Investigation on Practical Use of H/V Spectral Ratio for Microzoning Considering the History of Landform

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SUMMARY:
The shaking characteristics, predominant period and amplification, due to surface soil structure are very important for damage estimation for buildings before the earthquake occurrence (Aki, K. 1957). Up to now, we are using microtremor observation in order to check the purpose of microtremor utilization for seismic microzoning study and we investigated the predominant period distribution by performing the dense microtremor observation in Yokohama City, Japan about 6,500 sites dividing 250m interval and analyzed H/V spectra at each site. And the result is significantly good agreement between the predominant period obtained from H/V spectra and the general information of surface soil structure. In this paper, we summarized the observed H/V spectra in Yokohama City and we investigated about the relationship between predominant period and depth of unconsolidated soil layer considering the history of landform development.

Keywords: H/V Spectral Ratio, Microzoning, History of Landform Development

1. INTRODUCTION

In recent years, disaster prediction studies for damages from earthquakes have been conducted on a prefectural scale. It is predicted that even more specific disaster prediction studies will be conducted on a village, town, or city scale in the future as well. Ground shaking characteristics have been reflected in earthquake proofing design using the response and limit strength design methods that have come into effect recently. Included in the background behind this type of research activity is realizing the importance of being able to obtain more detailed information on ground shaking characteristics that are attributable to ground structures (Matsuzawa T. et al. 2003, Yamamoto T. et al. 2004). It is particularly important to clarify ground shaking characteristics for subsurface ground layers, which are evaluated using a wide variety of methods, one of which is through observations of constant microtremors. The ground shaking characteristics, predominant period and amplification, due to surface soil structure are very important for damage estimation for buildings before the earthquake occurrence (Navarro M. 2004). These shaking characteristics, especially predominant period, are able to calculate by soil structure with shear wave velocity obtained from SPT information and PS logging Test (Enomoto T. 2000). A simple method for estimation of predominant period of surface soil structure is to use the H/V spectra based on microtremor measurement and it's very useful and popular in the world (Yamamoto T. 2007). Up to now, we are using microtremor observation in order to check the purpose of microtremor utilization for seismic microzoning study and we investigated the predominant period distribution by performing the dense microtremor observation in Yokohama City, Japan about 6,500 sites dividing 250m interval and analysed H/V spectra at each site. And the result is very significantly good agreement between the predominant period obtained from H/V spectra and the general information of surface soil structure. By the way, the deposit soil materials accumulated on engineering basement, namely bearing soil layer for buildings, are constituted the geographical settlement, hill, table land and low land, and the history of landform development is influenced by the change of sea water level due to glacial period according to the meteorological change of earth and also the influence of ascent and descent due to crust movement in the geological history. In this paper, we summarized the H/V spectra observed in Yokohama City and made a database of predominant period and landform classification, lowland and table land according to the history of landform development in Yokohama City shown in Figure 1 (Yokohama City 2003), and we performed the investigation about the relationship between predominant period and depth of unconsolidated soil layer.

We picked up and summarized the H/V spectral ratios of microtremors obtained in the Tamagawa, Tsurumigawa and Kanazawa lowlands and also Shimosueyoshi and Sagamino Table Land, respectively. The relationship between their predominant periods and the total thickness of the latest Pleistcene and Holocene deposits was explained by the equation Y=A*X+B. In this equation, X and Y mean the total thickness and the predominant period, respectively. The values of A and B as well as the correlation coefficients reflect historical development of landforms and soils. We have obtained the clear relationship under consideration of history of landform development and we would like to present the results in this paper. We think that this result brings us that more effective use of microtremor observations is possible for seismic microzoning.

2. INTERPRETATION OF H/V SPECTRAL RATIOS FOR MICROTREMORS

Considering observations that have been made herewith and using a logical approach, it is thought that ground specific predominant periods can be estimated using H/V spectral ratios based on Rayleigh wave characteristics in ground structures built on sedimentation layers that are particularly relatively soft where surface wave components of microtremors are dominant. As a result of these findings, observation of microtremors has been attracting attention as it allows ground shaking characteristics to be determined easily, with a number of research projects being conducted to further investigate these conditions. As discussed above, although it is expected that disaster prediction studies for damages from earthquakes will be conducted even on a village, town, or city scale, it can be seen from experience that ground characteristics can vary quite dramatically from point to point, even for locations separated by distances of only several tens of meters. As a result, it is imperative that high-density observations be conducted to obtain more accurate results.

