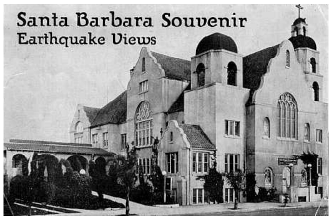

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A STUDY ON THE ESTIMATION METHOD FOR UNDERGROUND STRUCTURE USING MICROTREMORS AND ITS APPLICATION TO THE OSAKA PLAIN

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ABSTRACT

It is essential to evaluate a subsurface structure properly for extensive and highly precise estimation of strong ground motion. In order to evaluate the subsurface structure, we need to validate the previously proposed subsurface structure models based on the geological data and boring exploration data using the observation data of ground shaking. In this study, we observed microtremor in the southern part of the Osaka Plain in Japan where detailed geological information are comparatively less than the other areas in the Osaka Plain. We calculated predominant peak frequencies of the ground from H/V spectral ratio of microtremor data and compared these frequencies with those calculated from our initial model. For sites where predominant frequency of data and model does not match, we modified the 1-D structure at each site simply based on these predominant frequencies. We identified a modified subsurface structure along the two east-west lines in the southern part of the Osaka Plain and studied in detail the appropriateness of this identification approach. As a result, we found this identification approach is appropriate, yet there are some research issues to be solved.

INTRODUCTION

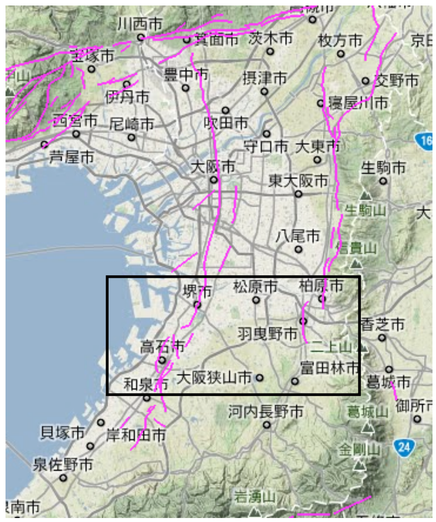
Japan is one of the most seismologically active areas in the world and most of the large cities in Japan are on the alluvial plains. In addition, surface geology has a great effect on the characteristics of the ground motion observed on these alluvial plains. Therefore, it is essential to evaluate a subsurface structure properly for extensive and highly precise estimation of strong ground motion in urban areas. We need to validate the previously proposed subsurface structure models based on the geological data and boring exploration data using the observation data of ground shaking

Under the initiative of The Headquarters for Earthquake Research Promotion, many subsurface structure models of the Osaka Plain have been proposed and some estimation of strong ground motion with those models considering the source rupture process has been reported. However, the southern part of the Osaka Plain has comparatively less detailed geological information today than other areas in the Osaka Plain. In addition, estimation of strong ground motion up to high frequency range taking in account of effects of surface geology has not been practiced yet.

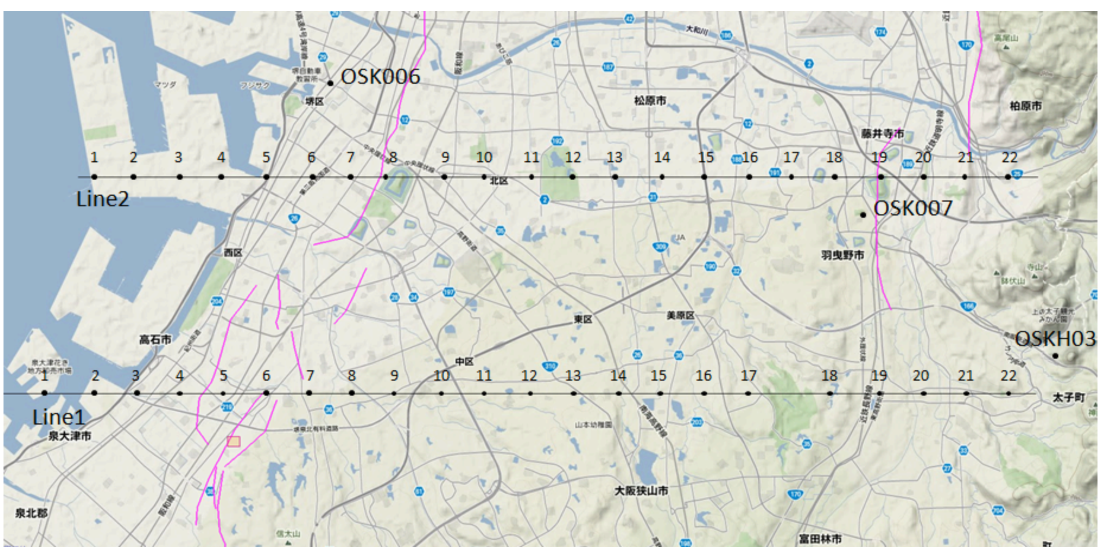
Therefore, in this study, we observed microtremor in the southern part of the Osaka Plain where detailed geological information are comparatively less than other areas in the Osaka Plain. We calculated predominant peak frequencies of the ground by using H/V spectral ratio from observed microtremor data and compared these frequencies with those calculated from our initial model consisting of model proposed by the National Research Institute for Earth Science and Disaster Prevention (NIED) for the deeper part and Geological Survey of Japan (GSJ) for the shallower part. For sites where predominant frequency of data and model does not match, we modified 1-D structure at each site simply based on these predominant frequencies. We identified a modified subsurface structure along the two east-west lines in the southern part of the Osaka Plain and studied in detail the appropriateness of this identification approach.

OUTLINE OF MICROTREMOR MEASUREMENT

We observed microtremor in the southern part of the Osaka Plain in the daytime on a weekday. We chose two east-west lines there which are located at an interval of 5km and go across Uemachi and Ikoma fault zones. Each line has 22 observation points which are located at intervals of 1km, so we observed microtremor at 44 observation points in all and also at K-NET (Kinoshita, 1998) and KiK-net (Aoi *et al.*, 2000) which are strong ground motion stations such as OSK006(Sakai), OSK007(Habikino), and OSKH03(Taishi) showed in Fig. 1. Figure 1 shows map of Osaka, the observation area and the distribution of observation points. Microtremor measurement was conducted at least twice in sets of 15 minutes at each observation point with an acceleration seismograph SMAR-6A3P. Sampling frequency was 100Hz and the signal was amplified 500 times but declined to 200 times when the observation points were noisy because of traffic, etc. Then we calculated H/V spectral ratio, or NS/UD and EW/UD spectral ratio, with acceleration time history data gained from microtremor measurement.



