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CONSIDERATION ABOUT EFFECTIVENESS ON MAGNIFIED CROSS-CORRELATION ANALYSIS IN FREQUENCY DOMAIN BY DETECTION OF UNDERGROUND PIPING

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Abstract

The purpose of this research is to detect underground piping, which are buried under 60 cm to 124 cm from surface using seismic method. Seismic method is generally used to inquire underground condition by receiving the reflection waves. Generally as a seismic source a hammer or gunpowder is used. However they are not capable of generating an arbitrary seismic wave. In this research, as a seismic source giant-magnetostriction vibrator was used. This vibrator can generate an arbitrary elastic wave in various frequency domains.

As a conventional method, cross-correlation analysis is applied to distinguish reflection waves and other waves. However it is not sufficient to obtain desirable result. Therefore as a new analysis Magnified Cross-Correlation Analysis in Frequency Domain was proposed. To consider effectiveness of this analysis, the experiments of detecting underground concrete blocks and piping were conducted using that analysis.

Concrete blocks and piping are buried underground the depth of 60cm to 124cm from the surface. As a result, the depth of underground piping and concrete blocks were estimated in high precision, and the effectiveness of Magnified Cross-Correlation Analysis in Frequency Domain was confirmed.

INTRODUCTION

When burring underground pipes, it is necessary to check the site of underground condition referring to the sign or the plan. However some obstacles such as an unknown pipe, which was buried incorrect place and a stone may be discovered under construction of piping. In these cases, they must be removed or the position where pipes are going to be buried must be reconsidered. To avoid these cases, it is necessary for inquiring the site of underground conditions before a construction. Seismic, Electrical and Electromagnetic methods are generally used. However, all methods have downsides. Electrical and Electromagnetic methods are difficult to use in swamps or where it rains hard. Because water content of soil and soil particle size influences electric currents and electromagnetic waves. Investigating those places, attained data must be revised considering water content.

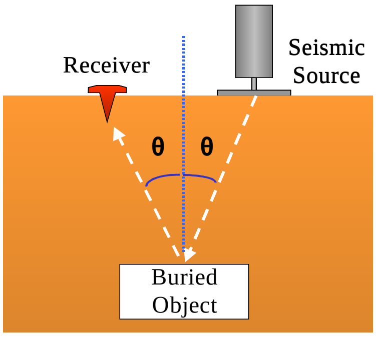

Figure 1 - Schematic of seismic method

Figure 1 shows the schematic of Seismic method. A seismic source generates seismic waves. Those waves are propagated underground and reflected by underground objects. Then receivers observe reflection waves. Using the arrival time of reflection wave and the velocity of elastic wave, a depth of buried object can be estimated. Giant-Magnetostriction vibrator was used as seismic source. This vibrator generates arbitrary large displacement seismic waveforms at high speed. Arbitrary waveforms are appropriate to obtain desirable result. Since output waveform is more stable than using unstable waveform, and frequency domain can be controlled. Then, the results of the cross-correlation analysis are going to be reliable.

The purpose of this research is to detect underground piping and objects. At first the experiment of detection underground concrete block was conducted. As a new analysis Magnified Cross-Correlation Analysis in Frequency Domain was proposed in this study. Second using that analysis the experiment of detection underground piping was conducted. Finally the effectiveness of that analysis was confirmed and underground piping and objects were detected.

THE EXPERIMENT OF DETECTION UNDERGROUN CONCRETE BLOCK

To detect underground objects, a concrete block that is larger than underground piping, was buried. And then, the experiment was conducted.

Experimental Set Up

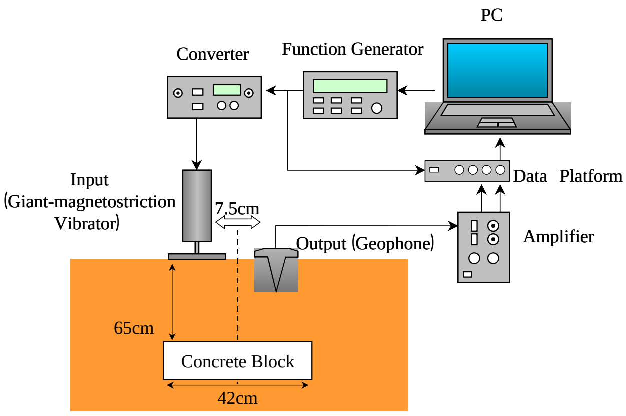

Figure 2 - Schematic of experimental set up

Figure 3 - Giant-Magnetostriction vibrator for Primary wave

Figure 2 shows the schematic of experimental set up and underground concrete block. In this study, a concrete block was buried 65 cm below ground. Concrete block is with dimensions of 42 cm major axis, 15 cm middle axis, and 12 cm minor axis. Figure 3 shows the picture of giant-magnetostriction vibrator. It was used as a seismic source and generates arbitrary primary waves. The vibrator was set on the surface of the upper part of the middle of the concrete block. And a geophone, which is function as velocity sensor was set on each surface at a distance of 7.5 cm from the vibrator along the major axis of concrete block.

