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SPECTRAL CHARACTERISTICS OF EARTHQUAKE GROUND MOTION IN HARD STRATUM CONFIRMED BY DATA OF STRONG MOTION OBSERVATION ARRAY

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SUMMARY

This paper describes the investigation of the theoretical evaluation equation of Fourier spectra for seismic ground motion with good accuracy acceleration records of rock sites. The evaluation equation Fourier spectra is expressed by means of source, propagation path, and transfer function of the ground. Through the regression analyses, characteristics of the regression coefficients $a_R(T)$, $b_R(T)$ and $c_R(T)$ are clarified. That is, short-period range of the source spectra are nearly conformed to $T^{2.5}$, Q-value of the path is $280f^{0.9}$, and $P = 2.4 \times 10^{19}$ for $c_R(T)$. Comparison of the evaluation equation with the average characteristics of the observed records generally indicates good correspondence except for the long-period range.

INTRODUCTION

For the purpose of enabling still better aseismatic design of structures, the authors have been performing strong motion observations of rock sites (Ref. 1) and investigating the physical meaning of the regression equation of Fourier spectra for seismic ground motion (Ref. 2). This equation considers source, propagation path, and site conditions. The investigation with this evaluation method was executed only for a simple example.

This paper used the records of rock sites with good accuracy and proper transfer functions of the ground, by which the properties of the evaluation equation for the average characteristics of the seismic ground motion are investigated. The records investigated here are for the horizontal component.

MEAN SPECTRA OF SEISMIC GROUND MOTION

The evaluation equation is basically derived from the previous paper (Ref. 2). The method used includes the stratification factor, so as to obtain the characteristics of the sites. F(T) is the Fourier spectrum of the seismic ground motion, it is expressed by the following equation by means of source, propagation path, and amplification in the ground (Ref. 2, 3).

$$F(T) = \frac{R\theta\phi\cdot\pi}{\rho Vs^3 X}\,\frac{Mo(T)}{T^2}\,\exp\{\frac{-\pi X}{QVsT}\}Hg(T) \qquad (1)$$

Here, Mo(T) and the magnitude M_J by the Japan Meteorological Agency are related to $Mo(T_M) = P10^{M_J}$, where P is a constant. When the short-period components of Mo(T) is in proportion to T^n, then n is also in proportion to kM_J, k >

0, where k is a constant. From these formulas, F(T) is expressed by the following equation.

$$\log F(T) = a_R(T)M - \{b_R(T)X + \log X\} + c_R(T) \quad (2)$$

$$a_R(T) = 1 - k \log (T_M/T) \quad (3)$$

$$b_R(T) = \pi/(QVsT \cdot \ln 10) \quad (4)$$

$$c_R(T) = \log \frac{Hg(T)}{T^2} + \log \frac{R\theta\phi.\pi.P}{\rho Vs^3 Cx} \quad (5)$$

Here, the stratification factor is used for $c_R(T)$, T_M is the mean period when M_J is decided, and Cx is a constant for adjustment of the units. For computation of F(T), the residual response spectrum $S_{VR}(T)$ of the damping coefficient h = 0 is used.

STRONG MOTION RECORDS

The strong motion records used here are obtained at the four sites of Higashi-matsuyama (HMY), Choshi (CHS), Tateyama (TTY), and Shuzenji (SZJ). The geological conditions and the installation positions of the acceleration meters are shown in Fig. 1. In this figure, the records used most frequently are those obtained at the upper portion of rock in the ground.

As shown in Fig. 2, these sites are located within 100 km from Tokyo. This figure also shows the epicenters of the earthquakes used herein. A total of 29 earthquakes was selected, and these locations are already shown in Fig. 2. The range for M_J is from 4.1 to 6.7, with an average of 5.5. There is a total of 102 components, and the relation between them and X is shown in Fig. 3. The number of records for each site is shown in Fig. 4. Amax is in the range from about 1 Gal to 70 Gal.

PHYSICAL CONSTANTS AND TRANSFER FUNCTIONS

The above mentioned records can be applied to equation (2), and the regression coefficients (3) to (5) can be obtained. When the respective physical constants are substituted into these equations (3) to (5), the equation (2) can be obtained theoretically. However, of these physical constants, P for $Mo(T_M)$ and M_J, and Hg(T) are especially important. Therefore, their handling is treated as follows.

Physical Constants In our previous paper (Ref. 2), two types of values for P were referred from the other paper. Here, once more, the above records are used to investigate the value of P. In reconsidering P, each item of equation (5) must be decided. As the acceleration records are used here, $R\theta\phi$ is assumed as 0.6. Taking the path of the seismic waves into consideration, ρ is assumed as 2.8, and Vs, as 3.7 km/s. 10^5 cm/km is used for Cx. For the Hg(T), as no sufficient information of damping has been obtained for the sites, careful considerations are required.

