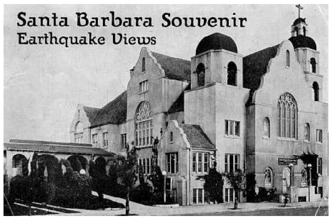

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DEEP S-WAVE VELOCITY STRUCTURES IN THE TOKYO METROPOLITAN AREA ESTIMATED BY THE H/V SPECTRAL RATIO USING CODA WAVES

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ABSTRACT

We estimated deep S-wave velocity structures in the Tokyo Metropolitan Area, using H/V spectral ratios of coda waves observed by MeSO-net (Metropolitan Seismic Observation network). We verified the stability of H/V spectral ratios of Coda waves by understanding the differences of H/V spectral ratios calculated by several earthquake recording data. The variability of H/V spectral ratios of Coda waves calculated by 9 earthquakes larger than Mj 6.5 was quite small. Also, we compared the dominant periods of H/V spectral ratios obtained by MeSO-net to the velocity structures in the Tokyo Metropolitan Area proposed by Yamanaka and Yamada (2006). We applied the Genetic Algorithm to the inversion of the H/V spectral ratios obtained. The estimated S-wave velocity structures are deeper than the previous model (Yamanaka and Yamada's model) for the west of the Tokyo Bay, where the calculated dominant periods of H/V spectral ratios were underestimated.

INTRODUCTION

The high-density seismic observation network at more than 200 stations, called MeSO-net (Sakai and Hirata, 2009), has been being installed at an interval distance of about 5 km in the Tokyo Metropolitan Area. By comparing numerical predictions to earthquake ground motions observed by MeSO-net, we found that the previous 3-D underground velocity model in the Tokyo Metropolitan Area proposed by Yamanaka and Yamada (2006) was still not constrained enough to accurately predict the observed earthquake ground motions for long periods larger than 1 second. Therefore, to improve the 3-D underground velocity model especially for bedrock and/or a deep boundary between layers, we evaluated the relationship between dominant periods of H/V spectral ratios of earthquake ground motions (Tsuno et al, 2011). In this paper, we applied the Genetic Algorithm (Yamanaka and Ishida, 1996) to estimate S-wave velocity structures in the Tokyo Metropolitan Area. We also discussed the influence from deeper underground structures than the seismic bedrock (Vs 3km/s) for ellipticities (H/V) of fundamental mode of Rayleigh waves.

H/V SPECTRAL RATIOS OF CODA WAVES

Data Set

To estimate dominant periods of H/V spectral ratios of Coda waves, we used seismic recording data at about 170 sites observed by MeSO-net in the Tokyo Metropolitan Area. To analyze long periods of earthquake ground motions larger than 10 seconds, we selected 9 earthquakes larger than Mj 6.5 occurred in and around Japan. Details of earthquakes used in this study is shown in Table 1. Locations of the hypocenters and MeSO-net are shown in Fig. 1 and Fig. 2, respectively.

Table 1. Details of earthquakes used in this study.

No.	Origin time	Location of hypocenter	Latitude	Longitude	Hypo. dist.	Depth	Magnitude
1	2009/8/9, 19:56	Off the south coast of Tokaido	33.1 N	138.5 E	250 km	340km	Mj 6.9
2	2009/8/11, 5:07	Suruga Bay	34.8 N	138.5 E	150 km	20 km	Mj 6.6
3	2009/8/13, 7:49	Off the east coast of Hachijojima	33.0 N	140.8 E	250 km	40 km	Mj 6.5
4	2009/8/17, 9:05	Ryukyu Islands	23.4 N	123.6 E	2000 km	50 km	Mj 6.7
5	2009/8/17, 19:10	Ryukyu Islands	23.3 N	123.7 E	2000 km	40 km	Mj 6.6
6	2009/10/30, 16:03	In the sea off Amami Oshima	29.2 N	129.9 E	1200 km	60 km	Mj 6.8
7	2010/2/27, 5:31	In the sea off Okinawa Island	25.9 N	128.7 E	1450 km	40 km	Mj 7.4
8	2010/3/14, 17:08	Offshore Fukushima prefecture	37.7 N	141.9 E	250 km	40 km	Mj 6.6
9	2010/4/26, 11:59	Ryukyu Islands	22.2 N	123.8 E	2000 km	50 km	Mj 6.6

