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ASSESSMENT ON GROUND STRUCTURE AND GROUND SHAKING CHARACTERISTICS USING MICROTREMORS OBSERVATIONS IN THE WEST BELT, YOKOHAMA CITY

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ABSTRACT

We are advancing the fundamental investigation on ground structure and ground shaking characteristics using borehole data and microtremors observations in order to estimate the seismic motions. Microtremors observation is very simple and low cost method for evaluating the ground structure and ground shaking characteristics which is very important information for the estimation of dynamic response of ground and for the prediction of damage on structures. In this paper, we investigated the relationship between the surface ground structure obtained from borehole data and the ground shaking characteristics obtained from spectrum or H/V spectral ratio by microtremors observation at simultaneous borehole site in the area of west hill belt, Yokohama City.

Introduction

Earthquake disasters are greatly influenced by the quality of the soil conditions. This fact has been studied empirically since the Ansei-Edo Earthquake in 1855, in the historical context of earthquakes such as the Kanto Earthquake (September 1923). Also, with the occurrence of each recent earthquake disaster, such as the Southern Hyogo Prefecture Earthquake (January 1995), the Western Tottori Prefecture Earthquake (October 2000), the Geiyo Earthquake (March 2001), and the Niigata Prefecture Chuetsu Earthquake (October 2004), the importance of earthquake disaster prevention is recognized anew, measures are set on a national level with regard to earthquake prediction and disaster prevention, and a variety of research is carried out. The influence of the soil condition on the earthquake damages were experienced not only in Japan but also in the world, for examples, 1985 Michoacan Eq. (Mexico), 1989 Loma Prieta Eq. (USA), 1999 Kocaeli Eq. (Turkey), 2002 Mula Eq. (Spain) and 2003 Colima Eq. (Mexico) etc. (Singh, K., et al., 1989, Enomoto, T., et al., 2004, Navarro, M., et al., 2006). Since surface soil structure has a large influence on ground motion characteristics, it is essential to understand geographical and geological structures in detail. Most of the surface soil distributed across the Yokohama City area is assessed as sediment from the Mid- to Late Pleistocene Epoch (Sagami Group and younger terrace deposits) and the Holocene Epoch. This inconsistently covers the engineering bedrock which belongs to the Kazusa Group (Oka, S., 1991, Sugimoto, M., et al., 1996). The fold structure of the Kazusa Group develops sequentially from the north to the NNW Tokyo Semi-Dome, the NW Mizonokuchi syncline, the NNW Hoshikawa Dome and the NW Tomioka syncline, with a gentle angle of inclination. The thickness of the surface soil layer depends greatly on the fold structure of the engineering bedrock. Also, the surface soil characteristics are closely related to the Sagami Plain and the sedimentary basin caused by the Kanto basin-forming movement (Sugimoto, M., 1994, Mitsunashi, S., et al., 1993).

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For earthquake disaster prevention and damage reduction in a large city with this kind of complicated underground environment, the analysis and evaluation of surface soil structure is an essential task. However, it appears that even if the need for surveys is recognized, in many cases soil information is not acquired because of the large cost involved. Microtremor observations, which can be surveyed cheaply and easily, offer one means of solving this problem and attempts have been made to use them to estimate surface soil structure (Ohmachi, T., et al., 1994, Shirai, K., et al., 2002). Problems such as verification/evaluation of accuracy and reproducibility exist, and there is room for further research. As surface soil structure has strong regional characteristics, it is necessary to proceed with an adequate understanding of the subject area's soil (diverse soil formations exist in urban areas across Japan). We performed a geological survey/analysis using borehole data and microtremor observations at various locations in the Yokohama City area. Based on the results, we carried out fundamental research concerning the relationship between the geographical/geological structure and the characteristics (H/V spectral ratios, predominant periods) of the microtremor observations.

For this report, we took as our subject area the west belt area, for which there exists a relatively large amount of borehole data, and performed soil surveys (Sugimoto, M., ed., 2003) and microtremor observations. Using the characteristics of the microtremor spectra (Rodriguez, V.H.S., et al., 2003), we examined their relationship with the surface soil structure of the relevant areas and their usefulness in the evaluation of ground motion characteristics.

