MODELING OF PROPELLER-CAVITATION PULSE FOR ESTIMATING RECEIVED SOUND EXPOSURE LEVEL

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There has been growing concerns on the potential impacts of anthropogenic underwater noises on marine mammals. For the environmental assessment of maritime transportation and engineering, evidences to estimate the impacts of noise on marine mammals are required. In response to this, in Japan, “research project on the underwater noise from commercial shipping on marine and coastal biodiversity” is launched to investigate possible impacts of ship noise on humpback whales in the sea surrounding Ogasawara Islands where is the world natural heritage site.

In this study, we calculated waveform of the impulsive propeller cavitation noise at some distances from the ship on the noise propagation path by the PE model taking account to the real environmental parameters using frequency spectrum of regular cargo-passenger liner Hahajimamaru measured as part of this project.

As a result, we found that the duration time of the propeller cavitation pulse is extended to about 50 ms through the propagation. In this case one pulse cannot attenuate before the next pulse, therefore the impulsive propeller cavitation noise can be near continuous sound. Moreover we calculated sound exposure level taking account to the exposure time.

The results showed that for accurate calculation of the sound exposure level of the impulsive propeller cavitation noise the frequency spectrum and the ocean bottom sediment must be accurately set.

Keywords: ambient noise, anthropogenic noise, ship noise, PE model, Ocean noise pollution

1. Introduction

There has been growing concerns on the potential impacts of anthropogenic underwater noises on marine mammals. For the environmental assessment of maritime transportation and engineering, evidences to estimate the impacts of noise on marine mammals are required. In response to this, in Japan, “research project on the underwater noise from commercial shipping on marine and coastal biodiversity” is launched to investigate possible impacts of ship noise on humpback whales in the sea surrounding Ogasawara Islands where is the world natural heritage site [1]. Figure 1 shows the trajectory of the ship and a whale acquired in the investigation in 18th and 22th February 2016.

The objective of our research is to estimate the accurate received level of marine mammals under noise exposure in actual sea investigation. Generally, it is known that the interference patterns vary complicately due to the many reflections of the pulse wave between the ocean bottom and the surface in shallow water [2]. Therefore, it is difficult to apply range-independent calculation methods such as sound ray and normal mode method. We calculated waveform of the impulsive propeller cavitation noise at some distances from the ship on the noise propagation path by using Parabolic Equation (PE) model “FOR3D” [3] taking account to the real environmental parameters using frequency spectrum of regular cargo-passenger liner Hahajimamaru measured as part of this project.

