Simplified Ground Modeling of Central Kochi City Using Microtremor Measurement

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A method of combining simple soil investigation (microtremor measurement) and a ground model that is derived as a best-simplified model has been proposed by the first author. This study applies the method to Kochi city which is exposed to a potential risk of being hit by Nankai Earthquake in the near future. The authors carried out microtremor measurements at 70 locations in Kochi city covering the central part of the city. The results showed that predominant frequency becomes smaller as alluvial soil deposit is expedted to become thicker by approaching river mouth and bay areas. Referring bedrock depth information in Kochi city area, the central area of Kochi plain is modeled by the simplified approach. Eigenvalue analysis shows that first mode vibration predominates at river mouth and bay areas where deep soft soil sedimentation forms.

Key Words : *ground model, Kochi city, microtremor measurement*

1. INTRODUCTION

For seismic analysis of wide-spread linear underground structures, we need to ascertain spatial variation of ground motions for some cases including undulating bedrock[1]. To achieve this, we need to calculate ground responses in a wide area, taking into account three-dimensional topographycal and geological conditions. It would be ideal if we could use a straightforward numerical method such as 3D FEM together with accurate soil data (such as PS logging) that provides all the three dimensional mesh properties for the analysis. However, it is usually cost-prohibitive to prepare such data for a wide area.

Soil boring information has recently been becoming available nation wide to the public through web sites such as Kunijiban[2]. However, those boring logs were originally prepared for the construction purpose of public works etc, distribution of data is not uniform. Boring depth is sometimes too shallow to reach engineering bedrock (e.g., sewage works usully need only about 10 meters boring). Appropriate interpolation and extrapolation technique is needed to model the ground under such circumstances. Another issue remains in accuracy converting from SPT blowcounts to shear wave velocities. In addtion to that, it needs to be considered in numerical analysis that mesh size in depth direction can not be too fine compared with horizontal mesh

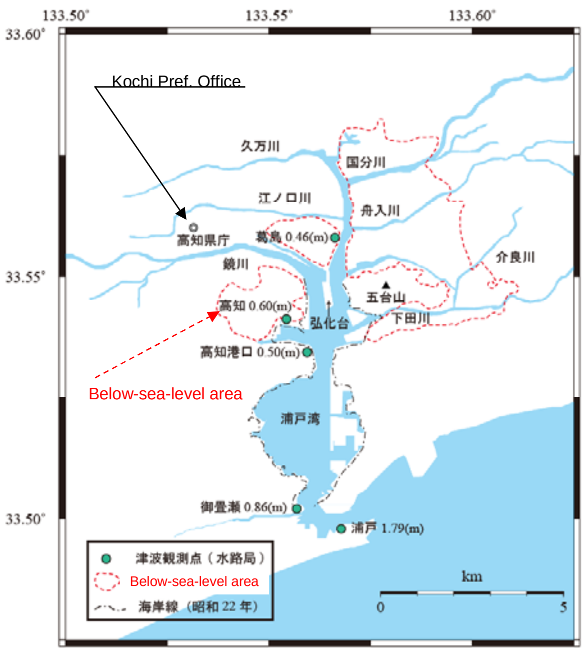

Fig.1 Kochi City

size to avoid too flat element.

These facts indicate that employment of a straight forward, costly approach may neither provide accurate results nor be reasonable.

Considering these facts, the first author has proposed a method that combines simple soil investigation (microtremor measurement) and a ground model that is derived as a best-simplified model for the soil investigation. The major emphasis of this study is placed on application of the method to Kochi city, with reporting results of microtremor measurements carried out at wide spread areas of the city.

Fig.1 shows downtown Kochi and its vicinity areas. Many rivers flow through the city of Kochi. Downtown Kochi city is located at the river mouth of these rivers, described geologically as an alluvial lowland area. Also, Kochi is geologically described as seismic settlement plane and it actually settled after every Nankai earthquakes. Hence below-sea-level areas spread throughout the city.

2. PROPOSED METHOD

The first author has previously proposed a method of developing a simplified ground model based on microtremor measurements as the model in congruity with preciseness of a simple soil investigation[3), 4)].

(1) Microtremor measurements

As a simple soil investigation that is applicable to a wide spread area, microtremor measurement conducted on a ground surface is employed. Three component microtremor measurements are carried out on the ground surface, and horizontal-to-vertical spectral ratio (H/V spectral ratio known as Nakamura's method[5)]) is calculated. This method is quite simple and cost-effective investigation without the need for heavy work, thus, it has the potential to be applicable to a wide area.

(2) Estimation of predominant frequency at a site

Three component servo type velocity meters (Tokyo Sokushin VSE-15D) with a portable vibration observing system (SPC-35) are used. At each site, microtremors are observed for approximately ten minutes with a sampling frequency of 100 Hz.

Observed three component microtremor time histories are Fourier transformed, then, power spectra is calculated. Smoothing with Parzen window that has bandwidth of 0.4(Hz) is then applied. By taking the ratio of smoothed horizontal and vertical spectrum of microtremors, H/V spectral ratio is calculated. H/V spectral ratios calculated by using NS and EW components are eventually averaged by computing root mean square to obtain the final H/V spectral ratio.

