Velocity Structure Model for Tsukuba Area in Japan, Estimated from a Geological Model and H/V Spectral Ratio of Microtremors.

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ABSTRACT :

We made a velocity structure model for Tsukuba area in Japan. The velocity model was based on a geological model and was developed by using microtremor surveys and its H/V spectral ratio analysis. The microtremor measurement was executed about 200 points over the Tsukuba Area. We used a technique of H/V spectrum ratio in the analysis of the data in order to model a velocity structure. The predominant periods estimated from H/V spectral ratios of microtremors become larger from north to south area. The estimated depth of seismic bedrock is approximately 800m at south part of Tsukuba area, and is 0-20m at north-east area where is near Mt. Tsukuba. From comparison between estimated depth and borehole data, we confirmed that the model is reasonable at all part of Tsukuba area. We also estimated the shallow structure that is from engineering bedrock to surface, based on the mean value of the geological layers by using an inversion technique. The theoretical H/V ratios of Rayleigh waves for the estimated velocity model were calculated at all observation sites, and were compared with those of microtremors. It was confirmed that the S wave velocity structural model for Tsukuba area is suitable for simulation of strong ground motion.

KEYWORDS: Microtremor, Velocity Structure Model, H/V Spectral Ratio, Inversion, Strong-motion prediction, geomorphologic land classification.

1. INTRODUCTION

It has become possible to collect more detailed information on seismic intensity thanks to the improved information network on intensity that the Meteorological Agency, municipalities, and the National Institute for Earth Science and Disaster Prevention (NIED) have jointly constructed. In a broad municipality, however, published intensity and S wave velocity do not necessarily represent the average for the area as a whole. Therefore, a detailed understanding of geological characteristics and underground structure is important to know in advance which part of the area is prone to quake.
In this study, We conducted a continuous microtremor survey with a complete understanding of the geographical and geological characteristics of the entire Tsukuba Area, and examined an optimal S wave velocity structure model that extends from the bedrock structure to the surface layer of the surrounding area.

2. SUMMARY OF SURVEY

We conducted continuous microtremor observations at 207 points that covered the interior of the Tsukuba Area and surrounding areas between July 2006 and July 2007. We used an integrated microtremor observation device, a GU-210 (made by Hakusan Corp.)[1)], equipped with a logger (LS-7000XT) and complete with two horizontal elements and one vertical element. We measured microtremors for at least 15 minutes using a frequency of 100 Hz at each observation point for sampling, mostly around the points with boring data that extended down to the engineering bedrock. Dividing the waveform pattern at intervals of 81.92 seconds to calculate H/V, I selected about 10 stable points that were rarely affected by noise caused by large amplitude, such as traffic vibration. Figure 1 shows the location of the observation points.

