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SEISMIC PULSES REPEATED IN CODA PART OF STRONG SEISMIC WAVES

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SUMMARY

The Waseda bore-hole seismometer array, Tokyo, Japan, occasionally records periodic repetition of seismic pulses in coda part of strong seismic waves. Seismological analyses of the records prove that a possible mechanism of the present pulse events is generation of local surface waves and multiple horizontal reflection of them between underground barriers.

From the engineering point of view, repetition of seismic pulses as above could be modeled as an intermittent vibratory input motion. Then, structural response to this type of motion was investigated. Large artificial structures of long period and low damping factor might undergo additional vibration by the pulses, if the characteristic periods fit the interval of the pulses.

INTRODUCTION

The Waseda bore-hole seismometer array, Tokyo, Japan, occasionally records periodic repetition of seismic pulses in coda part of strong seismic waves. Each pulse looks like a Ricker wavelet of several seconds duration, and of repetition interval for about 60 sec.

The purpose of this paper is to clarify their excitation mechanism in relation to the local soil structures. This sort of knowledge will be useful for better understanding of the ground structures as well as of very-long-period strong motions which affect seismic vibration of large artificial structures.

EARTHQUAKE OBSERVATION SYSTEM AND DATA SET

The seismometer array of the Science and Engineering Research Laboratory, Waseda University, controls three in-hole stations, Waseda, Kamata, and Urayasu, in the eastern part of Tokyo Metropolis. They are located at sites of various underground structures, and are mutually separated for about 17-20 km (Fig.1). The depths of the instruments from the surface are as follows: (Waseda) 1, 6, 17, 67, 110m; (Kamata) 8, 30, 80m; (Urayasu) 11, 31, 81m.

This paper will study displacement ground motions at the three stations, after time integration of the original velocity seismograms. It will also refer to supplemental records at several adjacent stations (Refs.1,2). Fig. 1 is the location map of the studied earthquakes, and Table 1 is the list of their parameters. The studied earthquakes are of intermediate magnitude and form two groups, which are located off the coast of Fukushima Prefecture (Fukushima-ken-oki) and southeast off the Boso Peninsula (Boso-oki), respectively. Both of the groups are at similar distances, ca. 230km, from our array, but their azimuths differ mutually for about 90 degrees.

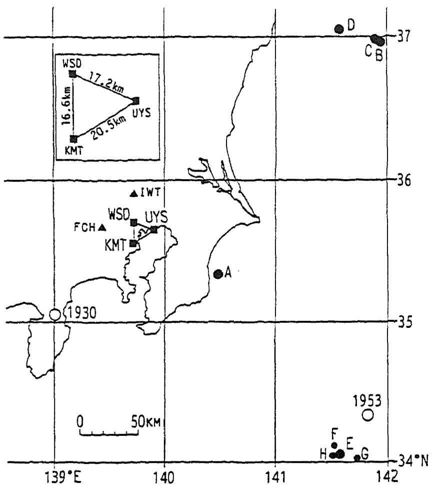

Fig.1 Map showing epicenters and observation sites.

Table 1 List of earthquakes for this study.

No.	Date & Time	Mag.	Depth(km)
A	871217 1108	6.7	58
B	870206 2124	6.4	18
C	870206 2216	6.7	31
D	870423 0514	6.5	49
E	840919 0202	6.6	13
F	840921 0156	5.8	5
G	840921 0653	5.7	28
H	840921 1830	5.7	22
	531126 0249	7.4	60
	301126 0403	7.3	0

DISCUSSION

Fig.2(a) illustrates the displacement records of the Fukushima-ken-oki (C) earthquake at the station Waseda, GL-110m. Predominant period of waves in their principal part is in a range of several to ten seconds, approximately. We also notice, in the coda part, a series of impulsive waves. They are repeated, in a certain interval, since about two minutes after the arrival of S-waves. These events are more or less seen at other two stations. We provisionally attribute them to horizontally traveling, long wavelength waves, since their amplitude and phase do not change much to the vertical direction. Some of the pulses are so predominant as to exceed in amplitude the principal part of waves. Long-continuing recurrence of pulses is another notable aspect of the present events. Fig.2(b) introduces us the orbits of ground motions in several representing pulse events. So far as these traces are concerned, the seismic pulses look like to be the combination of the Rayleigh and Love-type surface waves.

Fig.3 compares the running power spectra of the NS component of the event (C) at the three stations and illustrates temporal changes in amplitude and period of the ground motions. Their frequency characteristics precisely differ from station to station. But the general aspect of the repeated coda pulses look similar between the stations, having peak intensity at about 0.15-0.2Hz and having two kinds of repetition intervals for about 10-20 and 50-60sec, respectively. These trends of waves are also recognized in other Fukushima-ken-oki earthquakes.

