ON THE CHARACTERISTICS OF SEISMIC MOTION IN SOFT SOIL LAYERS

by

A. Asada[I], F. Kawakami[II] and M. Kamiyama[III]

SYNOPSIS

Three kinds of observations, namely tripartite observations of microtremor at the ground surface, observations of seismic motion performed simultaneously on the surface and under the ground, and similar ones of microtremor were carried out to investigate characteristics of seismic motion in soft soil ground. Comparing the results of observations with those of theoretical calculations, it was found that the seismic motion in soft soil ground had mainly the characteristics of dispersive Rayleigh waves.

INTRODUCTION

It has been learned often from the experiences of stronger earthquakes, for example, Kanto Earthquake (1923), Niigata Earthquake (1964) and Tokachioki Earhtquake (1968) that structures on soft ground were severely damaged. Under the stimulus of these experiences, many studies on the vibrational characteristics of soft ground have been performed. Recently, the researches on the liquefaction and the response characteristics of ground during earthquake have been developed in Japan. In the analysis of seismic response of structures, the shear wave (S-wave) is commonly used as the input seismic wave because it is easy to deal with. It is irrational to adopt only shear wave as input seismic wave, having a disregard of the surface waves, i.e. Rayleigh waves and Love waves, which may have considerable influence on the seismic motion of soft ground.

From this point of view, authors tried to confirm which of shear waves or surface waves have more influenced on the seismic motion of soft ground. They carried out the three kinds of observations, i.e. the tripartite observations of microtremor on the surface and under the ground, and similar ones of microtremor. Studies were performed by comparing the results of observations with those of theoretical calculations.

[I] Assistant Professor of Soil Mechanics, Tohoku Insitute of Technology, Sendai, Japan.

[II] Professor of Soil Mechanics, Faculty of Engineering, Tohoku University, Sendai, Japan.

[III] Assistant of Soil Mechanics, Tohoku Institute of Technology, Sendai, Japan.

SOIL CONDITIONS OF THE SITE

The observations of seismic motion and microtremor were carried out at the ground which was constructed by reclamation at the site of Sendai Steam Power Plants. A soil profile of the site is shown in Fig.1. From top to the depth of 10 m., soil profile consists of sand and gravel layers. Between 10 and 22 m. of depth, the material is soft clayey soil, which properties are shown in the same figure. Bedrock composed of shale lies beneath the depth of 22 m.. Velocities of S- and P-waves of soil layers, which were observed by the well shooting method, are shown in Fig.1. That is, velocity of S-wave is 130 mps. in a surface layer and 650 mps. in the bedrock. From the velocity of S- and P-wave, it was found that Poisson's ratio of a surface layer was close to 0.5.

PROCEDURES OF THE OBSERVATIONS OF SEISMIC MOTION AND MICROTREMOR

The observations of seismic motion of the soft ground have been performed since 1967, and 20 earthquakes were recorded. Three seismometers with natural periods of 0.1 sec. were settled at the depth of 0.5, 13.0 and 22.0 m. under the ground as shown in Fig.1, and the horizontal displacement in N-S direction were recorded. The seismic motions have been converted into electromagnetic oscillograph. The recording device begins to run by working of the automatic starter when a seismic shock of a certain intensity is felt. Every recorded seismic wave of the parts of large amplitude and 8 sec. long was analyzed.

The observations of microtremor, which were performed tripartitely on the ground surface and simultaneously under the ground, were carried out at the same site where the seismic motions have been observed. For the tripartite observations of microtremor, three seismometers with horizontal component and one with vertical component were settled as shown in Fig.2. For the simultaneous observations of microtremor on the surface and under the ground, two more movable seismometers with vertical and horizontal components were used in a bore hole as shown in the same figure. The simultaneous observations were carried out at every 2 meters from surface to the depth of 22 m.. The seismometers used for observations of microtremor have inverted pendulums of 1.0 sec. period, which are critical damped. They can record the displacements in the range of periods from 0.05 sec. to 1.0 sec.. The output signals from the transducers are integrated and recorded on a visigraph paper by using an electromagnetic oscillograph. The magnification of the instruments is 100,000 when lowpass fillter is used, and 10,000 when integrator is used. The observations were performed under the condition of small noise, and the tremors are recorded about 3 minutes.

RESULTS OF THE OBSERVATIONS AND CONSIDERATIONS

The comparison between the amplitude functions calculated theoretically and the response spectra of observed waves at the ground surface is shown in Fig.3. The values of response spectra of horizontal component on the ground surface are coincided at the predominant period of 0.70 sec. not only with those induced by the multiple reflection method of shear waves, but also with the values of amplitude function of dispersive Rayleigh waves and Love waves. Values of the observed response spectra at the periods of 0.20 and 0.30 sec. are coincided with those of S-waves and dispersive Rayleigh waves respectively. It was found from the observation of horizontal component of seismic waves at the ground surface that they are likely to be composed of S-waves, dispersive Rayleigh waves and Love waves in any case.

