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THE CHARACTERISTICS OF UNDERGROUND EARTHQUAKE MOTIONS OBSERVED IN THE MUD STONE LAYER IN TOKYO

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SUMMARY

In this paper, a number of earthquakes which have occurred around Tokyo are classified into eight focal regions and the characteristics of underground earthquake motions are investigated using the velocity response spectra of both the horizontal and vertical components for each of the regions. The response spectra for the largest earthquake expected to occur in each of the regions are also compared with those of design earthquake motions currently being used for aseismic designs. The shapes of the spectra in each region are shown to be different, and the envelope curve of the velocity response spectra of the largest earthquakes in each region is found to be lower than those of the design earthquake motions.

INTRODUCTION

The authors have conducted underground earthquake observations in the center of Tokyo since 1972, in order to determine typical earthquake motions which should be considered in the aseismic design of structures built in Tokyo. The observation stations were Uchisaiwai-cho in Chiyoda-ward, Toyosu and Etchujima in Koto-ward, and Shibaura in Minato-ward. At Shibaura, we have collected and digitized 44 earthquake records which occurred between July 1976 and December 1980 and at Etchujima, 129 earthquake records which occurred between October 1982 and May 1988. These data show a wide variation in seismic magnitude, hypocentral distance and focal regions. After we had compared the maximum accelerations, maximum velocities and response spectra of the earthquake motions collected at these different stations, it became clear that the earthquake motions observed in the mud stone layer with an S wave velocity of about 500 m/s are not much affected by the surface layer, and that we can consider that layer as the common base-layer in the center of Tokyo (Ref. 1).

OUTLINE OF OBSERVED DATA AND FOCAL REGIONS

The accelerograms used in this analysis were collected in the lowlands of Tokyo, at GL-60m in Shibaura and at GL-100m in Etchujima. These two stations are about 3.7km apart. The soil profiles of both stations are shown in Fig.1. The observation points are located in the mud stone layer with an S wave velocity of about 500m/s, which is generally used as a bearing stratum for high-rise buildings in Tokyo. 173 earthquake records have been collected at both stations. As has already been noted, the maximum amplitude or spectral characteristics of

Table 1 Focal Regions and Earthquake Data Used in This Analysis

No.	Focal Region	Mj	X (km)	$\bar{X}$ (km)	Components Horiz.	Components Vert.
1	N or Central Chiba Pref., E Tokyo Pref., N Tokyo Bay	4.0-6.1	60-100	78	55	24
2	SW or S Ibaragi Pref., Saitama chiba Border Region	4.2-6.0	68- 99	82	45	22
3	Central Kanagawa Pref., E Yamanashi Pref., Central Saitama Pref., Kanagawa Yamanashi Border Region	4.4-6.0	59- 82	70	10	5
4	E off Ibaragi Pref., E off Fukushima Pref.	5.0-5.9	133-206	166	24	-
5	N or W Nagano Pref.	5.6-6.8	198-211	205	8	-
6	Near Miyakejima Island	5.3-6.4	188-216	203	6	-
7	Around Izu Peninsula	5.4-7.0	95-130	114	12	-
8	SE off Boso Peninsula, E off Chiba Pref.	5.0-6.7	83-163	124	20	-

