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Application of microtremors to seismic microzoning procedure

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Abstract: *Due to the close relation between the nature of microtremors and the fundamental dynamic behavior of the surface soil layer, these small vibrations are well-known and useful in the field of earthquake engineering. The technique of microtremors measurement and analysis has been successful for microzoning in many places around the world. This technique has the advantage of being a fast and easy way to estimate the effect of ground motion characteristics due to an earthquake. This paper presents an experimental study of microtremors for investigation ground characteristics. In this study, 114 microtremors data were obtained from Shin-Yokohama area in Japan. A map showing the distribution of the site predominant periods was developed for microzonation purposes. These periods showed good agreement with periods of earthquake ground motions recorded during the July 1997 Chiba earthquake (M=5.3), the February 2000 Yamanashi earthquake (M=4.6) and the May 1998 Izu Peninsula earthquake (M=5.1). In the result of this study, it should be noted that the characteristics of microtremors are dependent on the type of soil deposits. Site effect plays an important role in microtremors measurements.*

Key words: *Seismic microzonation, microtremor, H/V spectral ratio, Nakamura method*

INTRODUCTION

Recent destructive earthquakes (California 1989, Philippines 1990, Northridge 1994, Kobe 1995, Columbia 1999, Turkey 1999) have clearly shown that near-surface geological and topographical conditions play a major role in the level of ground shaking. In post-disaster reconstruction as in mitigation, information on soft soil response to large earthquakes become of prime importance. Topographical and geological conditions can generate significant amplification and spatial variations of the earthquake ground motion. Seismic explorations are one of several methods to determine a subsurface structural model over a wide area, but these explorations are still economically and technically difficult to make, especially in urbanized areas.

However, microtremor observation is a popular tool to assess the effect of soil conditions in earthquake engineering (Bour et al., 1998). Microtremors have been investigated since the early of Omori (1908) in order to solve the following problems of both microtremors and microseisms problem: the nature of the source; the mechanism of the transmission over oceanic paths; and also the application of microtremor to estimate site effects in earthquake engineering. Early researchers have got some differences about the definition of microtremors. Engineering application of Microtremors was initially proposed by Kanai and Tanaka (1961). They pointed that microtremors be explained with multiple reflection of SH waves in parallel subsoil layer. Aki (1957) considered Love waves. Akamatsu (1961) considered mainly the combination of Love and Rayleigh waves. Douze (1964) studied on both P and

Rayleigh waves. Seo et al. (1990) considered S-wave and Rayleigh waves. Yamanaka (1994) focused on Rayleigh waves.

Ohta et al. (1978) observed the predominant period of the ground (2.5 s) in both microtremors and strong ground motions were attributable to the presence of deep alluvial deposits in Hachinohe, Japan. Kagami et al. (1986) used two dimensional approaches to study site effects in San Fernando Valley and produced a map with estimates of the amplification effects in the valley. In the recent time, Singh et al. (1988) estimated site amplification during the Michoacan earthquake of 1985 near Mexico City and they have good result where amplification factor in the lake bed zone are 8-50 times to the hilly zone. Masaki et al. (1988) agreed with this and demonstrated the predominant periods at several sites in Mexico City, using microtremors, were in good agreement with those obtained from the strong ground motion at the same sites during the earthquake. Kagami et al. (1982) and Yamanaka et al. (1994) pointed out simultaneous observation of long period microtremors was appropriate for the evaluation of the amplification due to the deep soil deposits. Seht et al. (1999) found microtremor measurements can be used to determine the thickness of soft cover layers and for this determination; Nakamura's technique is the most suitable method.

Although Nakamura's qualitative exploration looked at least questionable (Kudo 1995), various sets of experimental data (Lachet and Bard 1994; Duval et al. 1994; Duval et al. 1995; Kudo 1995; Gitterman et al. 1996; Riepl et al. 1998) confirmed that these rations are much more stable than the row noise spectra. Furthermore on soft soil sites, they usually exhibit a clear peak that is well correlated with the fundamental resonant frequency. These results are supported by several theoretical investigations (Field and Jacob 1993b; Lermo and Chavez-Garcia 1994) showing that synthetics obtained with randomly distributed near surface sources lead to horizontal to vertical ratios sharply peaked around the fundamental S-wave frequency, whenever the surface layers exhibit a sharp impedance contrast with the underlying bedrock. In addition to this point of view, no straightforward relation exists between the horizontal to vertical peak amplitude and the site amplification (Field at al. 1995; Bour et al. 1998).

In this study, we evaluate the characteristics and usage of microtremors and strong motion records, recorded at two stations in the studied area together for microzoning purposes. Those parameters are predominant period, classification of soil conditions, H/V spectral ratio and amplification ratio in site location. In this study, microtremor records were observed at 114 points in Shin-Yokohama, Japan and analyzed to draw microzoning maps for considered area.

THE GEOLOGICAL REGIME AND THE SETTLEMENT AT THE AREA OF INTEREST

According to geological and topographical maps, the area is located in the northern part of Yokohama city. There are two outcrop layers of Middle Pleistocene with rock and mudstone units on the hill area and Holocene with very soft soil conditions, observed mainly on the flat area mostly with silt content accumulated on the soft rocks of Middle Pleistocene (Fig. 1).

There are some numbers of necessities for applying microtremors observation at Shin-Yokohama. Before the 1923 Kanto earthquake, it was an agricultural area, where only a few farmers living along the hilly zone, whereas nowadays it is over-crowded area since 1960's with high development. At the same time, there was a quick attempt for constructing JR Shinkansen Station before the 1964 Tokyo Olympic Game. After that period high buildings began to be constructed over that area. But in our research field, there are no high rise buildings, because the area includes residential places and industrial parts. All above-mentioned steps in construction have been done without

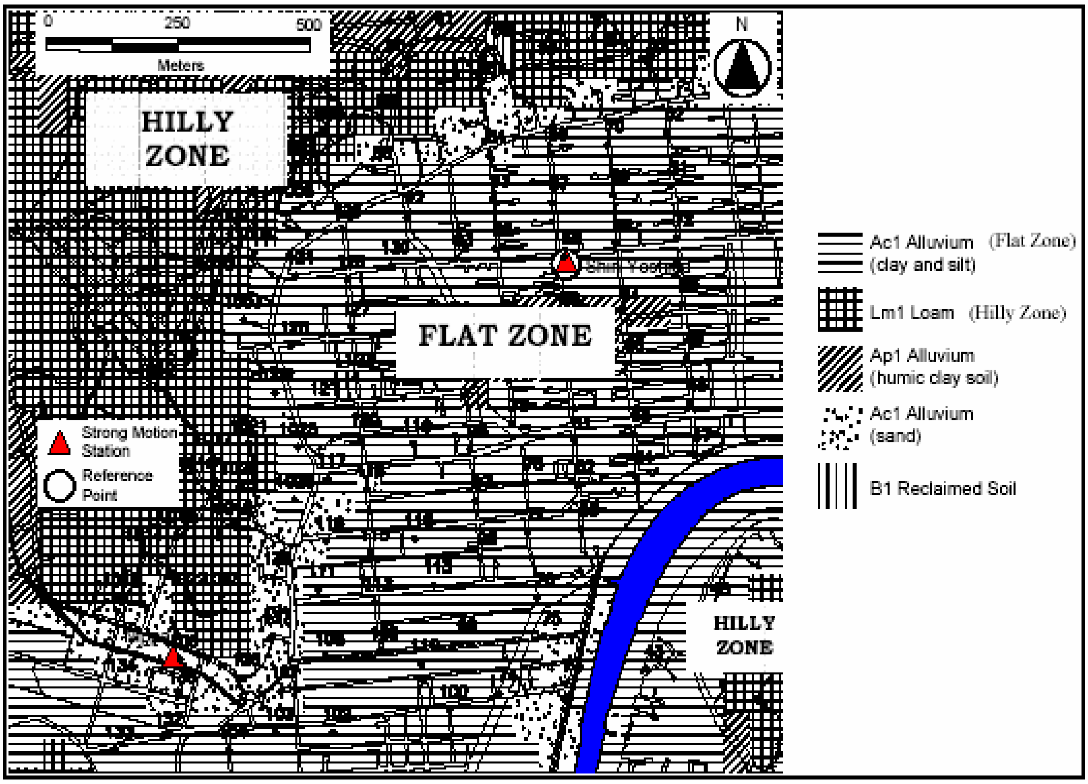

Figure 1. Geological map and observation points of microtremors

knowledge of site conditions. With that lack of knowledge there were constructed multi-stored buildings, roads and bridges. On top of all, over the area of study, the soil conditions change very much from place to place. Availability of borehole data also gives us the reason to compare microtremors data with them.

METHOD BASED ON RECORDINGS OF MICROTREMORS

Microtremors are ground vibrations with displacement amplitude about 0.1-1 micron, and velocity amplitude are 0.001-0.01cm/s., that can be detected by seismograph with high magnification. We can classify microtremors into two types according to period range. One comprises short-period microtremors with periods less than 1 second, and is related to shallow subsurface structures several tens of meters thick. The other is long-period microtremors with periods longer than 1 second, which is related to deeper soil structure down to a depth of the hard rock with an Swave velocity of 3 km/s.

Numerous investigations have been conducted to determine the nature of short period microtremors. One of the possible sources of short-period microtremors can be human activity, such as traffic and industrial noises.

Kanai and Tanaka (1961) observed short period microtremors at many sites, and they achieved a good agreement between the period distribution curves of microtremors and those of earthquake ground motions. Kanai's work is based on the assumption that SH-waves with the frequency characteristics of white noise, are incident vertically at the base of soil deposit, and that the observed spectral shape directly provides us with the transfer function of the soils. Although this assumption has still not been confirmed, this kind of procedure has been popularly applied in seismic microzonation work, because of the easy acquisition of short period microtremors data. He proposed a method of soil condition classification with only microtremors. Recently, many researches examined to estimate local sites effects (SE) by taking the ratio of horizontal to vertical spectra of microtremors at a single site. This idea was proposed by Nakamura (1989). According to Nakamura (1989), source effects might be removed from microtremor data by taking the spectral ratio of the horizontal record to the vertical record at a single site. He assumed that only horizontal microtremors are influenced by soil and that source spectral characteristics are maintained in vertical microtremors as well as in horizontal microtremors. Site effects due to surface geology are generally expressed as the spectral ratio (SR) between the horizontal component of earthquake recordings at the surface of the soft layer (H_S) and the ones at the ideally horizontal outcropping bedrock (H_B):

$$SR = \frac{H_S}{H_B}$$

The instrumental method chosen here has been used for many years in Japan and was described by Nakamura in 1989. This method is based on the following assumptions that:

- Microtremors are composed of several waves, but essentially Rayleigh waves propagating in the soft surface layer overlying a stiff substratum.
- The effect of the Rayleigh wave (E_{RW}) on the noise motion is included in the vertical spectrum at the surface (Vs), but not at the base of the layer (V_B):

$$E_{RW} = V_S / V_B$$

- The vertical component of microtremor motion is not amplified by the soft soil layer.
- The effect of the Rayleigh waves on microtremor motion is equivalent for the vertical and horizontal components. For a wide frequency range (0.2-20 Hz), the spectral ratio of the horizontal and vertical components of motion at the bottom of the layer is close the unity:

$$H_B / V_B = 1$$

- In these conditions, the spectral ratio between the horizontal and vertical components of the background noise recorded at the surface of a soft layer enables the effects of the Rayleigh waves (E_{RW}) to be eliminated, conserving only the effects resulting from the geological structure of the site (Bour et al. 1998):

$$SE = \frac{SR}{E_{RW}} = \frac{H_S}{V_S}$$

Many theoretical and experimental studies have shown that the spectral ratio called as H/V spectral ratio obtained in this manner enables an adequate determination of the site fundamental frequency. However, Nakamura method does not seem to be able to provide all the information required for a reliable estimation of the amplification of surface ground motion (Bour et al. 1998).

EXPERIMENTAL MEASUREMENTS

The experimental study was undertaken over a region of 4 km^2 in the Shin-Yokohama area, the northern part of Yokohama city. All the measurement points (114 in all) in the experiment are shown on the map in Figure 1.

The equipment used comprises an UP-255s, 3-component velocity seismometer with amplifier UPS-T3 and NS/A type PC as a data recorder. Natural periods of sensors are 1.0 s. In this experiment, the recording system operated continuously for about 10 min. The recorder includes a GPS system so that the geographic position of each measurement point is precisely known (Fig. 1). Microtremors recording were done every 100 meters between points and sampling rate was 100 Hz. Duration of each recording sample is 180 s. For each measurement points, the following procedures were applied:

- Each record was converted from binary to ASCII records (for Micplot).
- Waveforms were drawn by using MicPlot Version 1.1 for UNIX
- Fast Fourier Transform (FTT) was applied to 2000 point windows (It was advisable picking out 20 s data length bearing in mind best quality of data in terms of noise), so that 2048 data were registered after Fast Fourier Transform.
- For analyzing the data band-width for smoothing was chosen as 0.3 Hz.
- Velocity Spectrum was performed.
- Calculation of the H/V spectral ratios, defined by:

$$\sqrt{(NS^2 + EW^2} / V$$

Some spectra have two peaks with different amplitude. One of them has shorter period with higher amplitude and the other one has longer period with smaller amplitude. The peak with the highest amplitude was defined as predominant period. The longest peak was defined among peaks. Some spectrum has only one highest peak (Fig. 2). According to Nakamura (1989), H/V spectral ratio is considered as amplification factor that means transfer function due to surface layers.

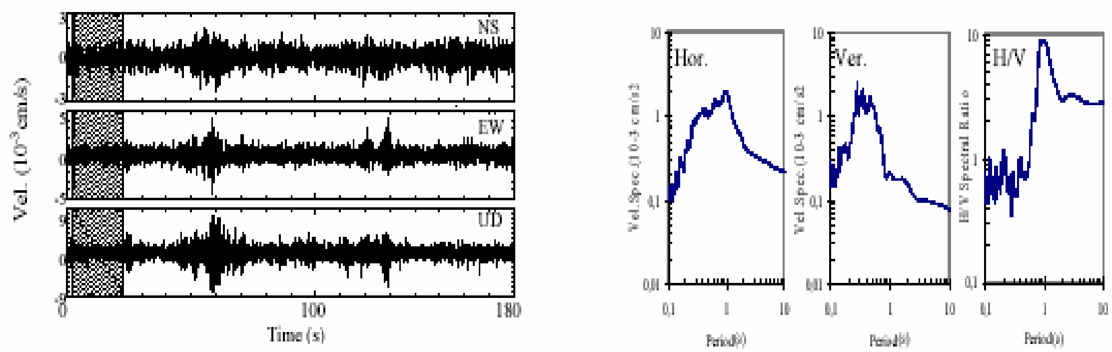

Figure 2. Observed microtremors (left) and the Fourier spectra (right) at the reference site

Dense Measurements of Microtremors

We mainly produced four maps. The first one, longest period distribution map was made by considering the longest periods (Fig. 3). Second is predominant period distribution map and was generated by predominant periods (Fig. 4). Third distribution map produced from peak periods using H/V spectral ratios (Fig. 5) and finally the last map produced by considering the highest amplitudes values (Fig. 6).

The size of each circles in the figures are associated with a period range as indicated the larger circles correspond to larger period or higher amplitude. According to the map of longer period distribution, there is confusion in the hilly zone. In such areas, short period distribution be expected but at that point, microseisms could be taken into account as microtremors with the longer period (Fig. 3). As for predominant period map, also the period in the hilly zone turned out to be evaluated much longer. The principle component in the hilly zone could be obviously microseisms (Fig. 4). For the period distribution map from H/V spectral ratios, microseisms in the hilly zone were eliminated. In addition to that, the long period zones coincide with the soft soil (flat) zone, whereas the hard and hill zones show short period. Although in some places in the hill zone long period has been found; this probably indicates the existence of local artificial soil deposits (Fig. 5). The highest amplitude distribution map showed that on hill amplitude zone is smaller than that of flat zone (Fig. 6). Kanai also took amplitude evaluation of soil condition into account. According to Kanai (1961), the predominant period of the short period appears on a very thick soft ground, because such ground consisted of plural layers and the influence of the uppermost layer is remarkable. The period distribution curves on fresh rock, bed rock and sand hill, show very long period, but amplitude is always very small. The comparison of Figure 3 (the longer period distribution map) and Figure 4 (the predominant period distribution map) shows that the period of the hill zone looks much longer than that of flat zone.

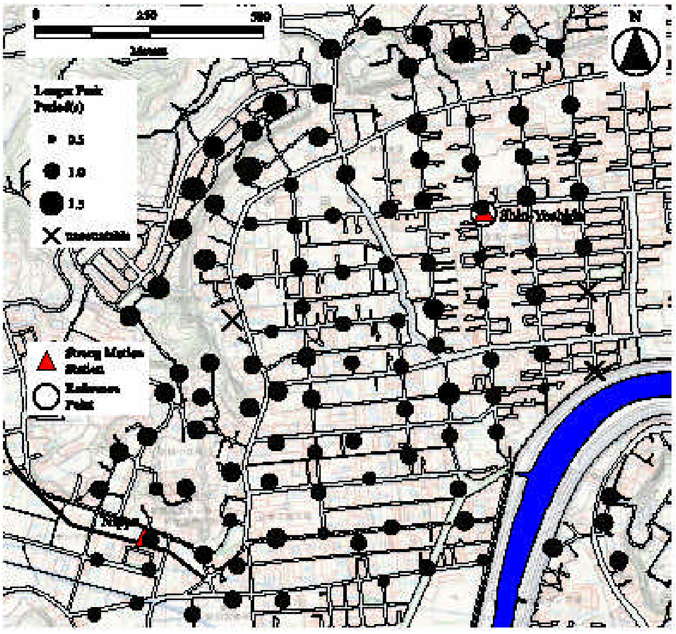

Figure 3. Longer period distribution map

Fundamental Characteristics of Weak Ground Motion at Reference Site

Three sets of earthquake ground motion records (deep, intermediate, shallow earthquake, respectively) were obtained recently at a strong motion stations, Shin-Yoshida and Nippa, are examined here. These earthquake records were obtained during the July 1997 Chiba earthquake (M=5.3), that is called as 97Eq, the February 2000 Yamanashi earthquake (M=4.6) that is called as 00Eq and the May 1998 Izu Peninsula earthquake (M=5.1) that is called as 98Eq, respectively. General information about these three events is presented in Table 1. Time histories and Fourier spectra for each motion are shown in Figure 7. The 98Eq at Shin-Yoshida station has longer period and contains mainly surface wave but the deep and intermediate earthquakes have shorter period. In addition to that, waveforms of Shin-Yoshida were compared with wave forms of Nippa Station (Fig. 7).

After comparison, through the analysis, it was concluded that Shin-Yoshida has longer period than Nippa.

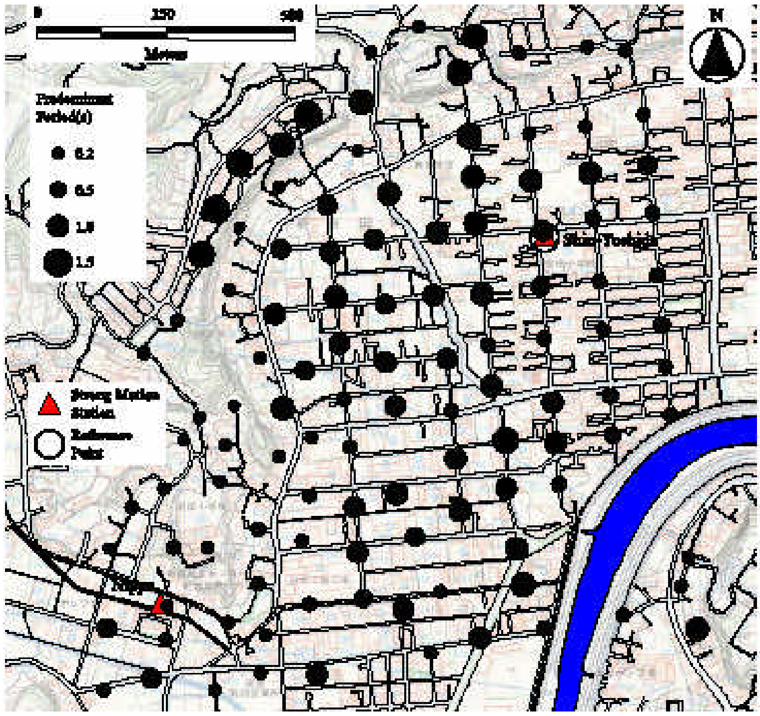

Figure 4. Predominant period distribution map

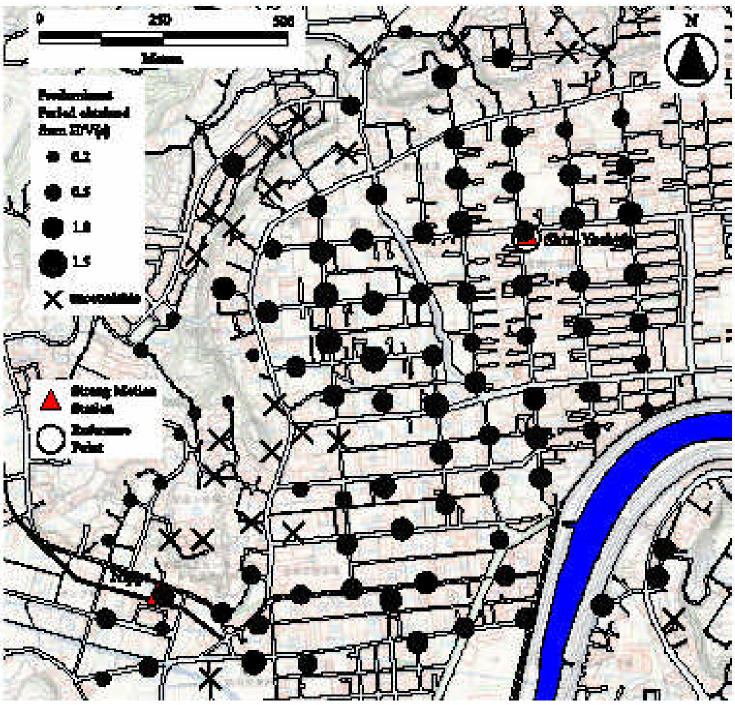

Figure 5. Period distribution map from H/V spectral ratio

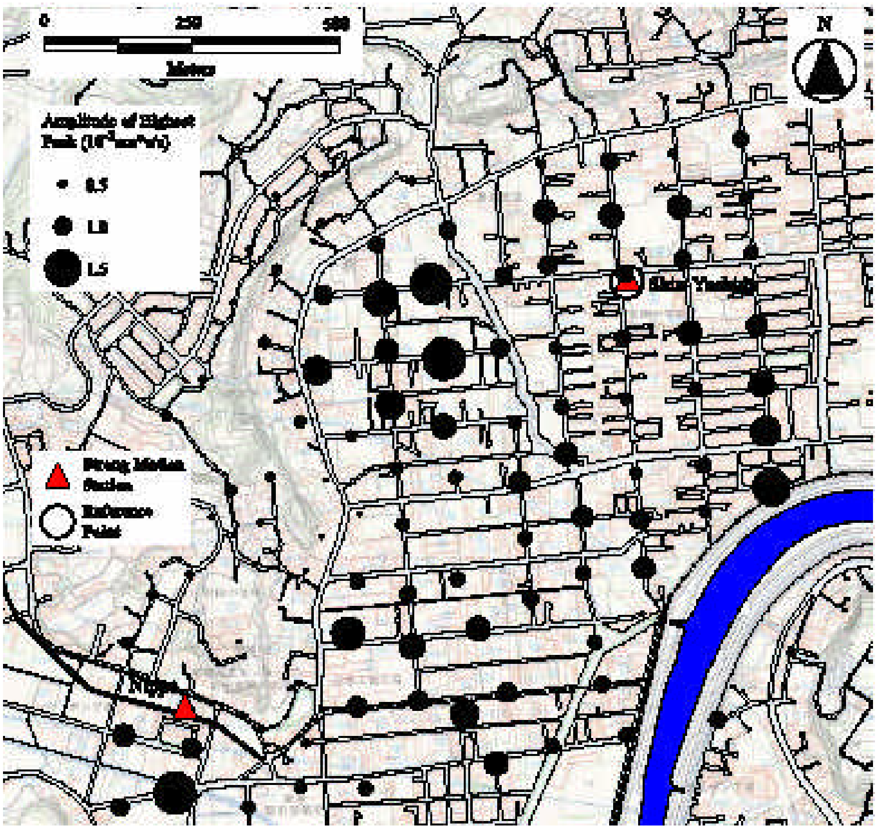

Figure 6. Highest amplitude distribution map

Table.1: Earthquakes considered in this study as the Source Information

Region Name	Date	Time	Mw	Longitude	Latitude	Depth(km)
Chiba Prefecture	1997.07.09	18:36	5.3	140.156	35.555	74.3
Yamanashi Pref.	2000.02.11	20:57	4.6	139.05	35.49	15
Izu Peninsula	1998.05.03	11:09	5.1	139.154	34.961	6.9

We calculated site period characteristics using borehole data at the strong motion stations (Shin-Yoshida and Nippa). After that, the microtremor spectrum and transfer functions belong to strong motion stations were compared with earthquake velocity spectrum. The predominant period turned out to be the same, but the amplitudes are different at the Shin-Yoshida station (Fig. 8). So, we selected Shin-Yoshida station as reference site.

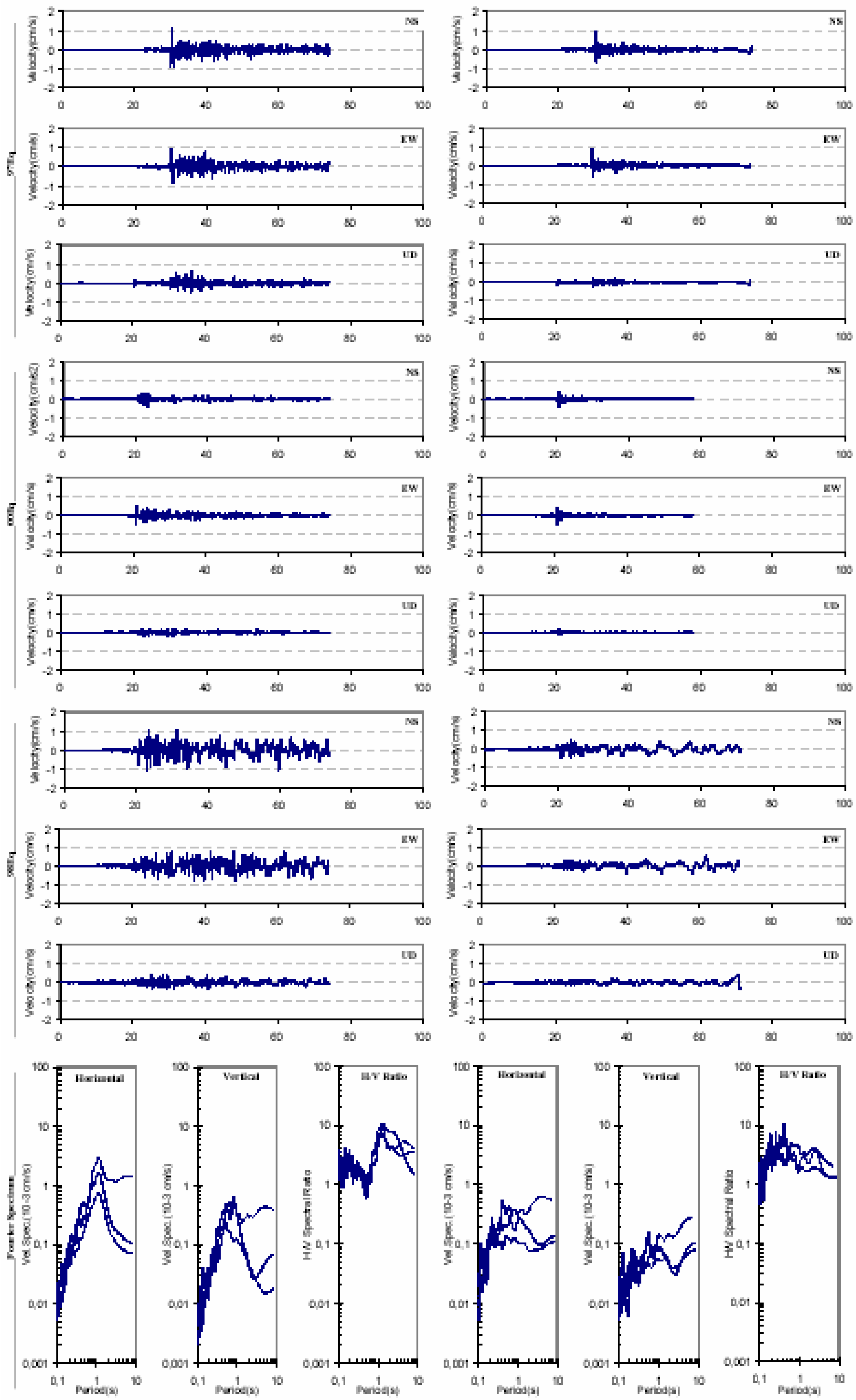

Figure 7. Velocity records and Fourier spectra of 97Eq(thin line), 00Eq (dashed) and 98Eq (dotted) at Shin-Yoshida station(left) and Nippa station(right).

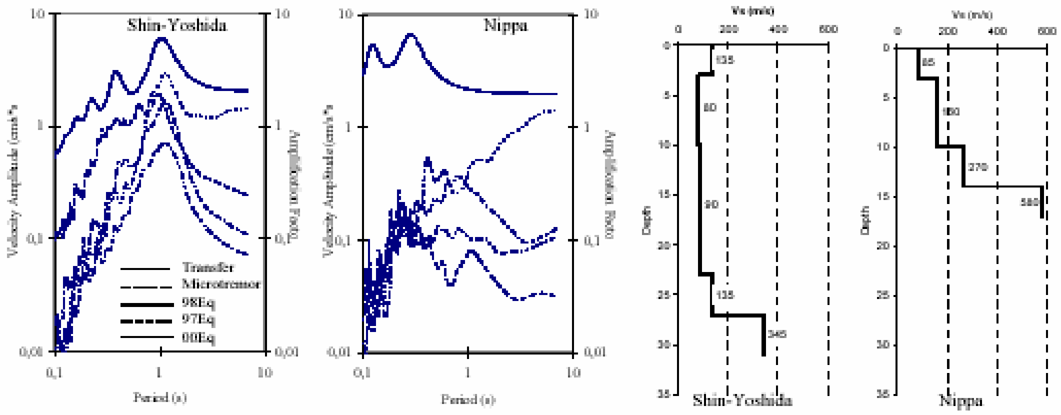

Figure 8. Comparison of the spectra obtained from the Earthquake and Microtremor with the calculated transfer function (left) obtained from log data (right)

ESTIMATION OF SEISMIC MOTION IN WIDE AREA

Kobayashi et al (1986) obtained spectral ratio of microtremors between an arbitrary site and referential strong motion site. They concluded that the product of the ratio and the spectrum of the strong motion at the reference site make predicted strong motion at arbitrary site. This method requires that the reference site should be in similar soil conditions with that the other site. The microtremor spectral ratio (H_A / H_R) were computed for each arbitrary site (H_A) to the reference site (H_R) for horizontal component. The 'pseudo-response spectrum' for 97Eq at the Shin-Yoshida reference site S_V as shown in Figure 9 was used as the reference. The seismic motion spectrum for each point were estimated by multiplying the (H_A / H_R) values to the response spectrum of the reference site as shown in Figure 9.

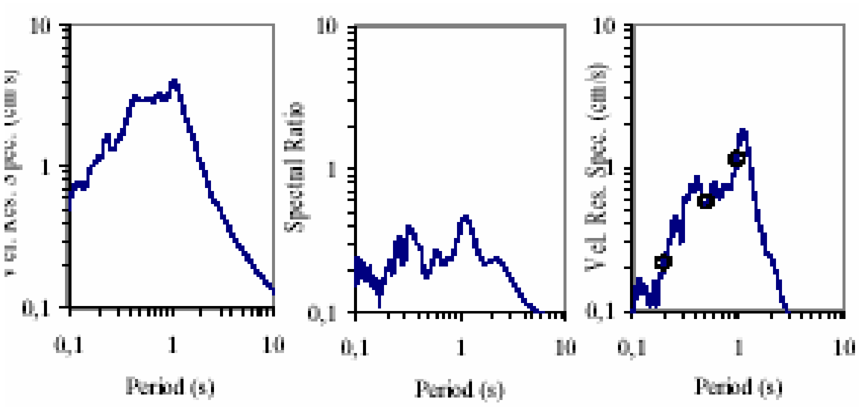

Figure 9. Velocity response spectrum at reference site (left), spectral ratio(center) and estimated velocity response spectrum at an arbitrary site (right)

The reason for picking those 0.2, 05, 1.0 seconds period in critical points (Fig. 9) was based on application to the type of buildings. 0.2 s is for wooden houses, 0.5 s is for reinforced concrete buildings, 1.0 s is for tall steel and concrete buildings.

As an example of the type of analysis performed, in Figure 10-a, b and c the seismic microzoning maps are presented. According to distribution of velocity response for 0.2 s period, it looks dangerous to construct wooden buildings on the flat zone considering the earthquake 97 Eq. As for velocity response for 0.5 s, flat zone of the eastern and south-eastern part of study area represent danger for reinforced concrete buildings. The last map for 1.0 sec, demonstrates that the southern part of flat zone over the study area and lowland of hilly zone in the north-western part of the study area represent the hazard for tall buildings. These three maps give the obvious reason to identify the region by velocity response spectrum analysis.

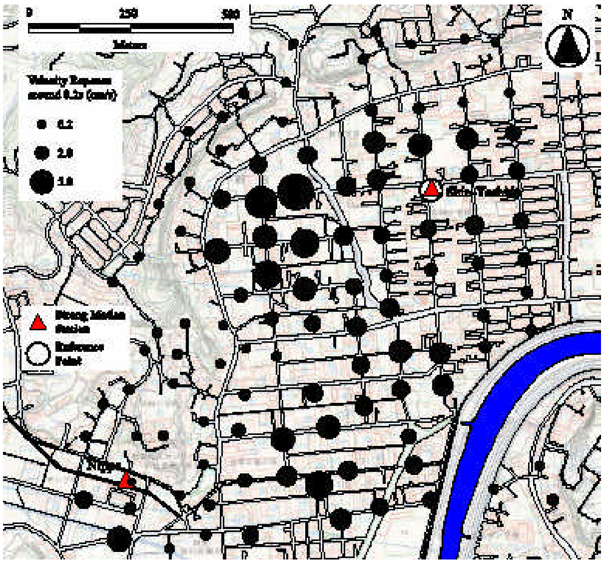

Figure 10. a) Distribution of maximum velocity response for 0.2 s.

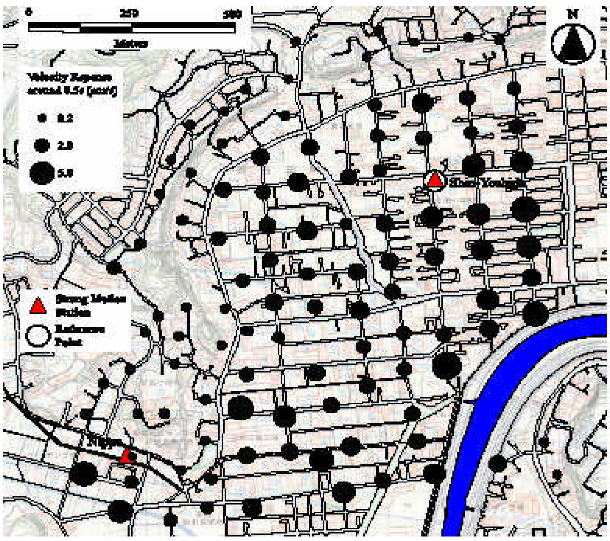

Figure 10. b) Distribution of maximum velocity response for 0.5 s.

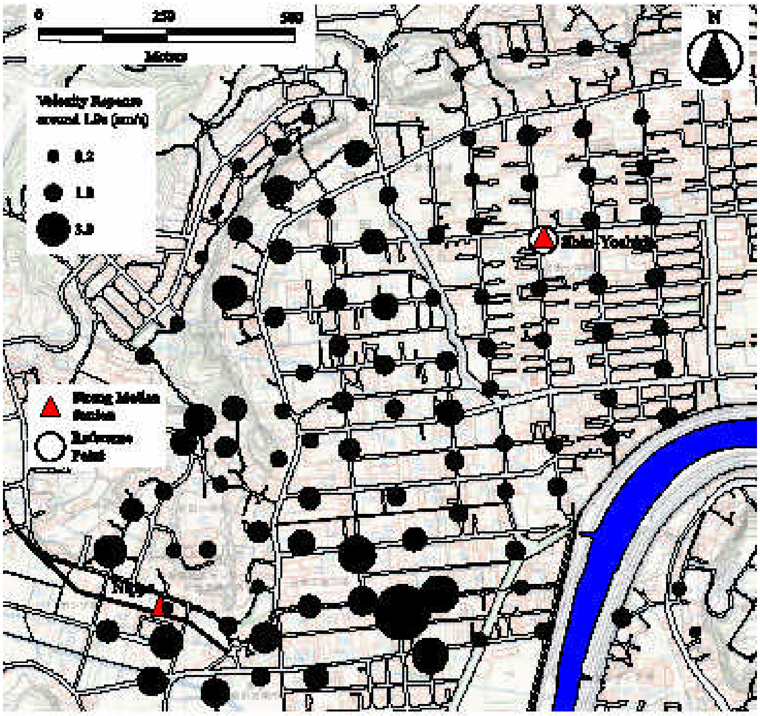

Figure 10. c) Distribution of maximum velocity response for 1.0 s.

DISCUSSION

As a result through investigation and significant observation of four above mentioned maps, it was found out that three zones appeared over the area of study: hilly, flat and intermediate zones. An intermediate zone is regarded as the transition zone between the lowland and the hilly zone. At the same time, that lowland of hilly zone is located adjacent to the flat zone. In hilly zone, the predominant period came up to around 1.0-1.5 s. Flat zone reaches the value of 0.6-1.0 s. And finally, as a result of careful observation, the intermediate zone seemed to have the value of 0.2-0.5 s. It was recommendable to compare the obtained value with the spectrum of earthquake properties and theoretical transfer function. And microtremor spectrum was in appropriate fitting with spectrum of earthquake peculiarities and theoretical transfer function. That fitting was important for the next estimation of ground motion at each point of the earthquake area. The result of fitting showed that the microtremors were the same as an earthquake motions at the same area in period characteristics.

The final three microzoning maps show the existence of risk at the same areas. Namely, wooden houses represent the certain risk at the flat zone of the central part of the area. There is a risk even for reinforced concrete buildings all the way through south eastward. At the same time, tall buildings have a certain risk all over the southern part of the researched area. Above-mentioned facts should be taken into consideration in engineering constructions.

Intermediate zone has a very interesting fact related to this research. Because we found a very small amplification in estimated earthquake ground motion in this area, we had an opportunity to communicate with residential people. They said ancient ages old people lived only in the area of this intermediate zone. The reason was that they noticed already that the area was very safe against earthquake disasters. Taking into consideration of the 1923 Kanto earthquake, for example, there was almost no damage around the intermediate zone. This fact looks very important for the disaster mitigation point of view. Nowadays, there is very dense population in all of the area. From that point of view, the situation seems to be very dangerous.

CONCLUSION

According to the result of the observations and analysis discussed before, the characteristics of microtremors are dependent on the type of deposits. At the same time, the amplitude is not stable. Site effect plays an important role in microtremors measurements. Presumably, the comparison of microtremors with both the earthquake peculiarities and the theoretical transfer function can be very beneficial and applied for engineering purpose, such for estimating site effects of strong ground motion. We were drawn experimental methods using microtremor recordings to establish a seismic microzonation. We showed that by comparison long period, predominant and H/V period distribution maps. H/V spectral ratio approach provides a simple means of determining the predominant frequency of a soil site. The H/V spectral ratio technique enabled us to establish a better distribution map of predominant frequency: this turned out to be a useful tool for establishing a seismic microzonation of the whole studied site.

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