# SIBIE procedure for the identification of ungrouted post-tensioning ducts in concrete

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ABSTRACT: SIBIE (Stack Imaging of Spectral Amplitudes Based on Impact-Echo) is an imaging procedure applied to the impact-echo data in the frequency domain. The procedure is developed to improve the impact-echo method and to visually identify locations of defects in concrete. SIBIE has been applied to identification of voids within post-tensioning tendon ducts in concrete. In order to investigate the effect of the distance between impact and detection points on SIBIE results and to improve the applicability of the procedure, a concrete slab containing post-tensioning tendon ducts of metal and plastic was tested. Locations of void within both metal and plastic ducts are identified visually by the SIBIE procedure.

## 1 INTRODUCTION

SIBIE (Stack Imaging of Spectral Amplitudes Based on Impact-Echo) procedure is developed to improve impact-echo method. The impact-echo method is very well-known as a nondestructive testing for concrete structures (Sansalone, 1997a, b). The method has been applied to such types of defects in concrete as 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 void in tendon-ducts (Sansalone, 1997 a, b, Jaeger, 1996). In principle, the location of void 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. Particularly, in the case of a plastic sheath, it becomes more difficult to interpret the frequency spectrum due to the existence of many peaks. This is because a plastic sheath has lower acoustic impedance than concrete or grout. In order to circumvent it, SIBIE procedure is developed (Ohtsu, 2002). SIBIE procedure has been applied to void detection within tendon ducts (Ata et al., 2005, Alver). In this study, the procedure is applied to a concrete specimen containing a metal and a plastic post-tensioning tendon duct. Two-accelerometer system is employed to improve SIBIE results.

The effect of the distance between impact and detection points is also investigated by changing the position of accelerometers at detection points.

## 2 SIBIE PROCEDURE

Since it is often not easy to identify the particular peaks in the frequency spectrum in the impact-echo method, an imaging procedure is applied to the result of FFT analysis as SIBIE (Stack Imaging of spectral amplitudes based on Impact-Echo). So far, SIBIE 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 1. Then, resonance frequencies due to reflections at each element are computed. The travel distance from the input location to the output through the element is calculated as (Ohtsu, 2002),

$$R = r_1 + r_2. \qquad (1)$$

Resonance frequencies due to reflections at each element are calculated from,

$$f_2' = \frac{C_p}{r_2}, \qquad \text{and} \qquad f_R = \frac{C_p}{R}. \qquad (2)$$

Spectral amplitudes corresponding to these two resonance frequencies in the frequency spectrum are summed up. Thus, reflection intensity at each element is estimated as a stack image. The minimum size of the square mesh Δ for the SIBIE analysis

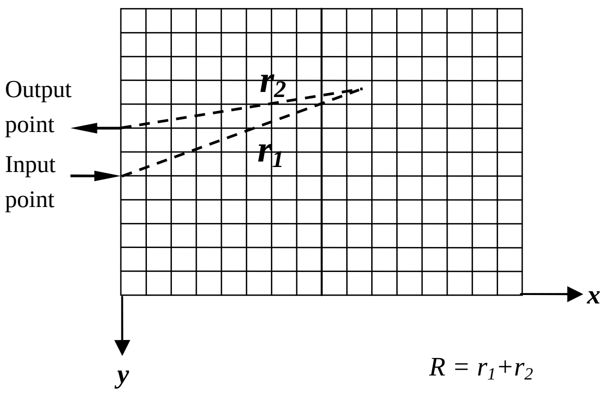



Figure 1. Spectral imaging model.

should be approximately equal to $C_p\Delta t/2$, where $C_p$ is the velocity of P-wave and $\Delta t$ is the sampling time of a recorded wave.

