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Estimation on Surface Soil Structure for Seismic Disaster Mitigation By Microtremor Miniature Array Observation Method in Yokohama, Japan

T. Enomoto[(1)], Ma He[(2)], T. Ochiai[(3)], M. Navarro[(4)], S. Senna[(5)]

[(1)] *Professor, Kanagawa University, Japan, enomot01@kanagawa-u.ac.jp*
[(2)]*Lecture, Hebei University of Science and Technology, China, r201670156bi@jindai.jp*
[(3)]*Research Associate, Kanagawa University, Japan, ochiai@kanagawa-u.ac.jp*
[(4)]*Professor, University of Almería, Spain, mnavarro@ual.es*
[(5)]*National Research Institute for Earth Science and Disaster Resilience (NIED), Japan, senna@bosai.go.jp*

Abstract

Recently, many research works related to the surface ground structure is took palace for earthquake disaster mitigation, for example, by using geological and geographical information in the area and bore hole data. In this study, we aimed to estimate the overall surface shallow ground structure of Yokohama City using microtremor array observation which expects the ground depth is around 50 to 100m with 1kmx1km grid. So that we can investigate the ground safety of earthquakes in various parts of Yokohama City in order to consider seismic disaster mitigation.

Yokohama City, Japan, is located in the eastern part of Kanagawa Prefecture, east to Tokyo Bay, and is an important foreign trade hub city in Japan. Also, it has a large population. Yokohama City is just located on the tectonic plate boundary between the Philippines Sea Plate and the North American Plate. This plate boundary is called Sagami Trough and is located in Sagami Bay in the southern part of Kanagawa Prefecture. The 1923 Great Kanto Earthquake (Mj7.9) was occurred on this plate boundary sub-ducting from Sagami Trough, causing a particularly large loss to Kanagawa Prefecture and Yokohama City. In the topography of Yokohama City, the hilly land and the plateau occupy about 70% of the whole city area, the remaining 30% are formed by alluvial lowland along the river and landfill in the coastal area. The Tsurumi River, the Ohooka River, the Katabira River and Sakai River flowing down from the western part where the hilly land continues. On the other hand, according to the urban development in Yokohama City, the land has been expanded by landfill, we also believe that it is necessary to confirm changes in the surface ground. There were very clear evidence that the very sever damages were mainly occurred at the alluvial lowland area. As a mechanism of plate boundary earthquake, next big earthquake will be predicted in same area near future. So, we think that it's very important to understand the most surface shallow ground structure. So, we measured the microtremors with miniature array observation method at the hole city area dividing about 1km x 1 km interval, according to SIP national project.

Before doing microtremor miniature array observation, we performed classifying soil type according to micro-landform and evaluated amplification of surface soil dividing small grid in order to understand surface soil characteristics. And we also performed single microtremor observation at about 6,500 sites in Yokohama City and calculated H/V spectra in order to obtain predominant period and amplification due to surface soil at each site. The result of comparison between soil classification and predominant period obtained from H/V spectra were good agreement with each other at many sites. But we don't have any detailed information about soil structure as like as s-wave velocity value of surface soil or AVS30 values at each site. So, we estimate surface soil structure by using microtremor miniature array method at about 200 sites. According to observed and analyzed result, we could understand surface soil structure with s-wave velocity and nice agreement with former investigated results with soil classification and predominant period. Especially, we understood soft soil deposit at hilly zones where are widely distributed in Yokohama city.

Keywords: Microtremor Observation, Miniature Array Observation, Surface Soil Structure, Yokohama

1. Introduction

It's very important to know soil conditions in order to predict seismic damage for human losses due to structural damage generated by ground shaking intensity in cases of earthquake event. In Japan, many local governments develop seismic damage predictions due to the possible seismic faults related to the areas covered by its governmental responsibility. In this case, the soil conditions are estimated by geotechnical data such as borehole data and geological maps, as well as the geographical maps scaled at 1:50,000 published by the Geospatial Information Authority of Japan. These data are very effective and useful for seismic disaster prevention in relatively wide areas on the scale of a city. These however use the static soil characteristics and do not take dynamic characteristics such as predominant period and amplification of soil into consideration in the seismic damage evaluation process. We think that it's also very important to know the dynamic characteristics of the soil condition, and so we would like to develop the high density microtremor observation and to know the predominant period and amplification of soil conditions. From past observations and applying a theoretical approach, it is presumed that surface wave components are dominant in microtremors, and that, especially in a ground structure in which relatively soft sedimentary layers are present, an H/V spectral ratio based on the features of the Rayleigh wave can be considered usable in estimating the predominant periods unique to the target ground. As for the method of ascertaining ground motion characteristics, soil boring, which can provide accurate data on the subsurface structure of the target area, is ideal, but is time-consuming and expensive. Therefore, microtremor observation, a simple method of identifying ground motion characteristics, has gained a great deal of attention and many studies have been carried out using this method (Example, Nakamura [1], Ohmachi et al. [2], Maruyama et al. [3], Motoki et al. [4]). Among the 50 major cities of the world, the Tokyo and Yokohama region, which includes many industrial zones, has a much higher risk index than cities in other countries according to "A Risk Index for Megacities," and is projected to suffer major damage if struck by earthquakes in particular [5]. In Europe, many hazard maps use ground characteristics like Navarro et al. [6], Benito et al. [7], Gaspar-Escribano et al. [8] and Rota et al. [9]. The same is true in the United States (Pertersen et al. [10]). In Japan, terrain classification data and ground amplification data are maintained for the whole of Japan (Wakamatsu et al. [11], Fujimoto et al. [12]. However, these are arranged in 250 m grids. The authors developed terrain classification and ground amplification on a 50 m grid for Kanagawa Prefecture (Ochiai et al. [13]).

