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THE EFFECT OF THE BASIN EDGE TO THE DIRECTIONAL DEPENDENT HORIZONTAL-TO-VERTICAL SPECTRAL RATIOS OF MICROTREMORS

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ABSTRACT

The authors have shown that it is possible to qualitatively simulate the significant directional dependency that can be seen in Horizontal-to-Vertical (H/V) spectral ratios of microtremors observed at sites on Uji campus, Kyoto University by using a numerical method such as the 3-D Spectral Element Method to calculate the Green's functions from 3-D wave propagation analysis using a 2-D basin structure. In this study, we focus on the effect of the basin edge to the H/V spectral ratios and study the relation between the basin edge shape and the difference between NS/UD and EW/UD by simulating the H/V spectral ratios at sites close to the basin edge by numerical calculation. We consider a simple 2-D basin model with one layer over bedrock and change the shape of the basin edge.

From the simulation results, we found that the condition of the basin edge changes the H/V spectral ratios drastically at sites close to the basin edge. If we accumulate the relation between the shape and condition of the basin edge to the shape of the H/V spectral ratios in two orthogonal horizontal directions, we will be able to use the information from the observed H/V spectral ratios of microtremors to determine the basin edge shape.

INTRODUCTION

Based on the diffuse field theory (Perton *et al*., 2009), Horizontal-to-Vertical (H/V) spectral ratios of microtremors (or ambient noise) correspond to the square root of the ratio of the imaginary part of horizontal displacement for a horizontally applied unit harmonic load, $\mathrm{Im}[G_{11}]$ and/or $\mathrm{Im}[G_{22}]$, and the imaginary part of vertical displacement for a vertically applied unit load, $\mathrm{Im}[G_{33}]$, where both the loads and receivers are at the same point on the free surface (Sánchez-Sesma *et al*., 2011). This theory can be applied to a site where the subsurface structure cannot be considered as sufficiently flat, horizontally layered (i.e., $\mathrm{Im}[G_{11}] \neq \mathrm{Im}[G_{22}]$), and lateral heterogeneity exists. The H/V spectral ratio of microtremors can be derived by Equation (1) (Matsushima *et al*., 2014).

$$\frac{H_m(\omega)}{V(\omega)} = \sqrt{\frac{\mathrm{Im}[G_{mm}(\mathbf{x},\mathbf{x};\omega)]}{\mathrm{Im}[G_{33}(\mathbf{x},\mathbf{x};\omega)]}}\,(m=1,2) \tag{1}$$

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where $\mathbf{x}$ is position vector, ω is circular frequency, Green's function $G_{mm}(\mathbf{x},\mathbf{x},\omega)$ is displacement at $\mathbf{x}$ in direction m produced by a unit load in direction m, $H_m(\omega)/V(\omega)$ is the H/V spectral ratio in direction m for circular frequency ω.

The authors have shown that by using a numerical method such as the 3-D Spectral Element Method (SEM) (e.g., De Martin, 2011) to calculate the Green's functions in Equation (1) from 3-D wave propagation analysis using a 2-D basin structure, it is possible to qualitatively simulate the significant directional dependency that can be seen in H/V spectral ratios of microtremors observed at sites on Uji campus, Kyoto University. Figure 1 shows the observed H/V spectral ratios at four sites on Uji campus. The NS/UD has higher peak amplitude and EW/UD has higher peak frequency at all four sites. Figure 2a shows the H/V spectral ratios at site C derived from Equation (1) using Green's functions calculated for a simple 2-D basin model with one layer over bedrock, shown in Figure 3a. We can see that the observed H/V spectral ratios are qualitatively simulated (Matsushima *et al.*, 2014). Also, Matsushima *et al.* (2014) has shown that the shape of the H/V spectral ratio is distorted at sites close to the basin edge. Figure 2b shows the H/V spectral ratio at site C' in Figure 3a. This is an indication that if we observe microtremors at several sites close to the assumed basin edge, there may be possibility to identify the shape of the basin edge in detail.

