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Estimation of Elastic Wave Velocity of Surface Sediment on Seafloor and Localization of Sound Source Based on Transmitted Wave Observation with an Ocean Bottom Seismometer

海底地震計による透過波観測に基づく海底表層の弾性波速度推定と音源定位

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1. Introduction

At the cabled seismic observatories off east Japan Pacific Ocean, fin whale vocalizations, whose frequency ranges are 15–20 Hz, have been found by ocean bottom seismometers (OBSs) [1)]. The localization of the fin whales by the cabled observatories would be of great contribution to the understanding of the ecology of the whales around Japan. At off Kushiro-Tokachi observatory, which has not only OBSs but also hydrophones, the sound source locatization of the fin whale vocalization was achieved by using both time difference of multipath arrival (TDOMA) of sound pressure data obtained with the hydrophone for horizontal range estimation and horizontal particle motion obtained with the OBSs for the estimation of incident orientation of the sound signal in Ref. 1. In the other seismic cabled observatories, however, it is not possible to localize the sound sources in the same way, because only the OBSs without the hydrophone are attached to them and therefore horizontal range estimation by TDOMA are not applicable. Meanwhile, in Ref. 2, the whale localization was tried by estimating incident angle and orientation of the vocalization signal observed by a single OBS. The incident angle was estimated from the emergent angle of the transmitted wave into the sediment on the seafloor. The problem in estimating the incident angle, which was used for the estimation of the horizontal range between the OBS and the whale, is that OBS can only observe apparent emergent angle of the transmitted wave which is the compsite of P-wave (pressure wave) and SV-wave (vertical share wave). Therefore, the relation between the incident angle and the apparent emergent angle depends not only on the P-wave velocity contrast between the water and the sediment but also on the S-wave velocity in the sediment. Thus, in order to localize the whales, the information on the P-wave velocity in both seawater and the sediment and S-wave velocity in the sediment is necessary, while the velocities in the sediment are usually unknown.

In this study, elastic wave velocities, i.e. P-wave and S-wave velocity in the sediment, were estimated based on the observation of the transmitted wave of the air-gun signal with an OBS at the cabled observatory off Kamaishi in Sanriku.

2. Observed Data and Analysis

The cabled observatory off Sanriku is composed of three OBSs (SOB1, SOB2 and SOB3), each of which has three accelerometers that are placed perpendicular to one another The X-axis of the OBS is parallel to the cable. The Y- and Z-axes are perpendicular to the cable. However, their inclinations are arbitrary and the direction of X-axis is unknown. Moreover, it is also unknown whether the coordinate is right-handed sytem or left-handed system. In a word, neither incident direction nor incident angle of the sound pressure signal can be identified with raw waveform data. First of all, deployed orientation of the OBS must be investigated. Under this situation, all pairs, i.e. four cases; right-handed / left-handed sytem with landward / seaward X-axis, were examined. The waveform data of OBS used in this study were obtained at SOB1 when the seismic reflection survey with the air-gun was carried out along survey line L4 in KR07-05 cruise of JAMSTEC's R/V "Kairei". The sampling rate of the waveform data is 100 Hz. The location of the observatory and the survey line L4 are shown in **Fig. 1**. First, I assumed that the submarine cable, i.e. the orientation of the X-axis, was deployed in east-west direction. Inclination of the axes can be estimated from the offset of the waveform data which reflect the gravity direction[3)]. By comparing the orientation of the R/V "Kairei" at SOB1, which were derived from the track data, and the incident direction of the air-gun signal at SOB1, which were estimated by the horizontal particle motion of OBS by principal component analysis, the left-handed sytem with landward X-axis case proved to be consistent. Based on the averaged difference between the orientation of the ship and that of the horizontal particle motion from 02:08 to 03:30 JST on Apr. 25th, 2007, the orientation of the X-axis was estimated to be 276 degrees.