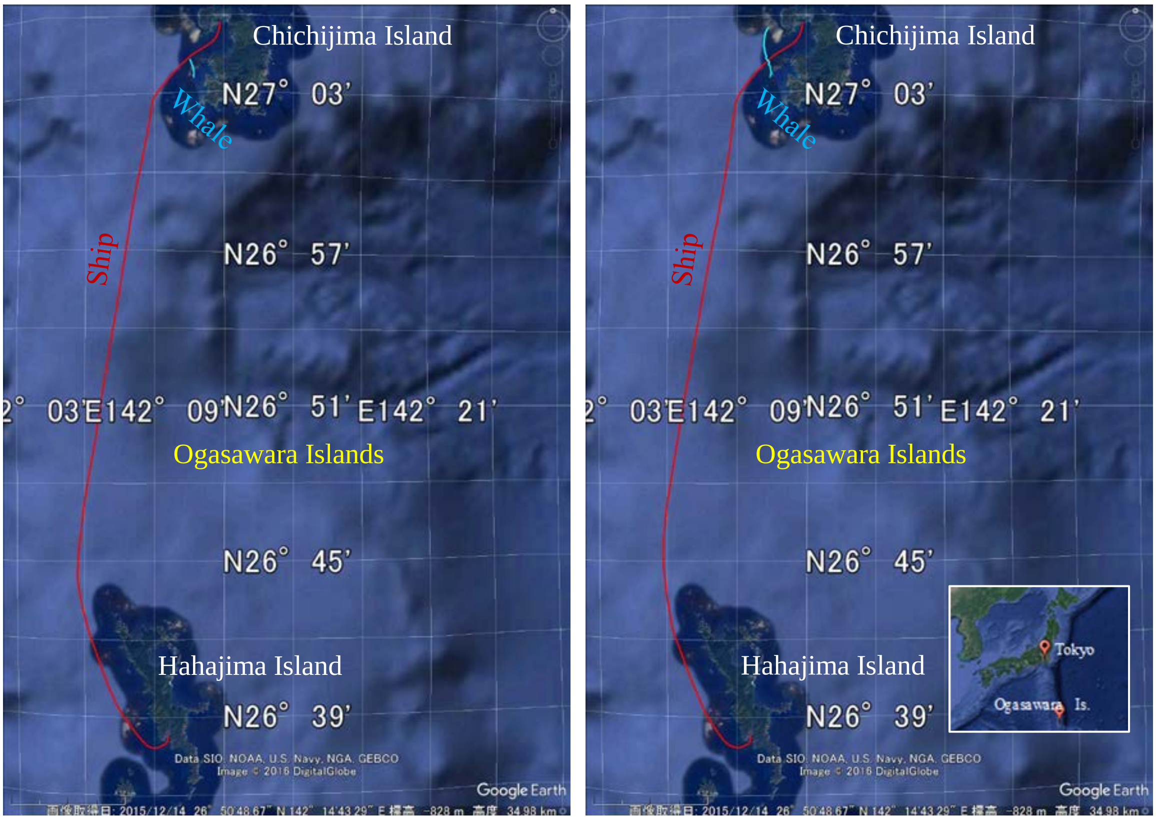

Fig.1 Trajectory of the ship and a whale acquired in the investigation in 18th and 22th February 2016.

2. Simulation conditions

We set the propagation paths on the ship trajectory (Fig. 2). The length of path A is 5 km and path B is 7km.For each path, we set real environmental parameters according to the data described below.

The ocean-bottom sediment distribution data was obtained from the Japan Oceanographic Data Centre [4] (Fig. 2). This data indicates that the ocean bottom sediment in the sea surrounding Ogasawara Islands is generally basalt, chalk, sand and fine sand. The geo-acoustic parameters (the density, compressional wave speed, and attenuation) [5] [6] of each sediment are summarized in Table 1.

The ocean-bottom topography data was obtained from the Japan Oceanographic Data Centre [4]. The maximum water depth of the propagation path A is 47m and path B is 156 m.

The sound speed (Fig. 3) was converted from temperature, salinity, water depth measured by CTD by the equation of UNESCO [7].

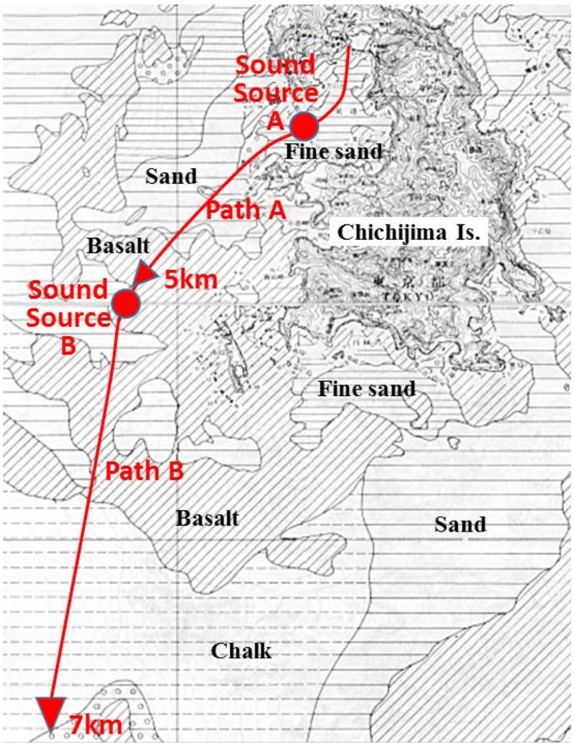

Fig. 2 Propagation paths and the ocean-bottom sediment distribution.

Table 1 Geo-acoustic parameters.