Summary of Geographical and Geological Conditions in the Survey Area

Yokohama City is located at the southern tip of the southern Kanto District, facing Tokyo Bay. It is composed of hills and plateaus, alluvial lowlands and reclaimed land, and is enclosed by the Tama River to the north and the Sagami River to the west. In terms of geographical classification, the extensive Musashino Plateau forms the area north of the Tama River, and the Sagamihara Plateau lies in the western Sagami River basin. In between the two, from eastern foot of the Kanto Mountains, the Tama Hills range eastwards and pass through the center of the city to join the Miura Hills. The plateau facing Tokyo Bay, on which Yokohama City stands, is lower than the Tama Hills, and the Shimosueyoshi Plateau, formed by the Shimosueyoshi transgression (a rise in sea level between 147,000 and 132,000 years ago), extends northwards. The plateau which develops westward from the Tama Hills corresponds to the eastern wing of the Sagamihara Plateau, and these form the hills and plateaus of Yokohama City.

The survey areas for this report are the Shimosueyoshi Plateau from the southern to the western side (70-60m), the Tama Hills (80-60m), and the Sagamihara Plateau (50-40m). Fig. 1 shows the topographic and geologic map of Yokohama City. Fig. 2 shows the bedrock depth (upper boundary of the Early Pleistocene Kazusa Group) in the southern Kanto District using iso-depth contours, and also the geography of the Tama Hills and the Shimosueyoshi Plateau in the middle of the map, the Musashino Plateau in the north-east, and the Sagamihara Plateau in the south-west. With regard to the shape of the upper boundary of the Kazusa Group (lower boundary of the Sagami Group), the central part of the sedimentary basin is in the vicinity of Imajuku in Hiratsuka City and it is settled deeply at approximately -320 ~ -300m. The surrounding depth contours are in the range of -200m around Chigasaki City, Samukawa-cho, Shimoiida-machi in Totsuka Ward, and Kanda-cho in Hiratsuka City; and -100m through Fujisawa City, Nakada-cho in Totsuka Ward, Ayase City, and Kaneme in Hiratsuka City. The area around Kamakura City, Kamiiida-machi in Totsuka Ward, Mitsukyo in Seya Ward, Tsuruma in Yamato City, Zama City, Tsumada in Atsugi City, and Kamikashiwaya in Isehara City is at sea level. From the Tama Hills (vicinity of Tama City) to the Shimosueyoshi Plateau (vicinity of Hodogaya Ward and Kanazawa Ward in Yokohama City) is a region of 100 ~ 40m above sea level. The height above sea level increases to over 100m in an area extending through the Miura Hills, around Yokosuka City and Zushi City, for example. From the vicinity of Totsuka-cho in Totsuka Ward of Yokohama City to the south-western Nakada-cho, Shimoiida-machi, Shonandai in Fujisawa City, and Samukawa-cho is a subsidence zone caused by a basin-forming movement, which takes the shape of deep valley bottoms. The sediment filling these valley bottoms consists of Mid- to Late Pleistocene (Sagami Group and younger terrace deposits) and Holocene sediment, which inconsistently covers the Kazusa Group bedrock.

