Long-period Ground Motion Characteristics of the Osaka Sedimentary Basin during the 2011 Great Tohoku Earthquake

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SUMMARY:
Long-period ground motion characteristics due to the 2011 Great Tohoku earthquake in the Osaka sedimentary basin are studied. Dense strong motion records of this event are collected in and around the Osaka basin. The pseudo-velocity response (pSv) map at 7s shows clear relationship between the amplitude and the basin depth of the model. Peak period of H/V spectral ratio of later phase portion shows spatial characteristics and it coincides with the peak period of R/V spectral ratio of the theoretical fundamental Rayleigh waves obtained from the 1D underground velocity structure model for most stations. We also found some stations where the observed peak period differs from the theoretical one located near the basin edge or the Uemachi elevation. Peak shape of the H/V spectral ratio is not clear and it would be caused by the contamination of other type of waves, Love and body-waves.

Keywords: Long period ground motion, the 2011 Tohoku earthquake, Osaka sedimentary basin

1. INTRODUCTION

Seismic risk by long-period ground motion is one of the present important issues in mega-cities in large sedimentary basins because the resonances of long-period structures such as oil tanks, long bridges, and high-rise buildings would cause the seismic disaster. Osaka sedimentary basin, where many long-period structures are existing, is the most populated area in western Japan and stands about 200 km from the source region of the anticipated Nankai and Tonankai mega-thrust earthquakes whose high probability of occurrence are about 60–70% within 30 years (Headquarters for Earthquake Research Promotion, 2011). Together with the source model, the seismic velocity structure model from the source to the target area including the sedimentary basin is needed for quantitative evaluation of long-period ground motions. For example, Iwata *et al.* (2008) has constructed the three-dimensional crustal and basin velocity structure models for ground motion prediction for future crustal and subduction earthquakes in southwestern Japan, and their models have been used for ground motion simulation studies (e.g., Iwaki and Iwata, 2010). They constructed these models by compiling a number of geophysical exploration results such as reflection profiles, receiver function profiles, seismic tomography, etc. We have to make constant efforts to validate how the existing three-dimensional velocity structure models explain the observed waveforms by ground motion simulations in the target periods. Especially, the confirmation of the Osaka sedimentary basin model is very important for accomplishing the reliable ground motion prediction.

The observed seismograms from large to moderate earthquakes, which have enough signal-to-noise ratios in the long-period range (ex. 2–10 s), are usually used for ground motion simulations. However, such events are not always uniformly distributed around the target region, and large events bringing a number of data with good signal-to-noise ratios do not occur very frequently. The 2011 Great Tohoku-Oki earthquake (Mw9.0) rocked all over Japan and its long-period ground motions are well-recorded in and around Osaka basin, where the source distance is about 600 km. We collected about 100 records at strong motion stations of many organizations and analysed propagation characteristics in the Osaka basin. As the long-period ground motion in period as long as 50 s has enough SN ratio, we could confirm the orientation of seismometer. After correcting the sensor's orientation, we map the pSv and discuss its relation to the basin depth. H/V spectral ratio for later phases is compared to the R/V spectral ratio of the theoretical fundamental Rayleigh wave of the 1D velocity structure model beneath the station.

2. GROUND MOTION DATA DURING THE GREAT TOHOKU EARTHQUAKE IN AND AROUND OSAKA BASIN AND ESTIMATION OF SEISMOMETER SETTING

From 1990s, geophysical surveys such as seismic refraction and reflection, gravity anomaly, microtremor, and borehole logging are conducted in the Osaka basin to construct the basin velocity structure model. Several research groups proposed their velocity structure models. The seismic bedrock depth of the model by Iwata *et al.* (2008), one of those researches, is shown in Fig. 2.1 (Left). The basin is approximately 80 km x 60 km in size, covering the most populated area in western Japan, including the cities of Osaka and Kobe. The basin thickness is at most 3 km under the Osaka bay and approximately 1.5 km at the coastal area of Osaka bay.

