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STUDY ON THE ESTIMATION OF 3-D SHALLOW SOIL STRUCTURE IN SAGAMI PLAIN USING SPATIALLY DENSE MICROTREMOR MEASUREMENTS

T. Yamamoto[1], T. Enomoto[1], T. Ochiai[2], N. Abeki[3], H. Hattori[4]

SUMMARY

It's very important to recognize and to understand the characteristics of underground structures and seismic wave propagation for the seismic resistant design and also for performing the seismic disaster mitigation countermeasures in specific area. Sagami Plain is located in the middle part of Kanagawa Prefecture, Japan where the Sagami River is flowing down from north to south direction and flow into Sagami Bay faced to Pacific Ocean. Many high-rise buildings, houses and facilities are distributed and the almost all area, mainly in southern part, is already urbanized area and developed on the alluvial deposit. About the tectonic condition, there located on the tectonic plate boundary, named Sagami Trough, and there are high seismic activities. The 1923 Great Kanto Earthquake (M7.9) was occurred just under the Sagami Bay and this area suffered serious damages, the ratio of destroyed wooden houses due was very high, 30-80%. So, we think that it's very important and useful to investigate the ground shaking characteristics by using microtremor measurements for the seismic disaster mitigation.

In this paper, we performed the spatially dense microtremor measurements, about 1,000 points, in Sagami Plain and evaluated the predominant period at each point by H/V spectral analysis and then we realized the distribution of predominant periods of surface soil constituted by Alluvial deposit and seismic microzoning considering the characteristics of surface soils and finally we considered the 3-D shallow soil structure in Sagami Plain. The evaluated predominant period are very different and distributed from 0.1 second to 1.4 second according to the location of Sagami Plain and the constitution of main soil category, for example, sandy soil or clayey soil. And the result of microzoning is very good agreement with the damage distribution due to the 1923 Great Kanto Earthquake.

INTRODUCTION

It's very important to recognize and to understand the characteristics of underground structures and seismic wave propagation for the seismic resistant design and also for performing the seismic disaster

[1]Kanagawa Univ., [2]Token Geotech Co.Ltd., [3]Kanto Gakuin Univ., [4]National Nagano College of Tecnology.

mitigation countermeasures in specific area. In general, it's much better to make the so much boreholes for getting such informations about actual soil structures but it could not be realized actually because it's required too much time and cost. Even if it's pointed out that in case of the microtremor, the source of microtremor generation is not specified and also the wave propagation of microtremor is not clear and simple, the microtremor measurements are used in the investigation of soil structure estimation and ground shaking characteristics in earthquake engineering field, because the microtremor measurements are performed by simple and low cost method and also there are many scientific reports showing the reliability of accuracy from the coincidence between the results of actual measurements of microtremor and the results obtained from the calculation of wave propagation. Then, the microtremor measurements were used from a point of view in earthquake engineering for evaluation of shallow soil structure.[1)2)3)]

Sagami Plain is located in the middle part of Kanagawa Prefecture, Japan where the Sagami River is flowing down from north to south direction and flow in Sagami Bay faced to Pacific Ocean. In the Sagami Plain, there many buildings, houses and facilities are existed and almost all area are developed to the urbanized area. About the tectonic condition of this area, there located on the tectonic plate boundary, named Sagami Trough, so there are many seismic activities. The 1923 Great Kanto Earthquake (M7.9) was occurred just under the Sagami Bay and this area was seriously damaged, the ratio of destroyed wooden houses due to this M7.9 earthquake was very high, 30-80%. [4)] So, we think that it's very important and useful to investigate the soil structure by using microtremor measurements for the seismic disaster mitigation taking into account the evaluation of seismic wave characteristics and the distribution of seismic intensity in Sagami Plain where the next big earthquake is expected in the future.

In this paper, we performed the spatially dense microtremor measurements in Sagami Plain and realized the distribution of predominant period and seismic microzoning considering the characteristics of surface soils and finally estimated the 3-D shallow soil structure in Sagami Plain.

OUTLINE OF SAGAMI PLAIN

Sagami Plain is located in the middle part of Kanagawa Prefecture and is constituted the fan developed by Sagami Rive. At the mouth of Sagami River, there developed the soft soil condition, and the depth of soft soil layer is reached about from 50m to 80m. The thickness of soft soil layer is changing depending on the location in this plain. The process of deposit constitution is very complex because at many places, the soil layers are constituted by clayey soil and sandy soil each other. And from the mouth to the upper region of Sagami River, the thickness of soft soil layer is decreasing as generally tendency. As a main situation of Sagami Plain, the southern part from Shinkansen Supper Express Railway, the surface soil is constituted by sandy soil and the northern part is constituted from clayey soil and we could consider this remarkable division of these two parts respectively. The maximum thickness of Alluvial deposit is about 80m deep at the mouth of Sagami River. Fig. 1 shows the distribution of microtremor measurement points in the fixed continuous measurements and in the moving measurements in Sagami Plain. And Fig.2 shows the cross section of soil structure along to the Shinkansen Super Express Railway Line.[5)]

