ESTIMATION OF SOUND EXPOSURE LEVEL BASED ON RELATIVE MOVEMENT OF SHIP AND WHALE

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There has been increasing concern on impacts of anthropogenic noise on marine mammals. The principal anthropogenic noise sources are shipping, seismic exploration, and pile driving. Increase of low-frequency ambient noise has been mainly contributed by shipping noise after the Industrial Revolution. Low-frequency noise of shipping have peak frequency bands, which overlap those of baleen whales are sensitive to and therefore can disturb their natural activities. We investigated short term behavioural changes by visual observation and estimated received levels of a humpback whale under the shipping noise exposure in the area of Ogasawara Islands. Result of investigation showed more rate and amount time of respiration on shipping than non-shipping days. Many research has been conducted to describe the behavioural responses of aquatic life to various sound sources. However few number of papers provide estimates modelled accurately or measurements of sound exposure levels (SEL), and very few take account that aquatic life and sound sources move in space and time. In order to estimate accurate SEL, we conducted a number of model runs using range-independent Parabolic Equation acoustic model with taking into account of environmental parameters (bathymetric profile, sound speed profile, seabed sediment) as well as relative movement of the whale and the ship based on each of the trajectory acquired in the investigation. Further we compared SEL calculated based on the modelled transmission loss and three ideal transmission loss. The results suggests that estimation of accurate sound exposure level require propagation modelling taking account to environmental parameters of actual sea and relative movement of the ship and the whale.

Keywords: underwater noise, ambient noise, anthropogenic noise, ship noise

1. Introduction

From 1970s, there have been concerns on the potential impacts of the underwater anthropogenic noise on aquatic life. Especially, low-frequency sound wave from shipping is the largest contributor to the underwater anthropogenic noise [1] [2]. Twelfth meeting of Conference of the Parties (COP12) to Convention on Biological Diversity (CBD) notes that there has been a significant amount of research into the impacts of underwater noise on aquatic life over the past few decades, but that there remain significant questions that require further study [3]. Moreover COP12 encourages stakeholders to take appropriate measures to avoid, minimize and mitigate the potential significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity [3]. In response to this, “research project on the underwater noise from commercial shipping on marine and coastal biodiversity” is launched by in Japan [4]. In February 2016, the investigation on behavioural response of humpback whales under the shipping noise exposure is conducted in the sea surrounding Ogasawara Islands as part of this project. This sea where there is no ships except a regular cargo-passenger liner “Hahajima-Maru” navigating once a day is quiet, so that is suitable for the investigation.

In actual sea investigation, the received sound pressure level of the receiver is obtained through the use of the sonar equation [5] [6]. The received level (RL) is given by Eq. (1):

$$RL = SL - TL. \tag{1}$$

where SL is the source level and TL is the transmission loss. In ideal sea, the transmission loss is given by Eq. (2) for shallow water:

$$\text{TL (dB re 1 m)} = 10\log_{10} r + 10\log_{10} D + \alpha r, \text{where r} > \text{D} \tag{2}$$

where r is the horizontal range between the source and the receiver (in m), the absorption coefficient α (in dB/m) and D is the water depth [7]. In shallow water, the sound waves is trapped in the waveguide between the surface and the bottom, so spread spherically at the distance from the sound source is less than D, and cylindrically at the distance is more than D. However, in actual sea, environmental parameters dominates the sound propagation. Furthermore, the sound source and the receiver move respectively, then exposure changes over space and time. The transmission loss is a complicated function of the source and receiver geometry, frequency, and environmental parameters of the water column and the seabed. Therefore the accurate received level cannot be given by Eq. (2).

