AN ENGINEERING STUDY OF LONG-PERIOD STRONG MOTION USING DISPLACEMENT SEISMOGRAPH RECORDS

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SUMMARY

Fourteen strong motion records obtained by the displacement type seismographs of the Japan Meteorological Agency's Network during the 1968 Tokachi-Oki earthquake ($M = 7.9$) were digitized and analyzed to investigate the engineering properties of long-period strong motion. The effect of subsurface structure was found much stronger than that of attenuation. It was found that the quantitative properties of 2 to 4 s period components estimated from the Japanese accelerograms are in good agreement with those estimated from the displacement records.

INTRODUCTION

In recent years, structures with natural periods longer than several seconds have been increasing in number. These structures include high-rise buildings, liquid storage tanks, suspension bridges, etc. To improve the method of earthquake-resistant design of such structures, it is of prime importance to clarify the engineering characteristics of long-period strong earthquake ground motion. The long-period strong motion here means those having the period components between approximately 2 s and 20 s and, therefore, distinction should be made from the much longer component waves often discussed in seismology.

One of the methods for investigating the engineering properties of the long-period strong motion is empirical and is generally based on observations. Acceleration strong-motion records are not adequate for this purpose because of their poor accuracy in the period range of about 5 s or longer. Consequently, the importance of long-period low-magnification seismograph records seems to have become more widely recognized recently. Kobayashi and Fujiwara (Ref. 1) digitized and analyzed eleven records obtained by the JMA's low-magnification displacement seismograph during the 1964 Niigata earthquake, the 1968 Tokachi-Oki earthquake and its largest aftershock. Tanaka, Yoshizawa and Osawa (Ref. 2) digitized low-magnification seismograph records obtained in Tokyo resulting from 29 earthquakes ($M \geq 6$) and investigated their engineering characteristics.

This paper attempts to study the characteristics of long-period strong motion during a large earthquake ($M = 7.9$) from direct information of low-magnification seismograph records obtained at over ten observation sites. Records obtained by the displacement type seismographs of the Japan Meteorological Agency were used because these seismographs have the most

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suitable instrumental characteristics in the period range of interest. The seismograph has the magnification factor of unity, the natural periods of 6 s and 5 s in the horizontal and the vertical direction, respectively, and the damping factor of 0.55.

ANALYZED RECORDS

Fourteen records (27 horizontal and 14 vertical components) obtained at 14 JMA stations during the 1968 Tokachi-Oki earthquake (JMA magnitude = 7.9) were digitized for analyses. This earthquake has left so far more usable records by the displacement seismograph than other large earthquakes in Japan. The epicentral distances for the 14 sites varied from 174 to 392 km with the average being 284 km. Figure 1 shows the locations of the 14 sites.

After digitizing the displacement records, several corrections were performed, which consist of baseline correction, eliminations of the effects of the arc and inclination of the mechanical arm, instrumental correction and band-pass filtering (Ref. 3). The band-pass filter having the cut-off periods of 2 s and 20 s was used to eliminate distortions caused by digitization.

ENGINEERING CHARACTERISTICS OBTAINED FROM DIGITIZED RECORDS

Figure 2 compares the time histories of the EW direction at Muroran. The upper curve shows the digitized displacement seismograph record, while the lower curve shows the displacement determined by the integration of strong motion accelerogram. It should be noted that the two sites in Muroran are different and that the time mark is only arbitrary because of the lack of the common clock. However, the difference in these two time histories is noteworthy.

Peak Values

The peak values of the 14 records are shown in Fig. 3 (a) through (c). Peak velocities and accelerations were obtained from the velocity and acceleration time histories determined by once and twice differentiating the displacement time history, respectively. The points in these figures scatter very widely and it is difficult to recognize the tendency of peak values to decrease with the distance from the epicenter.

The averages of the peak values and ratios of vertical peak to horizontal peak for the 14 records are shown in Table 1. The peak velocities and accelerations are relatively small for the level of displacement amplitude.

Fourier Acceleration Spectra

In order to clarify the properties of the records in the frequency domain, the Fourier spectra of accelerations were computed in the period range from 2 to 20 s by considering the cut-off periods of the filter used to obtain corrected displacements. Most computed spectra were found to have almost constant amplitudes in the period range from 2 to 20 s.

