SPECTRAL CHARACTERISTICS OF HARD ROCK MOTIONS

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SUMMARY

Multiple regression analysis of ground motions are carried out utilizing 60 accelerograms obtained on harder rock sites and 35 accelerograms on rather soft rock sites. Peak ground velocities and velocity response spectra for the two different geological conditions are obtained as the function of earthquake magnitude and hypocentral distance. On the basis of this analysis, characteristics of spectral shape on rock sites, difference between response velocities on harder and rather soft rock are discussed in this paper.

INTRODUCTION

It is widely recognized that the local soil and geological conditions may affect the characteristics of the ground motions developed at the site in terms of both peak ground motion and frequency content, and site-dependent spectra for various subsurface conditions have been proposed in Japan and the United States. The use of spectra for rock sites proposed in the previous studies, however, should be limited to motions on rather soft rock sites, because most of the records used were obtained on such rock and a few on hard rock conditions.

For harder rock sites, however, ground motion records available have been accumulated in Japan during last ten years, through the observations of earthquakes mostly on the bed-rock of nuclear plant sites. Based on these data, it appears possible to evaluate characteristics of hard rock motions for the purpose of establishing design spectra to be applied for nuclear plant facilities. The results of such a study are presented in this paper.

GROUND MOTION RECORDS

The ground motion records used in this study are accelerograms obtained at the sites where geological and geotechnical conditions were investigated in detail and considered to represent the free field rock motions; the records suspected to have been amplified by surface soil or affected by high topographical relief are excluded. Finally for this study 95 accelerograms provided mainly from the accelerographs located in nuclear power stations have been selected.

95 accelerograms were classified into the following two categories according to the geological and geotechnical conditions of the sites where they were obtained.

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Group A: 60 accelerograms for harder rock sites, obtained at 9 recording stations mostly in the western part of Japan. Geology of the site consists of granite, andesite and shale of Miocene or the earlier geological age, having S-wave velocity larger than approximately 1500 m/s or P-wave velocity larger than approximately 3000 m/s.

Group B: 35 accelerograms for rather soft rock sites, obtained at 4 recording stations mostly in the north-eastern part of Japan. Geology of the site are mudstone of Pliocene or late Miocene age, having S-wave velocity of 500 ~ 1000 m/s.

The geological features of each site are presented in Table 1, magnitude and epicentral distance of the earthquakes utilized are plotted in Fig. 1. It should be noted that intensities of these earthquake motions are not so large enough as to cause damage of the structures.

ANALYSIS

The ground motion parameters used in this analysis are peak ground velocity, response velocity, velocity amplification factor and spectral intensity, designated as V, Sv, q_v and SI, respectively. Velocities were obtained by integrating the observed accelerograms, response velocities were computed at 86 discrete periods between 0.02 sec and 5 sec for 5% of critical damping, and velocity amplification factors were obtained by normalizing the response velocities in terms of the peak ground velocities. SI is Housner's spectral intensity defined by the following equation.

$$SI(0.05) = \int_{0.1}^{2.5} Sv(0.05,\ T)\ dT$$

Peak ground velocity and response velocity are assumed to be the function of magnitude M and hypocentral distance X (km), and to be presented by the following expressions which have been used by many researchers (Kanai et al. 1966 [1], [2], Kobayashi et al. 1977 [3], Watabe et al. 1979 [4]).

$$\log V = a\ M - b\ \log X - c \qquad (1)$$

$$\log Sv = a'M - b'\log X - c' \qquad (2)$$

Using 60 accelerograms recorded on harder rock sites (Group A) and 35 accelerograms on rather soft rock sites (Group B), the regression coefficients a, b, c and a', b', c' have been obtained by least square fitting.

From the analysis, regression equation and multiple correlation coefficients of peak ground velocity are obtained as follows;

Category	Regression Equation	Multiple Correlation Coefficient
Group A	$V = 10^{0.65M - 1.36\log X - 2.00}$ (3)	0.89
Group B	$V = 10^{0.54M - 1.31\log X - 0.95}$ (4)	0.85

Regression coefficients a', b' and c' in Eq. 2, the multiple correlation coefficients, and the examples of velocity response spectra calculated by Eq. 2 are presented in Fig. 3, Fig. 4 and Fig. 5, respectively. From the values of multiple correlation coefficients, it is considered that peak ground velocity and response velocity can be reasonably expressed as the function of earthquake magnitude and hypocentral distance.

