Comparison of Estimated Pulses Waveform Calculating by FDTD Method and Observed Received Pulse in Shallow Water

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Abstract

Recently, the Acoustic thermometry of the ocean is being planned in shallow water. In order to know characteristics of sound propagation in shallow water, an accurate numerical method of sound propagation is required. We calculated the characteristics of sound propagation using by Finite Difference Time Domain (FDTD) method, because this method is very accurate and is useful for range-dependent model in shallow water.

NEC Corporation carried out the test measurement of synthetic aperture sonar in Uchiura bay in Japan. We compared the reflected pulse observed in the experiment and the estimated pulse from bottom calculated by the FDTD method.

In this paper, we calculated sound propagation characteristics using specification data of sonar in the model. It, however, is not good agreement between estimated pulse and observed pulse, because the bottom is assumed to be flat in the calculation model. In order to obtain good agreement between estimation and measured pulse, we have investigated about the influence of the bottom shape to the sound propagation in shallow water. It is obtained that the reflected sound pulse form bottom will be obtained if the bottom has a sinusoidal shape. A time-of-flight and waveform of reflected pulse agreed well with observed pulse.

Introduction

Ocean Acoustic Tomography (OAT) has been used to observe the phenomenon of global warming, because it has a potential to know the actual temperature structures of water using sound propagation times in ocean. The FDTD method is the famous calculation method in the electro-magnetic field [1]. The method is very useful method for calculate to sound propagation. But it do not applied calculation of sound propagation in deep water, because it is must be required large memory and long calculation time. Recently, the Acoustic thermometry of the ocean is being planned in shallow water. In order to know characteristics of sound propagation in shallow water, an accurate numerical method of sound propagation are required. So, we calculated the characteristics of sound propagation using by Finite Difference Time Domain (FDTD) method. Because this method is very accurate and useful for range-dependent model in shallow water and this method can be applied calculating of sound propagation in shallow water [2].

In this paper, we calculated sound propagation characteristics using specification data of sonar in the model. We compared with observed pulse wave and estimated pulse wave using by FDTD method. And, we have investigated about the influence of the bottom shape to the sound propagation in shallow water. It is obtained that the reflected sound pulse form bottom will be obtained if the bottom has a sinusoidal shape.

Finite Difference Time Domain Method

The FDTD method is the famous calculation method in the electromagnetic field. The basic equations taken account of attenuation in the x-y plane are given as follows [2],

$$-\frac{1}{K}\frac{\partial p}{\partial t}=\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y} \qquad (1)$$

$$-\rho\frac{\partial v_x}{\partial t}=\frac{\partial p}{\partial x}+\eta v_x \qquad (2)$$

$$-\rho\frac{\partial v_y}{\partial t}=\frac{\partial p}{\partial y}+\eta v_y \qquad (3)$$

where p is sound pressure, v_x, v_y are the particle velocity, K is the bulk modulus, ρ is the density and t is time. An attenuation of the medium cased by the absorption is taken account in the second part of the right hand side in eqs. (2) and (3). The velocity of sound c, bulk modules and resistance coefficient η are obtained as shown in eqs. (4) to (6)

$$c=\omega\Big/\sqrt{\gamma_1^2-\gamma_2^2} \qquad (4)$$

$$K=\omega^2\rho\Big/\left(\gamma_1^2-\gamma_2^2\right) \qquad (5)$$

$$\eta=\frac{2\gamma_1\gamma_2}{\sqrt{\gamma_1^2-\gamma_2^2}}\rho c \qquad (6)$$

where γ_1 and γ_2 is wave number and attenuation constant. The finite differential equations are obtained as a function of discrete position x, y in space and discrete time t.

Analysis method and experimental data

Calculation model

NEC Corporation carried out the test measurement of synthetic aperture sonar in Uchiura bay in Japan. In experiment, the center frequency of transducer is 7 kHz and half-bandwidth is 3.0 kHz. The transducer whose grazing angel is 45 degrees projects sound pulses for 20 ms. The half-bandwidth of the transducer in vertical plane is 53 degrees. The depth of transducer is 10 m. The depth in Uchiura bay is about 60 m. It is assumed that the sediment of bottom is sand, the sound speed is 1753 m/s and density is 1.957 g/cm^3.

