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Long-period ground motion characteristics in Osaka basin, Japan – examination of 3D basin structure model

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Introduction

Osaka area, the most populated area in western Japan, is located inside a sedimentary basin whose size is approximately 60km x 40km and the maximum depth of the bedrock is 3km. It is 200km distant from the Nankai trough, and has risk of being exposed to seismic hazard by long-period ground motions during future huge subduction earthquakes. Therefore accurate prediction of long-period ground motions in this area is an important issue.

In this study, we first evaluate the applicability of the 3D crustal and basin velocity structure model of the area by conducting long-period ground motion simulation (down to 3s) of a M6.5 subduction zone event. We compare the synthetics and the observations using waveforms and pseudo velocity responce spectra so as to specify the areas of good fit and insufficient fit. Next, we attempt to find the way to improve the basin velocity structure based on observation data. We seek for site-specific ground motion characteristics from observed long-period ground motion records. Horizontal-to-vertical amplitude spectral ratio of S-coda part (HV) are examined as site-specific characteristics. Comparing the observed HV, HV from simulations by 3D basin structure (3DHV) and theoretical ellipticity of fundamental Rayleigh mode (1DHV), we discuss the keys for rivising the basin velocity structure model.

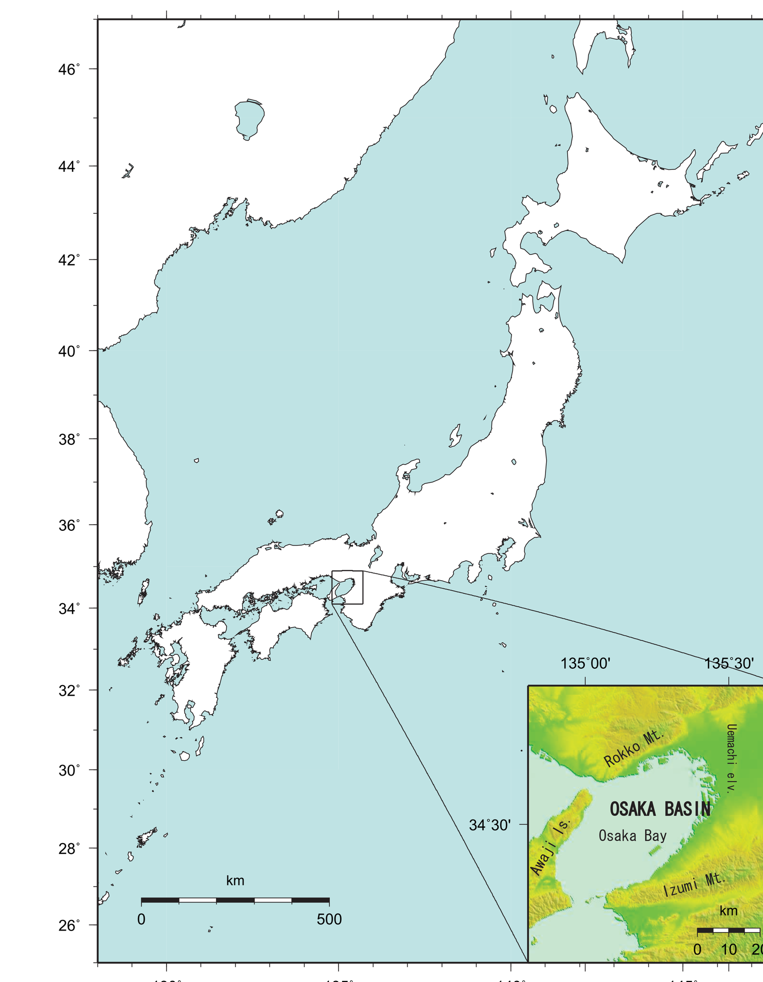


Figure 1. Map of study area and Japan.

Method and data

Simulation method

Ground motion simulations were conducted using velocity structure models based on Iwata et al. (2007) by 3D finite-difference method with nonuniform spacing (Pitarka, 1999).

[EVENT 1]

The largest aftershock of the 2004 Off Kii peninsula earthquake (2004/09/07 08:29JST, M_{JMA}6.5).

Simulation of EVENT 1 is especially importnat because its source was near the source region of the hypothetical Tonankai and Nankai earthquakes.

[EVENT 2]

The 2000 western Tottori earthquake (2000/10/06 13:30JST, M_{JMA}7.3)

	EVENT 1	EVENT 2 ***
Location	N33.209° E137.293° *	N35.239° E133.394°
Depth	25 km	6 km
strike, dip, slip	272° 49° 97° **	150° 85° -9°
duration	3.0 sec	5.0 sec
M_0	6.0×10^{18}Nm **	1.1×10^{19}Nm

*JMA **NIED ***Nagawa (2003)

Table 1. Source parameters.

Velocity structure model

[EVENT 1] 280km x 250km x 50km

[EVENT 2] 280km x 140km x 50km

FDM grid spacing varies from 0.125km (inside the basin) to 0.5km (outside the basin). Frequency range of the calculation is up to 0.33Hz.

