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PHASE VELOCITY OF SURFACE WAVES OBTAINED BY THREE DIMENSIONAL ARRAY OBSERVATION

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SUMMARY

This paper describes the phase velocity of surface waves generated during earthquakes. To evaluate the phase velocity of surface waves correctly, a three dimensional array earthquake observation has been carried out in YOKOSUKA city since 1983. From the general characteristics of surface waves and observations made in the field, including other earthquake observations, it can be concluded that the surface waves generated during earthquakes change to higher mode waves in accordance with an increase in frequency.

INTRODUCTION

In the seismic estimation of underground structures, it is very important to evaluate the seismic ground strain correctly. This seismic ground strain is dependent on the ground velocity and the propagating velocity of the ground motion. Therefore it is important to evaluate the propagating velocity particularly with a period which is less than 10 seconds, for the estimation of the general wave propagation characteristics.

In view of these facts a three dimensional array earthquake observation was carried out on the surface layers and tertiary formations of YOKOSUKA city for the purpose of evaluating the phase velocity of the seismic waves.

THREE DIMENSIONAL ARRAY OBSERVATION

A general view of the three earthquake observation stations, YASUURA, MIHARU and FUJIMI, is shown in Fig.1. The distance between YASUURA and MIHARU stations is 940m, between YASUURA and FUJIMI stations is 515m and between MIHARU and FUJIMI stations is 750m.

Fig.2 shows the sectional plans of the strata and the measurement instrument array. In each observation station 3 acceleration seismographs (3 components each) were installed, at the surface, at the boundary of the surface layer and tertiary formation, and in the tertiary formation respectively. Acceleration seismographs were installed at the same depth according to the average sea water level of Tokyo bay; FG1 at a depth of 73m at the FUJIMI station, YG1 and MG1 at a depth of 48m at the YASUURA and the MIHARU stations. The unconfined compressive strength and shear wave velocity of the tertiary formation which appeared around the observation stations were found to be 40~100kg/cm^2 and 500~800 m/sec respectively.

PHASE VELOCITY OF SURFACE WAVES OBTAINED BY ARRAY OBSERVATION

More than forty earthquakes have been observed since the installation of the instruments. Fig.3 shows the epicenters of the observed earthquakes, in which the magnitudes of 7 earthquakes were more than 6.0.

A closer investigation was made of the phase velocity of surface waves concerning 8 earthquakes with relatively large magnitudes and seismic intensities shown in Table 1. Fig.4 shows the theoretical dispersion curves of surface waves in the earthquake observation stations. As shown in Fig.4, the group velocity of Rayleigh waves becomes a minimum at the frequencies of 0.24Hz, 0.55Hz and 0.79Hz, and of Love waves becomes a minimum at the frequencies of 0.12Hz, 0.46Hz and 0.87Hz.

In this paper two methods were used to calculate the phase velocity. In the one (Method I) the band-pass-filter and the cross correlation method were used. In the other (Method II) the evolutionary spectra (Ref.1) were used. If the following 4 items were satisfied simultaneously, the waves were recognized to be surface waves.

1) In the horizontal direction, the phase velocity and the azimuth angle obtained by the array in the surface layers were almost the same as those obtained by the array in the tertiary formations.
2) The azimuth angle obtained by observed waves was similar to the angle formed by the epicenter and observation station.
3) In the vertical direction, the propagating velocity obtained by observed waves was much larger than the average shear velocity of the surface layers.
4) The coefficients of the cross correlation function were relatively large.

In Fig.5 the relationship between the phase velocity obtained by array observation and the theoretical dispersion curves of Rayleigh waves in the case of the Kanagawaken Seibu Earthquake is compared. As shown, the waves in the radial direction, with observed velocity in the frequency range of 0.10~0.20Hz almost coincide with 1st mode Rayleigh waves, while those with velocity in the range of 0.40~0.70Hz almost coincide with 3rd mode Rayleigh waves.