The comparisons of spectral shapes for the different geological conditions are shown in Fig. 6. It may be seen that the velocity amplification factors for Group A are slightly higher than those for Group B, but there are no significant difference between them. Characteristics common to both Group A and Group B spectra are found as follows.

Velocity amplification spectra can be represented by 3 straight line segments AB, BC, CD as shown by broken lines in Fig. 6. Segment BC indicates the frequency range where response accelerations become maximum and segment CD indicates the range where response velocities are constant. Period T_1 which corresponds to point B is about 0.1 sec, T_2 which corresponds to point C varies with earthquake magnitude and hypocentral distance from about 0.2 sec to 0.4 sec. These basic trends of spectral shape are considered to be consistent with those proposed in prior studies (Hisada et al. 1978 [5], Watabe et al. 1979 [4]).

It is clearly seen in Fig. 5 that response velocities derived from Group A are remarkably smaller than those derived from Group B for entire period of the spectrum. Such a difference may be caused primarily by the difference in peak ground velocities, since the difference between the spectral amplification factors in Group A and B spectra are less distinct than that exhibited by the velocity response spectra. In Fig. 7, peak ground velocities calculated by Eq. 3, Eq. 4 and Kanai's formula are compared. It may be seen that peak ground velocities on harder rock are significantly lower than those on rather soft rock and the latter are in good agreement with those calculated by Kanai's formula.

In Fig. 8, spectral intensities for Group A and B are plotted. It can be easily seen that the spectral intensities for Group A are about one half of those for Group B.

CONCLUSIONS

The peak ground velocity and the response velocity of rock motions can be reasonably estimated as the function of earthquake magnitude and hypocentral distance through the multiple regression analysis. From the analysis, the followings can be concluded.

(1) There are no significant differences between the spectral shapes estimated for harder rock site and rather soft rock site.

(2) The response velocities for harder rock site are about one half of those for rather soft rock site. This fact may be caused by the difference between the peak ground velocity on harder rock and that on rather soft rock.

(3) For practical design purposes, site-dependent spectra for a harder

rock site can be established on the basis of statistical analysis of ground motion records obtained at the proposed site or at the site with similar geological conditions. As an alternative procedure to obtain response spectra on harder rock sites, it may also be possible to make use of rather soft rock spectra by multiplying them by a constant reduction factor.

ACKNOWLEDGMENT

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REFERENCES

[1] Kanai, K., 1966, "Improved Empirical Formula for Characteristics of Strong Earthquake Motions," Proc. Japan Earthq. Symp., pp 1 – 4

[2] Kanai K., et al., 1966, "Comparative Studies of Earthquake Motions on the Ground and Underground. II," Bull. of the Earthq. Res. Inst., Vol. 44, pp 609 – 643

[3] Kobayashi, H. and Nagahashi, S., 1977, "Response Spectra on Seismic Bedrock during Earthquake," Proc. 6-WCEE, New Delhi, Vol. 1, pp 516 – 521

[4] Watabe, M. and Tohdo, M., 1979, "Analysis on Various Parameters for Simulations of Three-dimensional Earthquake Ground Motions," Proc. 5th Intern. Conf. on Structural Mechanics in Reactor Technology, Vol. K(A) pp 1 – 11

[5] Hisada, T., Ohsaki, Y., Watabe, M. and Ohta, T., 1978, "Design Spectra for Stiff Structures on Rock," Proc. 2nd Intern. Conf. on Microzonation for Safer Construction, Res. and App., Vol. III, pp 1187 – 1198

Table 1. Geological Characteristics of Each Site

Category	Station	Number of Earthquake Records	Geology	Elastic Wave Velocity (km/s)	
				Vs	Vp
Group A	A	10	granite		4.0
	B	8	agglomerate, andesite		2.9 — 3.5
	C	1	slate, sandstone	> 1.5	
	D	1	granite	1.6	3.9
	E	11	shale, tuff	1.8	
	F	7	tuff-breccia	> 1.5	
	G	2	granite		5.0
	H	10	andesite	> 1.5	
	I	10	andesite	> 1.5	
Group B	J	25	mudstone	0.6	1.7
	K	4	mudstone	0.75	1.9
	L	1	mudstone	0.5	1.7
	M	5	mudstone, sandstone	1.0	2.1