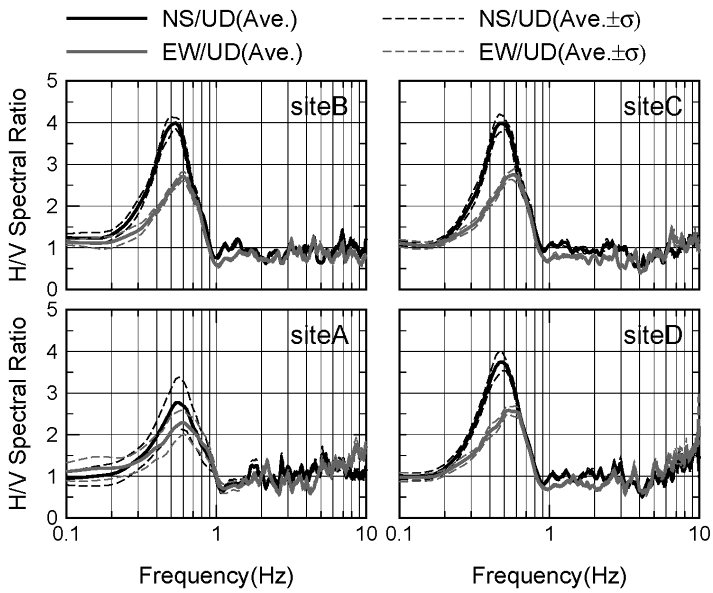


Figure 1. Observed H/V spectral ratios of microtremors at four sites on Uji campus, Kyoto University. The black and gray solid lines denote the average of NS/UD and EW/UD, respectively and the black and gray dotted lines denote the average±σ of NS/UD and EW/UD, respectively (Matsushima *et al.*, 2014).

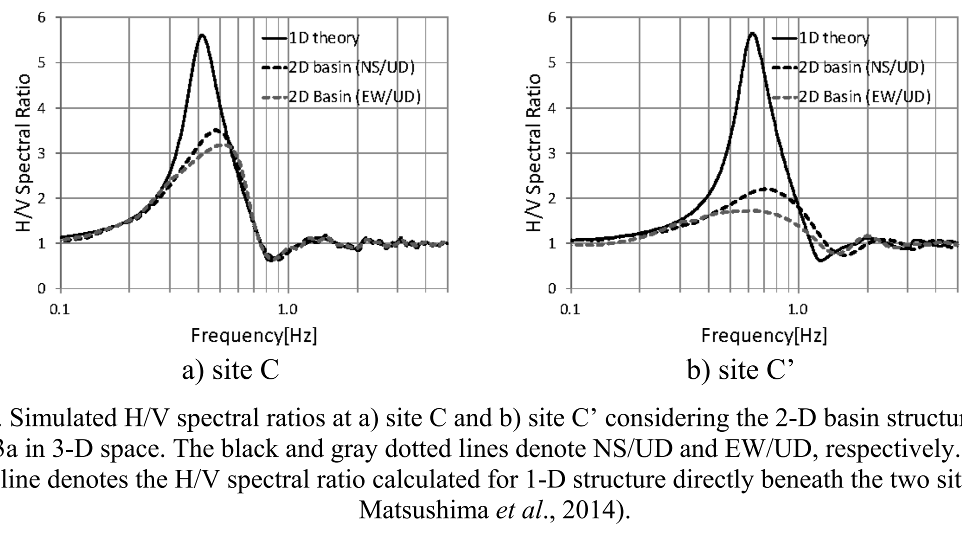


Figure 2. Simulated H/V spectral ratios at a) site C and b) site C' considering the 2-D basin structure shown in Figure 3a in 3-D space. The black and gray dotted lines denote NS/UD and EW/UD, respectively. The black solid line denotes the H/V spectral ratio calculated for 1-D structure directly beneath the two sites (after Matsushima *et al.*, 2014).

In this study, we focus on the effect of the basin edge to the H/V spectral ratios and study the relation between the basin edge shape and the difference between NS/UD and EW/UD by simulating the H/V spectral ratios at sites close to the basin edge by numerical calculation.

2-D Basin Structure

We consider a simple 2-D basin model in 3-D space with one layer over bedrock and change the shape of the basin edge. Table 1 shows the velocity model used for 3-D wave propagation analysis using SEM.

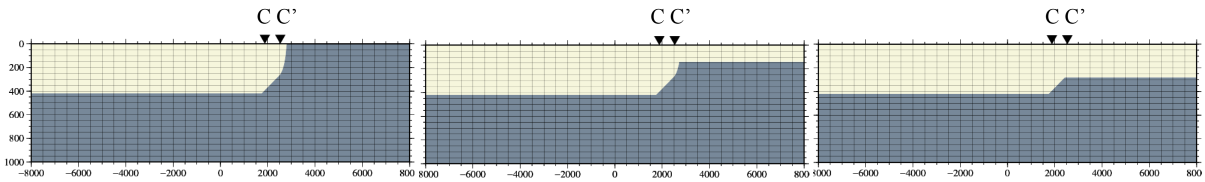
First, we consider three types of the basin edge as shown in Figure 3. Figure 3a is the standard model that the basin edge pinches out to the surface. Figure 3b is a model that the bedrock goes up to 2/3 of the basin depth at 140m. Figure 3c is a model that the bedrock goes up to only 1/3 of the basin depth at 280m.