Let us filtrate, from the records, the predominant spectral component around the period of 5sec, and employ the correlation method (Ref.3) to study the

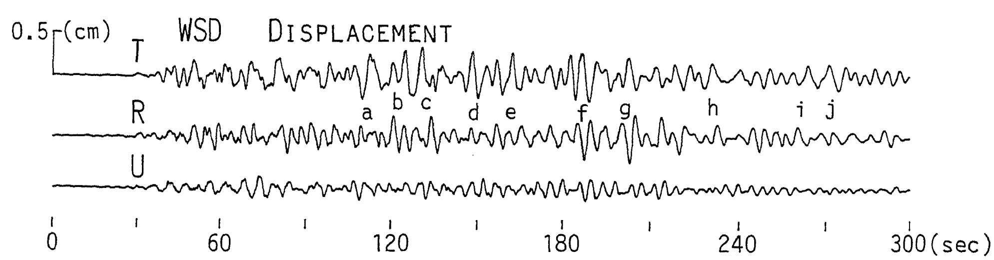

Fig.2(a) Ground motion at Waseda in the off Fukushima, M=6.7, earthquake, 6 Feb. 1987.

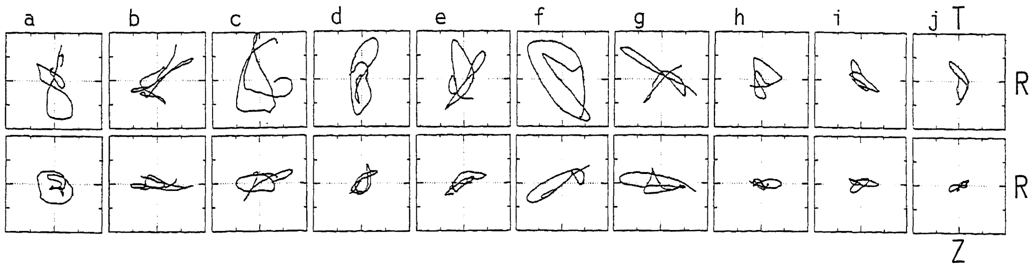

Fig.2(b) Ground motion orbit for specific pulses at Waseda site.

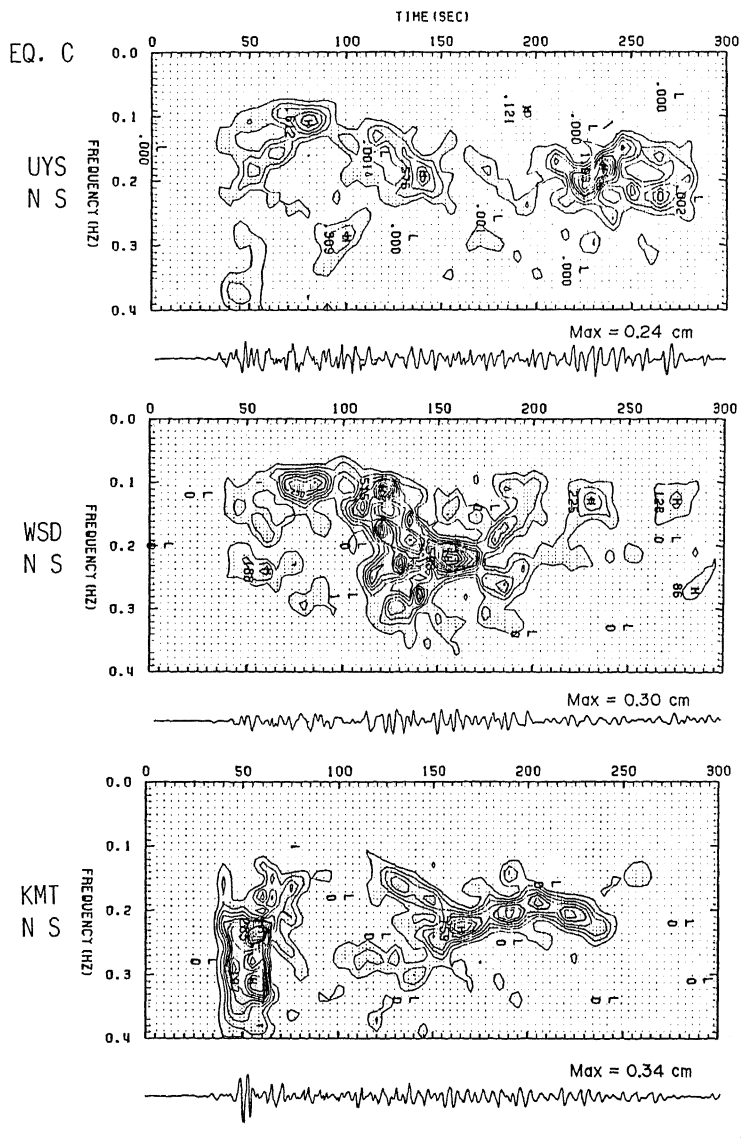

Fig.3 Running power spectra at the three sites.