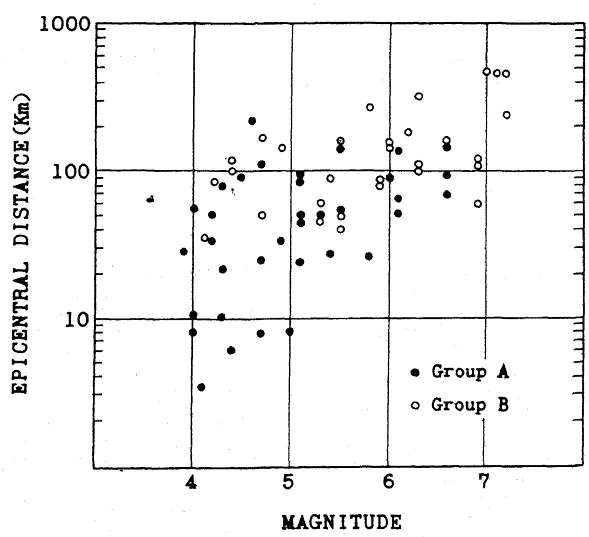


Fig. 1 Magnitude and epicentral distance of utilized earthquakes

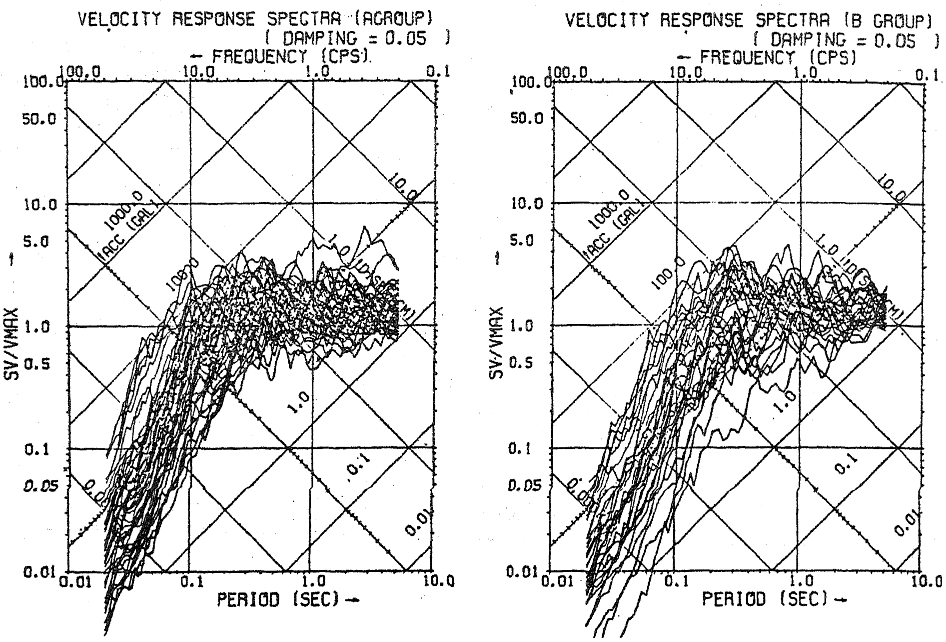
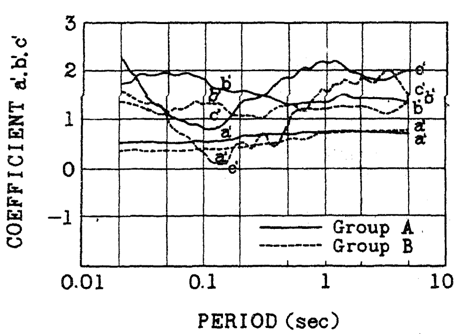


Fig. 2 Normalized velocity response spectra of observed accelerograms



(logSv=a'M−b'logX−C')

