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# Evaluation of ungrouted tendon ducts in prestressed concrete structure by SIBIE

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ABSTRACT: Stack Imaging of spectral amplitudes Based on Impact Echo (SIBIE) 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 concluded that results are successful.

## 1 INTRODUCTION

Stack Imaging of Spectral Amplitudes Based on Impact-Echo (SIBIE) procedure is developed to improve the impact-echo method. The impact-echo method is well known as a non-destructive testing for concrete structures (Sansalone 1997 a, 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 duct, it becomes more difficult to interpret the frequency spectrum due to the existence of many peaks. This is because a plastic duct 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 (Alver, 2007). In this study, the procedure is applied to a concrete specimen containing metal and plastic sheaths for post-tensioning tendon duct. Concrete slabs containing an ungrouted duct, a partially-grouted duct, and a fully-grouted duct of metal and polyethylene ducts are tested.

It is demonstrated that the void within tendon duct can be identified with reasonable accuracy by SIBIE in all the cases tested.

## 2 IMPACT-ECHO METHOD

The cross-section of specimen is shown in Figure 1. When the elastic wave is driven, the paths of the elastic wave are shown. Frequency spectrum is interpreted by applied a fast Fourier transform (FFT) analysis to obtained waveform from output point. In this spectrum, peak frequencies are appeared at $f_t$ and $f_{void}$, and 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 covered depth are obtained by substituting the $f_t$ or $f_{void}$ with $C_p$ into these equations.

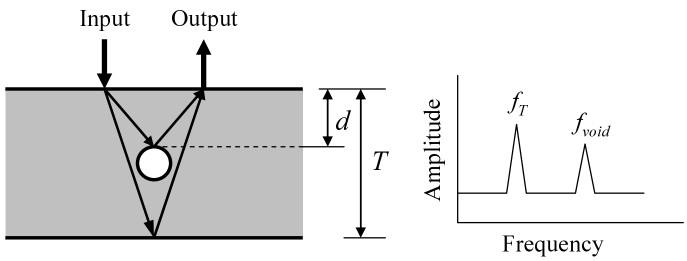



Figure 1. Principle of void detection.

## 3 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.

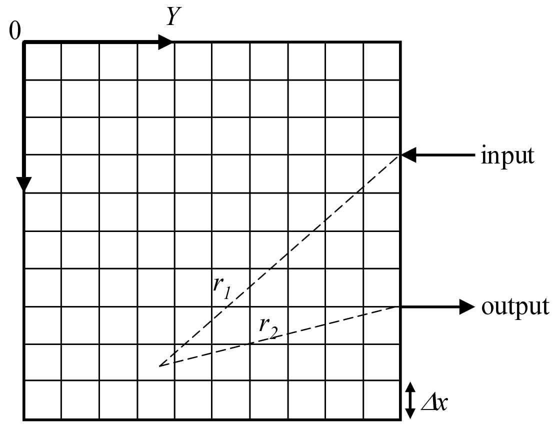



Figure 2. SIBIE imaging model.

Then, resonance frequencies due to reflections at each element are computed. The travel distance from the input location to the output via the element is calculated as (Ohtsu, 2002),

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

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

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

$$f_{r2} = C_p / r_2. \tag{5}$$

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 as Figure 3. The minimum size of the square mesh Δ for the SIBIE analysis should be approximately equal to $C_p \Delta t / 2$.

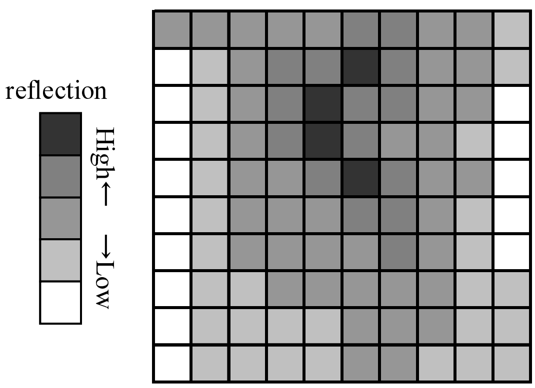



Figure 3. Example of SIBIE result.