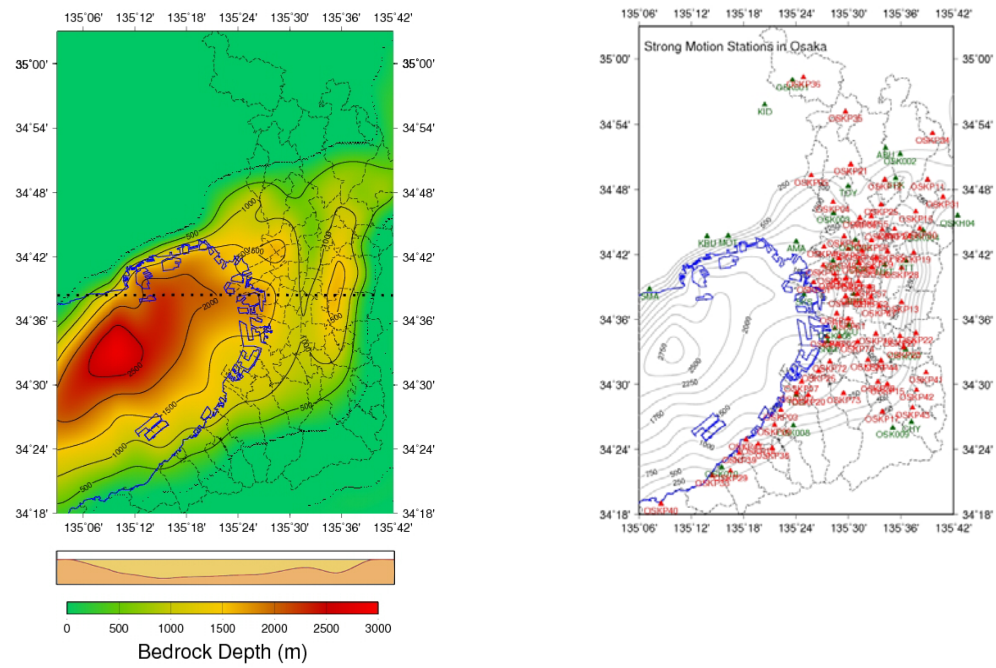

Figure 2.1. (Left) The bedrock depth in the Osaka sedimentary basin (Iwata *et al.*, 2008). The EW cross section at the centre of the basin is shown in bottom. (Right) Strong motion stations used in this study. The seismic intensity meters of Osaka prefecture are shown in red colours.

As the JMA seismic intensities are 2 or 3 in the Osaka area during the 2011 Tohoku earthquake, many strong motion stations are triggered. We collected strong motion data of many organizations, NIED, CEORKA, JMA, BRI, and Osaka prefecture government. Osaka prefecture government newly installed the JMA seismic intensity network in FY2010 and they observed this event records at 69 stations. In Fig. 2.1 (Right), the strong motion station map is shown. Original records of K-NET and KiK-net of NIED, JMA, BRI, and Osaka prefecture are acceleration, and those of F-net (strong motion) of NIED and CEORKA are velocity. All records have absolute timing corrected by the GPS signal. Most of stations are triggered stations and record lengths are 5 minutes in average, while those at some stations are 2 or 3 minutes. Taking the amplitude spectra of those records, we recognized the records have enough S/N ratios even at the period of 50 s both in velocity and acceleration records. Using this long-period ground motion data, we firstly confirmed the orientation of seismometer for all stations used in this study. The procedure to find the orientation setting difference is as follows, [1] Taking band-pass-filtered acceleration records between 0.02–0.03 Hz (33–50 s in period), [2] calculating cross correlation (time-lag) between the fixed two horizontal components at OSKH04 of NIED, as a reference, and the rotated (theta) two horizontal components at the target site for the length of 100s at the main portion of the ground motion, and [3] finding the time-lag and theta to give the maximum cross correlation value. We assume this long-period ground motion is approximately a plane wave. Using this value of theta, we got the difference of the orientation to the reference site. The following analysis will be done after correcting the setting orientation.

