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A study on the evaluation of Q-value and the attenuation characteristics of 1 second or shorter period earthquake ground motion in and around the Tokyo metropolitan area of Japan

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ABSTRACT: Since 1979, the Research Committee of Strong-Motion Earthquake Instrument Arrays on Rock Sites has continued the seismological array observation, the network of that is composed by twenty one points in total at the four main rock sites and the three supplementary rock sites surrounding the Tokyo metropolitan area of Japan. For these eleven years, a lot of accelerograms have been accumulated by this array network. Then the author, utilizing these valuable array records, studied the attenuation characteristics of 1 second or shorter period earthquake ground motion in and around the Tokyo metropolitan area.

1 INTRODUCTION

The study on the attenuation characteristics of earthquake ground motion is one of the important subjects in earthquake engineering, especially for prediction of strong motion. The seismic wave propagation characteristics, on the other hand, show the informations of crustal structure or upper mantle structure, so the regional characteristics of ground motion attenuation may give us an understanding of strong ground motion in relation to the deep underground structure.

Then, in this paper, the attenuation characteristics in and around the Tokyo metropolitan area of Japan was studied, making use of the data base accumulated by the seismological array observation surrounding the Kanto district.

2 DATA SET OF SEISMOLOGICAL ARRAY OBSERVATION

Since 1979, the Research Committee of Strong-Motion Earthquake Instrument Arrays on Rock Sites (Dr. Omote, the chairman of the committee) has continued the seismological array observation in and around the Tokyo metropolitan area of Japan. Fig.1 shows the four main sites (HMY, SZJ, CHS and TTY) set in 1978, and the three supplementary sites (OGW, OAR and TTY-A) set in 1983. The four main sites have the local array network respectively (Omote et al., 1980), so the present total number of observation points is 21 points, and the seismograph at each point records three components of ground motion acceleration. The physical characteristics with respect to S wave velocity and density of the rock ground at each site are shown in Table 1.

Since the biginning of the observation, a lot of seismograms have been recorded. Out of the total data set, only the accelerograms with comparatively large amplitude were used for the data set in this study, that is, on the condi-

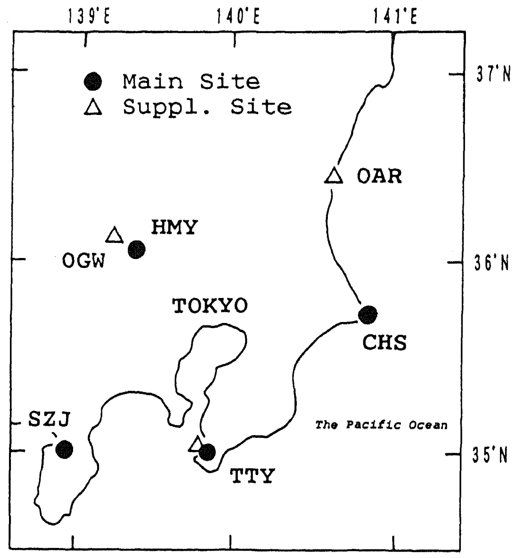

Figure 1. The Locations of the seven array observation stations in and around the Tokyo metropolitan area of Japan.

Table 1. The physical characteristics of the rock ground at the seven observation sites.

Observatory	Vs(km/sec)	Density(gr/cm^3)
H M Y	0.7 - 0.8	1.5 - 2.0
S Z J	0.65 - 0.70	1.4 - 2.0
C H S	1.4	2.4 - 2.5
T T Y	0.60 - 0.64	1.8
O G W	2.1	2.7
O A R	1.0	1.7
TTY-A	-	-

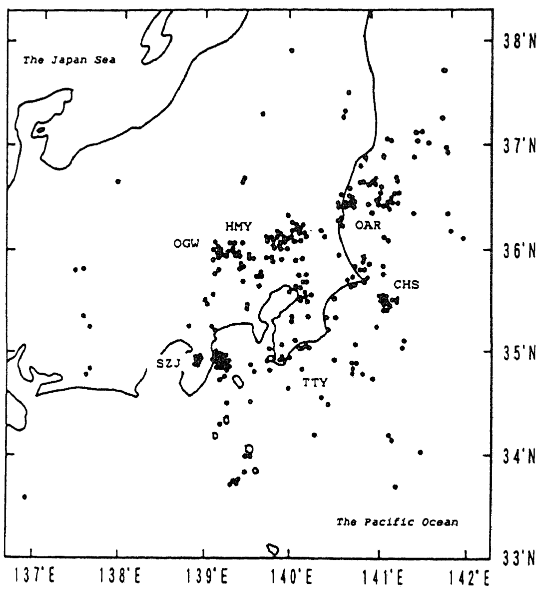

Figure 2. The locations of the epicenters of the 305 earthquakes events referred in this study.