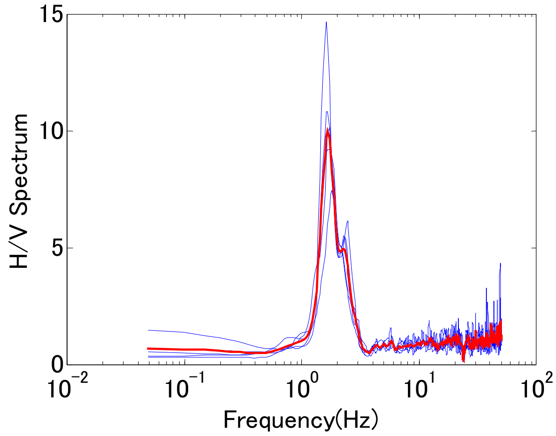

Fig.2 An example of H/V spectral ratio (K-NET Kochi)

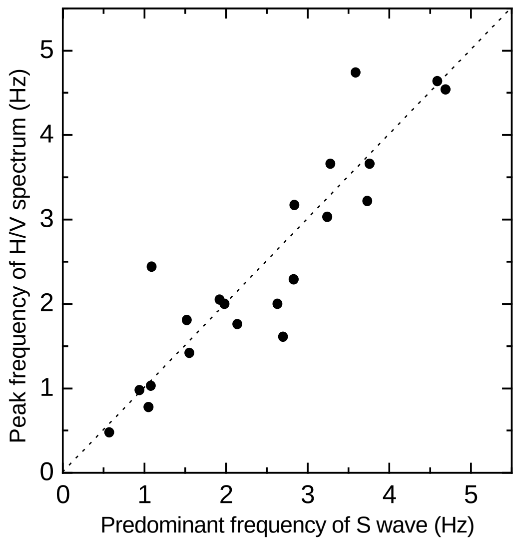

Fig.3 Predominant Frequency

Fig.2 shows an example of H/V spectral ratio. Five different segments (approximately 20 seconds data for each) were extracted from the horizontal and vertical components of microtremor time histories to calculate each H/V spectral ratio (blue curves). Then, they were averaged to obtain the final result (red curve). It seems that consensus has been formed on the point that the peak frequency of H/V spectral ratio indicates predominant frequency at the site.

To confirm this, microtremor measurements were conducted at sites where PS-logging information was available (such as K-NET and KiK-net sites). **Fig.3** shows the relationship between peak frequency of H/V spectral ratio and predominant frequency of S wave calculated based on the quarter-wavelength rule, respectively. Secondary peak of H/V spectral ratio was adopted in some cases based on engineering judgement. Peak frequency of H/V spectral ratio and predominant frequency of S wave show significant agreement with each other. This result indicates that fundamental frequency at a site can be evaluated from microtremor measurement conducted on a ground surface. Similar results can be seen in previous research such as Ohmachi et al.[6].

(3) Equivalent ground model

However, we can not identify each of the Vs and H simultaneously only from the H/V spectral ratio because there is a trade-off between Vs and H (i.e. fundamental frequency can be expressed by the ratio of Vs and H). Hence, we assume here that depths of the base rock can be ascertained from soil boring (such as the standard penetration test) information which recently has been becoming available nationwide to the public (such as KuniJiban by Public Works Research Institute[2]). Averaged Vs of the homogeneous soil deposit can then be estimated from microtremor measurement. In the following section, a multi-layered surface soil is replaced with a homogeneous soil overlying bedrock, and amplification characteristics are estimated.

(4) Replacement of original muti-layered ground with an equivalent homogeneous ground

Knowing the predominant frequency of a multi-layered ground from microtremor measurement, the multi-layered ground is replaced with an equivalent homogeneous soil overlying bedrock as shown in **Fig.4**. "Equivalent" indicates that the replaced homogeneous soil model has an identical predominant frequency as that of multi-layered ground.

In order to investigate site amplification characteristics of the replaced ground model, **Fig.5** compares one dimensional site response functions of a sample ground[7]. The thick line shows site response function of multi-layered soil and the dotted line indicates that of equivalent homogeneous ground. The response function calculated with homogeneous soil shows a good fit with the multi-layered soil in a relatively low frequency range(near the 1st mode). This result implies a reasonable approximation and further simplification that the soil model uses only the 1st mode along the depth of homogeneous soil.

(5) Further simplification of the ground model

At the end of the previous section, a simplified soil model that considers only the first mode along the depth of equivalent homogeneous soil was suggested as being further simplified but efficient modeling, taking into account the site amplification characteristics of the equivalent homogeneous ground derived

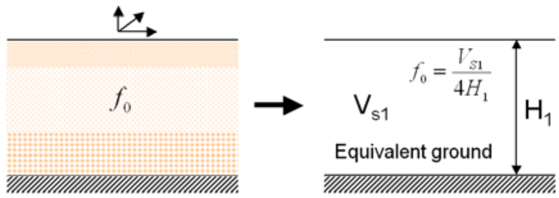

Fig.4 Replacement of multi-layer ground with an equivalent homogeneous ground

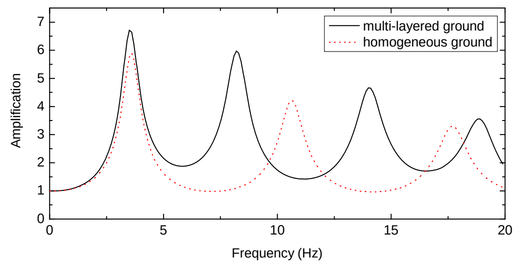

Fig.5 Site Response Functions (model ground)

as reasonable model to utilize microtremor measurements. Referring to previous work by Nogami et al.[7], further simplified model is derived in the followings starting from the three dimensional governing equation.