3. GROUND MOTION CHARACTERISTICS IN THE OSAKA SEDEIMENTARY BASIN DURING THE TOHOKU EARTHQUAKE

3.1 Pseudo velocity response distribution

On comparison between the Osaka basin velocity structure model and the observation, several researches are reported. Miyakoshi and Horike (2008) compared the peak period of the observed whole records of seismic ground motions of regional large earthquakes to the period of the Airy phases of Rayleigh (vertical component) and Love (horizontal component) waves of the 1D velocity model beneath the observed station. They analysed about 10 broad-band strong motion station data in the Osaka basin. Those observed peak periods of vertical and horizontal components are corresponding to those Airy phase periods. Iwaki and Iwata (2010) obtained spectral ratios of horizontal to vertical component (H/V spectral ratio) of later part or coda part of observed seismic ground motions at the sedimentary sites (ObsHV). They estimated the theoretical R/V spectral ratio of the 1D fundamental Rayleigh wave at the observed stations (1DHV) and the H/V spectral ratio by the numerical calculation for the 3D velocity structure model (3DHV). They concluded that both the 1DHV and the 3DHV fit well to the ObsHV at sites in relatively flat basin bed area. On the contrary, the 3DHV fits better to the ObsHV than the 1DHV at sites whose basement is inclined or near the edge of the basin. Here we obtain the pSv and the H/V spectral ratios of this event records, and show the characteristics.

Fig. 3.1 shows the comparison of velocity amplitude spectra of EW-component at ABU (rock site, north of the Osaka basin) and SKS (basin site) in the period range between 0.1 and 50 s. SKS is located in the area where sediments thickness is the largest in the land area in the Osaka basin. Amazingly, the maximum velocity amplitude spectra occurred at the period of about 40 s both at ABU and SKS. The velocity spectra both at ABU and SKS coincide to each other in the period longer than 20 s. The velocity spectrum at SKS is getting larger than that of ABU in the period range between 10 to 20 s. In the period range shorter than 10 s, the amplitude at SKS is much larger than that at ABU due to the basin effect. We mainly concern about the amplification characteristics observed shorter than 10 s which related to the basin effect. Therefore, we took pseudo velocity response (pSv) in the period range shorter than 10 s. In this period range, we found that the spatial distribution of pSv at 7 s shows systematic characteristics. Fig. 3.2 shows the pSv distribution at 7 s. The maximum pSv was observed at SKS, where a high-rise building of Osaka prefectural government was shook as long as ten minutes causing emergency stops of elevators and partial damages to the interior of the buildings (e.g. Osaka Prefectural Government, 2011). Larger pSv are observed along the coast and in south part of the centre of Osaka basin; those areas correspond to deeper bedrock area as shown in Fig. 2.1. This spatial distribution is similarly observed during the 2004 Kii-Hanto-Nanto-Oki earthquake (Iwata and Asano, 2005). However, Iwata and Asano (2005) pointed out that this kind of distribution of pSv was observed at 6 s. The difference between the predominant pSv periods would occur by the difference of the azimuthal direction of incident waves (E to ENE direction to the Osaka basin for the 2011 Tohoku and SE direction for the 2004 Kii-Hanto-Nanto-Oki) and/or the difference of period characteristics of incident waves. As shown in Fig. 3.1, wave energy at 7 s is stronger than the neighbour period range at ABU and that would affect the dominant period of pSv in the Osaka basin. We need to consider the cause of 7 s predomination both in the source effect and the propagation-path effect outside of the Osaka basin.