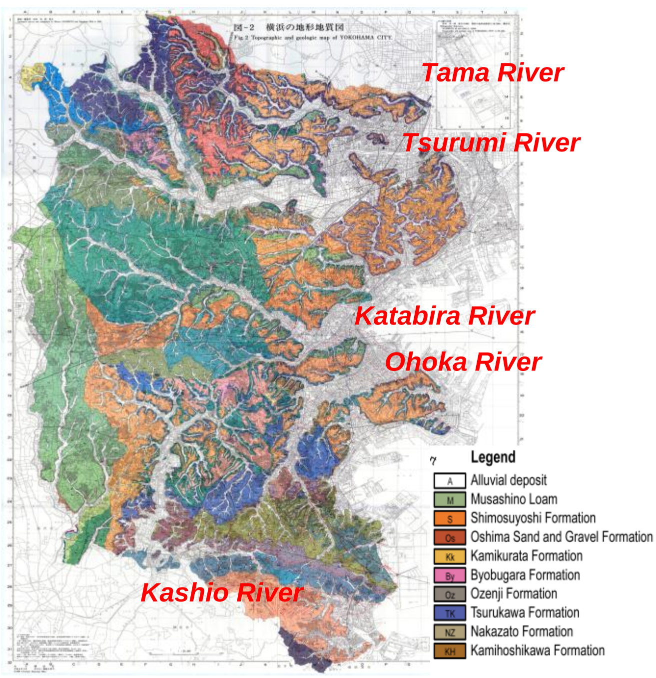

Figure 1 Geological and Geographical Map of Yokohama City

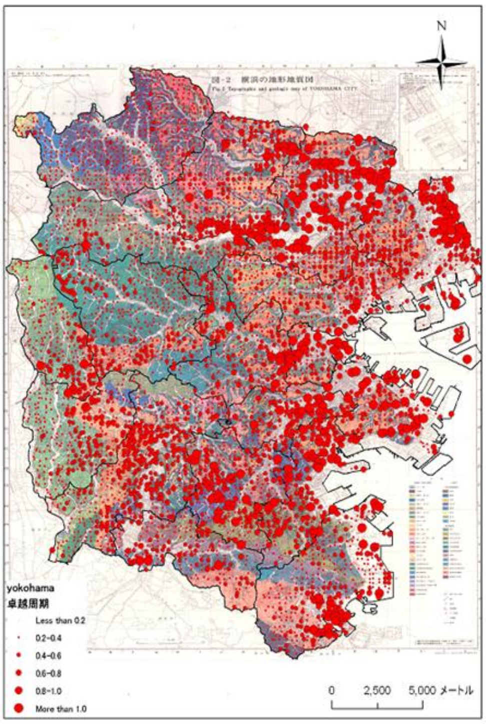

Figure 2 Distribution Map for Predominant Periods

3. OBSERVATIONS OF HIGH-DENSITY MICROTREMORS FROM STEADY MICROTREMORS

3.1 Observations of High-density Microtremors in Yokohama

The author began to conduct observations of high-density microtremors in Yokohama starting in 2005 with the purpose of clarifying details on ground shaking characteristics. Dividing the entire city of Yokohama up into sections defined using 250-m-wide meshes, the author observed approximately 6500 different points of those identified, not including those that were unobservable, near the center of each specified mesh. A servo speedometer was used to measure velocities, with the sampling frequency set to 100 Hz and the observation time to 180 seconds. Figure 2 shows a distribution map for predominant periods. The figure displays results for predominant periods corresponding to topography and geology as well as the ground for the city of Yokohama.

3.2 Relationship between H/V Spectra for Microtremors and Land/Ground Features

Geological classifications for different regions specified based on formation logs for topographical features are shown in Figure 3. Deposits on so-called engineering bedrock make up landforms such as hills, plateaus, and lowlands. The historical development of these landforms is greatly influenced by rises and falls in sea surface height due to climate change and accompanying glacial eustasy, as well as uplift and subsidence due to crustal movement. “In other words, ground conditions differ according to how the rivers that created the landforms responded to these external conditions.”
The author created a database for data from observations and analysis of constant microtremors for alluvial lowlands and plateaus in Yokohama, a city with complicated topography, and classified land features based on logs of when land features were formed in order to evaluate ground shaking characteristics in land features, with the evaluation being used to validate the correlativity between ground shaking characteristics and topographic effects.