	Density [Kg/m^3]	Compressional wave speed [m/s]	Attenuation [dB/m/kHz]
Fine sand	1950	1725	0.80
Sand	1900	1650	0.80
Chalk	2200	2400	0.20
Basalt	2700	5250	0.10

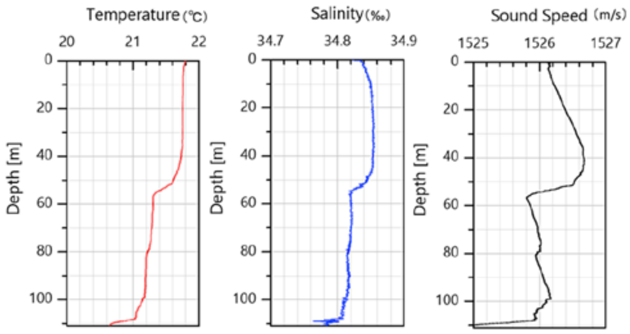

Fig. 3 Temperature, salinity, and sound Speed.

3. Sound source

The sound source is the propeller cavitation pulse generated by a regular cargo ship "Hahajima-maru". Figure 4 shows the appearance of a cargo ship "Hahajima-maru". The Principal particulars of “Hahajima-maru” is shown in Table 2. Figure 5 shows frequency spectrum of "Hahajima-maru". The maximum sound pressure level is 183 dB re 1 μPa at 1 m at 50 Hz. The pulse shape was determined from this spectrum by inverse fourier transformation. The pulse length was estimated to be about 10 ms.

Fig.4 Appearance of ”Hahajima-maru”..

Table 2 Principal particulars of “Hahajima-maru.”

Principal particulars	
Length (m)	56.65
Breadth (m)	9.0
Depth (m)	4.0
Gross tonnage (ton)	490
Normal speed (knot)	15.51
Propeller blade number	5
Propeller revolution number (rpm)	295.88

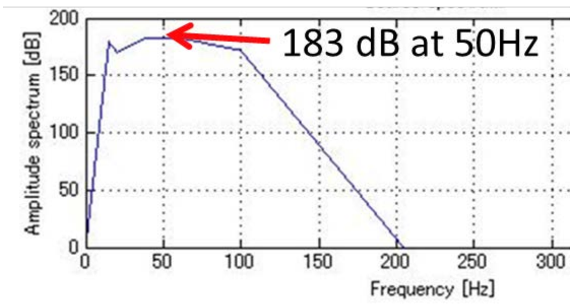

Fig. 5 Frequency spectrim of “Hahajima-maru”

4. Simulation results

The results of the propagation simulation of path A and B are shown in Fig. 6 and 7. The upper in these figures shows the propagation loss at the center frequency (50 Hz) of the propeller cavitation noise of the ship. The middle shows the propagation loss plot at the depth of 20 m. The lower shows received pulse waveform at each distance from the ship on the propagation path.

4.1 Path A

The lower in figure 6 shows that the pulse length changes from 10 ms to 50 ms. The pulse length is extended about five times although the time difference between the direct wave and the reflected wave is small because the maximum depth of path A is 47m.