In Fig.6 the relationship between the phase velocity obtained by array observation and the theoretical dispersion curves of Love waves in the case of the Naganoken Seibu Earthquake is compared. The waves in the transverse direction, with observed velocity in the frequency around 0.12Hz almost coincide with 1st mode Love waves, while those with velocity in the frequency range of 0.25~0.45Hz almost coincide with 2nd mode Love waves.

In Figs.5,6 the comparison of the observed phase velocity with the theoretical dispersion curves concerning a certain earthquake is shown. Then, in Fig.7 the relationship between the observed phase velocity and the theoretical dispersion curves of Rayleigh and Love waves concerning 8 earthquakes of Table 1 is shown. As indicated, the waves in the radial direction, with observed velocity in the frequency range of 0.10~0.21Hz almost coincide with 1st mode Rayleigh waves, while those with velocity in the range of 0.21~0.40Hz almost coincide with 2nd mode Rayleigh waves and those with velocity in the range of 0.40~0.70Hz almost coincide with 3rd mode Rayleigh waves. Also the waves in the transverse direction, with observed velocity in the frequency range of 0.10~0.15Hz almost coincide with 1st mode Love waves, while those with velocity in the range of 0.25~0.43Hz almost coincide with 2nd mode Love waves and those with velocity in the range of 0.43~0.70Hz almost coincide with 3rd mode Love waves. In short it can be concluded that the surface waves generated during earthquakes changed to higher mode waves in accordance with an increase in frequency in the YOKOSUKA observation station.

To verify the validity of this tendency, we have the comparison of the observed phase velocity with the theoretical dispersion curves from the other observation stations. In Fig.8 the relationship between the observed phase velocity and the theoretical dispersion curves of Rayleigh and Love waves at the observation station of KAWASAKI (Ref.2) is compared. Although the surface layers at the KAWASAKI station are softer than those at the YOKOSUKA station, the relationship between the observed phase velocity and the theoretical dispersion curves of the KAWASAKI station is similar to that of the YOKOSUKA station. In Fig.9 and Fig.10 the similar comparisons of observed and theoretical phase velocity are showed (Refs.3,4). The results are almost the same as those of the YOKOSUKA and the KAWASAKI stations. Although the range of frequencies and the modes of surface waves generated during earthquakes depend upon the depth and the area of the dislocation, and the general crust structure including the epicenter, the common points concerning surface waves in the four earthquake observation stations are that the surface waves generated during earthquakes change to higher mode waves in accordance with an increase in frequency.

CONCLUSION

The higher the wave mode, the frequency at which the group velocity becomes a minimum also becomes higher. In addition, the amplitude of surface waves becomes a maximum at the same frequency at which the group velocity becomes a minimum. From the general characteristics of surface waves and observations made in the field, it can be concluded that the frequency at which the i order mode changes to the i+1 order mode occurs at the average value of frequencies at which the i order and the i+1 order group velocity become a minimum. This analysis clearly explains the results of above-mentioned earthquake observations.

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REFERENCES

1. Kameda,H., "Evolutionary Spectra of Seismogram by Multifilter," Jour. Eng. Mech. Div., ASCE, Vol.101, No.EM6, 787-801, (1975).
2. Oishi,H. and Sekiguchi,K.,"Earthquake Observation of an Underground Pipeline and Seismic Response Analysis," Proc. of 8WCEE, Vol.5, 295-302, (1984).
3. Fukumori,Y., Sako,M., Kikuta,T. and Nakanishi,T., "Frequency Characteristics of Phase Velocity obtained by Three-dimensional Array Observation," Proc. of 6th Japan Earthquake Engineering Symposium, 249-256, (1982).
4. Sakaki,N., Suzuki,M., Koyama,K. and Watanabe,O., "A Study on In-ground Tank Strain observed during Earthquake," Proc. of 7th Japan Earthquake Engineering Symposium, 1855-1860, (1986).

