A STUDY ON EVALUATION OF INTENSITY OF EARTHQUAKE ROCK MOTION ON THE BASIS OF ACCELEROGRAMS BY SEISMOLOGICAL ARRAY OBSERVATION

Sumio Nagahashi (I)

SUMMARY

The characteristics with respect to the intensities of the earthquake rock motions are studied by the seismological array observation system, which was established at the four rock sites surrounding the Metropolitan Area of Japan. At first, the empirical formula of the intensity of rock motion is proposed in frequency domain. Next, by the use of this empirical formula, the earthquake magnitude for the intensities of earthquake motion in high frequency range is represented in frequency domain. Then, in conclusion, this representation is applied to evaluate the source characteristics of the earthquakes occurred in and near the southern Kanto district, Japan.

INTRODUCTION

It is a very important problem, especially from the point of view of aseismic engineering, to predict the intensities of ground motions in their short period range by future earthquakes. It is very difficult at present, however, to predict the intensities in short period range with some appropriate accuracy, even though many investigations have been tried with the aid of semi-empirical methods or theoritical methods by the mathematical models with respect to source mechanism or stress field along earthquake fault. Then, it may be regarded as the most essential study to accumulate many accelerograms of strong motion and abstract quantitatively the characteristics of intensity of ground motion in relation to several kinds of physical parameters.

The Research Committee of Strong-Motion Earthquake Instrument Arrays on Rock Sites (Dr. Syun'itiro Omote; the chairman of the committee) have continued with the seismological array observation of underground strong earthquake rock motions at the four sites surrounding the Metropolitan Area of Japan (Ref.1). The accelerometers are installed at sixteen observation points in all of this array network system, and three components, that is, NS, EW and UD components, are recorded at each observation point, so the 48 accelerograms as maximum can be recorded simultaneously in one earthquake. Because the accelerometers are installed mainly in the rock layers of geological period of the Miocene in the Tertiary or the Cretaceous in the Mesozoic, the reorded accelerograms may be regarded to be not so greatly effected by the local subsoil conditions of the soft surface layers. Since the array observation began in December 1978, nearly 900 earthquakes were recorded by this array network system, among which 13 earthquakes recorded simultaneously at all the four sites are contained. By the use of these data, in this paper, the intensities of the rock motions are studied with respect to layers of geological period of the Tertiary or the Mesozoic, and then the source characteristics of the earthquakes in and near the southern Kanto district, Japan, are examined.

(I) *Professor of Earthquake Engineering*, Dep. of Architecture and Building Science, Nagasaki Institute of Applied Science, Nagasaki, JAPAN

Table 1 The rock characteristics at the four observation sites.

SITE	GEOLOGY			DENSITY gr/cm^3	V p km/sec	V s km/sec
HIGASHIMATSUYAMA	MUDSTONE,	MIOCENE,	TERTIARY	1.7 - 1.8	2.1 - 2.4	0.7 - 0.8
SHUZENJI	TUFF,	MIOCENE,	TERTIARY	1.7 - 2.1	1.8 - 2.5	0.7
TATEYAMA	SANDSTONE MUDSTONE	MIOCENE,	TERTIARY	1.8 - 2.1	1.4 - 1.9	0.7 - 0.9
CHOSHI	SANDSTONE	CRETACEOUS,	MESOZOIC	2.4 - 2.5	3.1	1.4