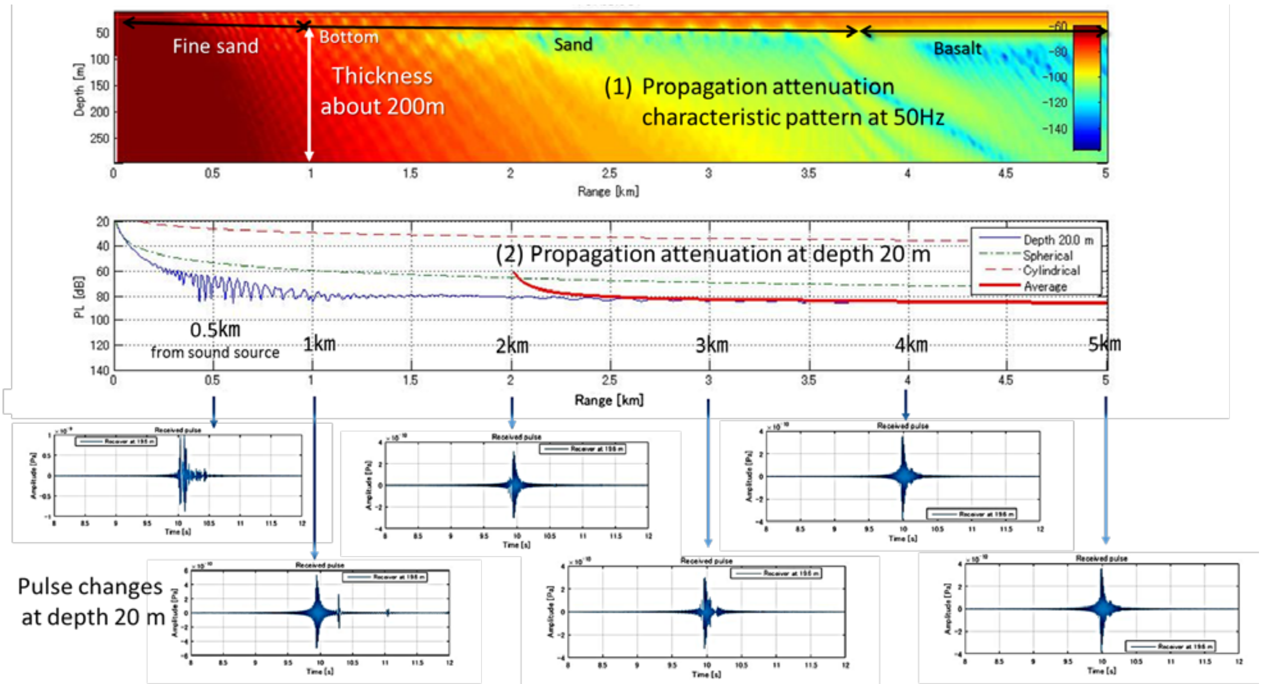

Fig.6 Propagation simulation results of path A

4.2 Path B

This upper and middle in figure 7 shows the occurrence of the section where the propagation loss increases by about 20 dB near the surface at the distances of 2.3, 4.3, and 6.6 km from the ship.

The lower in figure 7 shows the pulse length in next three cases of ocean bottom sediment setting, (a) Sand mud over the entire path, (b) According to the ocean-bottom sediment distribution data (Fig. 2), and (c) Basalt over the entire path. Comparing the pulse length of three cases, it is (a), (b), and (c) in the ascending order. The reason for this is presumed that in the case (c) Basalt, the ocean-bottom attenuation loss is small, so multiple reflection pulses overlapping is occur more frequently than in the case (a) Sand mud which attenuation loss is large. From these results, for accurate calculation of the waveform of the impulsive propeller cavitation pulse in shallow waters, the ocean-bottom sediment must be accurately set. In the case (b) According to the ocean-bottom sediment distribution data, the pulse length changes extend to 50 ms at the distance of 7 km from the ship.

Figure 8 shows the differences between two received pulse waveforms at the depth of 20 m and 100 m at a distance of 7 km from the ship. The pulse length at the depth of 100 m is smaller than the 20 m, and the received sound pressure level at the depth of 100 m is 10 dB larger than the 20 m by 10 dB. The reason for this is that the arrival time difference between the direct wave and the reflected wave by ocean-bottom at the depth of 20 m is larger than the 100 m.

From these results, we found that the duration time of the propeller cavitation pulse is extended to through the propagation especially in shallow water, one pulse cannot attenuate before the next pulse, therefore the impulsive propeller cavitation noise can be near continuous sound.