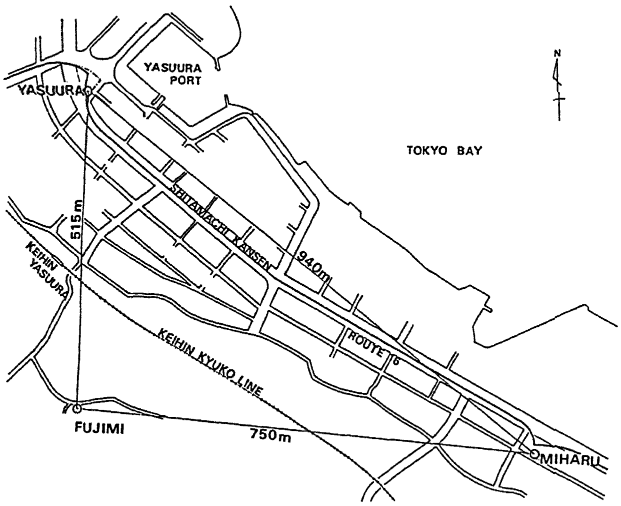


Fig.1 General View of Earthquake Observation Stations.

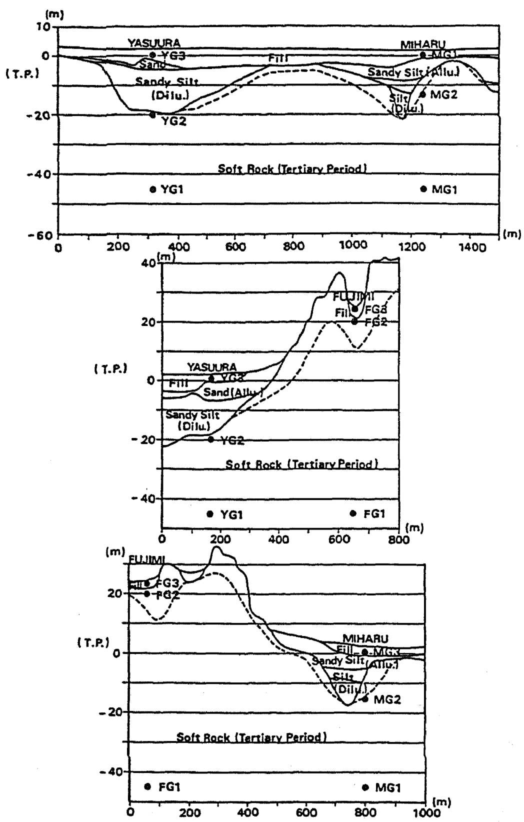


Fig.2 Sectional Plans of Strata and Measurement Instrumentation.

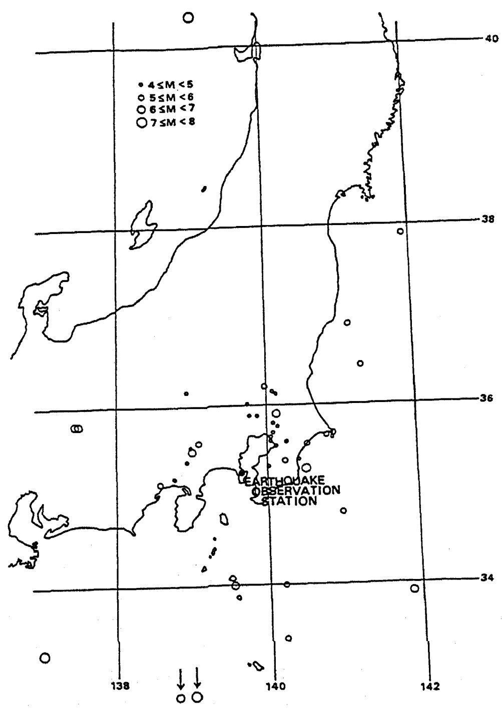


Fig.3 Epicenters of Observed Earthquakes.