In this study, as a first step, we aimed to organize the predominant period distribution obtained from the high density microtremor observations that have been conducted so far in Yokohama City, and to use the information of surface layer ground shaking characteristics using GIS. In addition, we compared the predominant period distribution with the 50 m grid terrain classification and ground amplification. These results, understanding of dynamic characteristics related to surface soil shaking, obtained from H/V spectral ratio from microtremor observation, are introduce us to directly image about surface soil structure, but it's still difficult to make the accurate soil structure.

So, we aimed to estimate the overall surface shallow ground structure of Yokohama City using microtremor miniature array observation which expects the ground depth is around 50 to 100m with 1km x 1km grid. So that we can investigate the ground safety of earthquakes in various parts of Yokohama City in order to seismic disaster prevention.

2. Topography of Yokohama City

Fig. 1 shows the Landform Classification of Yokohama City. This figure is a map developed by MLIT (Ministry of Land, Infrastructure, Transport and Tourism) and available as GIS data [14]. The topography of Yokohama City can be classified into hilly areas, plateaus, terraces, lowlands, and landfills. The hilly areas and plateaus account for approximately 70% of the whole city, with the remaining 30% consisting of alluvial plains along rivers and landfills in coastal areas [15].

Hilly areas are distributed somewhat to the west of the central area of the city, cutting through the city in the north-south direction. The north and south sides of these hilly areas exhibit different characteristics, separated as they are by the Katabira River, which runs through Hodogaya Ward, Asahi Ward, etc. The hilly area on the north side is located at the southern tip of the Tama Hills, and its elevation increases from 60 m to 100 m toward the north. The hilly area on the south side occupies the northern tip of the Miura Hills, which is adjacent to the Miura Peninsula, and its elevation increases from 80 m to 160 m toward the south.

The plateaus and terraces are located on both the east and west sides of the hilly areas. The plateau on the east side is called the Shimosueyoshi Plateau, named after an area in the Tsurumi Ward, and continues to an area near the Tsurumi River, with an elevation of between 40 m and 60 m. The plateau on the west side is located at the eastern tip of the Sagamihara Plateau and its elevation decreases from 70 m to 30 m toward the south. Additionally, the plateaus and terraces have been extensively eroded and, in terms of topography, the plateau spreads like tree branches and is full of undulations. Extensive deepening and lateral erosion have occurred in the Tsurumi, Katabira, Ohooka, Kashio, and Sakai Rivers, and their tributaries, cutting into the Kazusa Group of marine strata and creating alluvial formations with thick layers. In terms of geological distribution, the Kazusa Group forms the base of Yokohama City while the Sagami Group of marine strata inconsistently covers this base, forming the hilly areas and plateaus.

The lowlands include valley plains formed by rivers cutting into the hilly areas and plateaus, as well as coastal lowlands. There are also landfills on the coastal area, resulting in mostly artificial shorelines. As for islands, there is Nojima Island in Kanazawa Ward (Hakkeijima Island is an artificial island), making the Nojima Coast the only natural beach in Yokohama.

