Characteristics of Seismic Motions on Rock Sites Through Highly Accurate Strong-Motion Earthquake Observation Network

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SUMMARY

"Strong Motion Instruments Array" network was established June, 1979 at suitable rock sites surrounding Tokyo, and about 1000 accelerograms are obtained. This network is characterized with similar observation conditions about specifications of accelerometer and recording system.

Observed accelerograms are analyzed through the regression analysis to elucidate the differences of seismic-wave amplifications by the ground of hard-rock site ($V_s = 1.4 \text{km/s}$) and soft-rock site ($V_s = 0.7 \text{km/s}$). $V_s$ is shear wave velocity.

Obtained results are summarized as follows:

1) Peak accelerations in both horizontal and vertical components at hard-rock site are about 0.5 to 0.6 times smaller than the soft-rock site.

2) Horizontal peak accelerations are about 1.2 to 1.5 times of vertical ones at soft-rock site and about 1.1 to 1.4 times at hard-rock site for earthquakes with magnitude from 4 to 6.

3) Response spectra at the hard-rock site are about 0.4 to 0.6 times of those at the soft-rock site in the period range shorter than 0.2 second. This is approximately consistent with the result of peak accelerations.

4) Amount of long period components of response spectra relatively increases with earthquake magnitude. Hypocentral distance little affects the rate of frequency components of response spectrum, comparing with magnitude in the range of hypocentral distance shorter than 150 km.
1. INTRODUCTION

Recently, an estimation of strong ground motions due to future earthquakes becomes more indispensable for the seismic design of nuclear-power plant. Therefore, some design spectra have been made based on observed strong-motion data. One of typical examples for these spectra is proposed by Hisada et al.\(^1\), which is obtained for strong-motions at rock sites in relation to earthquake magnitudes and epicentral distances. These spectra are practically used for the design of nuclear-power plant in Japan. On the other hand, spectral characteristics of strong-motions have been investigated in relation to geological conditions of observation stations.\(^2\)(\(^3\)). Ohsaki et al.\(^4\) analyzed about 100 accelerograms observed at rock sites with various geological conditions and indicated that spectral amplitudes for harder-rock sites (\(V_s > 1.5\, \text{km/s}\)) were usually smaller than those for rather soft-rock sites (\(V_s = 0.5-1\, \text{km/s}\)).

About 1000 accelerograms obtained by a network of "Strong Motion Instrument Array\(^5\)" are analyzed to improve reliability of usual design spectra in consideration of characteristics of rocks under observation stations. As the first stage, we will quantitatively estimate differences of peak accelerations and response spectra of observed strong ground-motions at hard- and soft-rock sites in this study.

2. DATA

A strong-motion instruments array network has been established at suitable rock sites surrounding Tokyo by "Committee of Strong-Motion Instruments Array (Chairman is Prof. Ohtome)\(^6\). This network has 42 component accelerometers which were installed in rock with similar setup conditions. The same type (force-balanced type) accelerometers are used. Geological conditions of the observation sites are shown in Table-1. Shear wave velocity\((V_s)\) of rocks at Higashi-Matsuyama(HMY), Shuzenji(SZJ) and Tateyama(TTY) stations are about 0.7 km/s. The rock condition of HMY, SZJ and TTY will be represented as "soft-rock" in this paper. \(V_s\) at Choshi(CHS) station is about 1.4 km/s and that rock condition will be represented as "hard-rock". Analyzed data are obtained from June, 1979 to December, 1981 and the total number of accelerograms in horizontal components are 688 and that in vertical component are 344. Fig.1 shows the relation between magnitudes and hypocentral distances for analyzed earthquakes, and Figs.2 and 3 show the distribution of observed accelerograms for earthquake magnitudes and hypocentral distances.

3. EFFECTS OF GEOLOGICAL CONDITIONS RECOGNIZED VISUALLY FROM OBSERVED RECORDS

Some examples of accelerograms and response spectra are shown in Figs.4, 5, 6 and 7 to compare characteristics of observed seismic-waves at the hard- and the soft-rock sites. Figs.4 and 5 show examples of accelerograms and their response spectra observed at the hard- and soft-rock sites for an earthquake with the same hypocentral distances. SZJ and TTY stations are chosen as examples of soft-rock sites in Figs.4 and 5, respectively. Figs.6 and 7 show examples of accelerograms observed at different soft-rock sites. Some
remarkable features in those figures are summarized as follows:

1) Peak acceleration-ampitude observed at hard-rock site is smaller than that at soft-rock site for an earthquake with the same hypocentral distance. (see in Figs.4(a) and 5(a))

2) Amplitudes of response spectra in the period range shorter than 0.5 second at hard-rock site is smaller than those at soft-rock site. (see in Figs.4(c) and 5(c))

