TWO-DIMENSIONAL HORIZONTAL GROUND MOTIONS DURING EARTHQUAKE

by

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SYNOPSIS

The ground motion during earthquake is composed by body waves and surface waves, which are related to the geological conditions of layered soil ground, and each wave has its own direction of oscillation concerning with the direction of wave propagation. Authors tried to separate those wave components from strong earthquake motion records, which were obtained during the Tokachi-oki Earthquake of 1968, the Izu-hantoh-oki Earthquake of 1974 etc.. In this paper they showed two-dimensional horizontal ground motions due to earthquake using the methods of analysis of filtered particle orbit, two-dimensional response diagram, two-dimensional response spectrum and response ratio of maximum and minimum in horizontal plain.

INTRODUCTION

It is well known that the direction of ground motion due to earthquake is determined by the elemental particle motion due to body waves and surface waves. But observed records of ground motion are very complicated, and it is very difficult to find the direction of oscillation of ground motions. Usually the particle orbit of the ground motion were drawn from the records of seismograph, however, we can not obtain detailed ground motions from the particle orbit of the ground motion clearly.

The direction of the ground motions are very important as the information of elemental seismic waves which composed seismic ground motions. Authors tried to separate these wave components from strong earthquake ground motions. Filtered particle orbit and two-dimensional response analysis were used in this study.

1. FILTERED PARTICLE ORBIT

Using the convolution filtering technique, authors obtained the filtered particle orbit, whose filter has narrow frequency band of 10 percent wide of individual peak period of Fourier spectrum. They showed several examples of the filtered particle orbits in Figs. 1-a to 1-e. These particle orbits were drawn on the horizontal plain, and the period, which were indicated bottom of the figures, means the peak period of Fourier spectrum. In case of the Tokachi-oki Earthquake of 1968, the direction of the origin of earthquake is not so clear from these figures, because the source area of the earthquake is very large and epicentral distances are not so large, but others showed the direction of origin and transversal direction clearly. The shaps of the filtered particle orbit are very simple and largest amplitude portion of the particle orbit have a elliptical shap.

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2. TWO-DIMENSIONAL RESPONSE DIAGRAM

Two-dimensional response diagram presents response value of one degree of freedom system of corresponding period in all horizontal directions. Using both records of horizontal direction, whose relation of time axes was corrected carfully, they made the conversion of axes and obtained a component of given direction in horizontal plain. By this ground motion of component of given direction they analyzed the response of one degree of freedom system of individual period and plotted on the two-dimensional response diagram. In Figs.1-a to 1.e, they showed several examples of two-dimensional response diagram. The shap of this diagram is "cocoon type", generally, and it has pricipal axes , which correspond to the principal axes of the elliptical filtered particle orbit of ground motion, that is mentioned in previous section. The shaps of the filtered particle orbit of ground motion and two-dimensional response diagram were compared about the ratio of the maximum and minimum axes and the comparison of this ratio was shown in Fig.2. This figure shows a good agreement between the both the both shaps of filtered particle orbit and two-dimensional response diafram.

3. OVERALL RESPONSE DIAGRAM

From the results of two-dimensional response diagrams, they made overall response diagram as shown in Figs. 3-a to 3-e. Direction of major axis was plotted, position of radial direction means the period of analyzed one degree of freedom system, and diameter of the plotted mark shows response value of the two-dimensional response.

By these overall response diagrams, authors led general trends on the direction of ground oscillation due to earthquake as following:
(a) Case of big earthquake: Directions of ground oscillation are rather scatered, but they have vaguely trend, that is, on rather long period range, Hachinohe Fig.3-a and Aomori Fig.3-b are almost transversal direction and Muroran Fig.3-c is almost radial direction.
(b) Case of smaller earthquake: Direction of ground motion is very clear, that is either of radial or transversal direction to the focus of earthquake.
(c) Shorter period range: Direction of ground oscillation are almost transverse.