Table 1 Strong-motion Earthquake Records.

	event	date	epicenter		magnitude	focal depth(km)	epicentral distance(km)
1	Kanagawaken Seibu	1983. 8. 8	139.0°E	35.5°N	6.1	30	64
2	Tohkaidoh Harukaoki	1984. 1. 1	137.0°E	33.3°N	7.4	400	327
3	Kanagawa Yamanashi Kenkyo	1984. 2. 14	139.1°E	35.6°N	5.4	20	60
4	Torishima Kinkai	1984. 3. 6	139.0°E	29.1°N	7.9	400	673
5	Naganoken Seibu	1984. 9. 14	137.5°E	35.8°N	6.9	0	201
6	Bohsoh Hantohoki	1984. 9. 19	141.8°E	33.9°N	6.7	46	248
7	Ibaragi Chiba Kenkyo	1985. 10. 4	140.2°E	35.8°N	6.2	78	85
8	Chibaken Tohooki	1987. 12. 17	140.5°E	25.3°N	6.7	58	73

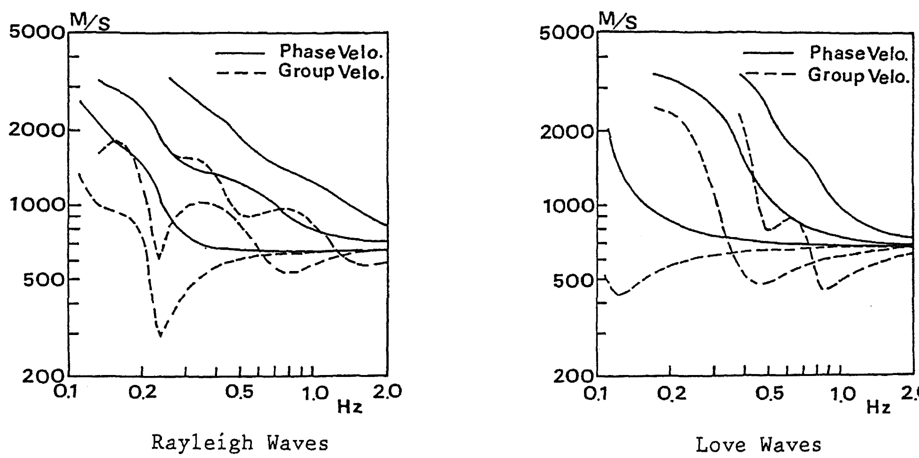


Fig.4 Theoretical Dispersion Curves.

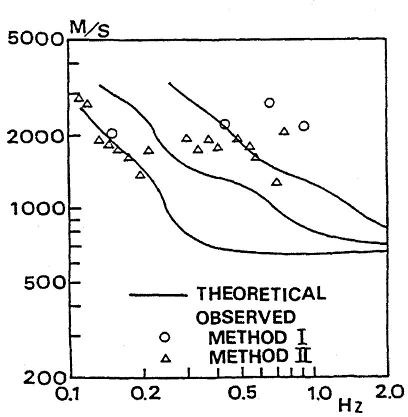


Fig.5 Theoretical Dispersion Curves and Observed Phase Velocity (Kanagawaken Seibu Earthquake)

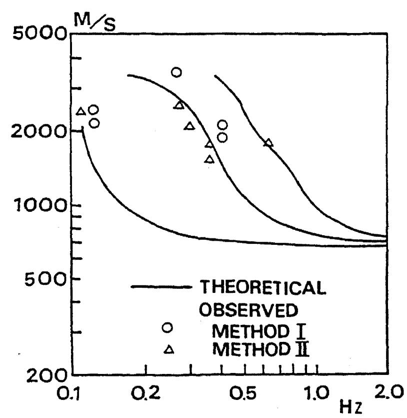
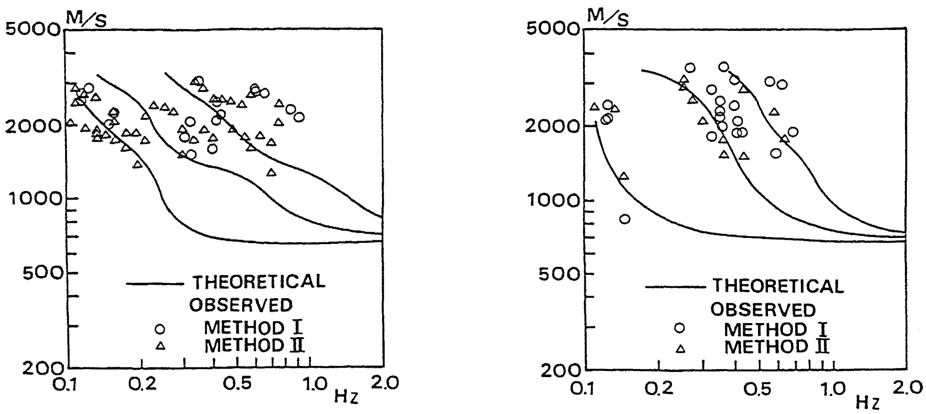