## 4 EXPERIMENTAL STUDIES

### 4.1 *Specimen*

For the experiment studies, a concrete specimen was used. The specimen was designed of dimensions 400 mm × 1000 mm × 260 mm and next case. Two post-tensioning tendon ducts were contained in the concrete specimen. The diameter of the metal duct is 60 mm, the polyethylene duct is 65 mm. It is located at 100 mm depth from the top of the specimen. In order to confirm an application of SIBIE to a Polyethylene tendon duct, a specimen containing a Polyethylene duct was made. The specimen is illustrated in Figure 4. First, the ducts were ungrouted at measurement. Next, the ducts were partially-grouted as a Figure 5, then the ducts were fully-grouted. 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.

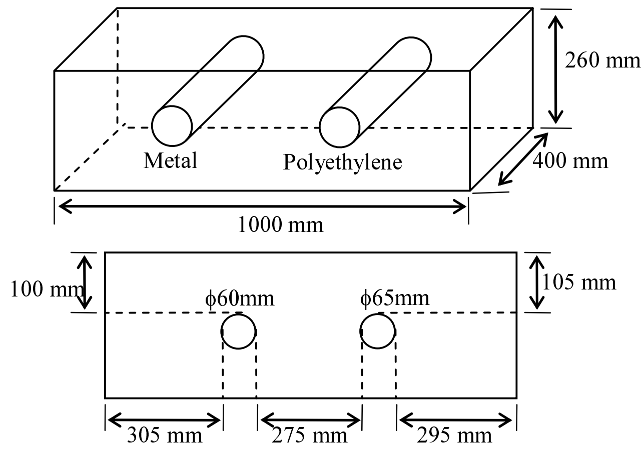



Figure 4. Overview and side view of the specimen.

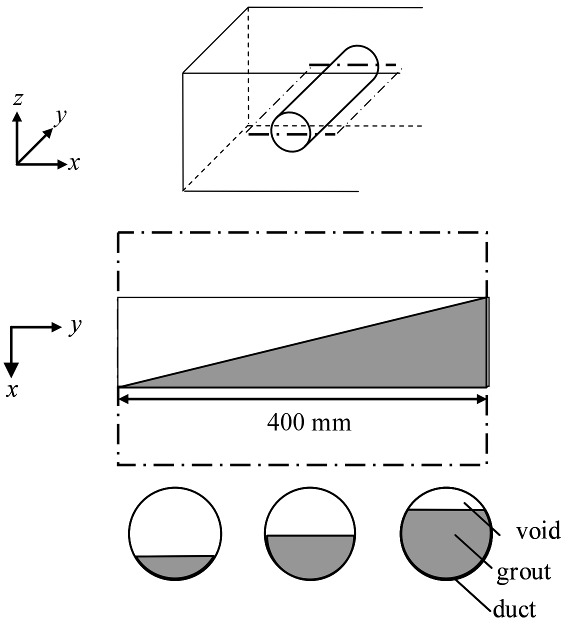



Figure 5. Grouting plan of the specimen.

Table 1. Mixture proportion and properties of concrete.

| Weight per unit volume (kg/m³) | | | | |
|---|---|---|---|---|
| W/C (%) | Water | Cement | Fine aggregate | Coarse aggregate |
| 55 | 182 | 331 | 743 | 1159 |

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 |

## 4.2 *Ultrasonic pulse-velocity test and Impact-test*

P-wave velocity is a very important parameter in using Impact-Echo method. P-wave velocity of the test specimen was obtained as 4025 m/s by the ultrasonic pulse-velocity test. Dimensions of the specimen tested are 100 mm × 100 mm × 400 mm as shown in Figure 6. In the impact test, the aluminum bullet of 8 mm diameter was shot by driving compressed air with 0.05 MPa pressure to generate elastic waves. Figure 7 shows the aluminum bullet. It is confirmed that the upper bound frequency due to the impact could cover up to 40 kHz, by using an accelerometer system. Fourier spectra of accelerations were analyzed by Fast Fourier Transform (FFT). 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 8. Two accelerometers were used at the detection points to record surface motions caused by reflections of the elastic waves.