(a) Map of Osaka and the location of the observation area.



(b) The observation area and the distribution of observation points.

Fig. 1. (a) Map of Osaka and the location of the observation area which is surrounded by black line, and (b) the observation area and the distribution of observation points. Dots with numbers on survey lines Line 1 and 2 denote the microtremor observation points, dots with 6 letter codes denote the strong motion observation station deployed by NIED and pink lines show the location of known active faults.(after Japan Seismic Hazard Information Station (J-SHIS))

Then, at some observation points at which the amplitudes at the predominant frequencies in the H/V spectral ratio were considerably small or judgments of the predominant frequencies in the H/V spectral ratio were comparatively difficult, we observed microtremor again in the daytime on a weekend which comparatively seems to have less traffic noise. The outline of the second measurement was same as that of the previous measurement. The targets for the second measurement were osk1-2,3,5,7,11,12,13,16,18,20,22 on Line 1 and osk2-1,3,4,5,6,8,11,14,19,20 on Line 2, so 21 points in all. The code for the observation points such as osk1-2 stands for point No.2 on Line 1 as shown in Fig. 1. After all, we excluded osk1-2,5,11,12,13,18,20 and osk2-4,6,8,14 from our analysis because the data did not improve the results at those points even after the second measurement.

RESULTS OF MICROTREMOR MESUREMENT

Waveform Processing of Microtremor

First, we cut off all the acceleration time history data of microtremor into 40.96-second data with overlap of 50 %. Then, we used the following formulas in waveform processing of microtremor.

$$S_{XX}(\omega) = \frac{2}{NT}\sum_{i=1}^{N}\left\{X_i(\omega)X_i^*(\omega)\right\} \tag{1}$$

$$S_{YY}(\omega) = \frac{2}{NT}\sum_{i=1}^{N}\left\{Y_i(\omega)Y_i^*(\omega)\right\} \tag{2}$$

$$R(\omega) = \sqrt{\frac{S_{YY}(\omega)}{S_{XX}(\omega)}} \tag{3}$$

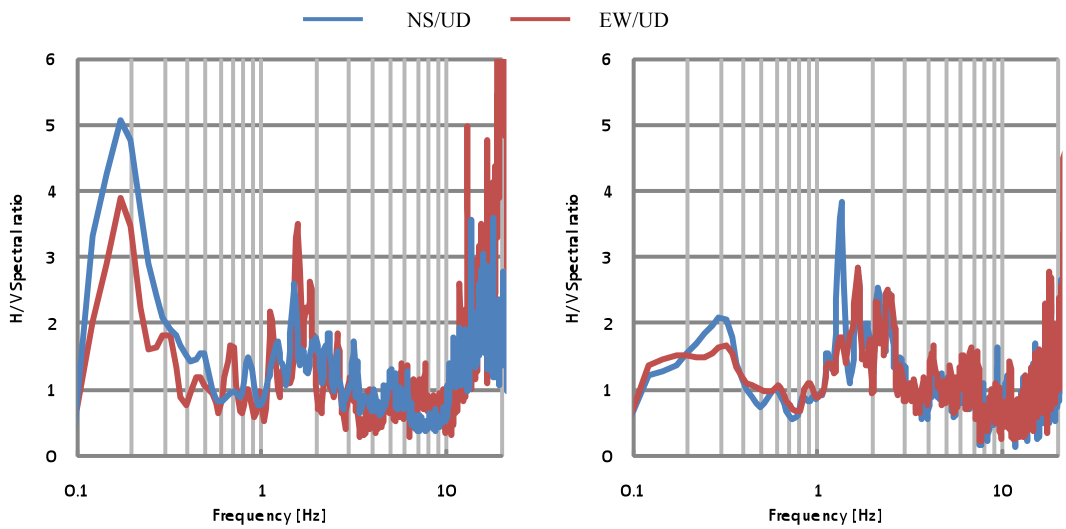
where $S_{XX}(\omega)$ and $S_{YY}(\omega)$ are power spectra, ω is circular frequency, N is the number of data, T is the duration time, $X_i(\omega)$ are finite Fourier transform of vertical microtremor records X_i by using Fast Fourier Transform(FFT), $Y_i(\omega)$ are finite Fourier transform of horizontal microtremor records Y_i by using FFT, $X_i^*(\omega)$ and $Y_i^*(\omega)$ are conjugate complex numbers of $X_i(\omega)$ and $Y_i(\omega)$ respectively, and $R(\omega)$ is the spectrum ratio of $S_{XX}(\omega)$ and $S_{YY}(\omega)$.

We used first and second peak frequencies as predominant frequencies in the microtremor H/V spectral ratio. When the predominant frequencies were not clear, comparing NS/UD spectral ratio with EW/UD spectral ratio and checking predominant frequencies in horizontal Fourier spectrum helped our decision.