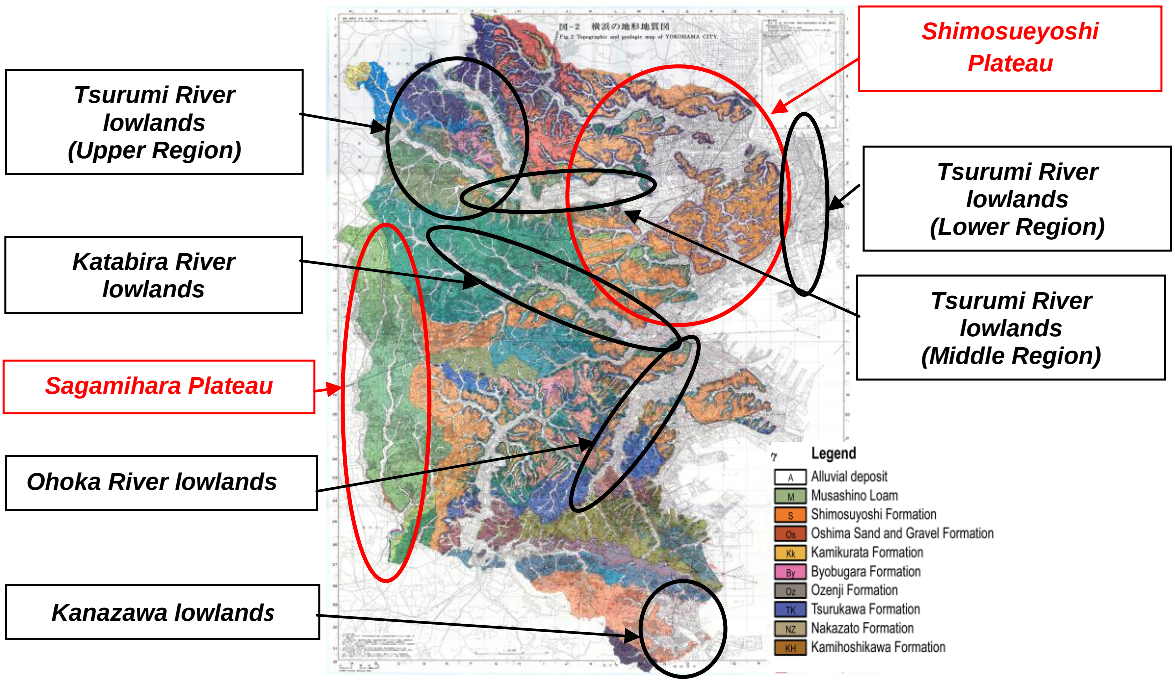

Figure 3 Geological Map of Yokohama Land Features

3.3 Types of H/V Spectra

As shown in Table 1, there are two broad types of H/V spectra, the first one used to classify spectra where there is only one clearly defined peak (Type 1, where predominant periods can be identified easily) and the other one used to classify spectra where there are two or more peaks (Type 2, which require predominant periods to be identified using specialized knowledge). The number of observation points used for each type is shown in Table 2. As listed in Table 2, there were 1670 observation points (approx. 26% of the total) from which the predominant periods could be determined easily, 4476 observation points (approx. 69% of the total) for which predominant periods could be estimated and determined using specialized knowledge (boring logs for specific points and surrounding areas, information on geological and topographical features, etc.), and 318 observation points (approx. 5% of the total) for which predominant periods could not be determined using H/V spectra.

Table 1 Types of H/V Spectra

	Type 1 Predominant period can be determined easily
	Type 2 Predominant period can be determined using specialized knowledge

Table 2 Relationship Between Topography Distribution and Number of Observation Points in Classified Types

Land Feature	Composition Layer	No. of points	No. of Type 1 points	Percentage
Hill Region 1	Tsuchiya/Tsuchihashi Loam Layer, Totsuka/Terao Layer Souda/Maioka Layer, Tsurumi/Maioka Layer	241	94	39%
Hill Region 2	Tama 2 Loam Layer, Oshinuma Sand Gravel Layer Sanodai Loam Layer, Kami-kurata Layer, Sanodai Sand Dune	704	203	29%
Hill Region 3	Byobugaura Layer, Naganuma Layer	227	21	9%
Hill Region 4	Kazusa Layer Group	1232	207	17%
Plateau 1	Tachikawa Loam Layer, Tachikawa gravel Layer	31	14	45%
Plateau 2	Upper/middle/lower sections of Musashino Loam Layer Nakadai Terrace Gravel Layer, Musashino Gravel Layer, Obaradai Sand Gravel Layer	581	196	34%
Plateau 3	Shimosueyoshi Loam Layer, Shimosueyoshi Layer	816	227	28%
Lowland	Lowlands	2314	708	31%
	Total	6146	1670	27%

3.4 Correspondence to Topographic Classifications

From comparisons of the distribution patterns for Type 1 and Type 2, it can be seen that Type 2 features are present locally in dominant regions whereas Type 1 features cannot be identified in dominant regions. The ratio of Type 1 observation points was calculated for land features in Yokohama, which were classified as hills, plateaus, or alluvial lowlands, and it was found that there was a relatively high rate of Type 1 observation points for Hill Region 1 and Plateau 1, but not, for example, for Hill Region 3, which had few Type 1 observation points compared to other hill regions.
The percentage of observation points in Yokohama for which the ground predominant periods could be identified easily using H/V spectra was almost 30%. Including the observation points for which the predominant periods could be determined using boring logs as well as geological information, topographical information and ground information for surrounding areas around observation points, predominant periods can be estimated for approximately 95% of all observation points, which demonstrates that observation of constant microtremors is an effective method to use to find ground predominant periods when used in conjunction with classification of regions.