## 3 EXPERIMENTAL STUDY

The experimental work was carried out in the laboratory. Impact tests were conducted by shooting an aluminum bullet at the surface of a concrete specimen. Dimensions of the specimen are 1000 mm x 400 mm x 260 mm which contains an ungrouted metal sheath and an ungrouted plastic sheath. In order to confirm application of SIBIE to a plastic tendon duct, a specimen containing a plastic sheath was made. The specimen is illustrated in Figure 2. Locations of the tendon ducts are shown in the figure. The aluminum bullet of 8 mm diameter was shot by driving compressed air with 0.05 MPa pressure to generate elastic waves. It is confirmed that the upper bound frequency due to the bullet could cover up to 40 kHz, by using an accelerometer system. Fourier spectra of accelerations were analyzed by FFT (Fast Fourier Transform). Sampling time was 4 μsec and the number of digitized data for each waveform was 2048. The locations of impact and detection are also shown in Figure 2. Two accelerometers were used at the detection points to record surface displacements caused by reflections of the elastic waves. The frequency range of the accelerometer system was from DC to 50 kHz. Locations of accelerometers attached were changed to investigate the effect of the distance between the impact and detection points. These distances are 20 mm, 30 mm, 40 mm, 50 mm and 90 mm. P-wave velocity of the test specimen was obtained as 4025 m/s by the ultrasonic pulse-velocity test. Mixture proportions of concrete are listed in Table 1, along with the slump value and air contents. Mechanical properties of concrete moisture-cured at 20°C for 28 days are summarized in Table 2.

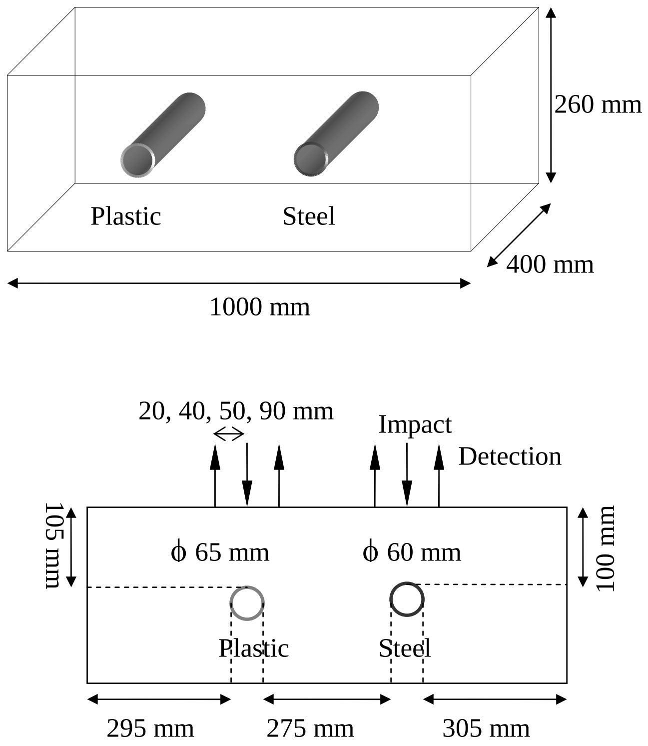



Figure 2. Concrete specimen tested.

Table 1 Mixture proportion and properties of concrete.

| | Weight per unit volume (kg/m$^3$) | | | |
|---|---|---|---|---|
| W/C (%) | Water | Cement | Fine aggregate | Coarse aggregate |
| 55 | 182 | 331 | 743 | 1159 |

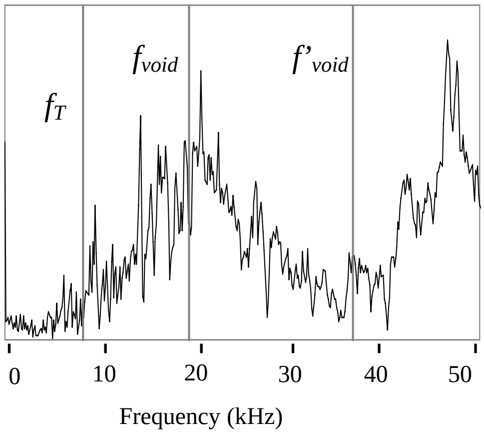
| Admixture (cc) | Slump (cm) | Air (%) | Maximum gravel size (mm) |
|---|---|---|---|
| 132 | 8 | 4.5 | 20 |

Table 2 Mechanical properties of concrete at 28- day standard cured.