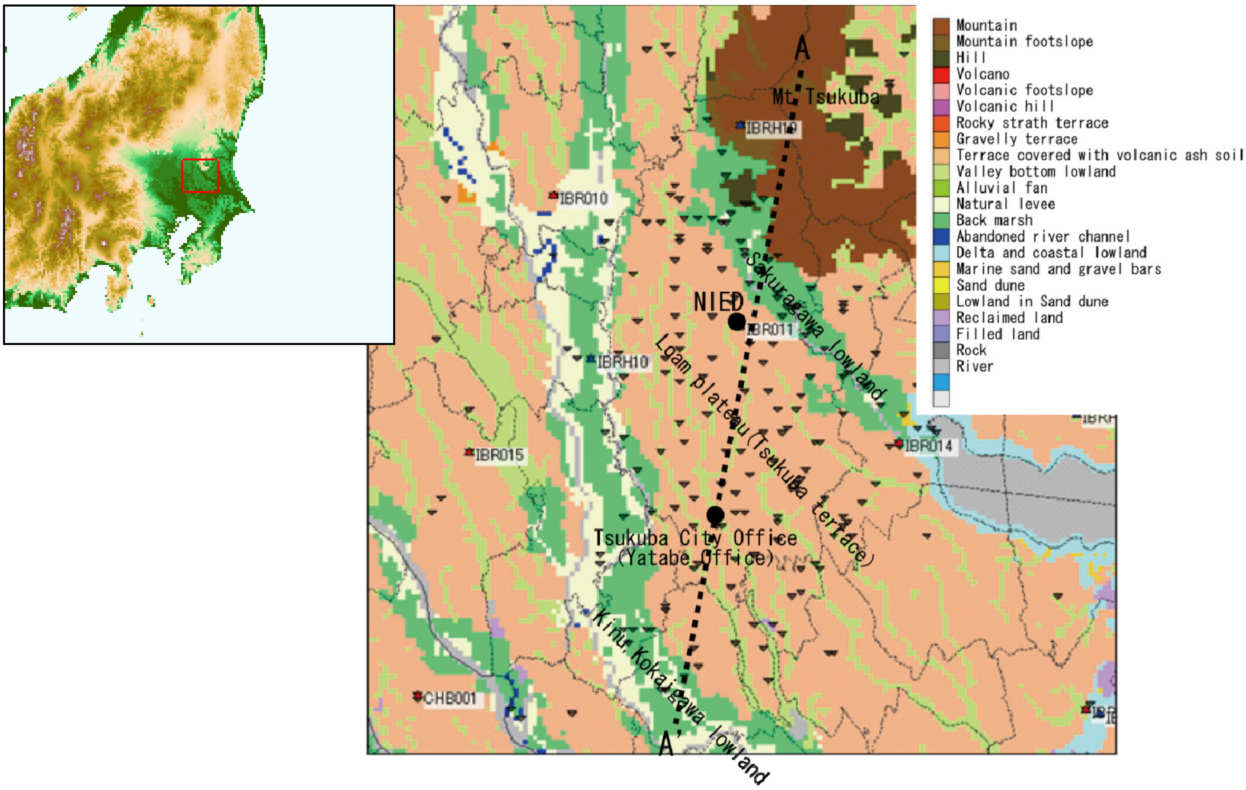


Figure 1 Microtopographical division of Tsukuba City and microtremor observation points (▼)Microtremor observation points around Tsukuba City (207 points)

3. ESTIMATING S-WAVE VELOCITY STRUCTURE AND FORMULATING GROUND MODEL

3.1 Geology and summary of Tsukuba City in existing materials

Looking into existing geological survey reports of the area around Tsukuba City, We found that Tsukuba granitic rocks (hereinafter referred to as bedrock) confirmed by boring around Mt. Tsukuba extend deeper the further they are from Mt. Tsukuba. In addition, We confirmed that the predominant cycle caused by H/V gradually grows shorter the nearer an observation point is to Mt. Tsukuba. (This was the evaluation in places where the subsurface ground did not need to be considered.) No data on deep boring were available to support these results. However, I correlated the results of seven PS well loggings around Tsukuba City, and found a great contrast in property value between the bedrock (Tsukuba granitic rocks) and the Kazusa and Shimousa layers on the bedrock, and that all seven PS well loggings have structurally almost the same sedimentary process. (See Table 1). Then, We conducted a forward simulation assuming a simple two-layer structure that had only the seismic bedrock and its suprastructure.

Table 1 Relationship between S wave velocity of bedrock (Tsukuba granitic rocks) in the PS well loggings of deep boring round Tsukuba City and S wave velocity of the layers on the bedrock (Shimousa and Kazusa layers).

