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Measurement of sound velocity using Doppler shift in water tank with temperature gradient

ドプラーシフトを利用した温度勾配が存在する水槽内の音速測定

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1. Introduction

In order to propagate sound waves in the ocean such as sonar, it is necessary to understand the water temperature and salinity structure of the ocean that affect the sound velocity. At present, it is possible to calculate approximate propagation paths using statistical water temperature and salinity distributions. However, the ocean structure changes from moment to moment, it is indispensable to update the data by on site measurement.

Expendable Bathy Thermograph (XBT) is widely used as an inexpensive and convenient method for measuring the vertical temperature distribution in the ocean, and the sound velocity vertical distribution can be obtained by converting the measured temperature distribution into sound velocity. At this time, the salt concentration is used for calculating a constant or statistical value. However, when the salinity concentration in the depth direction is different from the actual one, the error increases in this method. XCTD (Expendable Conductivity Temperature and Depth), which can measure salinity along with water temperature, is not as useful as XBT because it is expensive.

Therefore, we investigated a new method that can directly acquire the sound velocity. In this paper, we propose a remote sound velocity measurement method using acoustics and Doppler shift. The proposed method eliminates the need for information on temperature and salinity, and enables direct acquisition of the vertical sound velocity distribution. The authers conducted the water tank experiment by the proposed method and conducted multiple times and verified.

2. Theory

The Doppler velocimeter, which is widely used at present, calculates the flow velocity using the sound velocity near the velocity meter, but the new equation

$$\Delta f = 2\left(\frac{v_s}{c_s} - \frac{v_t}{c_t}\right) \cdot f \qquad (1)$$

is derivated by Tanaka *et al.* which considered the sound velocity near the reflector c_s. Here, Δf, v_s, and v_t are amount of Doppler shift, source speed and reflector speed.[1)]

In this paper, we consider a case where a sound wave propagates from a sound source moving in water at a moving speed v_s, to a fixed receiver. The reflector is replaced to the sound source, and the wave transducer is regarded as a wave receiver. The sound velocity near the sound source, and the sound velocity near the receiver are c_s and c_t. In Eq. 1, if the moving speed of the receiver is $v_t = 0$, the second term can be ignored.

If the transmitted signal is known, the Doppler shift amount can be calculated from the received waveform. If the moving speed of the sound source is known, the sound speed c_s near the sound source can be calculated. Therefore, the sound velocity profile on the sound source moving way can be acquired by moving the sound source.

For example, assuming that the sound velocity is 1500 m/s and $v_s = 1$ m/s, if the Doppler shift can be measured with an accuracy about $1 / 4.44 \times 10^{-7}$ against the transmission frequency, sound velocity can be calculated with an accuracy about 1 m/s when sound velocity conversion. The wave period to be actually measured is $T = 1 / f$, so the waveform measurement sampling rate must be very high when f is in the order of several tens kHz. On the other hand, when the frequency make be lower, the wave period T become a large value. However, in order to lower the transmission frequency, it is necessary to increase the size of the transmitter used as the sound source. Therefore, the signal emitted from the sound source is set as a burst, and T_b for the burst frequency f_b is measured, to artificially reduce the transmission frequency, and the Doppler shift amount is measured from the cycle T_b of the burst wave.

When measuring T_b, the measurement error is affected by measuring only one point, so the measurement error is reduced by calculating T_b for each sine wave included in the burst wave and averaging.[2-4)]

3. Water Tank Experiment

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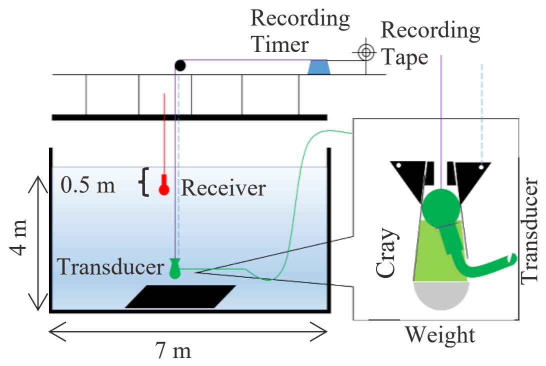

Fig. 1 The set up of experimental equipment.