3) Differences of spectral amplitudes at hard- and soft-rock sites become smaller in the period range longer than 0.5 second. (see in Figs.4(c) and 5(c))

4) Peak acceleration-amplitudes show almost similar values at the different soft-rock sites for an earthquakes with the same hypocentral distances. (see in Figs.6(a) and 7(a))

5) Amplitudes of response spectra show almost similar values in the period range from 0.7 to 2.0 second at the three soft-rock sites. (see in Figs.6(c) and 7(c))

4. RELATIONS AMONG PEAK ACCELERATION AMPLITUDE, HYPOCENTRAL DISTANCE AND MAGNITUDE

Regression analysis is conducted to obtain the relationships among peak acceleration-amplitude($A_{max}$), earthquake magnitude($M$) and hypocentral distance($X$). Used magnitudes are determined by the JMA(Japan Meteorological Agency). The regression equation is assumed as follows:

$$\log_{10} A_{max} = a_1 M - a_2 \log_{10} X + a_3 + da_3 \text{........................................... eq 1}$$

Where, $a_1, a_2$ and $a_3$ indicate regression coefficients determined from observed $A_{max}$ and $X$ at the four stations and $M$ of earthquakes. $\Delta a_3$ is averaged residual values which are separately obtained for observation stations at soft- and hard-rock sites. $\Delta a_3$ values may reflect differences of seismic-wave amplification by the ground of soft- and hard-rocks[6]. Determined coefficients of $a_1, a_2, a_3$ and $\Delta a_3$ are shown in Table-2. Regression results for soft- and hard-rock sites among $A_{max}$, $X$ and $M$ are shown in Fig.8 and Fig.9. Fig.8 indicates the result for peak accelerations in horizontal components and Fig.9 for those in vertical component.

Remarkable features demonstrated by those figures are as follows:

1) Peak accelerations in horizontal components at hard-rock site are about 0.5 times smaller than those at the soft-rock site.

2) Peak accelerations in vertical component at hard-rock site are about 0.6 times smaller than those at the soft-rock site.

3) Horizontal peak accelerations are about 1.2 to 1.5 times of vertical ones at soft-rock site and about 1.1 to 1.4 times at hard-rock site for earthquakes with magnitude from 4 to 5.

5. RELATIONS AMONG RESPONSE SPECTRUM, HYPOCENTRAL DISTANCE AND MAGNITUDE

Regression analysis are conducted to obtain the relation among response spectrum($S(T)$), earthquake magnitude($M$) and hypocentral distance($X$) which is represented by the following equation[7]:

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\[ \log_{10} S(T) = a_1(T)M - a_2(T)\log_{10}X + a_3(T) + d_3(T) \ldots \ldots \text{ eq 2} \]

Where \( S(T) \) is acceleration response-spectrum in horizontal components with damping coefficient \( h=5\% \). Coefficients of \( a_1(T), a_2(T) \) and \( a_3(T) \) are determined at each period of \( T \) by using \( S(T) \) and \( X \) at the four stations and \( M \) of earthquakes. \( \Delta a_3(T) \) is calculated as an averaged residual-value which is separately obtained for observation stations at soft- and hard-rock sites.

Determined coefficients of \( a_1(T), a_2(T) \) and \( a_3(T) \) are shown in Fig.10. Coefficient of \( " r " \) is defined from \( \Delta a_3(T) \) as

\[ r(T) = 10^{\Delta a_3} \ldots \ldots \text{ eq 3} \]

"\( r(T)_{\text{soft}} \)" and "\( r(T)_{\text{hard}} \)" correspond to \( r(T) \) values for soft- and hard-rock sites, respectively. Ratio of \( r(T)_{\text{hard}}/r(T)_{\text{soft}} \), which is shown in Fig.11, indicates the differences of spectral amplitudes at hard- and soft-rock sites.

It is found in Fig.11 that \( S(T) \) at the hard-rock site is about 0.4 to 0.6 times of that at the soft-rock site in the period range shorter than 0.2 sec. This is consistent with the result of peak accelerations. On the other hand, the differences of \( S(T) \) at the hard- and soft-rock sites are small in the period range longer than 0.3 sec, comparing with those in the period range shorter than 0.2 sec.