The objective of our research is to estimate the accurate received level of the receiver in actual sea investigation. We computed the transmission loss from the position 1 m from the ship to the whale as a function of time by using Parabolic Equation (PE) model "FOR3D" [8] taking account to the environmental parameters (bathymetric profile, sound speed profile, seabed sediment) as well as the relative movement of the whale and the ship based on each of the trajectory acquired in the investigation. We calculated the Sound Exposure Level (SEL) [9] based on the modelled transmission loss and three ideal transmission loss. The SEL is given by Eq. (3):

$$\text{SEL} = 10\log_{10}\int_0^T p^2(t)\,dt \tag{3}$$

2. Sound propagation modelling

2.1 Sound propagation transects

The modelling transect locations, the trajectory of the ship and the whale acquired in the investigation in 18th and 22th February 2016 are shown in Figure 1. The trajectory of the ship is recorded by the GPS logger, and that of the whale is by visual observation. The modelling transects connect points of the ship and the whale at the same time over each of the investigation day.

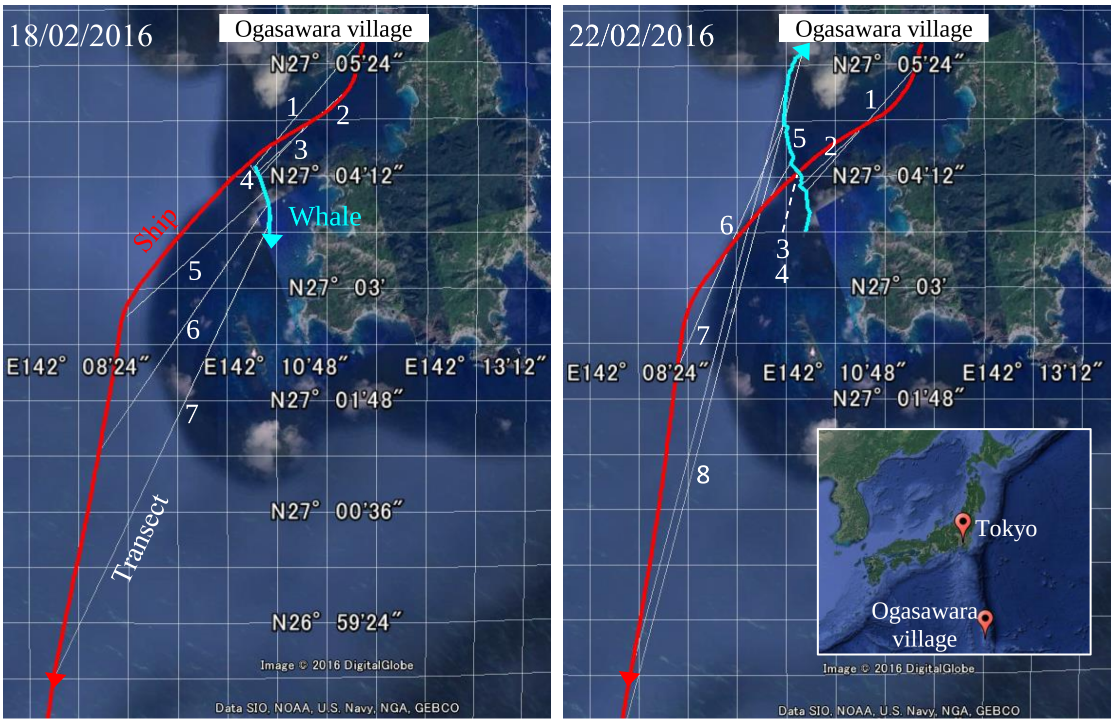

Figure 1: Trajectories of the ship and the whale and sound propagation transects.

The bathymetric profiles for each transect were obtained from water depth data transcribed from the Japan Oceanographic Data Centre [10]. The water depth data is shown in Figure 2. The bathymetric profiles along each transect are shown in Figure 3.

Figure 2: Water depth data.