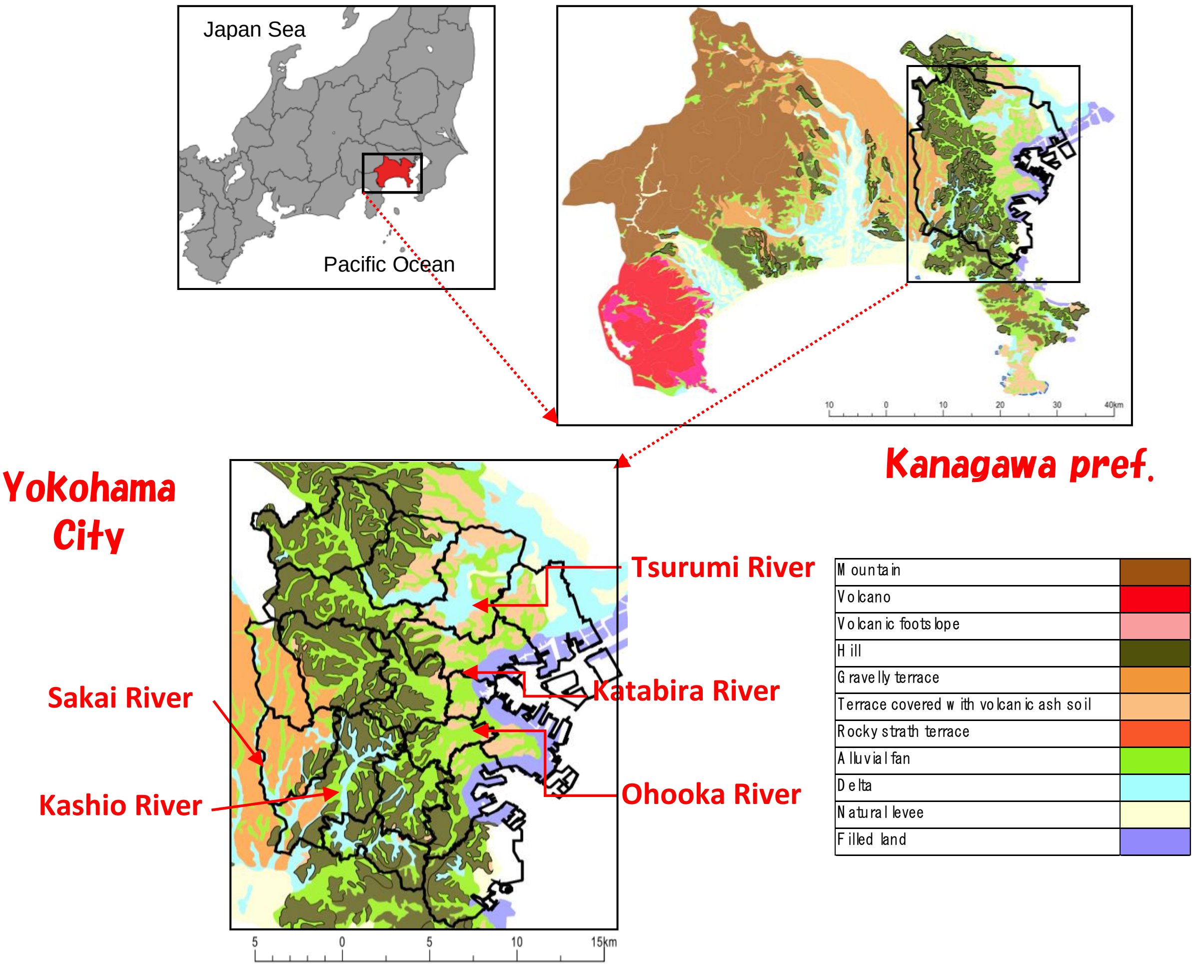


Fig. 1 Landform Classification Map of Yokohama City
(1/200,000 Landform Classification (Kanagawa) [15])

The landform in Yokohama city is shown in Fig.1, the hilly land and the plateau occupy about 70% of the whole city area, the remaining 30% is formed by the alluvial lowland along the river and the landfill in the coastal area. The Tsurumi River, the Ohooka River, the Katabira River and the Sakai River flowing down from the western part where the hilly land continues.

3. Single Site Observation

3.1 Observation Sites

The authors have been continuously carrying out high-density tremor observations since the 1990s, mainly in Kanagawa Prefecture (Example Ochiai *et al.* [16] and Ueno *et al.* [17]). The entirety of Yokohama City was divided into 250 m × 250 m meshes and their centers were used as microtremor observation sites. Excluding sites that could not be used due to geographical conditions, observations were made at approximately 5,700 sites. A servo velocity meter was used, and three components - two horizontal components (NS and EW) and a single up-down component (UD) - were observed. The mesh code conforms to JIS (JIS X 0410).

3.2 Microtremor Observation Method and Analysis Method

For microtremor observations, a servo velocity meter was used to obtain 18,000 pieces of velocity data (a total of three components, i.e., two horizontal components and a single up-down component) with a sampling frequency of 100 Hz and an observation time of 180 seconds. Channels 1, 2, and 3 of the microtremor sensor were used for the NS component (horizontal, north-south direction), the EW component (horizontal, east-west direction), and the UD component (up-down direction), respectively. The orientations of channels 1 and 2 were aligned using a compass, and channel 3 was placed horizontally based on a level provided in the microtremor sensor body. The observation site was selected avoiding places where traffic vibration was intense.

3.3 Investigation of Ground Shaking Characteristics

3.3.1 Investigation of Periods and elevation, topography

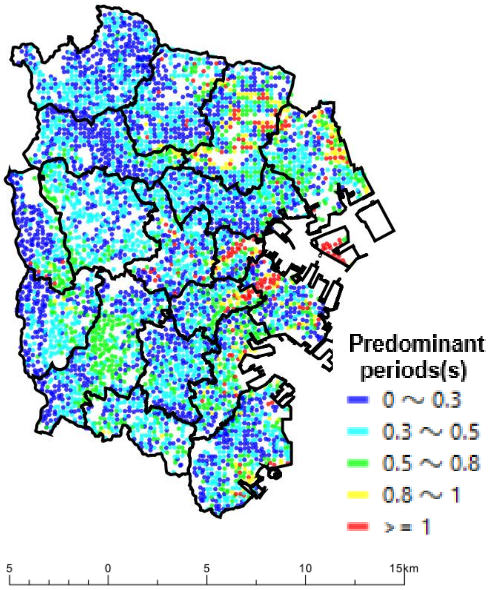
The distribution of the predominant periods of Yokohama City, the elevation distribution by 5 m DEM, and the land classification map according to the land classification survey are shown in Fig. 2 respectively. The 5 m DEM and land classification map are data published by the Geospatial Information Authority of Japan and the Ministry of Land, Infrastructure, Transport and Tourism [14]. The land classification map of Fig. 2 is more detailed than that of Fig. 1.