MICROTREMOR MEASUREMENTS AND MICROZONING

Measurements and analysis

Microtremor measurements were performed in two types of measurement. One is the fixed continuous measurement and the other is the moving measurement. In case of fixed continuous measurement, the measuring duration time was set up to 180 seconds with three components at every one hour during one day to one week depending on the location, respectively. And in case off moving measurements, the measurement at each point was only one time during 180 seconds with three components. In the data processing, we checked the waveform at each measurement and then we picked up the time window with 20.48 sec which do not appear the remarkable noise like a disturbance due to heavy traffic vehicle. Then we calculated the Fourier Spectrum by FFT Method and made the smoothing processing by using Parzen's Window with 0.3Hz bandwidth. We calculated the 2D horizontal Fourier Spectrum, 2DH, by combining the two horizontal components, NS and EW, and finally we calculated the H/V Spectrum as indicated following expressions.

$$2DH(\omega)=\sqrt{(NS(\omega)*EW(\omega))} \quad (1)$$

$$H/V(\omega)=2DH(\omega)/UD(\omega) \quad (2)$$

Where, $H/V(\omega)$: H/V spectrum

$2DH(\omega)$: 2D horizontal spectrum

$NS(\omega)$: Fourier Spectrum of NS Comp.

$EW(\omega)$: Fourier Spectrum of EW Comp.

$UD(\omega)$: Fourier Spectrum of UD Comp.

We evaluated the predominant period from H/V spectrum obtained from expression (2).

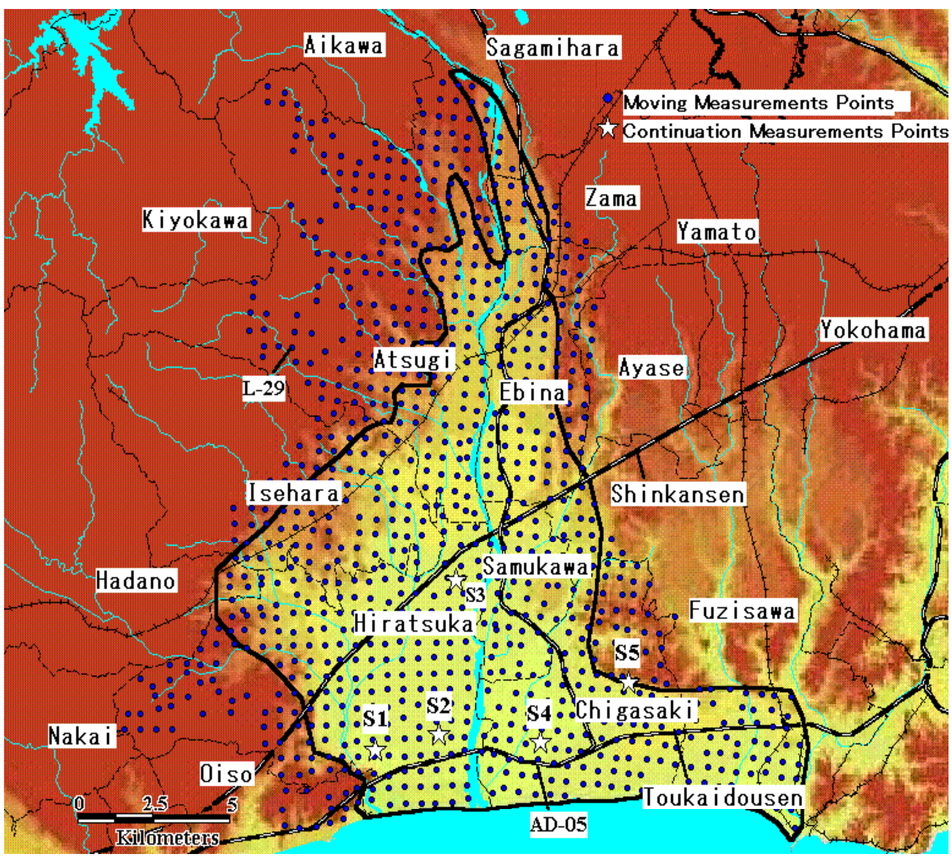


Fig. 1 Distribution of the microtremor observed points in densely moving measurements and in fixed measurements at five points in Sagami Plain.