The average Fourier spectra were computed in order to find the general characteristics of the Fourier acceleration spectra of all digitized records

(Fig. 4). The average Fourier spectrum of the horizontal components shows almost constant amplitudes in the period range from 2 to 20 s, except for a slight depression in the period range from 7 to 13 s. The average Fourier spectrum of the vertical components also shows almost constant amplitudes from 2 to 20 s. By looking closely, however, it is found that the spectrum has relatively smaller amplitude from 7 to 13 s and an obvious peak around 15 s. About 80 % of the Fourier acceleration spectra of vertical components were found to show similar tendencies. Therefore, the depression near 10 s and the peak around 15 s are presumed to be the general characteristics of vertical components. The peak around 15 s of Fourier spectrum of vertical component may be related to the focal mechanism of the 1968 Tokachi-Oki earthquake.

Since the Fourier acceleration spectrum is known to be approximately identical to the undamped velocity response spectrum, the level of Fourier acceleration spectrum is important for earthquake engineering purposes. The mean values between 2 and 20 s of the average Fourier spectrum of horizontal and vertical components shown in Fig. 4 were found to be 19 and 10 cm/s, respectively. Figure 5 shows the average acceleration spectral amplitudes plotted against the epicentral distance. It is difficult to find a simple relation between the average spectral amplitude and the epicentral distance.

EFFECT OF SUBSURFACE STRUCTURE ON LONG-PERIOD STRONG MOTIONS

Characteristics of strong ground motion are affected by a number of factors including focal mechanism, depth and area of focal region, propagating path, distance from source to site, subsurface structure around a site. Among other things, effect of subsurface structure on the long-period strong motion is investigated in this section.

Subsurface structures from several hundreds to several thousands of meters below the surface are known to have a significant effect on characteristics of the strong motion in the longer period range. However, such information is hardly available for the 14 sites under investigation. The "most probable amplification factor of seismic ground motion" defined and obtained by Okada and Kagami (Ref. 4) was used in this paper as an index expressing properties of subsurface structure around a recording site. The most probable amplification factor of seismic ground motion denoted by x is a relative measure and was determined by the analysis of maximum amplitudes of horizontal records obtained at about 100 JMA stations during 138 earthquakes. Since these maximum amplitudes were read off from the original uncorrected traces obtained mainly by the JMA's low-magnification displacement seismograph, the value of x may be considered to represent the effect of subsurface structure around a site on the seismic wave amplification in the approximate period range from 1 to 7 s. The 14 sites were divided into the following three classes according to their values of x:

Class 1 --- $x < 0.67$

Class 2 --- $0.67 \leq x < 1.0$

Class 3 --- $x \geq 1.0$

Class 3 sites are those at which subsurface structures show the highest amplification factors.

To analyze the effect of subsurface structure, average Fourier acceleration spectral amplitudes of horizontal components were computed for three period ranges (2 to 7 s, 7 to 13 s and 13 to 20 s) and were plotted in Fig. 6 (a) through (c). Different symbols were used to clearly show the different site subsurface structures. Figures 6 (a) and (b) seem to illustrate the systematic and consistent effect of subsurface structure on the average acceleration spectral amplitudes. Roughly speaking, the average spectral amplitude of a record belonging to Class 3 is about 4.5 times greater than that belonging to Class 1 in the period range from 2 to 7 s (Fig. 6 (a)), and the ratio is 2.4 in the period range from 7 to 13 s (Fig. 6 (b)). The attenuation of the average acceleration spectral amplitude with distance is still not clear for the range of epicentral distances investigated, but the empirical relation obtained by Tanaka et al. (Ref. 2) is at least not inconsistent with the data points belonging to Class 1 and 2 for the components between 2 and 7 s. The scatter of points in Fig. 6 (c) seems to indicate that the characteristics of component waves with periods between 13 and 20 s cannot be properly interpreted without the knowledge of deeper underground structure.

COMPARISONS WITH EXISTING RESEARCH RESULTS

It is interesting and informative to know whether or not the properties obtained from the horizontal displacement records of the 1968 Tokachi-Oki earthquake are consistent with those known from previous analyses on acceleration strong motion.