tion that the accelerograms may be reliable in the period range shorter than 2 seconds [Sa≥0.15 gal for T≤2sec and h=5%]. After all, 4966 accelerograms recorded in 305 earthquake events were used in this study. Figure 2 shows the epicenters of 305 earthquake events, and Table 2 shows the two-dimensional distribution with respect to hypocentral depth and earthquake magnitude M_{JMA} determined by Japan Meteorological Agency. The number of the accelerograms recorded in these 305 events are listed in Table 3 for each observation site.

3 EMPIRICAL FORMULA OF GROUND MOTION ATTENUATION

In the first place, the empirical formula of ground motion attenuation was proposed in frequency domain. Ground motion attenuation in frequency domain may be represented, with physical basis, by the following formula (Takemura et al.,1987).

$$log_{10}Sv(T)=A(T)\cdot M+[B(T)\cdot X+log_{10}X]+C(T)+\Delta_{ij}(T) \quad (1)$$

Here, in equation (1), Sv(T), M and X represent velocity response of one mass system with natural period of T, earthquake magnitude and hypocentral distance, respectively, and A(T), B(T) and C(T) are the regression coefficients as the function of period T [$D_{ij}(T)$ is the supplementary factor of local site condition for Point J at Site I]. Now it is a problem, as well known, that earthquake magnitude is used as substitute value for source parameter in wide frequency range. To eliminate the effects due to the quantitative unreliability of earthquake magnitude as well as possible, therefore, the differences between the values of $log_{10}Sv(T)$ of simultaneously observed ground motions at multiple sites in one earthquake event were used as the data set for regression analyses of B(T) and Δ_{10}, where the accelerograms were limited for data due to the earthquakes of magnitude M≥4.5, hypocentral depth H≤80km and hypocentral distance≤300km. The total number of earthquake events simultaneously recorded at multiple sites is 106, the detail of which is indicated in Table 4. As the result of the above mentioned regression analyses, the regression coefficients B(T) were get for each of three components of ground motion, that is, radial, transverse and vertical components. Figures 3 shows that there can not be found any significant differences among the coefficients B(T) of three components

Table 2. The distribution of magnitude and hypocentral depth of 305 earthquake events.

M　H	0km	30km	60km	80km	Total
7.0-7.9	1	1	0	4	6
6.5-6.9	5	3	1	4	13
6.0-6.4	3	8	2	2	15
5.5-5.9	5	14	3	3	25
5.0-5.4	9	17	11	5	42
4.5-4.9	21	20	19	11	71
4.0-4.4	27	34	7	6	74
< 3.9	52	6	1	0	59
Total	123	103	44	35	305

Table 3. The number of the used accelerograms.

Observatory	Earthquakes	Accelerograms
HMY	128	2342
SZJ	139	1225
CHS	65	386
TTY	74	742
OGW	24	69
OAR	44	124
TTY-A	27	78
TOTAL	305	4966

Table 4. The number of earthquake events recorded simultaneously at multiple sites.

Number of simultaneous recording observatories	Number of simultaneously recorded earthquake events
7 observatories	1
6 observatories	3
5 observatories	2
4 observatories	17
3 observatories	31
2 observatories	52
Total	106

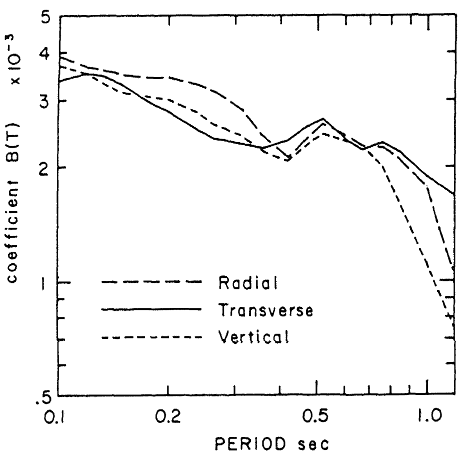

Figure 3. The regression coefficients B(T) for three components of earthquake ground motion.