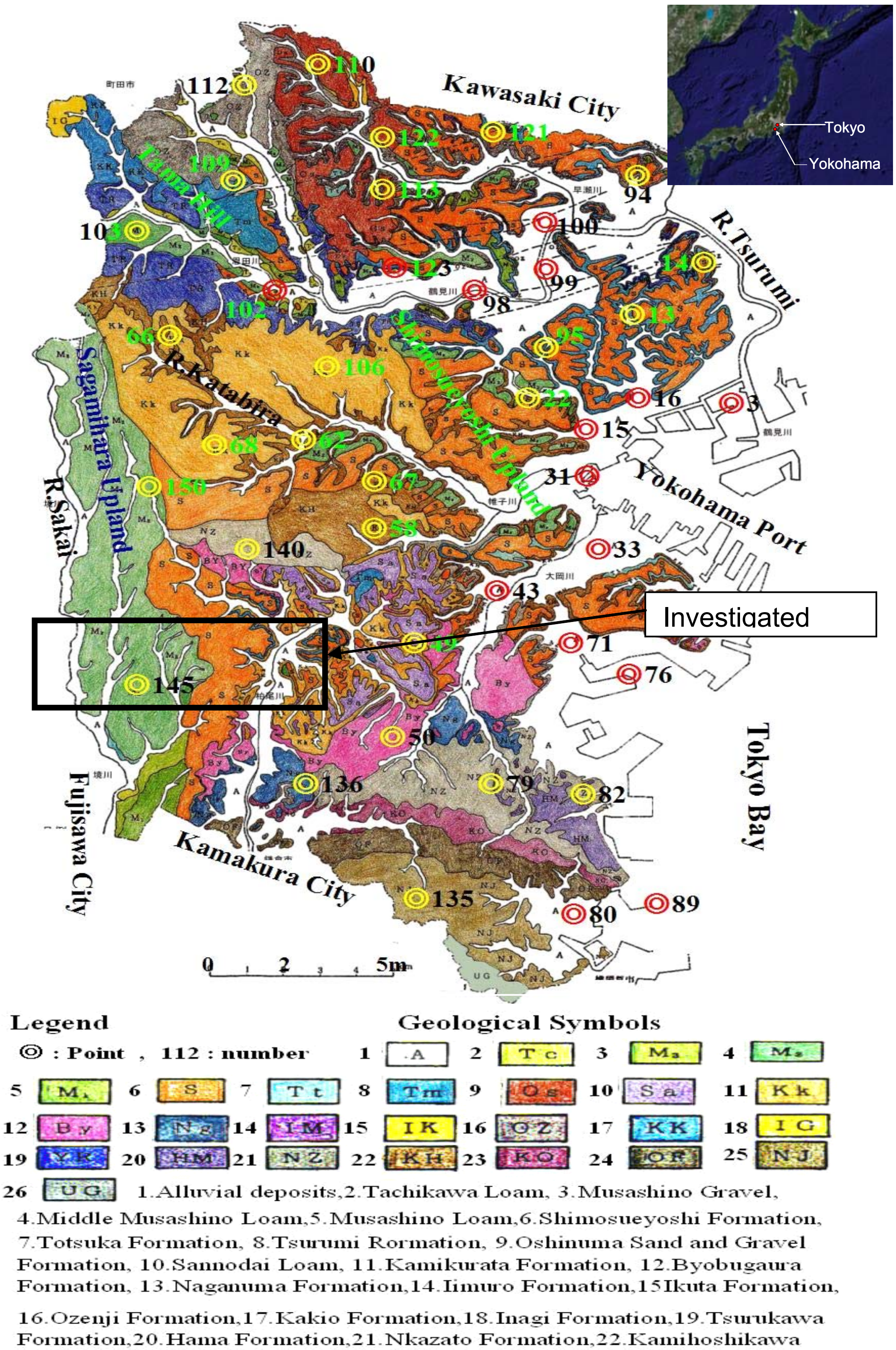

Figure 1. Topographic and geologic map of Yokohama City.

