VARIATION OF THE DYNAMIC PROPERTY OF A RECLAIMED GROUND DUE TO SUBSURFACE COMPLEXITIES

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ABSTRACT :

Although the reclaimed land has a completely flat landform, its predominant frequency varies a lot with location, according to our survey based on the microtremor measurement. The objective of this study is to account for this dynamic characteristic locality in the reclaimed land. In order for this, a large number of soil investigation data have been collected and a series of microtremor measurements have been conducted. From this study, it was found that: (1) the topography in the old times which is buried underground is the determining factor of the dynamic characteristics of the reclaimed land, (2) the predominant frequency corresponds to its scale, (3) the H/V spectrum has a sharp peak when the soil stiffness shows a remarkable change, (4) however, the spectral shape of microtremors does not have a sharp peak when the soil stiffness shows a gradual change.

KEYWORDS: Soil Structure Irregularity, Microtremor Measurement, Finite Element Analysis

1. INTRODUCTION

Prediction and mitigation of the damage due to natural disasters are the urgent demand of society. When looking into the damage, we often notice that the conditions of the landform and the soil are strongly associated with it. This fact indicates that it is essential to know these conditions when considering natural disaster mitigation as well as planning to construct any facilities.

Importance of topography for the damage due to earthquakes has been widely acknowledged in the community of earthquake engineering (AIJ, 1993). A number of studies have been made on the effect of a slope and a valley shaped soft soil (Kurita et al., 2005, Nagata et al., 2007). Results show that a large amplification is found near the top of the slope and in the midst of the alluvial valley. However, the existence of irregular topography is sometimes overlooked when the site under consideration is in the middle of a flat land such as the reclaimed land.

Although most reclaimed grounds are completely flat from the viewpoint of landform, the predominant frequency sometimes varies a lot with location, according to our survey based on the microtremor measurement conducted along the coast of Chiba city, which is located about 50 kilometers east of Tokyo, Japan. The survey also brought out that the frequency dependency of amplification characteristics changes with location as well. The objective of this study is to account for this dynamic characteristic locality in the reclaimed ground.

2. TARGET AREA

Figure 1 shows a map of landform classification of the eastern part of the Tokyo metropolitan area (Chiba Pref. Gov., 1975-81). According to this map, it is pointed out that the landform of this area consists of three elements: terrace, lowland, reclaimed land both inland and along the coast. Among them, the reclaimed land distinctively sweeps away along the coast of Tokyo bay. According to the history of this area, land reclamation began more than 100 years ago and was accelerated in late 1950's by filling in land which used to be a tidal flat. At the moment, about 33 square kilometers of reclaimed land are present along the coast in Chiba city. In this study, the reclaimed land along the coast of Chiba city has been chosen as a target area.