STRONG-MOTION ARRAY OBSERVATION NETWORK SYSTEM

The strong-motion array observation network system is composed of the four sub-array systems at Higashimatsuyama City (HMY), Shuzenji Town (SZJ), Tateyama City (TTY) and Choshi City (CHS) as shown in Fig.1-A. The details of the sub-arrays at Higashimatsuyama, Shuzenji and Tateyama are shown in Fig.1-B, Fig.1-C and Fig.1-D, respectively. The Higashimatsuyama Station is composed of five observation points in the rock layer of geological period of the Miocene in the Tertiary and one point in the surface ground. Both of the Shuzenji Station and the Tateyama Station are composed of four observation points in the rock layer of the same geological period to that at the Higashimatsuyama Station. The Choshi Station is composed of one observation point in the rock layer of geological period of the Cretaceous in the Mesozoic (Point No.2, GL-18M) and another point on the surface ground (Point No.1, GL+0.4M) right above the underground Point No.2. The physical constants of the rock characteristics at the four stations with respect to density and two kinds of propagation velocities of seismic body waves are listed in Table 1 in addition to the geological informations. Among the accelelograms recorded by this network system until now, about 1500 components of accelerograms with relatively large acceleration amplitude, which were recorded in the 75 earthquake events, are used for the analyses in this paper.

Although the distance in horizontal direction between two observation points at one station is shorter than 1km, the time histories of the accelerograms at two points are not necessarily same to each other, especially in the characteristics of shorter period components of rock motions, with respect to

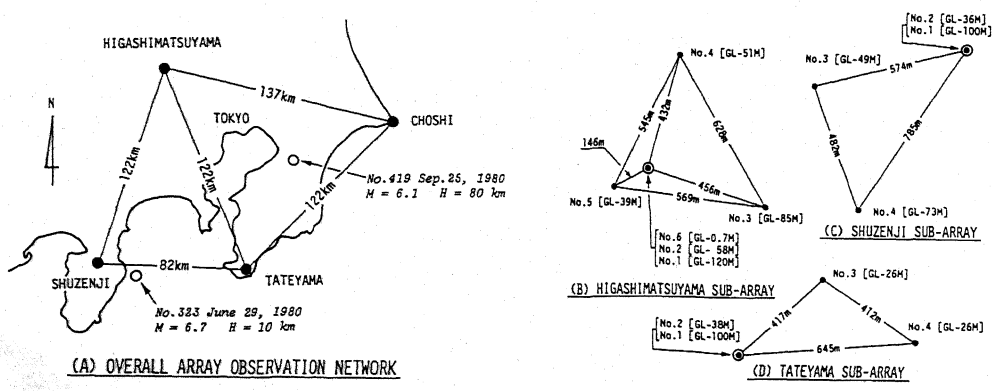


Fig.1 The overall array observation network and the details of the sub-arrays.

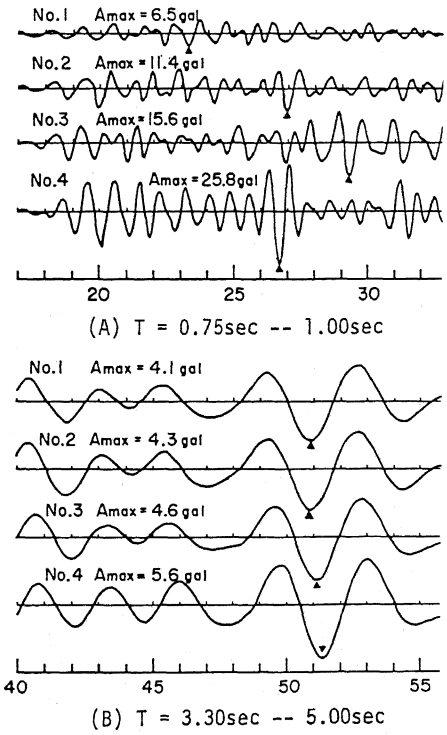


Fig.2 The time histories of the accelerograms filtered by two kinds of narrow pass band. [TTY No.323 June29,1980 Transverse component]