Since the attenuation effect was found almost negligible for the data of the present study, average amplitudes at periods of 2, 3 and 4 s were computed for the absolute acceleration response spectra with a damping factor of 0.05 obtained from 27 horizontal components of the 14 records treated in this paper. They are shown in Fig. 7 together with several estimated values obtained from existing empirical relations (Refs. 5-7). Predicted values were computed by using $M = 7.9$ and $\Delta = 284$ km, which is the average epicentral distance for the 14 records. The values predicted by the relation proposed by Trifunac and Anderson (Ref. 7) using the U.S. data set are considerably smaller than the average obtained from the displacement seismograms. However, the predicted response spectral amplitudes by using Japanese empirical relations (Refs. 5, 6) show good agreement with the average amplitudes computed from the Tokachi-Oki displacement seismograms. These results do not contradict with the previous research results (Ref. 1) obtained from comparisons of the JMA's low-magnification displacement seismograph records and the acceleration strong-motion records of the nearby sites. Consequently, these results seem to suggest that the properties of the long-period strong motion estimated from the displacement seismograms of the 1968 Tokachi-Oki earthquake are generally consistent with the properties known from the analyses of the accelerograms recorded in Japan.

CONCLUSIONS

From the analyses of the 14 records obtained by the JMA's low-magnification displacement seismograph during the 1968 Tokachi-Oki earthquake, the characteristics of the long-period strong motion at sites with $\Delta = 200$-400 km caused by a large earthquake ($M = 7.9$) were examined, and the following conclusions have been drawn:

(1) The attenuation of ground motion was difficult to observe for the records analyzed.
(2) The average acceleration Fourier spectrum of the horizontal components was found to be almost flat over the period range between 2 and 20 s.
(3) The subsurface structure of the recording site was found to cause significant amplification effect on the average acceleration spectral amplitude in the period range of 2 to 13 s.
(4) The properties in the period range of 2 to 4 s of the displacement records were found to be in reasonable agreement with the corresponding properties predicted by Japanese empirical relations obtained from statistical analyses on acceleration strong-motion records.

Although these results reveal some useful characteristics of the long-period strong motion, much more records of long-period low-magnification seismograph are needed to be analyzed in detail to confirm and more quantitatively understand the engineering characteristics of the long-period strong motion.

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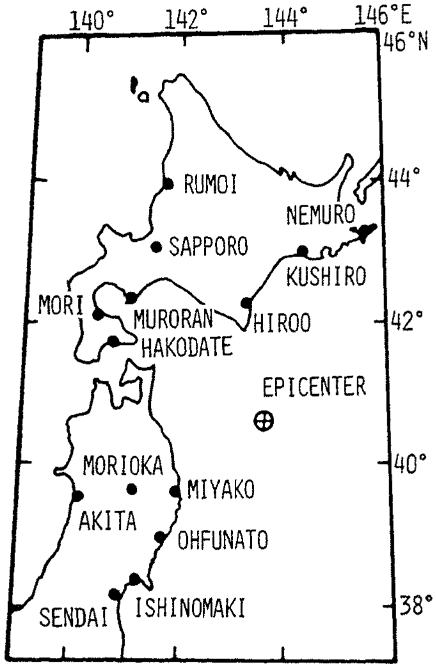


Fig.1. Locations of Recording Stations.

Table 1. Averages of Peak Values and Ratios of Vertical to Horizontal Peak Value.

Averaged Value	Dis. (cm)	Vel. (cm/s)	Acc. (cm/s^2)
Horizontal (H)	7.44	5.15	9.16
Vertical (V)	6.28	3.49	4.62
$\frac{V}{H}$	0.879	0.706	0.624