Results of Microtremor Measurement

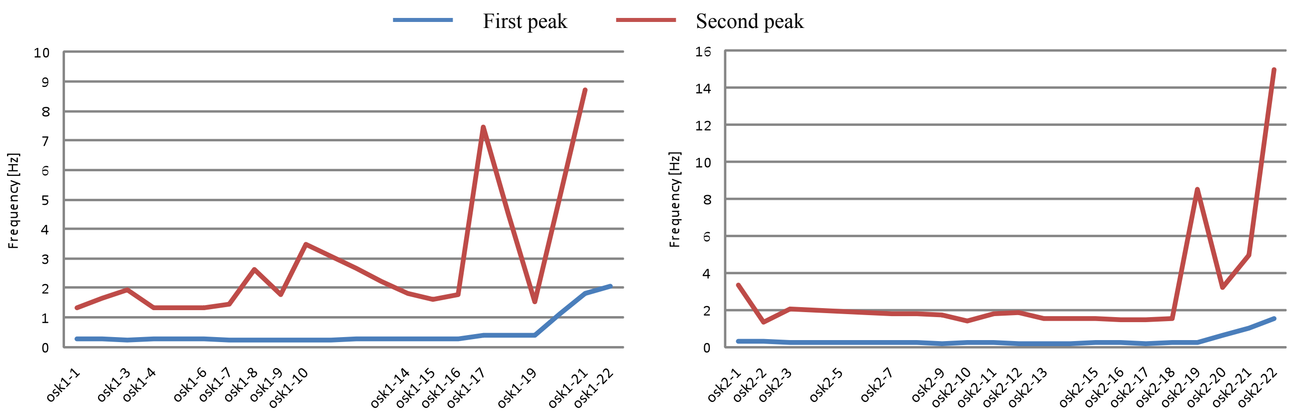
Figure 2 shows comparison of NS/UD spectral ratio with EW/UD spectral ratio gained from microtremor measurement at two typical observation points. At some points, predominant frequencies in NS/UD spectral ratio are correspondent to those in EW/UD spectral ratio as osk2-13 and at other points, those predominant frequencies are different as the second peak frequency as osk1-4. We guess these differences of predominant frequencies can be the result of lateral heterogeneity of the subsurface structure around faults because they were observed around faults.

Figure 3 shows distribution of predominant frequencies for points on Line 1 and Line 2. The west side of the Osaka Plain is the Osaka bay and the plain faces the mountains in the eastern part of it, so it can be assumed that in general the subsurface structure gets shallower, or predominant frequencies get higher toward east from west. In Fig. 3a Line 1, first peak frequency gets higher toward east at the eastern end of Line 1 and second peak frequency has fluctuations locally, but in general gets higher toward east. In Fig. 3b Line 2, first peak frequency gets higher toward east at the eastern end of Line 2 and second peak frequency is comparatively stable between osk2-1 and osk2-18 but fluctuates sharply between osk2-19 and osk2-22, so it can be said the subsurface structures around these points are changing locally.



(a) osk2-13 (b) osk1-4

Fig. 2. Comparison of NS/UD spectral ratio with EW/UD spectral ratio at point (a) osk2-13 and (b) osk1-4.



(a) Line 1 (b) Line 2

Fig. 3. Distribution of predominant frequencies of first and second peaks for points on (a) Line 1and (b) Line 2 in Fig. 1b.

VALIDATION FOR THEORETICAL CALCULATION AND IDENTIFICATION APPROACH

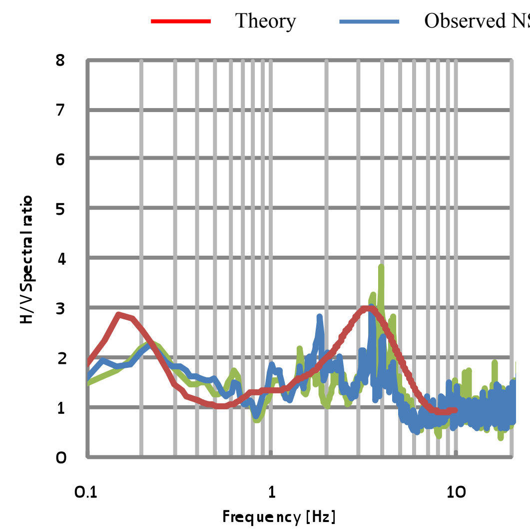
We used the code by Dr. Sánchez-Sesma which calculates theoretical microtremor H/V spectral ratio for a given subsurface structure model (Sánchez-Sesma *et al*., 2008; Sánchez-Sesma *et al*., 2011).

We calculated theoretical H/V spectral ratio from the subsurface structure models of 3 strong ground motion stations of NIED. By comparing the theoretical H/V spectral ratio with the observed, we tried to validate the theoretical calculation scheme and our estimation approach for a subsurface structure. It is important that we have a good initial model at each strong ground motion station. We add a shallow subsurface structure model from surveys at each strong ground motion station into a deeper subsurface structure model proposed by NIED and used the newly-constituted model in the theoretical calculation.

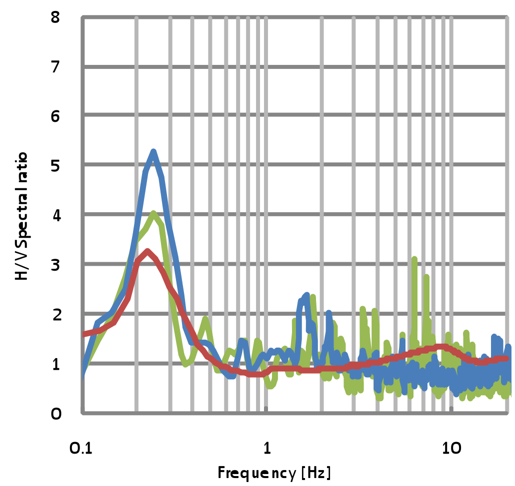
Figure 4 shows comparison of theoretical and observed H/V spectral ratios at the three strong ground motion stations. At OSK006, predominant frequencies and the amplitude of the peak in both H/V spectral ratios are almost same. At OSK007, first peak frequencies are similar, but the amplitude at second peak frequency for theory is considerably small. This can be the result that OSK007 is located in the western side of Ikoma fault zone which are reverse faults and the bedrock in the eastern part of Ikoma fault zone is uplifted because of the movement of the fault and the site has an effect of lateral heterogeneity of the subsurface structure. At

OSKH03, observed data is not stable and observed and theoretical H/V spectral ratios are not in good match as those at other stations. This can be because OSKH03 is in the mountains and influenced by effects of topography and lateral heterogeneity of the subsurface structure.

