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Measurement of acoustic characteristics in underground with groundwater
地下水のある地中での音響特性の計測

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1. Introduction

Recently, large underground constructs placed at deeper level such as tunnel are increasing to utilize the underground space at urban areas effectively. In case of long-distance tunnel, an alignment check is made via a vertical borehole drilled from the surface above a tunnel face because the measurement using a surveying instrument in the tunnel accumulates an error with a distance. But for a undersea tunnel and a tunnel beneath existing urban areas with the construction, we can not use the positioning technique using vertical borehole . An acoustic method is one of the promising positioing techniques in the underground under the ground water level. Estimation of acoustic characteristics in the soil under the groundwater is important for this technique. In this paper, we present the underground experiment to measure the acoustic characteristics and preliminary results of the acoustic characteristics measurement.

2. Field experiment in the underground

To measure the acoustic characteristics of the soil under the groundwater, we carried out the field experiment in the underground. **Figure 1** shows the measurement configuration in the underground experiment. Five boreholes were used in the measurement. A source was suspended in the borehole of 250 mm in diameter. Four receivers were respectively located in four boreholes of 50 mm in diameter at the depths of 13.8 to 15m. This depth levels were lower than ground water level at the experiment site. We changed the source depth from 15m to 24m. **Table 1** shows the depth of receivers and the distance between source and receiver when source depth is 15.07m. The transmitted signals are a 6th-order M-sequence signal and a burst signal. The carrier frequency was changed from 0.5 kHz to 8 kHz. The transmitted signal was received by each hydrophone. The received signal was digitized at a sampling rate of 1 MHz. The digitized M-sequence signal was

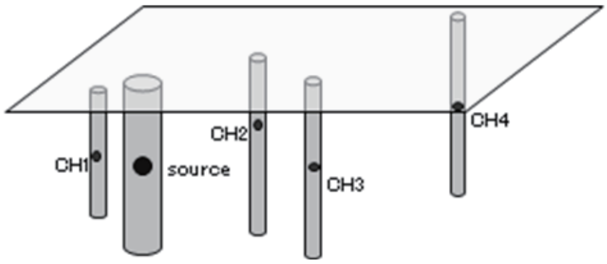

Fig. 1 Measurement configuration

Table 1 Receiver depth and distance from source

Receiver	CH 1	CH 2	CH 3	CH 4
Depth[m]	13.800	13.800	13.800	15.000
Distance from source[m]	3.073	9.034	18.162	49.738

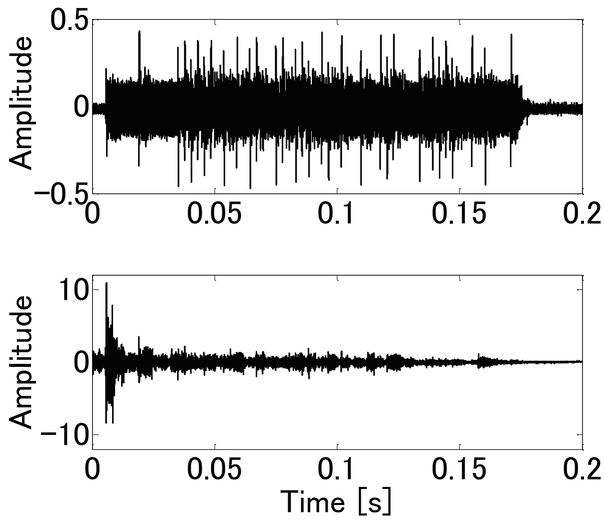

Fig. 2 Received and correlated signals. (3kHz : CH2)

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cross-correlated with a replica of the transmitted sequence to achieve an adequate signal-to-noise ratio and a high travel-time resolution. The predicted improvement of the signal-to-noise ratio for the Gaussian noise was 18 dB. Soil texture of this site was almost sand layer.

3. Results and discussion

Figure 2 shows the received and correlated signals at CH2. The correlated results are equivalent to the results when an eight-cycle pulse of 3 kHz is transmitted. **Figure 3** shows the correlated signals of CH1 and CH2. Because of the difference between the propagation path lengths of source and receivers, we can observe the travel time difference. From this difference, we estimated sound speed of soil layer. **Figure 4** shows the demodulated and correlated signal of CH2 at 3 kHz. From the time difference between the travel times of CH1 and CH2 using the maximum peak, we estimate the sound speed V_a. **Figure 5** shows the correlated signal and extracted leading part of signal using Tukey window. Tukey window is given by

$$\omega(n)=\begin{cases} 1.0 & \left(0\le |n| \le \alpha\dfrac{N}{2}\right) \\ \dfrac{1}{2}\left(1+\cos\left(\pi\dfrac{n-\alpha\frac{N}{2}}{2(1-\alpha)\frac{N}{2}}\right)\right) & \left(\alpha\dfrac{N}{2}\le |n| \le \dfrac{N}{2}\right) \end{cases}$$

where α is selected to be 0.6 in the analysis. From phase difference between extracted signals of CH1 and CH2, we estimated sound speed V_p. **Figure 6** shows the estimated sound speed V_a and V_p of soil layer.