Then, we consider three types of the basin models with different slope angles. Figure 4a is a model with slope angle of 11 degrees, which is the angle of the deeper part of basin edge of the standard model shown in Figure 3a, which is denoted by a thin black line. Figure 4b is a model with the slope angle of 20 degrees and Figure 4c is a model with the slope of 5 degrees. The depth is exaggerated in Figures 3 and 4.

Site C is 920m away from the basin edge at the surface of the standard model and site C' is 660m away from site C and 260m away from the basin edge.

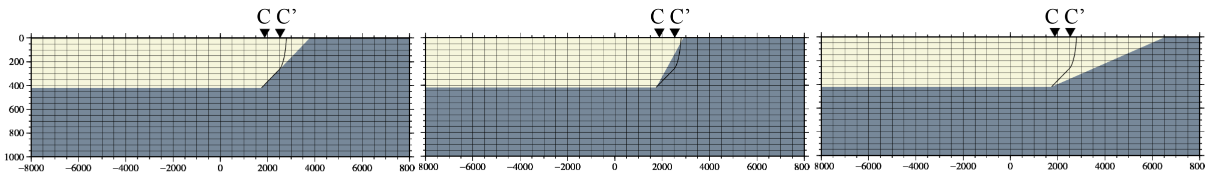
Table 1. One layer 2-D velocity model for SEM calculation

Layer	Thickness [m]	Vp [m/s]	Vs [m/s]	Density [kg/m^3]	Q
1	< 420	1,985	661	1,930	9999
Bedrock	-	5,083	2,348	2,600	9999



a) standard model b) 140m model c) 280m model

Figure 3. The section of the 2-D basin structure for a) standard model, b) 140m model and c) 280m model.



a) 11-degree slope model b) 20-degree slope model c) 5-degree slope model

Figure 4. The section of the 2-D basin structure for a) 11-degree model, b) 20-degree model and c) 5-degree model.

Comparison of Numerical H/V Spectral Ratios

In the 3-D wave propagation analysis for calculating the imaginary part of the Green's function in Equation (1), the NS component is the direction perpendicular to the section shown in Figures 3 and 4 and the EW component is the direction parallel to the section.

Figure 5 shows the simulated H/V spectral ratios at site C and C' derived from the three models shown in Figure 3. The blue, red and green thick lines denote the results for the standard model, 140m model (basin2) and 280m model (basin3), respectively. The dark and light lines denote the NS/UD and EW/UD, respectively for each color. The black and green thin lines denote the 1-D H/V spectral ratios at each site for the standard model (H=390m) and for the 280m model (H=280m), respectively. The results for the standard model are the same as those of Figure 2. If we compare the NS/UD and EW/UD of the standard model and 140m model at site C, the amplitude is greater and peak frequency is higher for the 140m model and the difference between NS/UD and EW/UD is relatively great. If we compare the 140m model and 280m model at site C, the NS/UD is similar but the EW/UD is different. As for site C', the shapes of the H/V spectral ratios is quite different for the three models. The difference between NS/UD and EW/UD for the 140m model is fairly small and is close to NS/UD of the standard model. The difference between NS/UD and EW/UD is also small for the 280m model and it gets close to the 1-D H/V spectral ratio at site C' for the 280m model, which is the flat part of the bedrock at the depth of 280m. As for the frequency of the dip at about 0.8Hz for site C, it does not change for the three models, but for site C' the dip frequency is about 1.5Hz for the standard model and 140m model but is about 1.1Hz for 280m model.