Generally, SH-waves are transverse and SV-waves are radial direction, and Rayleigh-waves are radial and Love-waves are transversal direction. For the ground motions in the period range shorter than 0.7 to 0.8 sec., the direction of oscillation is generally transverse to the epicenter, these seem to be due to SH-waves. In the period range longer than 1 sec., the direction of oscillation will be determined by the relative location of hypocenter and observed site. In cases of longer period range of Kushiro and Muroran, the directions are radial to the epicenter, so the seismic waves seem to be Rayleigh-waves, and in cases of Hachinohe, Aomori, and Midorigaoka, the directions are transverse, so they seem to be SH-waves or Love-waves.

4. PROPOSAL ON TWO-DIMENSIONAL RESPONSE SPECTRA

The usal response spectra of ground motion showed different spectra between the NS- and EW-components, sometimes. Reason of these differences can be explained by the filtered particle orbit or the two-dimensional response spectra. So the authors proposed two-dimensional response spectra as shown in Figs. 4-a to 4-e. These response spectra present the maximum response values of one degree of freedom system, these maximum values were taken from any direction in horizontal plain. In Figs. 4-a to 4-e, minimum response values were showed also. And ratio of the response values of maximum and minimum in accordance of the direction were illustrated in Figs. 5-a to 5-e. Maximum response values of Figs. 4-a to 4-e of two-dimensional response spectra and response ratio of Figs. 5-a to 5-e were very similar spectra.

On the other hand, they checked the predominat period of ground due to the propagation of SH-waves and the period of minimum group velocities of Rayleigh- and Love-waves in the layered soil ground. Then they compared these results of calculation and the shaps of filtered particle orbit or two-dimensional response diagram of the strong earthquake motions. Finally they showed a good agreement between two-dimensional response spectra and predominant period of layered soil ground.

CONCLUSIONS

Authors carried out the study on the direction of ground oscillation due to strong earthquake and they led following conclusions:

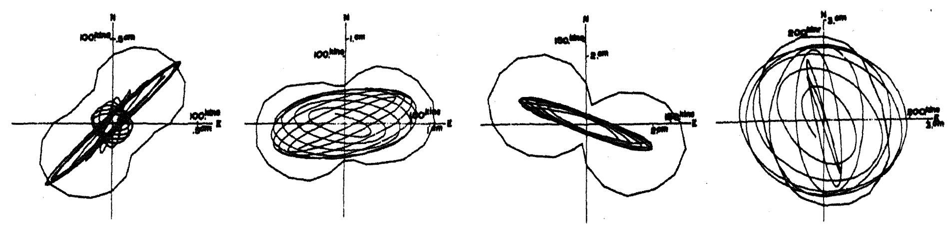
(1) The horizontal ground motion amplitude of individual peak period does not enlarge in all directions but in limited direction. Therefore the filtered particle orbit of ground oscillation of individual period showed simple elliptical shap and two-dimensional response diagram showed "cocoon" shap also.

(2) The direction of the filtered particle orbit and the major axis direction of the two-dimensional response diagram show a good agreement.

(3) The response ratios of the principal axes of two-dimensional response diagram at peak periods are generally larger than those at other periods.

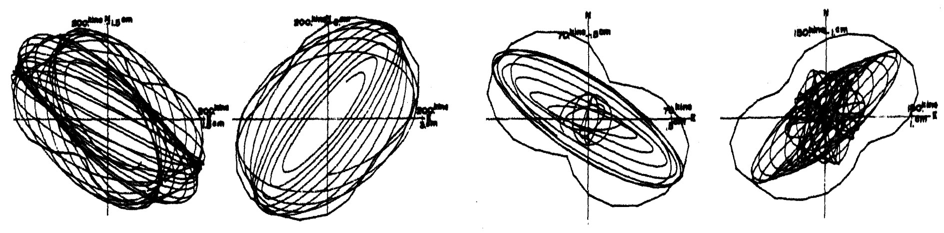
(4) For the ground oscillations in the period range shorter than 1 sec., the ground oscillation to be due to SH-waves, generally. In period range longer than 1 sec., the direction of ground oscillation will be determined by the relative location of hypocenter and observed site. Sometimes Rayleigh-waves are predominated and sometimes Love-waves or SH-waves are dominant.