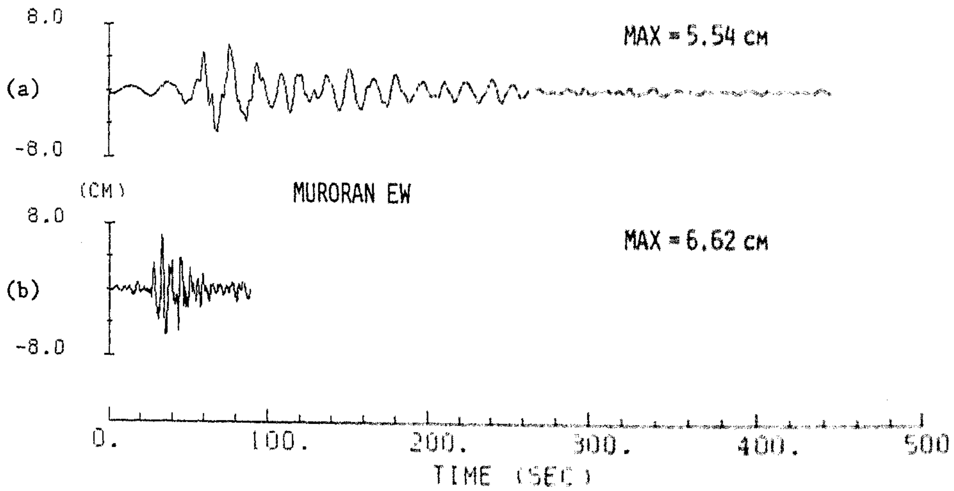


Fig.2. Displacement Time Histories for the EW Components at Muroran
(a) Obtained by Displacement Seismograph and
(b) Calculated from Strong-Motion Accelerogram.

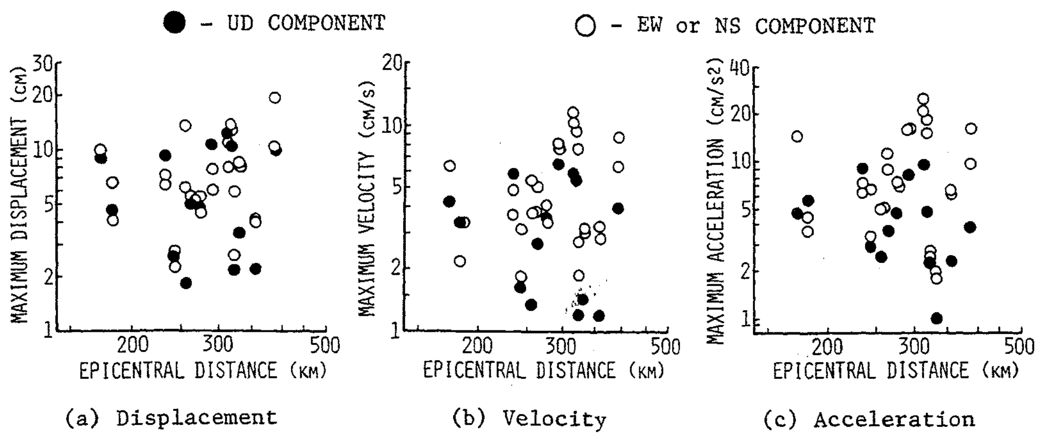


Fig.3. Peak Values for the 14 Displacement Seismograms.

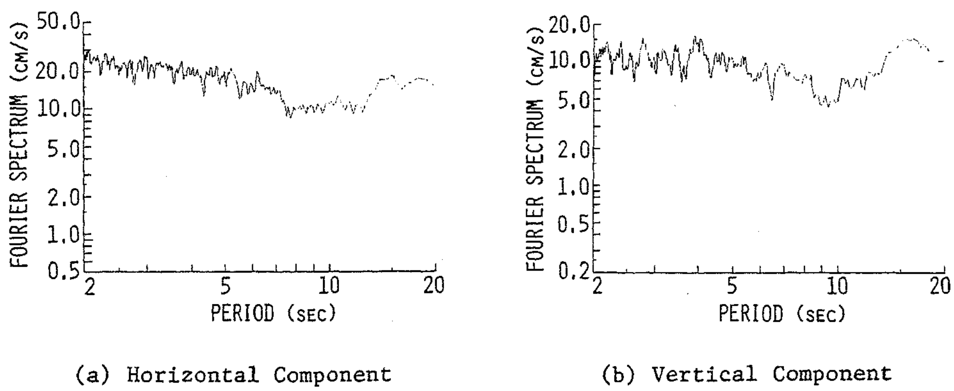


Fig.4. Average Fourier Acceleration Spectra Computed from the 14 Records.