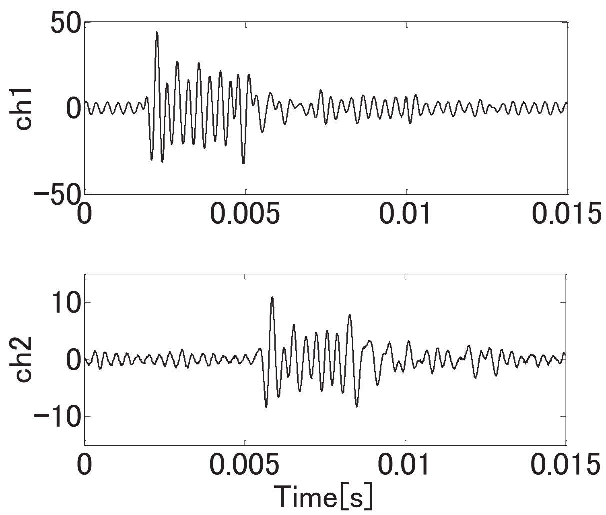

Fig. 3 Correlated signals of CH1 and CH2. (3 kHz)

4. Conclusion

We presented the underground experiment to measure the acoustic characteristics and preliminary results of the acoustic characteristics measurement. Estimated sound speed is about 1675 m/s at 3 kHz.

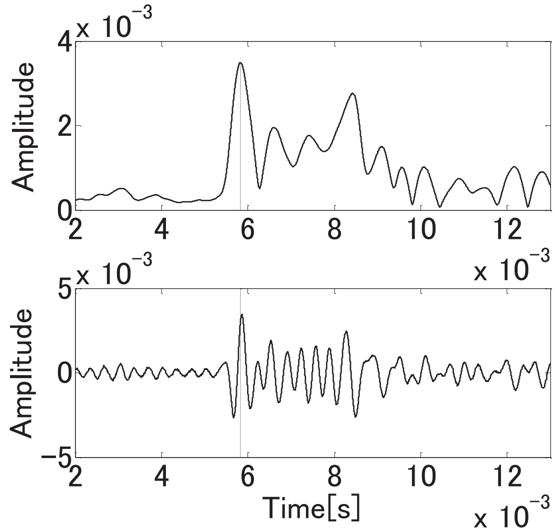

Fig. 4 Demodulated and received signals. (3kHz : CH2)

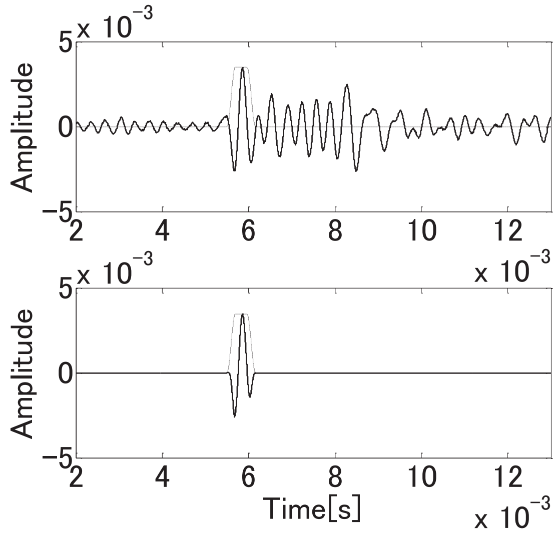

Fig. 5 Correlated signal and extracted leading part of signal using Tukey window. (3 kHz : CH2)

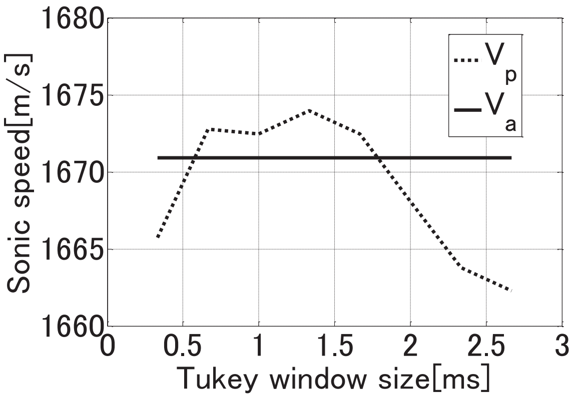

Fig. 6 Estimated sound speed. (3 kHz)