LONG-PERIOD GROUND MOTIONS FROM THE EARTHQUAKES IN THE REGION FAR EAST OFF THE BOSO PENINSULA, JAPAN

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Abstract

There are many studies about long-period strong ground motions that occur in the Tokyo metropolitan area but few discuss the ground motion from earthquakes far to the east of the region off Japan's Boso peninsula. However, the 1953 Boso-oki earthquake (M7.4) and the 1677 Enpou earthquake (M8) occurred in this area, and it is important to analyze ground motions from events here. An M6.7 earthquake occurred on the northern side of the triple junction in this area on Sept. 23, 2016, with a Japanese seismic intensity of 1 being observed in the Kanto district. The observed ground motions of this event in the Tokyo bay area were of long duration, having long-period waves and showing group dispersion characteristics. This means that the surface wave components were dominant in the record. The velocity response spectrum (h=5%) of the observed data showed a clear peak at around 10 seconds and the amplitude on the short period side was smaller than the peak at about 10 seconds. These characteristics were significant because of their difference from ground motion records observed for other events with the same magnitude and located at almost the same distance. On the southern side of the triple junction, two M5.9 earthquakes occurred on December 24, 2018 and one M5.7 earthquake occurred on December 25, 2018. These events were unfelt in the Kanto district. The observed characteristics of these events were similar to the 2016 event. To study the regionality of this source region, we searched the earthquake catalog from 2008 to 2018 for events of M5.5 or greater, located from the triple junction to the east off the Choshi-city area along the Japan Trench. Only 4 events were selected. One (M5.5; May 2, 2013) was located in the region off the Boso peninsula and other three were located eastward off the Choshi-city area (M6.1; March 12, 2011, M6.0; April 14, 2011, and M5.9; December 23, 2013). The velocity response spectra (h=5%) of the event on May 2, 2013 had a shape similar to the 2016 event, but the others had different characteristics. The spectral amplitudes of these three events were almost the same during the period from around 2 seconds to 10 seconds. This suggests that there is regionality in the seismic source characteristics along the Japan Trench.

Keywords: Surface wave, Tokyo Metropolitan Area, Regionality of Seismic Source

1. Introduction

There are many studies about long-period strong ground motions in the Tokyo metropolitan area during earthquakes that have occurred in the vicinity of the Kanto plain. When a shallow earthquake with magnitude over 6 occurred off the east coast of the Izu Peninsula, long-period ground motions were observed in the Kanto Plain. It is known that long-period surface waves not only travel through Sagami Bay, but also go around the Kanto Mountains on the western side of the Kanto plain [1, 2]. When an M7 class earthquake occurred in the Nankai Trough off the southeast coast of the Kii Peninsula, long-period ground motions with a period of 7 to 10 seconds were observed in the Kanto Plain [3]. When an M7 class earthquake occurred in the Niigata Chuetsu region, long-period ground motions with a dominant period of 6 to 7 seconds were observed in the Tokyo metropolitan area [4, 5]. Whether long-period ground motions are dominant depends on the location of the epicenter, and there are several reports showing little long-period dominance in the ground motion during earthquakes off the Pacific coast of the Tohoku region [6, 7, 8, 9]. A comparison of long-period ground motions due to a similar-scale earthquake in northern Nagano Prefecture indicates that the difference in excitation of long-period surface waves near the epicenter is responsible for the difference in long-period ground motions in the Tokyo metropolitan area [10]. Similar considerations have been made for long-period ground motions during events in the Nankai Trough plate boundary area [11].

Few studies discuss long-period strong ground motion from earthquakes occurring far to the east of the region off Japan's Boso Peninsula. Along the Japan Trench off the southeast coast of the Boso Peninsula, there have been few occurrences of earthquakes with magnitudes over 6, and there are few strong motion records available for the study of long-period ground motions. However, since large earthquakes such as the 1953 Boso-oki earthquake (M7.4) and the 1677 Enpou earthquake (M8) have occurred there in the past, it is important to study long-period strong ground motions from earthquakes in this area.

An M6.7 earthquake occurred far to the east of the Boso Peninsula on Sept. 23, 2016, triggering observations of Japanese seismic intensity scale 1 in the Kanto district. The observed ground motions around the Tokyo Bay during this event contained long-period components. We focused on this event and analyzed ground motions during earthquakes that have occurred in the region far to the east off the Boso Peninsula along the Japan Trench.