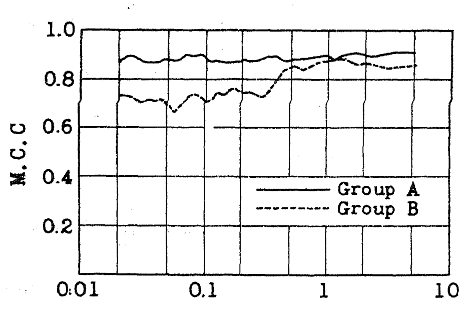


Fig. 3 Coefficients a', b' and c'

Fig. 4 Multiple correlation coefficients

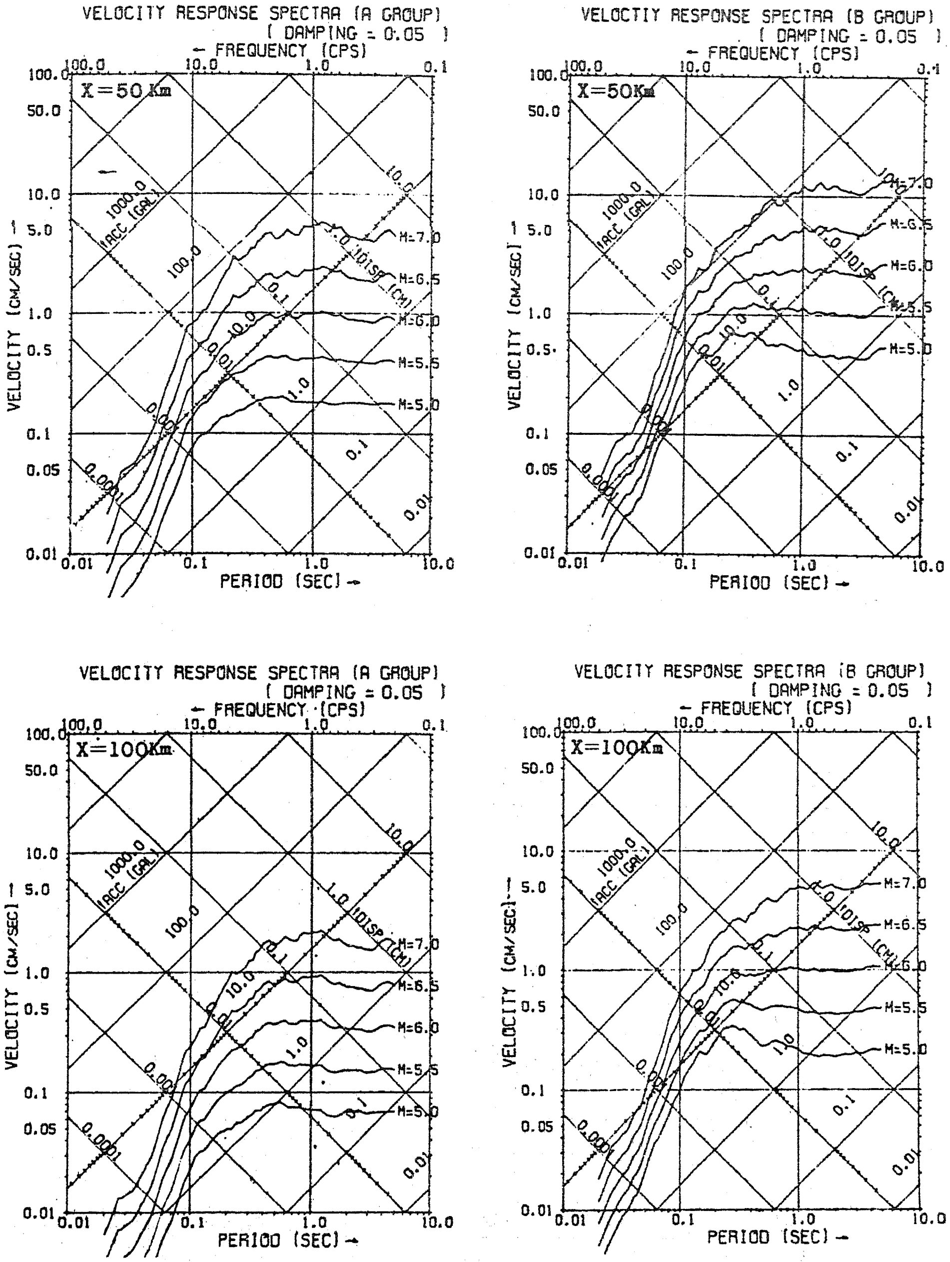


Fig. 5 Examples of velocity response spectra calculated by the regression equation