The governing equation for three dimensional soil is given as shown below.

$$\rho\frac{\partial^2 u}{\partial t^2} = \frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{xz}}{\partial z} \tag{1}$$

$$\rho\frac{\partial^2 v}{\partial t^2} = \frac{\partial \sigma_{yx}}{\partial x} + \frac{\partial \sigma_{yy}}{\partial y} + \frac{\partial \sigma_{yz}}{\partial z} \tag{2}$$

$$\rho\frac{\partial^2 w}{\partial t^2} = \frac{\partial \sigma_{zx}}{\partial x} + \frac{\partial \sigma_{zy}}{\partial y} + \frac{\partial \sigma_{zz}}{\partial z} \tag{3}$$

where σ_{ij} =stress components, ρ =soil density, $u, v, w =$ displacements in the *x*, *y*, *z* direction. Converting the equilibrium equations to the equation with respect to displacement, and ignoring vertical motion,

$$\rho\frac{\partial^2 u}{\partial t^2} = \frac{\partial}{\partial x}\left[\lambda\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+2\mu\frac{\partial u}{\partial x}\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\frac{\partial u}{\partial z}\right] \tag{4}$$

$$\rho\frac{\partial^2 v}{\partial t^2} = \frac{\partial}{\partial y}\left[\lambda\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+2\mu\frac{\partial v}{\partial y}\right]+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\frac{\partial v}{\partial z}\right] \tag{5}$$

where $\lambda, \mu =$ Lame's constants, Separation of variables as $u = U(x, y, t)\phi(z)$, $v = V(x, y, t)\phi(z)$, where $\phi(z)$ is vibration mode along the depth, is applied.

$$\rho \frac{\partial^2 U}{\partial t^2}\phi = (\lambda+\mu)\phi \frac{\partial}{\partial x}\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right) + \mu\phi\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)U + \mu U \frac{\partial^2 \phi}{\partial z^2} + \frac{\partial \mu}{\partial z}\frac{\partial \phi}{\partial z}U \tag{6}$$

$$\rho \frac{\partial^2 V}{\partial t^2}\phi = (\lambda+\mu)\phi \frac{\partial}{\partial y}\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right) + \mu\phi\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)V + \mu V \frac{\partial^2 \phi}{\partial z^2} + \frac{\partial \mu}{\partial z}\frac{\partial \phi}{\partial z}V \tag{7}$$

Galerkin's method is applied along the z direction as Nogami et al.[8],

$$\int_0^H \left(-\rho \frac{\partial^2 U}{\partial t^2}\phi + (\lambda+\mu)\phi \frac{\partial}{\partial x}\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right) + \mu\phi\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)U + \mu U \frac{\partial^2 \phi}{\partial z^2} + \frac{\partial \mu}{\partial z}\frac{\partial \phi}{\partial z}U\right)\phi dz = 0 \tag{8}$$

$$\int_0^H \left(-\rho \frac{\partial^2 V}{\partial t^2}\phi + (\lambda+\mu)\phi \frac{\partial}{\partial y}\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right) + \mu\phi\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)V + \mu V \frac{\partial^2 \phi}{\partial z^2} + \frac{\partial \mu}{\partial z}\frac{\partial \phi}{\partial z}V\right)\phi dz = 0 \tag{9}$$

Applying integration by parts to the last two terms, the following equations are finally obtained.

$$\rho^* \frac{\partial^2 U}{\partial t^2} + k^* U = (\lambda+\mu)^* \frac{\partial}{\partial x}\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right) + \mu^*\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)U \tag{10}$$

$$\rho^* \frac{\partial^2 V}{\partial t^2} + k^* V = (\lambda+\mu)^* \frac{\partial}{\partial y}\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right) + \mu^*\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)V \tag{11}$$

where $\rho^*, k^*, (\lambda+\mu)^*, \mu^*$ are parameters of the simplified model expressed as follows.

$$\rho^* = \int_0^H \rho\phi^2 dz \tag{12}$$

$$k^* = \int_0^H \mu\left(\frac{\partial \phi}{\partial z}\right)^2 dz \tag{13}$$

$$(\lambda+\mu)^* = \int_0^H (\lambda+\mu)\phi^2 dz \tag{14}$$

$$\mu^* = \int_0^H \mu\phi^2 dz \tag{15}$$

This resulting model is similar to the Quasi-Three-Dimensional Ground Model (Q3DGM) developed by Tamura et al.[9]. The difference is that the proposed method keeps the same fundamental frequencies of ground models before and after the simplification, whereas Q3DGM does not. Incidentally, the governing equation for a two dimensional case is given as can be seen below.

$$\rho \frac{\partial^2 u}{\partial t^2} = (\lambda+\mu)\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right) + \mu\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)u \tag{16}$$

$$\rho \frac{\partial^2 v}{\partial t^2} = (\lambda+\mu)\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right) + \mu\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)v \tag{17}$$

Comparing these 2D equations with Equations (10) and (11), the only difference is k^*U and k^*V terms which work as restoring force regarding relative horizontal displacement along the z direction.