2. Observed data

The epicenter of the 2016 event and observation stations used are shown in Fig. 1. The 2016 earthquake occurred on the northern side of the triple junction far to the east off the Boso Peninsula region on Sept. 23, 2016. The event's magnitude (Mj) was 6.7 and its focus depth was 32 km according to the Seismological Bulletin of Japan's Meteorological Agency [12]. Its moment magnitude (Mw) was 6.2 and the focus depth was 11 km based on observations by the F-net of the National Institute for Earthquake Science and Disaster Resilience [13]. The focal mechanism shown in the figure was also based on F-NET information. In this event, no acceleration record from trigger-type seismometers was obtained around Tokyo Bay. In this paper, ground motion characteristics are examined based on records from the broadband velocity-type strong-motion seismometers installed in thermal power plants on the Tokyo Bay shore [9]. There are five observation stations on the east side of Tokyo Bay and eight observation stations on the west side. The epicentral distance for the east side stations ranges from 205 to 210 km and while for the west side stations it ranges from 225 to 235 km except for station YKS (215 km). In addition to the main shock (9:14, Mj6.7), there are records from the same stations of a foreshock (0:57, Mj5.9) and three aftershocks (14:34, 15:13, 19:28, Mj5.7). The locations and mechanisms of these events are also shown in Fig. 1. The foreshock's source mechanism has not been determined. The aftershocks show different source mechanisms from that of the main shock.

The NS-components of the velocity waveforms observed at the stations around Tokyo Bay during the Mj6.7 event are shown in Fig. 2. These waveforms show a long duration with long-period waves. The peak ground velocity at the east side stations are twice those of the west side stations. Moreover, there is a tendency for the peak ground velocity to be larger toward the north side of Tokyo Bay. The result of multi-filter analysis [14] applied to the waveform from station CHB is shown in Fig. 3. Although the component of the frequency in the 0.1 Hz to 0.2 Hz range continues for a long time, the amplitude of the component near the frequency of 0.1 Hz is the largest from 120 seconds to 180 seconds on the time axis. The predominant frequency changes gradually from about 60 seconds to about 240 seconds on the time axis, showing group dispersion.

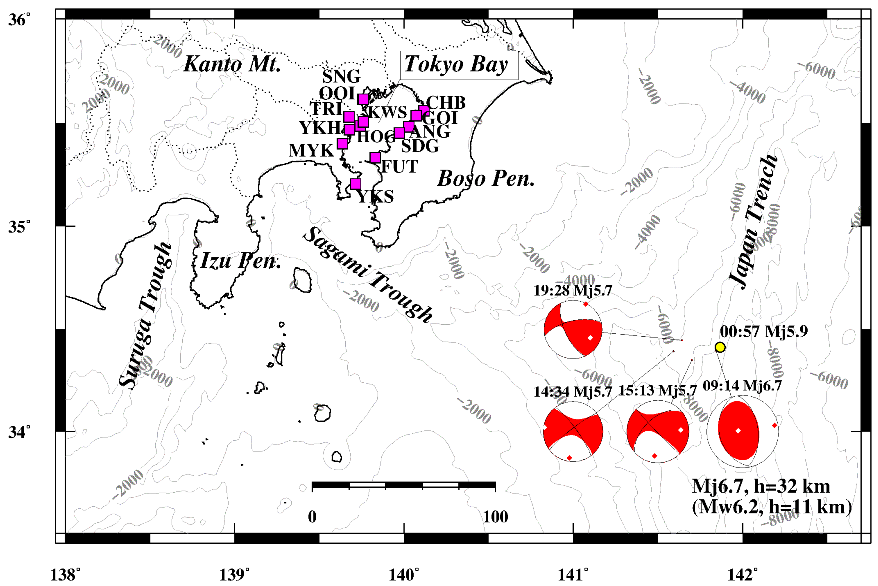

Fig. 1 – Epicenters of the earthquake sequence of Sep. 23, 2016 and observation stations used in this study