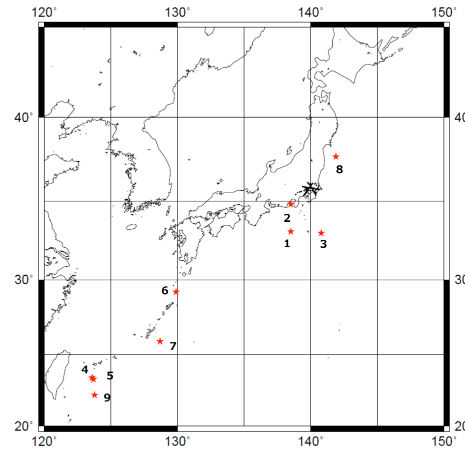


Fig. 1. Locations of hypocenters used in this study.

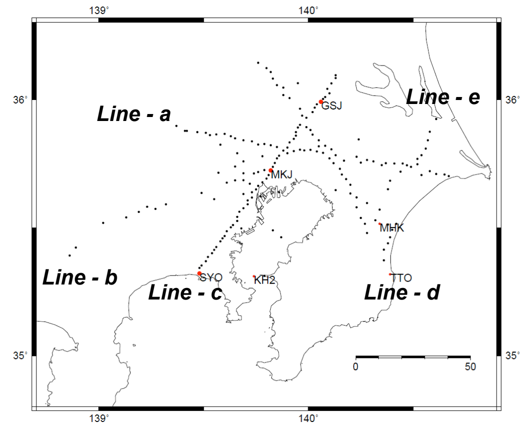


Fig. 2. Locations of seismic stations in MeSO-net.

Stability of H/V Spectral Ratios Derived from Different Earthquakes

H/V spectral ratios averaged by 9 different earthquakes (See Table 1) are shown in Fig. 1. Average of H/V spectral ratios has a quite small variability; therefore, it reflects the underground structure beneath the site at the station. We could accurately determine dominant periods of H/V spectral ratios at all the stations, using the average of H/V spectral ratios as shown in Fig. 3. Theoretical ellipticities of fundamental mode Rayleigh waves calculated by the S-wave velocity structures (Yamanaka and Yamada, 2006) are also shown in Fig. 3. The agreement between the observed H/V spectral ratio and the theoretical one at MKJ indicates that the velocity structure is well constraint at this site. On the other hand, the slight differences between the observed and the theoretical H/V spectral ratios (e.g. GSJ and MHK) require that the velocity structures beneath these sites will be improved.