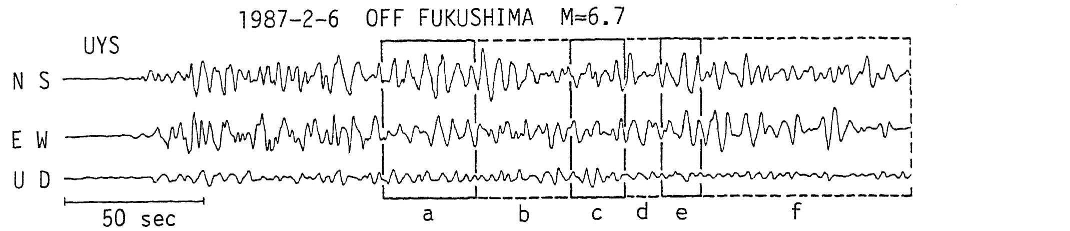

Fig.4 Ground motion at Urayasu. Solid and broken line frames respectively show the portions of forward and backward propagation of waves.

propagation azimuth of the respective pulse. Fig.4 summarizes the result and encloses, with solid and broken lines, the pulses of forward (from the epicenter) and backward (toward the epicenter) directions, respectively. We learn, from the figure, that the direction of propagation is reversed frequently from pulse to pulse.

We have studied, in the above, several fundamental aspects of the coda pulses as observed in the Fukushima-ken-oki earthquakes. Similar aspects, including the repetition period of 50-60sec, are also seen in the earthquakes of the Boso-oki group, although the shape of the unit pulse tends to appear as a wave-group rather than an impulse.

Our three stations have equally recorded the remarkable repetition of coda pulses, although their precise aspects differ from station to station. The next question, which may be naturally raised, is how widely and how deeply the present pulses have appeared around our array. For this problem, the records from the seismic network of the National Research Center for Disaster Prevention have been usefully available, by courtesy of the Center. Especially interesting are the acceleration seismograms at their deep bore-hole stations, Iwatsuki and Fuchu (see Fig.1 for their location) in the Fukushima-ken-oki earthquakes. The surface and shallow seismometers have registered similar repeated pulses in coda, but their deep seismometers (3500, and 2750m deep, respectively) have not recorded such type of events.

These sorts of information seem to suggest that the coda pulses of our interest could be observed in a considerably wide area in and around Tokyo Metropolis, and that they are presumably the locally excited surface waves, which travel horizontally in sedimentary layers, repeating reflection at the outer rim of the sedimentary plain. Further conclusion must be made after precise location of the reflectors.

RESPONSE OF A SINGLE-DEGREE-OF-FREEDOM SYSTEM TO INTERMITTENT SEISMIC VIBRATION

Another problem of engineering interest would be the vibration of a building by such intermittent coda pulses as studied above. Fig.5 is the result of our preliminary test and compares two displacement response spectra as derived from the same seismogram (Fukushima-ken-oki (C) earthquake, EW-component, Urayasu), taking different time windows. The window lengths of thick and thin curves are 75 and 300sec from the initial P-wave, respectively. In other words, the former window involves the principal part of the record in the conventional sense, whereas the latter extends to the end of the coda pulse series. Their difference is obvious in the figure, particularly for the period range around 5sec, where the thin curve appears almost twice as high as the thick curve. This result proves that the repeated coda pulses may play an important role in the seismic response of a long-period building or structure.

For numerical tests of the problem, let us simplify the observed coda pulses as given in the top of Fig.6 and call them the model signals of the intermittent coda pulses. The model 1 represents a series of sine wavelets of the same polarity, whereas their polarity is reversed alternately in model 2.