4. APPROACH FROM HISTORICAL DEVELOPMENT OF LANDFORMS AND SOILS

4.1 Methodology

In recent estimations of earthquake damage, velocity and acceleration at the ground surface are found based on AVS30, which is the average S-wave velocity from the ground to 30 m below the ground surface. It is extremely costly to measure AVS30 densely with identical accuracy, and so it is corrected for altitude and distance to rivers, etc. but it is found for each accessible microrelief. However, there are serious disadvantages in determining AVS30 for each microrelief.
In seismic microzoning targeting the buildings that exist everywhere in cities, deposits on so-called engineering bedrock is the target on so-called engineering bedrock. These deposits make up landforms such as hills, plateaus, and lowlands. The historical development of these landforms is greatly influenced by rises and falls in sea surface height due to climate change and accompanying glacial eustasy, as well as uplift and subsidence due to crustal movement. In other words, ground conditions differ according to how the rivers that created the landforms responded to these external conditions. Specifically, the type of deposit and its distribution, or the distribution of the ground, is determined according to the sediment transportation ability of the respective river. Therefore, seismic microzoning must be performed for each plain formed by the respective river and, in terms of microrelief, it is unreasonable to treat areas in between different plains in the same way. Also, even within the same plain, the microrelief does not represent the deposits to 30 m below the ground. The microrelief is the topography forming the ground surface, and it only represents the final stage in the historical development of the landforms. It does not reflect the state of the ground (deposits) to 30 m below the surface.
The authors of this paper investigated the practical use of microtremors in seismic microzoning. Here, considering historical development of landforms, we show that more effective use of microtremor observations is possible and that microtremor observations are valuable data for seismic microzoning.

4.2 Alluvium thickness and predominant period

Unlike carrying out seismic observation by installing seismometers, it is possible to measure microtremors at any time in any place and so a large volume of spatially-close data can be obtained. Predominant periods of approximately 2 seconds and below, which are important in earthquake damage to the low- and medium-rise buildings common in cities, are considered to be dependent on the nature (primarily, lithofacies and hardness) and thickness of the deposits in the surface layer. Therefore, taking alluvium thickness as X (m) and predominant period of microtremor as Y (sec.), the two are related using the following regression equation:

$$X=A*Y+B \qquad (4.1)$$

A indicates the contribution ratio of each 1 m of alluvium to the predominant period and is inversely proportional to S-wave velocity of the alluvium. Also, if B=0, the average S-wave velocity of the alluvium is 4/A. B indicates the contribution to the predominant period of deposits lower than the alluvium.

Figure 4 shows a geological cross-section of the area downstream of the Tama River lowlands prepared using boring data measured during the construction of the Yokohama/Haneda route of the Metropolitan Expressway. The vertical lines show the locations of the borings and they are numbered. Some numbers are omitted because it would complicate the diagram if all of the data were entered. Also, it must be kept in mind that the horizontal and vertical scales differ, so gradients are emphasized. From number 74 (hereafter, the word "number" will be omitted) to 87, a sandy gravel layer with its top face at from -47 to -53 m forms the basal gravel of the alluvium. It appears that the bottom face reaches -60 m. This deep valley is named the Paleo-Tama River Valley. From 108 to 132 is a buried wave-cut platform formed during the Jomon Transgression. Here, the alluvium is thin and the Kazusa Group that forms the bedrock is thickly covered by the Middle/Late Pleistocene Series (called the intermediate layer). From Figure 4, the ground subject to seismic microzoning is divided into three; bedrock, intermediate layer, and alluvium.