Figure 1 shows the calculation model of sound propagation in this paper. This model was set same acoustical parameter of observed data in experiment area. The area of calculation model is 60 m in depth and 140 m in propagation range. The boundary condition of sea surface is used pressure release boundary, which equals p = 0. It is necessary to take account the other boundary conditions to prevent the undesirable reflection from the end of computational windows. In this model, we use Mur's 1st older absorption boundary conditions [3]. This model has absorption layer as 400 grids around the calculation area. Figure 2 shows the temperature and sound speed profiles of Uchiura bay in winter. The temperature of sea is about constant value, because Uchiura bay is very silent sea in winter season and do not blow a wind in experiment days. The average value of sound speed is 1505 m/s. In calculation, it is assumed that sound speed of water is constant value, c_1 =1505 m/s, as shown in Fig. 1. The space grid Δx set 0.1 m. This grid size equals 1/20 times wavelength. And the time step set to 8.0 μs from the stability condition.

Observed received pulses

Figure 3(a) shows the observed received pulse waveform in experiment. Figure 3(b) shows logarithmic amplitude of received pulse that works smoothing method. The first pulse that reflected from bottom below transducer is arrival at 64 ms. It is seen that the pulse whose is received at 93 ms reflected from bottom on acoustical axis, because the distance from transducer to bottom on acoustical axis is 140 m.

Calculation results

Comparison with observed pulse wave and estimated pulse wave

We calculated sound propagation using by FDTD method in this model. Figure 4 shows the calculation results of received pulse for sea bottom. In this figure, it is clear that reflected pulse first arrived at 66 ms form sea bottom below the transducer. The 2nd pulse that is reflected bottom on acoustical axis arrive at 92 m. But, unexpected pulse appeared at 20 ms, 100 ms and 120 ms. It, however, is not good agreement between estimated pulse and observed pulse, because the bottom is assumed to be flat in the calculation

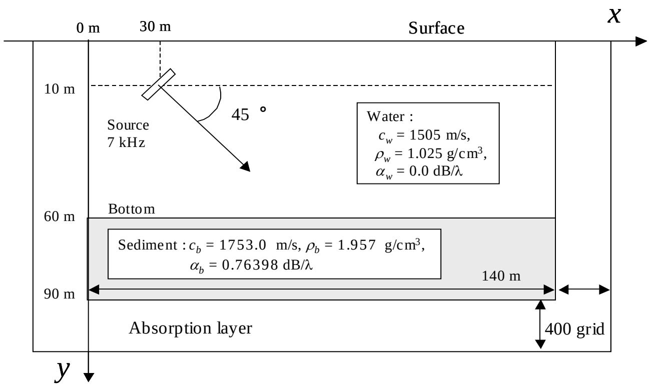
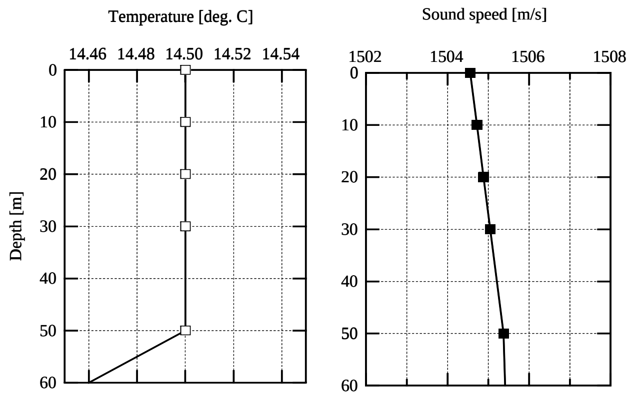


Figure 1 : Geometry of the calculation model of underwater sound propagation using by FDTD method on Uchiura bay in winter.



. Figure 2 : (a) Depth - Temperature profile. (b) Depth - Sound speed profile of Uchiura bay in winter season

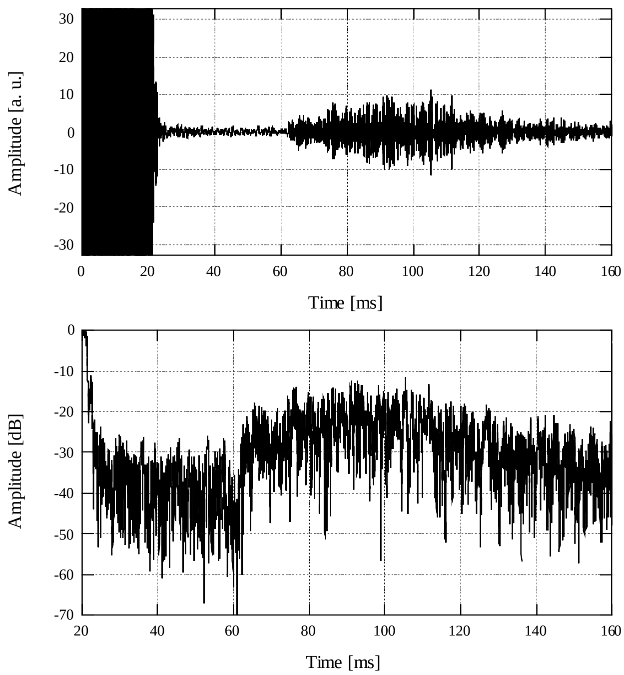


Figure 3 : Observed received pulse waveform. (a) Receiving waveform. (b) Smoothing waveform