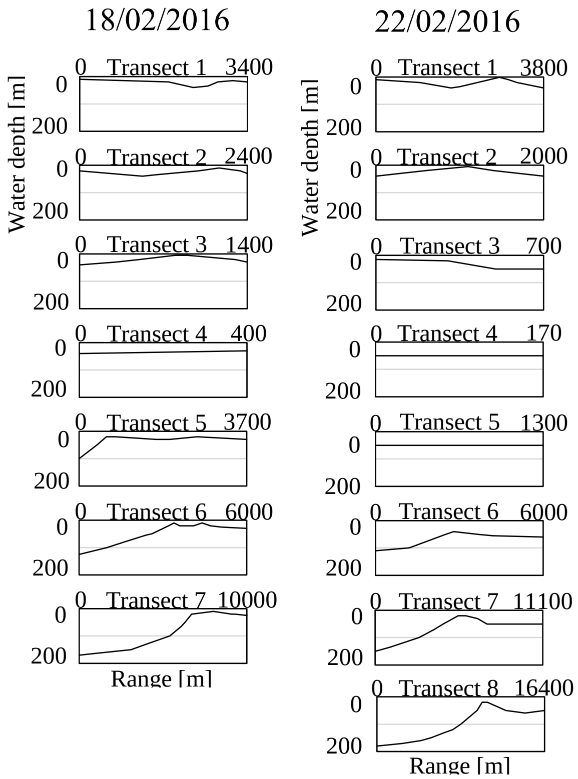

Figure 3: Bathymetric profiles for each transect.

2.2 Oceanographic data

The oceanographic data was acquired 5th February 2016 in the sea surrounding Ogasawara Islands. This consists of salinity, temperature, and depth and from which, the sound speed profile was reconstructed by the equation of UNESCO [11]. The sound speed profile is shown in Figure 4.

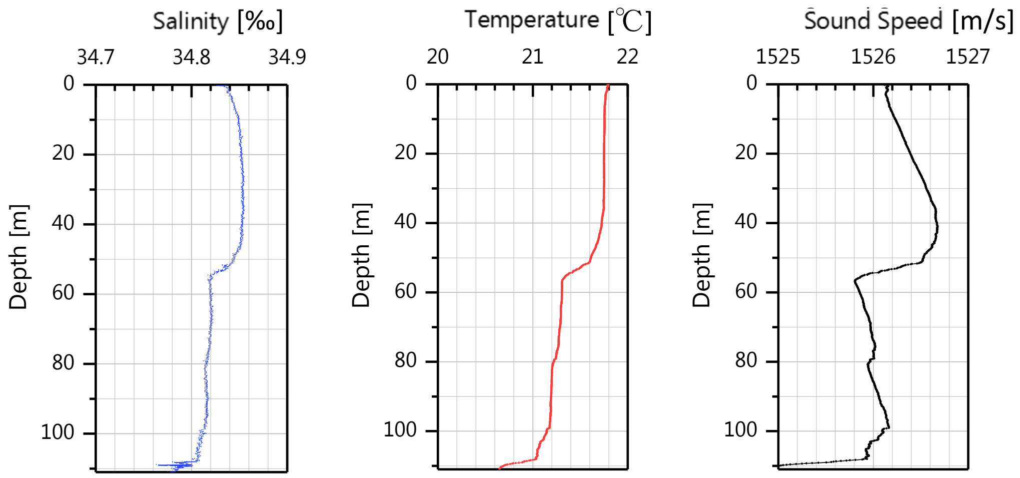

Figure 4: Salinity, temperature, and sound speed profile.

2.3 Geo-acoustic parameters

The seabed sediment data was transcribed from the Japan Oceanographic Data Centre [4]. This data indicates that the seabed sediment in the sea surrounding Ogasawara Islands is generally basalt, chalk, sand and fine sand. The density, sound speed and attenuation data is shown in Figure 4. The seabed sediment parameters are summarised in Table 1 [6] [12].