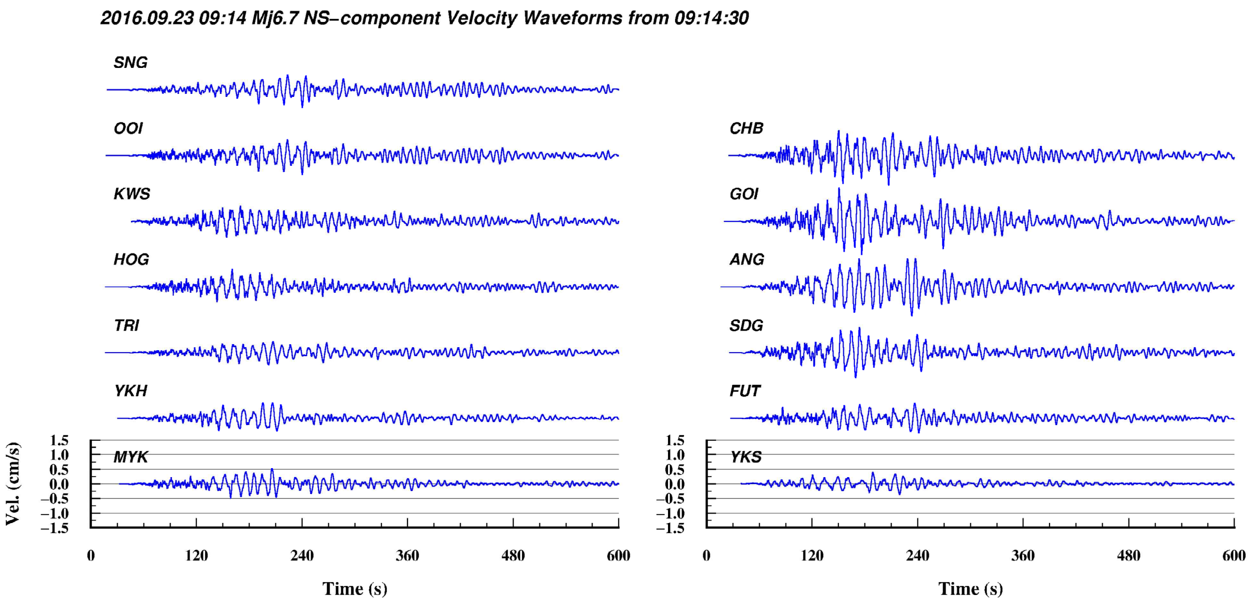

Fig. 2 – NS-component of velocity waveforms observed around Tokyo Bay

The velocity response spectra (h= 5%) calculated using data from the Mj6.7 event are shown in Fig. 4. There are significant peaks at a period of 10 seconds in the horizontal components for all stations and there are peaks at a period of about 6 seconds in the vertical component for the east side stations. The response spectrum calculated from the record of the foreshock and aftershocks at Chiba station (CHB) are shown in Fig. 5 in comparison with the Mj6.7 main shock spectra. It is interesting to note that earthquakes with different magnitudes and different source mechanisms have similar spectral shapes. The spectra of all the events peak at around 10 seconds in the horizontal components, similar to the main shock. However, the amplitudes of the response spectra are from 1/7 to 1/5 of the amplitude of the main shock in the period range from 1 to 15 seconds. Considering that the magnitude is one less than the main shock, this amplitude is reasonable.

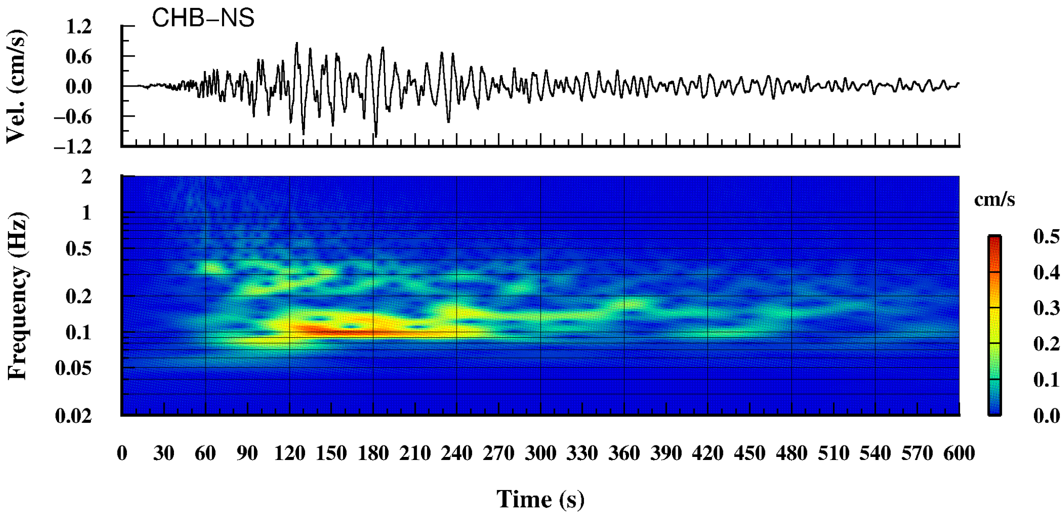

Fig. 3 – Multi-filter analysis of the velocity waveform's NS-component during the M6.7 event (station CHB)