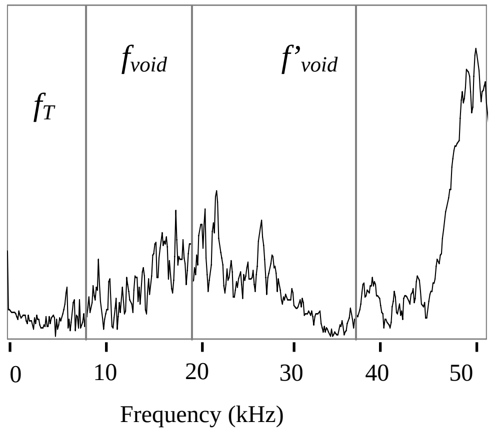
| Compressive strength (MPa) | Young's modulus (GPa) | Poisson's ratio |
|---|---|---|
| 32.5 | 29.8 | 0.28 |

## 4 RESULTS AND DISCUSSION

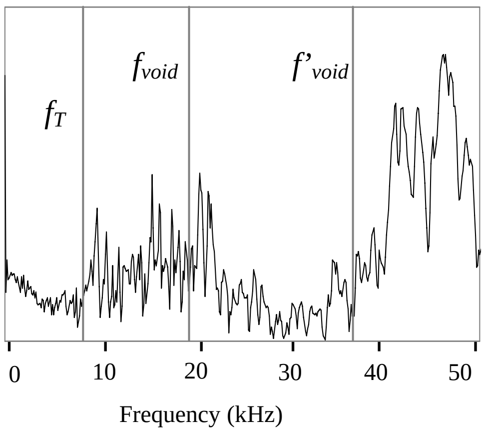
Frequency spectra obtained by the impact-test are given in Figure 3. Figure 3a and b are spectra of impact test of plastic sheath, the former is the result obtained by right accelerometer and the latter is the result obtained by left accelerometer. Figure c and d are results of metal sheath obtained by right and left accelerometers, respectively. Calculated values of



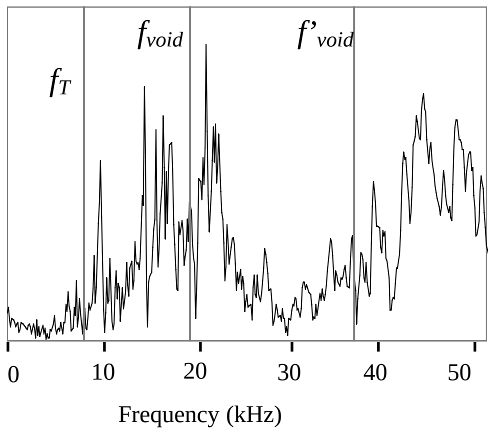

a) Right accelerometer above plastic sheath




b) Left accelerometer above plastic sheath




c) Right accelerometer above metal sheath



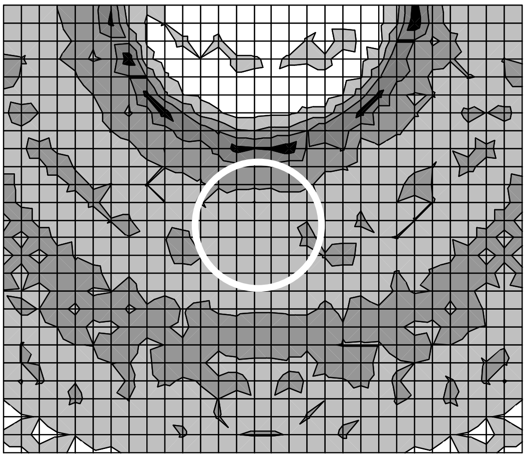

d) Left accelerometer above metal sheath

Figure 3. Frequency spectra obtained by the impact-test (the distance between impact and detection is 20 mm).

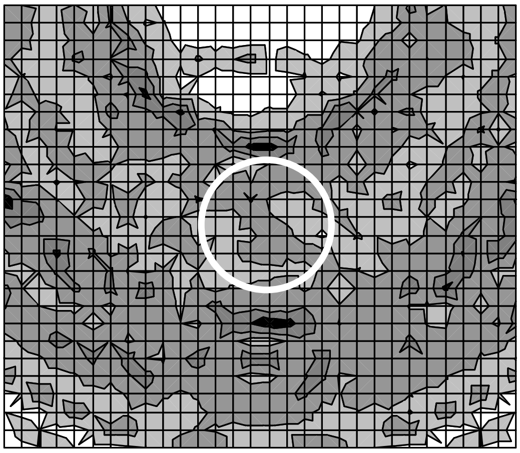
the resonance frequencies due to thickness, $f_T=C_p/2T$ and void, $f_{void}=C_p/2d$ and $f'_{void}=C_p/d$ are indicated with lines (Sansalone, 1997, Ohtsu, 2002). It can be seen from the frequency spectra that it is difficult to identify particular peaks since there exist many peaks. Even in the case of a metal sheath, it is still difficult to interpret the frequency spectra.