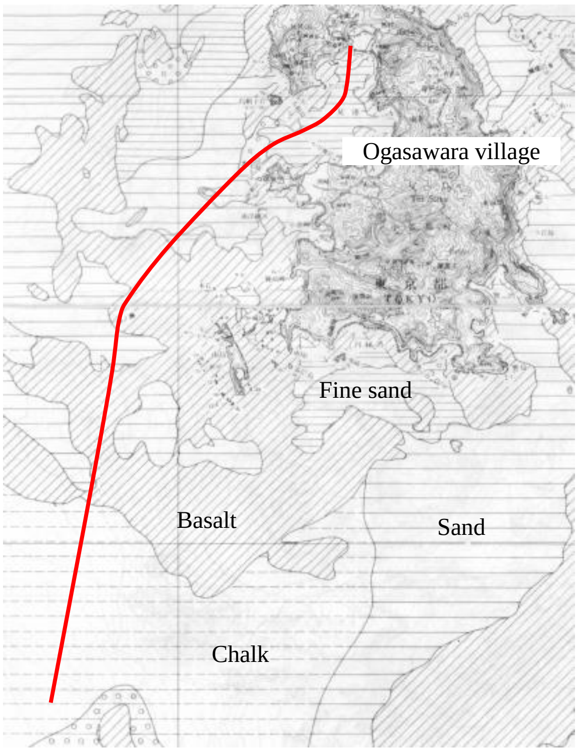

Figure 4: Seabed sediment data

Table 1: Seabed sediment 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

2.4 Sound source parameters

The sound emitted by a propeller of Hahajima-maru has three significant peak frequencies in the frequency spectrum of 1/3 octave. This spectrum was measured in accordance with ISO/DIS 16554.3 [13]. Spectral level at the position 1 m from the propeller of the ship was inferred by back propagating the sound from a number of far field measurement. The modelling input parameters are summarized in Table 2. The depth of the sound source is 2.46 m.

Table 2: Sound source parameters.

	Frequency [Hz]	Spectral level [dB re 1μPa at 1m]
Peak 1	25	160
Peak 2	50	162
Peak 3	100	168

3. Modelling results

3.1 Transmission loss

We conducted a number of model runs using the seabed bathymetric profiles, oceanographic data, Geo-acoustic parameters. The depth of the receiver is 10 m. The results are shown Figure 6 to 8. Figure 6 shows the distance between the ship and the whale in each transect. Figure 7 shows the modelled transmission loss and three ideal transmission loss in each transect. Both figures are as a function of time over each investigation time in 18th and 22th February 2016. The purpose of these is to assess the differences between modelled transmission loss and ideal transmission loss.

Figure 6 shows a decrease over the first about 500 seconds, followed by monotonic increase in the distance between the ship and the whale in both days. Figure 7 shows the modelled transmission loss change in accordance with the distance generally, however the differences between the modelled transmission loss and ideal transmission loss is significant. This may be explained by referring Figure 3. All Transects have very shallow area. In the very shallow water, the sound wave reflects many times at both the surface and the seabed, therefore the transmission loss is highly dependent on the distribution of various seabed sediment with different geo-acoustic parameters. In addition, these reflections produce interference patterns varying depending on frequencies in the water column. Therefore transmission loss can be variable from one location to another. These are the reason for the differences between the modelled transmission loss and ideal transmission loss.

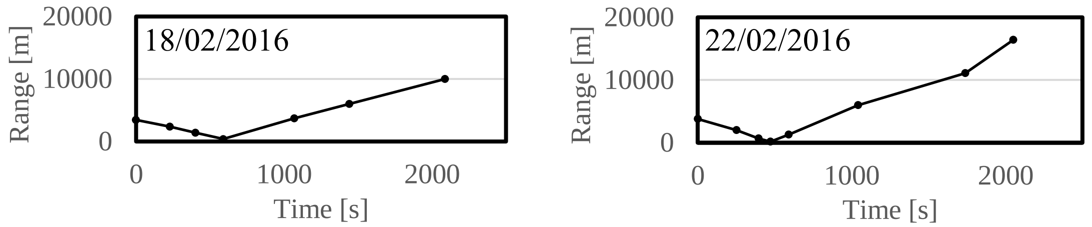

Figure 6: Distance between the ship and the whale in each transect as a function of time.