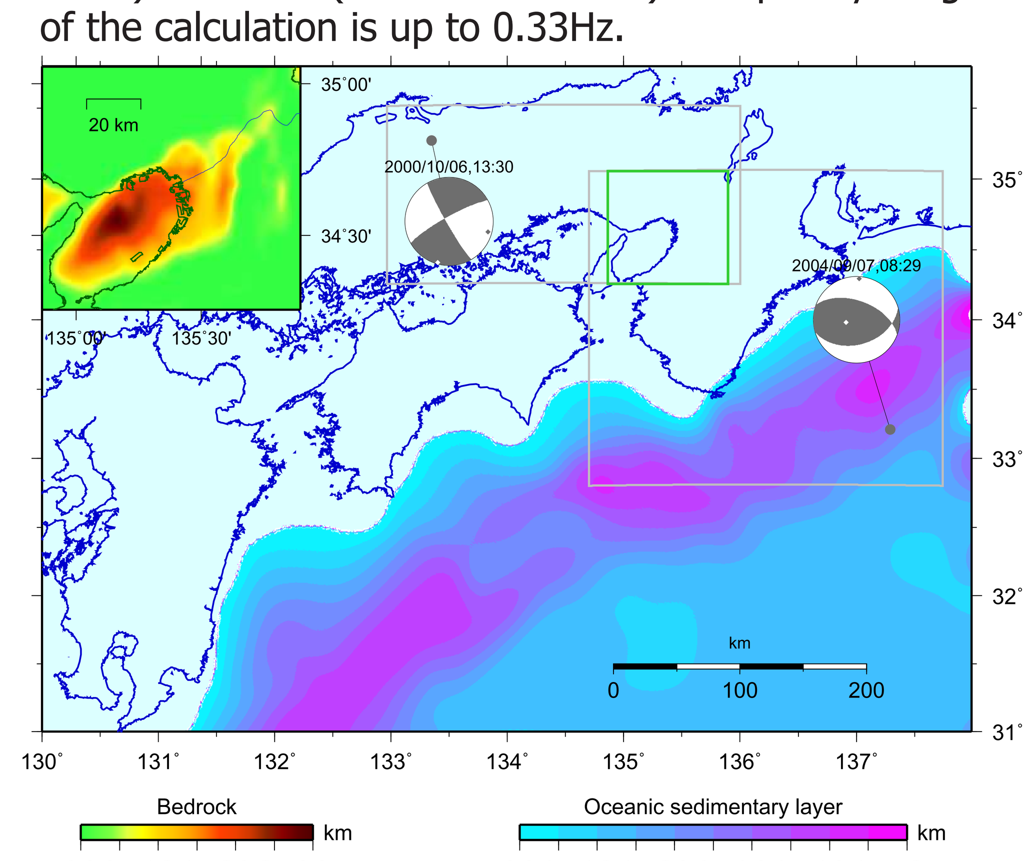


Figure 2. Model area for the calculation. Colors indicate depth distribution of oceanic sedimentary layer and bedrock.

Strong motion stations

We used as many as 49 strong motion stations so that they have sufficient coverage of the area.