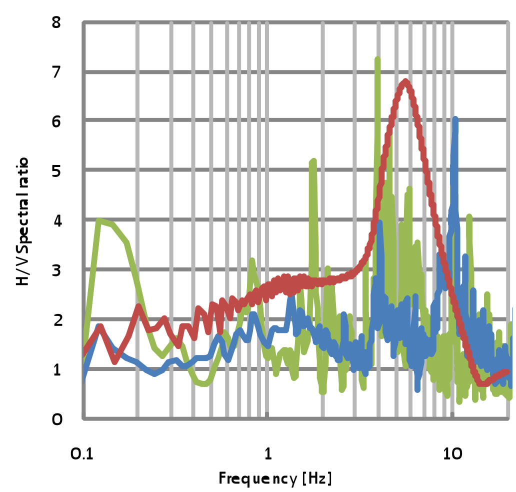
As a result, we made sure that both H/V spectral ratios gained from theoretical calculation and observation records were roughly similar excluding OSKH03 which is in the mountains. Therefore it is showed that we are able to identify a modified subsurface structure close to the real structure at an point by calculating H/V spectral ratio from an initial subsurface structure model based on previously proposed studies with our theoretical calculation program and to fit the observed H/V spectral ratios if the observation point is on alluvial plains.



(a) OSK006



(b) OSK007



(c) OSKH03

Fig. 4. Comparison of H/V spectral ratios for theory and observed at (a) OSK006, (b) OSK007, (c) OSKH03.

ESTIMATION OF SUBSURFACE STRUCTURES

Procedure for Identifying the Modified Subsurface Structure

We need an initial model for a subsurface structure to calculate theoretical H/V spectral ratio. We used an initial model consisting of models proposed by NIED (J-SHIS, 2011) for the deeper part and GSJ (Sekiguchi, 2005; Yoshida, 2010) for the shallower part. We added the GSJ model into the most surface layer of the NIED model and calculated theoretical H/V spectral ratio with it. In identifying a modified subsurface structure, we used the following procedure.

1) We judged that the first peak frequency among predominant frequencies reflects the deeper subsurface structure and the second peak reflects the shallower subsurface structure.

2) According to the fact that resonant phenomena follow 1/4 wavelength law, we multiplied the ratio of the first peak frequencies of H/V spectral ratios of observed and theory for the initial model to the whole layer thickness of the deeper subsurface structure of the initial model, as shown in Eq. (4). Similarly, we multiplied the ratio of the second peak frequencies of H/V spectral ratios of observed and theory for the initial model to the whole layer thickness of the shallower subsurface structure of the initial model, as shown in Eq. (5).

$$H_i^{deep} = H_i^{init}\left(\frac{f_1^{init}}{f_1^{obs}}\right) \tag{4}$$

$$H_i^{shallow} = H_i^{init}\left(\frac{f_2^{init}}{f_2^{obs}}\right) \tag{5}$$

where H_i^{deep} is the thickness of layer of modified deeper ground i, $H_i^{shallower}$ is the thickness of layer i of modified shallower ground, H_i^{init} is the thickness of layer i of initial ground, f_j^{init} (j=1,2) is the first or second peak frequency of H/V spectral ratio for the initial model, f_j^{obs} (j=1,2) is the first or second peak frequency of H/V spectral ratio for observed data.

3) If theoretical H/V spectral ratio for the modified model corresponds to the observed, the identification is ended at this point.

4) If theoretical H/V spectral ratio for the modified model does not correspond to the observed, we continued identifying based on the results of the identification for other observation points and the condition of variations of predominant frequencies for previous step.

Results of Modification

Figure 5 shows comparison of H/V spectral ratios for observed, initial and modified models at four typical observation points. At osk2-11, the predominant frequencies and the amplitudes at the frequencies for observed and modified model correspond well. At osk2-10, the predominant frequencies for the two correspond but the shape of H/V spectral ratio around the second peak frequency for the modified model remains flat. This can be because in the identification, we multiplied the whole layer thickness of the shallower subsurface structure of the initial model by the ratio of the second peak frequencies in H/V spectral ratios for observed and initial models. In order to solve this, it is not enough only to change the whole layer thickness of initial models and we should change each layer structure to increase contrasts among the layers by changing velocity structures. At osk1-17, the predominant frequencies for observed and modified model correspond but the amplitudes of their first peak frequency are considerably different. In addition, at osk1-4 the predominant frequencies for the two correspond but the shape of H/V spectral ratios for the two are considerably different. These differences are mainly observed around the edges of Lines 1 and 2, so the first peak may have been restrained from some particular effect in the mountains or the data was contaminated with noise.

Figures 6 and 7 show sections of the shallower and deeper subsurface structures for the initial and modified models of Line 1. Similarly, Figs. 8 and 9 show sections of the shallower and deeper subsurface structures for the two models of Line 2. As a result, the sections, especially of the deeper subsurface structures for the modified models are considerably different from our expectation that the subsurface structure in the Osaka Plain should be getting deeper toward west from east on Lines 1 and 2 in general, because the west of the Osaka Plain is Osaka bay and the eastern part of it faces the mountains, and also different from the sections for the initial models. These can be result of two points as we mentioned before. First is that we couldn't get precise data by noise and some particular effect in the mountains around the eastern edges of Lines 1 and 2. Second is that in the identification, the procedure to change the whole layer thickness of the initial model is may be too oversimplified.