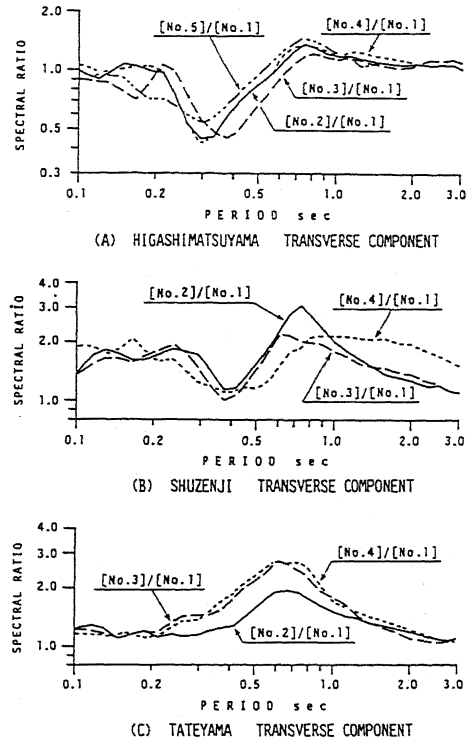
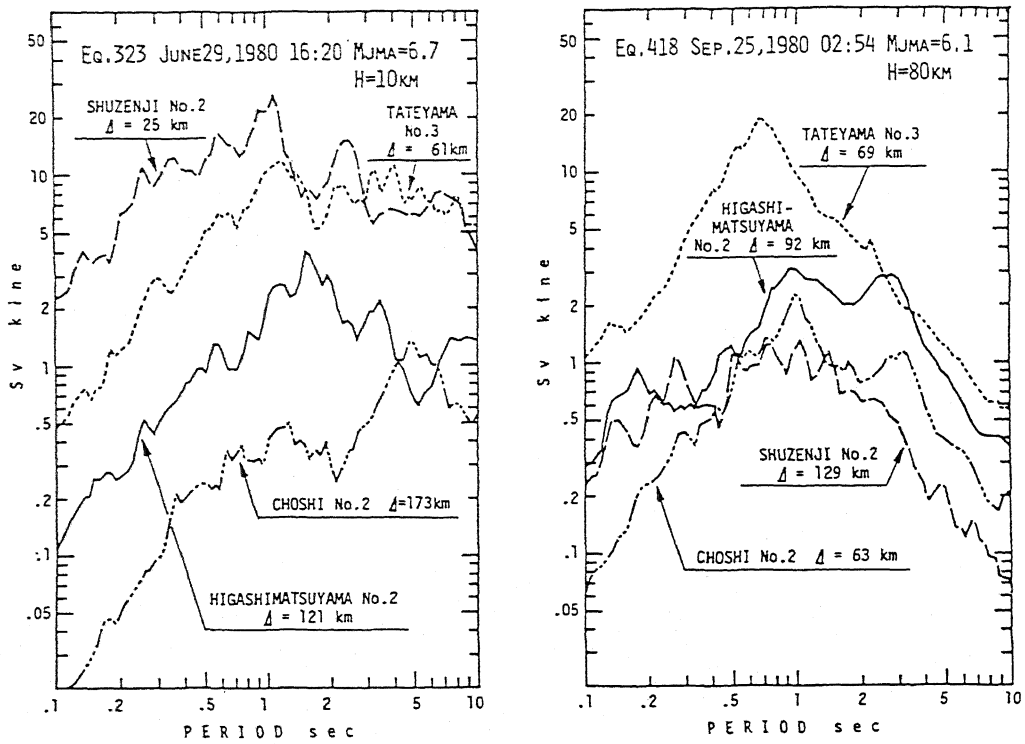


Fig.3 The mean Values of spectral ratio between the points in the upper part of the rock layer and the deepest point.

both amplitude and phase. Fig.2 illustrated the time histories of the accelerograms filtered by two kinds of narrow pass bands, that is, one is between 0.75sec and 1.0sec and another is between 3.3sec and 5.0sec. The accelerograms used in the analyses here are those recorded at the Tateyama Station in No.323 Earthquake, which was occurred at 61 km west from the Tateyama Station on June 29 in 1980 (M=6.7, H=10km). The epicenter is plotted by open circle in Fig.1-A. The time histories of the accelerograms filtered by the pass band between 3.3sec and 5.0sec show the similar characteristics of both amplitude and phase to each other. But those filtered by the pass band between 0.75sec and 1.0sec, on the other hand, are not a little different from each other with respect to the characteristics of both amplitude and phase. The cross correlation coefficients between the accelerograms filtered by narrow pass band for shorter period than 1 sec are less than 0.6 in general for the horizontal array. Fig.3 shows the response spectral ratios between the rock motion at the observation point in the upper part of the rock layer and that at the deepest point of each station. The spectral ratios in Fig.3 are the geometrical mean values for the multiple accelerogram data, that is, 38 data for the Higashimatsuyama Station, 41 data for the Shuzenji Station and 24 data for the Tateyama Station. Fig.3 shows that the spectral amplitudes of the earthquake rock motions in the same layer can be different from each other in both horizontal array and vertical array with the difference of 1.5 or 3 times for the components shorter than 1 sec or 2 sec.