The amplification characteristics above the base rock have been investigated in detail for the strong motion sites Iwaki (IWK) and Tomioka (TMK). Except for the top layer, TMK closely resembles HMY in regard to the characteristics of the layers. Especially, IWK and CHS have similar layer and depth to the base rock, by which sufficient reference is possible.

Thus it can be assumed that the damping coefficient h at CHS is close to the result investigated at IWK, and this can be useful (Ref. 4). From this, $h = h_1 f^{-\alpha} = 1/2Q$ is used. Here, h_1 is the damping coefficient at the frequency

$f = 1$ Hz, and α is a constant. As for the value of h_1 in a layer which exceeds the depth of the strong motion seismograph, h_1 shall be obtained from $15/Vs \geq 0.01$ with reference to the values at TMK. Lower limit of 0.01 is adopted from laboratory dynamic test results of bed rocks for IWK and TMK. α shall be 0.5 from the TMK results at $Vs = 1.2$ Km/s, or 0.9 from the average value of Q for the path by regression analysis described later at $Vs > 1.25$ Kms. The values of $2h = 1/Q$ for these are shown in Fig. 5.

Also, the amplification characteristics at the four sites can be obtained by using the records at the ground surface and in the ground. $Ap(T_1)$ is the averaged Fourier spectral ratios at the primary peak period, and the mean damping coefficient hp can be obtained according to $hp = 2/\pi Ap(T_1)$. This equation is used to determine hp shallower parts of the ground than the deepest seismographs, and these are also shown in Fig. 5. For comparison with the other data, $1/Q$ is used for the ordinate of Fig. 5.

Transfer Function The $1/Q$ shown in Fig. 5 and the geological constants of each site can be used to obtain Hg(T), and Fig. 6 shows Hg(T) for the four sites. Averaged and theoretical regression coefficients can be obtained according to the above. The appropriateness can be investigated by comparing the theoretical values with the regression coefficients according to the records.

REGRESSION COEFFICIENTS AND DISCUSSION

On the basis of the above described method and data, the regression coefficients according to the records were compared with the theoretical values.

Regression Coefficients The regression coefficients $a_R(T)$ according to the records are shown in Fig. 7. The theoretical values also have been entered into this figure. As the value for the constant k deciding the slope of $a_R(T)$, 0.44 is obtained. From Fig. 8, as the value, $n = 2$ to 3 is obtained for the gradient of the short-period range for the source spectra.

$b_R(T)$ is shown in Fig. 9 with values of 1/20 or less of the maximum value neglected. Fig. 10 shows the Q-value obtained from equation (4) with the mean value. The mean value is according to $Q = Q_1 f^{-\alpha}$. Here, Q_1 is the Q-value occurring at $f = 1$ Hz. According to Fig. 10, the value of α is 0.9, Q_1 is 280. Fig. 11 shows a comparison of the other studies of $1/Q$ with this study. This study has obtained comparatively small values for $1/Q$.

Fig. 12 shows the $c_R(T)$ analysis results obtained for the 4 sites. As Fig. 12 also shows the theoretical values, the process for obtaining these values shall be treated. Average values for $T = 1$ to 3 sec. are derived from $c_R(T)$ of the records of CHS. From this and Hg(T) of CHS, P is obtained as 2.4×10^{19}. This value of P is also common for the other 3 sites, then the other $c_R(T)$ is obtained.

According to Fig. 12, the theoretical values and the observed values are close to each other in the long-period range, but considerable differences are caused on the short-period range. Fig. 13 shows the Fourier spectra F(T) according to observation and theory. Depending on the period, there is a difference between the theoretical values and the observation values of F(T).

DISCUSSION Here, the difference between the observation values and the theoretical values was obtained, and this was shown as the residual difference $\Delta C(T)$. The results are shown in Fig. 14. According to this figure, $\Delta C(T)$ at $T \doteqdot 1.0$ sec. is close to zero. But only $\Delta C(T)$ of CHS is different from the others, and those of HMY and TTY less than 0.5 sec. are comparatively large. That is believed to be caused by the structures of the surface layers. On the period range longer than 1.5 sec., all of the $\Delta C(T)$ are smaller than zero. This result is considered why the longer-period components of surface layers appears not so large response for small earthquakes. There is still room for research in regard to the damping coefficients of the surface layers, evaluations of the surface waves, for instance. But the fact that the theoretical values and the observation values are close to each other seems to indicate the appropriateness of this evaluation method.