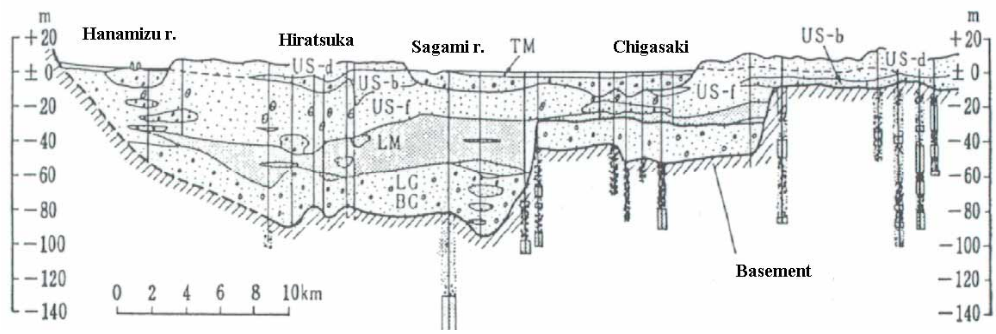


Fig. 2 Cross section of the east – west direction concerned to the underground structure at the mouth of Sagami River.

Fig. 3 shows the examples of H/V spectra obtained from different sites, one is located in table land, L-29, and the second is located in low land, AD-05, respectively. As shown in Fig.3, it could not be specified the peaks for predominant period at the site of table land even though it could be specified the clear peaks for the predominant period at the site of low land. And inside the Sagami Plain, it’s very clear tendency of the influence of surface soil structure and there appears very clear amplification due to surface soil structure.

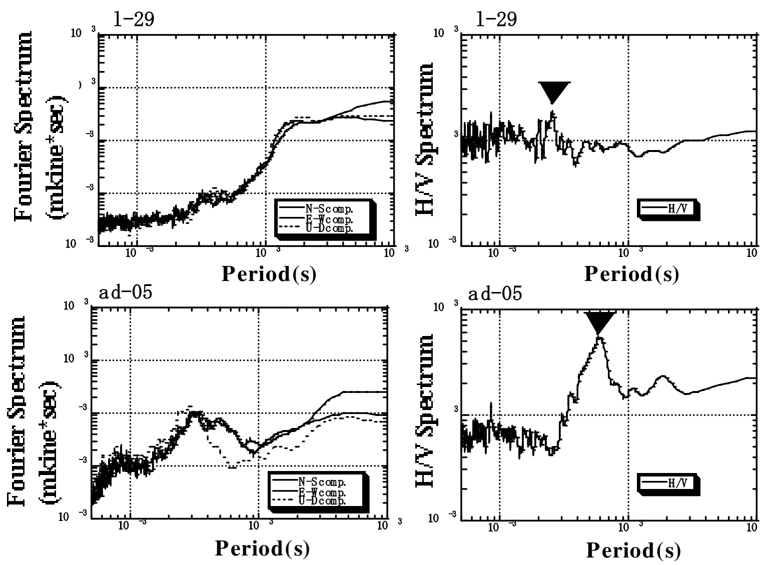


Fig. 3 Examples of Fourier Spectra and H/V Spectra obtained from microtremor measurements at L-29 and AD-05 points where were indicated in Fig. 1.

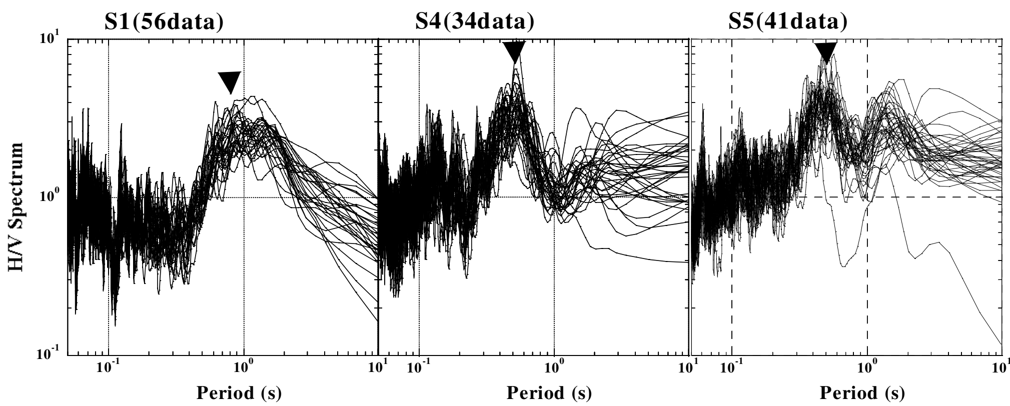
Fixed continuous measurement

In case of the results obtained from microtremor measurements, the amplitudes and remarkable periods in Fourier Spectra were changed depending on site and time by the influence of surrounding circumstances, for example of machinery noise, traffic condition generated by human activities. However, when we use the results obtained from microtremor measurements, it is required that the stability of the results against to the different time observation. So, we checked the stability of the results about the characteristics of H/V spectra by using the fixed continuous measurements at five points in Sagami Plain. Fig. 1 shows the locations of the fixed continuous measurements and these locations had different soil conditions, respectively. Table 1 is listed the conditions of fixed point continuous measurements at five points, respectively.

