Nankai Subduction Zone High Resolution Full Waveform Tomography

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1. Introduction

The Nankai subduction zone has hosted both many devastating earthquakes, such as 1944 Tonankai and 1946 Nankai earthquakes, and various slow earthquakes like tremors and low-frequency earthquakes. The physical properties of the subsurface structure, especially along the plate interface, are key to understand the factor controlling the occurrence of the wide-range of the subduction zone earthquakes.

An active source seismic survey using ocean bottom seismometers (OBSs) is an effective tool to reveal physical properties of the subsurface structure in the seismogenic subduction zones. Conventionally, the active source OBS data have been processed by the traditional ray-based methods such as first-arrival travel time (FAT) tomography (e.g., Zelt and Barton, 1998). However, the spatial resolution of the FAT tomographic results is not sufficiently high to discuss the physical properties controlling the wide-range of the earthquakes along the plate boundary faults. The full waveform inversion (FWI) that utilizes observed waveform itself is expected to be a good solution to overcome the limits of the FAT tomography.

FWI has been widely used in industry to investigate oil and gas reservoirs. In contrast, FWI has been rarely applied on academic lithospheric scale seismic explorations because the imaging targets of the academic studies are generally much bigger and deeper than those of the industry exploration. The first crust-scale waveform imaging was implemented in the Tokai area of the Eastern Nankai Trough (Dessa et al., 2004; Operto et al., 2006), but their results were not clear because the imaging techniques was not enough matured to apply the actual data sets. Later, with the updating of inversion techniques, the resolution and accuracy are greatly improved in the subsequent FWI applications in the Kumano basin (Kamei et al., 2013) and in the Tokai area (Górszczyk et al., 2017).

These former results adopted the FWI method implemented in the frequency domain, although the frequency-domain FWI has some shortcomings. Therefore, we perform the time-domain FWI, which could be more efficiency to deal with different frequency contents. However, the time-domain FWI requires much more computing resources than the frequency-domain FWI. And it remains various issues in applying the method to the actual data sets of the lithospheric-scale studies.

In this study, we first aim to establish correct and robust procedures for the FWI. Then, we will apply the FWI to the actual data set. The data set was obtained in 2019 using 100 OBSs deployed at a spacing of 1-km along a 2-D survey line in the central Nankai Trough off the Cape Shiono, Kii Peninsula. Our final goal is to discuss controlling factors on the various fault slip behaviors from the megathrust to the slow slips in this subduction zone.

2. Progress in year 2022

Previously, we tested the time-domain FWI on DA (Data analyzer) system of JAMSTEC. It ran correctly on DA but it took about 10 hours to update the model by FWI. As we expect more than a few hundred iterations are necessary to obtain one final seismic velocity structure by the iterative inversion processes and we need to apply the time-domain FWI many times to search the best parameters, it is unrealistic to apply the time-domain FWI on DA. Therefore, we have moved to ES4 from DA in 2022.

On ES4, firstly, we compiled the time-domain FWI code and tuned parameters for parallel computing. Thanks to the help of the supporting office of the ES4 (CEIST, JAMSTEC), the time-domain FWI runs very well on ES4 now.

We applied the time-domain FWI based on the inverted source function and a starting seismic velocity model developed by the first arrival tomography (FAT) (Qin et al., 2020). The FWI started to work and we succeeded in obtaining preliminary subsurface velocity models after 30 iterations, which show some interesting features underneath the Nankai Trough area with a higher resolution than the starting model, and the data based on the new velocity model have been improved, as now fit the observed data better than before (Fig. 1).

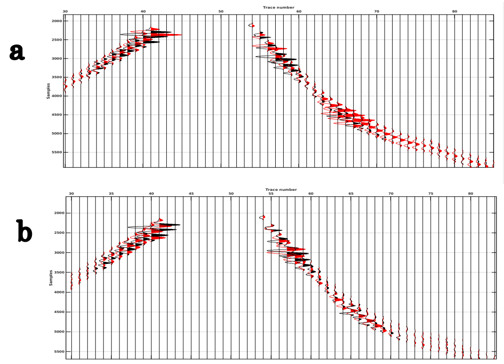

Figure 1. A comparison of observed OBS data (black) and modelling data based on the velocity model (red). (a) before inversion; (b) after inversion.

3. Plans for 2023

Based on our achievements in 2022, we found that data S/N also had a greater impact on the results than we had previously expected. Thus, first of all, we need to focus our efforts on data pre-processing to improve the S/N. Then, to find out the optimal combination of parameters, we need to run many tests on various combinations of many parameters that control behaviors of the time-domain FWI. After that, the uncertainty and spatial resolution of the results need to be evaluated before discussing the controlling factors on the various fault slip behaviors from the megathrust to the slow slip in this subduction zone.

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