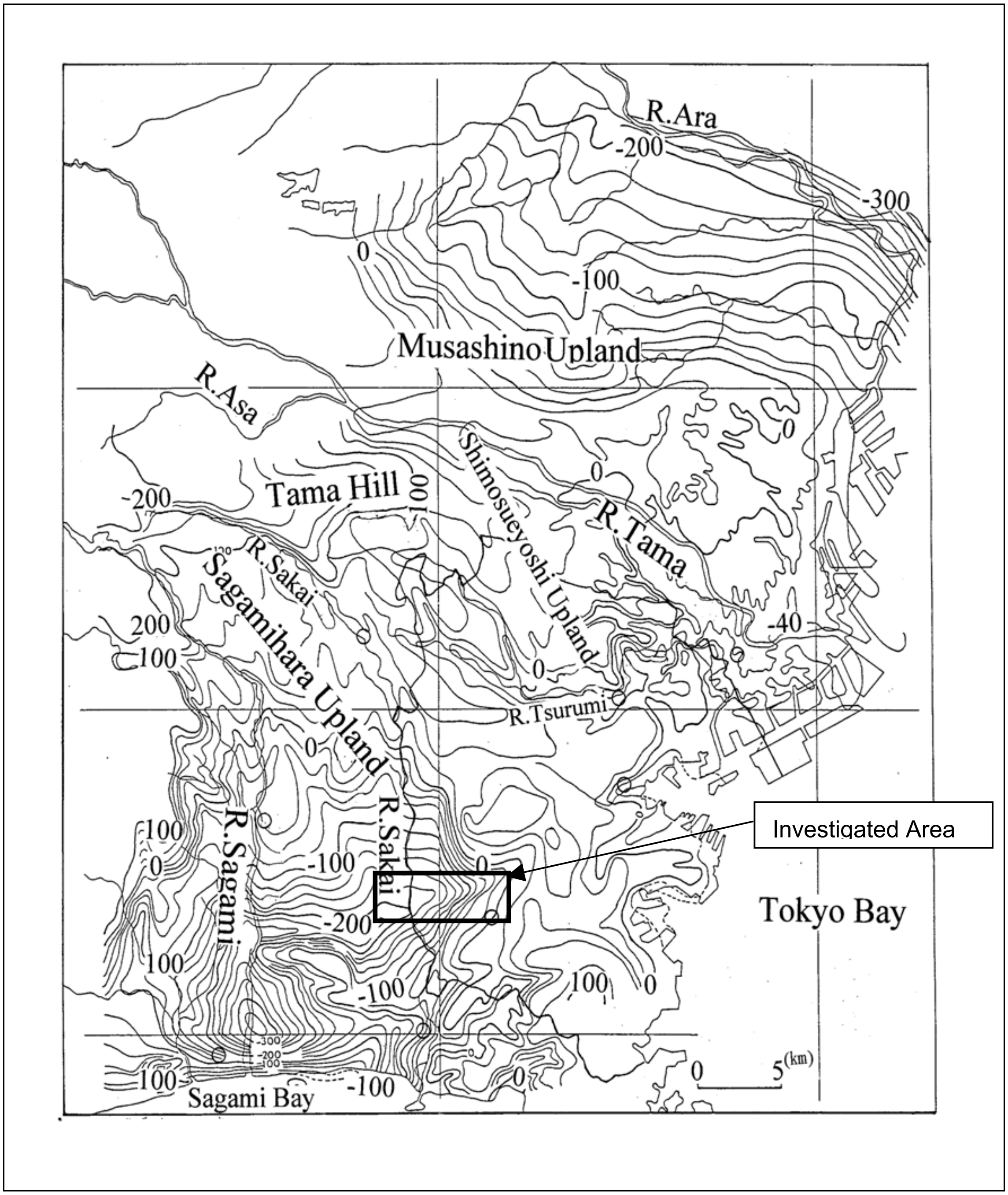

Figure 2. Equi-depth contour line of Engineering base-rock (Kazusa Group) and Geological map.

The sediment in the survey area is mainly Sagami Group, younger terrace deposits, and Holocene sediment. With regard to the stratigraphy of the survey area, the Kazusa Group bedrock is considered to be Nakazato Formation and the Sagami Group which covers this consists of sediment including Naganuma Formation, Byobugaura Formation, Kamikurata Formation, Totsuka Formation, Soda Formation, Tsuchiya Formation, Shimosueyoshi Formation, and Sagamino Gravel Formation.

The uppermost layer is covered by Shimosueyoshi Loam Formation and Musashino Loam Formation (1991).

Soil Survey, Microtremors Observation Method and Spectrum Analysis

Preparation of Soil Map

Borehole data was collected for the survey area and point locations were entered on a 1/10,000 city map. With reference to geological reports showing columnar sections, standard penetration tests (N values), existing geological map data (2003), and so on, a survey site location map and a geological profile were drawn up.

Microtremors Observation and Spectrum Analysis

Microtremors observations were carried out at 53 locations in the vicinity of borehole survey sites. Fig. 3 and Fig. 4 show the observation sites. Microtremors were observed using a servo-type vibrometer (SPC51K). The sensor was set up on a road surface and a total of 3 components - horizontal movement in 2 directions (NS/EW components) and vertical movement in 1 direction (UD component) - were observed at each observation point for 180 seconds (100Hz sampling). From the observed waveform, an amplitude spectrum was found for each 20.48 sec. window, smoothing was performed using the Parzen's Window of bandwidth 0.3 Hz, and a 180 seconds-long mean spectrum was found. Further, the geometric mean of the 2 horizontal components (H) was divided by the vertical component (V) to find the H/V spectrum and, taking the 3 components' spectra into account, the final predominant period (s) was read.