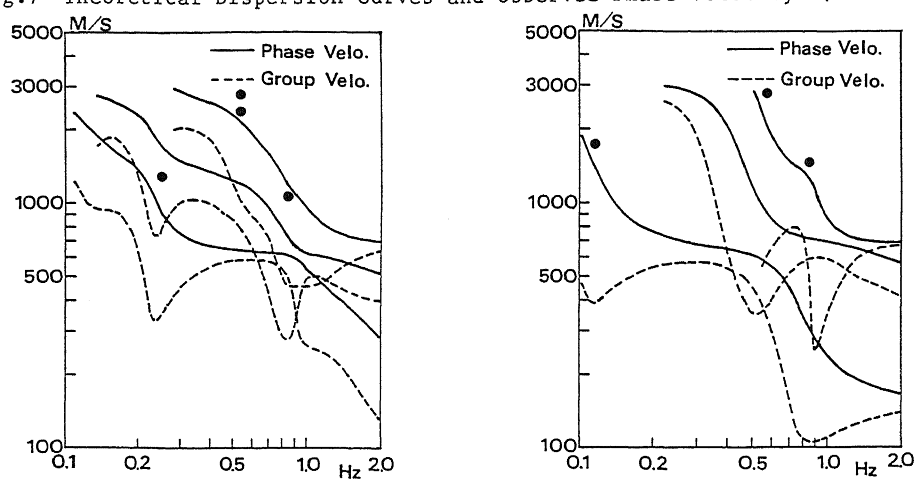
Fig.6 Theoretical Dispersion Curves and Observed Phase Velocity (Naganoken Seibu Earthquake)



Rayleigh Waves

Love Waves

Fig.7 Theoretical Dispersion Curves and Observed Phase Velocity (YOKOSUKA)



Rayleigh Waves

Love Waves

Fig.8 Theoretical Dispersion Curves and Observed Phase Velocity (KAWASAKI)

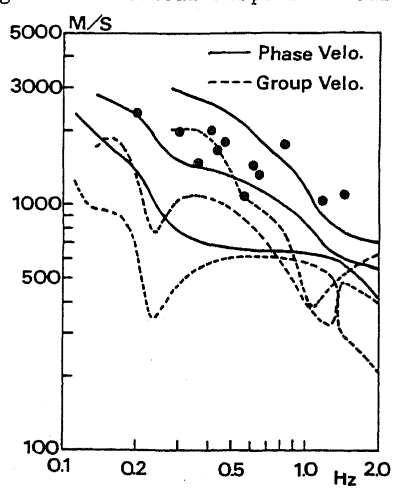


Fig.9 Theoretical Dispersion Curves and Observed Phase Velocity (SAITAMA)

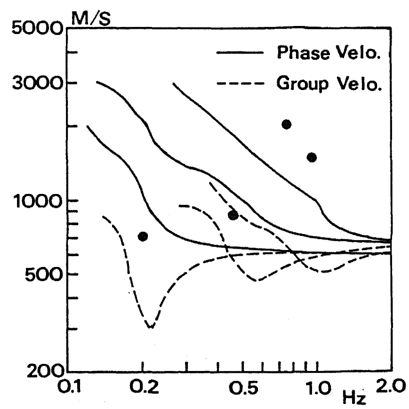


Fig.10 Theoretical Dispersion Curves and Observed Phase Velocity (YOKOHAMA)