Figure 5 shows a geological longitudinal section along the Paleo-Tama River Valley, and changes in the ground from the alluvial fan of the lowlands to the end of the delta can be seen. The Paleo-Tama River Valley was deeply eroded until the Last Glacial Maximum, so an intermediate layer is not distributed in this section. Figure 6 shows a geological cross-section of the Tsurumi River lowlands. Characteristics are that the mud layer is thick with a humic soil layer distributed close to the uppermost layer, and there is no intermediate layer. Figure 7 shows a geological longitudinal section of the Kanazawa lowlands, which is a small valley plain located at the southern end of the city of Yokohama. The bay entrance is blocked by a sandbar, and a mud layer is thickly distributed. The mud layer is divided into a lower continental layer and an upper marine layer, but there is no intermediate layer

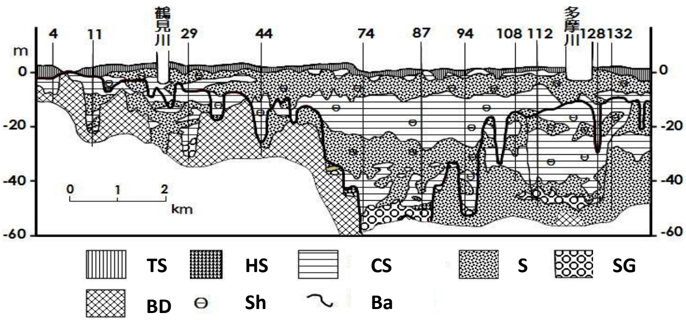

Figure 4 Geological cross-section downstream of Tama River lowlands

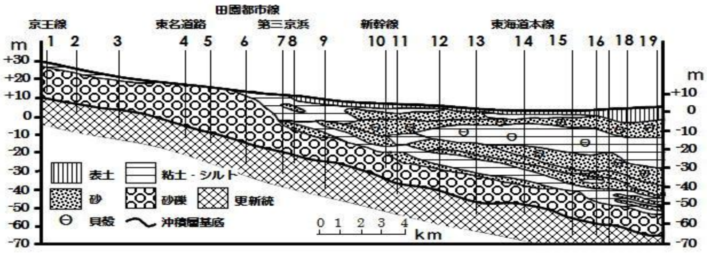

Figure 5 Geological longitudinal section along the Paleo-Tama River Valley

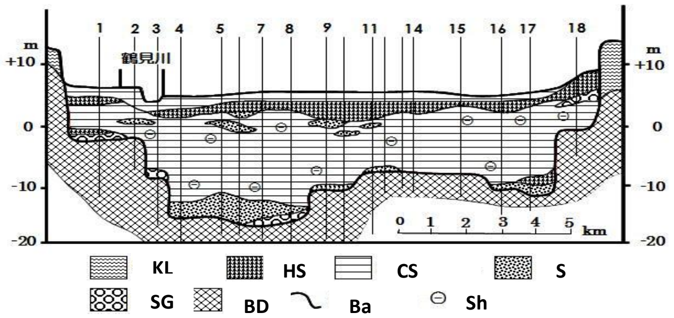

Figure 6 Geological cross-section of Tsurumi River lowlands

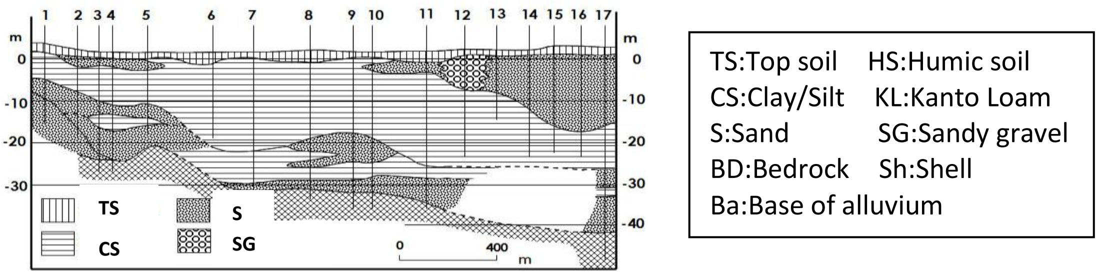

Figure 7 Geological longitudinal section of Kanazawa lowlands

Figure 8 shows the relationship between alluvium thickness and predominant period of microtremors observed in areas where the intermediate layer is thick on the left bank of the Paleo-Tama River Valley. The predominant period is taken to be the period at which the H/V spectral ratio reaches its greatest peak. Figures 9 and 10 show the same relationship obtained from above the Paleo-Tama River Valley, the Tsurumi River lowlands, where there is no intermediate layer. The linearly regressed equations and correlation coefficients (R) are as follows:

Tama River lowlands,
- With intermediate layer : Y=0.017X+0.543 R=0.62
- Without intermediate layer : Y=0.012X+0.190 R=0.86