CONCLUSION

The highly accurate strong motion records of rock sites were used to obtain the mean Fourier spectra for earthquake ground motions, and the evaluation equation was subjected to comparative investigation with the theoretical method of source, path, and site conditions. From the results, the following can be said.

1) A comparison of the mean characteristics of the proposed evaluation equation with those of the observation values less than 1.0 sec. shows a good correspondence.
2) The characteristics of the regression coefficients $a_R(T)$, $b_R(T)$, $c_R(T)$ are clarified. That is, gradient in the short-period range of the source spectra nearly conforms to $T^{2.5}$, $Q = 280f^{0.9}$, and $P = 2.4 \times 10^{19}$.

However, there are still problems in regard to the evaluation of the short-period components, attenuation of several periods in the ground, and surface wave problems, which must be clarified further in the future.

It is believed that the thoughts in regard to the earthquake ground motion confirmed in this research and the average characteristics of the records can be used as reference for other related research.

ACKNOWLEDGEMENTS

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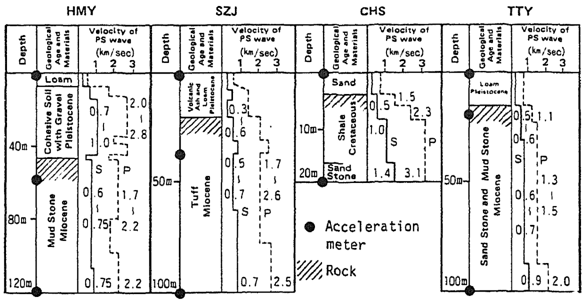


Fig.1 Geological Profiles of the four Sites and Positions of the Acceleration Meters