SIBIE analysis was conducted by simply adding two impact-echo results obtained from two accelerometers for each case to visually identify location of void in plastic and metal sheaths. The cross-section of the concrete specimen was divided into square elements to perform the SIBIE analysis. In this study, the size of square mesh for SIBIE analysis was set to 10 mm. SIBIE results for plastic sheath are given in Figure 4, which shows a cross-section of half of the specimen where the plastic sheath is located. In Figure 4a, SIBIE result of impact test for the case of impact-detection distance 20 mm, which is smaller than the plastic sheath diameter, is given. The dark color zones indicate the higher reflection due to the presence of void. It is clearly seen that there is a high reflection in front of the ungrouted plastic sheath. No other high reflections are observed. In Figure 4b, SIBIE result of impact test for the case of impact-detection distance 40 mm, which is slightly larger than the plastic sheath diameter, is shown. Black color of high reflection is clearly observed in front of the plastic sheath. There is another high reflection observed below the plastic sheath which might be due to a reflection at the bottom of the tendon-duct. The SIBIE result for the case of impact-detection distance 50 mm is shown in Figure 4c. High reflections are clearly observed in front of the plastic sheath. Similar to the former case, there are reflections observed at the bottom of the duct. For the case of impact-detection distance 90 mm, SIBIE result is given in Figure 4d. High reflections are observed in front of the plastic sheath. There are no other high reflections observed at the cross-section. Thus, it is confirmed that SIBIE procedure is available for void detection within plastic sheaths.

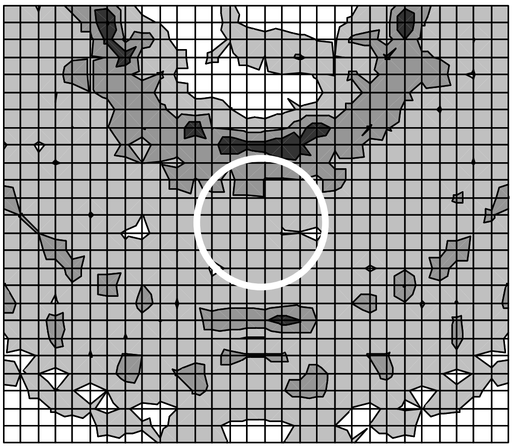
SIBIE results for metal sheath are given in Figure 5, which shows a cross-section of half of the specimen where the metal sheath is located. SIBIE result of impact test for the case of impact-detection distance 20 mm, which is smaller than the metal sheath



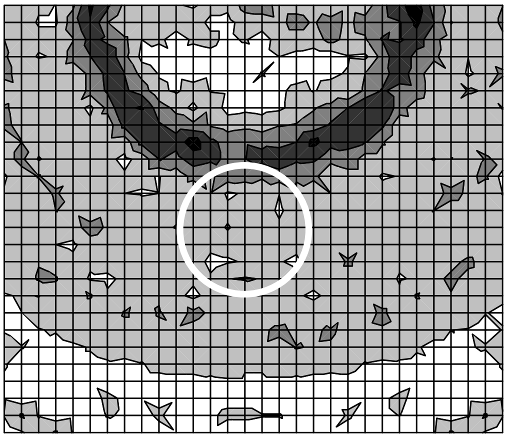
a) Distance between impact and detection is 20 mm.



b) Distance between impact and detection is 40 mm.



c) Distance between impact and detection is 50 mm.



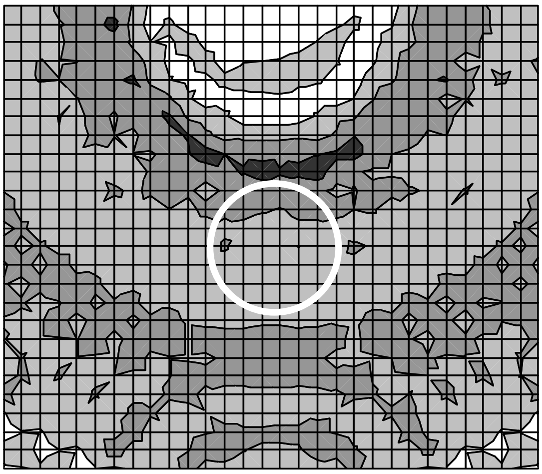
d) Distance between impact and detection is 90 mm.

Figure 5. SIBIE results for plastic sheath (different impact-detection distances).