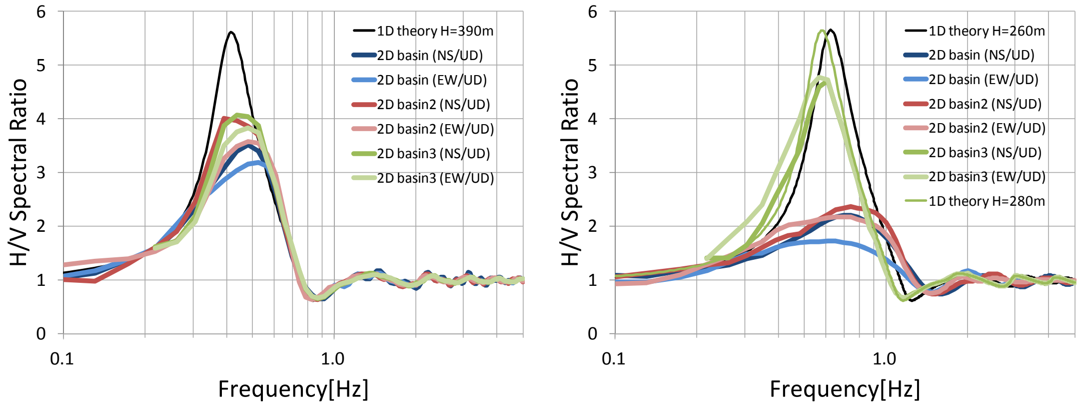
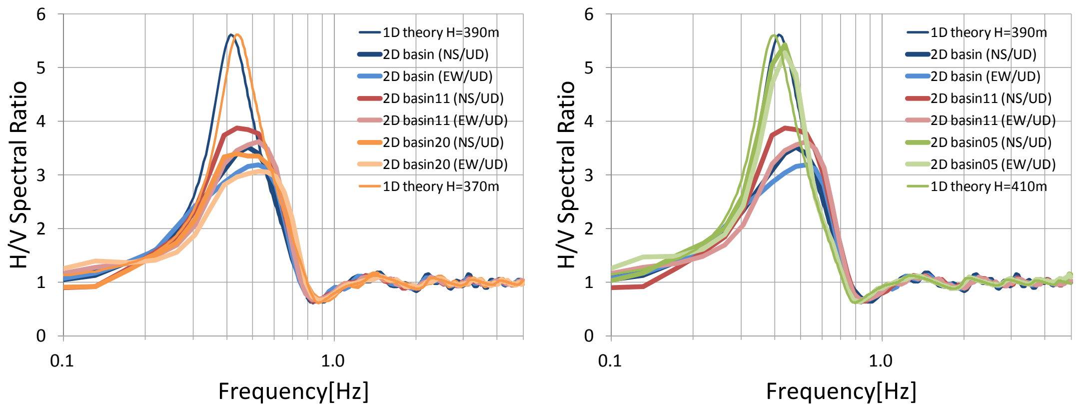


Figure 5. Simulated H/V spectral ratios using the standard model, 140m model and 280m model at a) site C and b) site C'. The blue, red and green thick lines denote the results for the standard model, 140m model (basin2) and 280m model (basin3), respectively. The dark and light lines denote the NS/UD and EW/UD, respectively for each color. The black and green thin lines denote the 1-D H/V spectral ratios at each site for the standard model (H=390m) and for 280m model (H=280m), respectively.

Figure 6 shows the simulated H/V spectral ratios at site C derived from the three models shown in Figure 4, compared with results for the standard model. The blue, red, orange and green thick lines denote the results for the standard model, 11-degree model, 20-degree model and 5-degree model, respectively. The dark and light lines denote the NS/UD and EW/UD, respectively for each color. The blue, orange and green thin lines denote the 1-D H/V spectral ratio at site C for the standard model (H=390m) (same for 11-degree model), 20-degree model (H=370m) and 5-degree model (H=410m), respectively. The results for the standard model are the same as those of Figure 2. If we compare the NS/UD and EW/UD of the standard model and 11-degree model, the peak frequency is close but the amplitude is greater for the 11-degree model. On the other hand, the NS/UD and EW/UD for the 20-degree model is close to the standard model. If we look at the results from 5-degree model, the difference between NS/UD and EW/UD is small and it looks like a 1-D H/V spectral ratio, but the peak frequency is not the same as those of the actual 1-D H/V spectral ratio at site C for 5-degree model (H=410m). As for the dip frequency at about 0.8-0.9Hz, it does not change drastically for all models.