Table1 Conditions of the fixed microtremor measurements at five points (s1 – s5), indicated in Fig. 1

	S1	S2	S3	S4	S5
Latitude	35.328	35.331	35.374	35.331	35.347
Longitude	139.336	139.359	139.366	139.395	139.395
Period	1999/6/27 19:00 ~7/4 18:00	1999/7/7 17:00 ~7/8 16:00	1999/7/8 17:00 ~7/9 16:00	1999/7/16 10:00 ~7/20 15:00	1999/7/16 10:00 ~7/21 7:00
Times	168	24	24	102	122

Fig. 4 shows the result of fixed point continuous measurements at three sites where the duration of measurement were very long and also this figure shows the results of superposition of H/V spectra calculated results at every 3 hours interval. As indicated in Fig. 4, there are some fluctuations in the spectral amplitude, vertical axes, but the predominant periods were appeared and almost stable clearly in horizontal axes and we can evaluate the predominant period by using H/V spectra.



(a) S1 site **(b) S4 site** **(c) S5 site**

Fig. 4 Examples of H/V spectra obtained from the fixed microtremor measurements at S1, S4 and S5, respectively.

Densely moving measurements

We recognized the stability of H/V spectra by using the results obtained from the fixed continuous measurements of microtremors as indicated in previous section. We performed the densely moving microtremor measurements at about 980 points as indicated in Fig. 1. Using these observed data, we calculated the H/V spectra as same as the expression (1) and (2) and the result of the predominant period distribution is shown in Fig. 5. And, for the seismic microzoning, we evaluated the predominant period at each grid using the mesh map divided into 500m x 500m in Sagami Plain. The grid system was referred JIS0410 System. If there were two sites and more in a grid, we evaluated the predominant period by using the averaged value in a grid. And if there were no site in a grid, we evaluated the predominant period by referring the surrounding grids and the value at the most neighborhood site and finally we used the averaged value of surrounding points. Fig. 6 shows the result for predominant period distribution converted into the mesh map in order to investigate the seismic microzoning and also shows the microtremor observation points in densely moving measurement. As shown in this figure, the distributed values of predominant period are changing complicatedly in Sagami Plain. The evaluated values for predominant period at hilly sides where are located to eastern and western side of Sagami Plain and also the northern part, upper side of Sagami River, are gradually changing to the shorter periods and, in these areas, there were some observation sites where didn't appear the predominant period remarkably.

Basically, the thickness of surface soil layer is going to be shallower toward the hilly sides and upper side of Sagami River but the distribution of predominant period, as indicated in Fig. 5 and Fig. 6, don't coincide to this basic trend of surface soil layer. There are existed some areas where appeared relatively long period for the predominant period of surface soil structure we could imagine that the locally strong influences of different soft materials had constituted the main deposit layer where were the old river traces of Sagami River.

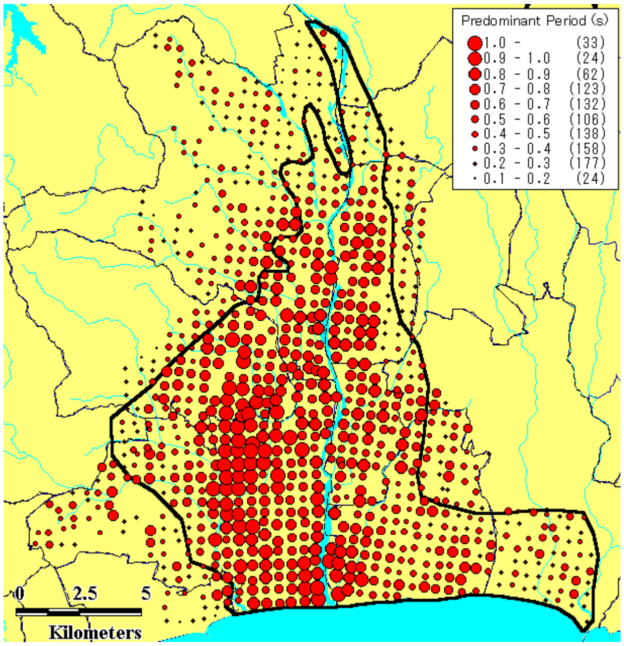


Fig. 5 Distribution of the predominant period at microtremor measured point evaluated by H/V Spectra from the densely moving micrtremor measurements.

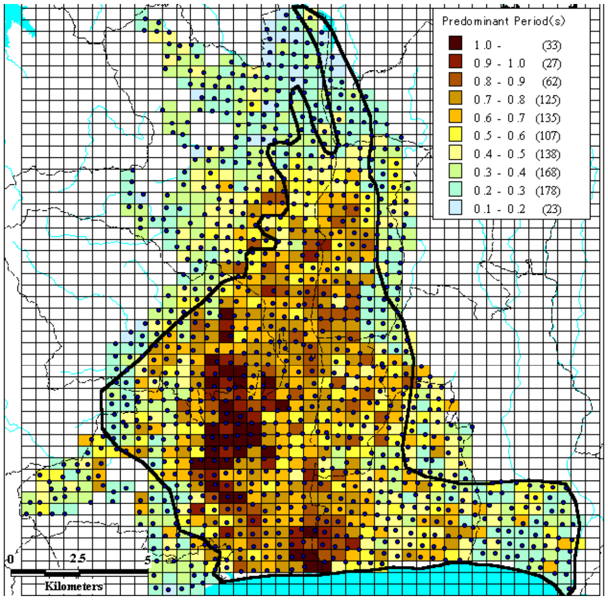


Fig. 6 Evaluation of the predominant period distribution using the mesh map in 500m x 500m grids in order to draw the seismic microzoning map.