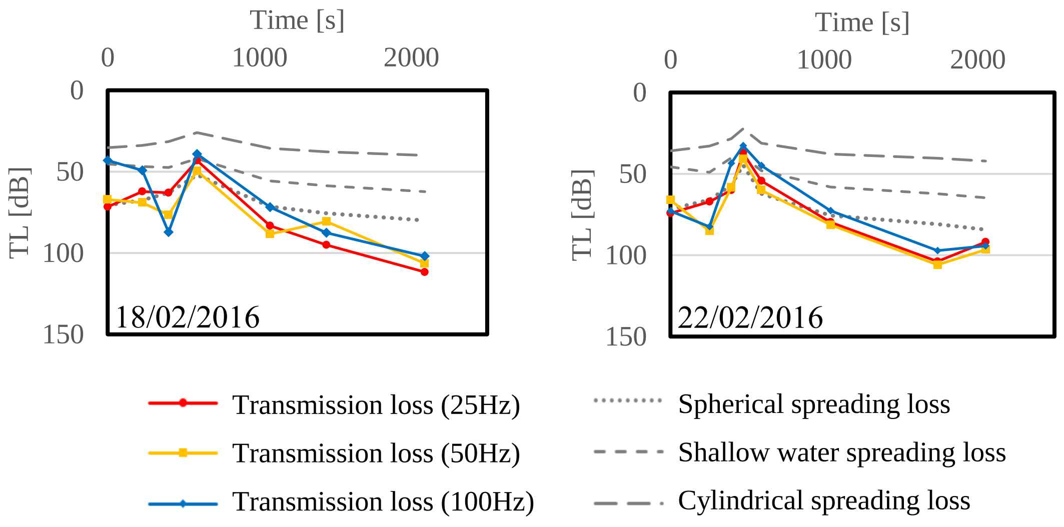

Figure 7: Modelled transmission loss and three ideal transmission loss in each transect as a function of time.

Figure 8 shows constructive and destructive interference patterns as the illustration examples. These indicate the complexity of propagation in shallow water.