Finally authors proposed two-dimensional response spectra for the evaluation of strong ground motions. These spectra can explain the amplification characteristics of layered soil ground.



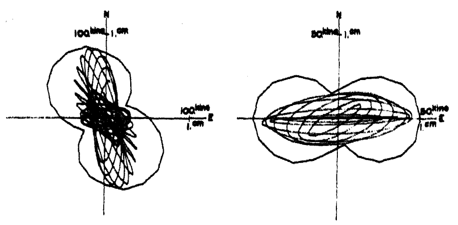
0.60 0.80 1.20 2.60 sec.

1-a Hachinohe Harbour 1968.5.16 (09:49)



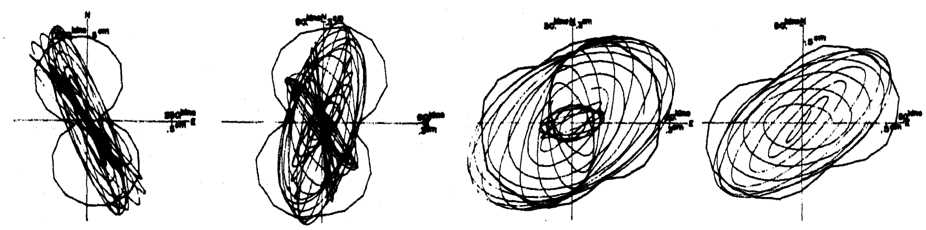
0.50 0.86 1.30 2.20 sec.

1-b Aomori Harbour 1968.5.16 (09:49)



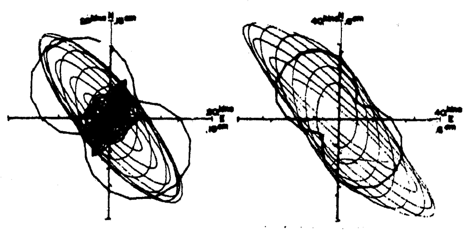
1.20 3.00 sec.

1-c Muroran Harbour 1968.5.16 (09:49)



0.33 0.50 0.80 1.30 sec.

1-d J.M.A. Kushiro Observatory 1962.4.23



1.00 3.30 sec.

1-e Midorigaoka 1974.5.9

Fig. 1 Filtered particle orbit of earthquake ground motion

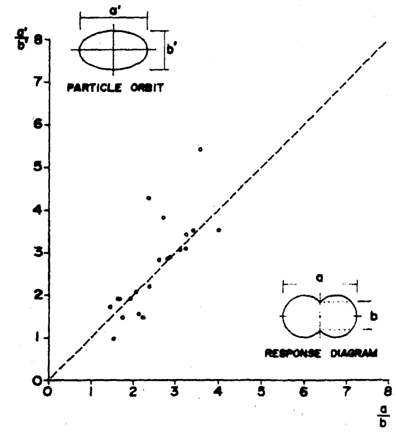
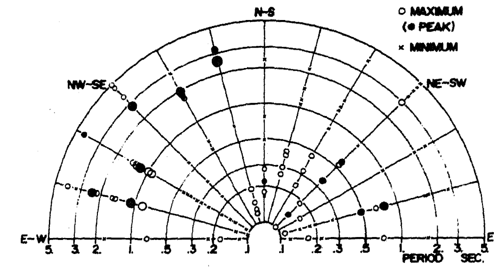
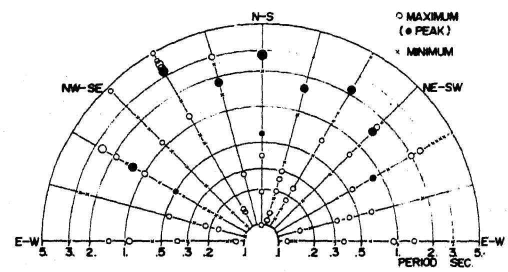