From the elevation distribution, it is understood that the elevation of Yokohama City tends to gradually increase from east to west. In the areas along the rivers where the predominant periods were expected to become longer because of the accumulated soft layers, they were instead found to be shorter moving toward the mountainous area on the western side of Yokohama City because this area has higher elevation and hosts the upstream portion of the rivers, as well as to be longer moving downstream. This is presumed to be because soft layers did not accumulate upstream but flowed downstream. Sites with long predominant periods were also found in the landfill areas along the coast in the eastern part of the city where soft ground layers accumulated and were covered with fill soil to increase the total layer thickness.

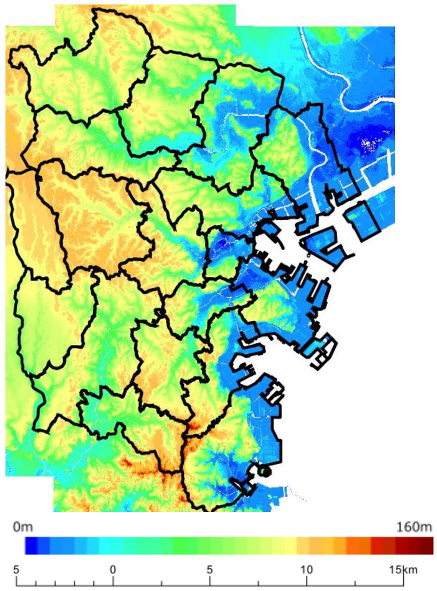
In the Asahi and Izumi Wards in the interior area, the opposite phenomenon from the coastal area was observed. That is, as the elevation increased, the predominant periods became longer. This is presumed to be because the mountainous sides of the wards contain accumulated loam layers, whose accumulated thickness caused the periods to become longer.

The predominant period is often long at low elevation where soft ground is deposited. However, even if the elevation is high as in the case, for example, where the surface soil structure includes the loam layer, the predominant period may be long. The difference between the change of the predominant period in the soft ground and the change of the predominant period in the loam plateau is presumed to be due to the characteristics of the soil. This will be further investigated in the future.

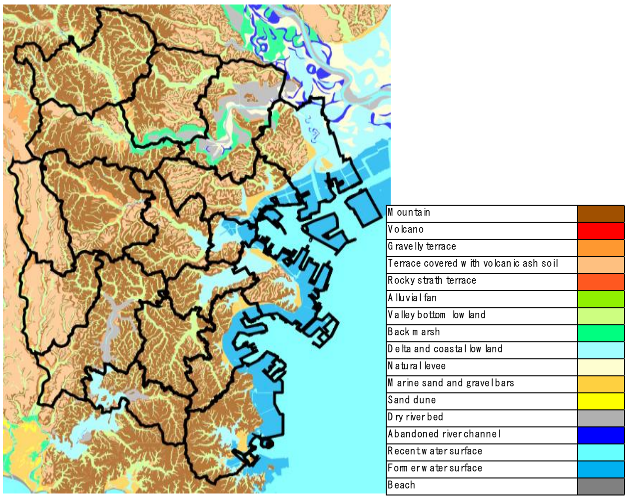
In Fig. 2, the valley bottom lowland can be confirmed in detail. However, the distribution of the predominant periods does not reflect the detailed valley bottom lowland. This microtremor observation is performed at intervals of 250 m. It is possible that detailed valley bottom lowlands can be reflected by making observations at a finer resolution.



(a) Distribution of predominant periods



(b) Elevation distribution by 5 m DEM



(c) Land Classification Map

(d) 18 Ward’s Name Map

Fig. 2 Distribution of predominant periods, Elevation distribution and Land Classification Map

3.3.2 Investigation of distribution of predominant periods and detailed topographical classification and amplification factors

The authors have created detailed topographical segmentation maps and ground amplification factor maps using GIS from the viewpoint of earthquake disaster prevention in Kanagawa Prefecture [13]. These maps are created by digitizing the existing paper-based topographic maps and surface geological maps and interpreting them on a 50 m x 50 m mesh basis. These maps also reflect detailed surface ground characteristics.