No.	Deep borehole place name	Depth of bedrock(GL−m)	Upper Bedrock		Bedrock	
			Vp(m/sec)	Vs(m/sec)	Vp(m/sec)	Vs(m/sec)
1	IBRH21(KiK−net)	725	1810～2000(1900)	700～760(733)	5290	2320
2	NIED	490	1600～2000(1900)	440～750(650)	5200	2520
3	IBRH07(KiK−net)	850	1660～1920(1850)	340～650(580)	4530	2530
4	IBRH17(KiK−net)	465	1700～2100(1900)	470～820(650)	5300	2300
5	OYO corp.	655	1700～1900(1830)	550～700(650)	5200	2550
6	GSJ	575	1700～2000(1900)	550～750(650)	5300	2450
7	IBRH10(KiK−net)	550	1900～2000(1950)	650(650)	5300	2350
8	IBRH19(KiK−net)	36	----	----	5100	2500
9	Akino Hot Spring	285	----	----	----	----

3.2 Analysis of microtremor data

Using the expected values of deep bedrock structure in 3.1, We formulated a theoretical H/V spectrum by combining elements of horizontal and vertical movements of the basic mode of Rayleigh waves with the help of forward modeling, and estimated the bedrock depth by comparing the theoretical spectrum with a microtremor H/V.
As for the shallow ground structure, We separated the above-mentioned information on the bedrock and conducted an inverse analysis with fixed layer thickness using given information, such as boring data and a three-dimensional shallow geological structure model[3], with the help of the approach taken by Arai and Tokimatsu (2004, 2005)[2]. We did so because an inverse problem can be evaluated in a relatively stable manner by eliminating the influence of the deep ground structure assumed in 3.1 and by focusing only on the influence of the surface ground. The parameters, including the default in inverse analysis, are all variable, and 20% of the layer thickness is variable in consideration of errors in the ground layer model. We conducted an inverse analysis only on the H/V spectrum, and calculated the average S wave velocity of each layer using the analysis results. We enabled only calculation results that brought about a rest error average under F=0.01, and formulated the ground model extending from the layer equivalent to seismic bedrock (bedrock) to the land surface. Figure 2 shows the overall flow from microtremor survey to analysis.