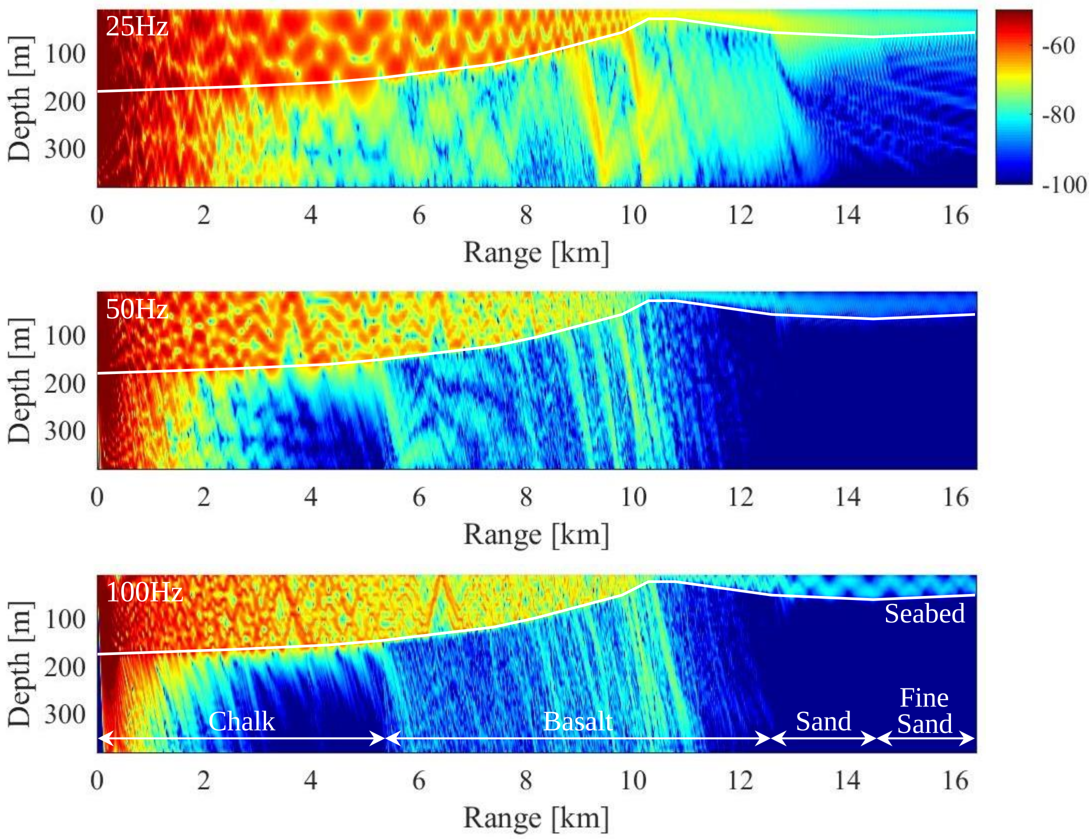

Figure8: Modelled transmission loss of each frequency over the transect 8 in 22th.

3.2 Sound Exposure Level

Figure 9 shows the comparison of the sound exposure level of the whale calculated based on modelled transmission loss and three ideal transmission loss. This figure indicate that modelled sound exposure level is different from any ideal spreading loss at all frequencies. Furthermore, the tendency is similar between both days, not frequencies. Therefore the accurate sound exposure level cannot be calculated based on any ideal transmission loss.

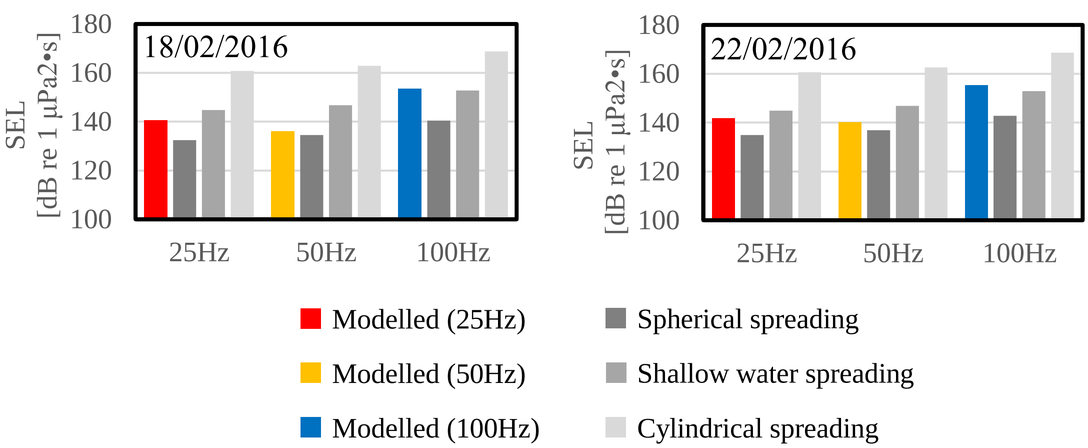

Figure 9: Sound exposure level calculated based on modelled and ideal transmission loss.

4. Conclusion

In order to estimate accurate sound exposure level, we calculated the sound exposure level of the whale under the shipping noise exposure in actual sea, based on some transmission loss. One transmission loss were modelled by parabolic equation and others were calculated assuming three ideal spreading. By comparing sound exposure level of each case, the results suggests that estimation of accurate sound exposure level require propagation modelling taking account to environmental parameters of actual sea and relative movement of the ship and the whale.

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