In Fig. 3.3, we show the azimuthal pSv characteristics at SKS for horizontal component. The maximum pSv occurred at 7s in the direction of about 10 degree, i.e. N010°E direction. The back-azimuth to the source is about N068°E based on the CMT solution. The predominant direction of pSv match neither the parallel to the source direction (as SV or Rayleigh waves) nor the perpendicular to the source direction (as SH or Love waves). In Fig. 3.2, we showed pSv at 7 s for the EW and NS components. The response of NS component is larger than that of EW component at most of stations. Those results show that the long-period ground motion in the predominant direction is generated by the basin induced surface waves and investigation of the predominant direction of pSv is necessary for understanding ground motion characteristics at the basin site.

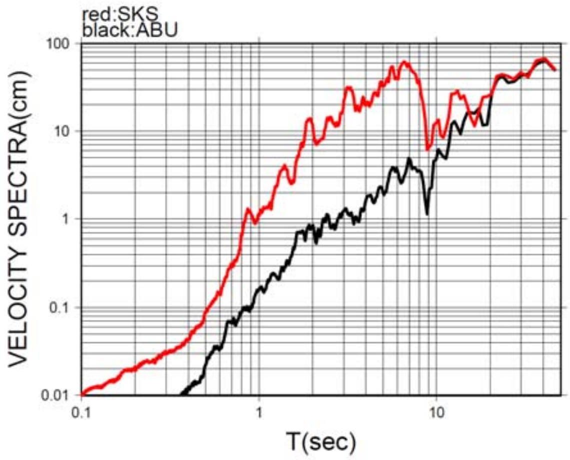

Figure 3.1. Comparison of velocity amplitude spectra of EW components between ABU (rock site) and SKS (basin site).

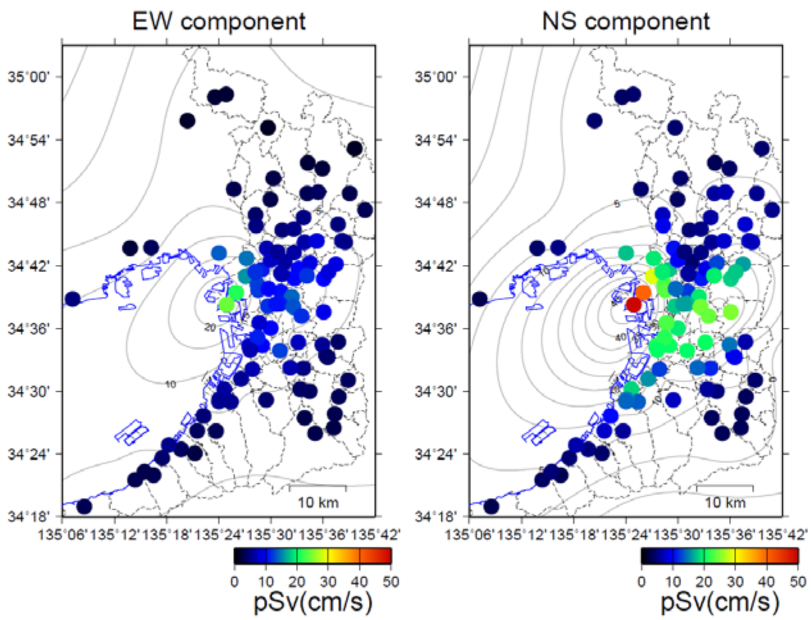

Figure 3.2. Map of pSv distributions of EW (left) and NS (right) components at 7s. Contours show the pSv distribution calculated from the observation.

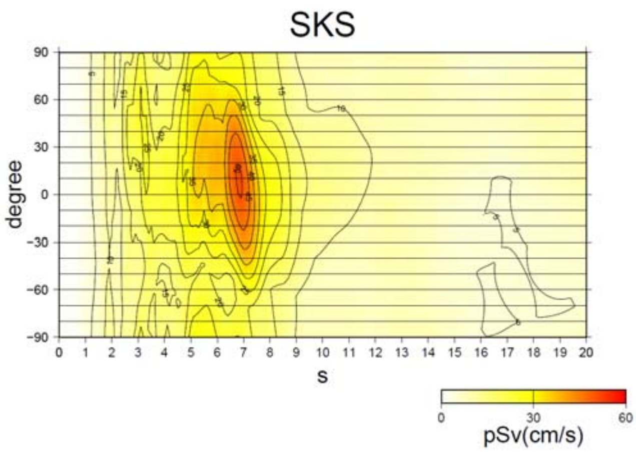

Figure 3.3. Azimuthal pSv at SKS. NS and EW directions are 0 and 90 degrees, respectively.