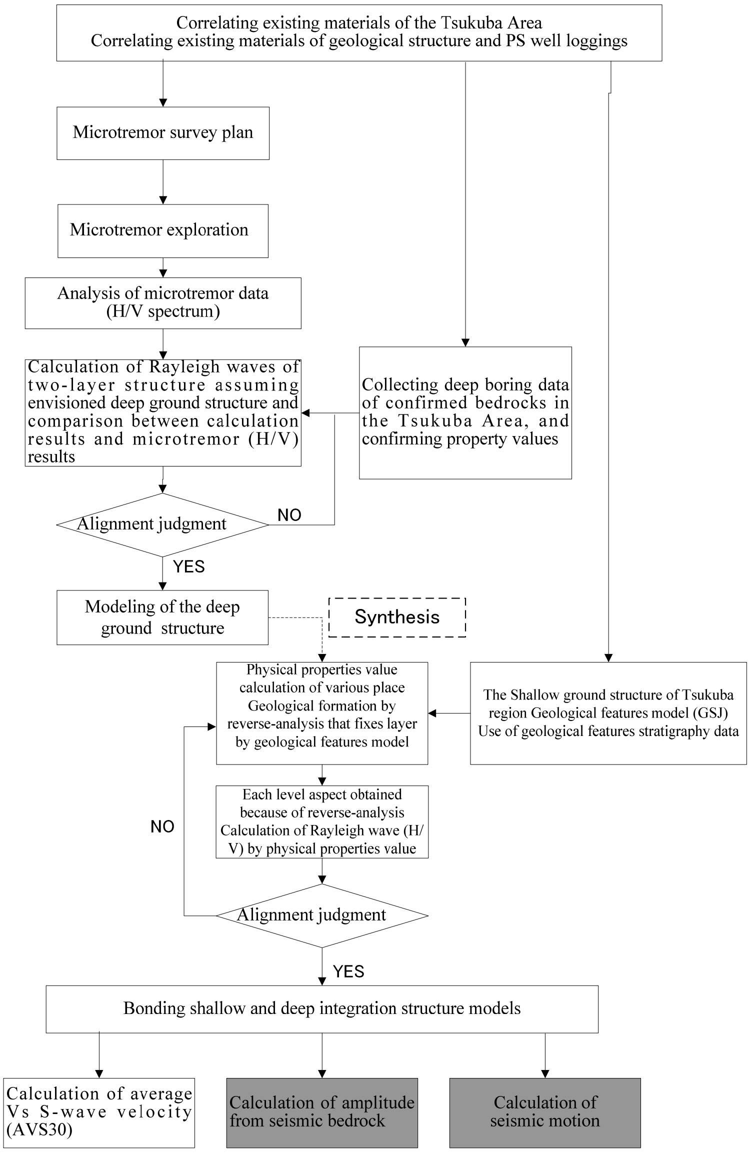


Figure 2 Flow of the survey (Shaded boxes indicate future schedule.)

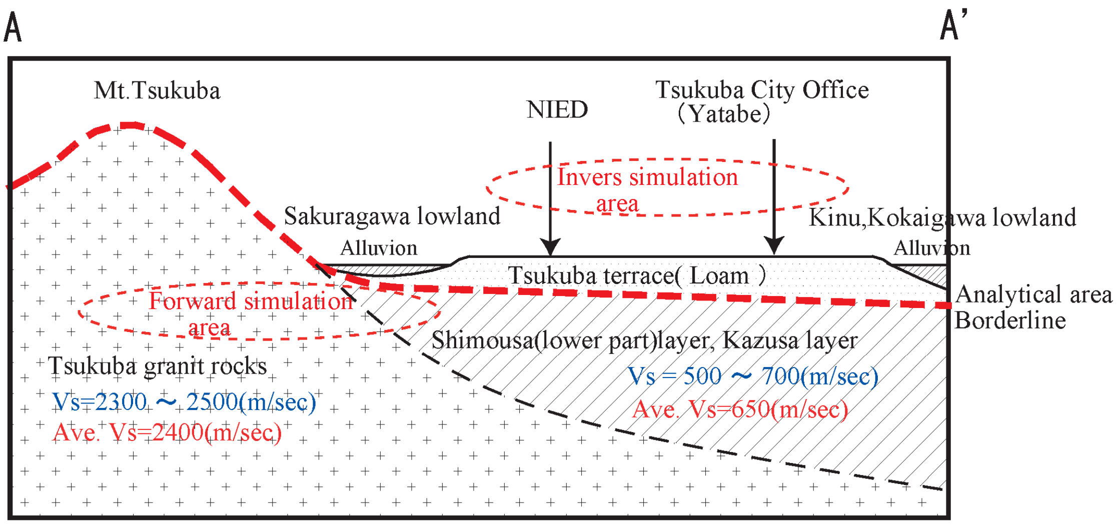


Figure 3 Conceptual diagram of envisaged ground structure of Tsukuba City and explanatory diagram of analysis area.