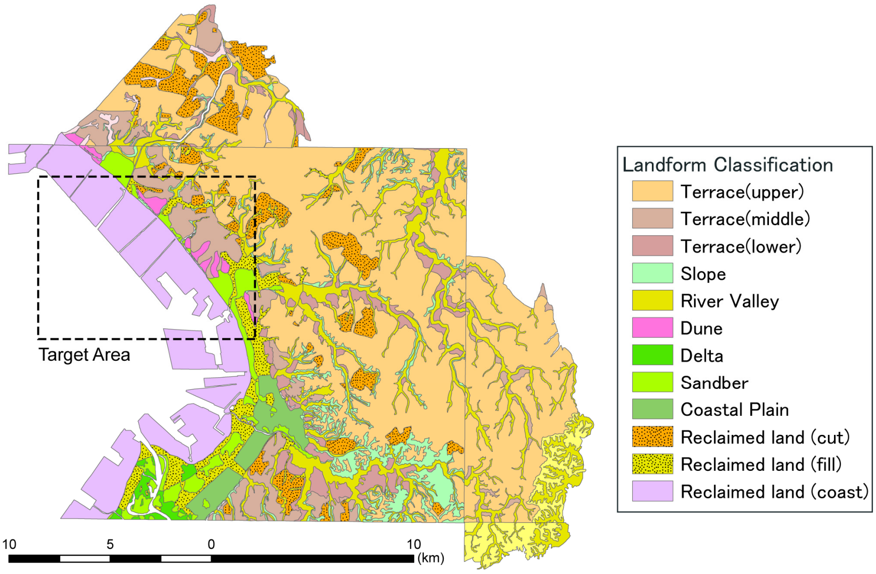

Figure 1 Landform classification of Chiba area

3. MICROTREMOR MEASUREMENTS

Figure 2 shows an enlarged map of the target area. Here, the area is partitioned into 6 blocks, A through F. The authors have conducted microtremor measurements at a total of 71 locations in this area in the period of 2000 and 2001. By computing the horizontal-to-vertical Fourier amplitude ratio, or the H/V spectrum, based on the measured record, the vibration characteristics such as predominant frequencies were examined. Here, the predominant frequency was chosen as a frequency that gives a maximum value of the H/V spectrum in the frequency range of 1 through 10 Hz. The distribution of predominant frequency at each location is also plotted in Figure 2. Figure 3 shows the relationship between the predominant frequency and the distance from the former coast line before reclamation, which approximately corresponds to the boundary between reclaimed land and terrace. From these figures, it is found that predominant frequencies become low when approaching the present coast line, while they vary a lot near the former coast line.

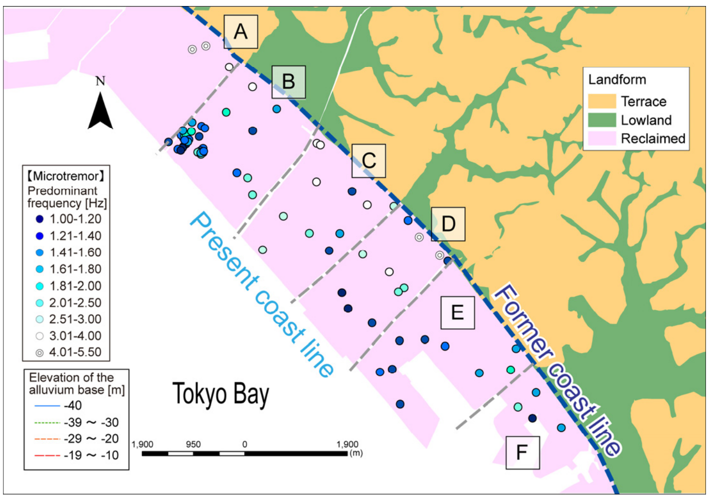

Figure 2 Target area of investigation

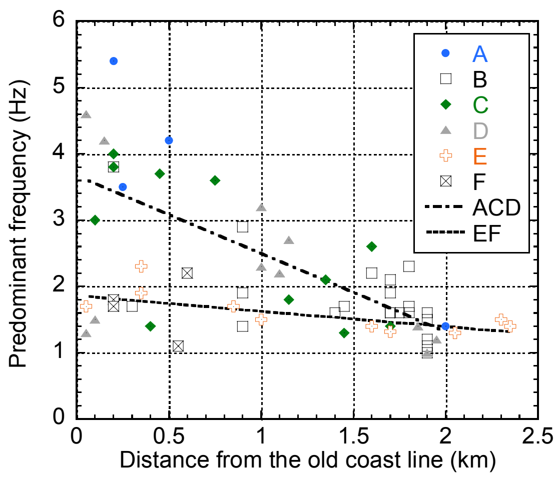

Figure 3 Relationship between predominant frequencies and distance from former coast line

3.1. A, C and D block

As can be seen in Figure 3, most of the predominant frequencies in the blocks A, C and D are close to around 4 Hz near the former coast line and they gradually become low toward the present coast line. At about 2 kilometers from the present shore line, the predominant frequency is about 1.5 Hz. One of the lines drawn in Figure 3 indicates this tendency. In Figure 4, typical H/V spectra in these blocks are compared. As described above, the general tendency of the predominant frequency in these blocks is that it gradually shifts from 4 Hz in the former coast line to 1.5 Hz in the present coast line. However, a number of exceptions are found near the old coast line, i.e., highest peaks fall in the low frequency range of 1 to 2 Hz, while secondary peaks are also found in the higher frequency range. This implies an accumulation of fairly soft soils with a larger thickness toward the present coast line. However, quite a few exceptions indicate that the situation is not that simple.