First, arbitrary waveforms are made on PC, and sent to the function generator. Then, voltage waveforms were transformed into the alternative current (AC) waveforms. The AC waveforms were inputted to the giant-magnetostriction vibrator. The output waveforms received by receiver geophones were analyzed on PC. In advance, the velocity of Primary wave was measured underground from 20 cm to 30 cm using vibrator and geophones. As input signals, up chirp signals that have various frequency domains from 250 Hz to 500 Hz were used. Input time is 5 ms.

The depths of detecting objects are very shallow. Hence it is assumed that soil is homogeneous and the velocity of primary wave is constant. In this experiment, the velocity of primary wave is 82.8 m/s.

Experimental Result (detection underground concrete block)

Figure 4 (a) shows one of the input up chirp signal from 300 Hz to 400 Hz. To reduce the noise and improve the received waveforms, output waveforms of 10 trials were averaged. Figure 4 (b) shows the averaged output waveform from the geophone. In Fig. 4 (b) the output waveform has same characteristic with the input waveform. However this characteristic is mainly caused by surface wave, which propagates along the surface. That is why reflection wave are not confirmed.

Then to distinguish between surface wave and reflection wave the cross-correlation analysis was applied to this waveform.

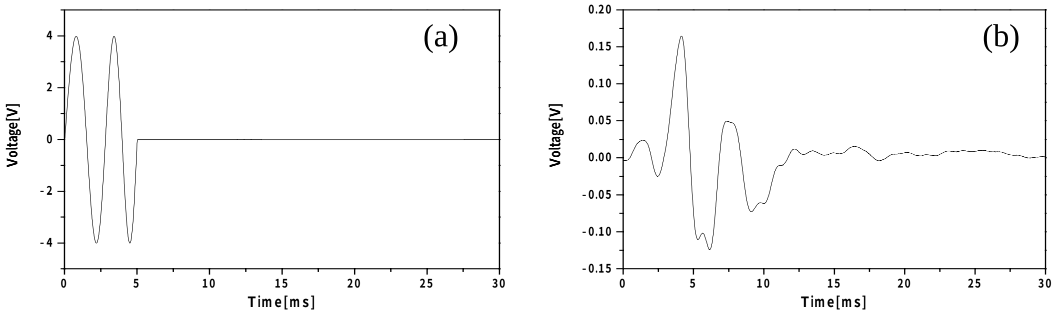

Figure 4 - Input waveform obtained from function generator and output waveform obtained from geophone, (a) Input up chirp signal from 300 Hz to 400 Hz, (b) Output waveform

Cross-Correlation Analysis

The cross-correlation analysis leads to the cross-correlation coefficient that is the similar degree between signal x and signal y. The cross-correlation coefficient $R(j)$ is calculated using eq. (1).

$$R(j) = \left| \frac{1}{N} \sum_{i=0}^{N-1} x_i \cdot y_{i+j} \right| \tag{1}$$

Here,
N : Sum of number of input data and number of output data,
x_i : Amplitude of the i th data of signal x,
y_{i+j} : Amplitude of the $i+j$ th data of signal y,

In this experiment, signal x and y are input waveform and output waveform respectively. It is known that reflection wave and rayleigh wave, which is one of the surface wave, have same frequency characteristic of input waveform [1][2]. Therefore applying the cross-correlation analysis to input waveform and output waveform is appropriate to know the arrival time of reflection wave and rayleigh wave.

Figure 5 (a)～(d) shows the results of cross-correlation analysis. Each figure is in the case of using up chirp signal in different frequency domain. The peak values indicate arrival time of surface wave and reflection wave. Based on this idea, look at these graphs. Plural peak values are shown in Fig.5 (a)～(d). It is not clear that which peak values indicate arrival time of reflection wave. And then comparing the appeared time of the peak values in each graph, those times are little bit different in each. The reason why a lot of peak values caused in different frequency domain is imagined that reflection waves from underground stones or plants are stacked. To distinguish surface waves and reflection wave from a concrete block, an assumption was considered. The peak value of reflection wave from a concrete block is larger than it from other reflection point. And, the time of the peak value of a reflection wave from concrete block is constant irrespective of input frequency domain. To satisfy this assumption, authors propose a new analysis that is named “Magnified Cross-Correlation Analysis in Frequency Domain”.