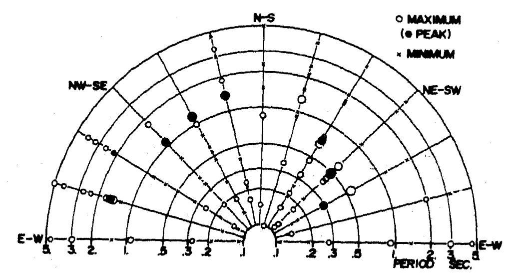
Fig. 2 Comparison between the shape of filtered particle orbit and two-dimensional response diagram



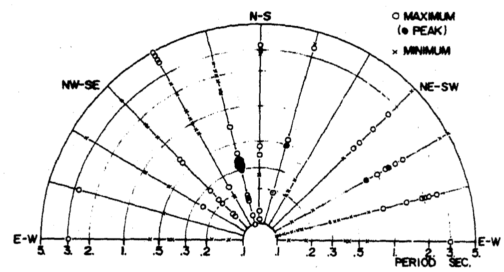
3-a Hachinohe Harbour 1968.5.16



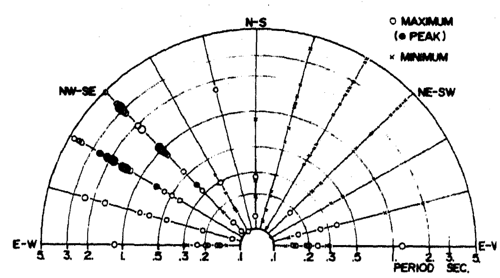
3-b Aomori Harbour 1968.5.16



3-c Muroran Harbour 1968.5.16

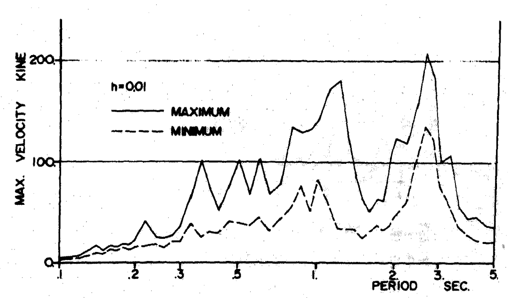


3-d J.M.A. Kushiro Observatory 1962



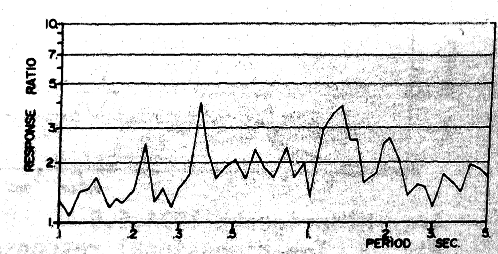
3-e Midorigaoka 1974.5.9

Fig.3 Overall response diagram



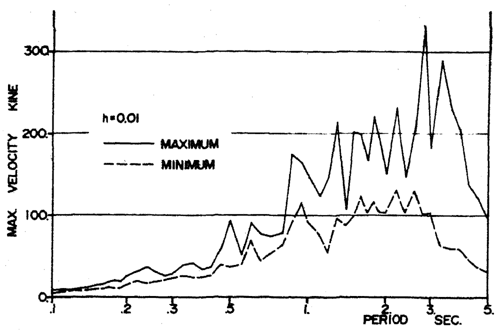
Hachinohe Harbour 1968.5.16

Fig. 4-a Two-dimensional response spectra

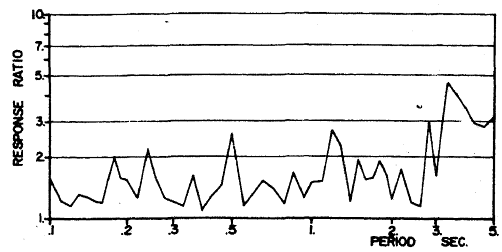