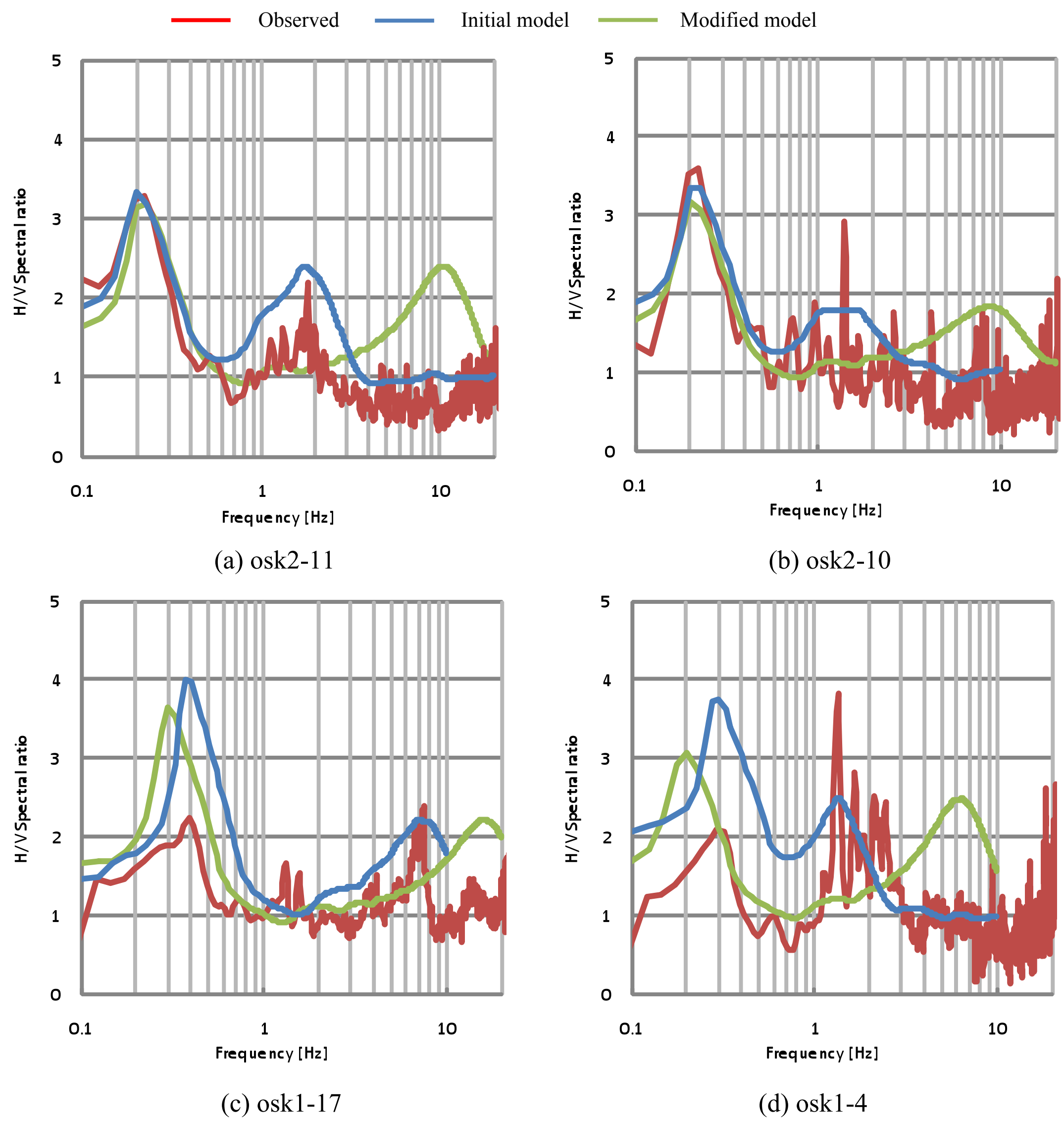
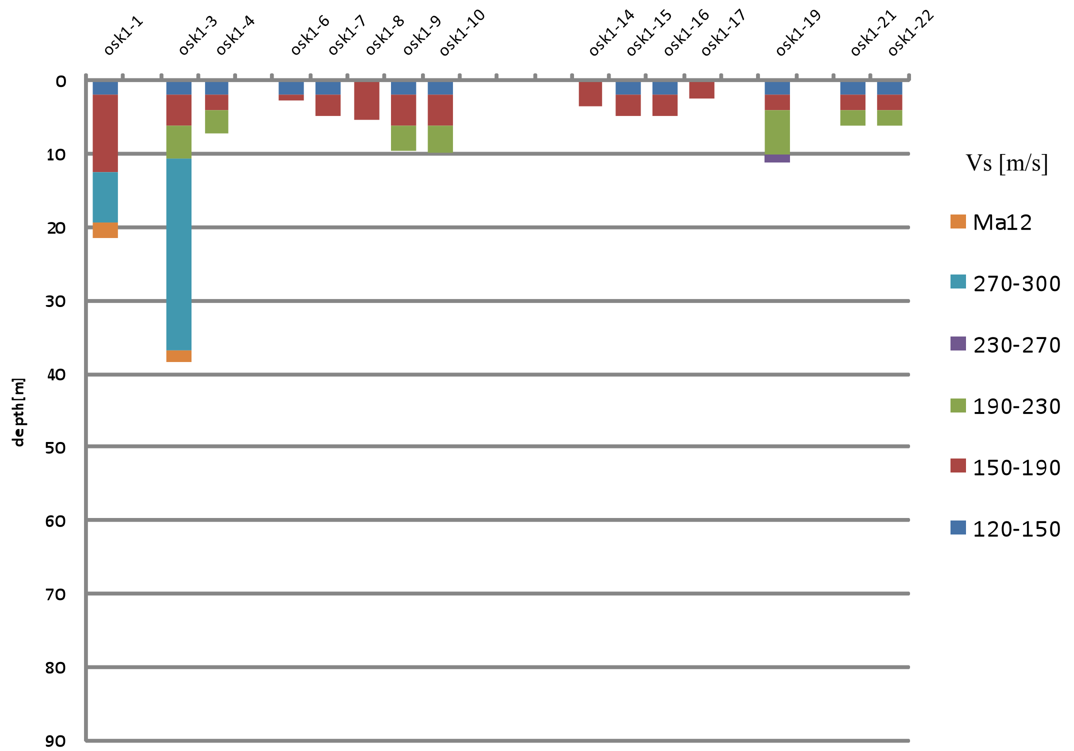
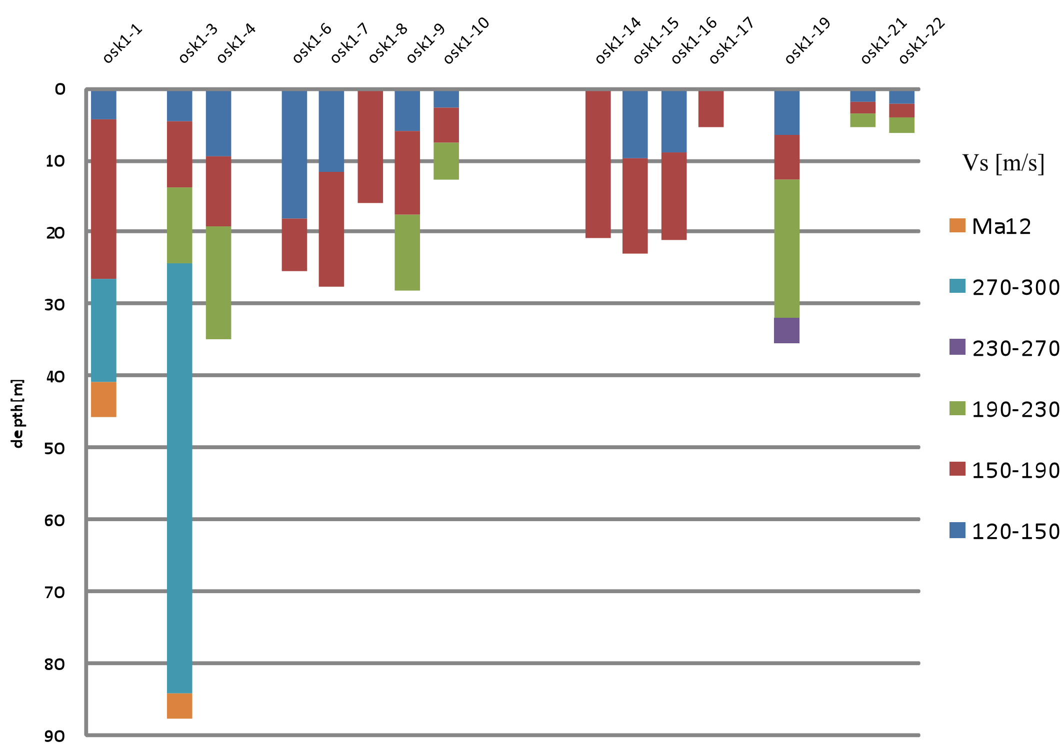