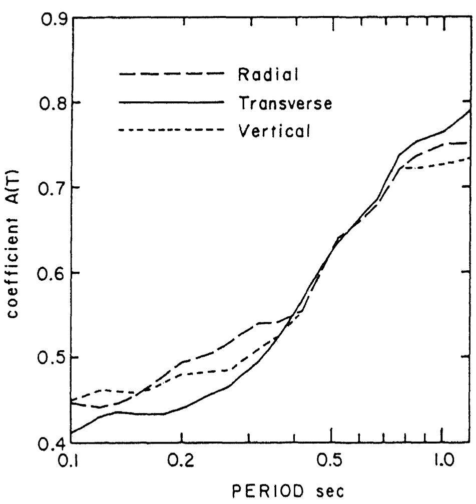

Figure 4. The regression coefficients A(T) for three components of earthquake ground motion.

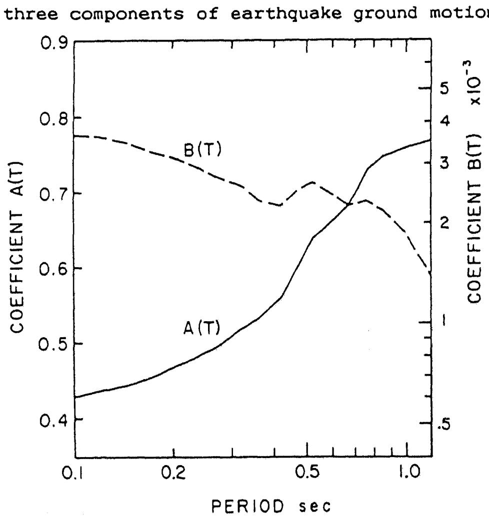

Figure 5. The mean values of A(T) and B(T).

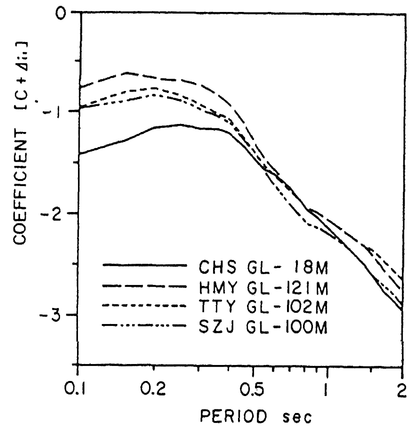

Figure 6. The regression coefficients C(T) supplemented by Δ_{i0} for transverse component.

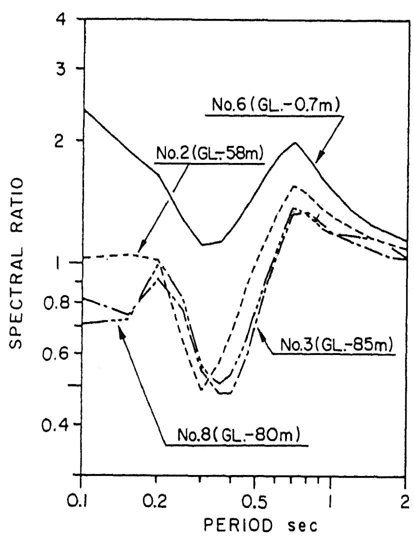

Figure 7. The mean spectral ratios to the deepest point (GL-120m) at HMY Site for transverse component.

for the period shorter than 1 sec. The same understanding may be applicable to the regression coefficients A(T) as shown in Figure 4. So, in the following of this paper, the regression coefficients A(T) and B(T) are those for all of three components of ground motion (Figure 5).

The regression coefficient C(T) supplemented by Δ_{ij} are illustrated, in Figure 6, for the transverse components of underground motion on the deepest points at the four main sites. This figure shows that the total values $[C(T)+\Delta_{i0}]$ for underground rock motion may be regarded to be of same level, independently of site, in period range longer than 0.4 sec. The amplification characteristics at one site, on the other hand, can not be ignored. Figure 7 shows the example of the mean spectral ratios of transverse component of ground motion at the respective depths to that on the deepest point of HMY site.