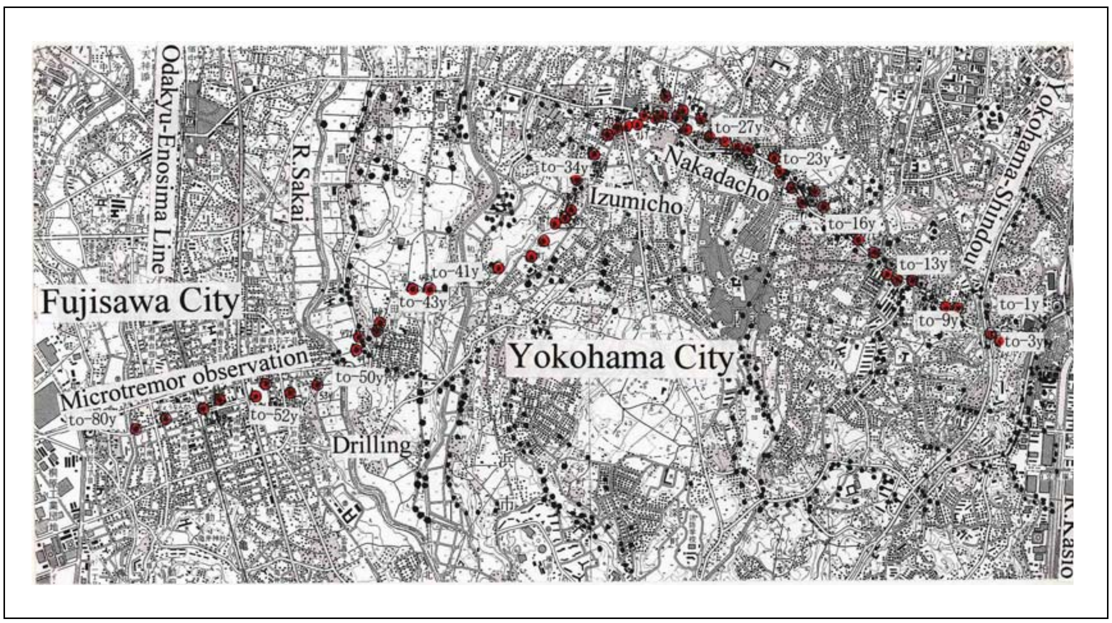

Figure 3. Comparison distribution map of microtrimors and location of drilling in the west belt,Yokohama City.

Survey Results and Observations

Soil Structure Characteristics

Fig. 3 shows the survey site location map, Fig. 4 shows the geological profile. On the east side is a congested area containing Japan Railway and Underground's Totsuka Station, National Route 1, and the Yokohama Shindo (Yokohama Bypass). The west side extends to Shonandai Station on the Odakyu and Enoshima lines in the area of Fujisawa City. From the columnar sections, the sediment is assumed to be Sagami Group with the main strata considered to include Kamikurata Formation, Totsuka Formation, Shimosueyoshi Formation, Sagamino Gravel Formation, Shimosueyoshi Loam Formation, and Musashino Loam Formation. The borehole surveys were stopped at an N value over 50; therefore the columnar sections end at the Sagamino Gravel Formation and strata below this level could not be investigated. Existing data leads us to believe that Sagami Group Byobugaura Formation is deposited. Below this, the strata and thickness are unidentified, but the bedrock is believed to be Kazusa Group.

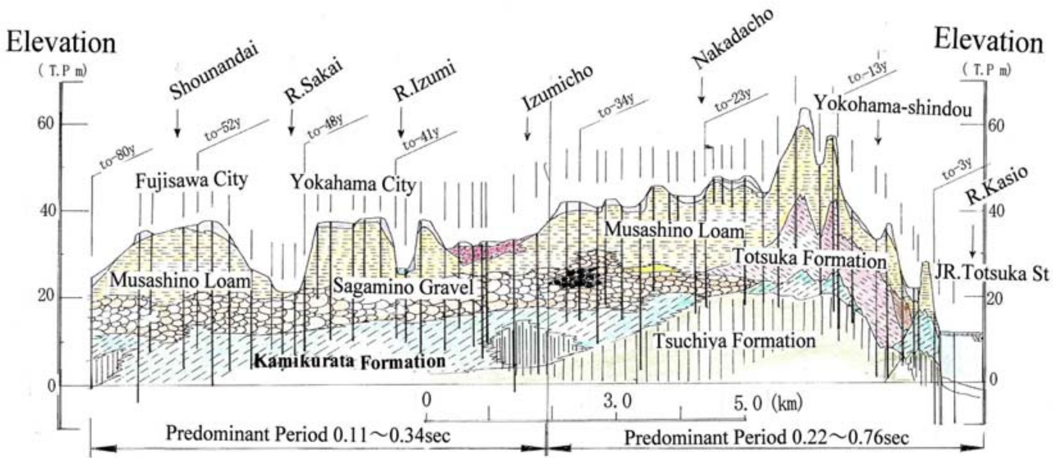

Figure 4. Geologic cross-section across.

