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Frequency characteristics of sound speed and attenuation in underground with groundwater
地下水のある地中の音速・減衰の周波数特性の検討

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1. Introduction

Recently, big underground constructions placed at deeper level such as tunnels are increasing to utilize the underground space effectively. In case of long-distance tunnel, an alignment is made via a vertical borehole drilled from the surface above a tunnel face. However, this positioning techinique cannot be applied to undersea tunnel constructions. So we proposed an acoustic positioning technique which can be applied in underground with groundwater, such as undersea[1)]. In underground, speed and attenuation of sound depend on frequency. Therefore, estimation of frequency characteristics of sound speed and attenuation in underground with groundwater is important for this technique. Underground consists of soil particles and groundwater. Biot-Stoll model is adequate model to explain this structure's acoustic charactaristics[2)]. In this paper, we present estimated results of acoustic characteristics in underground with groundwater from field experiment, and compared estimaton results from experiment with those from Biot-Stoll model.

2. Field experiments

To measure the acoustic characteristics in underground with groundwater, we carried out the sound propagation experiment. We drilled some boreholes in experimental field and placed source and hydrophones into each hole. Detail of the experimental configuration is shown in **Fig. 1**. In this field, groundwater level is 2~3m, and soil texture at a depth of experiment is fine sand. We transmitted 6th-order M-sequence signals (eight waves per a digit) and burst signals, which carrier frequencies were changed from 0.5 kHz to 8.0 kHz to measure frequency characteristics. And they were received by each hydrophone at a sampling rate of 1 MHz. The digitized M-sequence signal was cross-correlated with a replica of the transmitted sequence to achieve an adequate SNR and a high travel-time resolution. The predicted improvement of the SNR for the Gaussian noise was 18 dB. These signals are shown in **Fig. 2**.

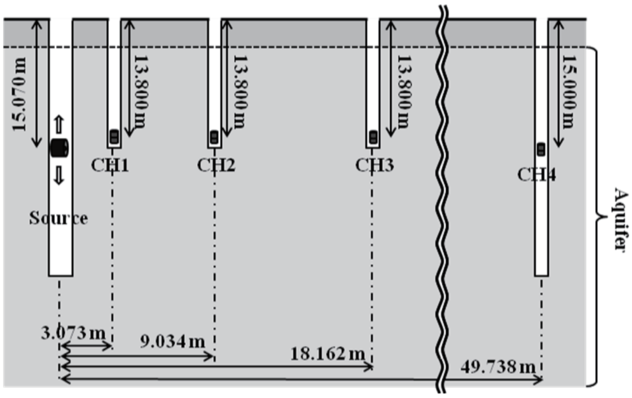
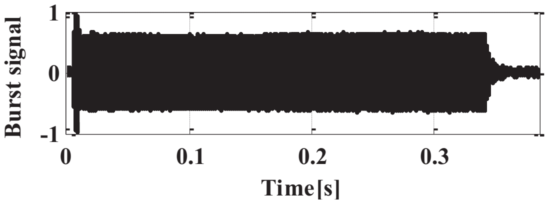
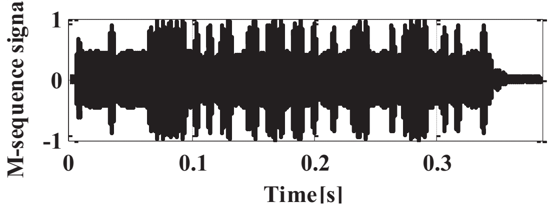


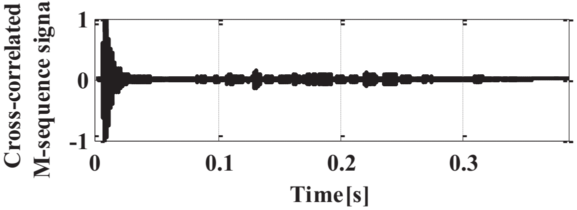
Fig. 1 Field experiment configuration



(a) Burst signal



(b) M-sequence signal



(c) Cross-correlated M-sequence signal

Fig. 2 Received and cross-correlated signals (1.5kHz, CH2)

3. Estimation of sound speed and attenuation

We estimated sound speed from arrival time difference between CH1 and CH2 because those waveforms are close correlation. We estimated arrival time difference by using two methods. One is the method in which we calculate arrival time difference between second zero-crossing points of CH1 and CH2 signals, and another is the method

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using phase difference. We extract the region around zero-crossing point from signal with rectangle window and transform the extracted signals with FFT. Then we calculate arrival time difference from phase difference with equation (1).

$$\Delta T = \frac{1}{2\pi} \cdot \frac{\Delta \theta}{\Delta f} \tag{1}$$

Second zero-crossing point is shown in **Fig. 3**. Extracted signal is shown in **Fig. 4**.