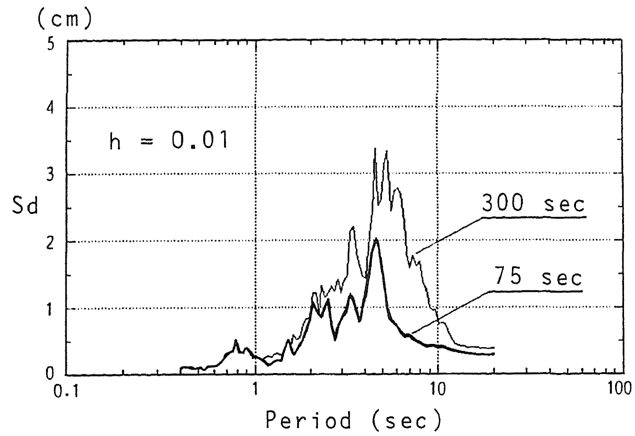

Fig.5 Comparison of displacement response spectra in different time windows. Thick and thin lines are for the principal part of the record and for the whole record, respectively. Damping factor 'h' is 1%.

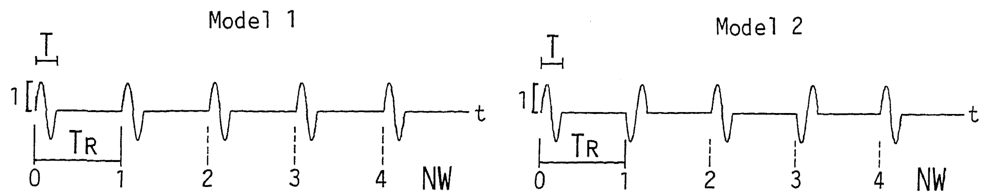

Fig.6 Intermittent vibration model. Model 1 repeats seismic pulses of same polarity, whereas the polarity is reversed alternately in model 2.

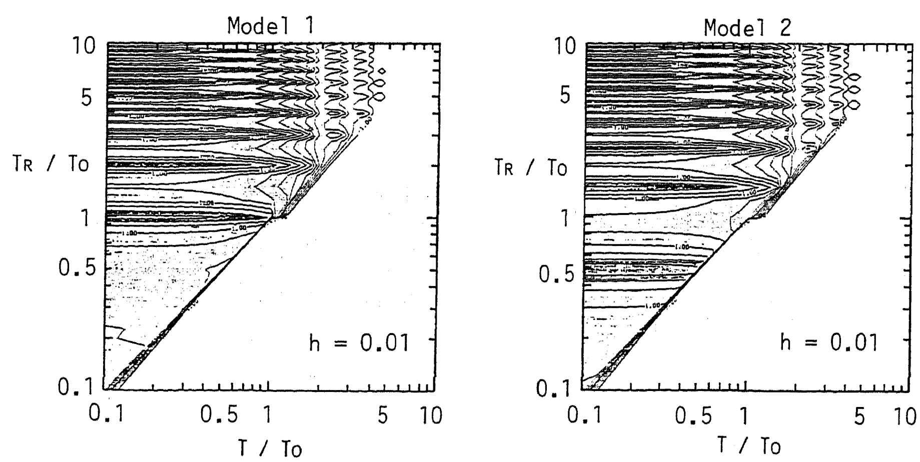

Fig.7 The amplification factor, in the two models, as a function of unit impulse period, T, recurrence time of the pulse, T_R, and the period of the system, To.

Then we employ a single-degree-of-freedom system as a building model. We also assume a long-period building and give a low damping factor, h, to the system (Ref.4).

Results of the numerical experiments are given in Fig.7. It illustrates with contour lines the calculated amplification factor of the system's response as a function of three parameters, they are, the unit pulse period, T, the recurrence time of the pulse, T_R, and the period of the system, To. The amplification factor here denotes the ratio of the maximum amplitude of the system to that of the pulse, after the system has received 10 repeated pulses. As seen in the figure, the factor depends seriously on the ratio T_R/To, reaching its peak values when the ratio takes the following values:

$T_R/To = 1, 2, 3,\ldots$ (model 1), $T_R/To = 0.5, 1.5, 2.5,\ldots$ (model 2).

This relationship is especially the case for small values of T/To. For its larger values, however, the amplification factor tends to decrease, as shown in the figure. The dependence of the factor on other parameters, as mentioned above, is understandable from the standpoint of the Fourier analysis of the model.

CONCLUSIONS

The repeated coda pulses in strong seismic motions, which we occasionally observe at the Waseda seismic array, are presumed to be locally excited surface waves, traveling horizontally in sedimentary layers. Observation at other stations seems to suggest that the present event appears in a considerably wide area in and around Tokyo Metropolis.

Numerical experiments based on a simple model has proved that this type of coda pulses may play an important role in seismic vibration of a long-period building or structures, if its period fits the repetition interval of pulses.

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