The stratigraphy of the entire cross-section shows deposits of Kamikurata Formation, Totsuka Formation, and Musashino Loam Formation (for convenience, referred to here as Totsuka multi-layer soil) from the eastern-most Kashiogawa Lowlands (vicinity of JR Totsuka Station) to an area approximately 2km north-west. Further west, there are deposits of Kamikurata Formation, Sagamino Gravel Formation, and Musashino Loam Formation (referred to as loam single-layer soil), and a difference can be recognized in the sedimentary environment. Namely, it is thought that in this vicinity the old Sagami River approached closest to the edge of Tokyo Bay, and this corresponds to the boundary which shapes the Sagamino Gravel Formation. The thickness of the gravel layer is approximately 10-15m, and it accumulates an abundance of underground water. The thickness of the loam layer is approximately 15-20m, and there are no deposits of soft clay in the alluvium.

Comparing average N values of columnar sections, the Sagamino Gravel Formation is over 50, the lower clay layer is approximately 12-48, the middle clay layer is approximately 2-35, and the loam layer is in the range of 1-15.

H/V Spectra and Predominant Periods

Notable examples of H/V spectrum and predominant period calculation results are shown in Fig. 5 (see to-4ly, to-52y, to-23y, to-13y in Fig. 3 and Fig. 4 for observation sites). The site of to-41y (0.11s) is alluvial lowland; to-52y (0.26s) consists of a gravel layer covered with a thick loam layer; to-23y (0.76s) is near the border of the strata where the gravel layer becomes thin; to-13y (0.50s) is in an area with a high volume of traffic consisting of thick clay and loam layers with no gravel layer deposits. The respective results show the soil characteristics and the distinctive local features. In this trend, the respective distinctive features for all of the observation sites were revealed, with the exception of one part. All the predominant periods are within the range of 0.11-0.76 seconds, but an average of approximately 0.2-0.3 seconds is frequently seen. In places where the loam layer is thick, 0.3-0.5 seconds is common. A disparity in the predominant periods is found when comparing the loam single-layer soil and the Totsuka multi-layer soil; the former’s predominant period is approximately 0.11-0.34 seconds (average 0.25s), while the latter’s is approximately 0.22-0.76 seconds (average 0.46s). Namely, a relatively long