3.2. B, E and F block

According to Figures 2 and 3, the predominant frequency is low in general and its change with the distance from the former coast line does not seem obvious in the blocks E and F. This may be due to a fairly complex configuration of the present coast line. In Figure 5, typical H/V spectra in these blocks are compared. Compared to these blocks, the block B is complex from the viewpoint of the frequency dependency. Here, two types of H/V spectral shapes are found. One is similar to the blocks A, C and D in that closer to the present coast line, lower the predominant frequency. The other is similar to the blocks E and F in that the predominant frequency does not seem to have a strong correlation with the distance from the former coast line.

From the above discussion, it is understood that the change of the depth of the soft surface soil is not as simple as the gradual increase in relation to the distance from the former coast line.

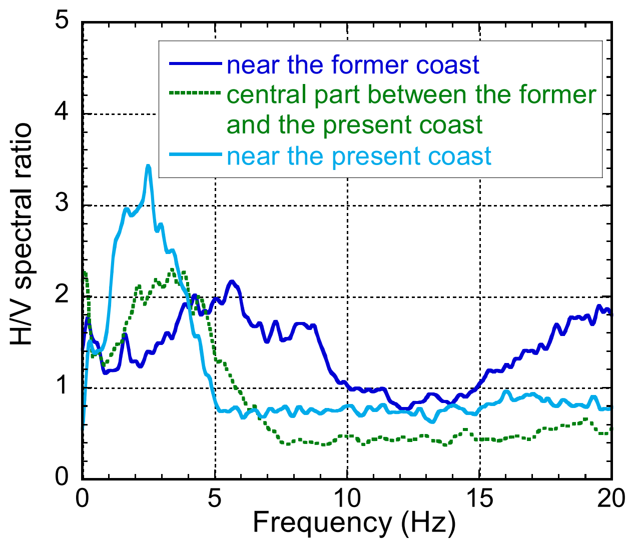

Figure 4 Typical H/V spectra in blocks A, C and D

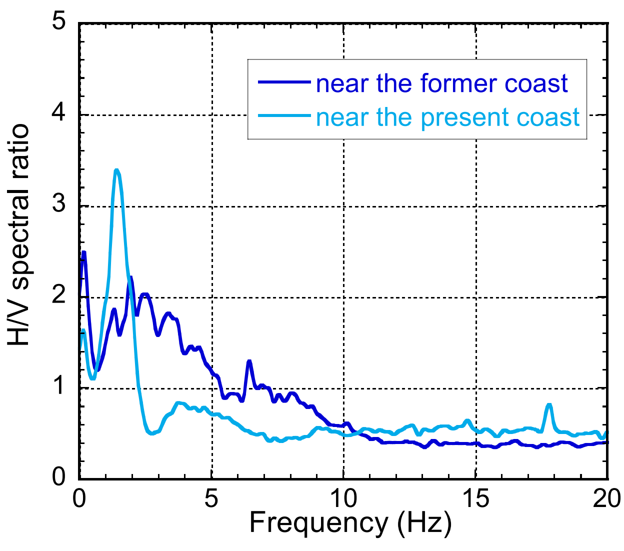

Figure 5 Typical H/V spectra in blocks E and F

4. COMPARISON WITH THE DEPTH OF THE ALLUVIUM BASE

4.1. The Process of Formation of Alluvium and the Former Coast Line

When the last glacial period was in its prime, the sea level is considered to have dropped down to as low as 140 meters below the present sea level. Thus, rivers at that time could have cut deep valleys in the area near the former coast line (before landfill), so it is likely that the landform at that time is buried underground. It is believed that there was no water in the area where Tokyo bay exists now, about 18,000 to 20,000 years ago when the last glacial period was in its prime. Since then the sea level gradually rose to the current level and alluvium continued to accumulate to form the coast line before landfill started about 100 years ago.