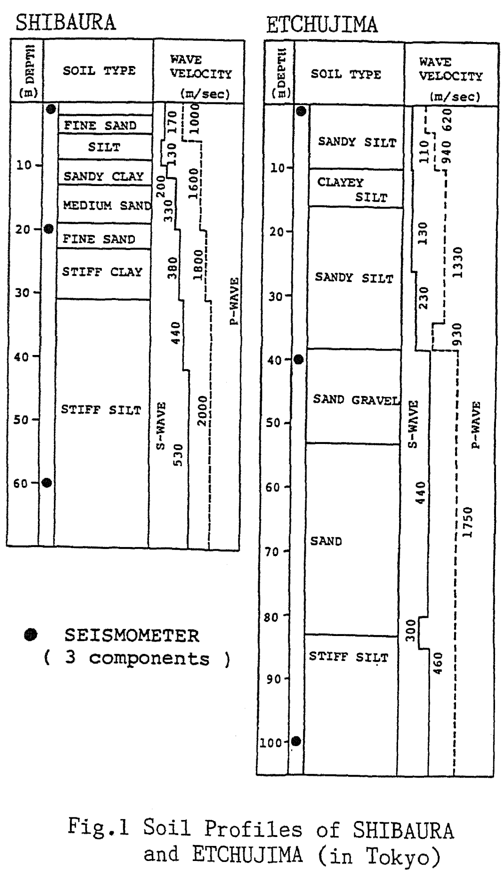

Fig.1 Soil Profiles of SHIBAURA and ETCHUJIMA (in Tokyo)

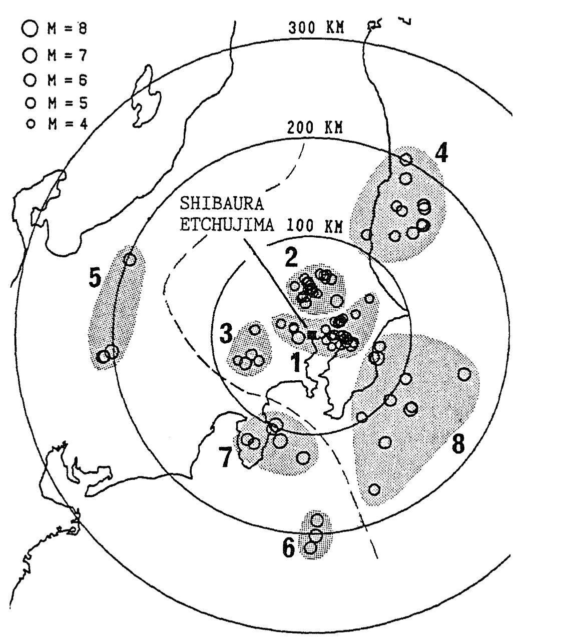

Fig.2 Epicenters of Earthquakes and Focal Regions (Numbers in this map correspond to those of focal regions as shown in Table 1)

earthquake motions in a classified focal region are similar (Ref. 2).

In this study, in order to consider the aseismic design of structures built in Tokyo, we chose the earthquake motions which occurred within an epicentral distance of about 200km, classified them into eight focal clusters as shown in Fig.2, and investigated the characteristics of the velocity response spectra, Sv, of each region. 180 horizontal components of ground motion from 92 earthquakes and 51 vertical components from 51 earthquakes were selected for this study. Table 1 shows the seismic magnitudes, hypocentral distances and the number of components of the earthquakes in each region. Region 1 is the nearest to Tokyo, of the so-called just-under-seated type. Regions 2 and 3 are inland, and within 100km of Tokyo. Regions 4 to 8 are farther away from Tokyo. Fig.3 shows the relationship between the epicentral distances and the focal depths of the earthquakes used in this analysis. The earthquakes in region 1 are located at relatively deep points, almost directly below the measuring stations. On the other hand the earthquakes in regions 5 to 7 are shallower and almost horizontal.

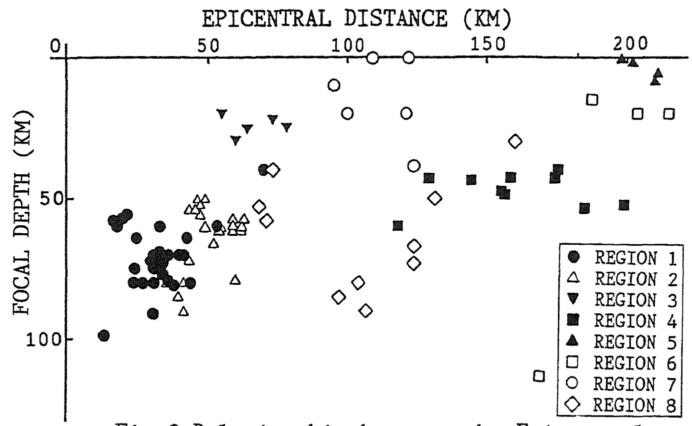

Fig.3 Relationship between the Epicentral Distances and the Focal Depths

CHARACTERISTICS OF HORIZONTAL SPECTRA

The velocity response spectra, Sv, for horizontal motions were calculated in the period range 0.1-10.0 seconds with a damping ratio, h, of 0.05. Responses were also calculated for the whole recorded duration, in order to estimate the effect of earthquake motions on structures.