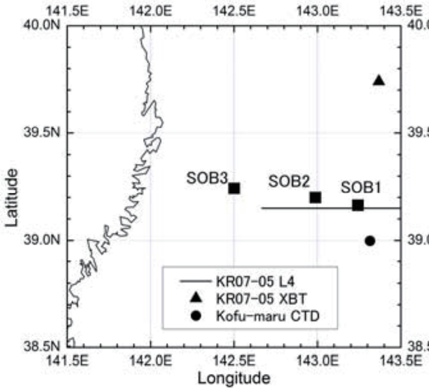

Fig. 1 Location of OBSs (SOB1, SOB2, SOB3), KR07-05 L4 survey line, KR07-05 XBT measurement, and CTD measurement by "Kofu-maru".

In order to estimate the incident angle of the pressure wave on the seafloor, vertical pressure wave (i.e. sound) velocity profile was calculated according to the UNESCO equation[4] by using water temperature profile obtained from XBT data in KR07-05 cruise and salinity profile obtained from CTD data observed by JMA's R/V "Kofu-maru" on May 26th, 2007. The observation sites are shown in **Fig. 1**. Based on this vertical sound velocity profile and ray tracing, the relation between the incident angle on the seafloor and the horizontal range between SOB1 and the sound source at the sea surface was calculated. The apparent emergent angle of the air gun signal transmitted into the sediment was derived from the vertical particle motion. The apparent emergent angle was then correlated with the incident angle on the basis of the corresponding horizontal range between SOB1 and the ship. The result is shown by dots in **Fig. 2**, The theoretical relation between the incident angle and the apparent emergent angle at the liquid-solid interface under various S-wave velocities in the sediment that was derived based on Ref. 5 is also shown in **Fig. 2**. The incident pressure wave velocity was estimated to be 1.50 km/s according to the calculated sound velocity profile. **Fig. 2** shows that the critical incident angle is about 73 degrees. Consequently, the P-wave velocity in the sediment is estimated to be 1.57 km/s, according to the Snell's law. The S-wave velocity is estimated to be about 0.15 km/s in comparison with the theoretical curves, although there is some systematic variation in observational result especially in small incident angle. Corresponding temporal variation was also recognized in the difference between the observational incident orientaion derived from the particle motion and that calculated from ship track as is denoted by the gray curve in **Fig. 3**. Preliminary examination shows that the systematic variation might be caused by the error of SOB1 location data. The black curve in **Fig. 3** shows the variation when SOB1 is assumed to be located 360 m south and 112 m west of the original location. The variation becomes less than half.

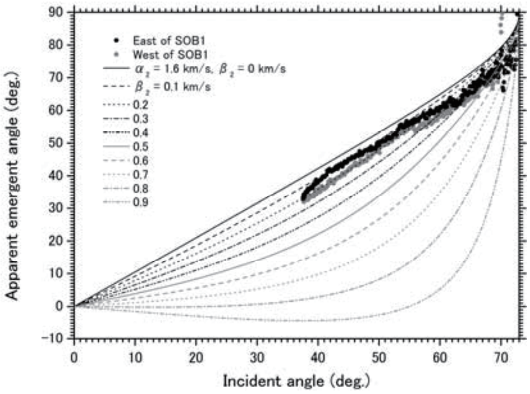

Fig. 2 The relation between incident angle and apparent emergent angle. Dots are observational results and curves are theoretical relations.

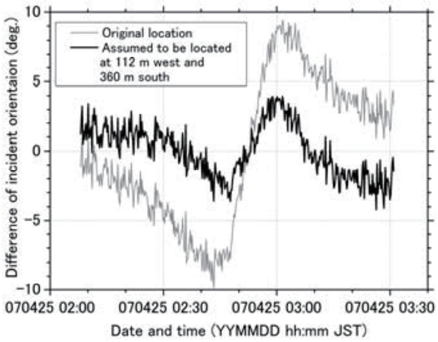

Fig. 3 Temporal variation of the difference of incident orientaion between observation and calculation.

3. Concluding Remarks

Elastic wave velocities in the sediment were estimated based on the transmitted wave observed with an OBS. Localization of the sound source would be possible by using the relations among the apparent emergent angle, the incident angle and the horizontal range obtained in this study, conversely.

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