When considering the process of formation of the former (before landfill) coast line and the process of subsequent reclamation, it is most likely that alluvium that has accumulated since the last glacial period exists below the landfill layer and further below this alluvium exists a landform in the old times. Examination of borehole data is carried out to determine the distribution of the alluvium base in this study.

4.2. Construction of Soil Profile and Alluvium Base

The authors have collected about 800 borehole data in the target area. The distribution of their locations is plotted in Figure 6 and estimated soil profiles along the lines No. 2 and No. 5 shown in the figure are illustrated in Figures 7 and 8, respectively. In these figures, an engineering bedrock was chosen as a layer that has SPT *N*-values of over 50 consistently.

It is seen from Figures 7 and 8 that the soil of the reclaimed land in this area consists of fill of 2 to 10 meters near the ground surface, alluvium of 5 to 30 meters and finally a thick layer of diluvium. The depth of the engineering bedrock in this area lies between 10 and 40 meters. According to Figure 7, the alluvium base becomes gradually deep toward the present coast line from inland along the line No. 2. It can also be seen from the soil profile along the line No. 5 that the depth of alluvium greatly varies even at the similar distance from the former coast line. This may be resulted from the process of alluvium formation and may reflect an undulating landform at that time. Figure 9 shows a thus obtained contour map of the depth of the alluvium base. It is consistent with the previous map found in a literature (Kaizuka, 1993), indicating the existence of a buried valley.

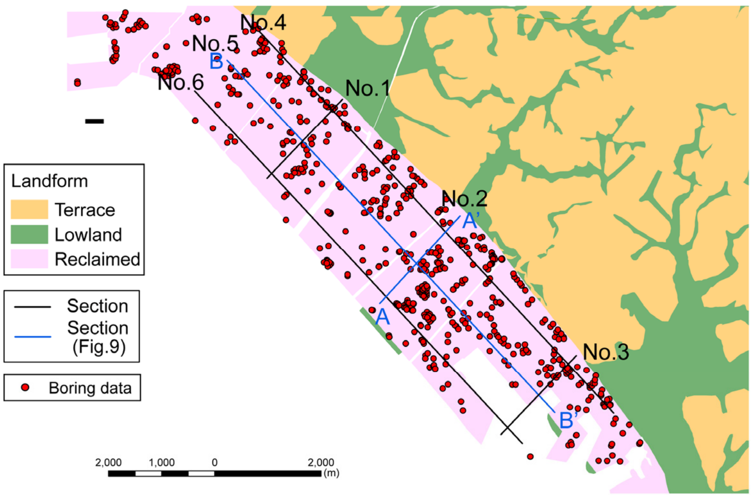

Figure 6 Borehole locations and soil profile lines

4.3. Comparison with the Distribution of Predominant Frequencies

Also plotted in Figure 9 is the distribution of microtremor observation locations and their predominant frequencies. It is obvious from this figure that deeper the depth of the alluvium base, lower the predominant frequency. There are, however, some exceptions especially in the blocks E and F.

5. ESTIMATION OF PREDOMINANT FREQUENCY BASED ON 1-D S-WAVE PROPAGATION THEORY

Based on the indication that the peak frequency of a H/V spectrum coincides with the predominant frequency of the surface soil, transfer functions of the ground due to one-dimensional S-wave propagation are examined. In the computation, the soil layering was determined based on the overall soil profile constructed in 4.2. and the undermost layer was set to the one with the S-wave velocity of over 400 m/s. Such layer is called an engineering bedrock in the practical design of buildings in Japan. It is noted that this engineering bedrock does not always correspond to the engineering bedrock found in Figures 7 and 8, in which it is defined based on SPT *N*-values. The S-wave velocity was estimated from the *N*-value and the depth by applying the regression expression proposed elsewhere (Nagata et al., 2008). The damping factor was assumed to be 0.02. Based on this, transfer functions between the engineering bedrock and the ground surface were computed, from which natural frequencies of the first order, predominant frequencies and maximum amplification factors were obtained. Here, predominant frequencies and maximum amplification factors are the ones found in the frequency range of 0 to 20 Hz.