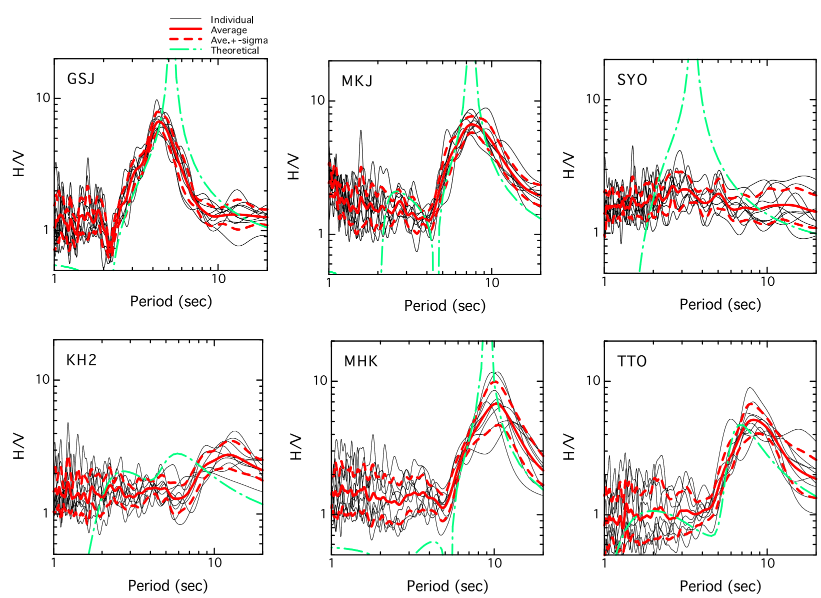


Fig. 3. H/V spectral ratios (Black line: individual H/V, red line: averaged, red dot line:+- sigma, green broken line: theoretical).

RELATIONSHIP BETWEEN H/V SPECTRAL RATIOS OF CODA WAVES AND DEEP UNDERGROUND STRUCTURES

Distribution of dominant periods of H/V spectral ratios observed by MeSO-net is shown in Fig. 4, in which dominant the periods estimated by Sato and Higashi (2006) using K-NET, KiK-net and SK-net in the Kanto Basin are included. Most of H/V spectral ratios in the Tokyo Metropolitan Area have periods larger than 5 seconds, due to deep underground structures (Yamanaka and Yamada, 2006). In particular, periods larger than 8 seconds are dominated in the west of the Tokyo Bay and the north of the Boso Peninsula. This tendency is a good agreement with depths of seismic bedrock integrated by the results of array microtremors observations more than 200 sites (Yamanaka and Yamada, 2006).

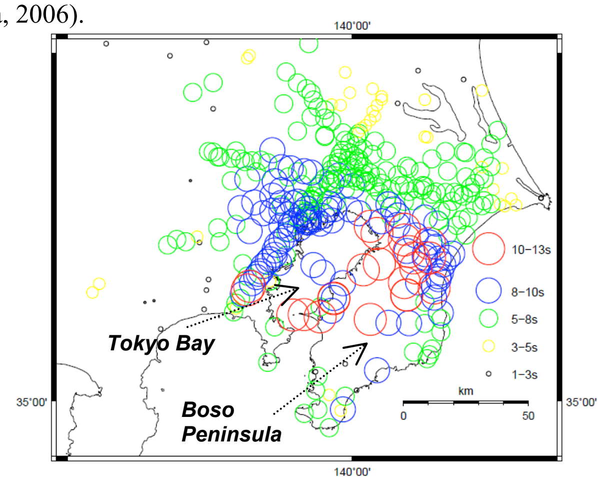


Fig. 4. Distribution of dominant periods of H/V spectral ratios in the Tokyo Metropolitan Area (Including the results from Sato and Higashi [2006]).

In Fig. 5, we compared the observed dominant periods of H/V spectral ratios to theoretical dominant periods of ellipticities of fundamental mode Rayleigh waves calculated by Yamanaka and Yamada's model, for 5 cross sections as shown in Fig. 2. Although the both dominant periods in Fig. 5 have the same tendency, they don't agree with each other in detail. Among sites in line C, for example, the theoretical dominant periods by Yamanaka and Yamada's model underestimate those observed. Dominant periods of H/V spectral ratios match well for sites where shallow basin structures are located; however, dominant periods of H/V spectral ratios don't match well for sites where deep basin structures are located. Yamanaka and Yamada's model is based on phase velocities of Rayleigh waves estimated by array microtremors observations; therefore, the uncertainty of underground structural model is increased when a phase velocity is not obtained for long periods.

