IDENTIFICATION OF IMPERFECTLY-GROUTED TENDON-DUCT IN CONCRETE BY SIBIE PROCEDURE

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ABSTRACT

SIBIE (Stack Imaging of Spectral Amplitudes Based on Impact-Echo) procedure is an improved alternative method to interpret impact echo data. It is an imaging technique applied to the impact-echo data in the frequency domain. In this study, the application of SIBIE in locating the grouting defects in a partially-grouted tendon duct embedded in a concrete specimen is investigated. Locations of reflectors such as a void or external surfaces can be visualized by SIBIE. Reflections due to the presence of imperfectly-grouted ducts can be visually identified by SIBIE. It is demonstrated that SIBIE is a promising technique for void detection in concrete.

Keywords: Impact-echo, SIBIE, imperfectly-grouted duct

INTRODUCTION

The impact-echo method is an effective method for nondestructive testing of concrete nondestructively. It is based on the use of low-frequency elastic waves that propagate in concrete to determine thickness or to detect internal flaws in concrete. The method was developed and applied by Carino, Sansalone and their co-workers for the detection of flaws or voids in concrete structures. It has been widely applied to identification of void in tendon-ducts [1-3]. In principle, the location of void is estimated by identifying peak frequencies in the frequency spectrum. However, the frequency spectrum can not always be interpreted successfully, because many peaks are often observed in the spectrum due to the multiple reflections and diffractions of body waves as well as the Rayleigh waves and the waves generated by their rebounding from the borders of the concrete member. In order to interpret the impact-echo data and improve the method, an imaging technique has been applied to the data in the frequency domain. This procedure is named SIBIE. SIBIE has been applied to void detection within tendon ducts [4-6]. In this study, the procedure was applied to identify the location of imperfection within a grouted tendon duct.

SIBIE PROCEDURE

Based on the inverse scattering theory in elastodynamics [7], the SIBIE procedure has been developed [8]. 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 [8],

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

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

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

Spectral amplitudes corresponding to these two resonance frequencies in the frequency spectrum are summed up at each mesh. Thus, reflection intensity is estimated as a stack image at each element. The minimum size of the square mesh Δ for the SIBIE analysis should be approximately equal to $C_p\Delta t/2$, where C_p is the velocity of P-wave and Δt is the sampling time of a recorded wave.

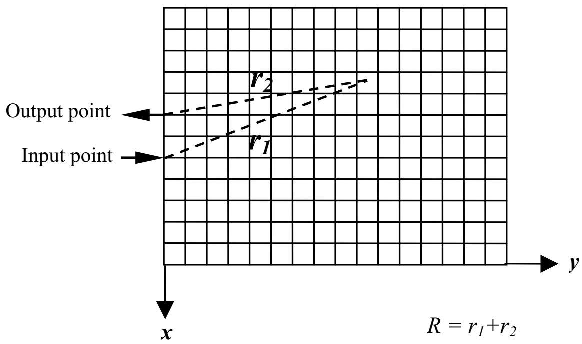


Figure 1 Spectral imaging model.

EXPERIMENTAL INVESTIGATION

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. 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.