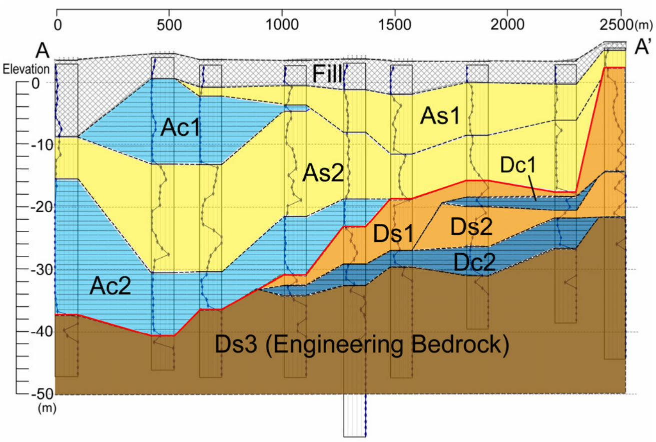

Figure 7 Soil profile along the line No.2

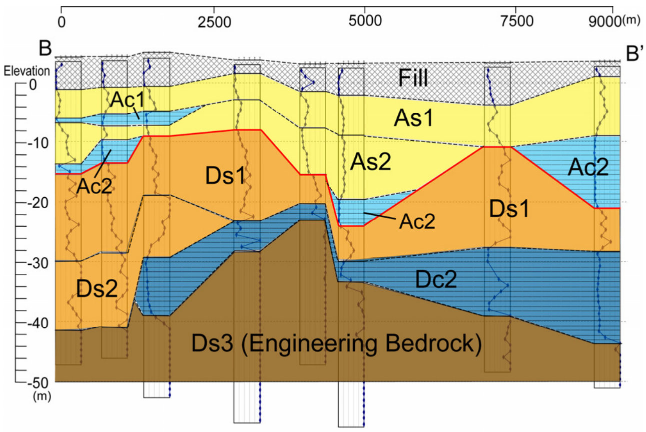

Figure 8 Soil profile along the line No. 5

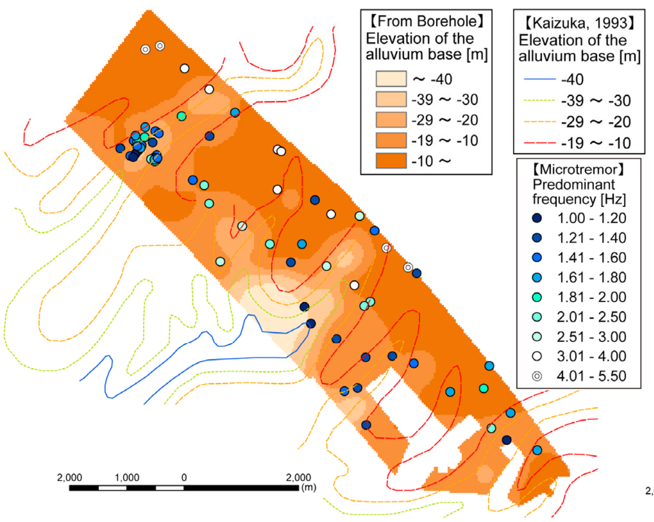

Figure 9 Depth of the alluvium base

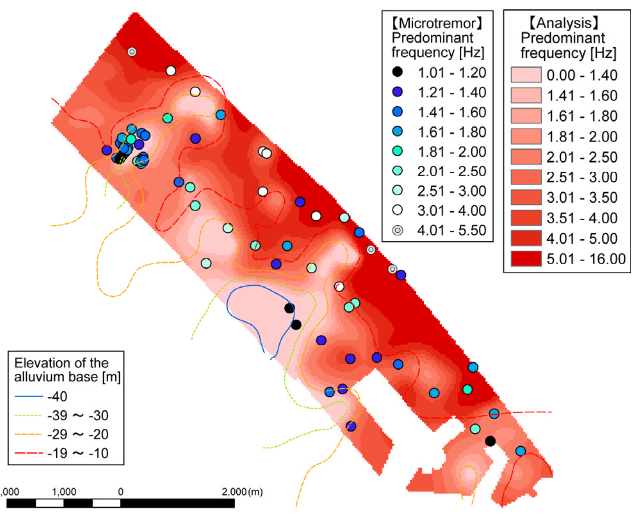

Figure 10 Depth of the engineering bedrock

Figure 10 compares the measured and computed predominant frequencies. Also plotted in the figure is the depth of the alluvium base which corresponds to the elevation of the alluvium base obtained from the borehole data as shown in Figure 9. From this figure, it is understood that the measured predominant frequency roughly corresponds to the computed one. By the fact that the computed value is based on the one-dimensional S-wave propagation theory and that the depth of the alluvium base does not always coincide with that of the engineering bedrock, it can be said that:

1) Predominant frequencies of the reclaimed land are approximately governed by the surface soil above the alluvium base.
2) However, in the case of a relatively small value of wave impedance ratio at its base, they are governed instead by the surface soil above the engineering bedrock defined as $V_S \geq 400\,\mathrm{m/s}$.

6. EFFECT OF BURIED VALLEYS ON THE DYNAMIC CHARACTERISTICS OF THE GROUND