As Fig. 3 shows, Yokohama City has many artificially-remodeled lands, so the distribution of predominant periods was not uniform. This is presumed to be due to the fact that the interior region of Yokohama City is hilly and has undulating topography, as well as the fact that the top layer is covered by loam and a lot of artificially transformed land is located throughout the city. The following can be presumed regarding artificially transformed land: The strata of cut earth made by scraping of hills are stable, and therefore have short predominant periods. In contrast, embankments consisting of new strata are unstable and soft, and therefore have long predominant periods. At present, the detailed data of such alteration sites is being organized. In the future, we think that further examination can be performed by comparing with those data.

Wide variations in predominant periods were observed among landfills and reclaimed land. It is presumed that since the landfills and reclaimed land on the western side of the old coastline were created by filling in areas that used to be hilly, the depth of the soft ground layer is shallow, making the predominant periods short. In contrast, the landfills and reclaimed land on the eastern side of the old coastline were created by filling in areas of the sea along the coast, leaving a deep soft ground layer made up of sludge, etc., which results in long predominant periods. However, it is speculated that the ground characteristics of landfill sites vary greatly depending on the soil used for landfill and the landfill method.

Fig. 4 is map of amplification factors. The amplification factor was set using the empirical formula of AVS30 and the amplification factor of peak velocity, by obtaining AVS30 from the created topographical map. The amplification factor was set by Midorikawa *et al.* [18]. And AVS30 was set by Matsuoka *et al.* [19]. Amplification characteristics increase as the ground becomes softer. Consequently, where the ground is soft, earthquake damage might be more severe, such as causing buildings to collapse, and shaking is sometimes more violent, even if the site is far away from the epicenter. In Yokohama City, the site amplification factor is 2.0 or greater in the reclaimed lands, and the number gets smaller moving toward the interior, indicating clear correlation with the predominant period distribution according to Fig. 4.

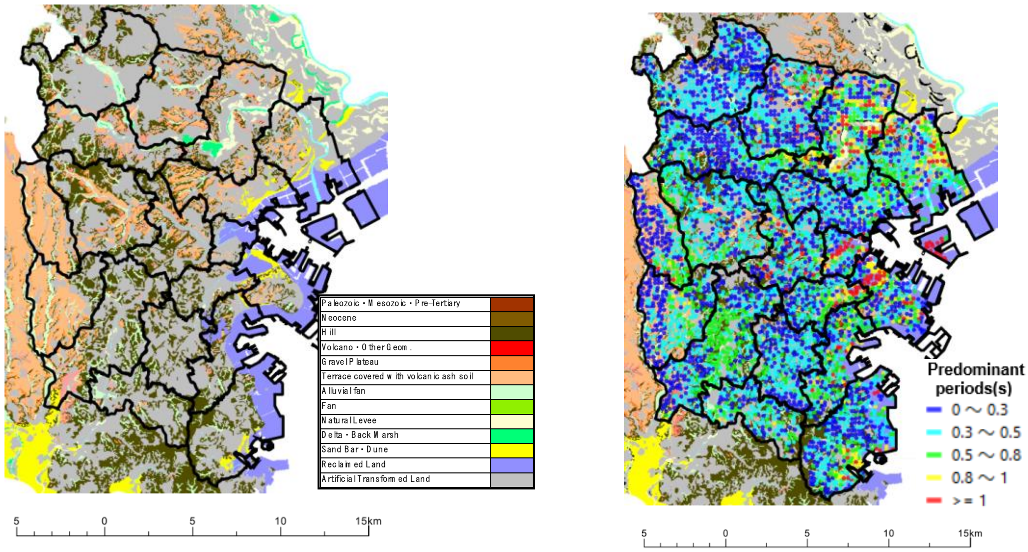


Fig. 3 Detailed Topographical Segmentation Map and Distribution of predominant periods in the Yokohama City

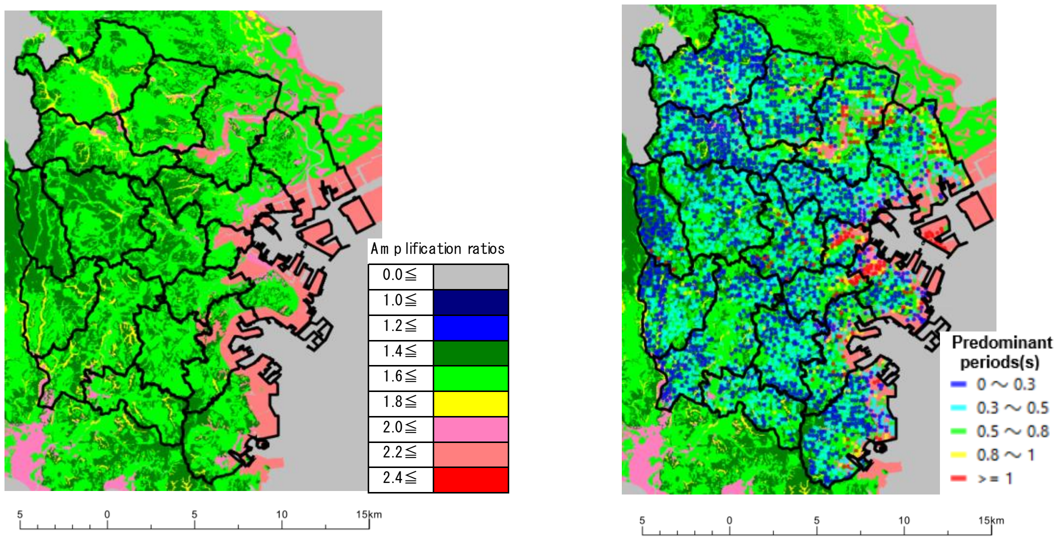


Fig. 4 Ground Amplification Factor maps and Distribution of predominant periods in the Yokohama City