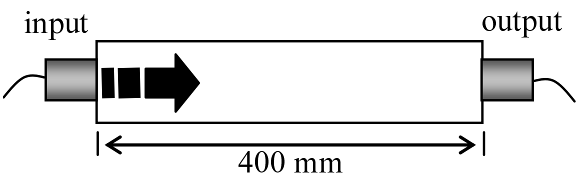



Figure 6. Ultrasonic pulse-velocity test.

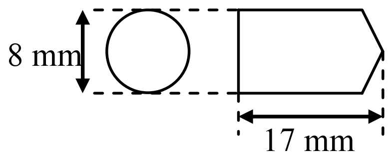
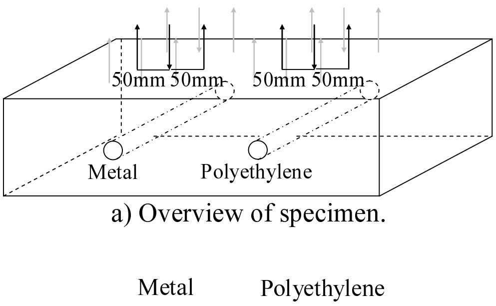
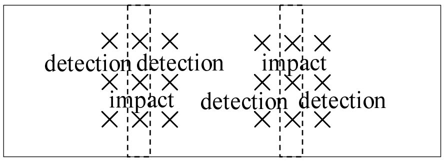


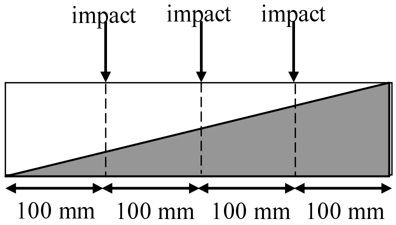

Figure 7. Aluminum bullet.




a) Overview of specimen.




b) Top view of specimen.




c) Cross section view of duct.

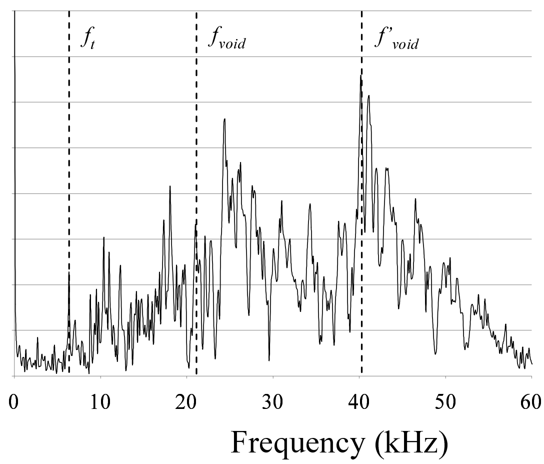
Figure 8. Impact point.

# 5 RESULTS AND DISCUSSION

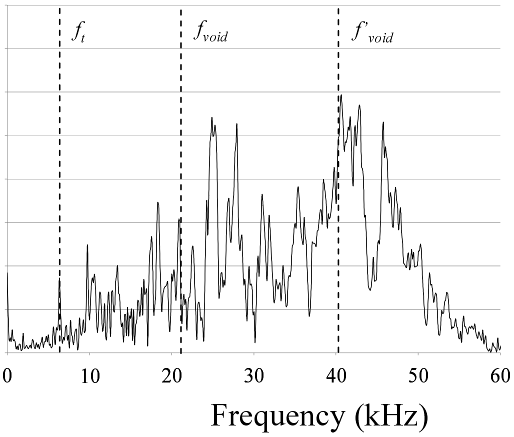
## 5.1 *Results of ungrouted ducts*

Frequency spectra obtained by the impact-test are given in Figure 9. Figures 9a and 9b are spectra of the impact test at the ungrouted polyethylene duct, the former is the result obtained by right accelerometer and the latter is the result obtained by left accelerometer. Figures 9c and 9d are results of the ungrouted metal duct obtained by right and left accelerometers, respectively. Calculated values of the resonance frequencies due to thickness, $f_T = C_p/2T$, void, $f_{void} = C_p / 2d$ and $f'_{void} = C_p / d$ are indicated with lines (Sansalone, 1997, and Ohtsu, 2002). It can be seen from the frequency spectra that it is difficult to identify particular peaks since there are many peaks.