Mean Response Spectra   Fig.4 shows the mean velocity response spectra of each region, which are normalized using the spectral intensity (period 0.1-2.5 seconds, h=0.05). Clearly, the shapes of the Sv can be divided roughly into two groups. The spectra of the northern and western parts of Nagano prefecture (region 5), the area near Miyakejima Island (region 6) and the area around the Izu Peninsula (region 7), whose focal depths are relatively shallow and whose predominant periods are rather long , are similar but differ from the spectra of the other five regions. In order to investigate the characteristics of spectra whose shapes differ from region to region, it is necessary to regress Sv for each region, or to introduce new parameters which demonstrate the differences between the characteristics.

Regression of the Velocity Response Spectra   As the focal regions can be roughly divided into two groups, we first estimated Sv of these two groups using the multiple regression analysis. Group A consists of the regions 1 to 4 and 8, and includes 154 components from 75 earthquakes. Group B consists of the regions 5, 6 and 7, whose predominant periods are rather long, and includes 26 components from 17 earthquakes.
The well known regression formula used in this analysis is as follows :

$$\log Sv(T) = a(T) M + b(T) \log X + c(T) \tag{1}$$

where $a(T)$, $b(T)$, $c(T)$: partial regression coefficients with regard to the seismic magnitude M, the hypocentral distance X, the residual respectively

$Sv(T)$: regressed velocity response spectrum

From the results, a(T), of both groups, with regard to M are distributed in the range 0.5-1.0. The multiple correlation coefficient of Group A is greater than 0.7 for periods longer than 0.3 second, and that of Group B is generally over 0.7 for the whole period range.

Figs. 5(1)-(2) show the results of multiple regression analyses of Sv for these two groups. The results for Group A, with an Sv of M5,6,7 and an epicentral distance of 50km (broken lines), and with an Sv of M6,7,8 and an epicentral distance of 100km (solid lines) are shown in Fig. 5(1). The results for Group B, with an Sv of M6,7,8 and an epicentral distance of 100km are shown in Fig.5(2), where earthquakes with epicentral distances less than 100km are not included in this group. It is clear from Figs.5(1)-(2) that the shapes of the spectra of these two groups are different. The spectra of Group A are superior in the period range 0.1-4 seconds, and those of Group B are superior in the period range 4-10 seconds. Thus the period characteristics and the spectral amplitudes for each group should be treated separately in the aseismic design of buildings.

Regression of Sv for Each Region In order to investigate the characteristics of Sv in detail, we regressed Sv for each of the eight regions. The velocity response spectra for the largest earthquake in each of the regions were estimated using the magnitude of largest historical earthquakes in the region. Table 2 shows the magnitudes and the name of the large earthquakes used in this analysis. The great Kanto Earthquakes in 1703(M7.9-8.2) and 1923(M7.9) were excluded as they exceed the permissible range of extrapolation from observed data. The results are shown in Fig.6. Every spectrum is different and shows the characteristics of each region. The envelope curve is similar to the spectrum of M8.0 with an X of 100km in Group A, as shown in Fig.5(1). In the period range 0.5-3 seconds, the earthquake with an Sv of M7.2 in region 2(Ibaragi prefecture) is the largest, and in the range 8-10 seconds, that with an Sv of M7.3 in region 7(around the Izu Peninsula) is larger than the other spectra.

The envelope curve of the Sv was then compared with the Sv of design earthquake motions currently being used for aseismic design (e.g. EL CENTRO 1940). The results are shown in Fig.7. The design earthquake motions were normalized to a max. of 50cm/s, they are often used for elasto-plastic response analysis of high rise buildings in Japan. The spectra for the large historical earthquakes are lower than those used for design, and is equivalent to the Sv normalized to a max. of 25cm/s, which are used for elastic analysis.