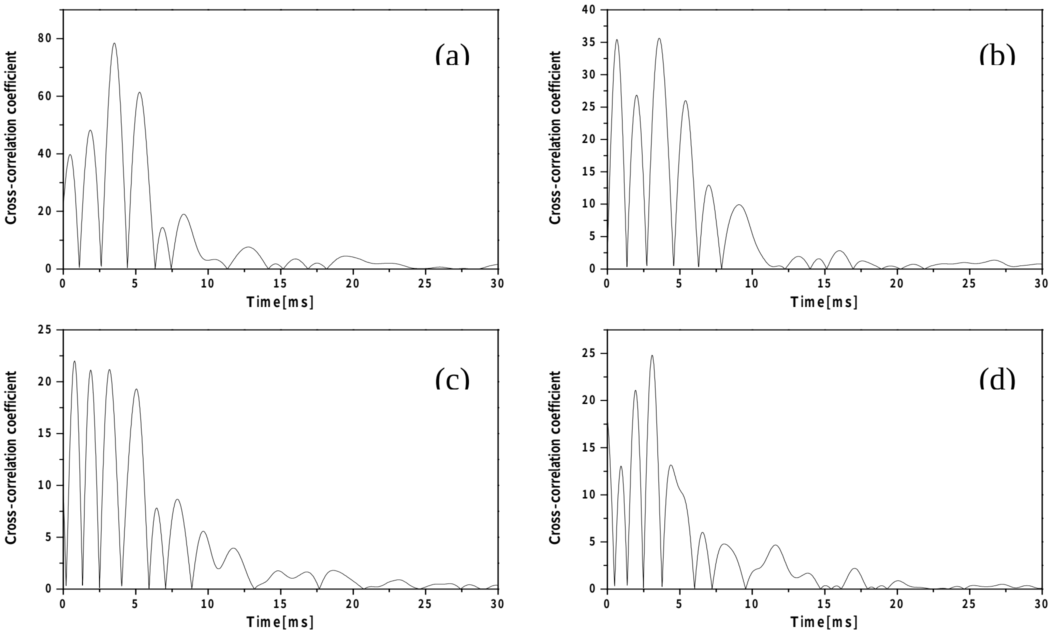

Figure 5 - The result of cross-correlation analysis,
(a) In case of input up chirp signal from 250 Hz to350 Hz, (b) In case of input up chirp signal from 300 Hz to 400 Hz, (c) In case of input up chirp signal from 350 Hz to450 Hz, (d) In case of input up chirp signal from 400 Hz to 500 Hz

Magnified Cross-Correlation Analysis in Frequency Domain

The magnified cross-correlation analysis in frequency domain leads to the magnified cross-correlation coefficient. The magnified cross-correlation coefficient is calculated using eq. (2).

$$M(j) = \prod_{k=1}^{N} R_k(j) \qquad (2)$$

Here,
N : sum of number of the result of cross - correlation analysis,
$R_k(j)$: k th result of cross - correlation analysis of the j th cross - correlation coefficient,

This analysis magnifies peak values that are caused in same time in Fig. 5 (a) ～ (d) by multiplying cross-correlation coefficient. Figure 6 (a) shows the result of magnified cross-correlation analysis in frequency domain. The largest peak value is considered the peak value caused by surface wave. Figure 6 (b) is magnified Fig. 6 (a) from 5 ms to 25 ms referring to the estimated arrival time of reflection wave using the velocity of primary wave. In Fig. 6 (b), the peak value is observed after damping the largest peak value. The appeared time of this peak value was considered to be the arrival time of reflection wave. The arrival time of reflection wave is 16.5 ms. Using the velocity of primary wave the depth of concrete block is estimated as 68 cm. The error is 5 %. The concrete block was detected with high accuracy. Then the experiment of detection underground piping was carried out using magnified cross-correlation analysis in frequency domain.