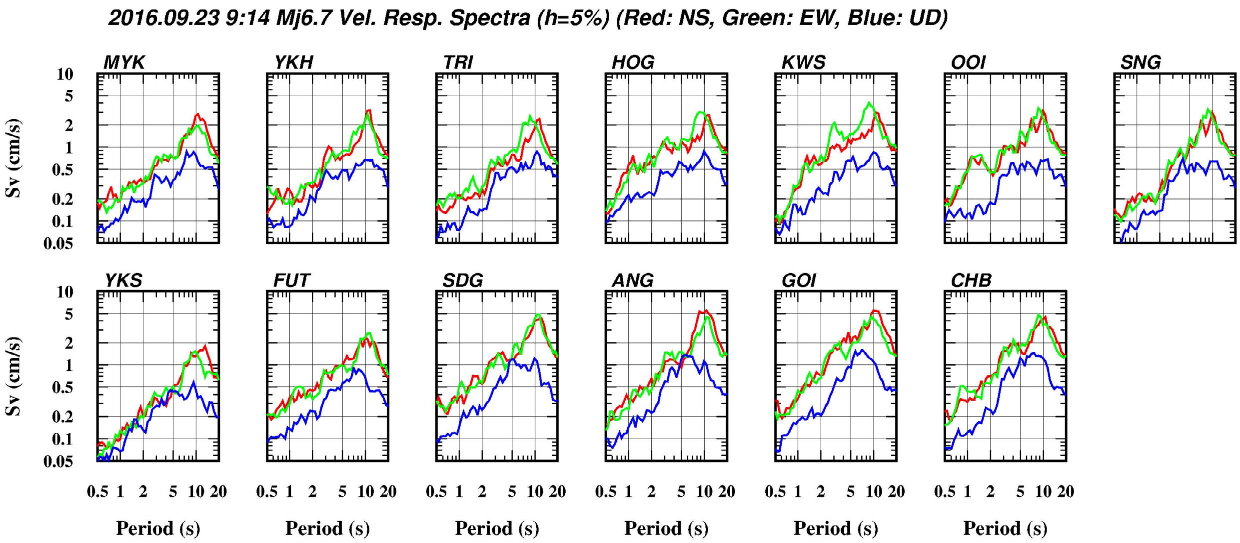

Fig. 4 – Velocity response spectra (h= 5%) calculated from the M6.7 event data

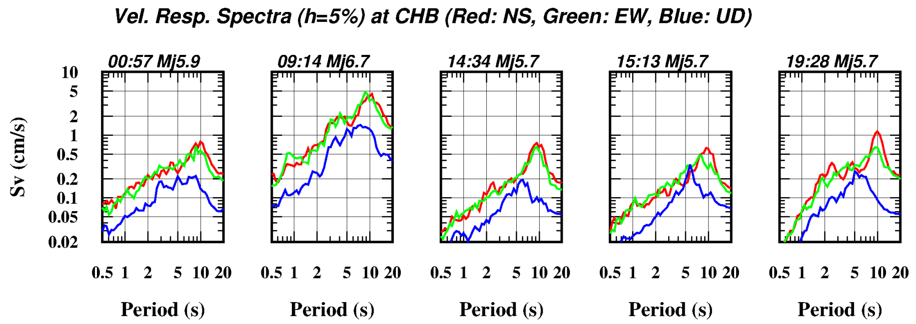

Fig. 5 – Velocity response spectra (h=5%) for the earthquake sequence on Sep. 23, 2016 at station CHB

3. Comparison with similar-class event data

3.1 Comparison with the event that occurred to the east off the Boso Peninsula

An earthquake of Mj6.3 (Mw6.2) occurred on June 06, 2012 closer to the Boso Peninsula than the 2016 event. In this earthquake, seismic intensities of 2 or 3 were observed in the Tokyo Bay area. This event's epicenter and source mechanism are shown in Fig. 6 for comparison with the 2016 event. The source mechanisms differ but the moment magnitudes are the same (6.2). The epicentral distances to station CHB, the closest station to the epicenters, are 205 km for the 2016 event and 131 km for the 2012 event.

The velocity waveforms observed at station CHB are shown in Fig. 6. Although the distances differ, the velocity amplitudes at station CHB are comparable. However, the apparent predominant periods of the two events are different and the predominant period of the 2016 event is longer than that of the 2012 event.

The velocity response spectra calculated from observed data are shown in Fig. 7. The velocity response spectrum of the 2012 event doesn't peak at 10 seconds and is flat in the period range from 1 to 10 seconds. The velocity spectrum of the 2016 event has a significant peak at about 10 seconds and the peak level is twice that of the 2012 event. However, the spectrum level of the 2016 event is 1/4 that of the 2012 event in the period range between 1 to 2 seconds.