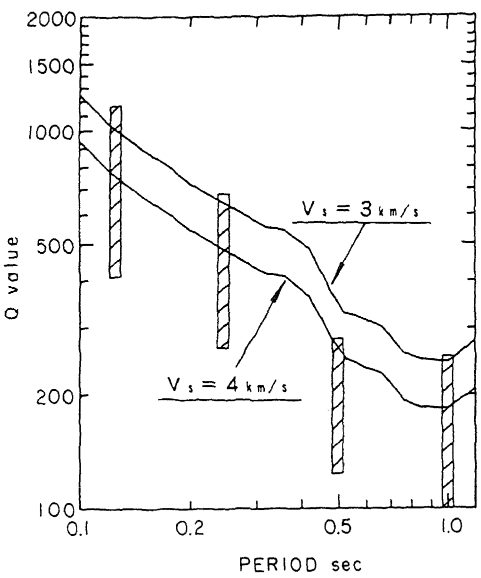

Figure 8. The Q values as the function of period T evaluated by B(T) in Figure 5.

4 EVALUATION OF Q-VALUE FOR PROPAGATION OF SEISMIC WAVE OF SHORTER PERIOD THAN 1 SECOND

The regression coefficients B(T), obtained by the above-mentioned method, should be verified the quantitative validity. So, at first, B(T) were transformed into Q values, and after then the Q values in this study were compared to those by the past seismological research.

After Takemura et al.(1987), there are following relation between B(T) and Q values.

$$B(T)=\pi\cdot(Q\cdot Vs\cdot T\cdot \ln 10)^{-1} \qquad (2)$$

Here, in equation (2), Vs means S-wave velocity and T is period of seismic wave. Thus the regression coefficients B(T) in Figure 5 were transformed into Q values in Figure 8, where the Q values were calculated in the two cases of S-wave velocity, that is, one is for Vs=3km/sec and another is for Vs=4km/sec. Furthermore, in figure 8, the Q values transformed from B(T) were compared to those proposed by Sato and Matumura(1980). Sato and Matsumura(1980), analyzing the velocity vibrogram data recorded on the bottom(GL-3510m) of the deep borehole at Iwatsuki Observatory due to 53 micro-earthquakes (magnitude of M_{JMA}=2.3-3.3, hypocentral depth of H=5- 125km, and epicentral distance of Δ=20-120km), proposed the Q^{-1} values for S-waves (2-32Hz) under the Kanto District in Central Japan, the converted Q values from those are indicated by the shaded portions in Figure 8. Figure 8 shows that the Q values transformed from the regression coefficients B(T) in this study coincide with the seismological results. And besides, Figure 8 shows that there exists the clear dependence of Q value on frequency of seismic wave higer than 1 Hz.

Now, applying the regression line for the Q values for shorter period than 1 second in Figure 8, the following equations were formulated for each assumption of S-wave velocity.

$$Q(T)=227\cdot T^{-0.73} \quad [\text{ for Vs=3km/sec}] \qquad (3\text{-}1)$$
$$Q(T)=170\cdot T^{-0.73} \quad [\text{ for Vs=4km/sec}] \qquad (3\text{-}2)$$

These equations show that $Q\propto f^{0.73}$. The power of frequency of "0.73" in this proportional expression coincides in rough with the other seismological results. For example, Sato(1986) analyzed the records of 95 local earthquakes at 10 stations in the Kanto-Tokai district, the central part of the Main Island of Japan, and measured the frequency dependence of Qc(Coda Q) from 1 to 16Hz. He found, in conclusion, the regional differences in the "n" value of the form $Qc\propto f^n$, that is, the n value is close to 0.6 in the south-eastern Kanto, and close to 0.9 in the Tokai and the western Kanto, and 0.86 on average. For one another example, Iwata & Irikura(1986) analyzed the data sets from 1983 Japan-Sea Earthquake (M=7.4) and its aftershocks, and obtained the Q-values of S-waves proportional to the 0.6 power of frequency in the range of 0.5-8.0Hz, that is, $Qs=100f^{0.6}$.

5 EVALUATION OF THE REGIONAL CHARACTERISTICS WITH RESPECT TO GROUND MOTION ATTENUATION

Figure 10 shows the comparisons among the velocity response spectra of the transverse components of the underground rock motions, which were recorded at TTY Site due to the six earthquake events, the locations of the epicenters of those are indicated in Figure 9. Although Event B(M=6.1, X=110km) is not only smaller in earthquake magnitude but also much longer in hypocentral distance than Event A(M=6.7, X=63 km) and Event F(M=6.5, X=64km), the rock motion due to Event B is much stronger than those due to Event A and Event F in short period (T<1sec). The same correlation in the intensities of rock motions may found between the spectra due to Event C and Event D.