4. Miniature Array Microtremor Observation

4.1 Observation Method

The microtremor miniature array observation and analysis method for soil structure, s-wave velocity structure, is developed by I. Cho *et al.* [19] and S. Senna *et al.* [20] based on SPAC method and recently this method is widely used for various purposes, for examples, soil structure analysis, soil condition survey for structural design and underground water survey etc. As for the seismic microzoning study, this method was used by T. Enomoto *et al.* [21] and T. Ochiai *et al.* [22].

The observation point is shown in Fig. 5, each observation point was set at about 1 km interval. Fig. 6 shows the distribution map of AVS30 distributed by Yokohama City and the soft soil condition zones, AVS30 value is very ow, 100m/s – 150m/s, are indicated in this map. And the observation sites are also covered these zones as indicated in Fig.5. The equipment used for microtremor observation is JU-410 (manufactured by Hakusan Industry Co., Ltd.), and the array arrangement is shown in Fig 7. We used a miniature array with a radius of 0.6m and an irregular array with an edge length of about 5m, and observed for 15 minutes at one point. The observed components are three directions (EW, NS, UD).

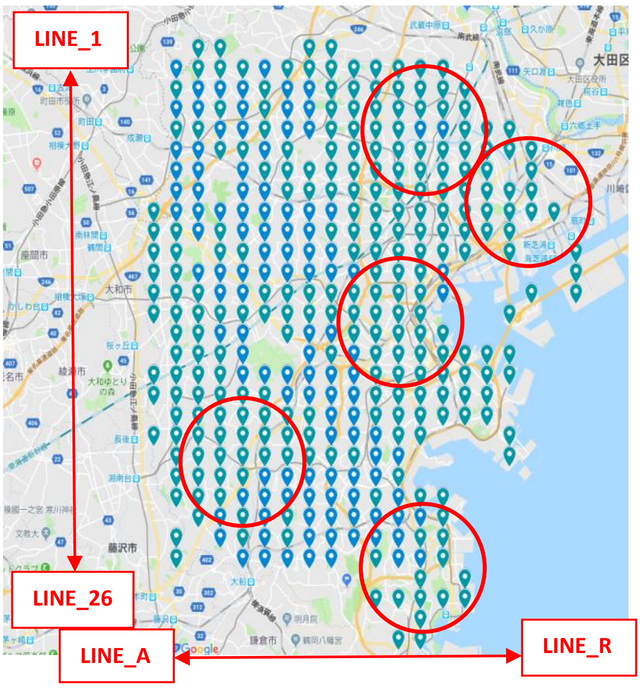


Fig. 5 Distribution of Miniature Array Observation Sites and Line

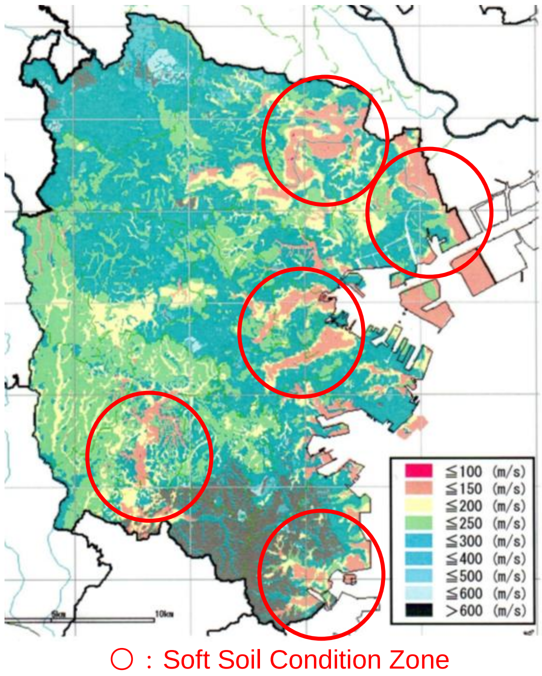


Fig. 6 Evaluated AVS30 Value in Yokohama City

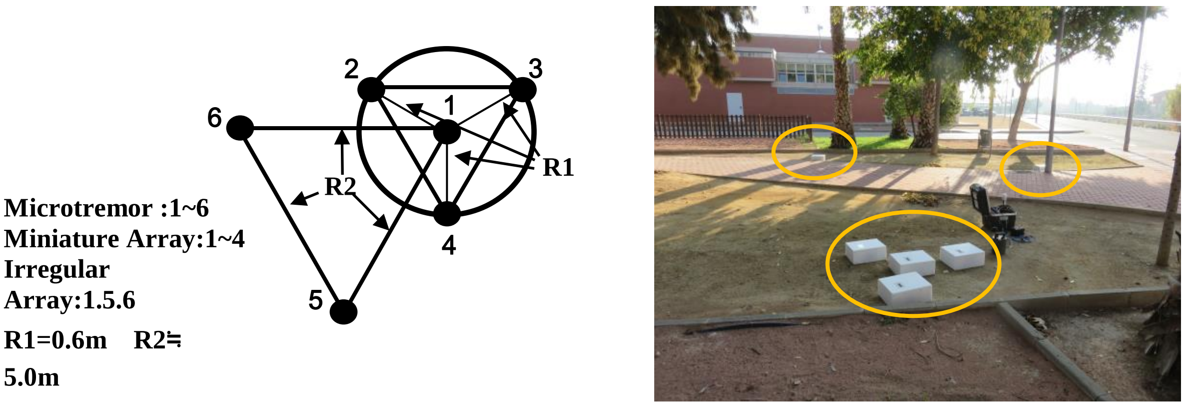


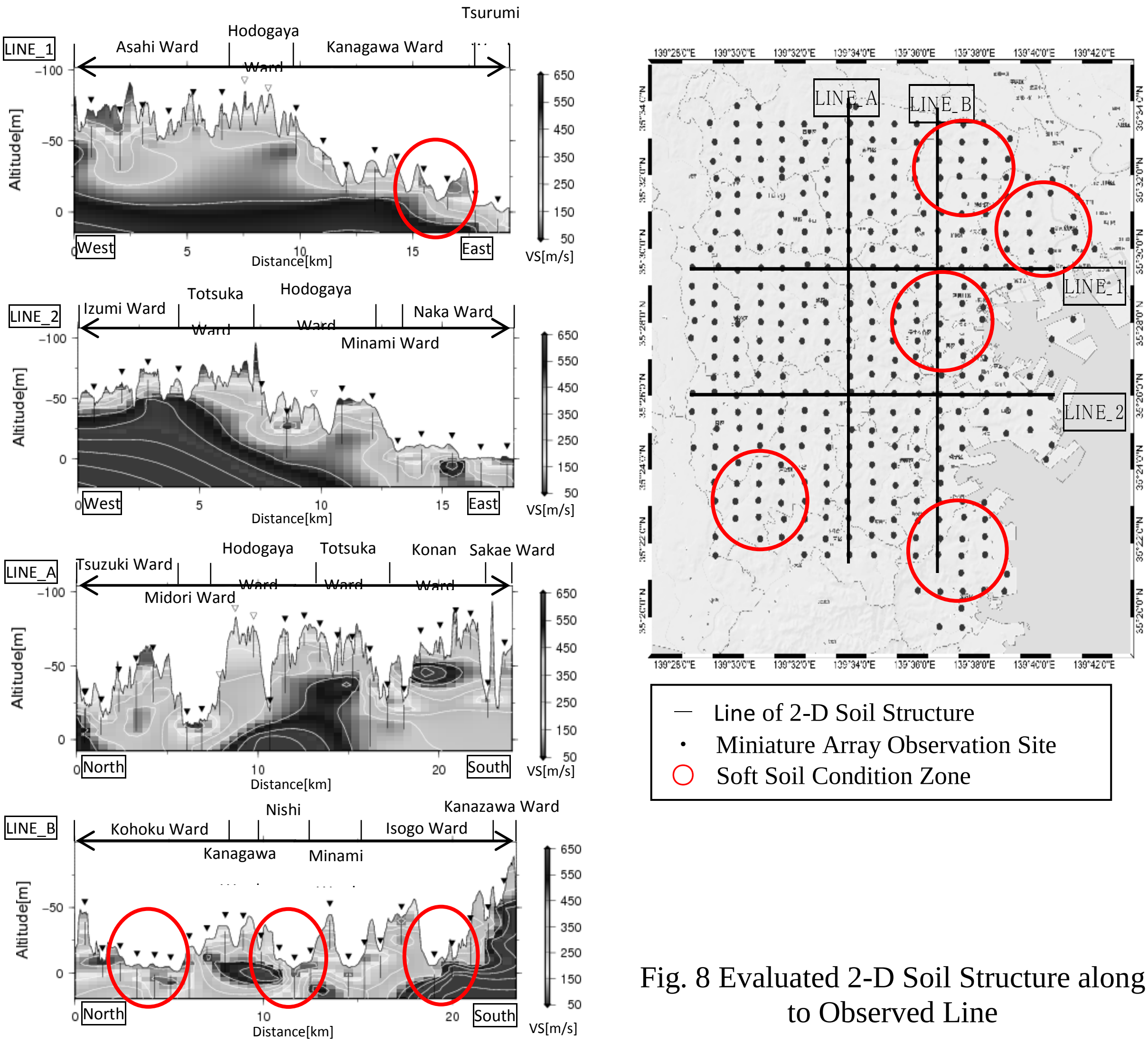
Fig. 7 Equipment Layout Diagram

4.2 Analysis Method

In this study, to calculate the phase velocity, it was used the nc-CCA method and CCA method. It performs a correlation analysis of Rayleigh waves from the measured waveform, dispersion relation curve is obtained. Further, to estimate the depth distribution of the S-wave velocity by analysing the obtained dispersion relation curves. Analysis of the velocity distribution is to calculate the model of dispersion relation curves for the velocity structure, measurement dispersion relation curve was calculated and the theoretical dispersion relation curve is obtain the velocity structure by repeatedly modify the model to match as an inversion process. Continuously conduct exploration along the observation survey line, to calculate the two-dimensional S-wave velocity cross-sectional view by enter one's velocity distribution of one-dimensional.