(A) Earthquake No.323 M=6.7 H=10km (B) Earthquake No.418 M=6.1 H=80km

Fig.4 Velocity response spectra of the rock motions by the two earthquakes.

EMPIRICAL FORMULA OF RESPONSE SPECTRUM OF EARTHQUAKE ROCK MOTION

As mentioned above in the preceeding section, the underground accelerometers at Higashimatsuyama, Shuzenji and Tateyama are installed in the rock layers of geological period of the Miocene in the Tertiary, and that at Choshi, on the other hand, is in the rock layer of the Cretaceous in the Mesozoic. The propagation velocities of shear wave, as one example of the physical constans, are 0.7 km/sec to 0.9 km/sec for the rock layers at the former three stations, and 1.4 km/sec at Choshi. Furthermore, the characteristics of the structures of the rock layers at the much deeper depth than that of the observation points, in addition to the differences with respect to the geological conditions nearby the observation points, may be expected to affect the rock motions. Fig.4 illustrates the comparisons of the velocity response spectra of the rock motions in the upper parts of the rock layers at the four sub-array stations, which were recorded in No.323 Earthquake of M=6.7 and H=10km and in No.418 Eartquake of M=6.1 and H=80km (the epicenters of these earthquakes are plotted in Fig.1-A). The comparisons of the spectral amplitudes among TTY(Δ=69km), HMY(Δ=92km), SZJ(Δ=129km) and CHS(Δ=63km) in Fig.4-B and those between TTY(M=6.7,Δ=61km) and TTY(M=6.1,Δ=69km) in Fig.4-A and Fig.4-B suggest that the intensities of earthquake rock motions are remarkably influenced due to the earthquake source mechanism and the local site conditions, in addition to earthquake magnitude and hypocentral distance.

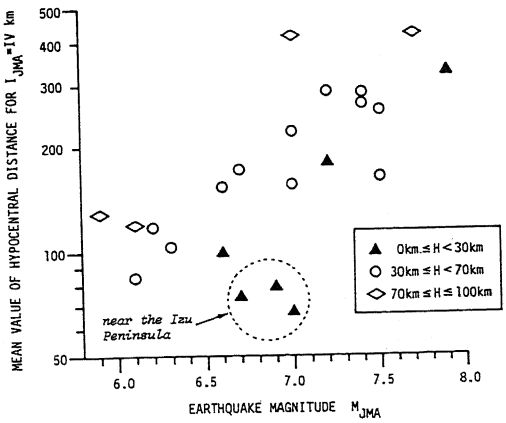


Fig.5 The mean values of hypocentral distance at the sites for $I_{JMA} = 4$.

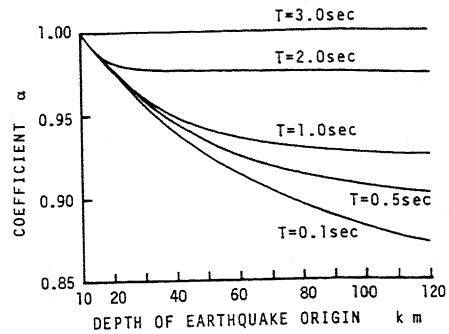


Fig.6 The variations of coefficient α(H,T) against depth of earthquake origin.