Table 2 The Largest Historical Earthquake in Each Region

Region No.	Origin Date	Earthquake Name	M
Region 1	1855.11.11	The Edo Earthquake	7.0
Region 2	1895. 1.18		7.2
Region 3	1924. 1.15	An Aftershock of the Great Kanto Earthquake	7.3
Region 4	1938.11. 5	The Fukushima-Ken-Toho-Oki Earthquake	7.5
Region 7	1930.11.26	The Kita-Izu Earthquake	7.3
Region 8	1923. 9. 2	An Aftershock of the Great Kanto Earthquake	7.3

CHARACTERISTICS OF VERTICAL SPECTRA

The characteristics of vertical motions were investigated for the focal regions 1,2 and 3, whose epicentral distances are within 100km of Tokyo. The Sv for vertical motions were calculated in the period range 0.05-5.0 seconds with a damping ratio, h, of 0.05.

Figs. 8(1)-(3) show the regressed vertical Sv of M5,6,7 at the average epicentral distance of each region. The horizontal Sv are also shown in these figures using broken lines. Generally, the vertical Sv of region 2 are larger than those of the other two regions, but in the period range 0.05–0.5 seconds, the Sv of region 1 are larger. The amplitudes of the vertical Sv are generally half to one-thirds of those of the horizontal Sv, and the differences are larger for periods longer than 1 second. For focal region 3, the amplitudes of the vertical Sv are almost as large as those of the horizontal Sv in the period range 0.5–1 seconds, and it is evident from this figure that we cannot neglect the vertical motions.

Therefore, study of the vertical components of earthquake motions should be an important factor, when considering the vertical responses of high-rise buildings or long-spanned slabs.

CONCLUSION

Classifying earthquakes into focal regions and estimating the velocity response spectra, Sv, for the largest earthquake in each of the regions, were found to be effective in determining typical earthquake motions for the aseismic design of buildings. In addition, study of the vertical components of earthquake motions was found to be an important factor when considering aseismic design.

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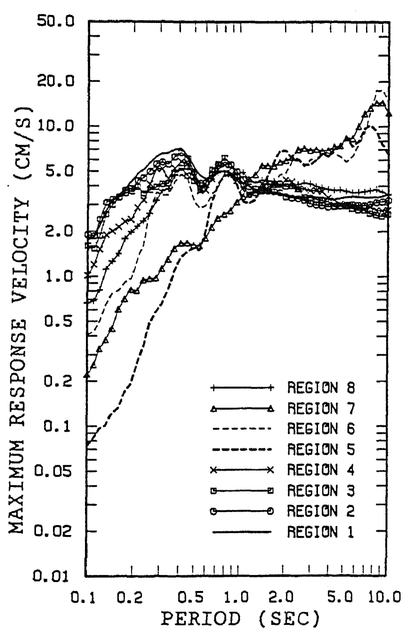
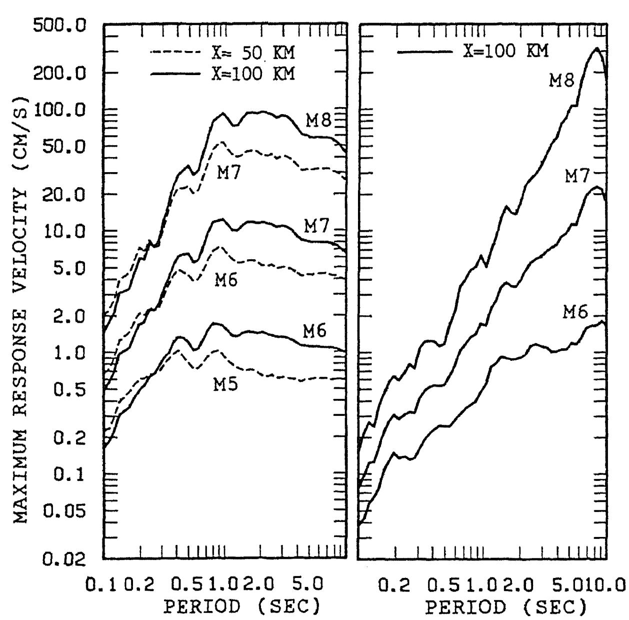