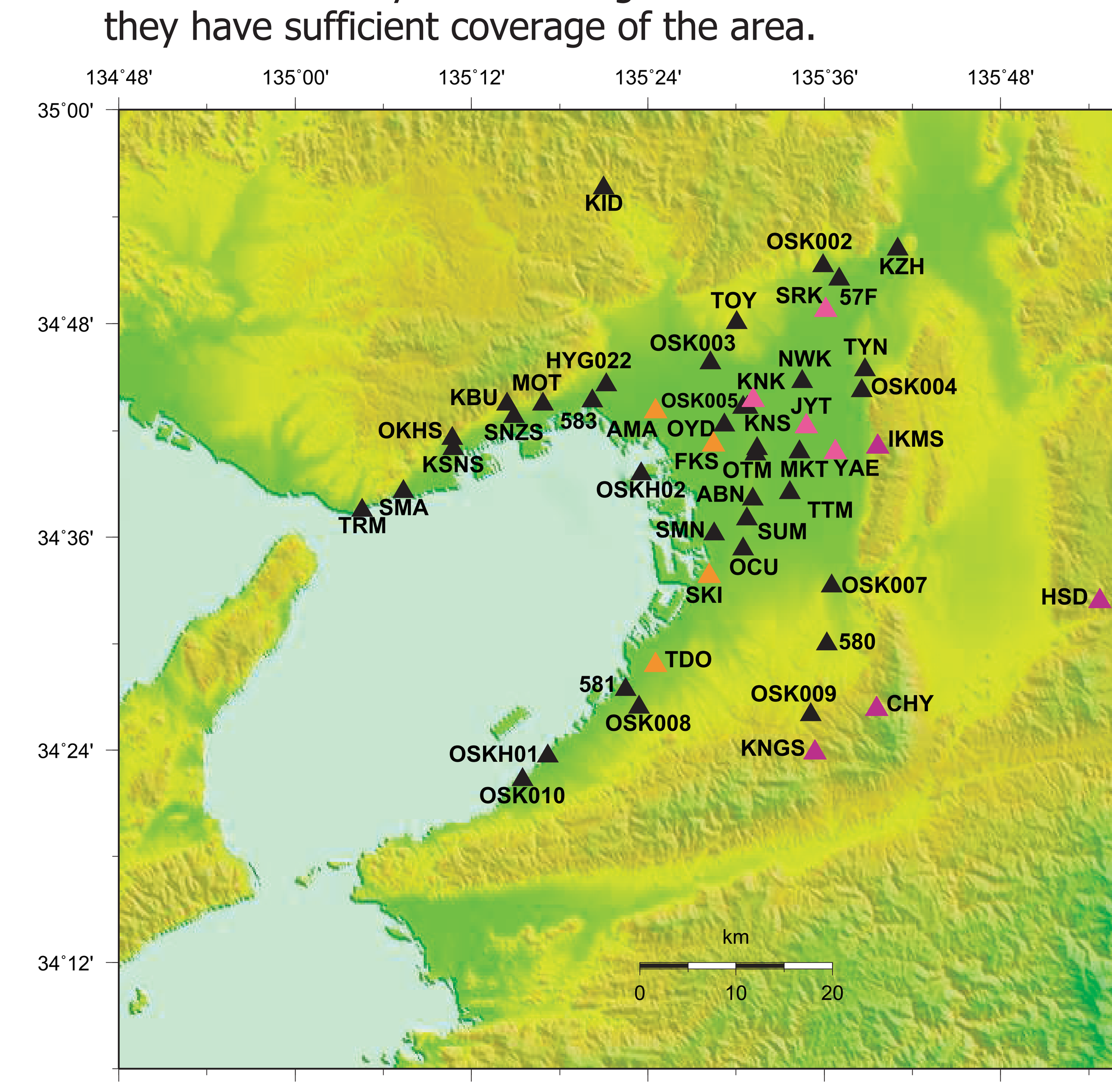


Figure 3. Strong motion stations used in this study.

Simulation results

Waveforms

The synthetic waveforms of EVENT 1 are compared with the observations.

At rock sites (HSD, CHY, KNGS, IKMS), the synthetics reproduced the observations quite well.

Inside the basin, waveform fit is good at the stations in the bay area (AMA, FKS, SKI, TDO), while the synthetics are overestimating the observations at stations located in the eastern area of the basin (SRK, KNK, JYT, YAE).