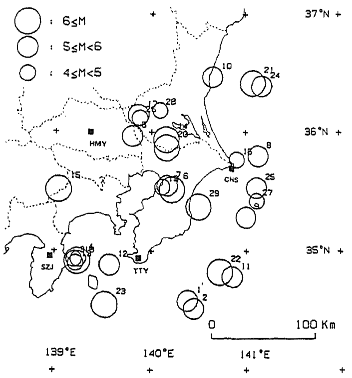


Fig.2 Epicenters of the Analyzed Data

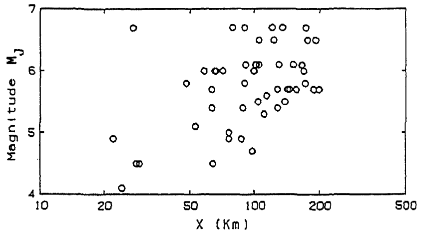


Fig.3 Relation between Hypocentral Distance and Magnitude of Analyzed Data

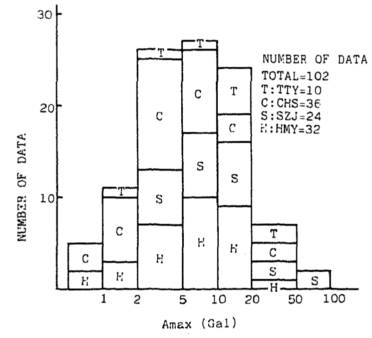


Fig.4 Relation between Amax and Number of Data

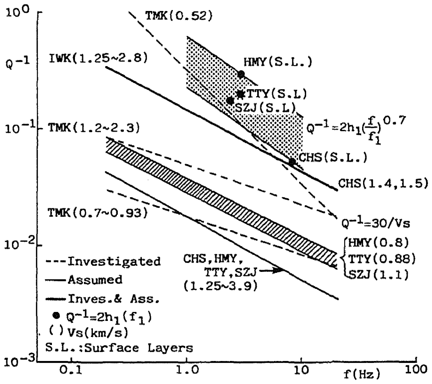


Fig.5 Q-Values in Surface Layers

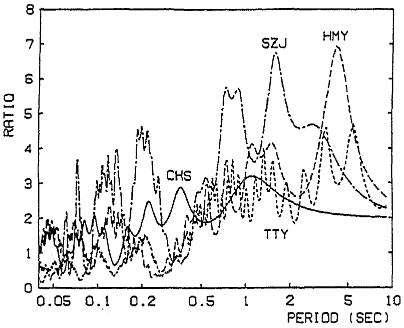


Fig.6 Transfer Functions from Base Rock to Ground Surface

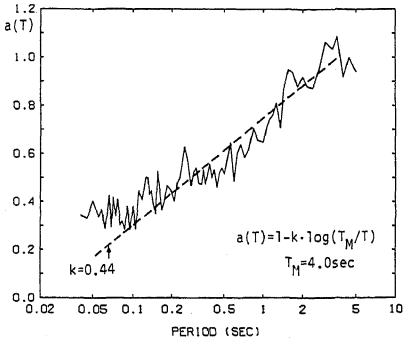


Fig.7 Coefficient a(T) Obtained from Regression Analysis

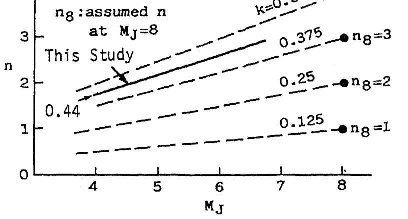


Fig.8 Source Spectra Scaling Coefficients in Short Period Range

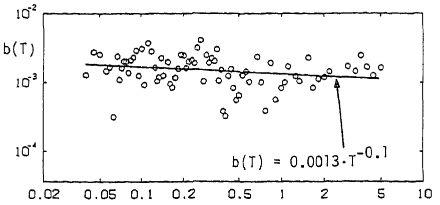


Fig.9 Coefficient b(T) Obtained from the Regression Analysis

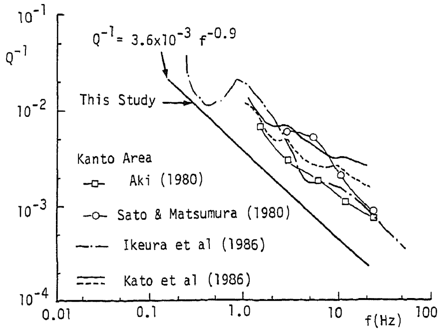
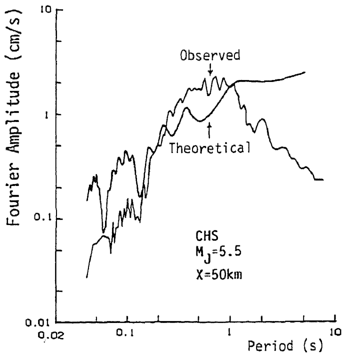
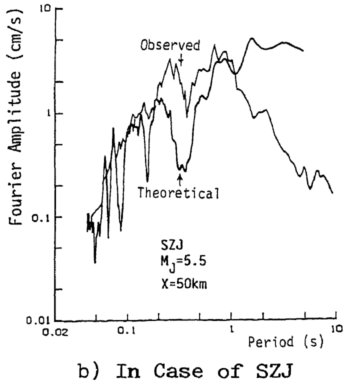


Fig.11 Evaluated 1/Q Values in Propagation Path and the Other Researches



a) In Case of CHS



b) In Case of SZJ

Fig.13 Observed and Theoretical Average Spectra, M_J=5.5, X=50km

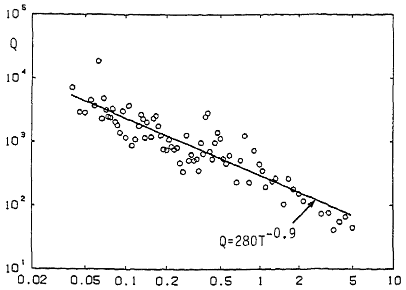
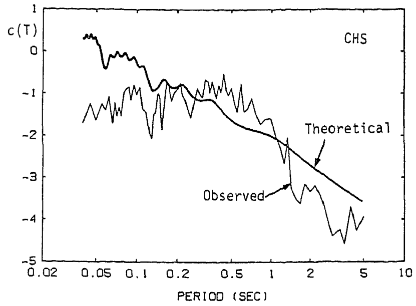
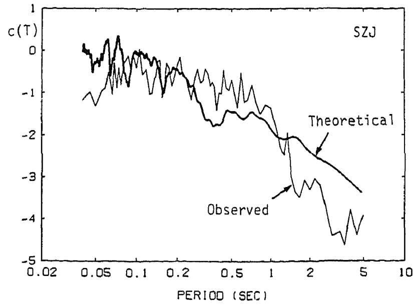


Fig.10 Q-Value in Propagation Path Obtained from This Study



a) In Case of CHS



b) In Case of SZJ

Fig.12 Observed and Theoretical c(T)

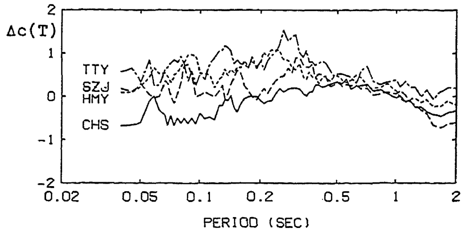


Fig.14 Residual Difference Δc(T) between Theoretical and Observed Average Spectra