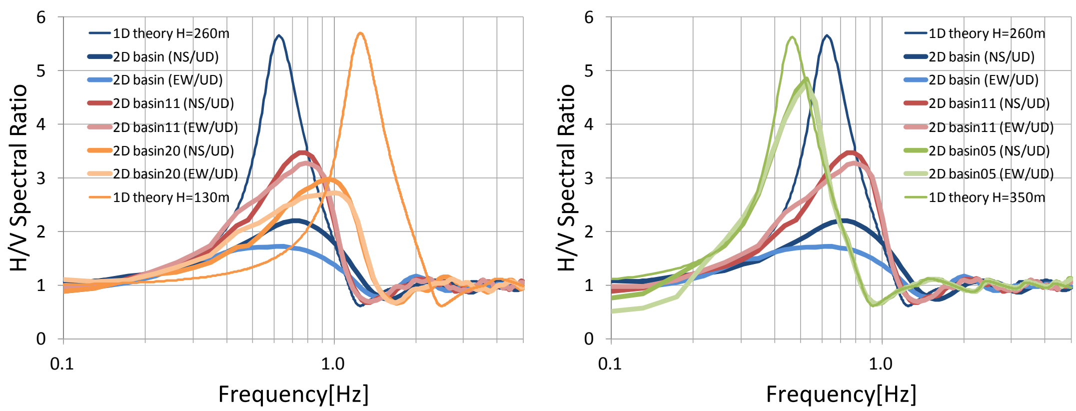
Figure 7 shows the simulated H/V spectral ratios at site C' derived from the three models shown in Figure 4, compared with results for the standard model. The blue, red, orange and green thick lines denote the results for the standard model, 11-degree model, 20-degree model and 5-degree model, respectively. The dark and light lines denote the NS/UD and EW/UD, respectively for each color. The blue, orange and green thin lines denote the 1-D H/V spectral ratio at site C' for the standard model (H=260m) (same for 11-degree model), 20-degree model (H=130m) and 5-degree model (H=350m), respectively. The results for the standard model are the same as those of Figure 2. If we compare the 11-degree model with the standard model, the peak frequency is similar but the amplitude is quite different and the difference between NS/UD and EW/UD is smaller. The peak frequency for the standard model and 11-degree model is higher than the 1-D H/V spectral ratio (H=260m). On the other hand, for 20-degree model the peak frequency is higher than 11-degree model, but is lower than the 1-D H/V spectral ratio (H=130m). As for the 5-degree model the difference between NS/UD and EW/UD is very small and it looks like the 1-D H/V spectral ratio, but the peak frequency is higher compared to the 1-D H/V spectral ratio for 5-degree model (H=350m). If we focus on the dip frequency, it is different from one model to another and it ranges from about 0.9Hz for the 5-degree model to about 1.7Hz for the 20-degree model.

From Figures 6a and 7a, we can find that even if the H/V spectral ratios for the 20-degree model is similar to those for the standard model at site C and we may assume that the distance to the basin edge is playing the role for determining the shape, those at site C' is quite different for the two models and it suggests that the shape is not determined by just the distance to the basin edge but the shape of the basin edge is influential as well.



a) 11-degree and 20-degree model b) 11-degree and 5-degree model

Figure 6. Simulated H/V spectral ratios at site C for different slope angle models, a) 11-degree and 20-degree model, b) 11-degree and 5-degree model, compared with results for the standard model. The blue, red, orange and green thick lines denote the results for the standard model, 11-degree model, 20-degree model and 5-degree model, respectively. The dark and light lines denote the NS/UD and EW/UD, respectively for each color. The blue, orange and green thin lines denote the 1-D H/V spectral ratios at site C for the standard model (H=390m) (same for 11-degree model), 20-degree model (H=370m) and 5-degree model (H=410m), respectively.



a) 11-degree and 20-degree model b) 11-degree and 5-degree model

Figure 7. Simulated H/V spectral ratios at site C' for different slope angle models, a) 11-degree and 20-degree model, b) 11-degree and 5-degree model, compared with results for the standard model. The blue, red, orange and green thick lines denote the results for the standard model, 11-degree model, 20-degree model and 5-degree model, respectively. The dark and light lines denote the NS/UD and EW/UD, respectively for each color. The blue, orange and green thin lines denote the 1-D H/V spectral ratios at site C' for the standard model (H=260m) (same for 11-degree model), 20-degree model (H=130m) and 5-degree model (H=350m), respectively.

CONCLUSIONS

We have shown that it is possible to simulate the directional dependent H/V spectral ratios of microtremors considering the heterogeneous subsurface structure using the Spectral Element Method. From the results that we have shown, we can see that the condition of the basin edge changes the shape as well as the difference between NS/UD and EW/UD of the H/V spectral ratios drastically at sites close to the basin edge and the influence of the basin edge is different for the two sites that are only 660m apart. If we accumulate the relation between the conditions of the basin edge to the characteristics of the H/V spectral ratios in two orthogonal horizontal directions, if we have microtremor observation data at several sites close to the basin edge, we will be able to use the information from those observed H/V spectral ratios of microtremors to determine the basin edge shape.

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