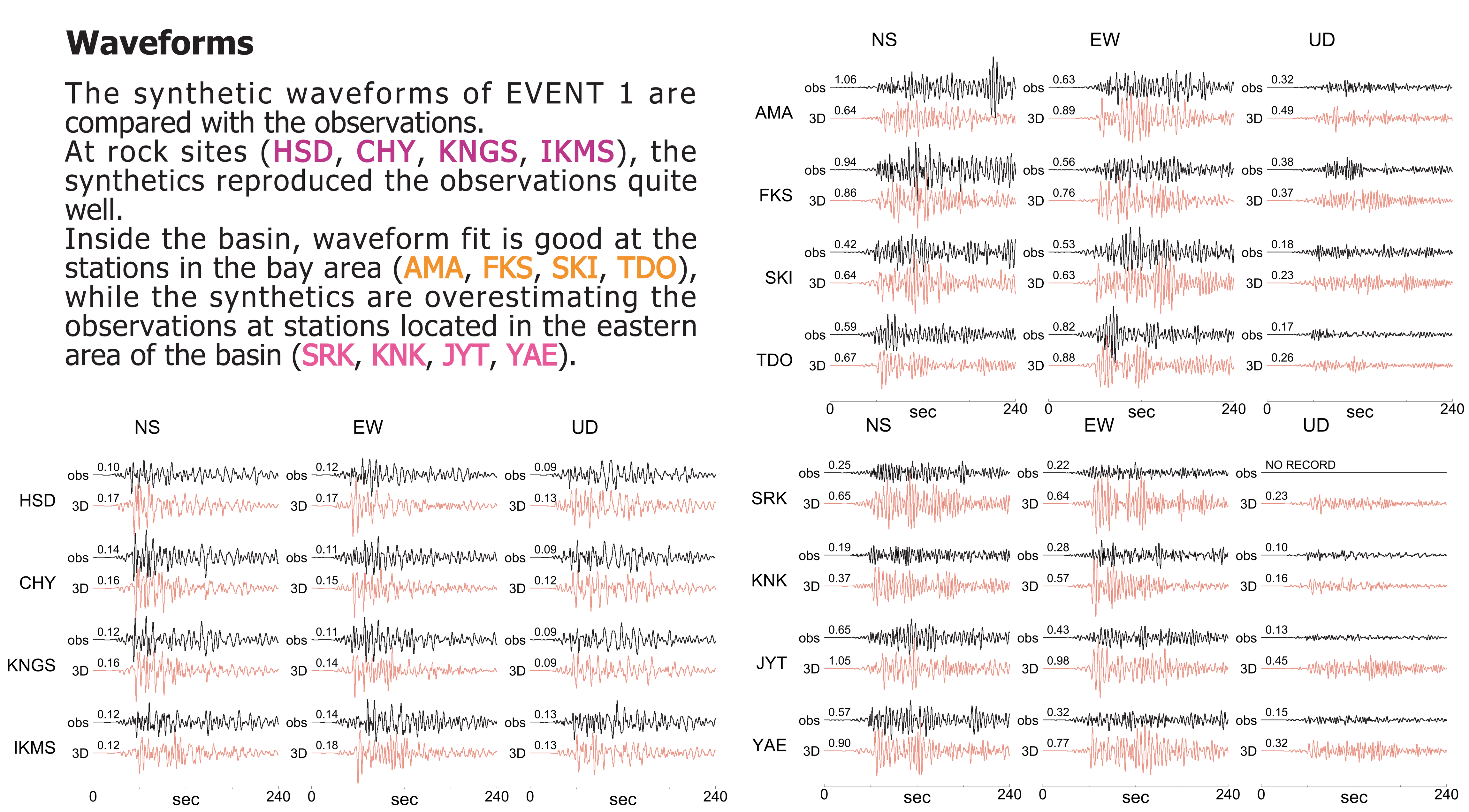


Figure 4. Comparison of the observed waveforms (black trace) and the synthetic waveforms (red trace) at rock sites (left), bay area sites (right top), and the eastern sites (right bottom). Band-pass filtered at 3-20s.

Psuedo velocity responce spectra

We calculated psudo velocity responce spectra (h=5%), and estimated goodness of fit between the synthetic and the observed pSv (3-20s) using the following factor.

$$f = 1 - \frac{\sum\{(p(T)^2_{obs} - p(T)^2_{syn})dT\}}{\sum\{(p(T)^2_{obs} + p(T)^2_{syn})dT\}}$$

The synthetics generally explains the observations well at many stations. In the eastern area of the basin (YAE, KNK, etc.) the value of **f** is smaller.

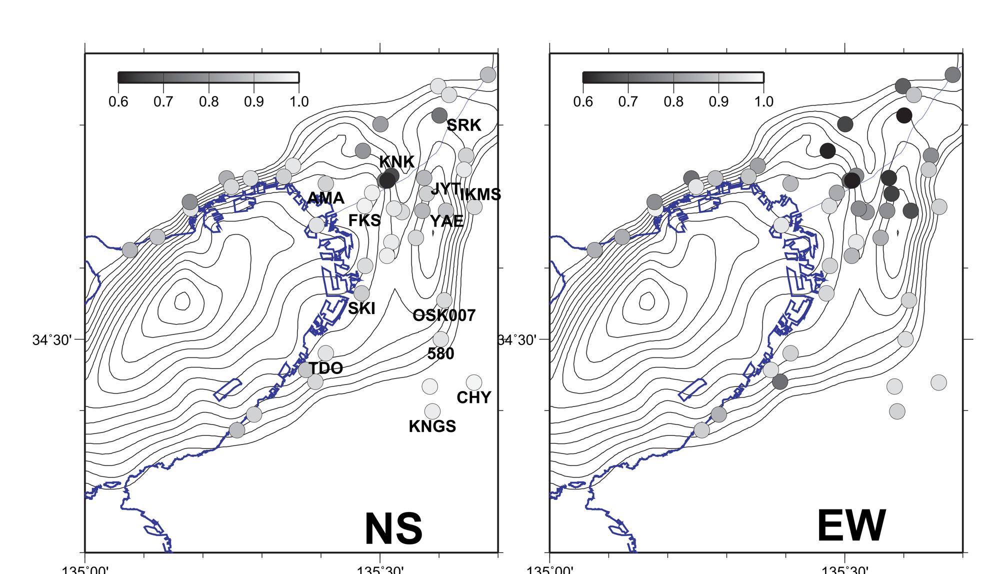


Figure 5. Goodness-of-fit factor f for pSv (periods 3-20s). The fit is perfect when f=1. Contour lines indicate the distribution of bedrock depth.