In this section, an effect of the existence of buried valleys on the vibration characteristics is discussed in detail. As mentioned earlier, a buried valley is likely in the block B of the target area shown in Figure 2, where a series of microtremor measurements and two-dimensional finite element analyses have been performed by looking at a site of large commercial facilities located in this block.

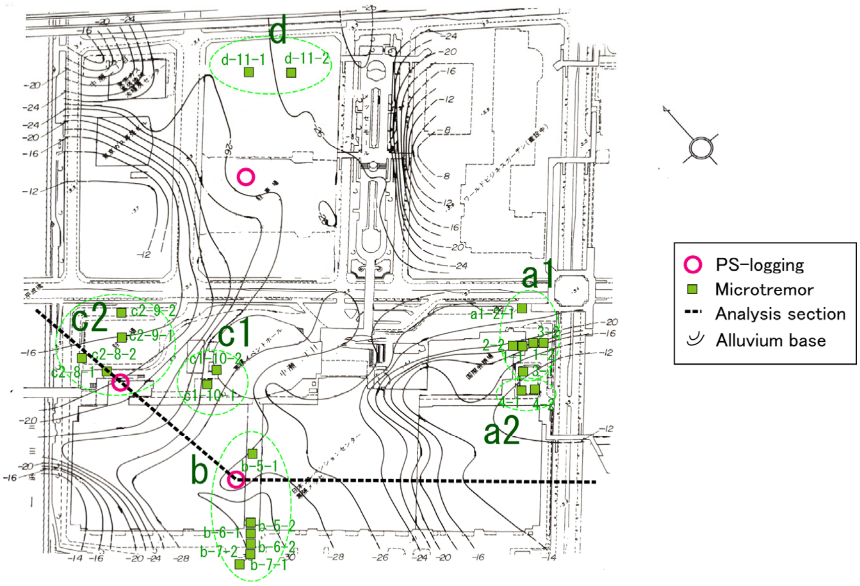

Figure 11 Target site for the investigation of a buried valley

6.1. Soil Profile of the Target Site

According to the subsurface investigation, the configuration of the soil profile is a little complex and a buried river valley is presumed, as shown in Figure 11. The soil layer of this site consists of fills, alluvial soils and diluvial sands. The fill has the thickness of about 7 meters. The thickness of alluvium is about 25 meters at the center of the buried valley and 10 meters at the shallowest. Alluvium in this site consists mostly of sands in the shallower depth but there exists a very soft clay at the bottom of the valley. Alluvium is underlain by a very dense diluvial sand. Its N-value reaches quickly over 50 at the center of the valley but it gradually increases in the area where the depth of alluvium is shallow.