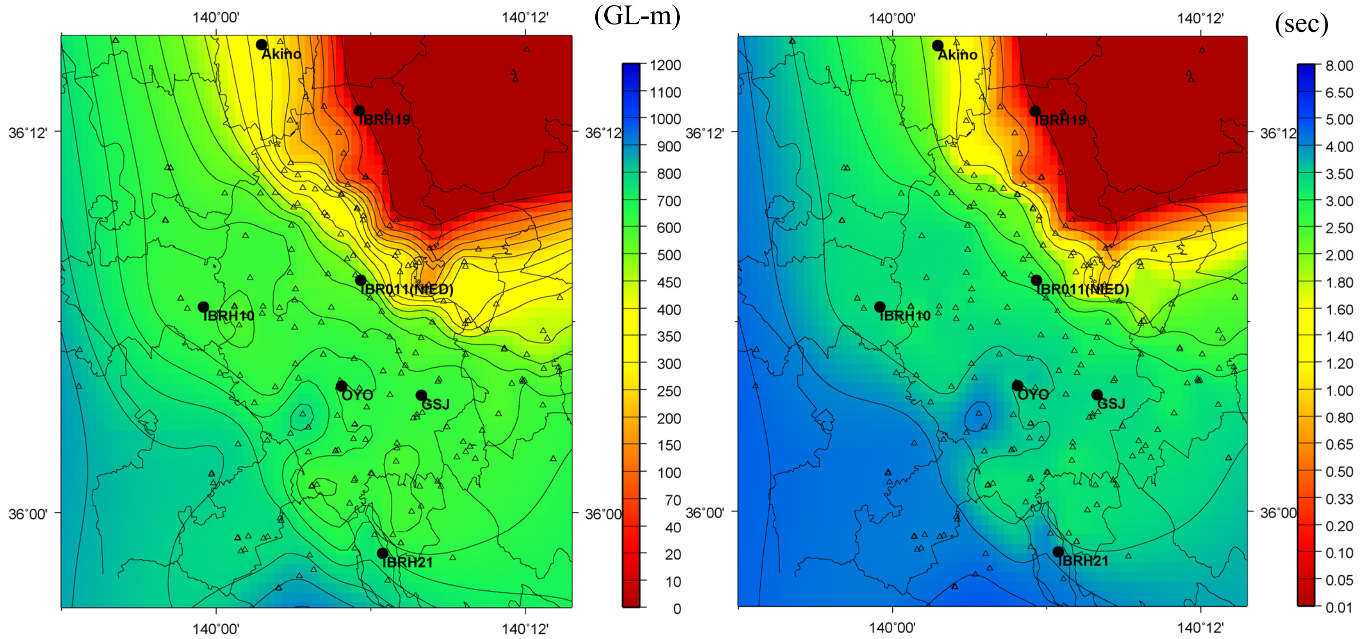
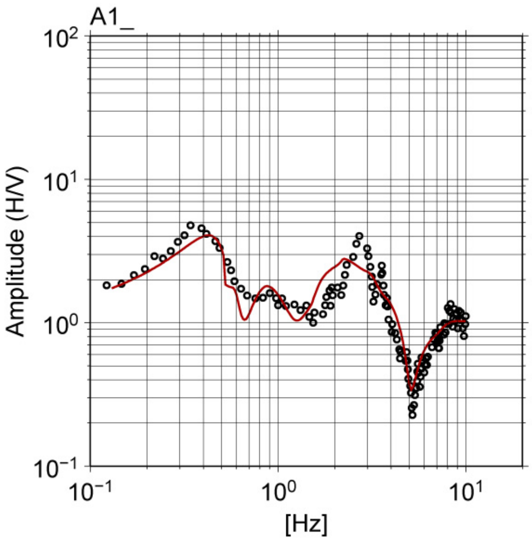


Figure 4 Depth distribution (GL-m) (left figure) and Peak period(sec) (right figure)of the bedrock (Vs=2,400 m/s) estimated from the H/V spectral ratio of a microtremor. Symbols in the figure indicate observation points. (Solid black circles indicate observation points with deep boring that reached bedrock.)

Figure 4 shows the distribution chart of the depth and peak period of the bedrock, and Figure 5 illustrates the comparison between the observed H/V of arbitrary microtremor observation points and the theoretical H/V calculated by inversion. We calculated the theoretical H/V in the fourth mode of the surface wave. (The ratio of Love wave to Rayleigh wave is 0.7.)[2)]

The bedrock structure (Vs=2,400 m/s) grows deeper to the south of Mt. Tsukuba (Tsukuba observation point: IBRH19(KiK-net)). The depth is assumed to be 800m in the southernmost part of Tsukuba City (0.25 Hz, in about 4 seconds, in terms of predominant frequency.) As for shallow ground structure, We explained the observation results using envisioned property values at many observation points through inversion that used a detailed geological structure model. Figure 5 shows samples of the inversion results, and Table 2 and Figure 6 give a list of results for all layers. Figure 7 illustrates the results We obtained by calculating the observation results in the basic mode of Rayleigh waves at arbitrary observation points using the results We obtained in Figures 5 and 6 and Table 2.