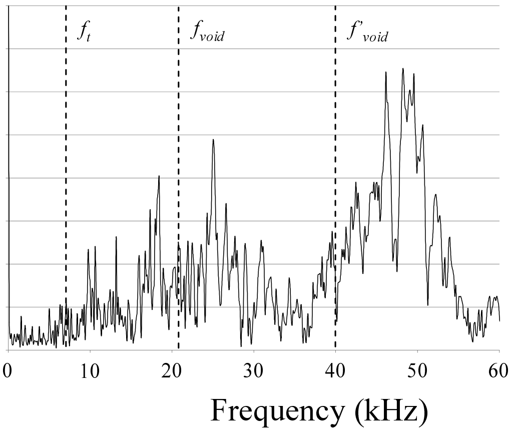
SIBIE analysis was conducted by simply adding two impact-echo results obtained from two accelerometers for each case to visually identify location of the void in polyethylene and metal ducts. The cross-section of the concrete specimen was divided into square elements to perform the SIBIE analysis. In this study, the size of square mesh for SIBIE analysis was set to 10 mm. By using the frequency spectra given in Figure 9, the SIBIE analysis was conducted to visually identify the location of the void within the tendon duct. The SIBIE results for polyethylene duct and metal duct are given in Figure 10, which shows a cross-section of half of the specimen where the ducts are located.



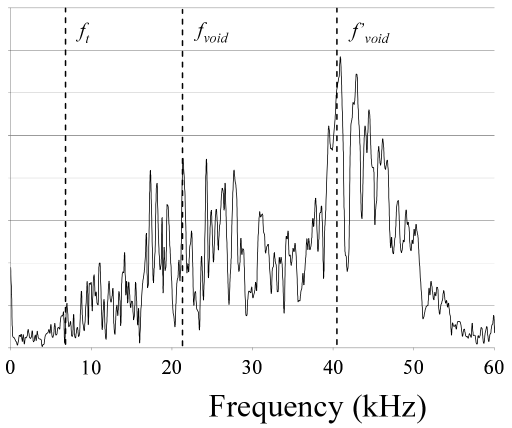

a) Right accelerometer above polyethylene duct.



b) Left accelerometer above polyethylene duct.

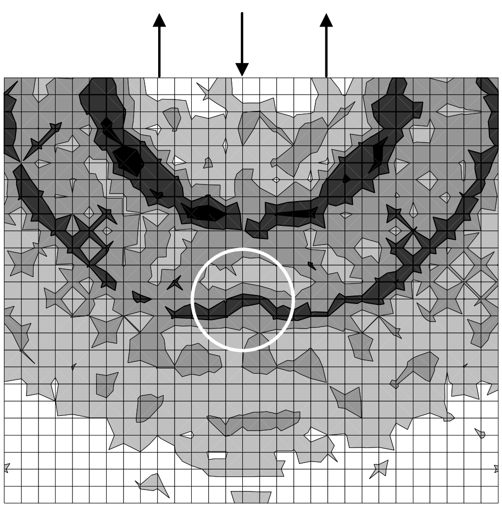


c) Right accelerometer above metal duct.

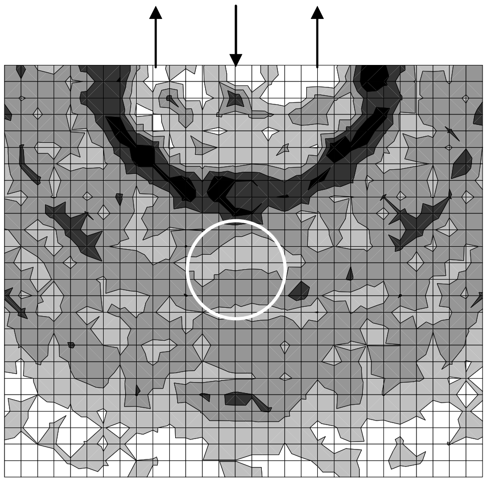


d) Left accelerometer above metal duct.

Figure 9. Frequency spectra obtained by the impact-test (the ducts were undrouted condition).