model. In order to investigate to the path of these pulses, we calculated propagation of short pulse in the same model. The pulse length is 10 wavelengths. Figure 5 shows the snapshot of sound pressure calculating by FDTD method. Figure 5 (a) shows its snapshot at 25.6 ms.. In this figure, the black horizontal line was shown the boundary of bottom whose depth is 60 m. It is shown that the sound beam propagated in the direction of sea bottom, as shown Fig. 5 (a). The edge wave that was radiated a left edge was propagated to the bottom below the source. The edge pulse of right side was propagated to sea bottom after reflection of sea bottom. Propagation sound that was radiated from the back face of transducer was reflected sea surface. Figure 5 (b) shows a snapshot of sound pressure at 64 ms after sound radiation. In this figure, it is no reflected pulse that was propagated in direction of transducer after reflection from bottom. It is assumed that reflected pulse do not received to transducer, because the bottom is assumed to be flat in the calculation model. It is assumed that the received pulse arrived at 93 ms is edge pulse. The propagation pass of received pulse is multi reflection between sea surface to bottom. First, The edge pulse propagated to the direction of sea bottom below the transducer. The reflected pulse of sea bottom propagated to the direction of transducer. However, the pulse passes thorough the transducer, because sound source in FDTD method is passes thorough waves after projection. Finally, the pulse received the transducer after reflection of surface. The time of receiving pulse is 94 ms, because the total length of propagation pass is 140 m. The pulse wave received at 94 ms was not reflected sea bottom on acoustical axis.

New calculation model with bottom shape

In order to obtain good agreement between estimation and measured pulse, we have investigated about the influence of the bottom shape to the sound propagation in shallow water. The equation of bottom shape is given as follows,

$$\Delta h = a\lambda\cos^2(2\pi x/(\lambda/a)) \qquad (7)$$

where, Δh is height of sea bottom and a is roughness parameter of sea bottom. Δh is proportional to wavelength as shown in eq. (7). It is necessary to prevent the undesirable reflection from the surface. It is assumed that the boundary condition of sea surface used Mur's 1st boundary condition. Figure 6 shows the calculation results of received pulse for sea bottom with sinusoidal shape when length of pulse is 10 wavelengths. In this Figure, pulse wave received at 96 ms. A time-of-flight of reflected pulse agreed well with observed pulse. Figure 7 shows the snapshot of sound pressure calculating by FDTD method in case of new model with sinusoidal bottom. It is observed

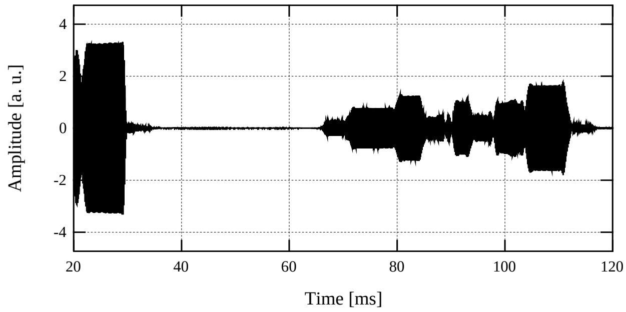


Figure 4 : Estimated pulse waveform whose reflected form sea bottom using by FDTD method.