Layer symbol	Layer name	Layer thickness (m)	Vs(m/s)	Vp(m/s)	ρ (t/m3)
A	Alluvion	13	148.00	500.00	1.50
Ka	Kamiiwahashi layer	11	300.00	1100.00	1.90
Km	Kamiizumi layer	11	240.00	1200.00	1.90
Yb	Yabu layer(Boundary layer of K layer)	46	457.00	1600.00	2.00
K	Jizo layer, Shimousa and Kazusa layer	671	650.00	1900.00	2.10
B	Bedrock	∞	2400.00	5100.00	2.45

Figure 5 Comparison between observed H/V spectrum and theoretical H/V at microtremor observation point A1. (Heavily-shaded parts and lightly-shaded cells indicate fixed values and values with a 20% variability, respectively, and unshaded cells indicate variable values.)

Table 2 Results of inverse analysis fixed by the layer model of Tsukuba City and values of parameters

Layer symbol	Layer name	Vs(m/s)	Vp(m/s)	ρ (t/m3)
A	Alluvion	122	500	1.50
YL2	New loam layer in Kanto District 2	140	500	1.70
Tg	Terrace deposit	220	650	1.80
YL1	New loamy layer in Kanto District 1	187	550	1.70
Jy	Joso layer	222	600	1.80
Ry	Ryugasaki layer	223	1000	1.90
Ki	Kinoshita layer	286	1100	1.90
Ka	Kamiiwahashi layer	257	1100	1.90
Km	Kamiizumi layer	324	1200	1.90
Yb	Yabu layer(Boundary layer of K layer)	530	1600	2.00
K	Jizo layer, Shimousa and Kazusa layer	650	1900	2.10
B	Bedrock	2400	5300	2.45

notes : Vp indicates the value estimated by PS well logging, density examination, and density well logg

Value by PS well logging (Fixed value)
Average value by inverse analysis

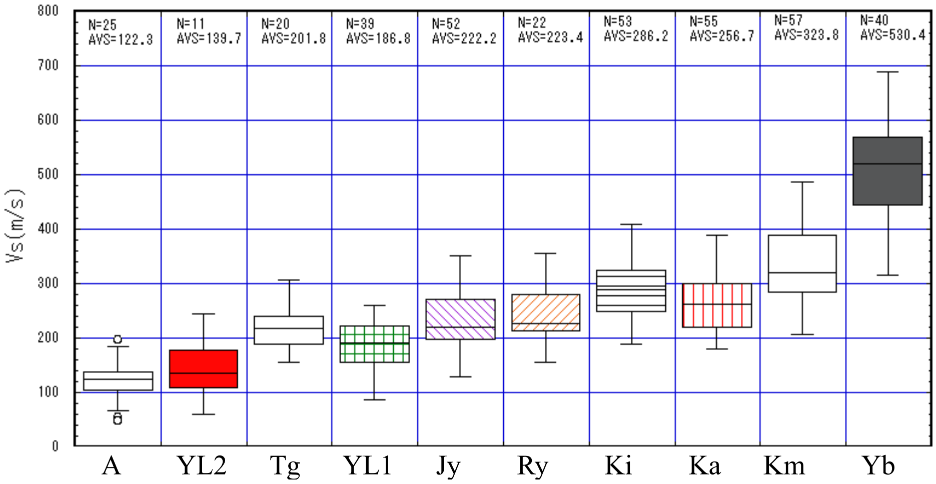
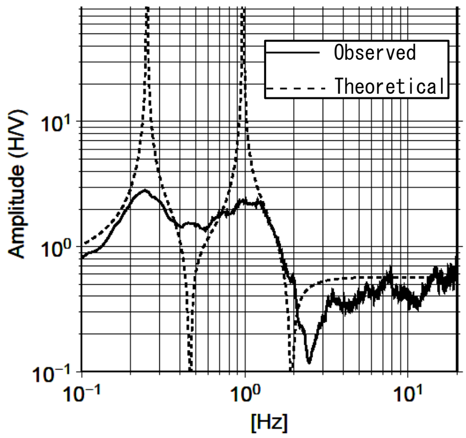