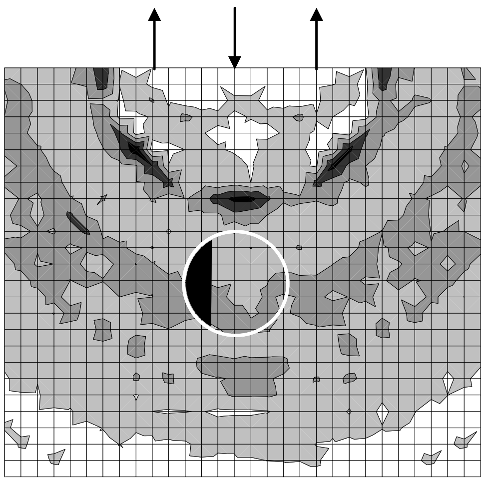
a) Result of SIBIE analysis at polyethylene duct.



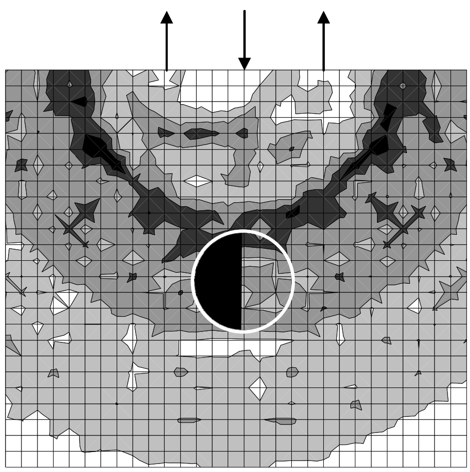
b) Result of SIBIE analysis at metal duct.

Figure 10. Results of SIBIE analysis (the ducts were ungrouted condition).

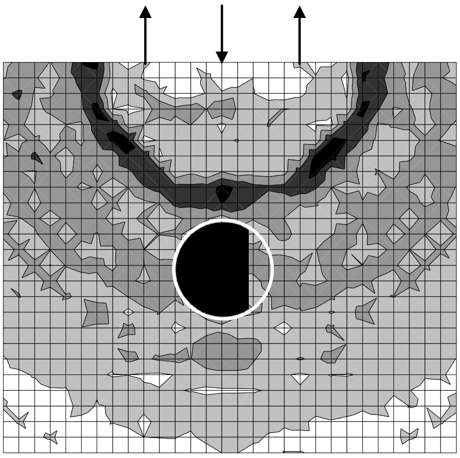
The dark color regions indicate the higher reflection due to presence of void. Open circles indicate the ducts, and the impact point and the detection points are indicated by up-pointing arrows and a down-pointing arrow, respectively. It is clearly seen that there exists high reflection zone in front of the ungrouted metal and polyethylene ducts. There are no other high reflections observed at the cross-section. It is also confirmed that the location of polyethylene duct can be cleary identified by SIBIE procedure.



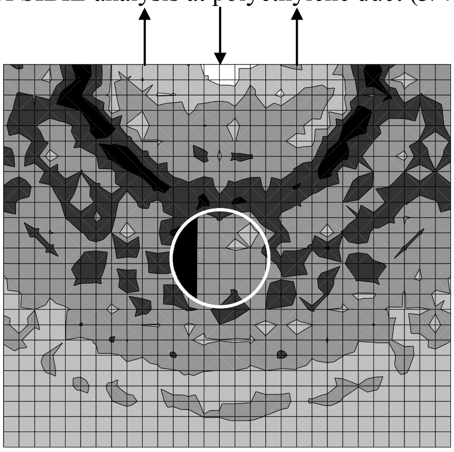
a) Result of SIBIE analysis at polyethylene duct (1/4 grouted).



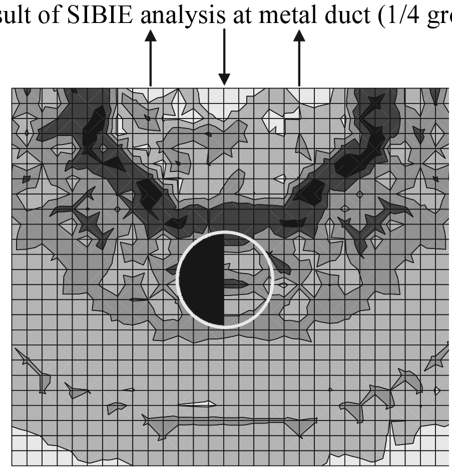
b) Result of SIBIE analysis at polyethylene duct (1/2 grouted).