3. MICROTREMOR MEASUREMENT IN KOCHI CITY

(1) Geomorphorogical and geological features of Kochi city

Geomorphorogical and geological features of Kochi plain can be found at Katto et al.[10] as below. Kochi plain consists of zones of alluvial fans followed by natural levees and deltas near the river mouth. Central Kochi city (focused area) is located at natural levee and delta zones. Backmarsh is formed in lowland between natural levees.

Geological characteristics of baserock in Kochi plain is devided into several zones by geological lines that crosses Kochi plane from west to east forming imbricate structure with newer geologic stratum toward the south. In Kochi plain, tectonic basin is filled by diluvium and alluvium of Quaternary period. Alluvium is thought to be underlain by diluvium in nearly entire region of Kochi plain.

(2) Baserock of Kochi city

Fig.6 shows contour of bottom level of alluvial layer drawn on the 1/25,000 map issued by the Geospatial Information Authority of Japan(GSI), by referring "The Ground Diagram of Kochi (Kochi Jibanzu)"[11]. This contour is determined from more than 1000 boring logs at Kochi plain. Another contour that shows top level of base rock is also presented in this book, describing the depths of the bedrock underneath the unconsolidated layer of Quarternary Period.

(3) Microtremor measuresments

The authors have conducted microtremor measurements at 70 locations in Kochi city by the end of March, 2014. The locations are shown in **Fig.6**. The measurements are usually carried out at parks or school grounds on fine days with no wind and no rain. Data samples that are not contaminated by traffic noise are extracted for the study.

Fig.7 shows an example of H/V spectral ratio. Blues lines show H/V spectra from each of the segments and the red line shows the averaged spectrum of the blues lines. The peak frequency provides approximation of the predominant frequency of the site. Based on the author's experience to date, H/V spectrum calculated from microtremors in Kochi usually show an outstanding peak shape.

All the predominant frequencies of evaluated mi-

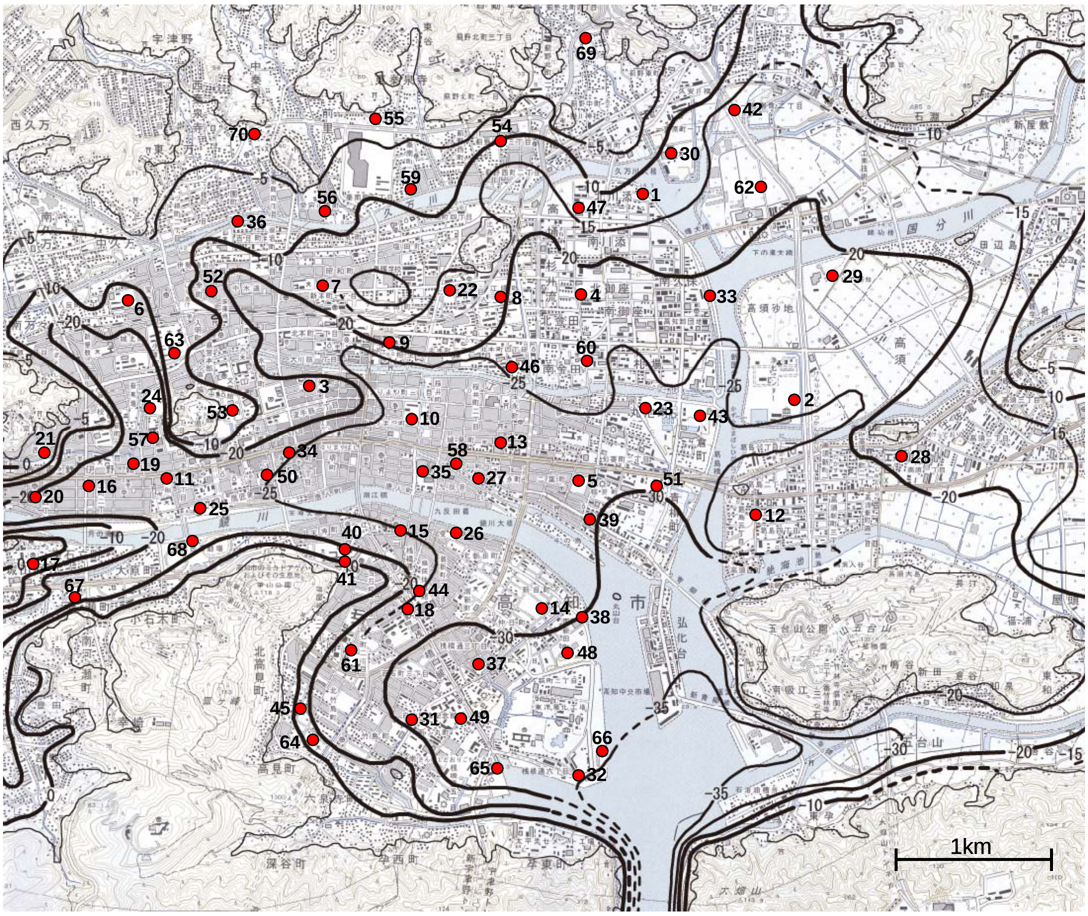

Fig.6 Microtremor Observation StationsTopographical map issued by GSI was used.
Contour (bottom of alluvial layer, unit for contours in meters) was added referring "The Ground Diagram of Kochi[11]"