Response spectra of earthquakes with \( M=4,5,6 \) are calculated for \( X=50 \text{ km} \) by using the determined regression coefficients and are shown in Fig.12. We can find in Fig.12 that amount of long period components relatively increases with earthquake magnitudes in \( S(T) \)'s at both the hard and soft rock sites. \( S(T) \)'s of earthquakes with \( M=6 \) are shown for \( X=50,100,150 \text{ km} \) in Fig.13. Fig.13 indicates that hypocentral distance little affect the rate of frequency components of response spectra comparing with magnitude in the range of hypocentral distance shorter than 150km. Spectra in Figs.12 and 13 are plotted in the amplitude range larger than 0.16Gal, which is the noise level deduced from the study of instrumental confidence level(8). (see in Fig.14)

5. CONCLUSION

The regression analysis was performed with the observed data of "Committee of Strong Motion Instruments Array" to elucidate the differences of seismic-wave amplifications by the ground of hard- and soft-rock site. Accelerograms at HNY, SZJ and TY stations are chosen as the data for soft-rock site and those at CHS station for hard-rock site. Obtained important results are summarized as follows:

1) Peak accelerations in both horizontal and vertical components at hard-rock site are about 0.5 to 0.6 times smaller than those at the soft-rock site.
2) Response spectra at the hard-rock site are about 0.4 to 0.6 times of those at the soft-rock site in the period range shorter than 0.2 second. This is approximately consistent with the result of peak accelerations.
3) Differences of spectral amplitudes at hard- and soft-rock sites is small in the period range longer than 0.3 second, comparing with those in the range shorter than 0.2 second.
4) Amount of long period components of response spectrum relatively increases with earthquake magnitudes. Hypocentral distance little affect the ratio of frequency components of response spectrum, comparing with magnitude in the range of hypocentral distance shorter than 150km.

7. ACKNOWLEDGMENTS

This work is a part of studies by "Committee of Strong-Motion Instruments Array" (Chairman is Prof. S. Omote). We are indebted to members of this Committee who provide us with variable advices and discussion.

REFERENCES

Table 1 GEOLOGICAL CONDITION OF OBSERVATION SITES

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<tr>
<th>site</th>
<th>Higashi-Matsuyama (HMY)</th>
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Fig. 1 RELATIONS BETWEEN MAGNITUDE AND HYPOCENTRAL DISTANCE OF OBSERVED EARTHQUAKE

Fig. 2 RELATIONS BETWEEN NUMBER OF COMPONENT AND MAGNITUDE

Fig. 3 RELATIONS BETWEEN NUMBER OF COMPONENT AND HYPOCENTRAL DISTANCE
Fig. 4(a) Comparison of Accelerograms Recorded at CHS and SZJ (Aug. 12, 1979)

- CHS Max = 0.76 Gal
- SZJ Max = 1.97 Gal

Fig. 4(b) Locations of Epicenter and Observed Sites (Aug. 12, 1979)

Fig. 4(c) Comparison of Response Spectra at CHS and SZJ (Aug. 12, 1979)

- TTY Max = 3.00 Gal
- CHS Max = 0.95 Gal

Fig. 5(a) Comparison of Accelerograms Recorded at CHS and TTY (Sep. 25, 1980)

Fig. 5(b) Locations of Epicenter and Observed Sites (Sep. 25, 1980)

Fig. 5(c) Comparison of Response Spectra at CHS and TTY (Sep. 25, 1980)
Fig. 6(a) COMPARISON OF ACCELEROMETERS RECORDED AT HMY AND SZJ (MAR. 12, 1980)

Fig. 6(b) LOCATIONS OF EPICENTER AND OBSERVED SITES (MAR. 12, 1980)

Fig. 6(c) COMPARISON OF RESPONSE SPECTRA AT HMY AND SZJ (MAR. 12, 1980)

Fig. 7(a) COMPARISON OF ACCELEROMETERS RECORDED AT HMY AND TTY (JUN. 18, 1980)

Fig. 7(b) LOCATIONS OF EPICENTER AND OBSERVED SITES (JUN. 16, 1980)

Fig. 7(c) COMPARISON OF RESPONSE SPECTRA AT HMY AND TTY (JUN. 18, 1980)
Table 2

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Fig. 8 Relations between horizontal peak acceleration and hypocentral distance for magnitude

Fig. 9 Relations between vertical peak acceleration and hypocentral distance for magnitude

Fig. 10 Coefficients of $a_1(T), a_2(T), a_3(T)$

Fig. 11 Ratio of $r(T)_{\text{hard}}/r(T)_{\text{soft}}$
FIG. 12 COMPARISON OF RESPONSE SPECTRA AT HARD ROCK AND AT SOFT ROCK SITE FOR \( x = 50 \text{km} \) (\( \eta = 0.15 \)) (HORIZONTAL COMPONENT)

FIG. 13 COMPARISON OF RESPONSE SPECTRA AT HARD ROCK AND AT SOFT ROCK SITE FOR \( M = 6.0 \) (\( \eta = 0.05 \)) (HORIZONTAL COMPONENT)

FIG. 14 RESPONSE SPECTRUM OF SEISMIC-MOTION ACCELEROMETER AND INSTRUMENTS NOISE SIGNAL

Noise levels of Analog Data Recording system (ADR) and Digital Data Recording system (DDR) are recognized to be about 0.1 Gal in this figure.