Characteristics of HV spectral ratio

HV characteristics observed in Osaka basin

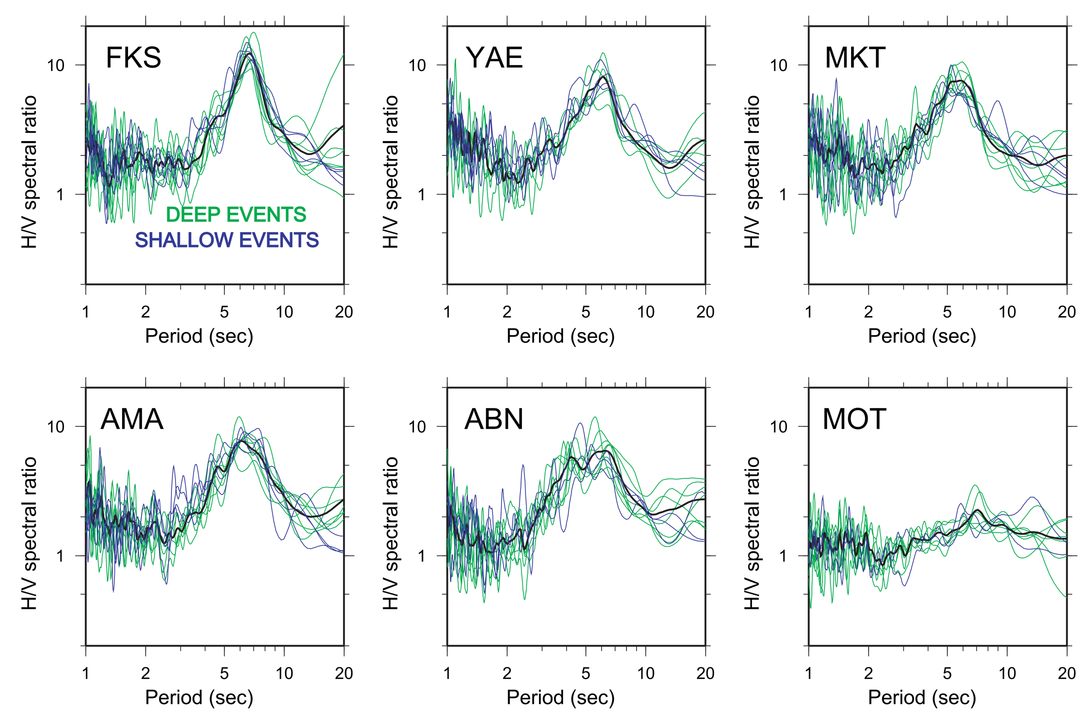


Figure 6. HV spectral ratio of 4 deep events (blue traces) and 7 shallow events (green traces), using 240-seconds time windows from 60s after S-wave arrivals. Black trace indicates the average.

We sought for site-specific characteristics in long-period ground motions from distant large earthquakes observed in Osaka basin. S-coda part of ground motion data from 7 major inland earthquakes and 4 deep earthquakes (Fig.8) were used to calculate horizontal-to-vertical spectral ratio (HV).

HVs show stable values at each stations. THey are independent of deep and shallow events, and show site-specific characteristics. We can assume that HV characteristics are mainly controlled by the underground structure.