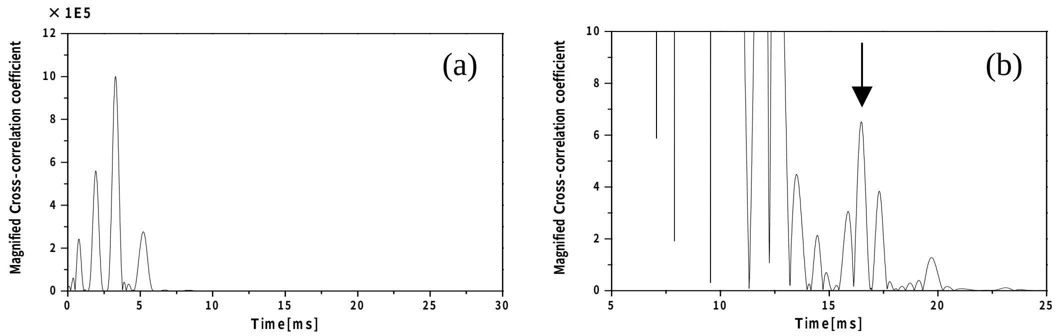

Figure 6 - (a) The result of magnified cross-correlation analysis in frequency domain, (b) Magnified (a) from 5ms to 25ms referring to the estimated arrival time of reflection wave using the velocity of primary wave

THE EXPERIMENT OF DETECTION UNDERGROUND PIPING

The experiment of detection underground piping, which is smaller than concrete block, was carried out.

Experimental Set Up

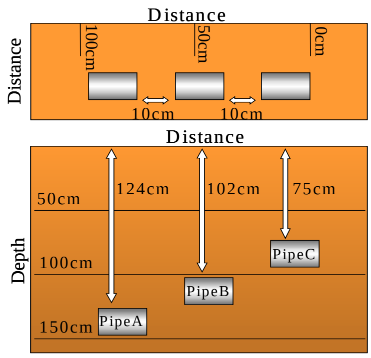

Figure 7 - Schematic of underground piping
Underground piping were buried from 75 cm to 124 cm

Figure 7 shows the underground piping as the targets of detection. In this study, 3 pipes that was made of vinyl chloride, with dimensions of 25 cm major axis, 16.5 cm diameter, were used. These pipes were buried under 75 cm to 124 cm from surface. For convenience each pipes were named A, B and C, respectively. The depth was determined referring to the Tokyo water supply regulations. Experimental set up of detection underground piping is same as it of the experiment of detection underground concrete block. As input signals down chirp signals are used. The frequency domains of them are from 100 Hz to 500 Hz. The velocity of primary wave is 143.7 m/s. Input times are 5 ms, 10 ms and 20 ms. Six variety of input waveform was used.

Experimental Result (detection underground piping)