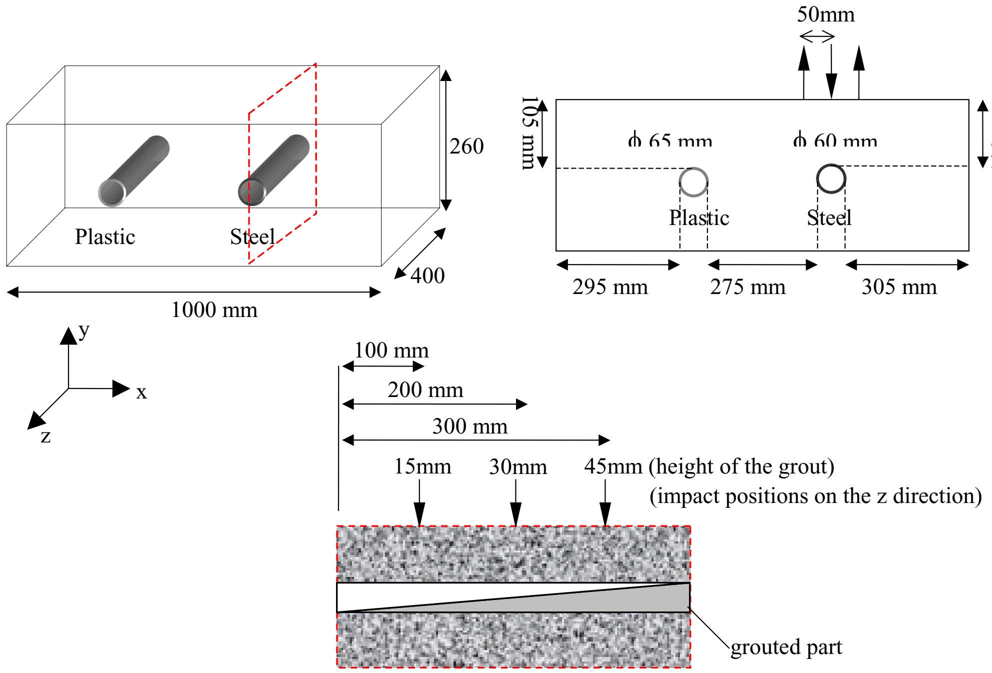


Figure 2 Concrete specimen tested.

Table 1 Mixture proportion and properties of concrete.

W/C (%)	Water	Cement	Fine aggregate	Coarse aggregate	Admixture (cc)	Slump (cm)	Air (%)	Maximum gravel size (mm)
	Weight per unit volume (kg/m^3)							
55	182	331	743	1159	132	8	4.5	20

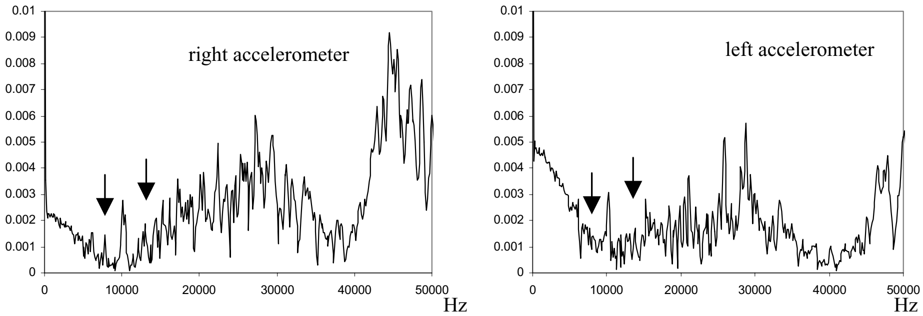
Table 2 Mechanical properties of concrete at 28- day standard cured.

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

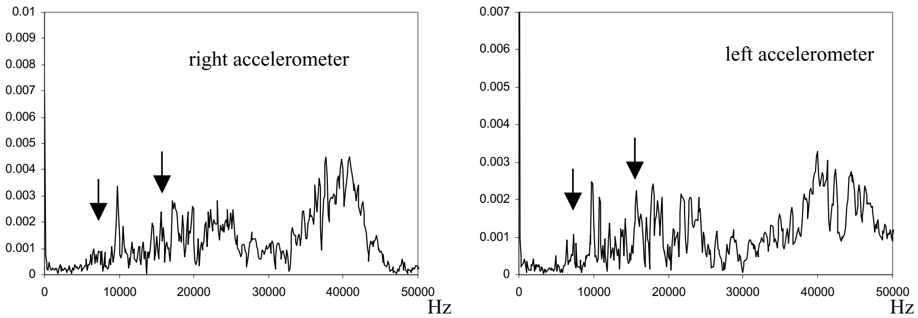
P-wave velocity of the test specimen was obtained as 4025 m/s by the ultrasonic pulse-velocity test. Mixture proportions of concrete are listed in Table 1, along with the slump value and air contents. Mechanical properties of concrete moisture-cured at 20°C for 28 days are summarized in Table 2.