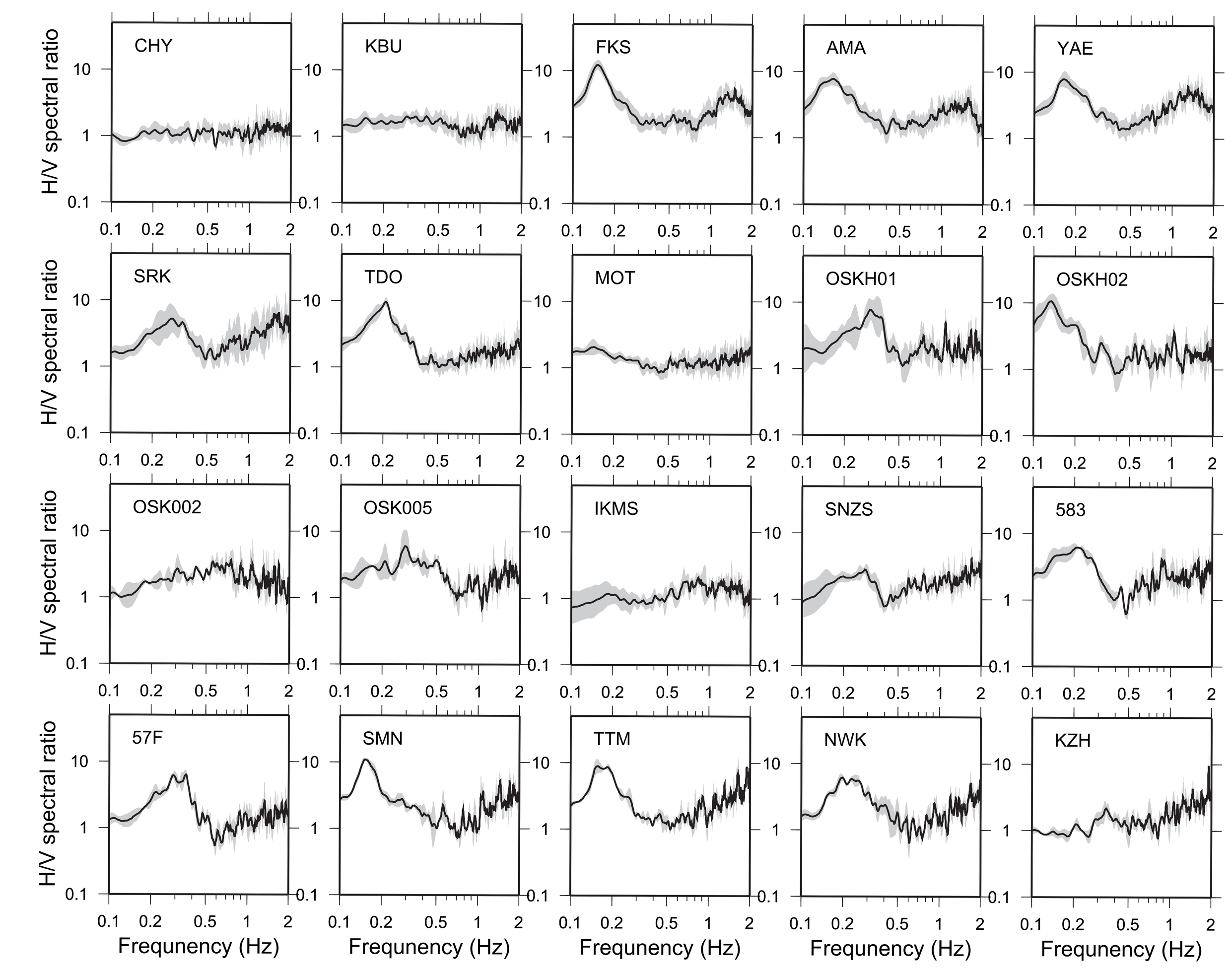


Figure 7. Average HV spectral ratio of 11 events using 240-s time windows from 60s after S-wave arrivals. Grey shade indicates standard deviation.

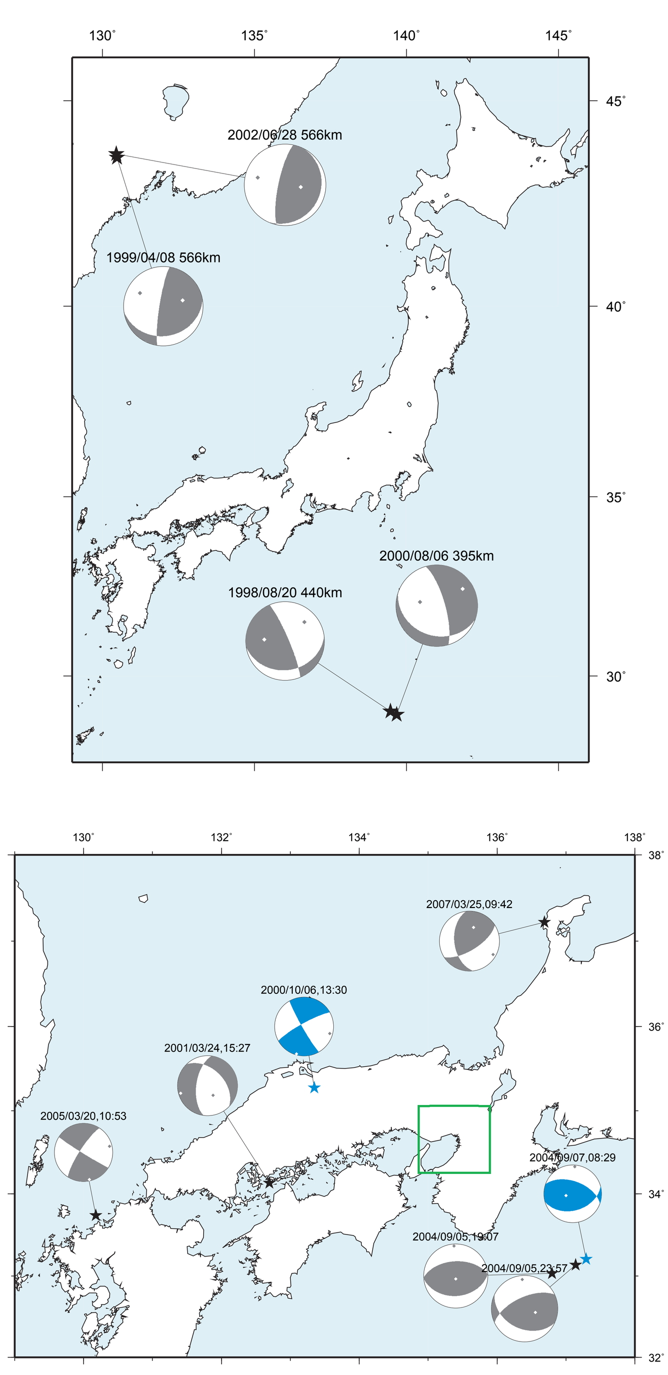


Figure 8. 4 deep earthquakes (M_W>7) (top) and 7 shallow earthquakes (M_{JMA}>6.5) (bottom) used in the HV study shown in Figure 6 and 7. EVENT 1 and EVENT 2 used in the simulations are colored blue.

HV characteristics from simulations (3DHV)

We calculated HVs using S-coda parts of the synthetic waveforms (3DHV) from simulations EVENT 1 and EVENT 2, and compared them with the observed HV. 3DHVs explain the observations very well at SKI and TDO, while there are discrepancies at YAE and JYT.
Next we compared 3DHV with the theoretical ellipticity of fundamental Rayleigh mode (1DHV) obtained from 1D underground structure beneath each site. 3DHV and 1DHV peak seem to correspond to each other at these stations except for YAE.
3DHV and 1DHV peak may not necessarily correspond to each other especially where the underground structure changes complexly.