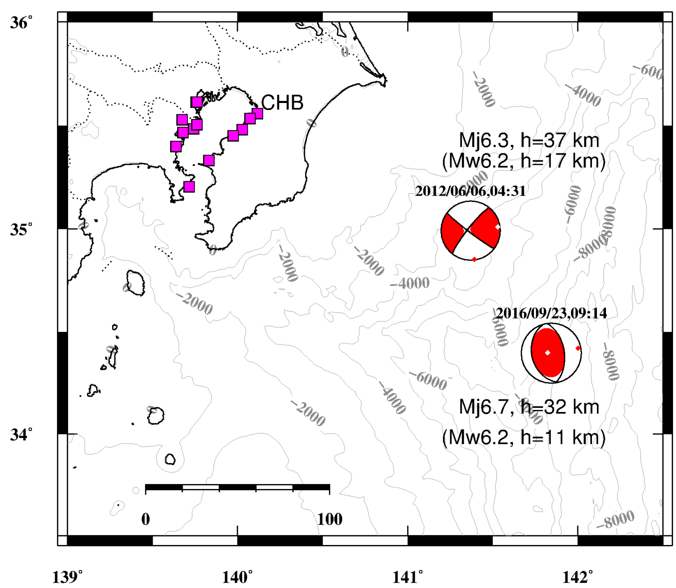

Fig. 6 – Epicenters of the 2012 and 2016 events

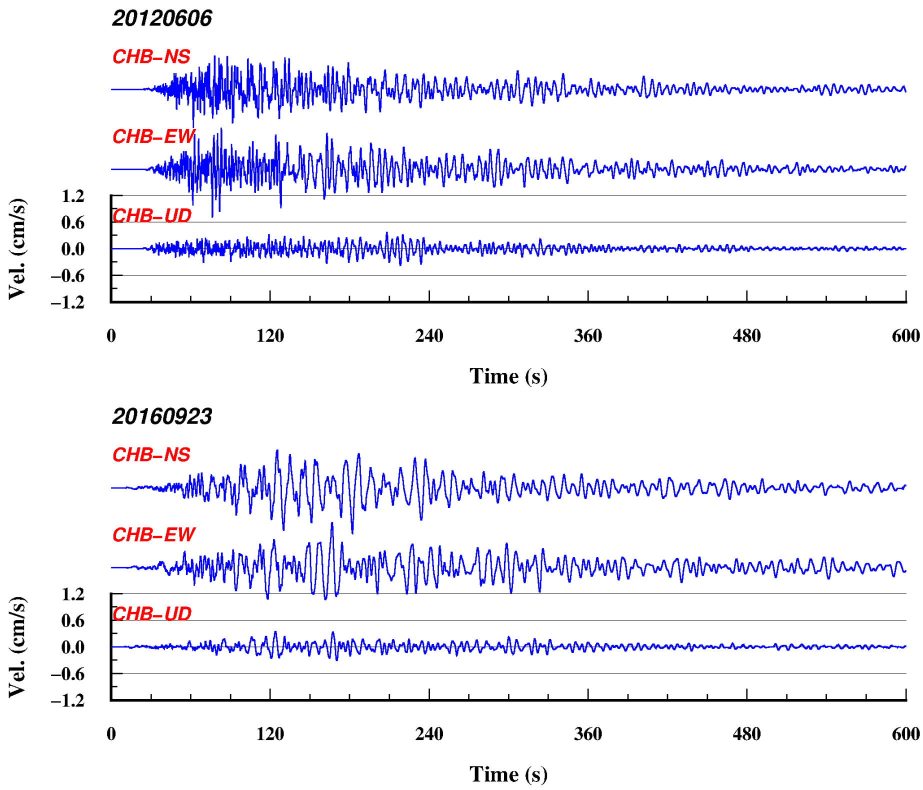

Fig. 7 – Comparison of velocity waveforms at station CHB during the 2016 and 2012 events

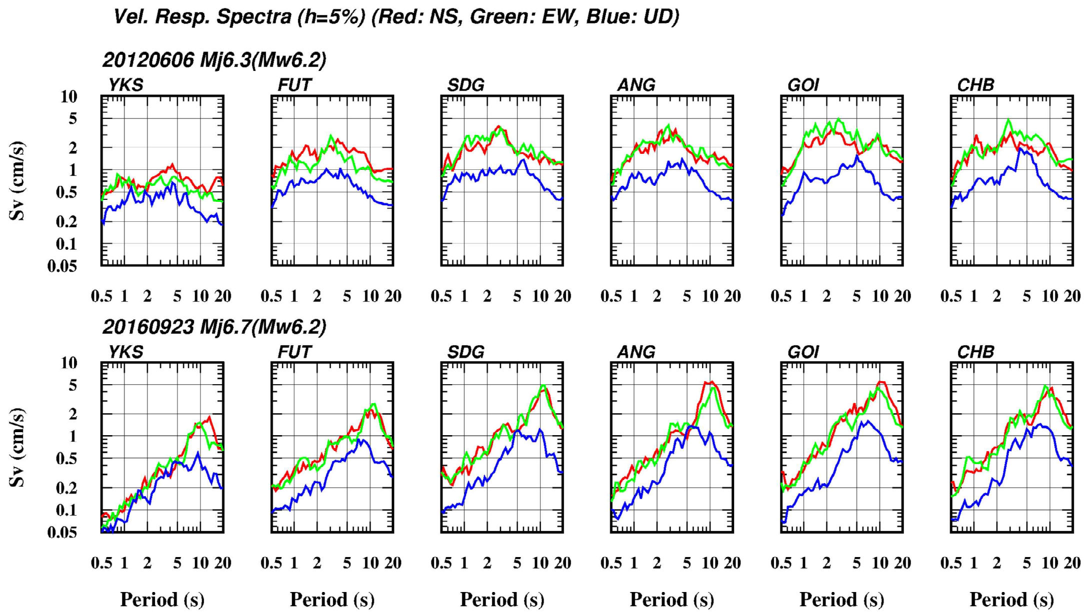

Fig. 8 – Comparison of velocity response spectra (h=5%) for the 2016 and 2012 events