3.2 H/V spectral ratio

We took an H/V spectral ratio, a receiver function in seismology, to find the relationship between ground motion characteristics and sedimentary basin model, as Iwaki and Iwata (2010) studied. They analysed coda part (starting from 60 s after the time of S-wave onset) of regional large event records. For the 2011 Tohoku earthquake, as the source distance is larger than their cases and most of records are triggered finite records length, we analysed later part of observed records after the main ground motions. Fig. 3.4 shows an example of the analysed part in the record. We use a 163.84s time window to take a Fourier spectrum with 10% smoothing window of each component. We calculated the H/V spectral ratio by the ratio of the vector summation of NS and EW components to UD component. Fig. 3.5 shows examples of the H/V spectral ratios. We picked up the period band that shows dominant H/V spectral ratio together with the period of peak H/V ratio (Tp). We compared the observed Tp to the peak period of R/V spectral ratio of the fundamental Rayleigh waves computed using the 1D velocity structure model at the site, which is extracted from the modified version of the 3D velocity structure model (Iwaki and Iwata, 2011) from that by Iwata *et al.* (2008). Fig. 3.6 shows the comparison of the observed Tp and the theoretical Tp. The observed Tp is in good agreement with the theoretical one except for some stations. This result shows our basin velocity structure model is reasonable in this period range (2-10s) at the area covered by this network. At some stations, the observed Tp differ from the theoretical Tp. We found those stations were located near the edge of the basin or near the Uemachi elevation. These areas seem to be modelled insufficiently by the sedimentary velocity model, because that model uses the B-spline function to describe the boundary shape which is not easy to explain the sharp boundary shape well.

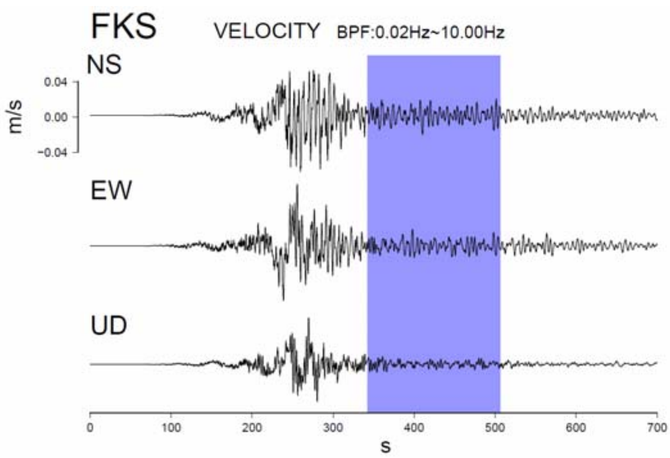

Figure 3.4. Example of the observed velocity waveforms and analysis portion for H/V spectral ratio, at FKS, the basin site. Blue-shaded area indicates the analysis window.