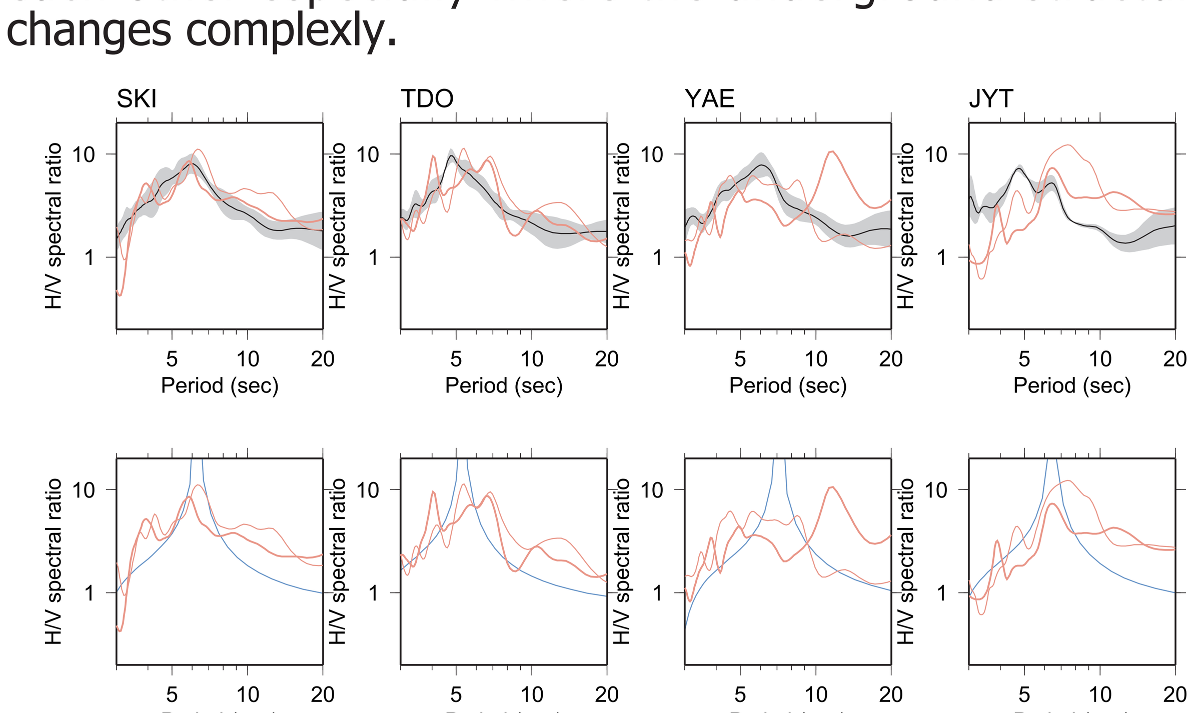
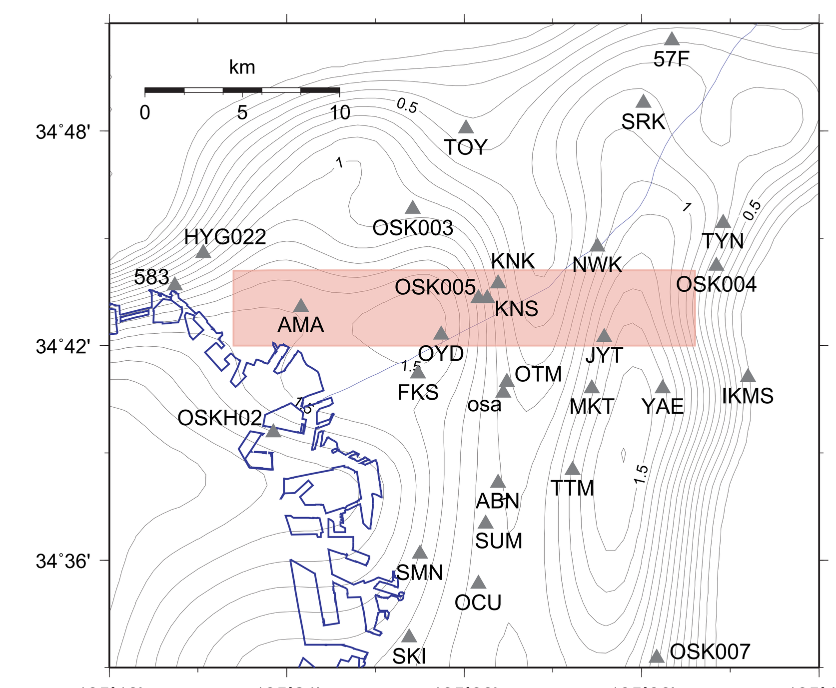


Figure 9. [Top] 3DHV of EVENT 1 (thick pink trace) and EVENT 2 (thin pink trace) compared with average observed HV (black trace). Grey shade indicates standard deviation. [Bottom] 3DHVs (pink trace) compared with theoretical ellipticity of fundamental Rayleigh mode (1DHV) (blue trace).