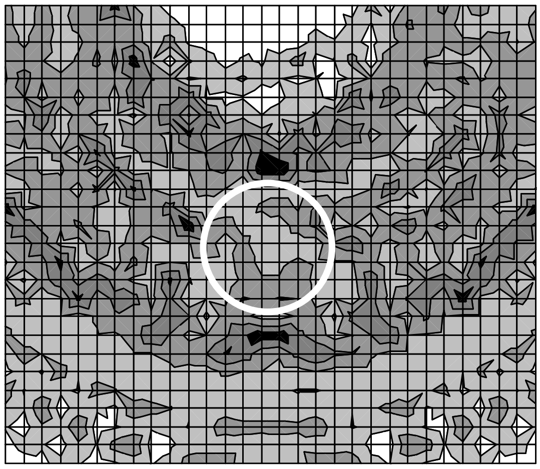
diameter, is given in Figure 5a. High reflections are observed in front of the metal sheath. In case of impact-detection distance 40 mm and 50 mm, SIBIE results are shown in Figure 5b and c, respectively. Reflections are observed in front of the duct and at the bottom of the duct for both cases due to the reflection at the bottom of the metal sheath. . For the case of impact-detection distance 90 mm, SIBIE result is given in Figure 5d. High reflections are observed in front of the metal sheath. There are no other high reflections observed at the cross-section. These demonstrate that SIBIE procedure could identify the location of an ungrouted metal duct.

## 5 CONCLUSION

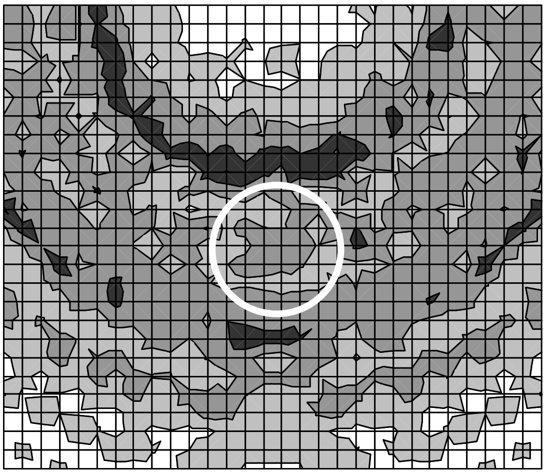
A concrete specimen containing a metal and a plastic post-tensioning tendon duct was tested by applying the SIBIE procedure. Two-accelerometer system was used to detect elastic waves. Impact was applied at the top of the tendon ducts. Distance of impact and detection locations were changed to investigate the effect of it to SIBIE results. Frequency spectra obtained by the impact test show the difficulty to identify the resonance frequencies of void and thickness only from the spectra due to existence of many peaks. In the case of the impact-detection distance is smaller or relatively larger than the sheath diameter, reflections are observed in front of the duct. In the case of the impact-detection distance is almost equal to the sheath diameter, reflections are observed in front and at the bottom of the duct. The most suitable test configuration is the case of the impact-detection distance is almost equal to the sheath diameter. Reflections from both the top and bottom of the tendon ducts can be observed in this case. In all cases, locations of metal and plastic sheaths were identified by SIBIE. Thus, it is demonstrated that SIBIE procedure is available to detect unfilled ducts in prestressed concrete structures.



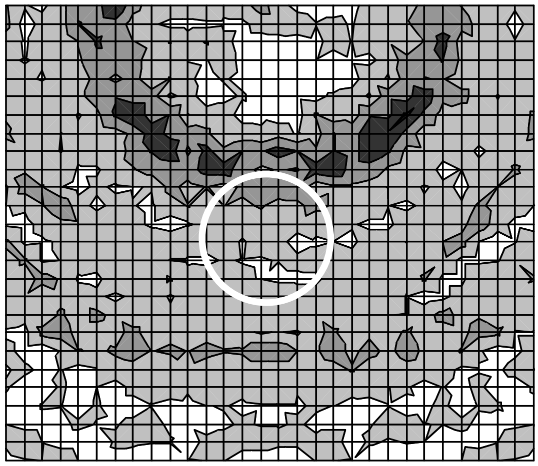
a) Distance between impact and detection is 20 mm.



b) Distance between impact and detection is 40 mm.



c) Distance between impact and detection is 50 mm.



d) Distance between impact and detection is 90 mm.

Figure 6. SIBIE results for metal sheath (different impact-detection distances).

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