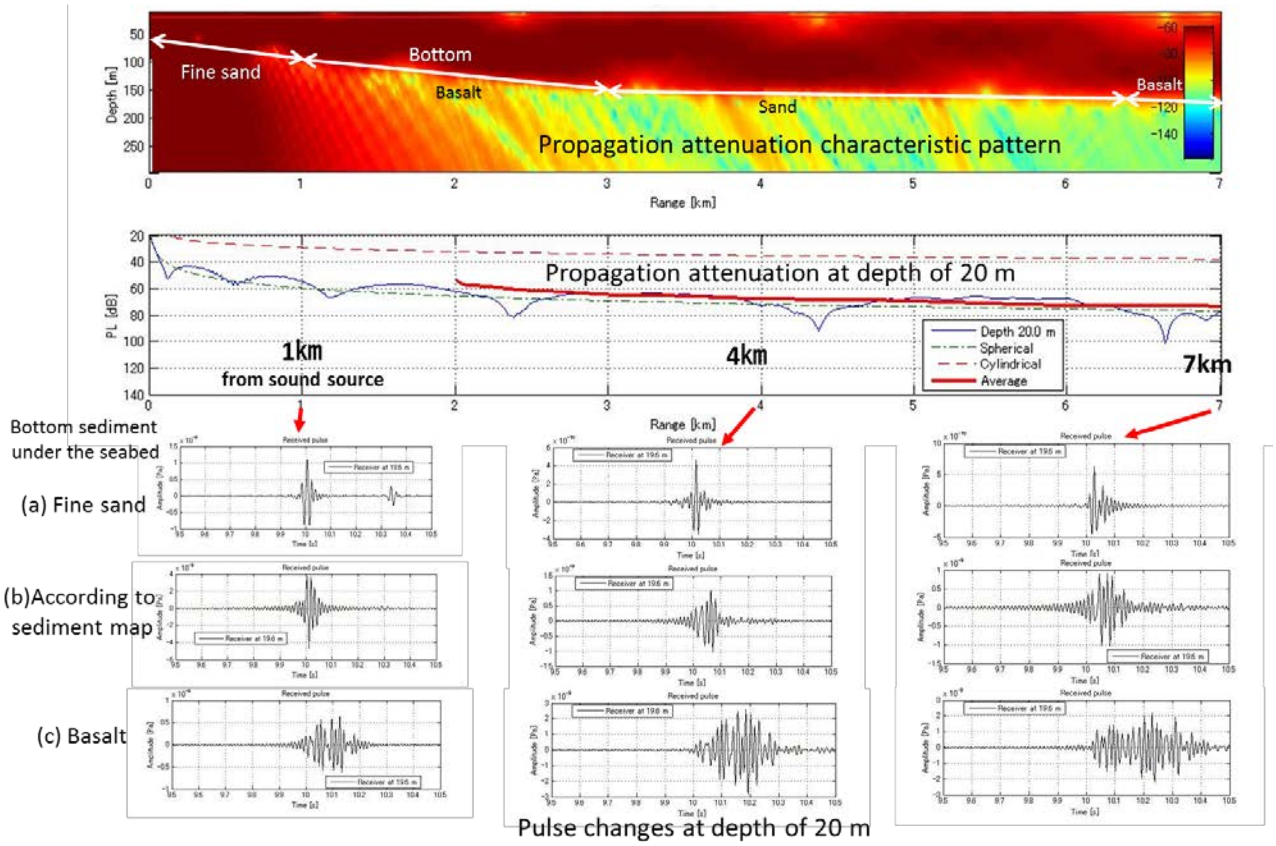

Fig.7 Propagation simulation results of path B.

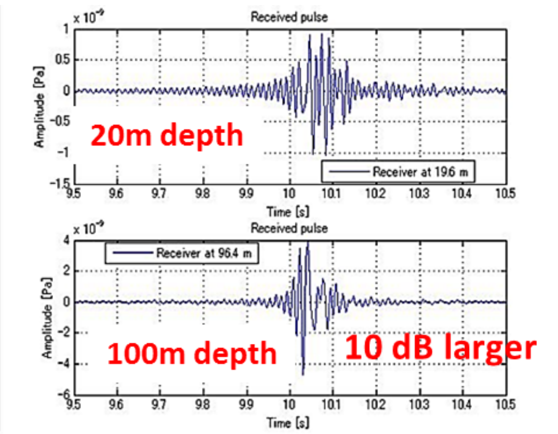

Fig 8 Received waveform at the two depth.

4.1 Sound Exposure Level (SEL)

We calculated the Sound Exposure Level (SEL) at the distance of 1 km from the ship based on the simulation results. The SEL is given by Eq. (1) [8] :

$$\mathrm{SEL} = 10\log_{10}\int_0^T p^2(t)\,dt \tag{1}$$

In the investigation in 18th and 22th February 2016, the closest distance between the ship and humpback whales is 170 m and the amount diving time of humpback whale was 231.7 seconds on average under ship noise exposure. The SEL of a humpback whale supposed to diving for 231.7 seconds at a distance of 170 m from the ship is about 155 dB re 1 μPa^2.

5. Conclusion

We calculated waveform of the impulsive propeller cavitation noise at some distances from the ship on the noise propagation path by using Parabolic Equation (PE) model "FOR3D" [3] taking account to the real environmental parameters using frequency spectrum of regular cargo-passenger liner Hahajimamaru measured as part of this project.

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