Fig. 5. Comparison of H/V spectral ratios for observed, initial and modified models for points (a) osk2-11, (b) osk2-10, (c) osk1-17 and (d) osk1-4. For the observed, either NS/UD or EW/UD spectral ratio is selected for comparison.

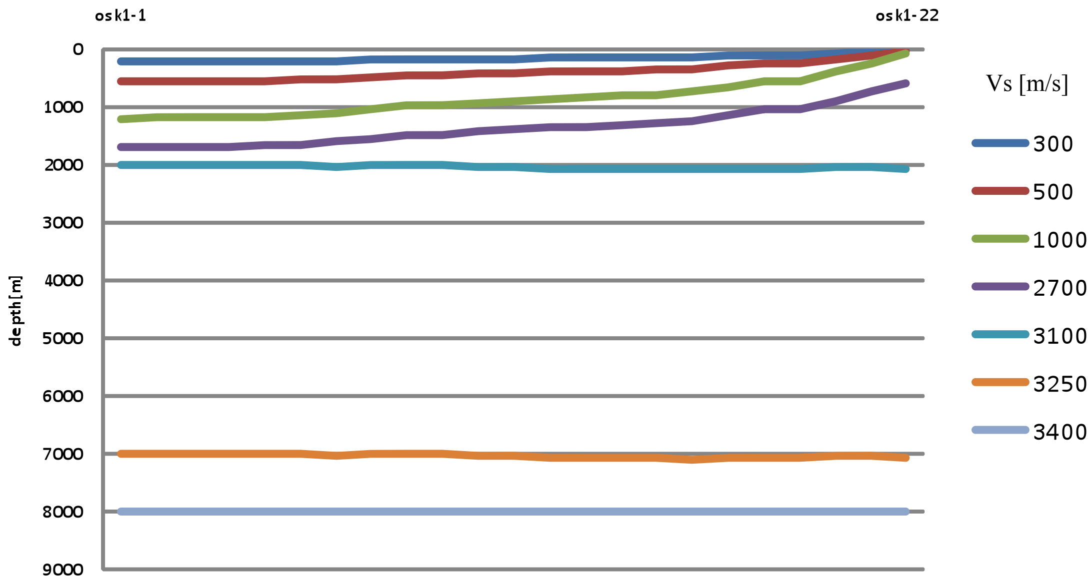


(a) Initial model

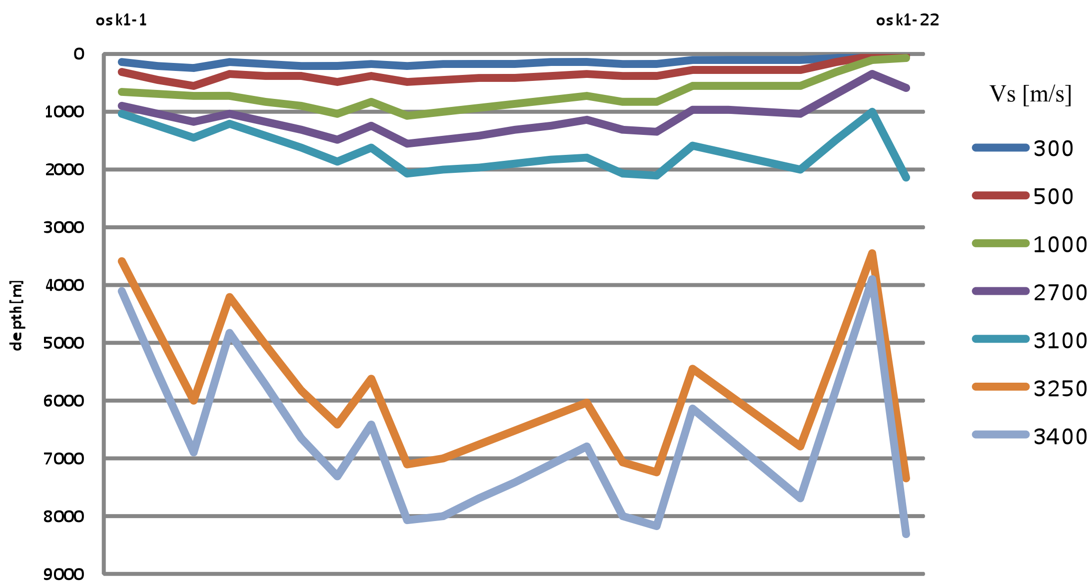


(b) Modified model

Fig. 6. Sections of the shallower subsurface structures of the (a) initial and (b) modified models of Line 1.