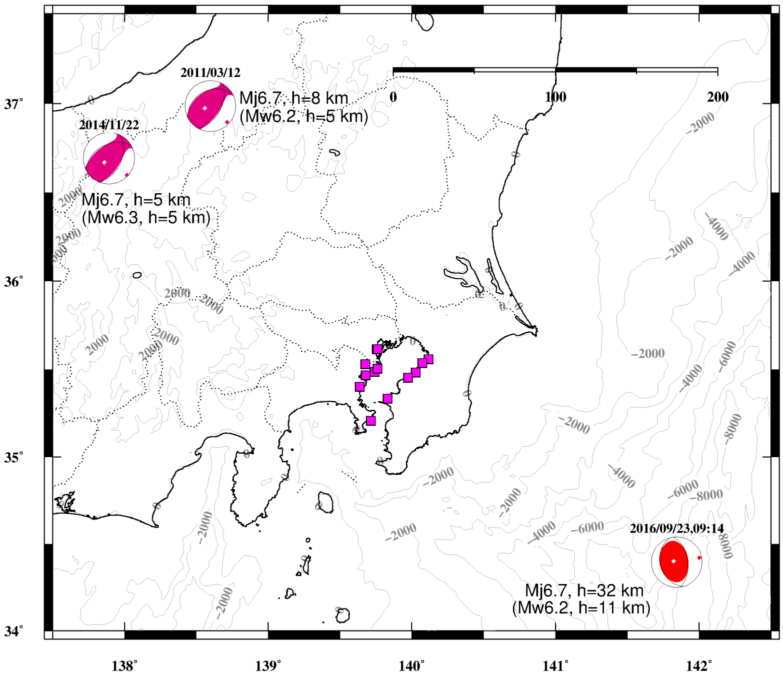

Fig. 9 – Epicenters of the 2011, 2014 and 2016 events

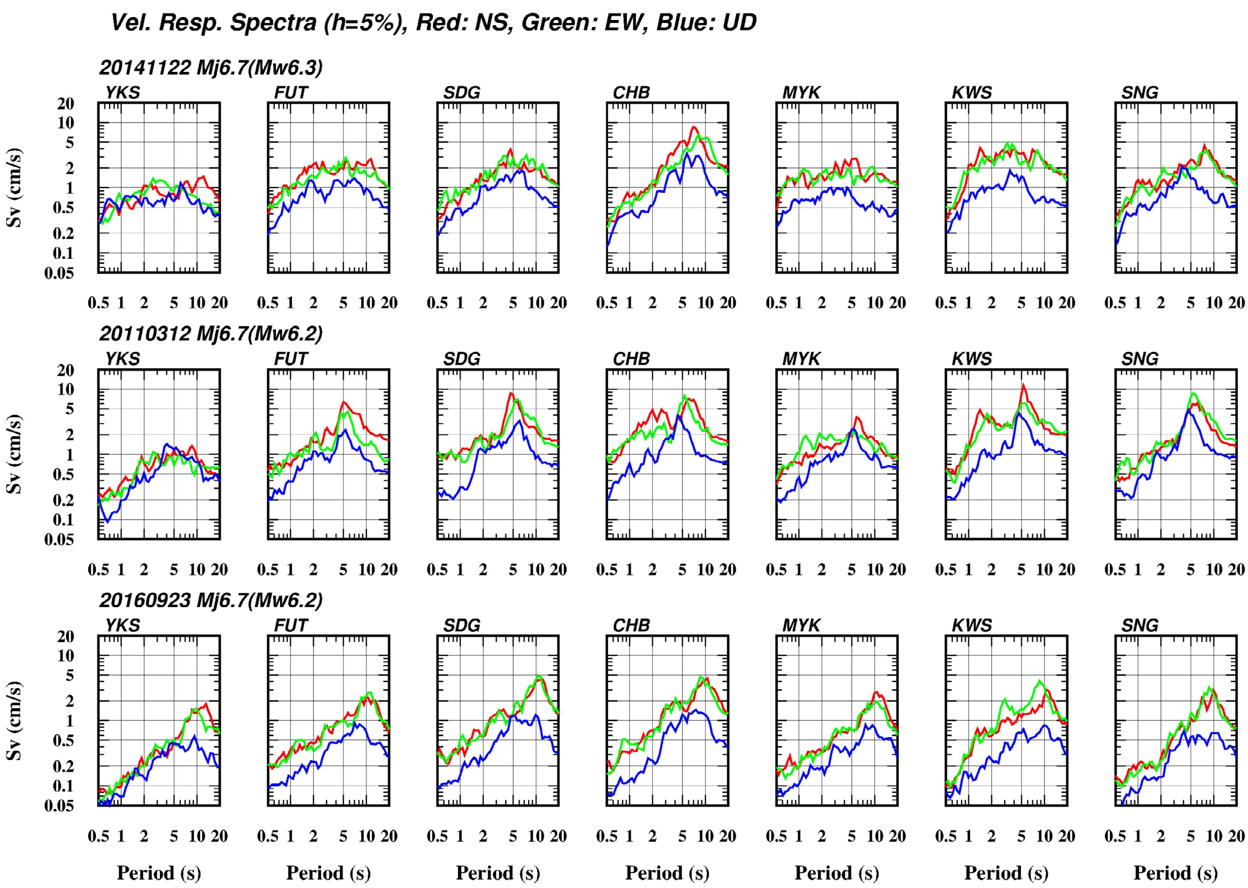

Fig. 10 – Comparison of velocity response spectra (h=5%) for the 2014, 2011 and 2016 events

3.2 Comparison with events in Northern Nagano prefecture

Two inland Mj6.7 earthquakes occurred in Northern Nagano prefecture in 2011 and 2014. The epicenters of these events and the source mechanisms are shown in Fig. 9, along with the epicenter of the 2016 event that occurred east of the Boso peninsula. The distance of the two Nagano earthquakes to the Tokyo Bay coast is about the same as the 2016 earthquake. For observation stations on the east side of Tokyo Bay, the epicenter distances of the 2011 and 2016 events are nearly the same, while for stations on the west of the bay, the epicenter distances of the 2014 and 2016 earthquakes were very similar. The source mechanisms of the 2011 and 2014 events are both reverse fault types, the same as the 2016 event. In the 2016 earthquake, Japanese seismic intensities of 1 or less were observed on the Tokyo Bay shore, whereas in the 2011 and 2014 earthquakes, seismic intensities of about 3 were observed in the same locations.

The velocity response spectra calculated from observed data for the 2011, 2014 and 2016 events are shown in Fig. 10. The difference between the spectral characteristics of the 2011 and 2014 events is not considered here. The spectral amplitudes of those two earthquakes and the 2016 earthquake were compared, taking into account the difference in epicenter distances. The velocity response of the 2016 event in the period from 1 to 2 seconds is low, about 1/2 of those of the other two events, but at 10 seconds it is a little larger than the 2011 event at the eastern stations and the 2014 event at the western stations. The spectrum amplitude of the 2016 event showed that the short-period side was smaller than that of earthquakes of the same magnitude, but was equal to or greater than those earthquakes at around 10 seconds.