Tsurumi River : Y=0.026X+0.209 R=0.75
Kanazawa lowlands : Y=0.021X+0.052 R=0.80

Figures 11 and 12 show the same results obtained from the Sagamino Plateau and Shimosueyoshi Plateau in the city of Yokohama in order to make a comparison with alluvial lowland. With regard to the Shimosueyoshi Plateau, which is a marine-built platform, the layer at which the N-value exceeds 50 is taken as the bedrock, and the relationship between the predominant period and thickness of the deposit (primarily, Shimosueyoshi Formation and Kanto Loam Formation) covering the bedrock is found. While with regard to the Sagamino Plateau, which is a fluvial terrace, the relationship between the predominant period and the thickness of the Kanto Loam Formation covering the terrace gravel is found. The results obtained are as follows:

Shimosueyoshi Plateau : Y=0.006X+0.244 R=0.56
Sagamino Plateau : Y=0.004X+0.232 R=0.34

In these figures, Figures 8 - 12, the thickness of the deposit is alluvium thickness in case of lowlands, and deposits up to N-value 50 in case of plateaus.

The above results are summarized in Figure 13. The following can be understood from Figure 13.

1) When there is no intermediate layer in lowlands, the correlation coefficient is high and the value of B is small. When there is an intermediate layer, the correlation coefficient is small and the value of B is large. The influence of the intermediate layer is obvious here.

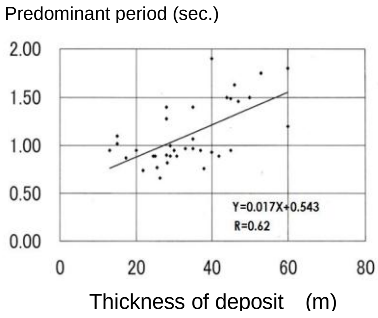

Figure 8 Tama River lowlands
(With intermediate layer)

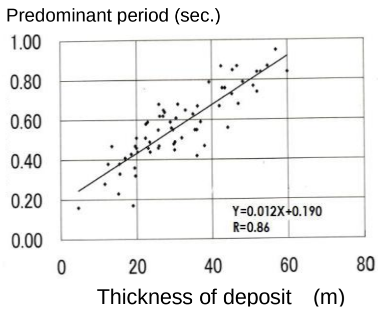

Figure 9 Tama River lowlands
(Without intermediate layer)

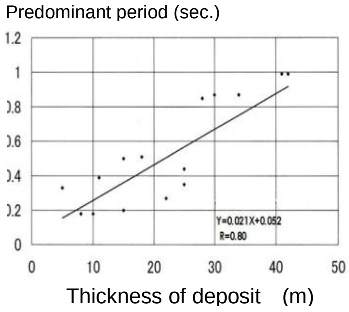

Figure 10 Kanazawa lowlands
(Without intermediate layer)

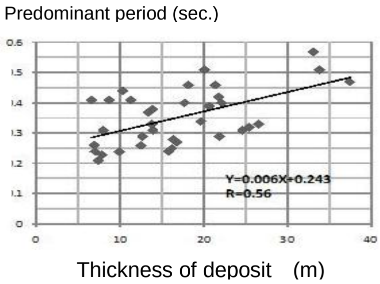

Figure 11 Shimosueyoshi
Plateau -marine terrace

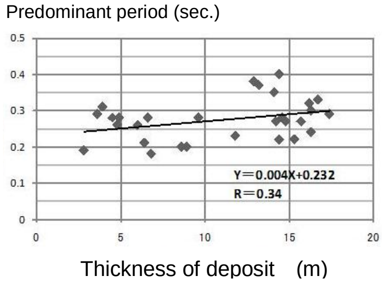

Figure 12 Sagamino Plateau
-fluvial terrace

2) The fact that the value of A in the Kanazawa lowlands and Tsurumi River lowlands is larger than in the Tama River lowlands indicates that the average S-wave velocity in the alluvium of the Kanazawa and Tsurumi River lowlands is slower than in the Tama River lowlands. In other words, the alluvium is soft.

3) The fact that the value of B in the Kanazawa lowlands is smaller than in the Tama River lowlands without an intermediate layer and smaller than in the Tsurumi River lowlands indicates that the predominant period is more dependent on the alluvium in the Kanazawa lowlands. In other words, in the Kanazawa lowlands, there is a large contrast between the bedrock and the alluvium. This result is consistent with the fact that the bedrock of the Kanazawa lowlands is made up of older deposits.