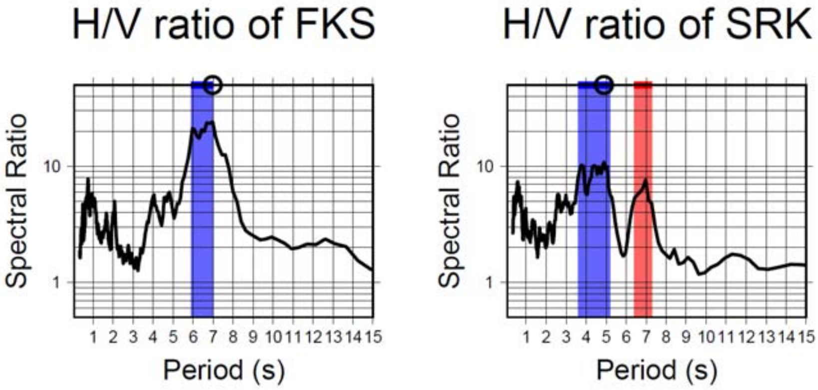

Figure 3.5. Example of the H/V spectral ratios. We picked the peak period as indicated by the open circle. Blue shaded area show larger H/V ratios. In the case of obvious two peaks in the H/V spectral ratio, We also took the second peak area indicated as the red shaded area as shown in the right figure.

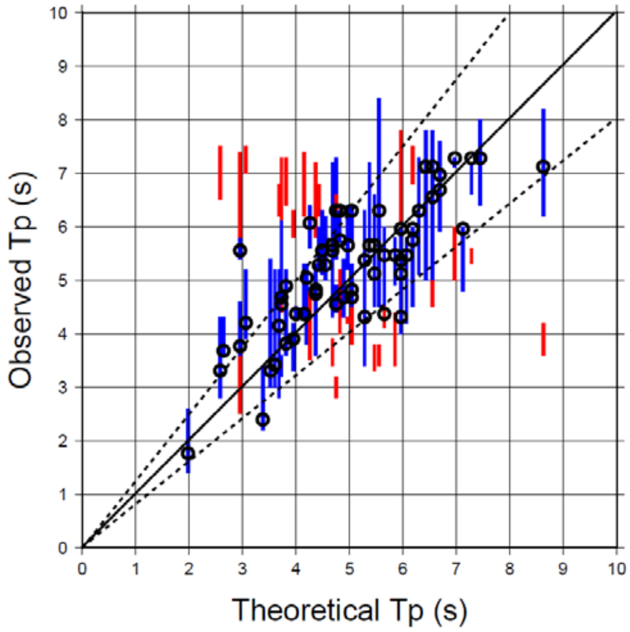

Figure 3.6. Comparison between the observed peak period of H/V spectral ratio and the theoretical peak period of R/V spectral ratio of the fundamental Rayleigh wave under the assumption of 1D underground velocity structure at the site. Open circles show the peak period. Blue and red bars indicate dominant period area of the first and the second peak, respectively. Solid and dashed lines indicate 1:1 and 20% difference, respectively.

4. DISCUSSION AND CONCLUSION

Long-period ground motion characteristics due to the 2011 Great Tohoku earthquake in the Osaka sedimentary basin are studied. We collected about 100 strong motion records of this event. Using long-period (more than 30 s) ground motion records, which has sufficient S/N ratio, we estimated the orientation of seismometers. This process is very important for discussing ground motion generation and propagation in the basin. At this moment, we obtained pSv and H/V spectral ratios of this record. The pSv map at 7 s shows clear relationship between the amplitude and the basin depth of the model. Peak of H/V spectral ratio of later phase portion showed spatial characteristics, and it is related to the peak of R/V spectral ratio of the theoretical fundamental Rayleigh waves obtained from the 1D underground velocity structure model (Iwaki and Iwata, 2011; Iwata *et al.*, 2008) at most stations. The basin velocity model can be confirmed for the long-period (2–10 s) ground motion simulation. However, the peak shape of the H/V spectral ratio is sometimes complex, e.g. two distinctive peaks, or flat dominant portion of H/V. It would be caused by the contamination of other type of waves, Love and body-waves and we will further think about this effect. Detailed comparisons of these characteristics due to the 2011 Tohoku earthquake and other events will be future works for investigating generation and propagation of ground motions in the Osaka basin and discussing the performance of the basin model.

ACKNOWLEDGEMENTS

We used strong motion data obtained by K-NET, KiK-net and F-net of NIED, CEORKA, BRI, JMA, and Osaka prefecture. JMA unified hypocentre catalogue was used. Figures are drawn using the Generic Mapping Tools (Wessel and Smith, 1998).

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