4. Spectral variation for events occurring along the Japan-trench

South of the epicenters of the 2016 events, two Mj5.9 earthquakes occurred on December 24, 2018, and one Mj5.7 earthquake occurred on December 25, 2018. These events had a Japanese seismic intensity of 0 (not felt) in the Tokyo Bay area, but ground motion data was obtained for stations on the Tokyo Bay shore. We compared these earthquake records with those of the 2016 event. Furthermore, we compared the ground motions of the 2016 event with those of events that occurred on the north side of the epicenter along the Japan Trench. Events of at least Mj5.7 that occurred north of the triple junction to the east off Choshi-city (about 35.7 degrees north) in 2008 to 2018 were selected. There are few occurrences of large earthquakes in this area, and the following 4 events were selected: an Mj5.5 event on May 2, 2013, an Mj6.1 event on March 12, 2011, an Mj6.0 event on April 14, 2011 and an Mj5.9 event on 23 December 2013. The locations of these events and their source mechanisms as per F-NET are shown Fig. 11.

The velocity response spectra (h=5%) calculated from observed data at station CHB are shown in Fig. 12. For the three 2018 events, there is a peak at around 10 seconds and the short period side is small. The amplitude of the spectra at 1 to 2 seconds is under one-fifth of the amplitude at 10 seconds. These features are similar to the Mj6.7 event in 2016. The velocity response spectra of the May 2, 2013 event shows a similar shape to the events in the vicinity of the triple junction, but those of the other three events differ. The velocity response spectra of these three events are large on the short period side and almost the same amplitude from around 2 seconds to 10 seconds. The spectrum amplitude on the short-period side of the earthquake near the Japan Trench triple junction was small and around 10 seconds tended to be dominant.