Figure 6 S wave velocity distribution of each layer calculated by inversion



Layer symbol	Layer name	Layer thickness (m)	Vs(m/s)	Vp(m/s)	ρ (t/m3)
A	Alluvion	32	122	500	1.50
Tg	Terrace deposit	8	220	650	1.80
Km	Kamiizumi layer	5	324	1200	1.90
K	Jizo layer, Shimousa and Kazusa layer	636	650	1900	2.10
B	Bedrock	∞	2400	5100	2.45

Value by PS logging (Fixed value)
Average of inverse analysis
Value of geological model

Figure 7 Comparison of inversion results with observed H/V results at arbitrary microtremor observation point E1 arrived at by a calculation of the theoretical amplification of Rayleigh waves (basic mode) using an S wave structure through inverse analysis (Shaded cells in the parameter table indicate average value by inversion.)

We calculated the average S wave velocity (AVS30) using the formulated model (See Figure 8). We obtained almost the same results as Matsuoka (2005) [4] and Fujimoto and Midorikawa(2006) [5] in the loam terrace and valley floor plain that cover Tsukuba City, but found that the average S wave is faster in the south of Mt.Tsukuba (Sakuragawa terrace) than in the terrace, despite the back marsh.
That is because the soft sedimentary layers in this area are thinner than those around Kokaigawa, indicating that there are some areas whose amplification rate cannot be explained solely by the average S wave velocity (AVS30) that utilizes microtopography. We confirmed from existing boring materials that alluvion is thin in this area, and obtained the same results even if We calculated AVS30 using the relationship between the N value of boring[6] and Vs. (See Figure 10)

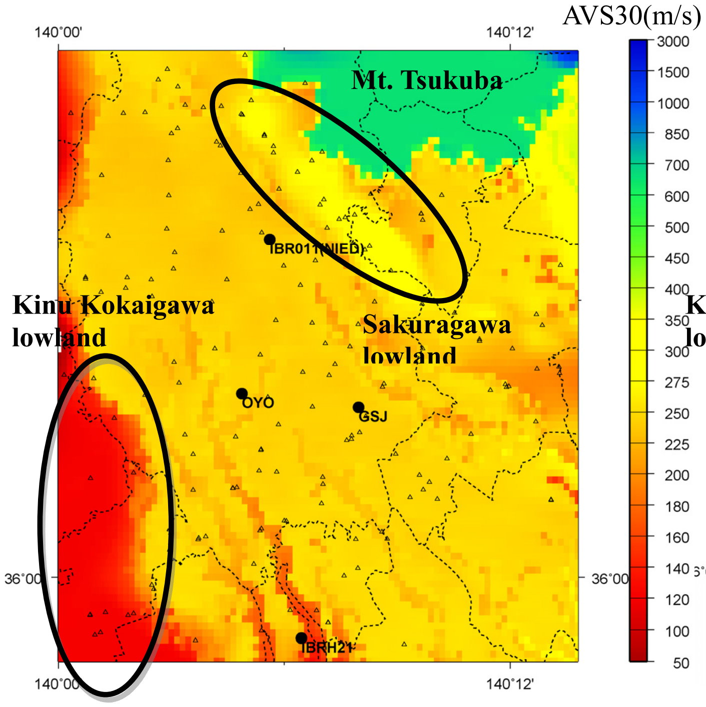


Figure 8 Average S wave velocity (AVS30) in the ground structure model of Tsukuba City formulated in the survey Map is drawn on a 100 m grid basis.