SEISMIC MICROZONING

We investigated the seismic microzoning based on the map indicated the predominant period distribution using the mesh map. Fig. 7 shows the result of seismic microzoning based on the predominant period. The areas located at close to the mouth of Sagami River and at close to the western side of Shinkansen Super Express Railway Line are indicated the largest predominant period, about 1.2 sec, and these areas are named As, Ac Zone. The areas at western side of the lower part of Sagami River and at both sides of Sagami River along to the Shinkansen Line, these areas are named to Bs and Bc Zone (about 0.8 sec). The areas at eastern side of the middle and lower part of Sagami River and at the northwestern part of Sagami Plain are named Cs and Cc Zone (about 0.5 sec). And the other areas at eastern, northern and western end of Sagami Plain are named Ds, Dc Zone (about 0.3 sec). The suffix “s” means the sandy soil and also “c” means the clayey soil. From the result of seismic microzoning, the predominant period of As Zone which has the deepest thickness of Alluvial deposit is similar to the predominant period of Ac Zone which has relatively thin of Alluvial layer. This is the reason why the characteristics of deposit soil are influenced to the softness of surface soil condition, namely related to the predominant period. Then, the predominant period Is changed by not only the depth of surface soil layer but also the constituted material characteristics. And also, the seriously damages of wooden houses by the 1923 Great Kanto Earthquake are coincided to the Zone which has more than 0.7 sec of predominant period.

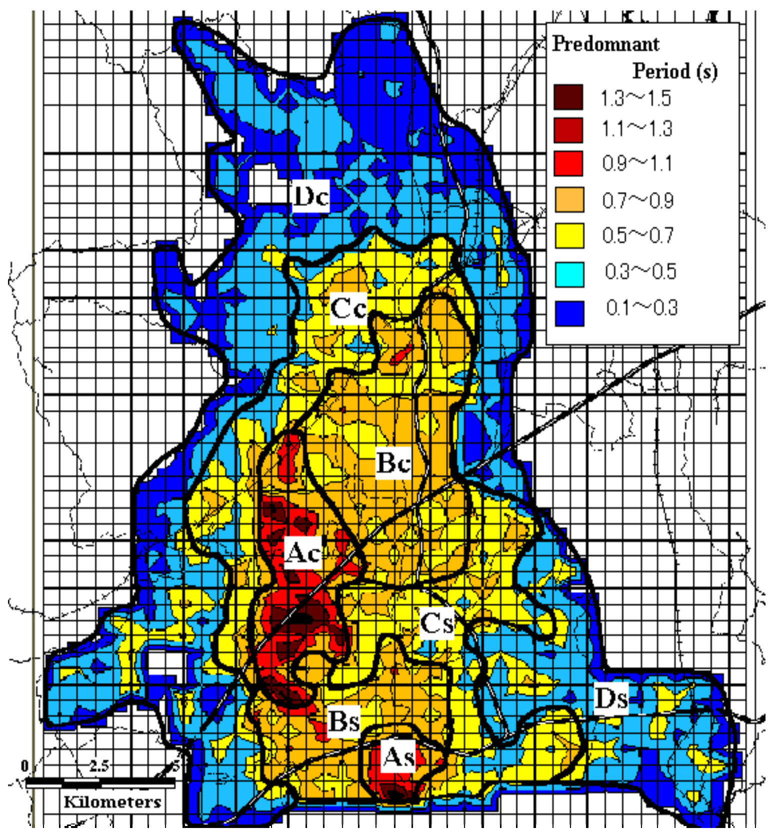


Fig. 7 Result of seismic microzoning map concernrd to the distribution of predominant period in Sagami Plain.