Fig.4 The Mean Velocity Response Spectra for Each of the Eight Focal Regions



(1) Sv for Group A (2) Sv for Group B

Fig.5 Regression Results for Group A and B

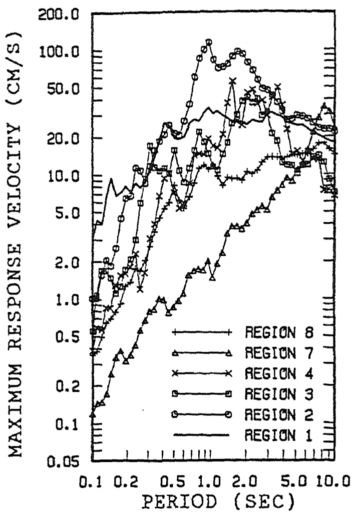


Fig.6 The Sv of the Largest Earthquake Motion in Each of the Region

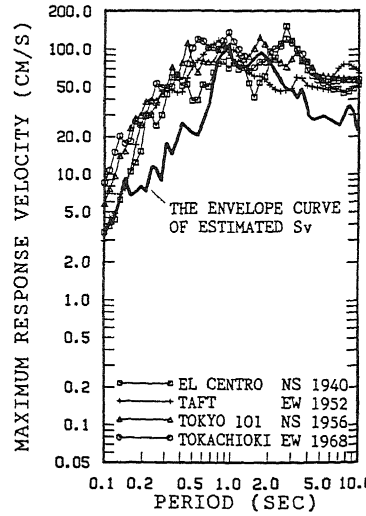
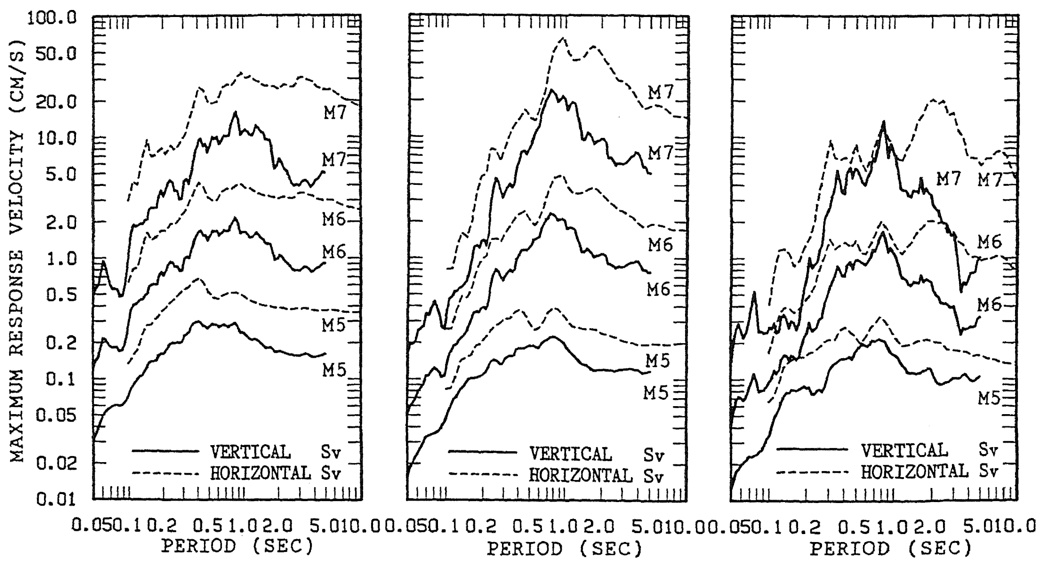


Fig.7 Comparison of the Estimated Sv with those of Design Earthquake Motions



(1) Region 1 (2) Region 2 (3) Region 3

Fig.8 Comparison of the Vertical Sv with the Horizontal Sv

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