Then, at first in this paper, the empirical formula of earthquake rock motion is estblished in order to evaluate the effects on the intensities of earthquake rock motions due to earthquake magnitude, propagation path and local site condition.

$$\log_{10} Sv_{ijk}(T) = A(T)\cdot M - B(T)\cdot\alpha(H,T)\cdot\log_{10} X_i + C_{ijk}(T) \quad \cdots\cdots\cdots\cdots\cdots \quad (1)$$

in which, $Sv_{ijk}(T)$ is velocity response of the one mass system of fundamental period T due to earthquake rock motion observed at No.j Point at No.i Sub-Array Station in the earthquake event of magnitude M and earthquake depth H, X_i is hypocentral distance at No.i Station, and A(T), B(T) and C(T) are the coefficients as the functions of T (k means the component of rock motion, that is, k=1 for radial component, k=2 for transverse component and k=3 for vertical component). The coefficient α(H,T) represents the effect on attenuation of seismic wave component of the period T due to earthquake origin depth H. The coefficient α should be considered by the following reason. Fig.5 shows the effect on ground motion amplitude due to earthquake depth. The ordinate in Fig.5 is the mean value of the hypocentral distances at the sites evaluated as JMA Intensity Scale of 4, which is equivalent to ground motion acceleration between 25gal and 80gal. Fig.5 shows that the ground motion acceleration may be much more strongly attenuated due to distance in the case of shallow earthquake than in the case of deeper earthquake. Fig.6 shows the coefficient α as function of H and T. Fig.7 shows the coefficient B multiplied by the coefficient α for H=10km and H=100km, in addition to the coefficient A, in correlation to period T. The correlations of the coefficients A and B against period T in Fig.7 clarify the following facts; (a) the spectral amplitude of earthquake rock motion is influenced in the shorter period range with smaller effect due to earthquake magnitude than in the longer period, (b) the attenuation effect on the shorter period range due to hypocentral distance is much stronger than on the longer period range. These inclinations have been already pointed out by the study on the basis of the SMAC accelerograms observed in Japan (Ref.2). The empirical formula (1) may be applied to evaluate the diffrences with respect to spectral amplitudes of the rock motions between two stations, by adjusting the effects of hypocentral distances for the accelerograms recorded in the same earthquake.

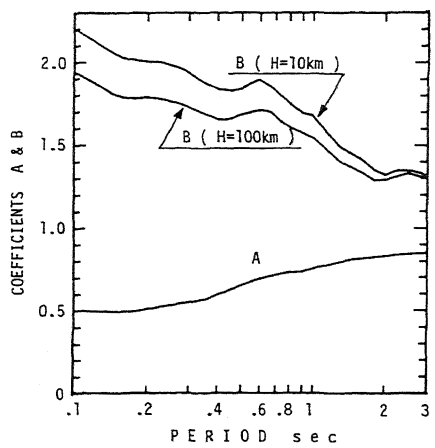


Fig.7 The variations of Coefficients A(T) and B(T) modified by α(H,T).

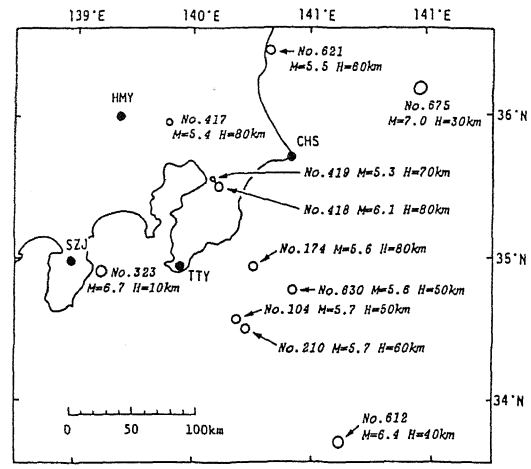


Fig.8 Map of the epicenters.