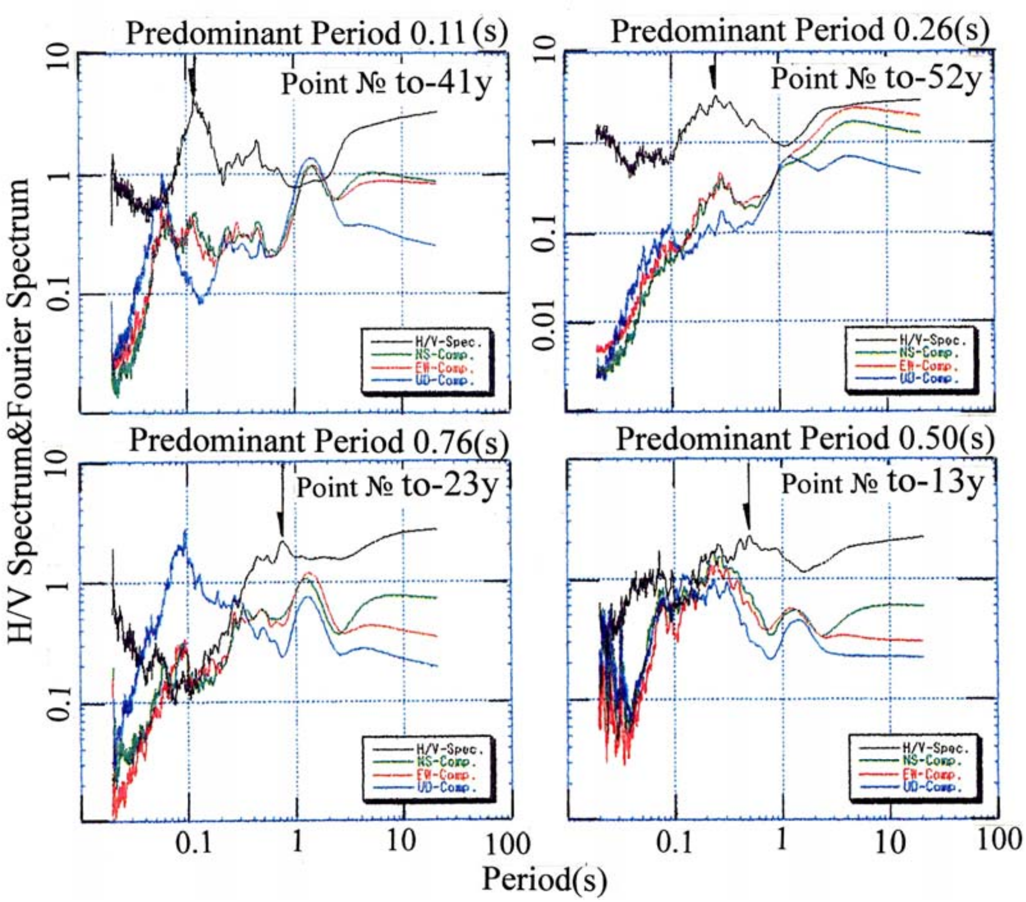

Figure 5. H/V spectrum ratio superposition.

predominant period is found in the Totsuka multi-layer soil, while the predominant period of the loam single-layer soil is relatively short. In the loam single-layer soil, a thick gravel layer with N value over 50 is deposited beneath the loam layer; the Totsuka multi-layer soil is characterized by no gravel layer deposits.

Soil Classification Determined by Microtremors Observations

The soil was classified according to the characteristics of the H/V spectra and predominant periods found using the microtremors observations, with reference to factors such as the geographical/geological features, stratigraphy, bedrock depth, and engineering qualities of the soil.
Fig. 6(a) and 6(b) compare the predominant period characteristics of the microtremors data with approximately 38-55m thick Holocene sediment (commonly called alluvium). (a) and (b) are similar and the soil contrast is clearly shown. This means that it is possible to understand the soil characteristics, such as that the sediment covering the bedrock is a relatively uniform soft clay layer.
Fig. 6(d) and 6(e) are the results of microtremors observations in locations where the total thickness of the surface soil (Mid-to Late Pleistocene Sagami Group and younger terrace deposit layer, younger loam layer) is approximately 19-38m. Compared to Fig. 6 (a) and (b), the soil contrast is slightly unclear in places, but it is possible to identify rough predominant period peak values.

However, in places where Formations from very different sedimentary environments are deposited, totally unclear soil contrasts are often found. Research needs to be done into the cause for this. Fig. 6 (c) and (f) show data observed in places where the strata covering the Kazusa Group is top soil, embankment, or

