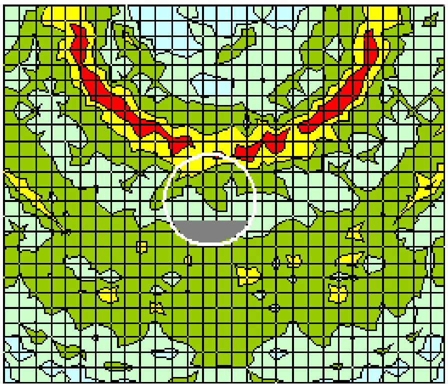
Figure 8. *SIBIE results in polyethylene sheath.*

5 Conclusions

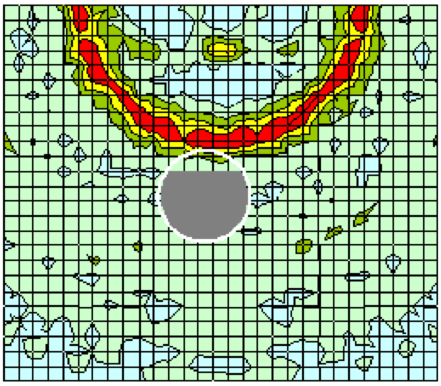
In the impact-echo method, the presence and the locations of defects in concrete are estimated by identifying peak frequencies in the frequency spectra. In practical applications, however, spectra obtained include so many peak frequencies that it is very difficult to identify particular peak frequencies only associated with defects.

Consequently, in this study, the SIBIE procedure is applied to identify ungrouted post-tensioning ducts in prestressed concrete. Conclusions are summarized, as follows:

1. An applicability of the procedure to identify ungrouted tendon ducts in post-tensioned concrete girders is examined in the two cases of polyethylene and steel sheaths. Successful results are obtained in the case of polyethylene sheath as well as metal.
2. In addition, the case of imperfectly grouted sheaths is tested. Results are also successful for identifying ungrouted ducts,
3. All results show a great promise for inspecting imperfectly-grouted ducts in pre-stressed concrete bridges.

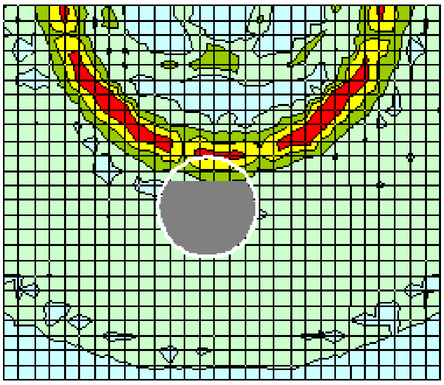


(a) 1/4-section grouted

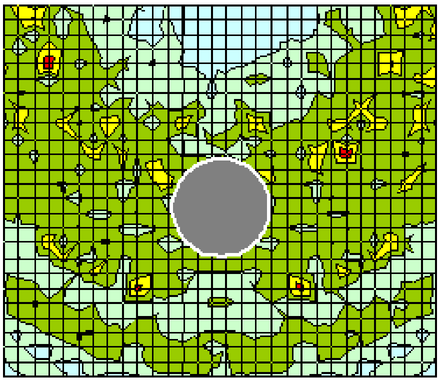


(b) 3/4-section grouted

Figure 9. *The case of metal sheath.*



(a) 3/4-section grouted



(b) fully grouted

Figure 10. *The case of polyethylene sheath.*

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