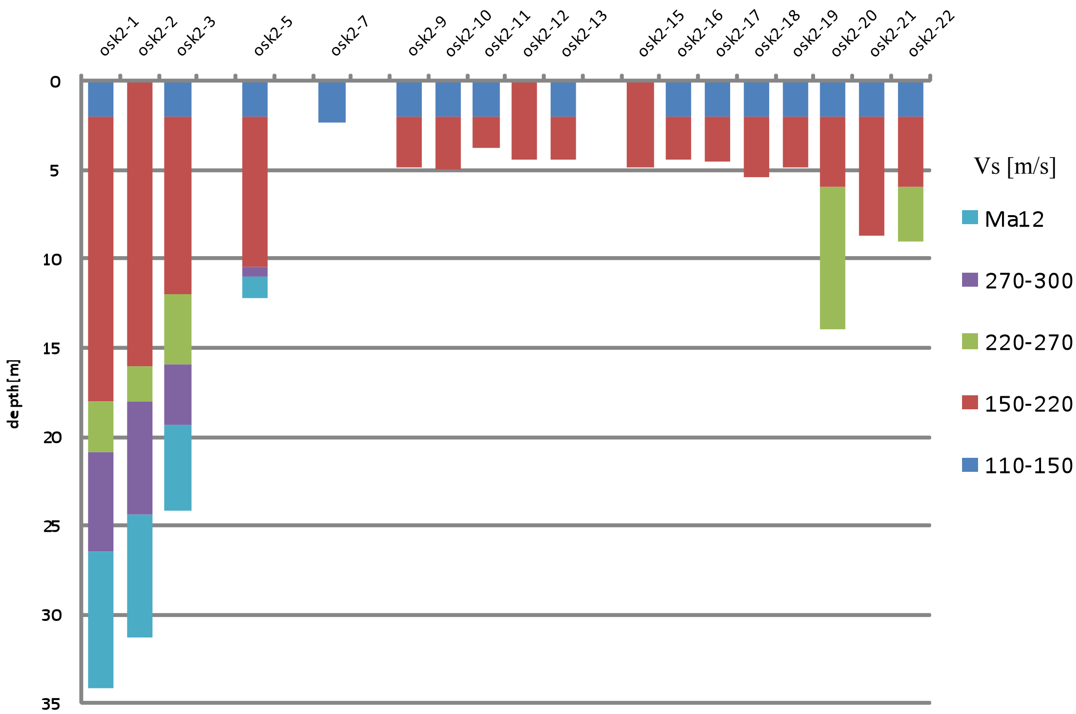


(a) Initial model

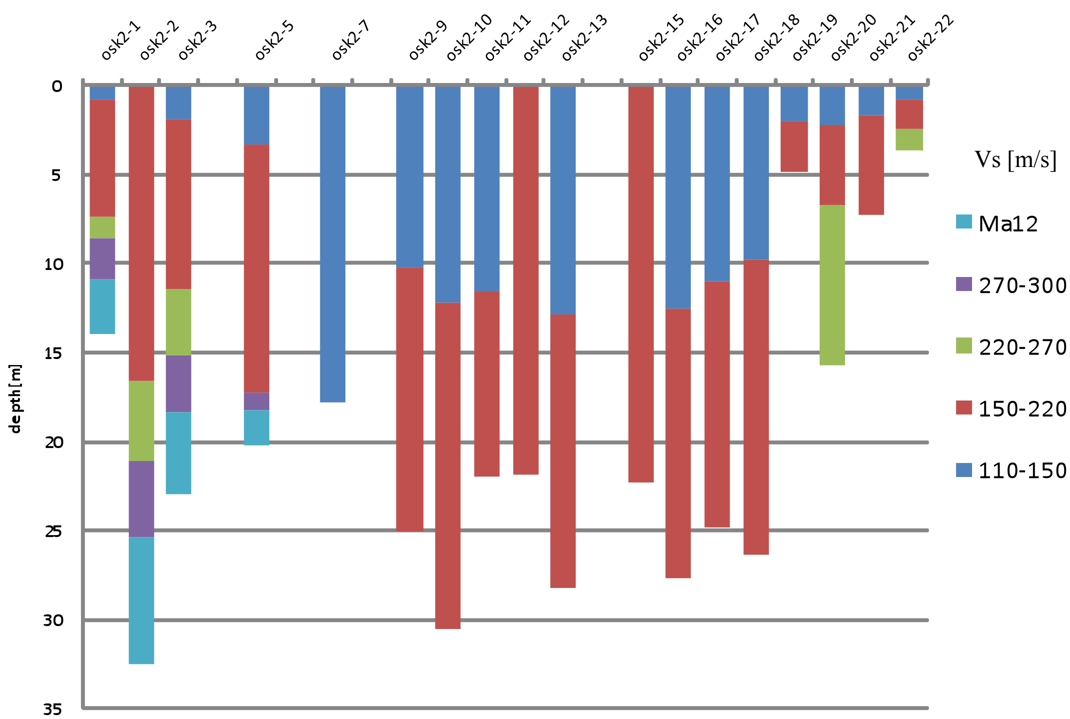


(b) Modified model

Fig. 7. Sections of the deeper subsurface structures of the (a) initial and (b) modified models of Line 1.