5. Conclusions

We analyzed velocity records observed around the Tokyo Bay during the Mj6.7 (Mw6.2) earthquake that occurred near the triple junction off the east coast of the Boso Peninsula. The observed waveforms on the Tokyo Bay shore show a long duration with long-period waves. The peak ground velocity on the east coast of Tokyo Bay is larger than those on the west coast. In the velocity response spectra (h = 5%), a period of 10 seconds was dominant at stations around the Tokyo bay. The predominant period of the response spectrum is longer and the amplitude is larger than those of events of the same magnitude and at similar distances, but the amplitude in the shorter period range is smaller than those comparable events. It should be noted that long-period ground motions can be large even for earthquakes with low seismic intensity.

The spectral characteristics of M6 class earthquakes that occurred along the Japan Trench from the triple junction to the east off Choshi-city were investigated. Earthquakes on the southern side from 35 degrees north latitude are shorter on the short-period side and dominant at 10 seconds. For earthquakes to the east off Choshi-city, the spectrum amplitude was the same from the vicinity of 2 seconds to about 10 seconds, and the short side has a large spectrum shape. This suggests that there is a regional variation in the seismic source characteristics of earthquakes along the Japan Trench.

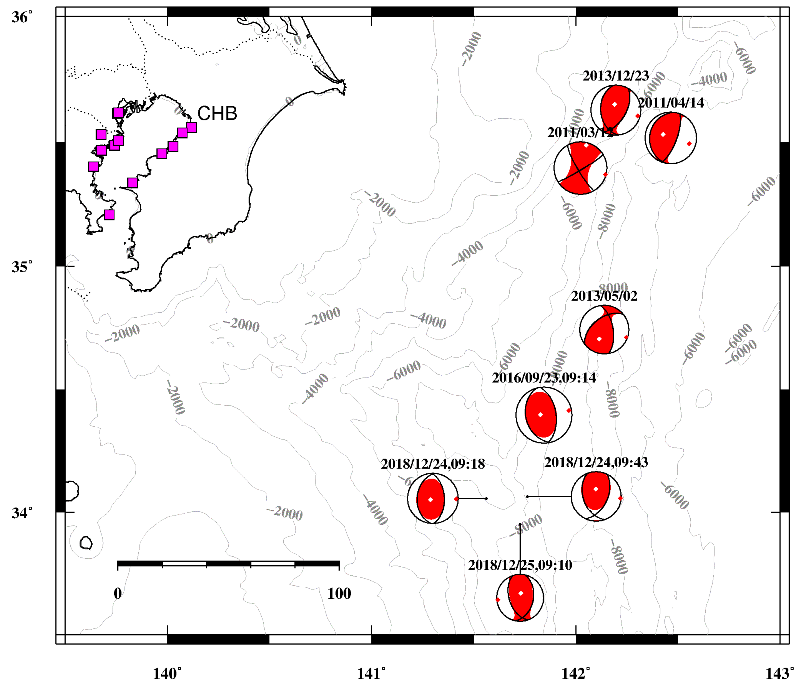

Fig. 11 – Epicenters of M6 class events along the Japan Trench.

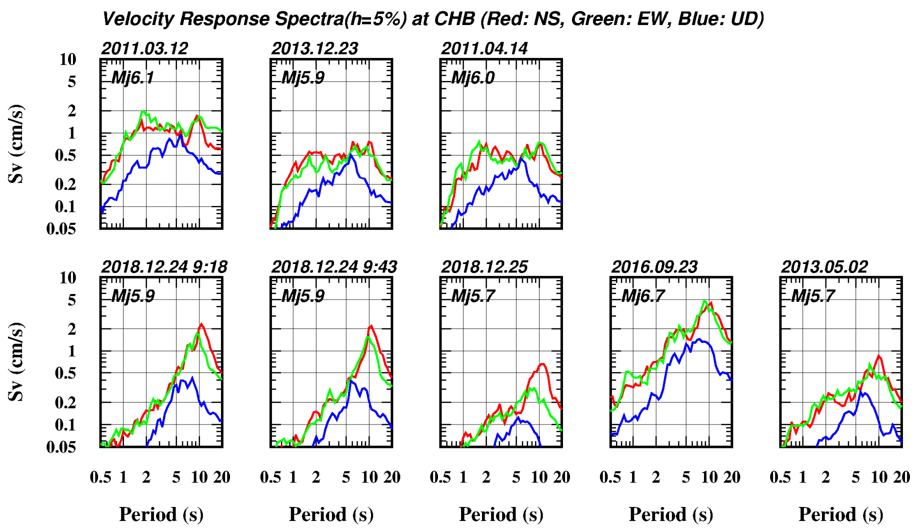

Fig. 12 – Comparison of velocity response spectra (h=5%) for events along the Japan Trench.

6. Acknowledgements

Earthquake source parameters determined by the Japan Meteorological Agency and F-NET of NIED were used in this study. ETOPO1 [15] was used for the seabed topography. GMT [16] was used for drawing figures in this paper. We appreciate the contribution each of these resources made to the writing of this paper.

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