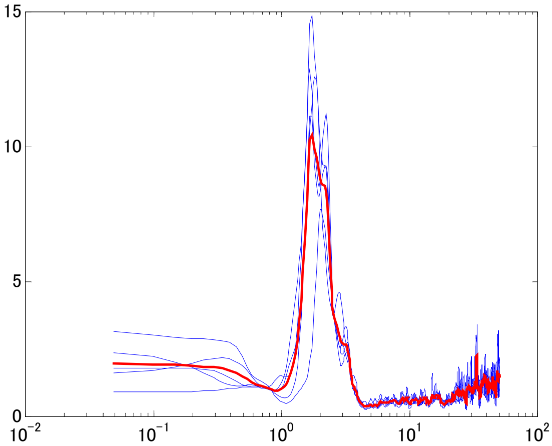

Fig.7 H/V spectral ratio at station 22

crotremor recordings are summarized in **Table 1**.

Fig.8 shows a distribution of predominant frequencies evaluated from microtremor by showing color dots. It is clearly evident that peak frequency becomes smaller when alluvial soil deposits become thicker, approaching to the river mouth and bay areas.

4. APPLICATION OF THE METHOD TO KOCHI CITY

(1) Depth to the bedrock

After determination of peak frequency at each site, depths to the bedrock need to be evaluated. As mentioned previously, two kinds of depths are read from the map; one is bottom level of alluvial layer and the other is the top level of base rock. Examination using PS logging concludes that the latter base is the one related to the H/V peak frequency. As the latter contour is prepared only up to –60m in the book ("The Ground Diagram of Kochi")[11], Ohori's estimation[12] equation is used complementarily.

$$D_P = 70.1 T_P \qquad (18)$$

where D_P is the depth to the bedrock (m) and T_P is predominant frequency at the site.

Table 1 Summary of ground model

Site	Pred. Freq. (Hz)	Bottom of alluvium H_1(m)	Top of baserock H_2(m)	$70.1T_P$ (m)	Cokriging (m)	Averaged $Vs,_1$	Averaged $Vs,_{21}$	Averaged $Vs,_{22}$
1	1.42	12	-	46	43.8	72	280	249
2	0.98	16	-	72	62.4	63	280	245
3	1.32	18	34	-	33.2	95	180	175
4	0.88	22	>60	80	50.7	77	280	178
5	0.78	28	>60	90	76.8	87	280	240
6	2.29	12	30	-	27.7	110	275	254
7	1.56	17	42	-	46.9	106	262	293
8	1.27	20	45	-	48.7	101	229	248
9	1.27	20	55	-	41.0	101	279	208
10	0.93	27	>60	75	62.9	100	280	234
11	1.42	23	50	-	48.9	131	284	278
12	1.46	23	-	48	53.3	134	280	311
13	0.93	27	>60	75	72.1	100	284	268
14	0.78	28	>60	90	67.5	87	280	210
15	1.07	25	>60	50	42.8	107	214	183
16	2.73	22	-	26	23.4	240	280	255
17	2.05	-	14	-	24.8	-	115	203
18	1.42	20	35	-	57.0	114	199	323
19	1.46	22	50	-	39.5	128	292	230
20	2.39	20	-	29	23.0	191	280	220
21	2.64	-	25	-	18.4	-	264	195
22	1.71	16	40	-	35.8	122	304	245
23	0.98	27	>60	72	85.7	106	280	336
24	1.66	23	27	-	20.4	153	179	135
25	1.81	23	-	45	40.0	171	335	290
26	1.07	26	>60	66	54.1	111	280	232
27	0.93	27	>60	75	64.1	100	280	238
28	1.95	19	-	36	47.9	148	280	374
29	0.88	21	-	80	57.9	74	280	204
30	1.66	11	-	42	44.6	73	280	296
31	1.03	30	-	68	35.1	124	280	145
32	1.12	35	>60	63	35.5	157	280	159
33	0.83	22	>60	84	66.4	106	280	220
34	1.61	25	-	44	40.0	161	280	257
35	0.88	27	-	80	60.1	95	280	211
36	1.61	8	30	-	33.1	51	193	213
37	0.68	32	>60	103	62.5	87	280	170
38	0.78	30	>60	84	66.8	100	280	208
39	0.88	30	>60	80	69.0	106	280	243
40	1.76	20	35	-	51.8	141	246	365
41	2.54	10	11	-	51.1	102	112	519
42	1.81	11	-	39	34.5	80	280	250
43	0.88	26	>60	72	99.8	102	280	351
44	1.32	25	>60	53	59.2	132	280	313
45	2.10	10	-	34	28.8	82	246	242
46	0.98	24	>60	72	64.2	94	280	252
47	1.07	13	>50	63	34.4	58	280	147
48	0.78	31	>60	90	62.3	97	280	194
49	0.78	32	>60	90	54.0	100	280	169
50	1.37	25	-	51	42.1	137	280	231