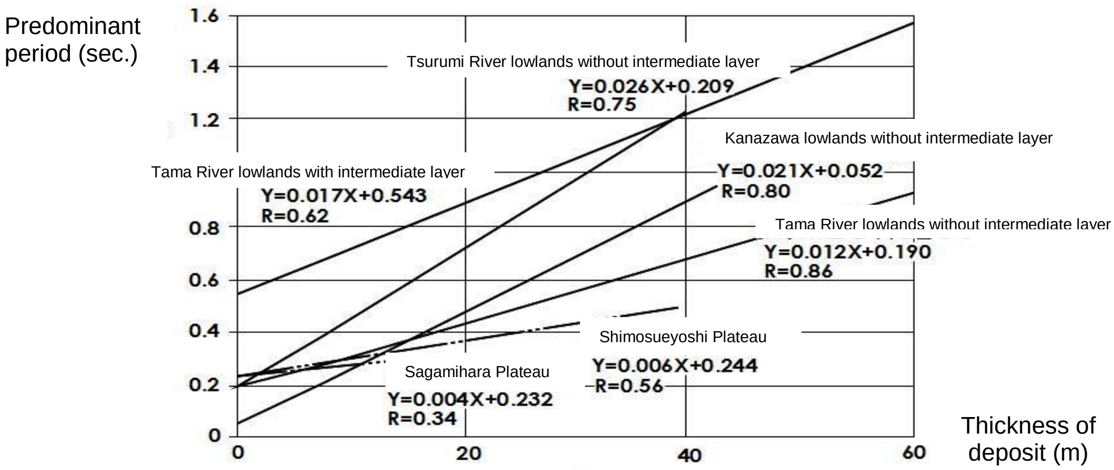

Figure 13 Relationship between predominant period and sedimentary layer thickness
(In case of lowlands, alluvium thickness; In case of plateaus, deposits up to N-value 50)

4) In the plateaus, the value of A is small. This is consistent with the fact that deposits in the surface layer of plateaus are more consolidated than in alluvial lowlands.
5) In the plateaus, the correlation coefficient is small. This shows that the deposits in the surface layer of the plateaus are non-uniform.

5. MODELING OF RELATIONSHIP BETWEEN PREDOMINANT PERIOD AND HISTORICAL DEVELOPMENT OF LANDFORMS

Although more data must be collected in the future because the number of examples is small, the results obtained from the previous section are used to model the relationship between predominant period and ground thickness as shown in Figure 14. The horizontal axis shows ground thickness (depth to bedrock) and not just thickness of alluvium. Also, ground thickness and ground composition layers are greatly influenced by the response of rivers to glacial eustasy as well as by whether the area is an uplift zone or a subsidence zone as a result of crustal movement. Therefore, Figures 15 - 17 show schematic diagrams of geographical cross-sections of lowlands and surrounding areas so that the state of the ground is easy to understand.

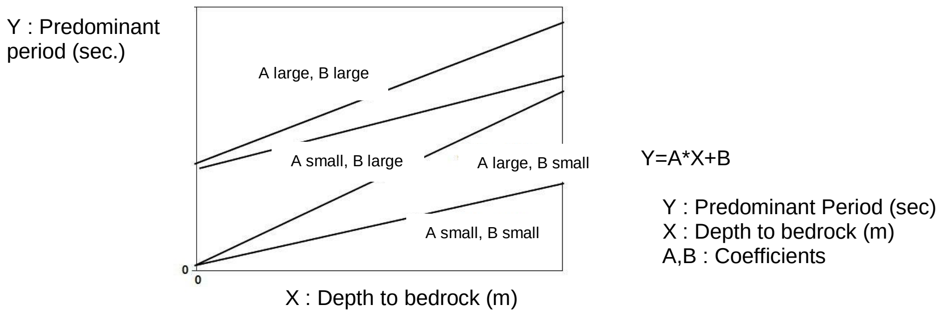

Figure 14 Schematic diagram of relationship between ground thickness and predominant period

1) A is large, B is small ;
The nature of the ground is reflected most effectively in microtremor data. The spectral ratio is large, the predominant period is clear, and the H/V spectrum is unimodal. The correlation coefficient is also large. A small valley plain in an uplift zone is typical, with no intermediate layer and a large contrast between the bedrock and the ground (Figure 16). The lowland downstream of a large river, if its in an uplift zone, is the same, but the contrast between the bedrock and the ground decreases and so the value of A decreases slightly.
2) A is small, B is also small :
The predominant period is clear and the H/V spectrum is unimodal, but the spectral ratio is small. The contrast between the bedrock and the ground is not large, but the composition of the ground is simple. Fluvial terraces with exposed terrace deposits and coastal terraces are typical examples, and sandy gravel-dominated alluvial fans and basins are also expected to be the same.
3) B is large ;
With the predominant period not very dependent on ground thickness, R becomes smaller. The composition of the ground is complicated, and it is made up of deposits of different hardness (S-wave velocity) and layer thickness. Also, the surface distribution of each deposit is uneven. It is expected that the H/V spectrum will be multimodal. Lowland in a subsidence zone (Figure 17) is typical, and this relationship can also be found in plains downstream of a large river where the amount of crustal movement is not large and the effects of glacial eustasy easily remain (Figures 4, 8). Also, in fluvial terraces and marine-built platforms composed of thick volcanic ash and deposits with different properties, the value of B becomes relatively large and R decreases (Figures 11, 12). If the entire ground is soft, the value of A increases; while if consolidation of the ground has progressed, the value of A decreases.