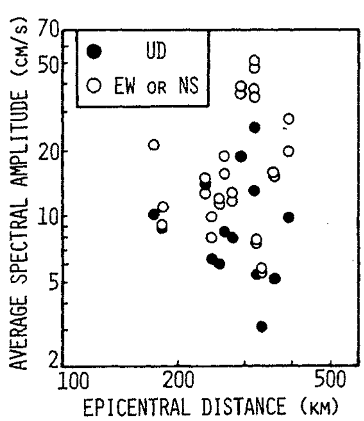
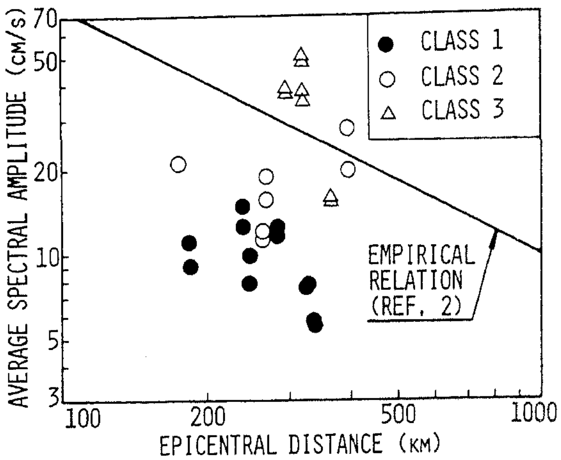
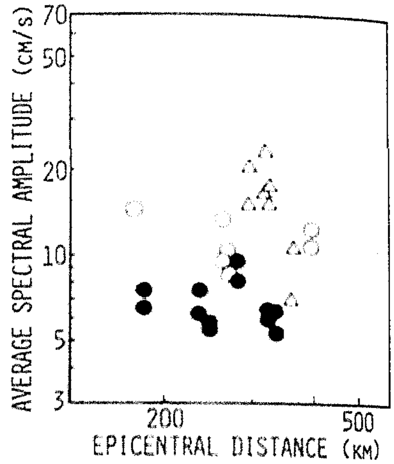


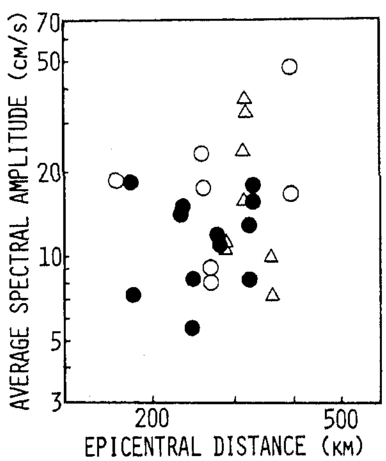
Fig.5. Average Amplitudes of Fourier Acceleration Spectra in the Period Range of 2 - 20 s for the 14 Records.



(a) Period Range of 2 - 7 s

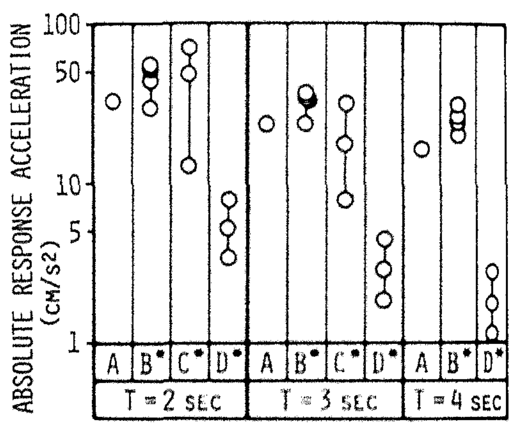


(b) Period Range of 7 - 13 s



(c) Period Range of 13 - 20 s

Fig.6. Average Amplitudes of Fourier Horizontal Acceleration Spectra in Three Period Ranges for the 14 Records.



A	Average of 27 Horizontal Components
B	Predicted by Japanese Empirical Relation (Ref.5)
C	Predicted by Japanese Empirical Relation (Ref.6)
D	Predicted by U.S. Empirical Relation (Ref.7)
*	Scatter Shows Different Site Conditions.

Fig.7. Acceleration Response Spectra of (A) Displacement Seismograms and (B-D) Predicted by Empirical Relation Based on Accelerograms. (M = 7.9, Δ = 284 km, Horizontal Motion, Damping = 0.05)