The impact test was applied over the metal duct. The duct was grouted inclined which at one side it was fully empty and at the other side it was fully grouted. The metal duct was tested at three different locations as shown in Figure 2. The height of the grout is 15, 30 and 45 mm in y direction at the positions that impact test was applied.

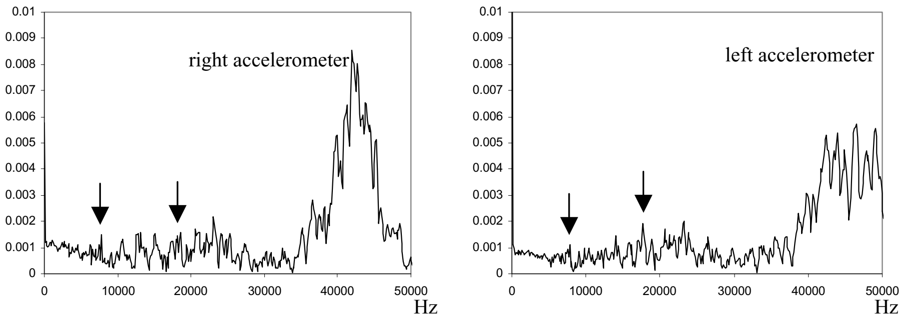
Frequency spectra obtained by the impact-test are given in Figure 3. Figure 3 (a) shows Fourier spectra of the impact test applied at 10 cm in Fig. 2, where the height of the grout is 15 mm, obtained by the right accelerometer and the left accelerometer. Figure 3 (b) shows results of the test at 20 cm where the grouted height is 30 mm. Figure 3 (c) shows results of the test at 30 cm where the grouted height is 45 mm. Calculated values of the resonance frequencies due to thickness, $f_T=C_p/2T$ and void, $f_{void}=C_p/2d$ are indicated with arrows [1, 2]. It can be seen from the frequency spectra that it is difficult to identify particular peaks since there exist many peaks.



(a) Impact applied at 10 cm where grout was 15 mm

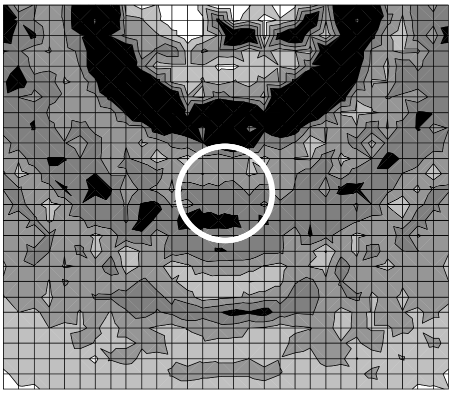


(b) Impact applied at 20 cm where grout was 30 mm

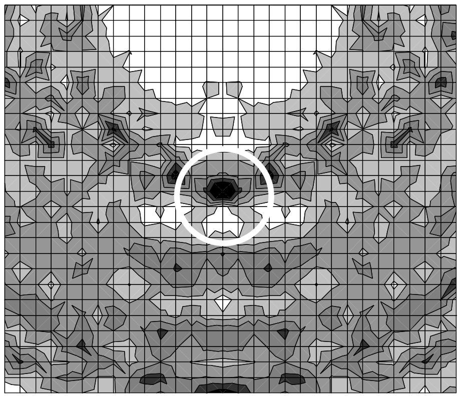


(c) Impact applied at 30 cm where grout was 45 mm

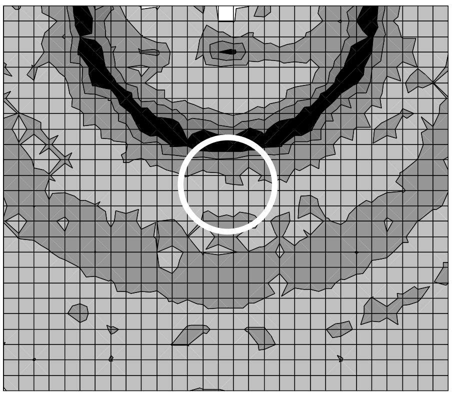
Figure 3 Frequency spectra obtained by impact-test (the impact was applied on top of the partially-grouted tendon-duct.)