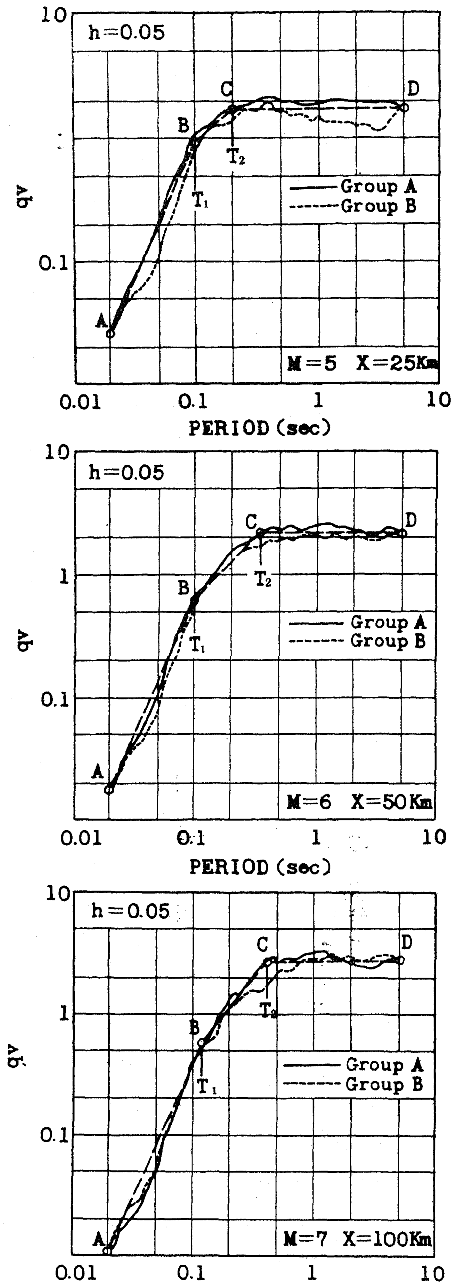


Fig. 6 Velocity amplification factors

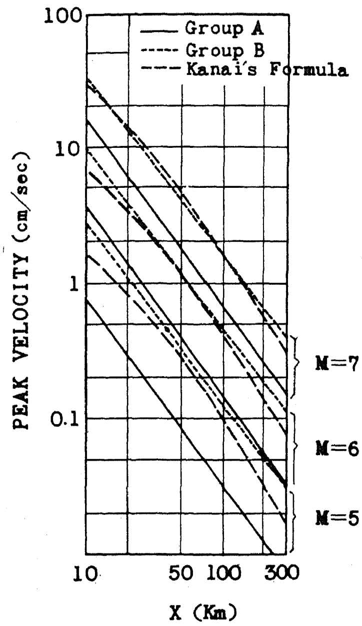


Fig. 7 Peak ground velocities

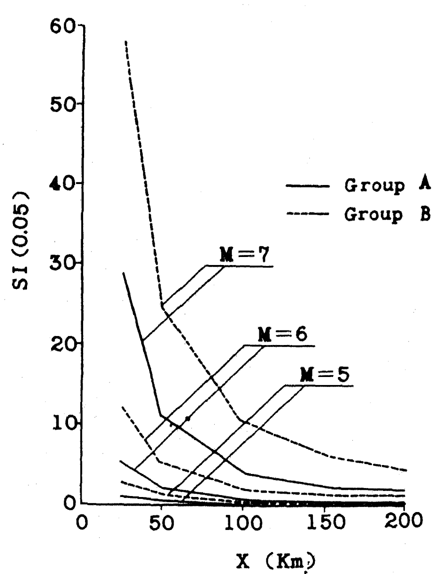


Fig. 8 Spectral intensities