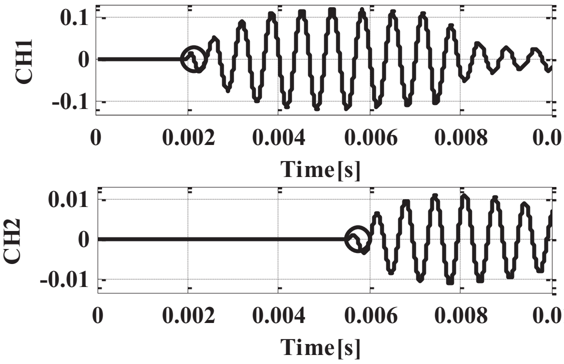


Fig. 3 Zero-crossing points (1.5kHz, CH1 and CH2)

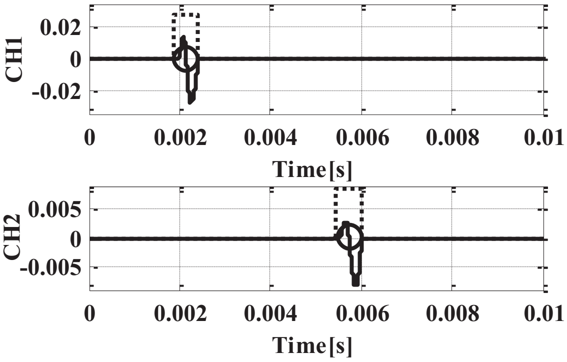


Fig. 4 Extracted signals (1.5kHz, CH1 and CH2)

We also estimated attenuation constant from amplitude of CH1 and CH3. We demodulated each signal and get complex data. This data contains two components, noise component and signal component. We get amplitude as distance between signal component average and zero in complex field. Estimated amplitude is shown in **Fig. 5**.

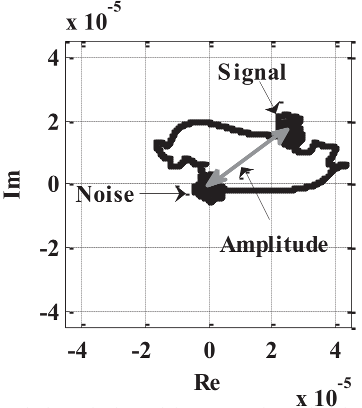
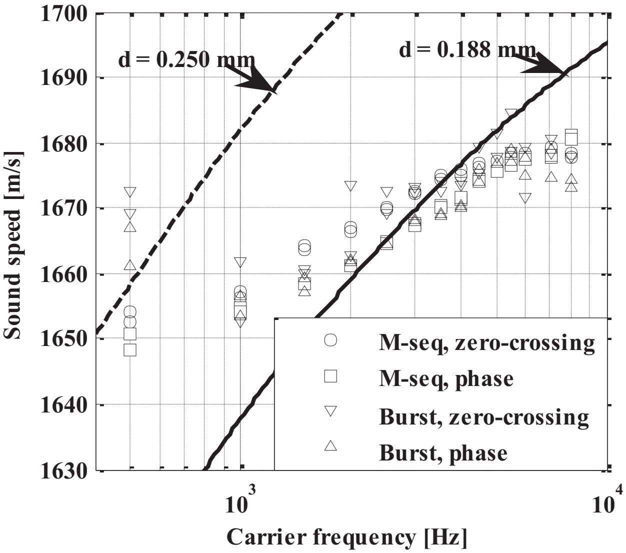


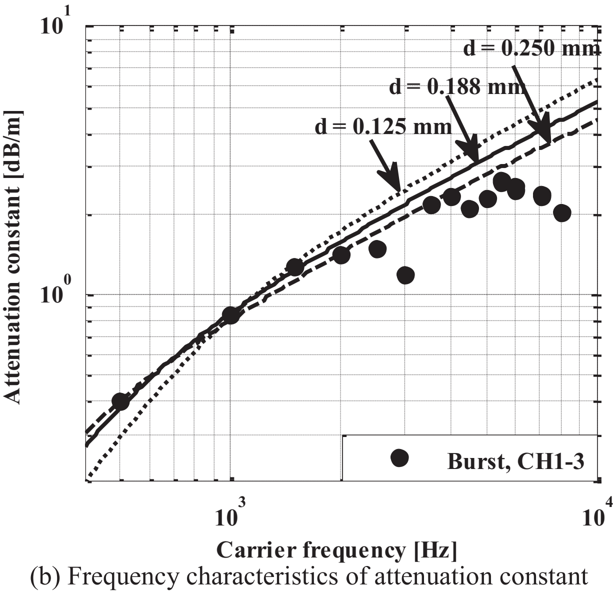
Fig. 5 Demodulated signal in complex field (1.5kHz, CH3)

4. Results

We estimate frequency characteristics of sound speed and attenuation. Estimated results are shown in **Fig. 6**. Solid, dashed and dotted lines correspond to Biot-Stoll model's results, and variable d is an average diameter of soil particle.



(a) Frequency characteristics of sound speed



(b) Frequency characteristics of attenuation constant

Fig. 6 Estimation results of sound speed and attenuation constant.

5. Conclusion

We conducted sound propagation experiment in underground and estimated frequency characteristics of sound speed and attenuation. Estimated results from experiment agree with calculated results from Biot-Stoll model.

References

1. H. Hachiya, T. Nishiyama et al.: Proc. Symp. Ultrason. Electron., **30** (2009) 261.
2. M. Kimura『Mikoketsu taisekibutsu』Marine Acoust. Soc. Jpn., 2000. (in Japanese)