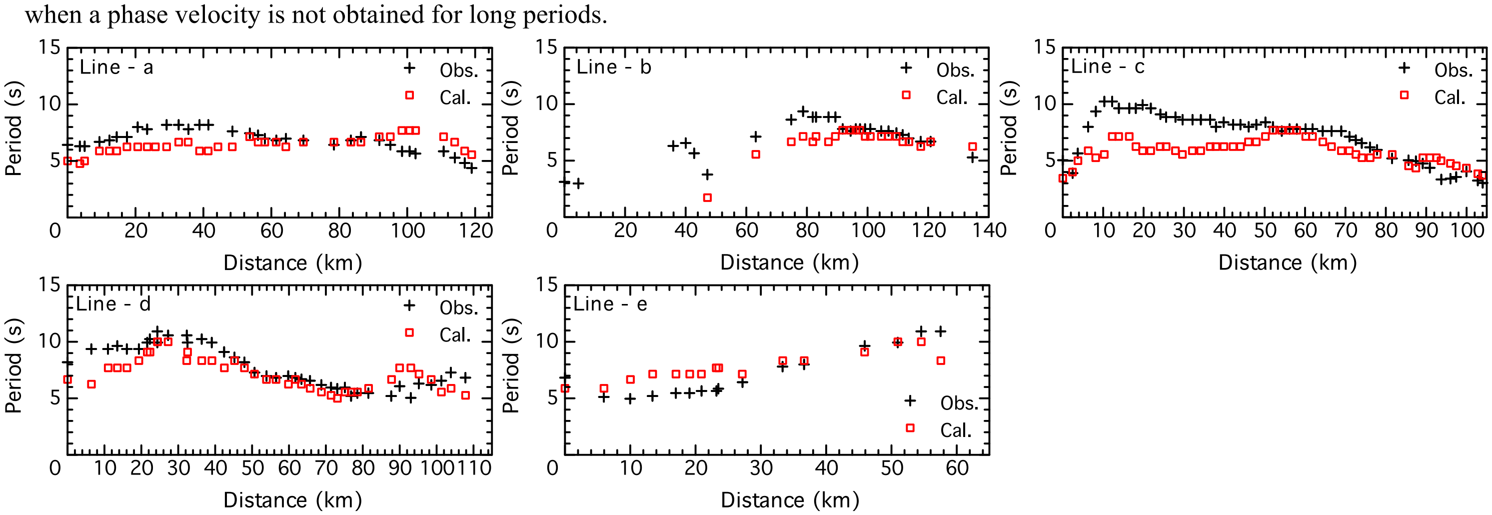


Fig. 5. Comparison of the observed dominant periods of H/V spectral ratios to the theoretical ones for 5 cross-sections.

INVERSION OF H/V SPECTRAL RATIOS TO S-WAVE VELOCITY STRUCTURES

We estimated S-wave velocity structures, by fitting the observed H/V spectral ratios on and around dominant periods to the theoretical elliplicities of fundamental mode Rayleigh waves. We adapted the Genetic Algorithm (Yamanaka and Ishida, 1996) to the inversion method. The 4 layers model proposed by Yamanaka and Yamada (2006) was used in the inversion process, to be constraint of S-wave velocities such as, Vs 300 to 600 m/s, 1km/s, 1.5km/s and 3km/s (the seismic bedrock) from the surface layer. In general, H/V spectral ratios around dominant periods reflect deep structures and therefore; we aimed to estimate only the thickness of the second and the third layers. As for the thickness of the 1st layer, Yamanaka and Yamada's model was used in the inversion process. Finally, the minimum misfit among 5 trials with different random numbers was selected as the estimated S-wave velocity structural model.

The comparison of the observed H/V spectral ratio to the theoretical ellipticity (H/V) of Rayleigh waves at GSJ is shown in Fig. 6 (Left). The theoretical H/V matched the observed better than the previous model (Yamanaka and Yamada, 2006), especially for the dominant period. The estimated S-wave velocity structure at GSJ was shown in Fig. 6 (Right). The improved structural model was estimated about 700m shallower than the previous model for the depth of bedrock (Vs 3km/s).