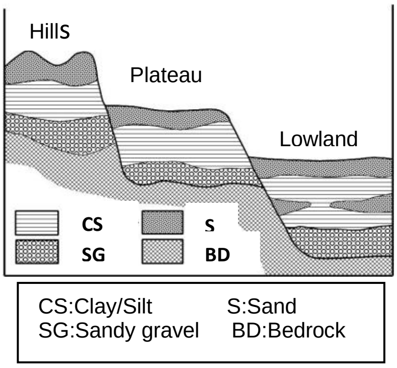

Figure 15 Geological cross-section along large river in uplift zone (schematic diagram). Example in which three glacio-eustatic cycles are recorded.

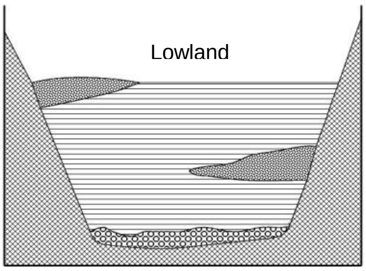

Figure 16 Geological cross-section of small valley bottom in uplift zone (schematic diagram). Example in which only deposits resulting from one glacio-eustatic cycle can be seen. Deposits are soft.

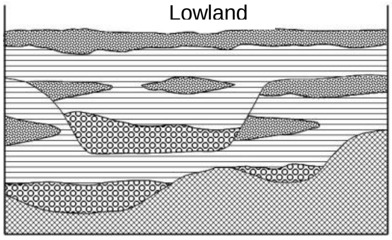

Figure 17 Geological cross-section of lowland downstream of large river in subsidence zone (schematic diagram). Example in which two glacio-eustatic cycles overlap.

6. CONCLUSION

The nature of the bedrock and ground is reflected in the predominant period of microtremors, and so analysis of the historical development of landforms and ground is essential in seismic microzoning. As an example, the zoning procedure shall be as follows: Landform classification maps will be created from field surveys and interpretation of aerial photographs, and if possible, geographical sections will be created by collecting boring data. Next, with reference to these maps and sections, the historical development of the landforms will be compiled. Based on these results, deposits will be classified, and units will be established for conducting area classification from their combinations. Furthermore, microtremors will be measured and area classification will be conducted by confirming consistency with distribution of predominant periods of the microtremors. Response calculations will be carried out for each area-classified unit, and seismic motion characteristics will be assigned to each zone.

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REFERENCES

Aki, K. (1957), "Space and time spectra of stationary stochastic wave, with special reference to microtremors", Bulletin of the Earthquake Research Institute, Vol. 35, Pages 415-456.
Enomoto, T., Kuriyama, T. Abeki, N. Iwatate, T. Navarro M. and Nagumo M., (2000). "Study on microtremor characteristics based on simultaneous measurements between basement and surface using borehole", Proceedings of 12WCEE, Paper No. 0918, 1-8.
Matsuzawa T. et al. (2003) "Investigation on Ground Shaking Characteristics in Northern Part of Ashigara Basin Using Boring Data and Microtremor Observation", Summaries of Technical Papers of Annual Convention (Tokai), Architectural Institute of Japan, p279-282.
Navarro, M., Vidal, F., Feriche, M., Enomoto, T., Sanchez, F.J. and Matsuda, I. (2004) "Expected ground RC building structures resonance phenomena in Granada city (southern Spain)", Proc. of the 13th World Conference on Earthquake Engineering, Vancouver, BC, Canada, 2004. Paper No. 3308.
Yamamoto T. et al. (2004) "Investigation on Ground Shaking Characteristics in Southern Part of Ashigara Basin Using Microtremor Observation, Part I/Part II", Annual Convention of Architectural Institute of Japan.
Yamamoto, T., Enomoto, T., Sugimoto, M., Navarro, M. and Rahimian, M. (2007) "Investigation on Applicability of H/V Spectrum Obtained from Microtremors to Seismic Microzoning Study", Proceedings, Ninth Canadian Conference on Earthquake Engineering, Paper No. 1238, 2007.
Yokohama City (2003), Geological and Geographical Map of Yokohama City, Institute for Environment of Yokohama City