The spectral amplitudes of the rock motions observed in the layers of similar geological condition are compared in Fig.9. Although both of the accelerometers at Higashimatsuyama and those at Shuzenji are installed in the rock layers of geological period of the Miocene in the Tertiary of Vs=0.7-0.8 km/sec, the spectral amplitudes of the rock motions at Higashimatsuyama may be regarded as to be larger than those at Shuzenji. The data used in this calculation are the accelerograms recorded simultaneously at both Higashimatsuyama and Shuzenji in 19 earthquake events, in which the spectral amplitudes are modified for the same condition of hypocentral distance to each other by use of Eq.1. Fig.9 shows that the rock motion at HMY No.1 Point is 1.5 times or 2 times stronger in spectral amplitudes in the shorter period range than that at SZJ No.1 Point. But the deviations of the response spectral ratios between two sites are 50% to 100% of standard deviation as shown in Fig.9, so it should be considered that

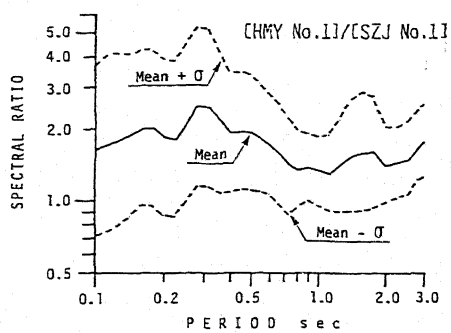


Fig.9 The response spectral ratios between [HMY No.1] and [SZJ No.1]. (Transverse Component)

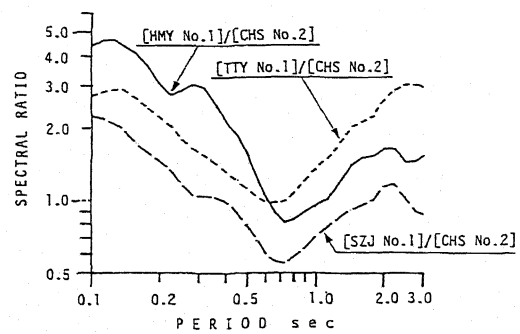


Fig.10 The mean values of response spectral ratio of [HMY No.1], [SZJ No.1] & [TTY No.1] to [CHS No.2]. (Transverse Component)

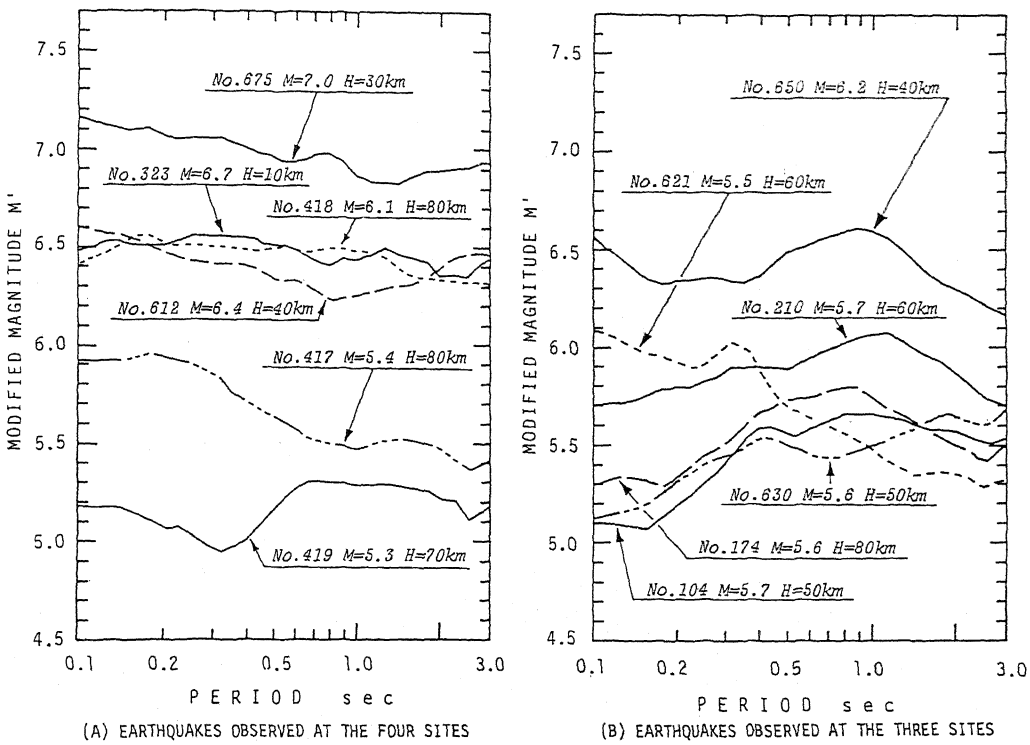


Fig.11 The spectral representations of the modified earthquake magnitude.