The author, in the preceding paper (Nagahashi, 1984), studied these kind of problems from the point of view of the effects on ground motion attenuation due to the hypocentral depth. Indeed the structure of the crust and the upper-mantle in this district, as well known by the existence of the so-called triple junction, are very complex due to the subduction of the multiple plates, and the complexity of the underground structure may cause the regional characteristics of seismic wave propagation, that is, ground motion attenuation. So, in this study, the regional characteristics of ground motion attenuation in and around the Tokyo metropolitan area were investigated on the basis of the mentioned-above empirical formula proposed by equation (1) as the simple scale. That is, the ratio of the response spectra of observed rock motions to those calculated by equation (1) are discussed in the following.

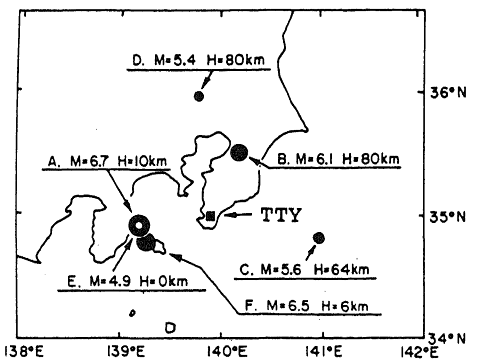

Figure 9. The locations of the epicenters of the earthquake events referred in Figure 9.

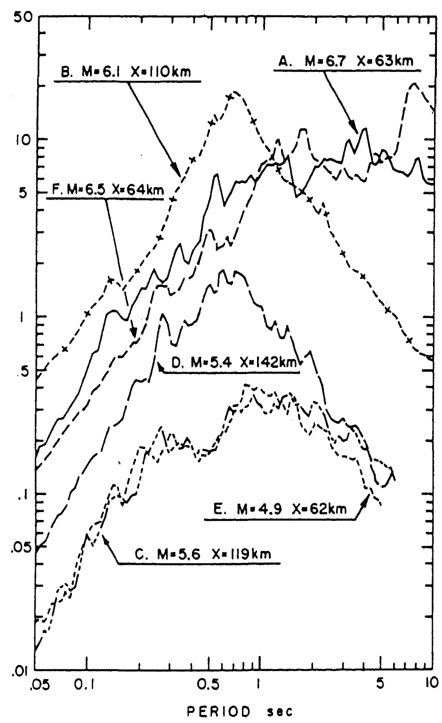

Figure 10. The comparisons of the velocity response spectra of the rock motions observed at TTY Site in the earthquake events in Figure 9.

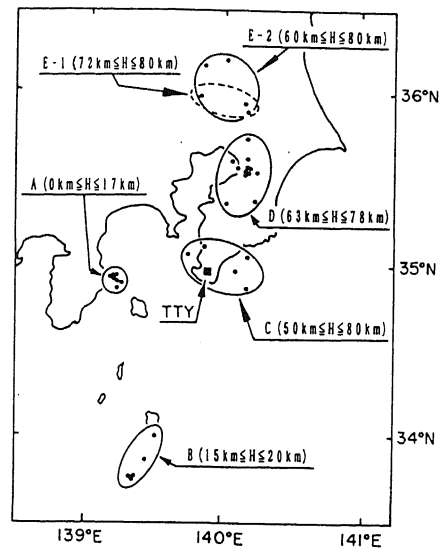

Figure 11. The zoning of the hypocenters referred in Figure 12.

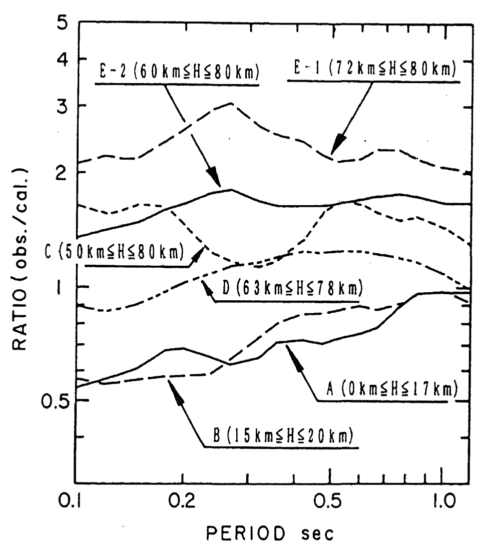

Figure 12. The mean spectral ratios of the observed motion at TTY Site to the calculated one for each zone in Figure 11.