4.3 Analysis Result

The 2-dimensional models of LINE_1, LINE_2, LINE_A, LINE_B are shown in Fig. 8 as analysis results for the survey lines, also, shown in Fig. 8.



— Line of 2-D Soil Structure
• Miniature Array Observation Site
○ Soft Soil Condition Zone

Fig. 8 Evaluated 2-D Soil Structure along to Observed Line

LINE_1 is survey line set from Tsurumi Ward in Asahi Ward, LINE_2 from Naka Ward to Izumi Ward, respectively in the east-west direction, LINE_A from Sakae Ward to Tsuzuki Ward, LINE_B from Kanazawa Ward to Kohoku Ward, respectively, observation set in the north- south direction. In LINE_1, we can see the soft soil of Vs=50~150m/s at the surface ground of the west side of Asahi Ward and the east side of Kanagawa Ward, and at a depth of 50m, soil of Vs=450 to 550m/s is spreading in the ground. In LINE_2, Vs=550~650m/s is shown from Izumi Ward to Hodogaya Ward, showing a solid foundation and it can be confirmed that the hilly land spreads. On the east side is Naka Ward, which is a lowland. Basically, the surface layer of LINE_A has a value of Vs=200 to 350m/s, but soft ground is distributed in the Midori Ward and a part of Tsuzuki Ward. About LINE_B, we can see that most of the surface layers in the Minami Ward, Nishi Ward and Kohoku Wards, there is soft ground. The soft soil of these surface layers are formed in the river basin, but the accumulation of the thick Kanto loam layer on the hilltop is also conceivable.

5. Conclusion

The distribution maps of predominant periods in Yokohama City show that the city contains a lot of artificially transformed land, and consequently the distribution of predominant periods is not uniform. However, it can be seen that the periods become gradually longer moving from the eastern part with higher elevation toward the western part with lower elevation. This is presumed to be due to the fact that the interior region of Yokohama City is hilly and has undulating topography, as well as the fact that the top layer is covered by loam and a lot of artificially transformed land is located throughout the city. The following can be presumed regarding artificially-transformed land: The strata of cut earth made by scraping hills are stable, and therefore have short predominant periods. In contrast, embankments consisting of new strata are unstable and soft, and therefore have long predominant periods. Investigation of the site amplification