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Time Reversal and Azimuth of Seismic Wave in Suruga Bay
駿河湾における地震波のタイムリバーサルと方位性

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1. Introduction

We have examined the application of the result concerning a time reversal in the ocean to underground seismic waves[1, 2)]. The time reversal processes have performed to seismic waves in Izu peninsula[1)]. In underwater, a pulse formed with the time reversal process in a source location and a transmitted pulse become the same shapes. However, processing result to the seismic waves in Izu peninsula did not become a same deal with underwater. Then, to examine it more widely this time, the seismic waves that occurred in the vicinity of the center of Suruga Bay are examined by using the observation of the seismometer set up in the surroundings. The earthquake occurred at 23.3 km in depth on August 11, 2009. The time reversal processes are performed by using the observation by 44 seismometers set up around the hypocenter. As a result, it is clarified that the time reversal pulses are greatly different according to the azimuth from the hypocenter.

2. Time Reversal

A time reversal sound field in a time domain is given by[3)]

$$P_{pc}(r,z;t) = \sum_{m=1}^{M} \int G_\omega(r,z,z_m) G_\omega^*(R;z_m,z_{ps}) \times e^{i\omega T} S^*(\omega) e^{-i\omega t} d\omega \qquad (1)$$

Where $G_\omega(R;z_m,z_{ps})$ is Green's function exerted from a sound source on an array element m, and $G_\omega(r,z,z_m)$ is Green's function exerted from the array element m on a point $p(r,z)$. $S(\omega)$ is the Fourier transformation of a pulse radiated from the sound source. In general, the propagation environment when two Green's functions are obtained should be the same and be already-known. On the other hand, the product of $G_\omega(R;z_m,z_{ps})$ and $S(\omega)$ is reflected in the signal that receives by the array element. The product of the Fourier transformation of the signal to which the signal received in the array is time-reversed and $G_\omega(r,z,z_m)$ is reflected in the time reversal pulse.

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Therefore, if the propagation environment is already known, the time reversal pulse can be formed at the hypocenter position by giving the time reversal processing to the signal received by the seismometer, and transmitting the signal from the same depth as the seismometer in the propagation environment. The wave formed in the hypocenter is the time reversal pulse.

3. Observation Points

The observation stations (○ mark) around Suruga Bay and the hypocenter (x mark) are shown in **Fig.1**. These observation stations are distributed in the angular range of about 260 degrees where the hypocenter is enclosed. The ranges from the hypocenter to the observation stations are spread out from about 20 km to 90 km. Moreover, the installation depth of the seismometer is widely distributed from 900 m to -1000 m in the sea level. The vibration velocities in the vertical direction and horizontal direction (east-west, north-south) of the seismic waves are always observed at each observation station.

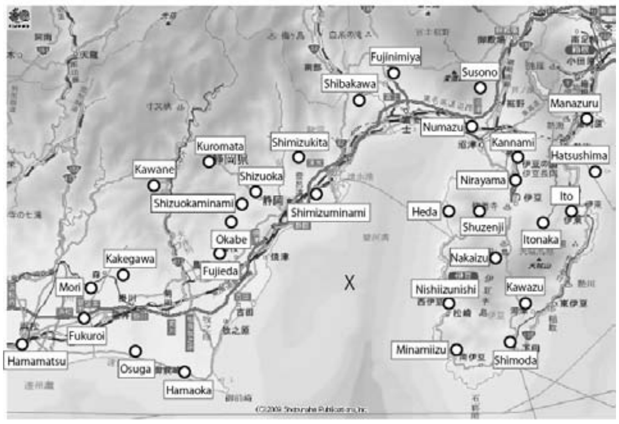

Fig.1 Observation stations around Suruga Bay and hypocenter (x mark)

3. Time Reversal Pulse

After a time reversal processing is performed to the signal received by a seismometer, the reversed signal is radiated from the received position. In this case, the wave formed at the hypocenter position is the time reversal pulse. The vibration velocities that the seismometer detects are all the combination of P waves and S waves, but only the P wave component in the front with a little effect of the propagation environment is used here. First, the orientation dependency of the time reversal pulse is examined. The observation points of about 7° , 87°, and 297° (a: Shibakawa, b: Nishiizunishi, and c: Fujieda) are elected so that azimuth spacing from the hypocenter to the observation point might become about 90°. These observation points are located near the hypocenter in those azimuths, and those ranges are about 46 km, 25 km, and 30 km, respectively. Moreover, the installation depth of the seismometers is -225.5 m, 25.5 m, and 12.5 m, respectively. The time reversal process are performed to the east-west horizontal velocity component received at these observation stations, and the pulse formed at the hypocenter position, that is, the time reversal pulse are shown in **Fig.2.** This figure clearly shows the waveform of the time reversal pulse is greatly different according to the azimuth from the hypocenter. As for the time reversal pulse to a point source like an underwater sound source, the time reversal pulse almost stands up at 0 s on time axis. However, the rise time of the pulse shown in Fig.2 shifts greatly from 0 s. It is suggested that an earthquake source has specific shape and size though the reason for the time shift depends on the difference of the propagation environment. Next, the range dependent of the time reversal pulse is described. The time reversal pulse for the observation stations in the same azimuth (a: Osuga, b: Fukuroi, and c: Hamamatsu) are shown in **Fig.3**. Because the azimuth from the hypocenter to them is about 256°, 271°, and 259°, respectively, those azimuths are almost the same. The ranges from the hypocenter to the observation stations are about 45 km, 54 km, and 70 km, respectively. On the other hand, the installation depths of those seismometers are -64.8 m, -428.8 m, and -1006.5 m in sea level, respectively. There is no big difference in the waveform of Fig.3 compared with Fig.2. That is, the shape of the time reversal pulse is similar and all those rises start from a negative direction. And, there is no difference big as for the width of pulse. However, the rise time of the pulse shown in Fig.2 shifts greatly from 0 s. It is suggested that

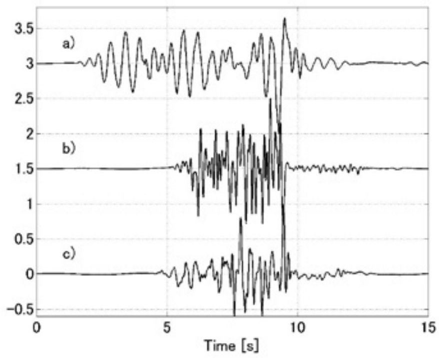

Fig.2 The orientation dependency of time reversal pulse. a: 7° , b:87°, c:297°

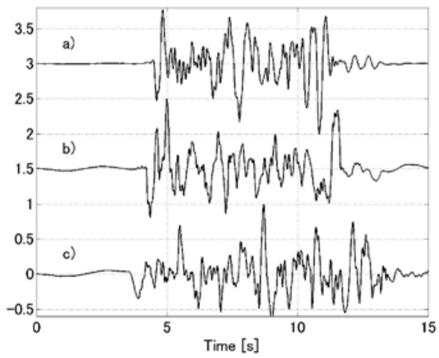

Fig.3 The range dependent of time reversal pulse. a:45km, b:54km,c:70km.

the structure of the sound source be more important than that of the effect of the propagation environment. Similarly, the time reversal pulse is obtained by using the south-north velocity component. The result is similar to the result to the east-west velocity component. However, a peculiar waveform is seen for a specific azimuth.

4. Summary

The azimuth and the range from the hypocenter were widened to clarify the characteristics of the time reversal pulse of the seismic waves, and the time reversal pulse was examined. As a result, the orientation change's effect appeared greatly from the distance change. It is suggested that the earthquake source have specific shape and the size.

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