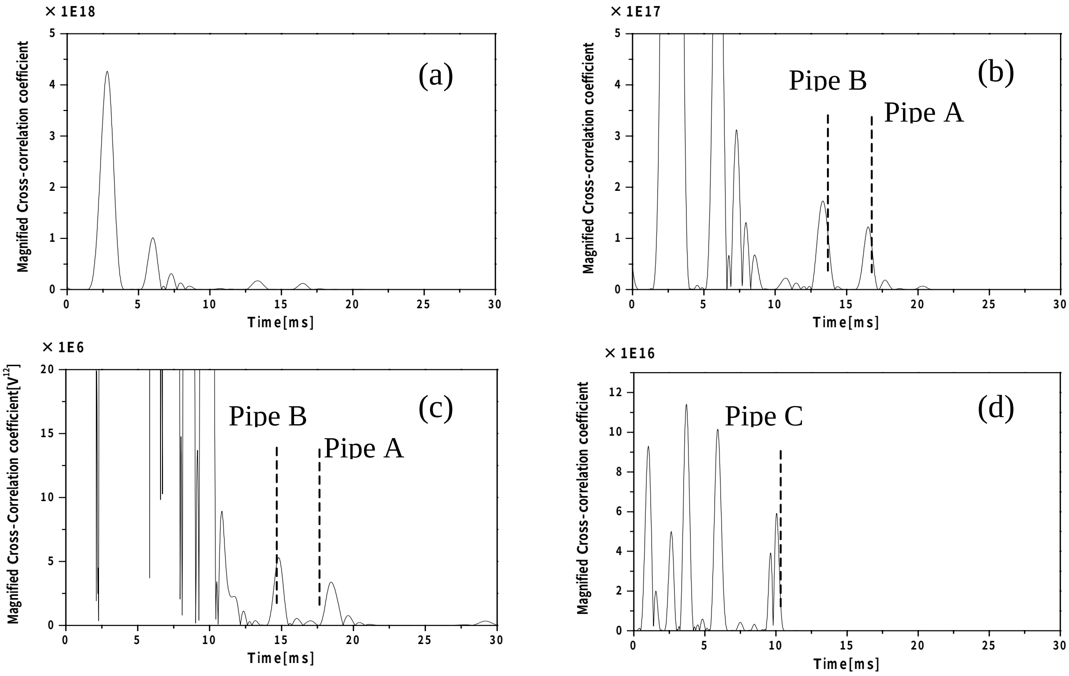

Figure 8 - Result of magnified cross-correlation analysis in frequency domain (a) In case of the giant-magnetostriction vibrator run on pipe A, (b) Magnified (a), (c) In case of the giant-magnetostriction vibrator run on pipe B, (d) In case of the giant-magnetostriction vibrator run on pipe C

Figure 8 (a) shows the result of magnified cross-correlation analysis in frequency domain. Fig. 8 (b) shows the magnified Fig. 8 (a) referring to the estimated arrival time of reflection wave using the velocity of primary wave. Fig. 8 (a) (b) shows the result in case of the giant-magnetostriction vibrator run on middle of pipe A. In Fig. 8 (a), large peak values are shown, it is assumed caused by surface wave. After the enough time damping the influence of surface wave, in other words, the peak values of surface wave are sufficiently damping, two peak values are shown in Fig. 8 (b). The broken lines indicate the estimated arrival time of reflection wave from pipe B and A using the velocity of primary wave. Comparing them with these peak values, it is considered that these peak values indicate reflection wave from pipe B and pipe A respectively. Likewise Fig. 8 (c) and (d) are the results of magnified cross-correlation analysis in frequency domain in case of the vibrator run on the middle of pipe B and C respectively. In Fig. 8 (c) the broken lines indicate the estimated arrival time of reflection wave from pipe B and A. The same trend in Fig. 8 (a) is observed. Therefore it is determined these peak values are caused by reflection wave from pipe B and A. In Fig. 8 (d) the broken line points the estimated arrival time from pipe C. The peak value after damping large peak values is about same time of the estimated arrival time. Accordingly this peak value is determined as the peak value of reflection wave from pipe C.

Using the time of these peak values of analytical results of each pipe and the velocity of primary wave, the depth of underground piping was estimated. Table 1 shows the estimated depth of underground piping. Maximal error was under 7 %. From this result, it is observed that this supposed analysis “Magnified Cross-Correlation Analysis in Frequency Domain” can be used to detect underground piping.

Object to detect	Depth [cm]	Estimated Depth [cm]	Error [%]
Pipe A	124	121	2.4
Pipe B	102	109	-6.7
Pipe C	75	75	0.5

Table 1 - Estimated depth of underground piping and error

CONCLUSION

Underground piping and concrete block were detected with high accuracy using magnified cross-correlation analysis in frequency domain. With this analysis, the same time of peak values in various frequency domains can be magnified. Then the peak values of reflection waves are clearer than by using cross-correlation analysis.

By the way, input frequency is important to conduct seismic method. If low frequency were used, input wave penetrated objects or if high frequency were used, seismic wave quickly damped on the way from seismic source to underground objects. However, using magnified cross-correlation analysis in frequency domain, the trial and error is decrease which frequencies use the best. Since this analysis includes various frequency domains. This analysis is appropriate to detect underground objects. Nevertheless, if very shallow area was wanted to investigate, input times have to be much shorter. Short input times can’t generate enough seismic wave to propagate underground. In the future, to detect objects we want to use cepstrum analysis.

REFERENCES

[1] Books: T. Lay, T. C. Wallace and T. Yanagidani, J*ishin-Gaku (Modern Global Seismology)*, (Kokon sho-in, Tokyo, 2002) [in Japanese].

[2] Books: Society of Exploration Geophysicists of Japan, *Buturi-Tansa*,, (Society of Exploration Geophysicists of Japan, Tokyo, 1989).

[3] Books: A. E. Clerk and H.Eda, *Chojiwai Zairyo (Giant-magnetostriction element)*, (Nikkan Kogyo Shimbun, Tokyo, 1995) p.83 [in Japanese].

[4] Periodicals: Y. Kawamura, T. Ko, K.Noro, K. Mizutani, and N. Aoshima, ” Study on Detecting Underground Piping using Giant-Magnetostriction Vibrator ”, Proc. Symp. Ultrason. 26, 429-430, (2005).