6.2. Microtremor Measurements

Figure 12 shows the H/V spectra computed from microtremor measurement records. Measurements were conducted in a total of 22 locations in 6 areas, as shown in Figure 12. Although in the area **b** the spectrum does not have a remarkable peak due probably to traffic vibrations, in the area **d** it has a distinctive peak at the frequency of about 1.5 Hz and a relatively low peak near 4 Hz. These two areas are located in the central part of the buried valley. On its slope where the thickness of alluvium varies, **c1** with a gentle slope has a highest peak at the frequency similar to **d** but the first peak is not so clear. At **a1** with a steep slope there exists a sharp peak at 1.5 Hz with no other distinctive peaks. At **a2** and **c2** which are located in the slope with thick alluvium, the predominant frequency moves toward higher frequency.

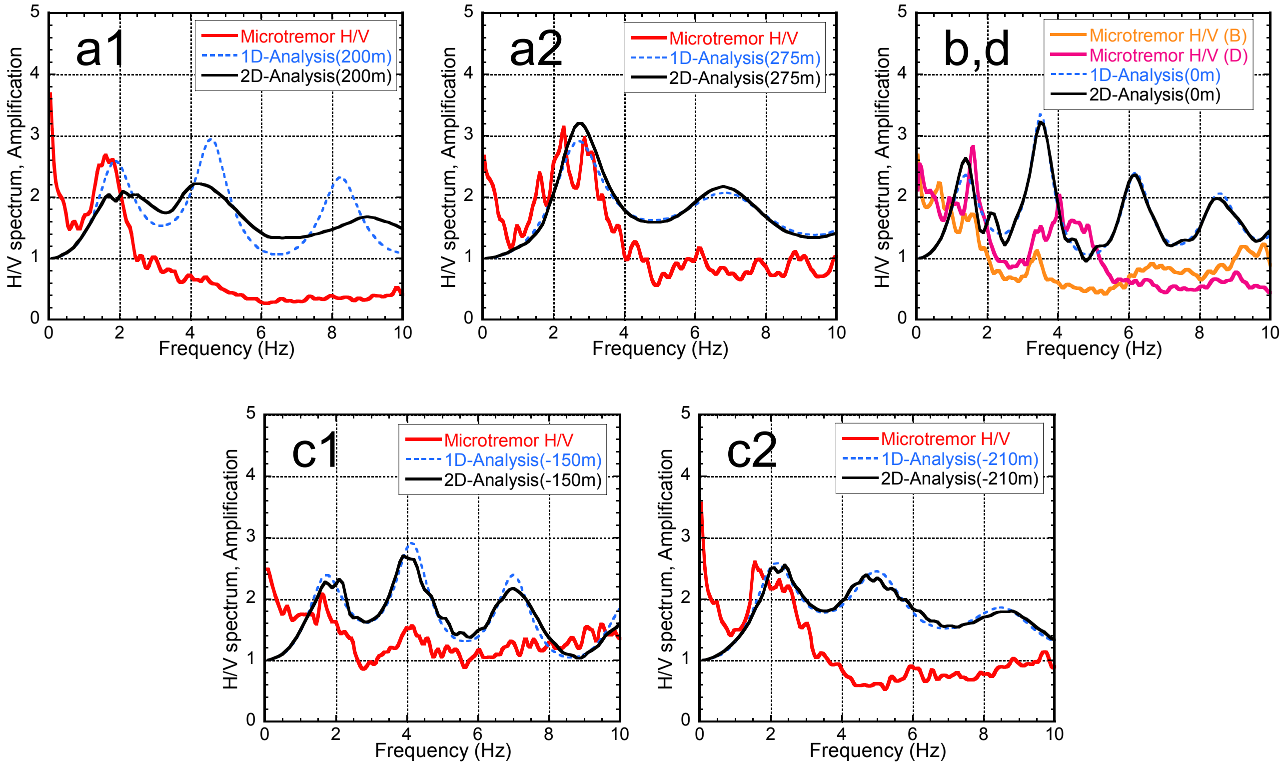

Figure 12 Comparison of predominant frequencies at various areas

6.3. Two-Dimensional Finite Element Analyses

Figure 13 shows a model for the two-dimensional finite element analysis that has been constructed along the line shown in Figure 11. The dynamic properties of the soil layers were determined from the two sets of borehole data located on the line. S-wave velocities were estimated from the average N-values and damping factors were assumed to be 0.02. Table 1 summarizes the dynamic properties used in the analysis. In addition to the two-dimensional analysis, a one-dimensional analysis was also carried out by assuming a horizontal layering at each evaluation point. Transfer functions between the bottom of the model and the ground surface were computed.