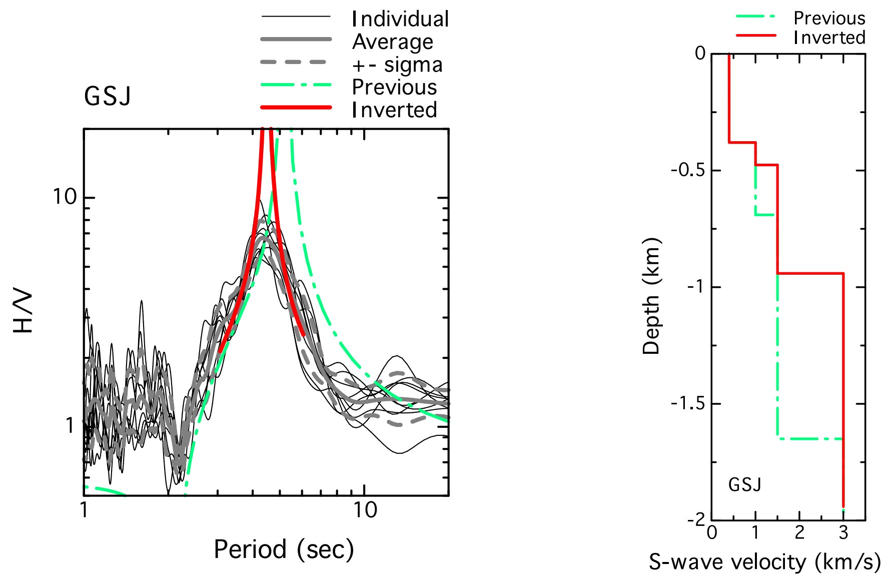
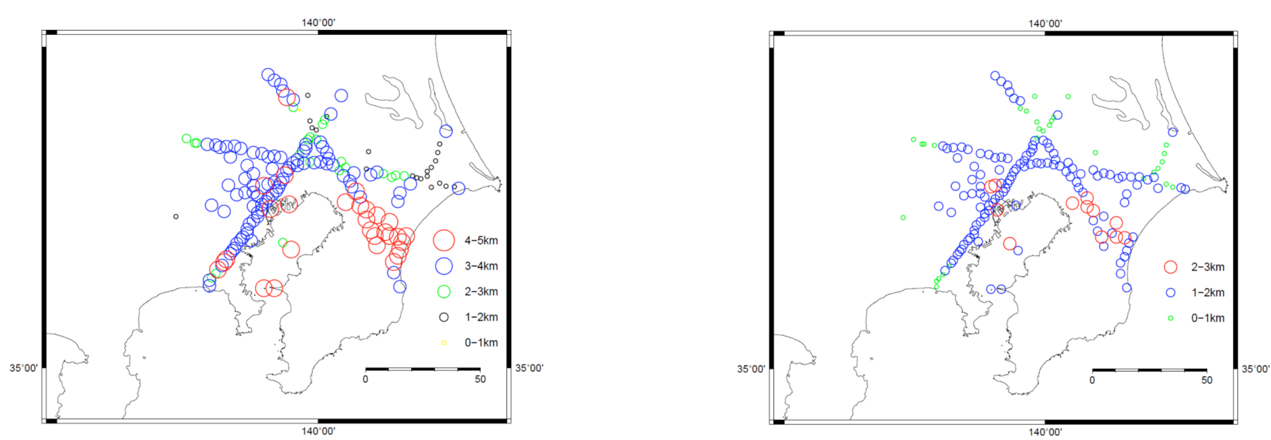


Fig. 6. (Left) Fitting of H/V spectral ratio inverted by the Genetic Algorithm to the observation at GSJ. (Right) The estimated S-wave velocity structure at GSJ.