Table 1 Summary of ground model (cont'd)

Site	Pred. Freq. (Hz)	Bottom of alluvium H_1(m)	Top of base-rock H_2(m)	$70.1T_P$ (m)	Cokriging (m)	Averaged Vs, 1	Averaged Vs, 21	Averaged Vs, 22
51	0.93	30	>60	75	74.1	112	280	276
52	1.66	15	42	-	28.5	100	279	189
53	5.86	7	-	12	25.2	163	280	592
54	2.05	10	33	-	22.1	82	271	181
55	4.83	4	10	-	17.3	77	193	334
56	2.1	8	31	-	36.9	67	260	310
57	1.46	21	33		31.4	123	193	183
58	0.98	27	>60	72	66.6	106	280	261
59	3.08	8	33		25.0	99	407	308
60	0.68	24	>60	103	69.4	65	280	189
61	1.17	25	30		44.5	117	140	208
62	1.12	18	-	63	54.4	81	280	244
63	3.32	9	20		21.1	120	266	280
64	1.56	13	20		29.2	81	125	182
65	0.83	31	>50	84	50.5	103	280	168
66	1.17	34	-	60	40.7	159	280	191
67	2.59	21	25		31.3	218	259	324
68	1.90	21	42		20.3	160	319	154
69	8.54	2	-	8.2	-	68	280	-
70	5.47	5	5		20.2	109	109	443

Also shown in **Table 1** (6th column) is estimation of bedrock depth by Taniguchi and Mikami[13] with the aid of Cokriging technique.

(2) Averaged shear wave velocity of equivalent ground model

Knowing the depth H to the base at each site, averaged shear wave velocity $\bar{V}_S$ is evaluated based on the following equation.

$$T = \frac{4H}{\bar{V}_S} \tag{19}$$

Estimated results are shown in **Table 1** as $V_{S,1}$ and $V_{S,21}$ and $V_{S,22}$. $V_{S,1}$ and $V_{S,2X}$ correspond to H_1 and H_2, respectively. $V_{S,21}$ and $V_{S,22}$ correspond to H_2 estimated by the contour map or Ohari's equation, and H_2 by Taniguchi and Mikami (Cokriging). Here, H_1 is depth from the surface to the bottom of alluvial soil deposit and H_2 is depth from the surface to the top of base rock.

For the verification of the results, H/V spectral ratio observed at station 40 is shown in **Fig.9**. Peak frequency estimated from H/V spectral ratio is 1.76(Hz) at this station. **Fig.10** shows PS logging. Top of bederock can be found at approximately 35m. Predominant frequency is evaluated as 1.64(Hz) with using this profile.

5. NUMERICAL EXAMPLE

(1) Generation of mesh

To carry out eigenvalue analysis using the simplified model, the area is divided by a mesh generated as shown in **Fig.11**. At least one microtremor observation point is included to represent the characteristics of the mesh area. If there are more than two microtremor stations within a mesh, the one close to the mesh center is used. If their distances from the mesh center are about the same, their evaluations are averaged in order to obtain a representative value of the mesh. Two kinds of boundary conditions are prepared; one is a free boundary at all the outer boundaries and the other is mixture of free and fixed boundaries (fixed boundaries are shown by red circle in **Fig.11**). Soil density is assumed to be 1,800(kg/m^3) and Poisson's ratio 0.4. Plane-stress assumption is adopted to the 2D plane of the proposed model in the analysis.

(2) Numerical results

As an numerical example, the simplified ground model with predominant frequency and bedrock depth estimated by Cokriging is used here.

Results are shown in **Fig.12** and **Fig.13** for free boundary and mixed boundary, respectively. Natural