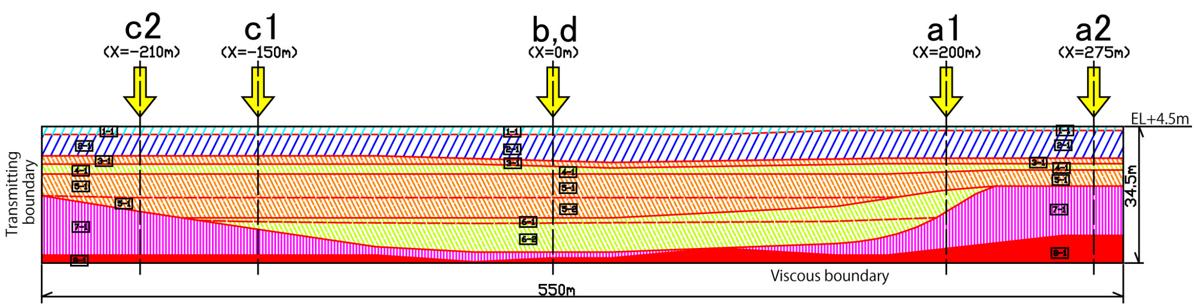

Figure 13 Model for 2-D finite element analysis

Figure 12 compares 2-D and 1-D transfer functions from the analysis and H/V spectra based on the microtremor measurement. It is seen that the two analyses give the transfer functions with a similar frequency dependency in that their natural frequencies are close to the predominant frequency of the H/V spectrum. If we look into detail, however, there are some differences among them. First, in the case of microtremor, the first peak around 2 Hz is the highest, while the second peak around 4 Hz is the highest in the case of analysis. As for the difference between the 1-D and 2-D analyses, at the bottom and near the slope of the valley, the 2-D analysis gives lower first peak and higher second peak compared to the 1-D analysis. The peaks tend to become higher in the 2-D analysis.

At **a1** where the soil structure irregularity is noticeable, the difference between the two analyses are significant, meaning that the slope of the boundary between the soft surface soil and the hard underlying bedrock affects the vibration characteristics of the ground.

Table 1 Dynamic properties of the analysis model

Layer	No.	S-wave velocity Vs (m/s)	Density ρ (t/m^3)	Poisson's ratio ν	Damping ratio h
Fs	1-1	100	1.60	0.495	0.02
Fc	2-1	105	1.60	0.498	0.02
	2-2	125	1.60	0.498	0.02
	2-3	130	1.60	0.498	0.02
As1	3-1	180	1.70	0.494	0.02
Ac1	4-1	150	1.70	0.494	0.02
As2	5-1	190	1.80	0.491	0.02
	5-2	200	1.80	0.491	0.02
Ac2	6-1	165	1.60	0.493	0.02
	6-2	170	1.60	0.493	0.02
Ds1	7-1	350	1.80	0.479	0.02
Ds2	8-1	390	1.80	0.479	0.02

7. CONCLUSIONS

In order to shed light on the fact that, although most of the reclaimed land along the coast has a completely flat landform, the dynamic characteristics vary a lot with location, a series of studies were conducted based on the microtremor measurement and the two dimensional finit element analysis. The following conclusions can be made through this study:

1) Microtremor measurement revealed that the variation of the depth of the soft surface soil is not as simple as the gradual increase in relation to the distance from the former coast line toward the present one.

2) The fairly complex locality of the vibration characteristics of the reclaimed land can be explained by the process of formation of alluvium and the former coast line before reclamation in this area.

3) At the locations where soil structure irregularity is noticeable, such as on a buried valley, the irregularity affects the vibration characteristics of the ground.

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