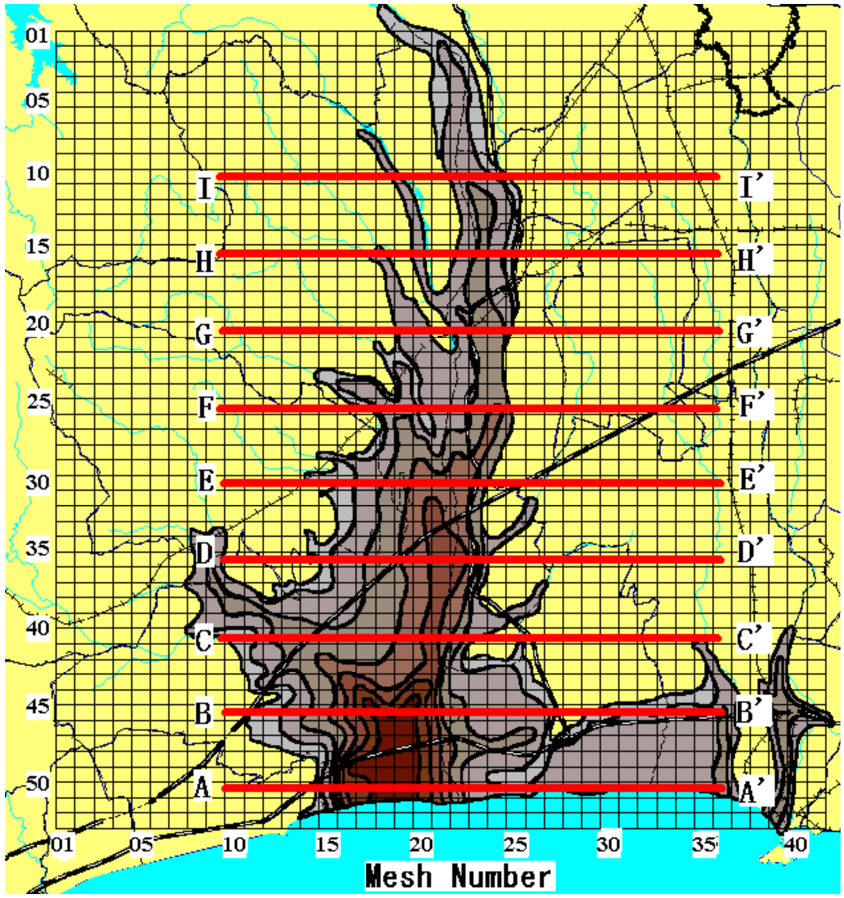


Fig. 8 Estimated contour lines concerned to the Alluvial Soil deposits in Sagami Plain and the locations of referenced cross section in order to investigate the relationship between the evaluated value for the predominant period of soil and the thickness of Alluvial deposit.

ESTIMATION OF 3-D SHALLOW SOIL STRUCTURE

Investigation in 2-D shallow soil structure

We selected the nine sections across the Sagami Plain in east-west direction and we investigated the relationship between the depth of alluvial deposit and the predominant period. In this paper, we would like to show the results of A Section which has the deepest thickness of alluvial deposit and also F Section which has a relatively thin layer. Fig. 9 and Fig. 10 show the results of these relations and these figures have very well agreements with the thickness of Alluvial layer and the predominant period obtained from microtremor.

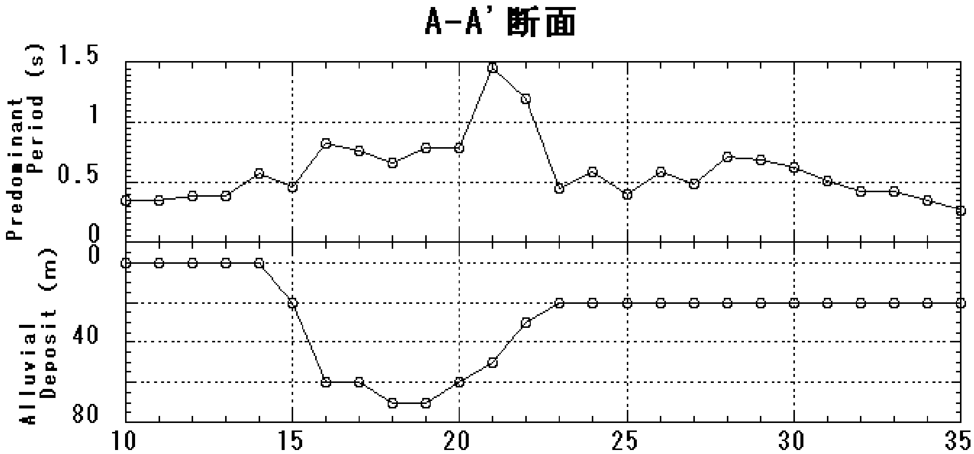


Fig. 9 Relationship between the predominant period and the thickness of Alluvial deposit along to A-A' section.