the effects on attenuation of seismic wave are not necessarily dominated due to hypocentral distance. Fig.10 illustrates the mean values of spectral ratios by the coefficients C(T) in Eq.1 between the rock sites of the Miocene in the Tertiary (HHM, SZJ and TTY) and that of the Cretaceous in the Mesozoic (CHS).

REPRESENTATION OF EARTHQUAKE MAGNITUDE IN FREQUENCY DOMAIN

There are several kinds of definitions of earthquake magnitude, for example, M_w, M_{100}, M_s, m_b, M_J, M_L, M_K and so on. The differences of the definition depend on the differences of the frequency range of ground motion under consideration. Then the representation of earthquake magnitude in frequency domain is proposed by Eq.1.

$$M(T) = [\frac{1}{I}\sum_i \{\frac{1}{N_i}\sum_j \frac{1}{3}\sum_k (\log_{10}Sv_{ijk}(T)+B(T)\cdot\alpha(H,T)\cdot\log_{10}X_i-C_{ijk}(T))\}]/A(T) \quad \cdots\cdots(2)$$

in which, "I" is the number of the sub-array stations where the accelerograms were recorded. Fig.11 illustrates the representations of the earthquake magnitudes in frequency domain for the period range shorter than 3 seconds. Fig. 11-A shows the magnitudes of the earthquakes observed by all the four sites, that is, I=4, and Fig.11-B shows those by the three sites. The epicenters of the earthquakes are plotted in Fig.8. These representations may be regarded as one kind of the representation with respect to the characteristics of source

spectrum of earthquake origin. When these representations of earthquake magnitude in frequency domain are applied to evaluate the effects on the rock motion caused by the earthquake in and near Kanto District of Japan, Fig.11 implies some important informations. For instance, the spectral values of M(T) for the periods shorter than 0.3sec or 0.4sec are smaller than those for the longer periods in the earthquakes occurred at the southeast region off the Boso Peninsula, that is, No.174, No.630, No.104 and No.210 earthquakes. On the contrary, No.417, No.675 and No.621 earthquakes, which occurred at the northern part than lat. about 36°N in Kanto District, have the inverse source characteristics of M(T) in comparison with the above-mentioned four earthquakes. These properties with respect to so called "softness" of earthquake (Ref.3) agree well with the regional variation of predominant period of the ground motion, which was indicated on the basis of the seismograms observed at the Dodaira (35°59'54"N, 139°11'36"E) and the Tsukuba Station (36°12'39"N, 140°06'35"E) in the earthquakes occurred in Kanto District (Ref.4, Ref.5).

CONCLUSIONS

The intensities of the earthquake motions in the rock layers of geological period of the Miocene in the Tertiary or the Cretaceous in the Mesozoic, which have been observed by the seismological array network system surrounding the Metropolitan Area of Japan, were discussed by the use of the empirical formula of response spectrum of rock motion, which was established by the method of least squares on the basis of about 1500 accelerograms observed at the four sub-array stations in 75 earthquakes in and near the southern Kanto district. This empirical formula was applied to evaluate the earthquake magnitude M(T) represented in frequency domain, and then the source characteristics of the earthquakes in and near the southern Kanto district were discussed by the scale of earthquake magnitude in frequency domain M(T). The spectral characteristics of earthquake motions in the rock layers of the shear wave velocity between 0.7 km/sec and 1.4 km/sec seem to be not so little affected due to the much deeper rock layers, so they should be compared quantitatively with those at so called " seismic bed rock " of Vs larger than 3 km/sec.

ACKNOWLEDGEMENTS

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