Authors confirmed whether the sound velocity can be measured theoretically by the proposed method in the experimental tank.

The right side of **Fig. 1** shows schematically the sound source part of the device. The XBT probe is used as a weight. The internal sensor of the XBT probe are removed, and inserting the transmitter into the cleared space. The transmitter was tied a drop - distance measuring wire, and the probe body was tied a stopping wire after the device was activated. The probe was packed with clay to fix the transmitter inside the probe and to absorb the shock when the stopping wire was cut and dropped.

The left side of **Fig. 1** shows schematically the experimental water tank and the set up equipment. The water tank has a length 7 m × width 9 m ×and depth 4 m, and there is a temperature gradient of about 20 °C at the top and about 14 °C at the bottom. There is a bridge near the center that can pass through the upper the tank, and an experimental equipment was installed on this bridge. The probe begins to fall near the surface of the water, passes next to the receiver, and falls. At this time, a fixed point camera is installed at the top of the device and it is confirmed that the probe is falling straightly. The stopping wire using a nylon with good elongation is fixed to the handrail at the top of the water tank, and absorbs the impact after the sound source falls. The measuring wire uses a polyethylene that does not stretch and is attached directly to the recording tape.

The distance traveled in 1 / 100 s is measured on this recording tape to hit the dots 100 Hz by a recording timer to measure v_s. The receiver was suspended at a water depth of 0.5 m in consideration of separation signal and reflected waves from the water surface. The start of signal transmission and hitting the dots are electrically synchronized.

4. Results and discuttion

Fig. 2 shows the relationship between sound velocity and depth about the results of four times experiments. In addition, the values converted into the sound velocity by the UNESCO equation[5,6] from the 5 times CTD measurement results are also shown. The experimental result values close to the sound velocity value calculated by CTD. In the experimental results, the sound velocity was calculated using the sound source moving speed measured by the recording timer and the Doppler shift amount obtained from the received waveform. However, there is a temporal difference between these two data, which is considered to be an electrical delay. Since it occurs, the acoustic data when calculating the Doppler shift amount is shifted by 0.006 to 0.01 seconds for calculation. Although this electrical delay has some differences, it can be considered that it is due to the experimental device because it is roughly quantifiable.

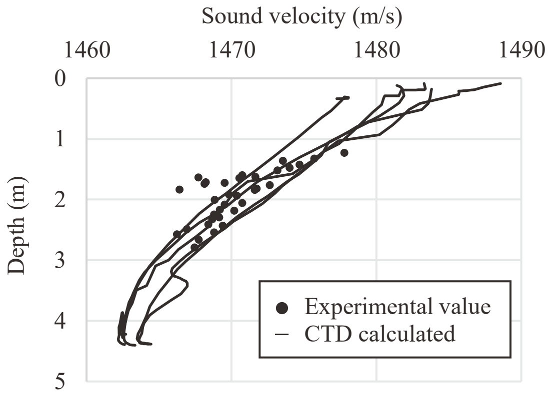

Fig. 2 Result of experiment and CTD calculated

5. Conclusion

In this paper, we proposed a new sound velocity measurement method using Doppler shift, and confirmed the results in a tank experiment. In the tank experiment, we could obtain experimental results that were close to sound velocity calculated by CTD. The time delay when calculating the experimental results was not clearly confirmed about numerical quantitativeness. Author pursued this point and improved accuracy in subsequent study.

References

1. S. Tanaka, H. Nomura, and T. Kamakura: Ultrasonics 94 (2019) 65
2. M. Yoshiguchi, H. Ogasawara and K. Mori: Proc. Marine Acoust. Soc. Jpn. (2020) 1-R-28 [In Japanese]
3. M. Yoshiguchi, H. Ogasawara and K. Mori: Proc. 2020 Spring Meet. Acoust. Soc. Jpn (2020) 20-10 [In Japanese]
4. M. Yoshiguchi, H. Ogasawara and K. Mori: IEICE Technical Report (2020) ?? [In Japanese]
5. C. T. Chen, and F. J. Millero: J. Acoust. Soc. Am. 62 (1977) 1129
6. G. S. K. Wong and S. Zhu: J. Acoust. Soc. Am. 97 (1995) 1732