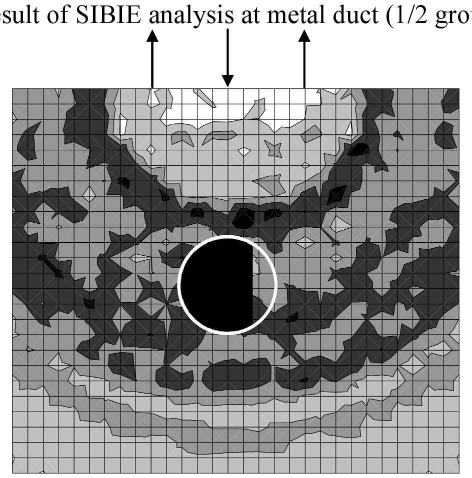
c) Result of SIBIE analysis at polyethylene duct (3/4 grouted).



d) Result of SIBIE analysis at metal duct (1/4 grouted).



e) R esult of SIBIE analysis at metal duct (1/2 grouted).



f) Result of SIBIE analysis at metal duct (3/4 grouted).

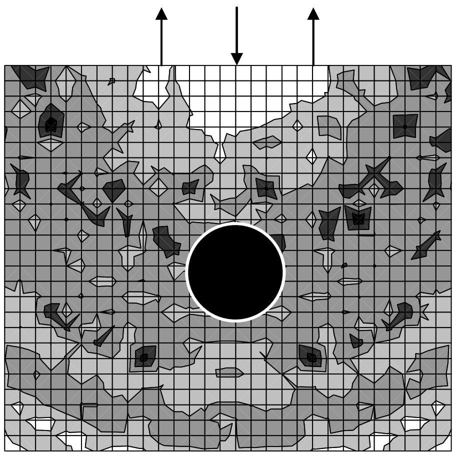
Figure 11. Results of SIBIE analysis (the ducts were partially-grouted condition).

### 5.2 *Results of partially-grouted ducts*

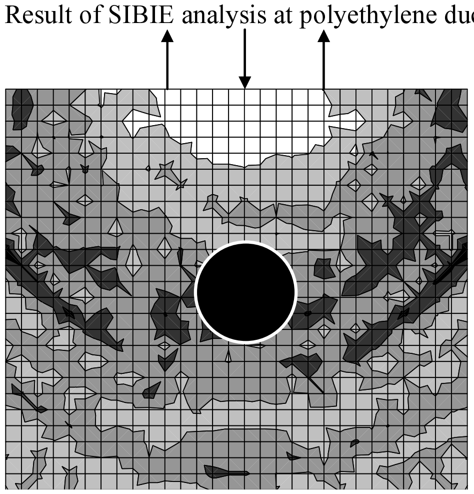
In Figure 11, SIBIE results of impact test for the case of partially-grouted ducts are shown. Black color of high reflection is clearly observed in front of the both types of the ducts. There are no other high reflections observed at the cross-section. It is also confirmed that the location of polyethylene duct can be identified by SIBIE procedure.

### 5.3 *Results of fully-grouted ducts*

The SIBIE results for the case of fully grouted is shown in Figure 12. Reflections can not observe in front of the polyethylene duct. Similar to the metal duct, reflections can not observe in front of the duct. Thus, it is confirmed that the SIBIE procedure is available for void detection within post-tensioning tendon duct.



a) Result of SIBIE analysis at polyethylene duct.



b) Result of SIBIE analysis at metal duct.

Figure 12. Results of SIBIE analysis (the ducts were fully-grouted condition).

## 6 CONCLUSIONS

Results obtained are summarized as follows:

(1) 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.

(2)The specimen were analyzed by SIBIE procedure. Locations of ungrouted ducts and partially-grouted ducts are visualized successfully. In contrast, no reflections are observed around the fully grouted ducts.

Thus, it is demonstrated that the void within tendon duct can be identified with reasonable accuracy by SIBIE procedure.

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