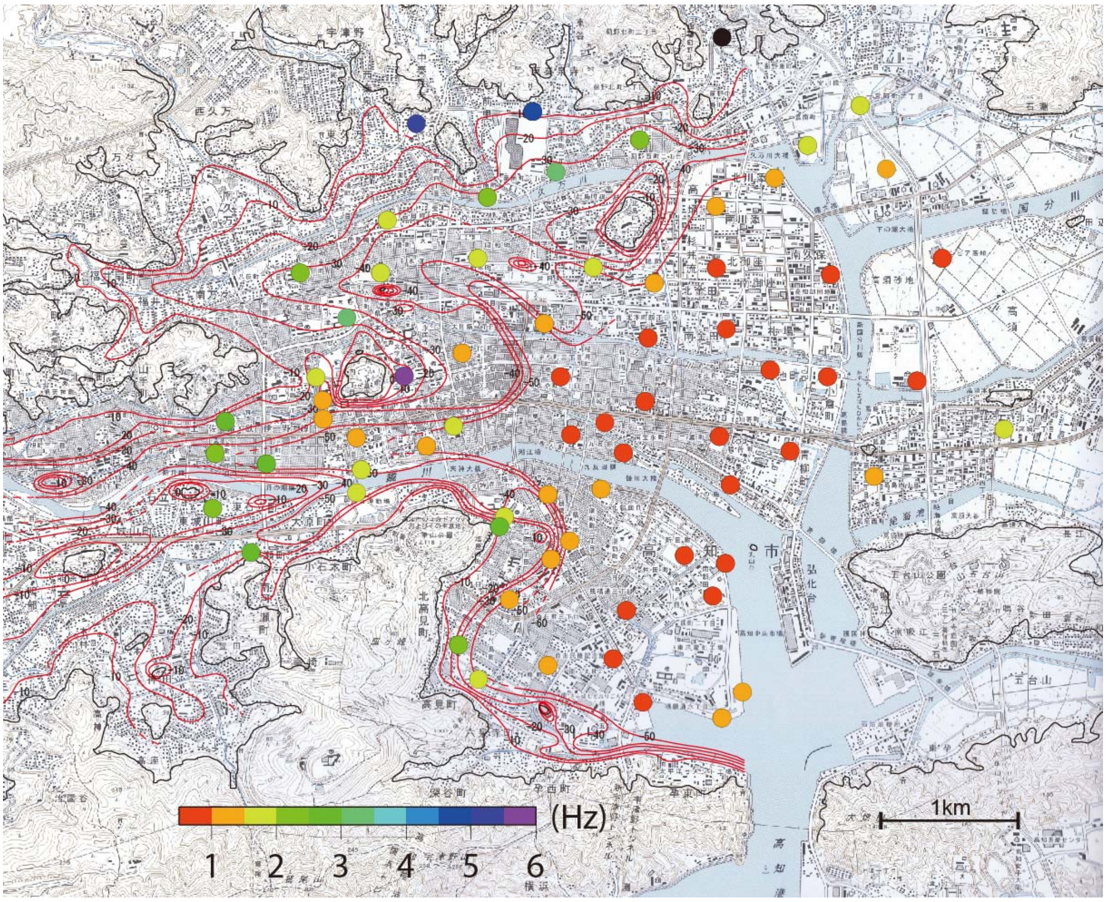

Fig.8 Distribution of predominant frequency of ground (Topographical map issued by GSI was used. Contour (top of baserock) was added referring "The Ground Diagram of Kochi (Kochi Jibanzu)")

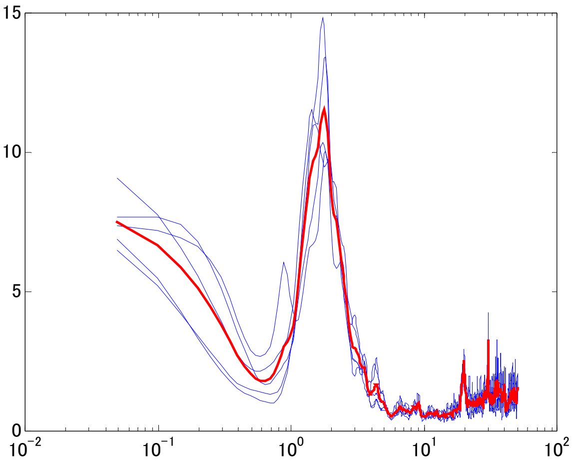

Fig.9 H/V spectral ratio observed at station 40. Predominant frequency is estimated as 1.76(Hz).

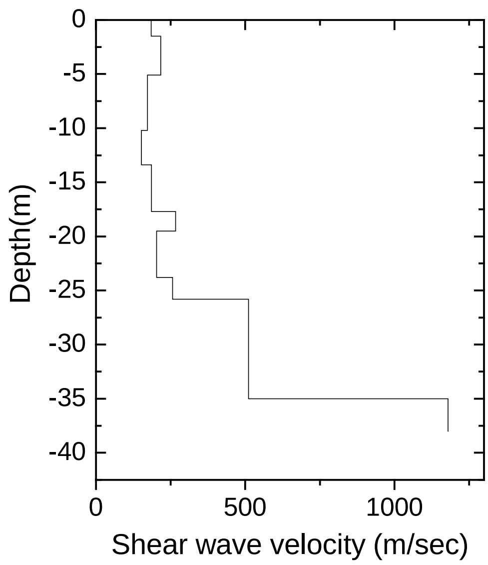

Fig.10 PS logging (S wave velocity profile) (Shear wave distribution along the depth at station 40)

frequencies are 1.27(Hz) for the free boundary model and 6.81(Hz) for the partially fixed boundary model. Both models show predominant vibration near the river mouth area and bay area. A significantly higher natural frequency when some points of the boundary is fixed implies that the generated mesh is too coarse at this moment, thus, a finer mesh and more microtremor measurements are needed in future revision of the model.