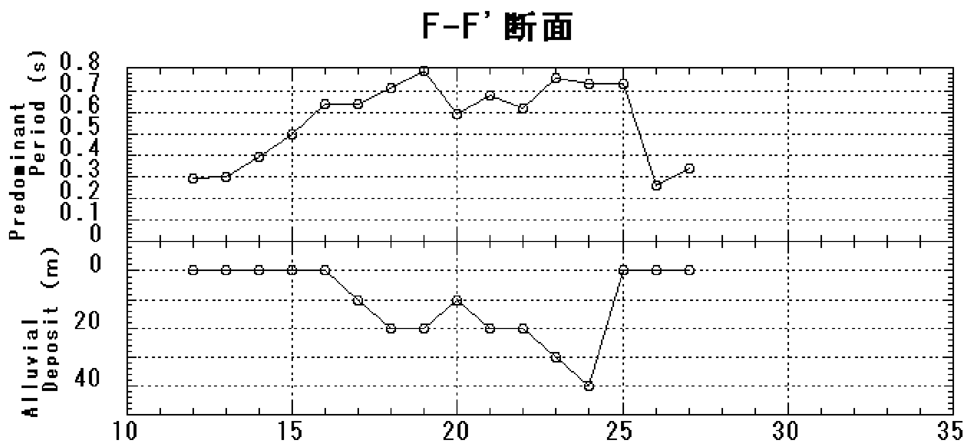


Fig.10 Relationship between the predominant period and the thickness of Alluvial deposit along to F-F' section.

Evaluation of S wave velocity

Based on the results of predominant period distribution obtained from densely moving microtremor measurements, we investigated the relationship between the predominant period and the thickness of Alluvial deposit at the middle part of Sagami Plain.[6)7)] Dividing into two types of mainly constituted surface soil layer, indicated "s" and "c", we analyzed the regression relations. Fig. 11 shows the results. In this figure, the regression relations are included in the Base. We assumed that the surface soil layer is clean and single layer for the surface soil structure, namely two layered structure. Then we calculated the averaged S wave velocity of surface soils by using the 1/4 wave length method as indicated following expression (3).

$$Vs = (4 \times H)/T \qquad (3)$$

where, Vs : S wave velocity(m/sec)

H : thickness of layer(m)

T : Predominant period(sec)

As indicated in Fig. 11, Vs for sandy soil is 245m/sec and Vs for clayey soil is 164m/sec.

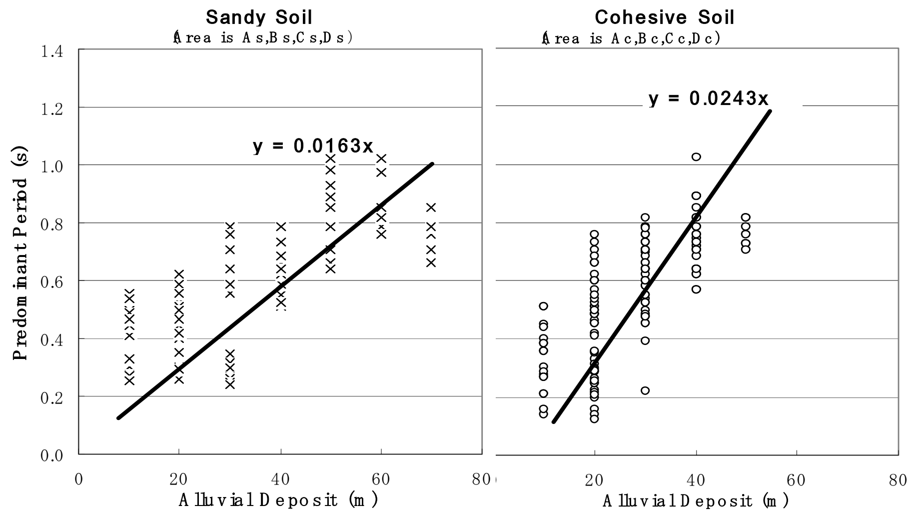


Fig.11 Regression relationship between the predominant period and the Alluvial deposit in considering the difference of main soil materials, sandy soil and cohesive (clayey) soil.

ESTIMATION OF 3-D SHALLOW SOIL STRUCTURE

We estimated the thickness of surface soil, H(m), by using the evaluated S wave velocity evaluated by regression analysis as indicated previous section including the division in "s" and "c" and the predominant period obtained from microtremor measurements. Fig. 12 shows the already prepared 3-D shallow soil structure, the depth of alluvial layer mainly obtained from geological information. Fig. 13 shows the estimation of 3-D shallow soil structure using expression (3) and this result is covering almost all areas of Sagami Plain about surface soil conditions. Comparing between Fig. 12 and Fig. 13, the estimated shallow soil structure is expanded to eastern part and also western part of Sagami Plain and the depth of surface soil in Ac Zone is estimated a little bit larger than the estimated depth in Fig. 12 from geological information. The reason why the shallow soil structure was expanded to eastern and western part is that even if it estimated that there were no deposit of Alluvial layer in geological information, but in the result of microtremor measurements, there appeared the predominant period in short period range. So, the depth of surface layer was evaluated by expression (3) and the 3-D shallow structure is expanded to eastern part and western part of Sagami Plain where are located in the both edges of plain, respectively. And the reason why the depth of surface soil in Ac Zone was estimated deeper than the estimated depth in Fig. 12 is that there several small rivers were concentrated and, sometimes in the historical record, these small rivers generated and repeated the large scaled flood. So, we guessed that these small rivers generation and large flood phenomena realized the very deep deposit and the very soft soil condition at the surface and the predominant periods obtained from microtremors are very long. The evaluation of the depth of this zone was used same estimated value of S wave for clayey soil, 164m/sec, so the estimated depth of deposit layer was estimated depth of deposit layer was evaluated deeper than that estimated from geological information in Fig. 12. In these local zones where have a specific condition, we must consider the effect of local condition by applying the other method, for example, simple S wave prospecting test for the evaluation of surface soil condition or checking the N-Value by using borehole data. And we must make more dense measurements of microtremors for checking the difference of characteristics of H/V spectrum carefully and we need the accuracy of shallow soil structure.