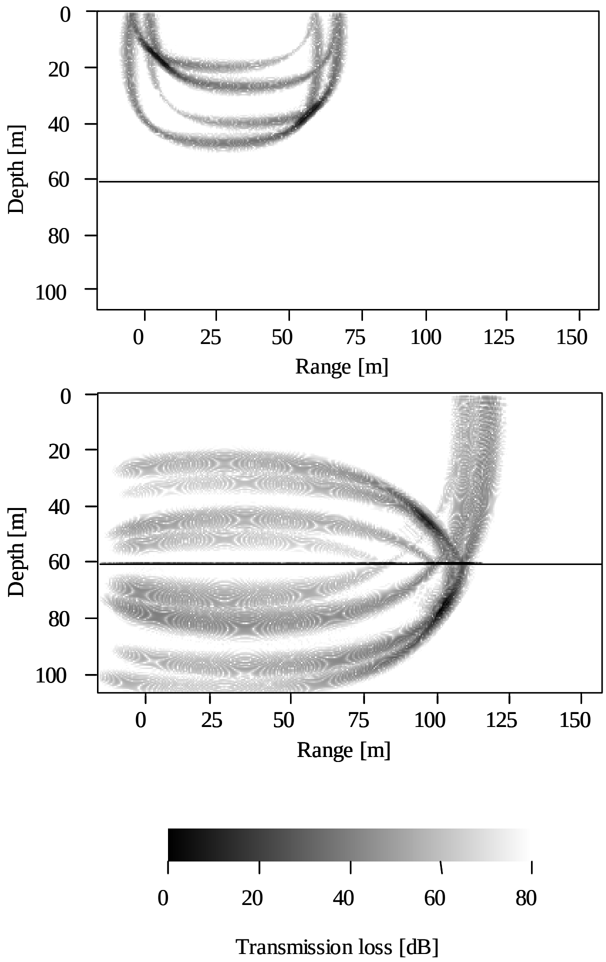


Figure 5 : Snapshot of sound propagation when pulse length is 10 wavelengths.

(a) Snapshot at 25.6 ms after pulse radiation.
(b) Snapshot at 64.0 ms after pulse radiation.

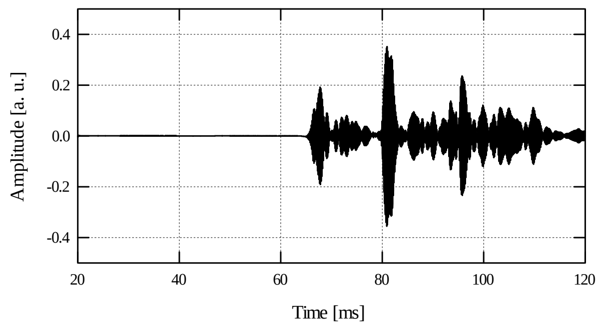


Figure 6 : Estimated pulse waveform whose reflected form sea bottom with sinusoidal bottom shape.

reflected pulse form bottom. Reflected pulse propagated to the transducer.

We calculated sound propagation characteristics using specification data of sonar in the model with sinusoidal bottom shape. Figure 8 shows the result of calculation of received pulse from sea bottom. A time-of-flight and waveform of reflected pulse agreed well with observed pulse.

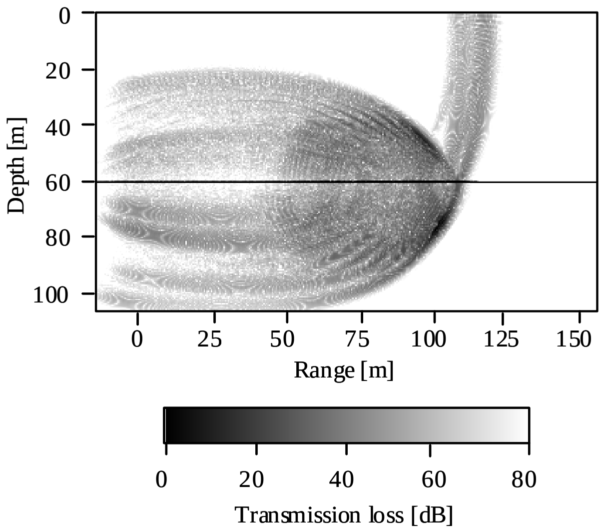


Figure 7 : Snapshot of sound propagation with sinusoidal bottom shape when pulse length is 10 wavelength

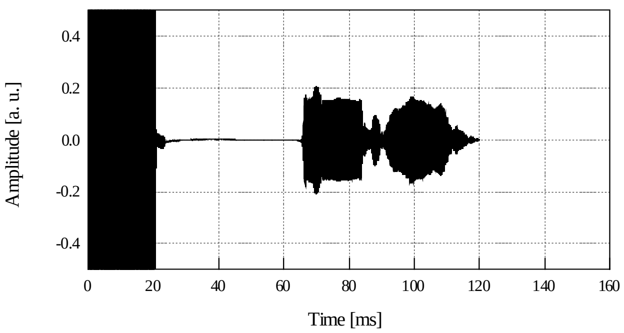


Figure 8 : S Estimated received waveforms with sinusoidal bottom shape when pulse length is 20 ms

Conclusion

In this paper, we calculated sound propagation characteristics using specification data of sonar in the model. It, however, is not good agreement between estimated pulse and observed pulse, because the bottom is assumed to be flat in the calculation model. In order to obtain good agreement between estimation and measured pulse, we have investigated about the influence of the bottom shape to the sound propagation in shallow water. It is obtained that the reflected sound pulse form bottom will be obtained if the bottom has a sinusoidal shape. A time-of-flight and waveform of reflected pulse agreed well with observed pulse.

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