DISTRIBUTION OF SEISMIC BEDROCK IN AND AROUND THE TOKYO METROPOLITAN AREA

We applied this inversion process to all the H/V spectral ratios of Coda waves obtained by MeSO-net. The depths of seismic bedrock (Vs 3km/sec) and the interface between layers of Vs 1km/sec and Vs 1.5km/sec in and around the Tokyo Metropolitan Area are shown in Fig.7 (a) and Fig.7 (b), respectively. The spatial distribution of dominant periods of H/V spectral ratios (See Fig. 4) matches better the depth of the seismic bedrock (Fig.7a) than the depth of the interface between Vs 1km/sec and Vs 1.5km/sec (Fig.7b). The dominant periods of H/V spectral ratios are strongly influenced from the layer of Vs 1.5km/sec. Specially, the estimated models were 500m to 1km deeper than Yamanaka and Yamada's model in the west of Tokyo Bay.



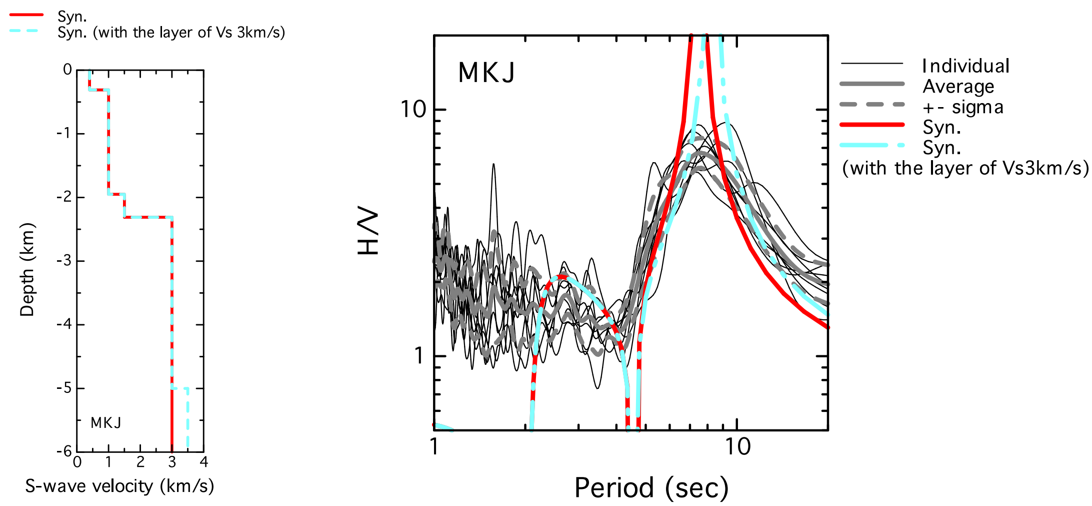
(a) Depths of the seismic bedrock (Vs 3km/s). *(b) Depths of the interface between layers of Vs 1km/s and Vs 1.5km/s.*

Fig. 7. Distribution of depths of the seismic bedrock (Vs 3km/s) and the interface between layers of Vs 1km/s and Vs 1.5km/s.

DISCUSSIONS

We verified the effects to H/V spectral ratios of Coda waves from deeper underground structures than the seismic bedrock (Vs 3km/s). We compared theoretical ellipticities (H/V) of fundamental mode Rayleigh waves with and without a certain thickness of the seismic bedrock. In case that the seismic bedrock has a certain thickness (for example, a thickness of about 2.5km at MKJ), the layer of Vs 3.5 km/s is assumed as the lowest layer below the seismic bedrock. The S-wave velocity structures at MKJ are shown in Fig. 8 (a) and the H/V spectral ratios using the both structures are shown in Fig.8 (b). We can see a slight difference from the both H/V spectral ratios for long periods and the dominant periods of those H/V spectral ratios. It indicates that the information of layers deeper than the seismic bedrock (Vs 3km/s) is required to evaluate H/V spectral ratios for long periods.