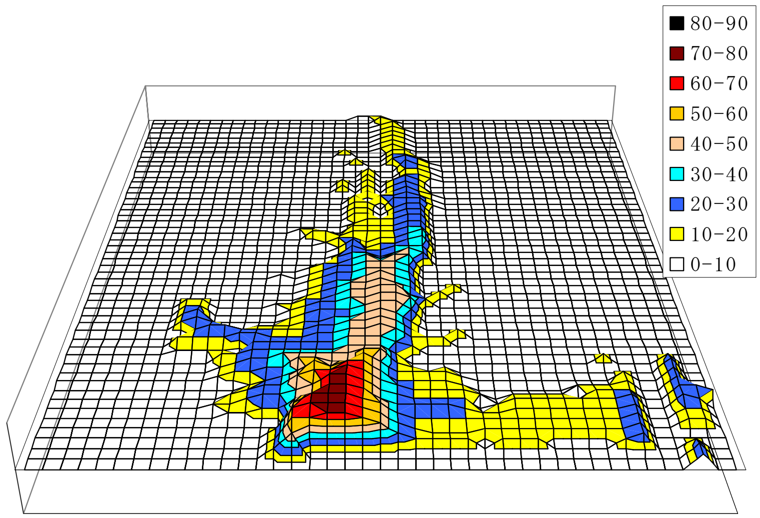


Fig.12 3-D surface soil structure by using the contour lines of Alluvial deposit indicated in Fig. 8

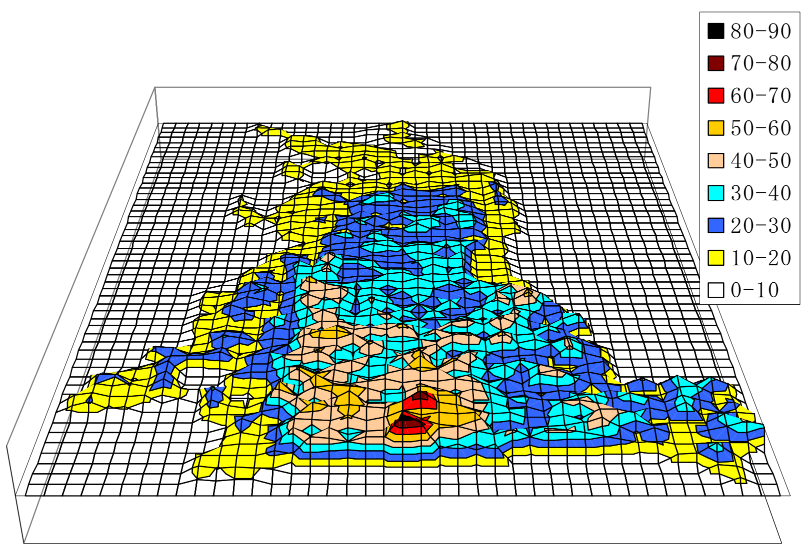


Fig.13 3-D surface soil structure evaluated by the relationship between the predominant period and the thickness of Alluvial deposit as indicated in Fig. 11 obtained from microtremor measurements in this study.

CONCLUSIONS

We performed the microtremor measurements densely in Sagami Plain where was affected very serious damages due to the 1923 Great Kanto Earthquake and we evaluated the predominant period of surface soil. For the application of the result of microtremor measurement, we investigated the seismic microzoning and the 3-D shallow soil structure. The conclusions are summarized as follows.

(1) The distribution of the predominant period is obtained in Sagami Plain clearly and there appeared the different characteristics of ground shaking, locally. Then the seismic microzoning is completed covering almost all areas of Sagami Plain.
(2) The result of seismic microzoning is able to explain the serious damages due to the Great Kanto Earthquake and the characteristics of deposit layer as surface soil condition had a very strong influence to the damages.
(3) 3-D shallow soil structure is evaluated from the result of dense microtremor measurements. There are some areas where appear the differences by the influences of local soil condition.

From these conclusions, we can apply to the evaluation on 3-D shallow soil structure by using microtremors considering the already prepared borehole data but, in locally specific area must be treated carefully. Also we need the ground shaking characteristics obtained from strong motion observation records in this same areas and the consideration of the study for the seismic wave propagation analysis including the irregularity of soil structure for confirming the applicability of microtremor measurements and for the positively use these results to the seismic risk assessment for the future expected big earthquake.

ACKNOWLEDGEMENT

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