(a) Impact applied at 10 cm where grout was 15 mm



(b) Impact applied at 20 cm where grout was 30 mm



(c) Impact applied at 30 cm where grout was 45 mm

Figure 4 SIBIE results

SIBIE analysis was conducted by simply adding two impact-echo results obtained from two accelerometers for each case to visually identify location of grouting faults within the metal sheath. 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 metal sheath are given in Figure 4, which shows a cross-section of half of the specimen where the metal sheath is located. SIBIE result for the impact test applied at 10 cm where the grout is 15 mm is shown in Figure 4 (a). The dark color zones indicate the higher reflection due to the presence of void. There is a high reflection observed in front of the duct and it can be seen that there is a high reflection in front of the ungrouted portion of the duct as well. SIBIE result for the impact test applied at 20 cm where the grout is 30 mm is shown in Figure 4 (b). There is a clear reflection in front of the ungrouted part of the duct. Other reflections are also observed at the back-side surface of the specimen. The result for impact applied at 30 cm where the grout is 45 mm is shown in Figure 4 (c). The high amplitude intensity regions can be seen in front of the ungrouted part of the duct which is slightly away from the exact location due to mesh arrangement. Thus, the location of imperfectly-grouted tendon ducts can be visually identified by SIBIE procedure.

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. Frequency spectra obtained from impact test show that due to existence of numerous peaks it is difficult to interpret the data. In order to visually identify location of grout condition inside the duct, SIBIE procedure was conducted. Reflections in front of an ungrouted part of the duct could be observed. Thus, it can be concluded that high intense regions are observed at locations of reflectors such as voids or external surfaces. Consequently, SIBIE is a promising technique to locate voids in concrete.

REFERENCES

1. Sansalone M.J., and W.B. Streett. *Impact-echo*, Ithaca. NY Bullbrier Press, 1997.
2. Sansalone M. Impact-echo: The complete story. *ACI Structural Journal*, Vol. 94, No. 6, 1997, pp. 777-786.
3. Jaeger B.J. and M.J. Sansalone. Detecting voids in grouted tendon ducts of post tensioned concrete structures using the impact-echo method. *ACI Structural Journal*, Vol. 93, No. 4, 1996, pp. 462-472.
4. Ata, N., S. Mihara, and M. Ohtsu. BEM analysis on dynamic behavior of concrete member due to impact. *Journal of Materials, Concrete Structures and Pavements, JSCE,* Vol.68, 2005, pp.157-163.
5. Alver N. and M. Ohtsu. BEM analysis of dynamic behavior of concrete in impact-echo test. *Construction and Building Materials*, Vol. 21, No. 3, 2007, pp. 519-526.
6. Ata, N., S. Mihara, and M. Ohtsu. Imaging of ungrouted tendon ducts in prestressed concrete by improved SIBIE. *NDT&E International*, Vol. 40, No. 3, 2007, pp. 258-264.
7. Nakahara K. and M. Kitahara. Inversion of defects by linearized inverse scattering methods with measured waveforms. *Proceedings International Symposium on Inverse Problems in Engineering Mechanics (ISIP2000)*, Berlin, Springer, 2002, pp. 9-18.
8. Ohtsu M. and T. Watanabe. Stack imaging of spectral amplitudes based on impact-echo for flaw detection. *NDT&E International*, Vol. 35, No. 3, 2002, pp. 189-196.

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