Also, relative displacement distributions against depths (eigen functions) at MKJ using the structural model without a thickness of the seismic bedrock (Vs 3km/s) are shown in Fig. 9. Although the seismic bedrock is located at a depth of 2.3km, amplitudes of fundamental mode Rayleigh waves for periods of 8sec and 10sec have large influences from deeper underground structures than the seismic bedrock. On the other hand, amplitudes of fundamental mode Rayleigh waves for a period of 5sec have an influence from shallower structures than the seismic bedrock. In Fig. 8 (b), the amplitudes of H/V spectral ratios for a period of 5sec in case of deeper structures with the 3km thickness of Vs 3km/s is as same as those in case of the structure without a thickness of Vs 3km/s.



(a) S-wave velocity structures. *(b) Synthetic ellipticities (H/V).*

Fig. 8. Theoretical ellipticities of fundamental mode Rayleigh waves with and without a thickness of Vs 3km/s (MKJ).

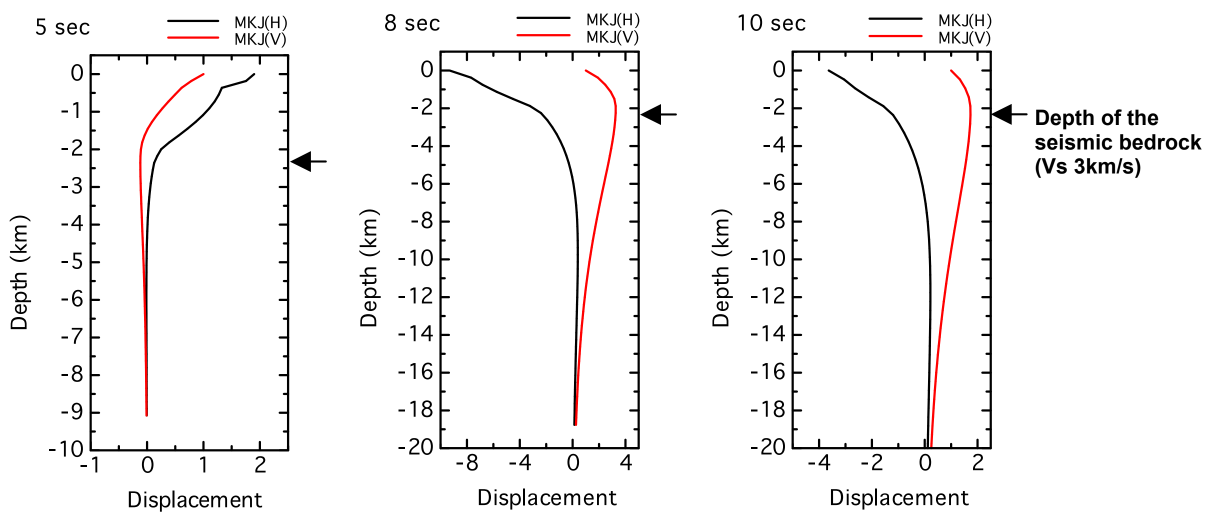


Fig. 9. Relative displacement distributions against depths (MKJ) normalized by the vertical displacement on the surface.

CONCLUSIONS

The variability of H/V spectral ratios of Coda waves observed by 9 earthquakes larger than Mj 6.5 was quite small. We concluded that dominant periods of H/V spectral ratios of Coda waves would be useful for creating a 3-D underground velocity structural model. Dominant periods of H/V spectral ratios matched well for sites where shallow basin structures are located; however, dominant periods of H/V spectral ratios didn't match well for sites where deep basin structures are located. Therefore, we applied the Genetic Algorithm to the inversion of H/V spectral ratios of Coda waves. The estimated S-wave velocity structures were estimated deeper than the previous models proposed by Yamanaka and Yamada (2006) for the west of the Tokyo Bay, where the theoretical dominant periods of H/V spectral ratios were underestimated.

We need to include the information of deeper underground structures than the seismic bedrock (Vs 3km/s) for the inversion of H/V spectral ratios of Coda waves. In the future, we will simulate long periods of strong ground motions in the Tokyo Metropolitan Area, using the improved S-wave velocity structures.

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