Hachinohe Harbour 1968.5.16

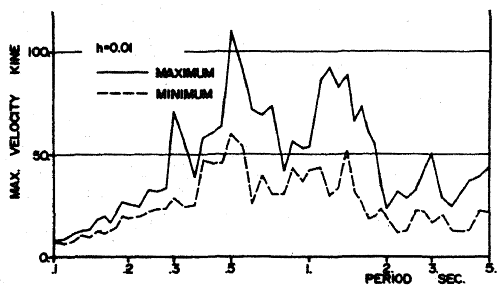
Fig. 5-a Response ratio



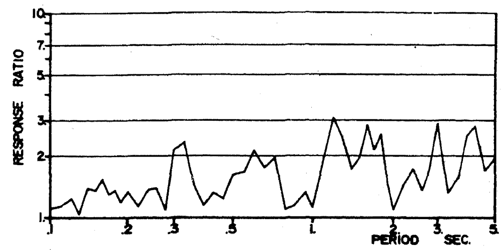
4-b Aomori Harbour 1968.5.16



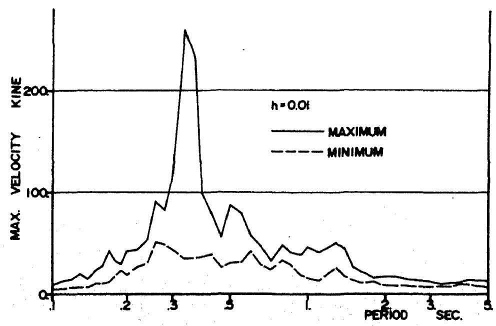
5-b Aomori Harbour 1968.5.16



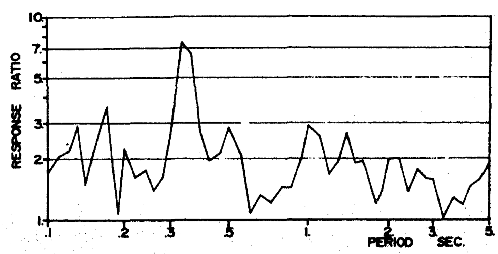
4-c Muroran Harbour 1968.5.16



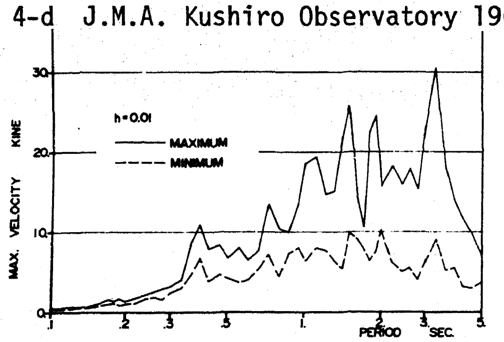
5-c Muroran Harbour 1968.5.16



4-d J.M.A. Kushiro Observatory 1962

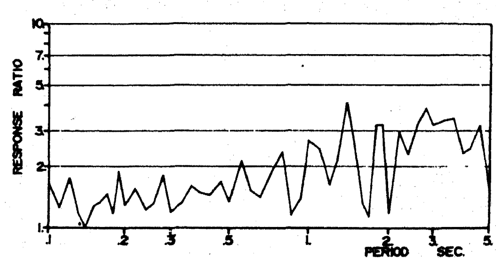


5-d J.M.A. Kushiro Observatory 1962



4-e Midorigaoka 1974.5.9

Fig. 4 Two-dimensional response spectra



5-e Midorigaoka 1974.5.9

Fig. 5 Response ratio of Max. and Min. in horizontal plain