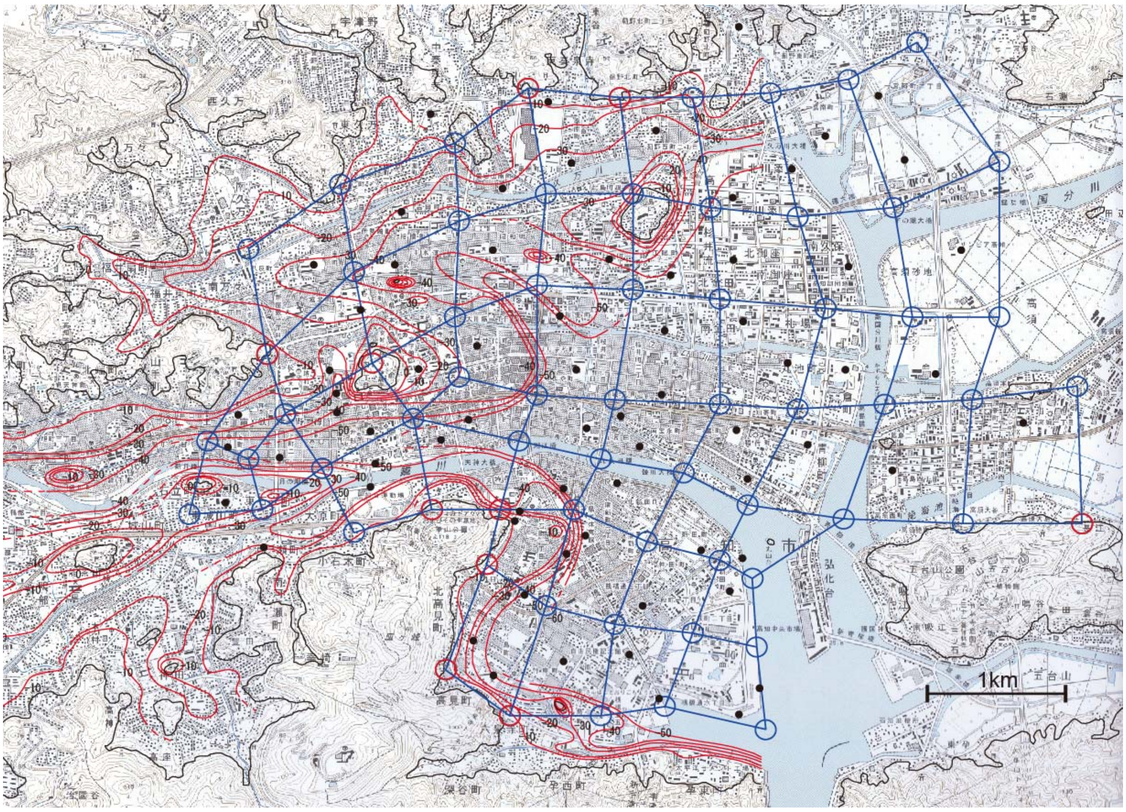

Fig.11 Generation of Mesh for the Analysis
Topographical map issued by GSI was used. Contour (top of baserock) was added referring "The Ground Diagram of Kochi (Kochi Jibanzu)"

6. CONCLUSIONS

A method of combining microtremor measurement of ground and a ground model that is derived as a best-simplified model has been previously proposed by the first author. This study applied the method to the local city of Koch which is exposed to a potential risk of being hit by a major earthquake in the near future. Microtremor measurements were carried out at 70 locations in Kochi city covering the Kochi alluvial plain to establish a simplified ground model. The results generally show that predominant frequency of ground becomes smaller when alluvial soil becomes thicker, approaching river mouth and bay area. Using the measured microtremor data together with available depth information of the base rock, the best-simplified model for surface soil deposit is derived. Finally, eigenvalue analysis using the simplified model was conducted as an numerical example. Results show that 1st mode exhibits predominant vibration at river mouth and bay areas.

ACKNOWLEDGMENT: This work was supported by JSPS KAKENHI Grant Number 25420486. Some of the figures were created by using GMT (Generic Mapping Tools). Acknowledgment is due Mrs. N. Tsujino and some previous students to have helped to conduct microtremor measurements and to draw contour maps.

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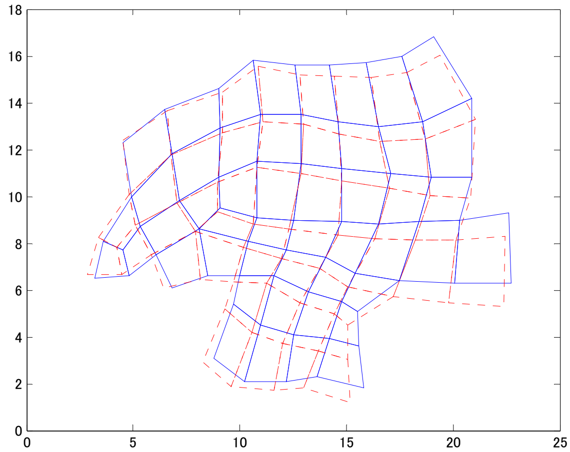

Fig.12 1st mode vibration (free-boundary)

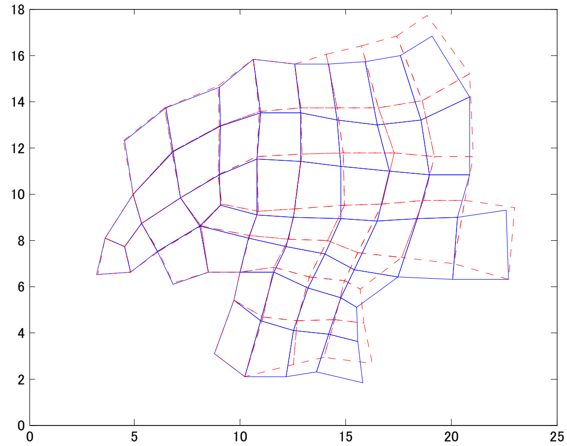

Fig.13 1st mode vibration
(mixture of free and fixed boundary)

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