Difference between 3DHV peak and 1DHV peak

Distribution of the difference between 3DHV peak and 1DHV peak was investigated every 1km in the area highlighted in the map below.
The peak difference distributions seem to be related to the 2D (or 3D) underground structure.
This suggests that HV peak is controlled by an area with some spatial extent; it is not determined by the 1D underground structure beneath the site.



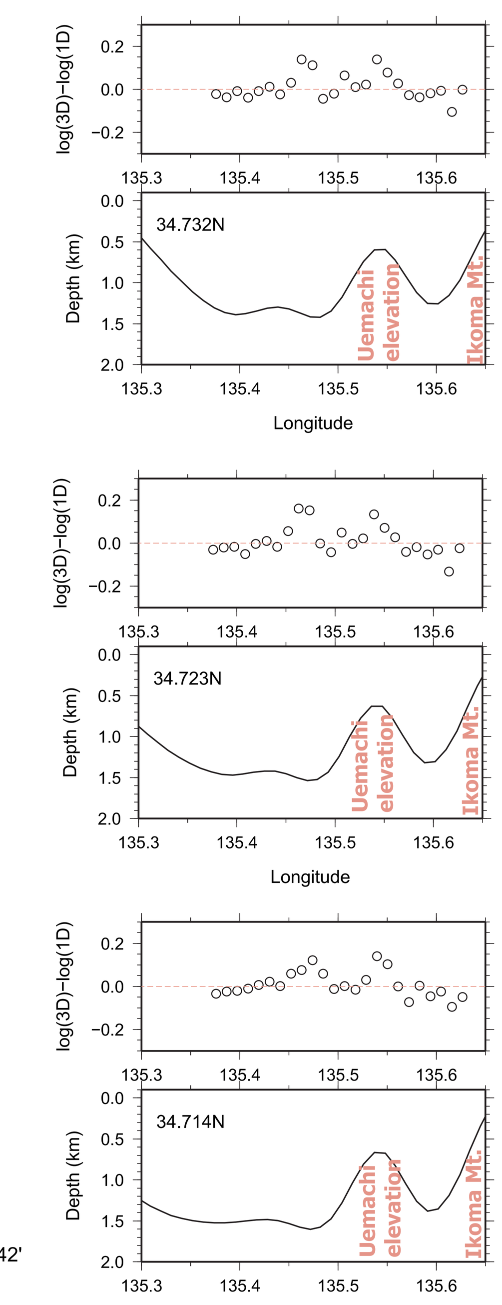


Figure 10. [Right] Cross-section views of 3D-1DHVpeak difference (top) and bedrock depth (bottom) along latitudinal lines. [Left] Study area is highlighted pink. Contour lines indicate bedrock depth.

Conclusion

1) We evaluated the applicability of the three-dimensional crustal and basin structure of Osaka area by conducting long-period ground motion simulations of a M6.5 subducting zone event. The crustal model very well explained the observed waveforms at rock sites outside the basin. Inside the basin, the synthetic and the observed waveforms and pSv showed good agreement at many stations. There were discrepancies between the synthetics and the observations at stations located in the eastern part of the basin. These discrepancies may be due to probable inaccuracy of the local basin structure.

2) We calculated HV of S-coda part using strong motion data from 11 distant large earthquakes, and showed that HV has site-specific characteristics independent of the events. Simulated HV (3DHV) and theoretical ellipticity of fundamental Rayleigh mode (1DHV) did not necessarily correspond to each other, suggesting that HV characteristics are not determined by the one-dimensional underground structure beneath the site.

Because of the three-dimensional effect of Oska basin structure on ground motions, it is not easy to reflect the site-specific characteristics at each site to rivising the basin velocity model, especially where the distribution of seismic bedrock depth is complex, e.g. Uemachi elevation (Fig. 10). Estimation of spatial extent of three-dimensional effects is needed for the improvement of the basin velocity structure model.

Table 2. Velocity structure model (Iwata et al., 2007)

	Vp (km/s)	Vs (km/s)	ρ (g/cm^3)
Sedimentary layer 1	1.60	0.35	1.70
Sedimentary layer 2	1.80	0.55	1.80
Sedeimentary layer 3	2.50	1.00	2.10
Bedrock	5.40	3.20	2.70
Oceanic sedimentary layer	2.00	1.00	2.00
Surface low-velocity layer	5.00	2.70	2.74
Upper crust	6.00	3.45	2.80
Lower crust	6.70	3.90	2.90
Mantle wedge	7.70	4.45	3.10
Oceanic crust layer 2	6.00	3.45	2.90
Oceanic crust layer 3	6.70	3.90	2.80
Slab	8.00	4.63	3.22
Upper mantle	7.90	4.57	3.10

References

Iwata et al., 2007, J. Seismol., submitted.
Pitarka, 1999, Bull. Seism. Soc. Am. 89, 54-68.
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Acknowledgements

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