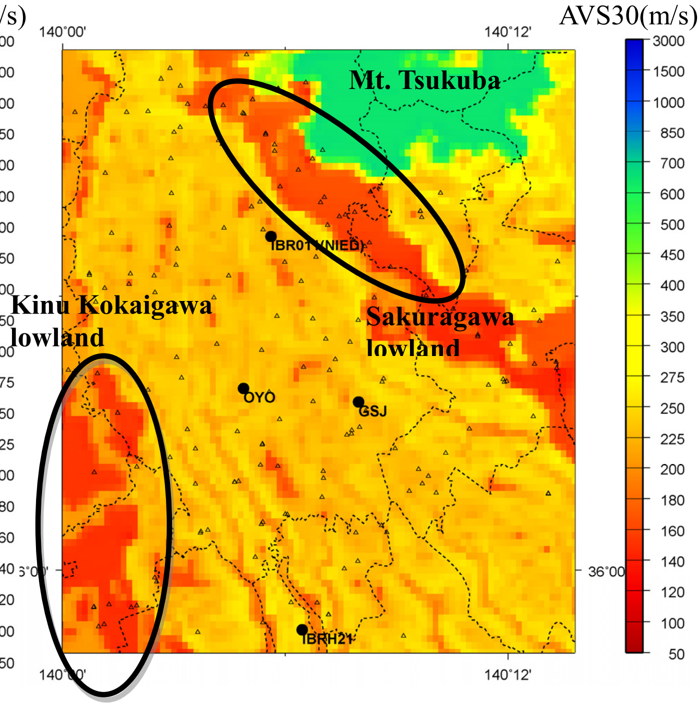


Figure 9 Average S wave velocity (AVS30) in the ground structure model of Tsukuba City drawn using Matsuoka et al. (2005) (Outline parts on a colored background indicate river parts whose ground amplification ratio was not calculated.)

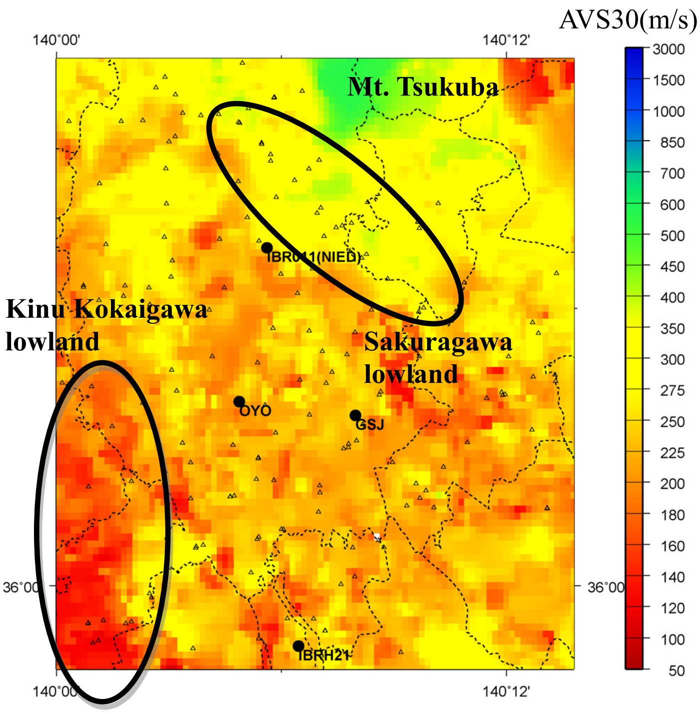


Figure 10 Average S wave velocity (AVS30)
AVS30 made by borehole data(Central Disaster Prevention Conference [6])

4. CONCLUSIONS

In this survey, We examined the H/V spectral ratio of microtremors and a detailed ground structure using a geological model around Tsukuba City and formulated a detailed S-Wave velocity structure model that can explain the predominant period. Using this S-Wave velocity structure mode, We will examine not only the compatibility of predominant periods, but also amplification and topological levels to construct an optimal ground model for forecasting seismic motion.

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