Generally speaking, the characteristics of earthquake ground motion are not so simple, because ground motion is affected variously by source, attenuation through propagation path, ground amplification and so on. For example, Figure 13 shows the difference between the comparisons of the velocity response spectra of ground motions observed simultaneously at TTY Site and TTY-A Site due to the two earthquake events. The distance between two sites is only 6km. Comparing the spectra at the two sites in details, the differences between the spectra of ground motions at the two sites are different due to the earthquake event. To eliminate the effects due to the source and abstract the effects of attenuation through the propagation path, therefore, it is desirable that so many seismograms as possible are used for analyses.

Now, from the distribution of the epicenters of the earthquake events referred in this paper, the whole of the epicenters in Figure 2 may be divided into the six zones of relatively dense occurrences of earthquake events in and around the Tokyo metropolitan area, which are shown in Figure 11. So the mean ratios of the response spectra of the transverse components of the

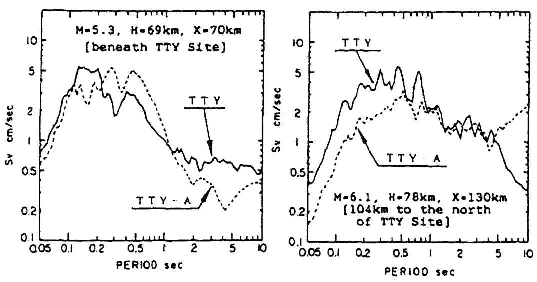

Figure 13. The comparisons between the response spectra of the ground motions recorded simultaneously at TTY Site and TTY-A Site due to the two earthquake events.

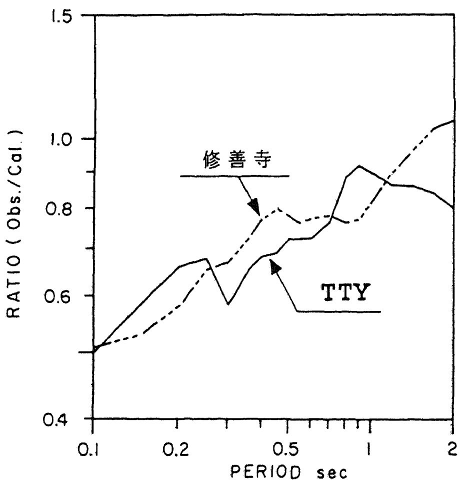

Figure 14. The mean spectral ratios of the observed motion at TTY Site and SZJ Site to the calculated one for Zone A in Figure 11.

observed rock motions at TTY Site to the calculated spectra by equation (1) are shown in Figure 12 for each seismic zone. This figure suggests that the earthquake events occurred in the seismic region to the east of the Izu Peninsula (Zone A) are generally apt to be recorded by the ground motions with small amplitudes in short period range, and that the earthquake events occurred under the south-west part of Ibaraki Prefecture (Zone E), which is the seismic region of the collision of the Philippine Sea plate on the subducted Pacific plate, on the other hand, may generate the ground motions with large amplitudes in short period range. Also Figure 13 shows, in comparison to the ratios at TTY Site, the mean ratios of the response spectra of the observed rock motions at SZJ Site due to the earthquake events in Zone A to the calculated spectra. This figure may show the characteristics of ground motions due to the earthquake events occurred in Zone A. Anyway such the general characteristics of ground motions observed in the Tokyo metropolitan area can be regarded to coincide with the regional characteristics of the value "$f \cdot Qc(f)^{-1}$"(Sato, 1986).

This coincidence may suggest that the ground motion characteristics are considerably affected by the regional characteristics of seismic wave propagation.

6 CONCLUSIONS

On the basis of a lot of accelelograms data observed by the seismological array observation network in and around the Tokyo metropolitan area of Japan, the empirical formulae with respect to ground motion attenuation for shorter period than 1 second were proposed in frequency domain.

As the result of the regression analyses, the Q values in the Kanto district of the Central Japan were evaluated as the function of frequency of ground motion, and it was shown that the Q values are proportional to frequency with the exponent of 0.73, that is, $Q(f) \propto f^{0.73}$.

Using these empirical formulae as the standard scale for evaluation of ground motion intensity in frequency domain, a simple method to understand the regional characteristics with respect to ground motion attenuation was proposed.

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