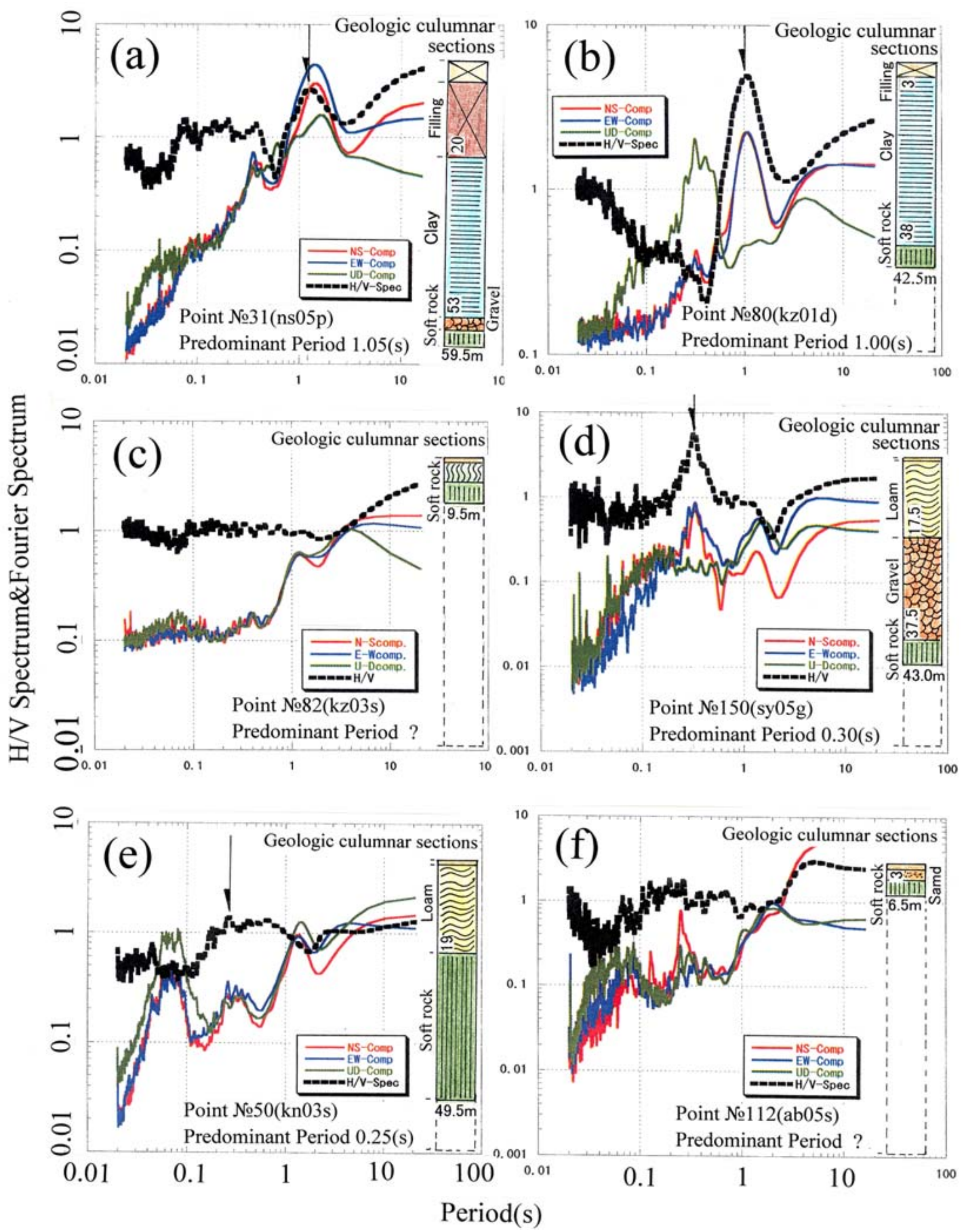

Figure 6. H/V spectrum ratio Superposition.

pavement. For this kind of soil, the contrast is unclear at all locations. Paradoxically, when this kind of data is obtained the bedrock can be considered to be thin at that location.

In light of the features of the above 3 cases, the soil can be classified into the following patterns with relation to microtremors observations; (1) "single-layer soil" in which a single clay or loam layer covers the bedrock; (2) "multi-layer soil" in which the sediment form is repeated and complex, and each Formation covers the bedrock; (3) "engineering bedrock" which is Kazusa Group.

Conclusions

The relationship between soil structure and ground motion characteristics in the west belt, Yokohama City, was examined by preparing a soil map and observing microtremors. As a result, the following information was obtained:

(1) Differences were found in H/V spectra and predominant periods according to the type of sediment. There appears to be correspondence between sediment type and microtremor characteristics, and the microtremor observation method is considered useful in investigating surface soil structure.

(2) Strata on the JR Totsuka Station side were found to have relatively long predominant periods of approximately 0.40-0.76 seconds.

(3) Strata near Sakai River and Fujisawa City show predominant periods in the range of approximately 0.11-0.34 seconds. This is thought to be due to the Sagamino Gravel Formation deposited beneath the loam layer and, in comparison to (2), the strata display local differences forming the soil.

It was shown that soil can be classified in relation to microtremor observations as; (1) “single-layer soil” in which a single clay or loam layer covers the bedrock; (2) “multi-layer soil” in which the sediment form is repeated and complex, and each Formation covers the bedrock; (3) “engineering bedrock” which is Kazusa Group.

In the future, we would like to further expand the survey range and advance our investigation of surface soil structure using microtremors observations.

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