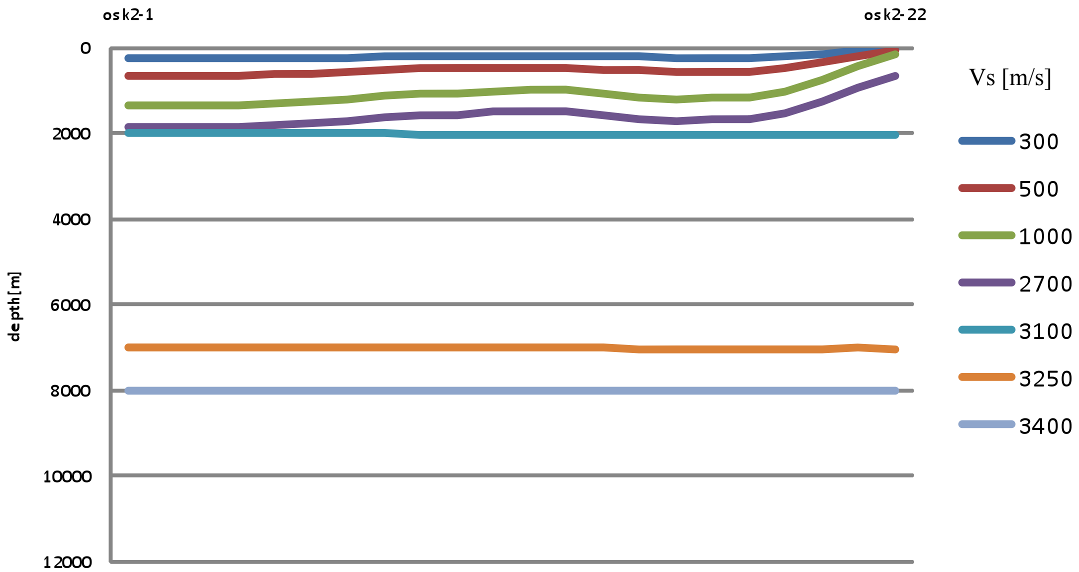


(a) Initial model

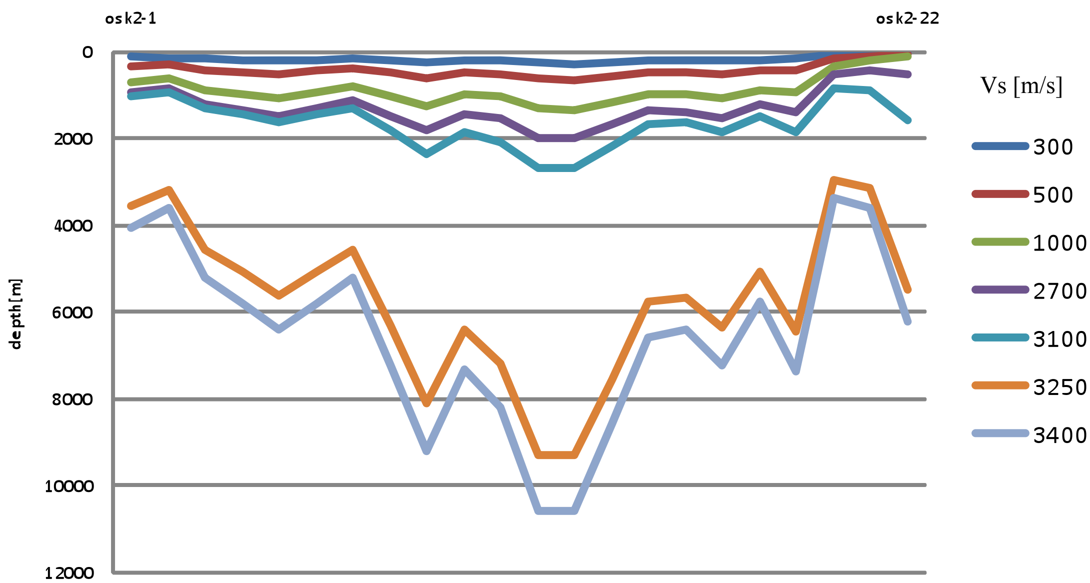


(b) Modified model

Fig. 8. Sections of the shallower subsurface structures of the (a) initial and (b) modified models on Line 2.



(a) Initial model



(b) Modified model

Fig. 9. Sections of the deeper subsurface structures for the (a) initial and (b) identified models on Line 2.

DISCUSSIONS AND CONCLUSIONS

We observed microtremors at 44 points on 2 lines and 3 strong ground motion stations in the southern part of the Osaka Plain. Then, for the points at which the data were inappropriate we observed microtremor again and sorted the data used in our analysis. By comparing H/V spectral ratios calculated from microtremor measurement and theoretical calculation and searching for the matching 1-D structure at each site simply based on predominant frequencies, we estimated subsurface structures and found this identification approach was appropriate. On the other hand, at some observation points the shapes of H/V spectral ratios for the modified models were considerably different from those of the initial models, and the modified subsurface structures needed to be changed dramatically from the initial basement depth. Therefore, we have to compare an identification approach to match the shape of H/V spectral ratio by minimizing the sum of squares of residuals with our identification approach and study the two approaches in detail. We are planning to observe microtremor at night at some observation points we excluded in our analysis because of poor quality of data. In addition, we are thinking of studying the appropriateness of using microtremor for an estimation of complex subsurface structures around faults. Also, we would like to estimate strong ground motion extensively with high precision by combining our estimated subsurface structures and source models of previously proposed studies together.

ACKNOWLEDGEMENTS

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REFERENCES

Aoi, S., K. Obara, S. Hori, K. Kasahara, and Y, Okada [2000]. "New strong-motion observation network: KiK-net", Eos Trans. AGU, 81(48), Fall Meet. Suppl., Abstract S71A-05.

Japan Seismic Hazard Information Station, http://www.j-shis.bosai.go.jp/, 2011/7/15

Kinoshita, S. [1998]. " Kyoshin Net (K-NET)", Seism. Res. Lett., 69, pp. 309-332.

Sánchez-Sesma F. J., J. A. Pérez-Ruiz, F. Luzón, M. Campillo, and A. Rodoríguez-Castellanos [2008]. "Diffuse fields in dynamic elasticity", Wave Motion*,* 45, pp.641-654.

Sánchez-Sesma, F. J., M. Rodríguez, U. Iturrarán-Viveros, F. Luzón, M. Campillo, L. Margerin, A. García-Jerez, M. Suarez, M. A. Santoyo, A., and Rodríguez- Castellanos [2011]. "A theory for microtremor H/V spectral ratio: Application for a layered medium", Geophys. J. Int. Exp. Lett., In press, doi: 10.1111/j.1365-246X.2011.05064.x.

Sekiguchi, H., N. Kitada, H. Ito, and Y. Sugiyama [2005]. "PS and density logging in a 300 m borehole at Nakanoshima in Kita Ward", Osaka City", Annual Report on Active Fault and Paleoearthquake Researches, No. 5, pp. 109-113.

Yoshida, K., H. Sekiguchi, and K. Yamamoto [2010]. "Shallow structure model of the Osaka sedimentary basin CD-ROM", Geological Survey of Japan Interim Report no. 52, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology.