OBSERVATION OF EARTHQUAKE RESPONSE
OF THICK SEDIMENTARY LAYERS

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SUMMARY

In order to estimate the response characteristics of sedimentary layers with a thickness of several kilometers during earthquakes, a tentative estimation procedure is proposed. This method is based both upon a model for estimating the spectral characteristics of the bedrock motions and upon a set of surface ground motion records for a specific region. The results obtained are compared with the response characteristics of the thick sedimentary layers obtained by the direct measurement of surface ground motion and bedrock motion by means of boreholes, and with the calculated wave-transfer function of the thick sedimentary layers for the SH-waves.

INTRODUCTION

To investigate the earthquake response of the alluvium, observation of the earthquake motions by using the seismometers installed both on the surface ground and under the alluvium by means of a borehole, has been carried out. As the thickness of the alluvium is a hundred meters at the outside in the Tokyo metropolitan area, borehole observation was practical and economical. During the last ten years, the earthquake response of the alluvium was investigated using borehole observation at many sites in this area.

Recently, in Japan, the pre-Tertiary basement has been recognized as being seismic bedrock. As a result, it has become necessary to investigate the earthquake response of thick sedimentary layers with a thickness of several kilometers on the bedrock. The method used tc investigate the earthquake response of the alluvium became impractical, however, because observation of earthquake motions in the pre-Tertiary basement by means of a borehole is expensive and difficult. Observation was thus restricted to the earthquake motions on the surface ground, and bedrock motions were observed at the only three sites.

Instead of using the data of the bedrock motions, which are directly observable by means of a deep borehole, it is economical and useful to use a model for estimating the spectral characteristics of the bedrock motions , if such model is available. In this report, as a tentative method of estimating the earthquake response of thick sedimentary layers, we examined a method that used the data of the surface ground motions and a model for estimating the spectral characteristics of bedrock motions. The response characteristics R(T) of the thick sedimentary layers are defined as

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$$R(T) = SV_o(T)/SV_i(T),$$

where $SV_i(T)$ and $SV_o(T)$ are the zero-damped velocity response spectra at the time T of the bedrock motion and the surface ground motion, respectively. $SV_i(T)$ is obtained from the prediction model and $SV_o(T)$ is obtained from the data observed on the surface ground. The purpose of the report is to estimate the regional average of R(T) by using the above-mentioned tentative method and to compare the estimated results with the observed results of $SV_o(T)/SV_i(T)$ obtained by the data from the seismometers installed both at the bottom of deep boreholes and on the surface ground.

METHOD

The response characteristics of the thick sedimentary layers is estimated by the following relation;

$$R(T) = \frac{1}{K} \sum_{n=1}^{K} SV_o(T;\ M,\ R_n)/SV_i(T;\ M,\ \overline{R}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where

$$\overline{R} = \frac{1}{K} \sum_{n=1}^{K} R_n$$

is the average hypocentral distance to the array observation and the hypocentral distance of the n-th site is denoted as R_n. In relation (1), $SV_o(T;\ M,\ R_n)$ is the zero-damped velocity response spectrum of the data obtained at the n-th site and $SV_i(T;\ M,\ \overline{R})$ is the estimated zero-damped velocity response spectrum of the bedrock motion with an earthquake magnitude M and a hypocentral distance $\overline{R}$. Estimated R(T) means the regional average of the thick sedimentary layers in this area where the array observation sites are situated.

The zero-damped velocity response spectrum $SV_i(T;\ M,\ R)$ of the bedrock motion is estimated by the following relation;

$$SV_i(T;\ M,\ R) = 10^{a(T)M - b(T)\log_{10} R + c(T)}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The coefficients a(T), b(T), and c(T) at each period T, are given in Figure 1. The results in Figure 1 were obtained from the acceleration data observed at the bottom of deep boreholes in the three sites shown in Figure 2; Iwatsuki (IWT, G.L.-3510m), Shimohsa (SHM, G.L.-2310m), and Fuchu (FCH, G.L.-2750m).

RESULTS

The region for estimation of R(T) is limitted to the Fuchu area, west of Tokyo (See Figure 2). In this area, a simple array observation shown in Figure 3, has been made. Average response characteristics of the thick sedimentary layers in this area were estimated by using the horizontal component data recorded at FCH, ING, KFC, HFC TMA and CHF during an earthquake on February 27, 1983. Figure 4 shows the observed velocity waves. Such records are transformed into acceleration waves. The regional average SV_o of twelve horizontal components and the SV_i estimated from the the relation (2) are shown in Figure 6. The SV_i was calculated by using $M = 6.0$ and $\overline{R} = 100$ km. The regional average R(T) is shown in Figure 7. The hypocentral distance R_n of the n-th site is in the range of $|R_n - \overline{R}| < 3$ km for all sites.

DISCUSSION

Discussion is to be narrowed down to the evaluation of the R(T) obtained in the preceding section. Comparison will be made between R(T) and G(T) or $G_1(T)$: G(T) is the ratio of two zero-damped velocity response spectra, namely, those calculated from the acceleration data of the surface ground motions and the bedrock motions at the site of FCH, and $G_1(T)$ is the response characteristics of the thick sedimentary layers for the SH-waves at FCH.

The estimated G(T) is shown in Figure 7. The G(T) is the average of two zero-damped velocity response spectrum's ratios. The data for calculation of the zero-damped velocity response spectra were obtained from two earthquakes; the dates of the earthquakes are September 24, 1980 ($M = 5.4$) and September 25, 1980 ($M = 6.1$) (See Table 1). Figure 8 shows the acceleration waves of the N48°E-component obtained at the site of FCH during the earthquake on September 25, 1980. Good concordance of the R(T) and the G(T) is seen in periods of more than 0.5 s.

In addition, as the primary approximation of the response characteristics of the thick sedimentary layers, the wave-transfer function for the obliquely incident SH-waves was well used. The $G_1(T)$ is calculated based upon the three parameters, the velocity structure of the thick sedimentary layers and the bedrock, the internal damping factor for the layers, and the incident angle in the bedrock. At the site of FCH, the velocity structure of the thick sedimentary layers and the bedrock, and the internal damping factor of the S-waves for the layers were investigated. The velocity structure of the S-waves is shown in Table 2 (Ref. 1). The internal damping factor was estimated as 0.01T for the period of from 0.5 to 5 seconds by one of the authors (Ref. 2). Therefore, the $G_1(T)$ was calculated if the incident angle θ in the bedrock had been estimated. The incident angle in the bedrock was roughly estimated from the phase velocity V_c as

$$\theta = \sin^{-1}(V_b/V_c),$$

where V_b denotes the S-wave velocity in the bedrock. The phase velocity is estimated from the peak point of the frequency-wavenumber spectra obtained by using the array observation data. The frequency-wavenumber spectra obtained by using the transverse component data recorded during the earthquake of February 27, 1983 is shown in Figure 9. The data section corresponding to the S-wave in this figure was used for calculation. As V_b is about 2.5 km/s and V_c is estimated as about 6 km/s from Figure 9, the incident angle is estimated as $15° \sim 25°$. In Figure 7, the $G_1(T)$ is calculated by using the incident angle of 20°. The G(T) will be interpreted as indicative that the $G_1(T)$ has become smooth.

The above discussion indicates that the R(T) obtained by our tentative method represents the regional response characteristics of the thick sedimentary layers in this area and also approximately the wave-transfer function for the SH-waves in periods of more than 0.5 s.

CONCLUSION

Based upon the model used to estimate the spectral characteristics of the bedrock motions, we estimated the response characteristics of sedimentary layers with a thickness of several kilometers during an earthquake , by using the array data in a specific region. In the present report, a tentative estimation was made for the simple array observation data on the surface ground in the Fuchu area, west of Tokyo, where the velocity structure of the S-waves and the internal damping factor of the S-waves for the thick sedimentary layers had already been investigated. The results obtained indicate that our tentative method may be used to estimate the response characteristics of the thick sedimentary layers in the Tokyo metropolitan area. The method is considered an application of the small-scale mobile array observation system.

REFERENCES

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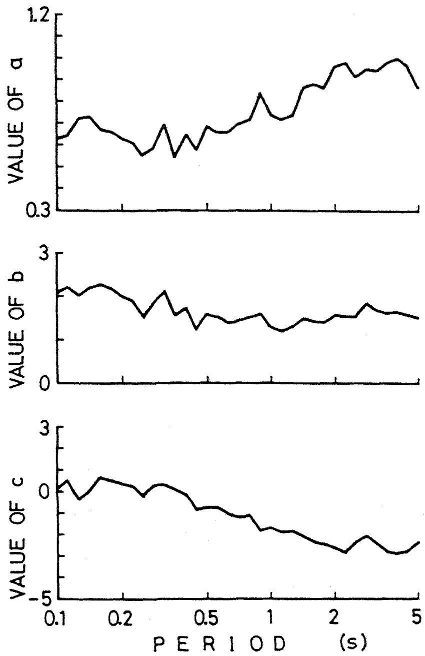

Figure 1. Values of coefficients a, b, and c versus period.

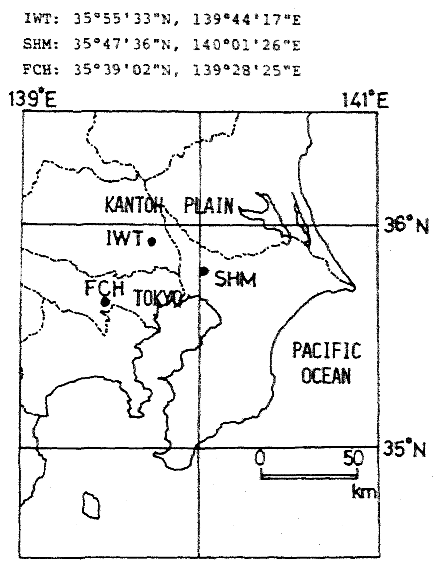

Figure 2. Locations of the three observatories.

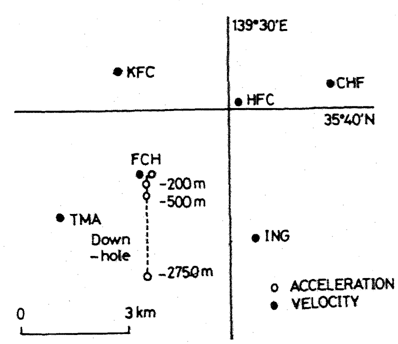

Figure 3. Layout of seismometers at the Fuchu area.

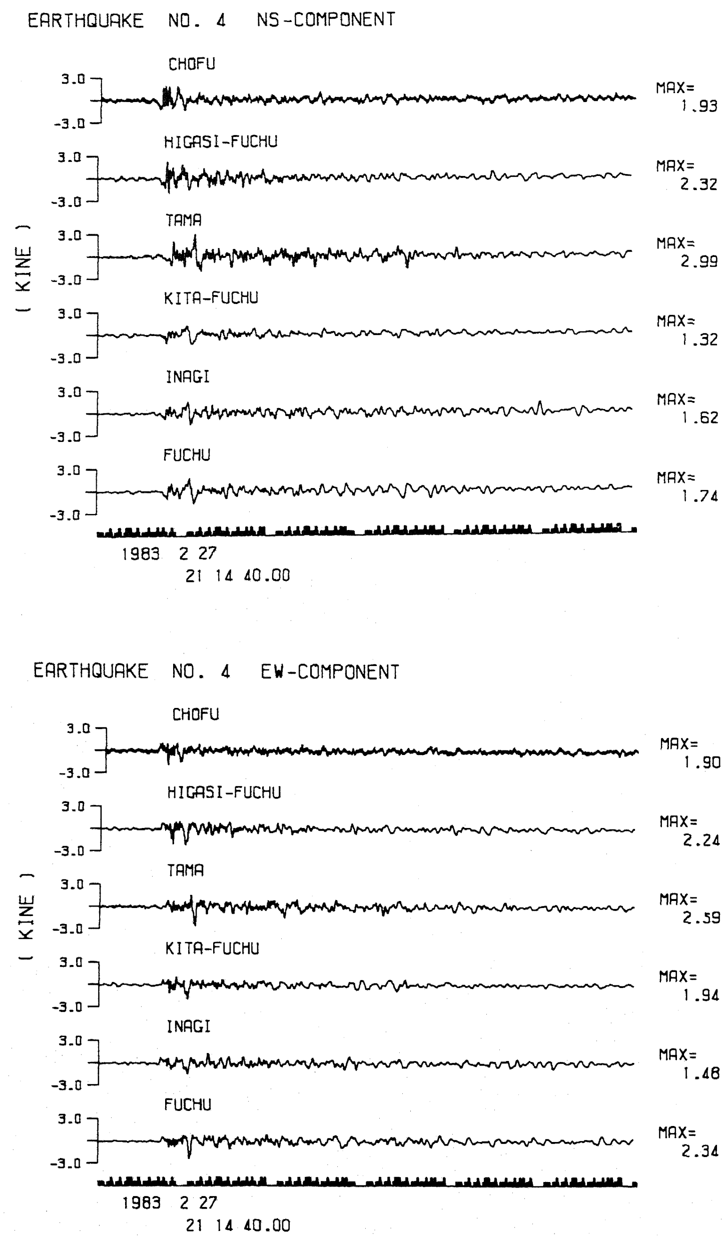

Figure 4. Velocity waves obtained by the horizontal array observation shown in Figure 3.

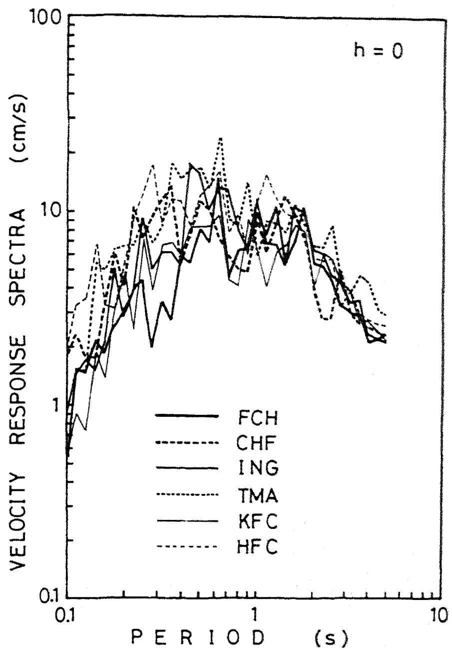

Figure 5. Zero-damped velocity response spectra of the data shown in Figure 4. (NS-component)

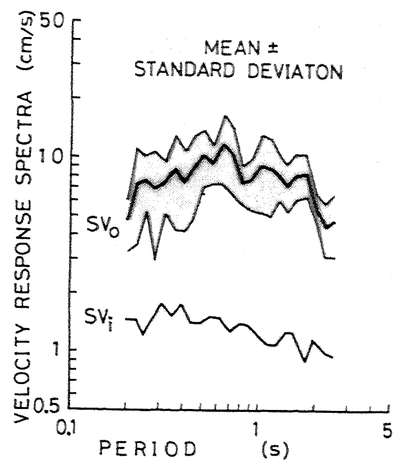

Figure 6. Regional average of zero-damped velocity response spectrum SV_o and estimated response spectrum SV_i of the bedrock motion.

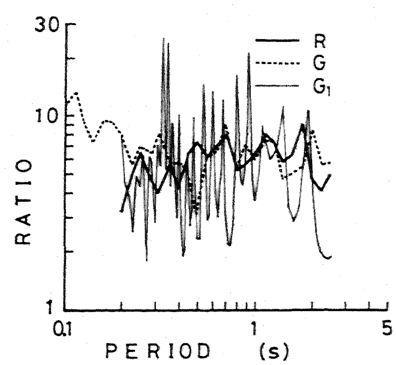

Figure 7. Three response functions for the response characteristics of the thick sedimentary layers.

Date	Latitude	Longitude	Depth (km)	Magnitude
Sep. 24, 1980	35° 58'	139° 48'	80	5.4
Sep. 25, 1980	35° 31'	140° 13'	80	6.1
Feb. 27, 1983	35° 56'	140° 09'	70	6.1

Table 1. Earthquake data.

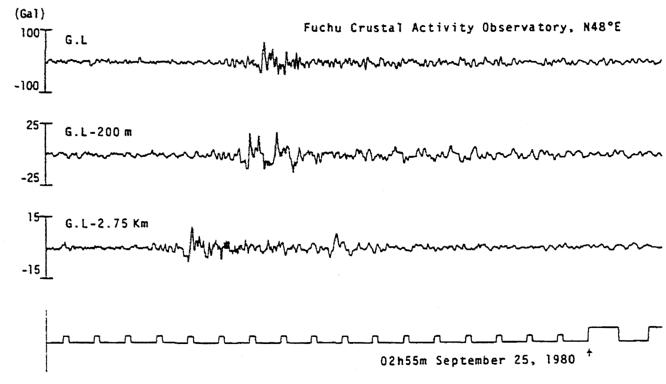

Figure 8.

Acceleration waves obtained by the vertical array observation at the site of FCH.

No.	Thickness (m)	Velocity (m/s)	Density (t/m^3)
1	4	140	1.7
2	12	350	1.8
3	6	420	1.8
4	22	360	1.8
5	6	530	1.8
6	6	600	1.9
7	20	440	1.8
8	14	460	1.9
9	115	540	2.0
10	856	780	2.0
11	963	1190	2.2
12	726	2530	2.5
13		2530	2.5

Table 2. Velocity structure of the S-waves at the site of FCH. (after Yamamizu et al., 1981)

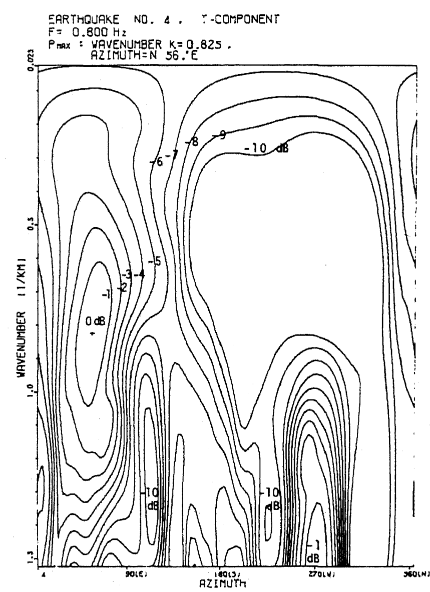

Figure 9. Estimated frequency-wavenumber spectrum (f = 0.8 Hz).