factors and detailed topographical classifications indicates a clear correlation with the predominant period distribution. The author is also examining not only the predominant period, but also the value of the H/V spectrum ratio. In the future, we would like to promote further research so that they can be used to obtain useful data for earthquake disaster prevention. And in the future, I would like to use the distribution of the predominant periods obtained here as a base map and combine it with other information (population, buildings, groundwater, etc.) to improve disaster prevention capabilities.

In this research, array observation data was analysed for the purpose of estimating the ground structure of the whole city of Yokohama. From the S-wave velocity structure, we can see the solid ground with Vs=550 to 650m/s is prominent in the hillside of the Tama Hills. The lowland that can be confirmed on the east side of LINE_2 is considered to be the lowland around the Port of Yokohama. There are weak strata somewhere in hilly areas are thought to be due to sedimentation of river basins and Kanto loam layers. In addition, because of the topography of Yokohama is rugged terrain, there are many created areas of cutting and banking, and this may make some places weak ground. We think that the predominant period distribution obtained from singe site microtremor observation and the surface soil structure obtained from microtremor miniature array observation are good agreement with topography map and distribution of AVS30 value in Yokohama City. So, we are thinking to more detailed observation by using miniature array observation in order to investigate the seismic microzoning for urban safety against to future seismic disaster.

6. Acknowledgment

This study was received cooperation from Mr. Kohei Asahina, a graduate of the Faculty of Engineering, Kanagawa University, and many graduates contributed to microtremor observation at many sites in Yokohama City for long period. And also we are thankful to Mr. Naohiro Ueno and Mr. Shun Inoue who had arranged and summarized large data of microtremor observation, graduates of the Master Course in graduated school of Kanagawa University. We would like to express my appreciation here. We also special thankful to Mr. Toshio Yamamoto, former Research Associate of our laboratory at Kanagawa University.

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