However, the results of simultaneous observations at the surface and under the ground indicate that the phase lag between at the surface and under the ground in about 180° at the higher frequencies as shown in Fig. 4. This fact suggests that the seismic wave in soft ground is not Love waves.

Then, authors tried to solve which of shear waves of dispersive Rayleigh waves should compose the seismic waves in the soft ground. They carried out the observations of microtremor performed simultaneously at the surface and under the ground. The results of observation were compared with the those of theoretical calculations. The amplitude ratio distributions for various periods, i.e. the ratio of displacement amplitude at the surface to that under the ground, are shown together with those of S-waves and dispersive Rayleigh waves calculated theoretically in Fig.5. Amplitude distributions of seismic waves obtained from the observations in the soft ground are coincided at the periods of 0.2 and 0.3 sec. with neither S-waves nor dispersive Rayleigh waves calculated theoretically, but with the superposed amplitude of both waves. Amplitude distributions are coincided at the predominant periods of 0.7 and 0.8 sec. with those of both waves, especially to those of dispersive Rayleigh waves.

Next, the wave forms obtained from the observation and calculated ones in the depth of 6, 14 and 22 m. are shown in Fig.6. The forms of seismic waves observed at the depths of 6 and 14 m. in the soft soil layers are extremely similar to those of S-waves and dispersive Rayleigh waves calculated theoretically. The waves at the depth of 22 m. are more similar to those of dispersive Rayleigh waves than S-waves. From the considerations on the wave forms and the amplitude distributions, it is known that the seismic waves in the soft ground are more depended on dispersive Rayleigh waves than S-waves.

This fact was also proved from the following results of tripartite observations on microtremor. The dispersive velocities of seismic wave obtained from the tripartite observation are shown in Fig.7 together with the phase and group velocity curves for M_{11}, M_{12}, M_{21}, and L_0 calculated theoretically. Comparing the results of observations with those of theoretical calculations, it was found that the observed dispersive velocities coincided well with the computed group velocities of fundamental mode of dispersive Rayleigh waves (M_{11}), at the predominant periods of 0.6-0.7 sec. when the group velocity of M_{11} had minimum value. It was suggested that the seismic waves in the soft ground were composed mostly of dispersive Rayleigh waves.

The particle orbits of the seismic wave obtained from the three component observations on the ground were studied. Typical patterns of particle orbits are shown in Fig.8. It was also known that the seismic waves in the soft ground were supposed to be composed mostly of dispersive Rayleigh waves because the particle orbits were Rayleigh wave type.

It was mentioned above on the results of observations on the seismic motion in the horizontal direction. Next, authors will discussed on those of seismic motion in the vertical direction. The response spectrum of microtremor obtained from the observation on the vertical direction is shown in Fig.9(a). The response spectrum of multiple reflected P-waves and the theoretical dispersive curves of fundamental mode of dispersive Rayleigh wave are shown in Fig.9(b). Comparing the results of observations with those of theoretical calculations, it was known as follows. The response spectrum of observed seismic wave in the vertical direction was different from the computed spectrum induced by the multiple reflection method of P-waves. The predominant period derived from the observed response spectrum was 0.3 sec. and coincided with the period of the minimum group velocity of dispersive Rayleigh wave. Therefore, the seismic waves in the vertical direction should be composed of dispersive Rayleigh waves.

CONCLUSIONS

From the observations of a horizontal component of seismic waves at the surface of the soft ground, which we have used to perform, the seismic motion on the soft ground seems to depend on S-waves, dispersive Rayleigh waves and Love waves in any case. On the other hand, from the simultaneous observations of seismic waves at the surface and under the ground, it looks that the seismic waves are not composed of Love waves, but of the combination of S-waves and dispersive Rayleigh waves in the case of the higher frequency range, and only on the dispersive Rayleigh waves in the case of the lower frequency range. Furthermore, the dispersion curves obtained from the tripartite observations and the particle orbits from three component observations show that the seismic waves are more composed of dispersive Rayleigh waves than S-waves. Then, it should be concluded that the seismic motions in the soft ground have mainly the characteristies of dispersive Rayleigh waves.

It is important to use the dispersive Rayleigh waves more frequently than S-waves as the input seismic waves in the aseismic design of structures on the soft ground in future, especially tall buildings, suspension bridges and pipe lines.

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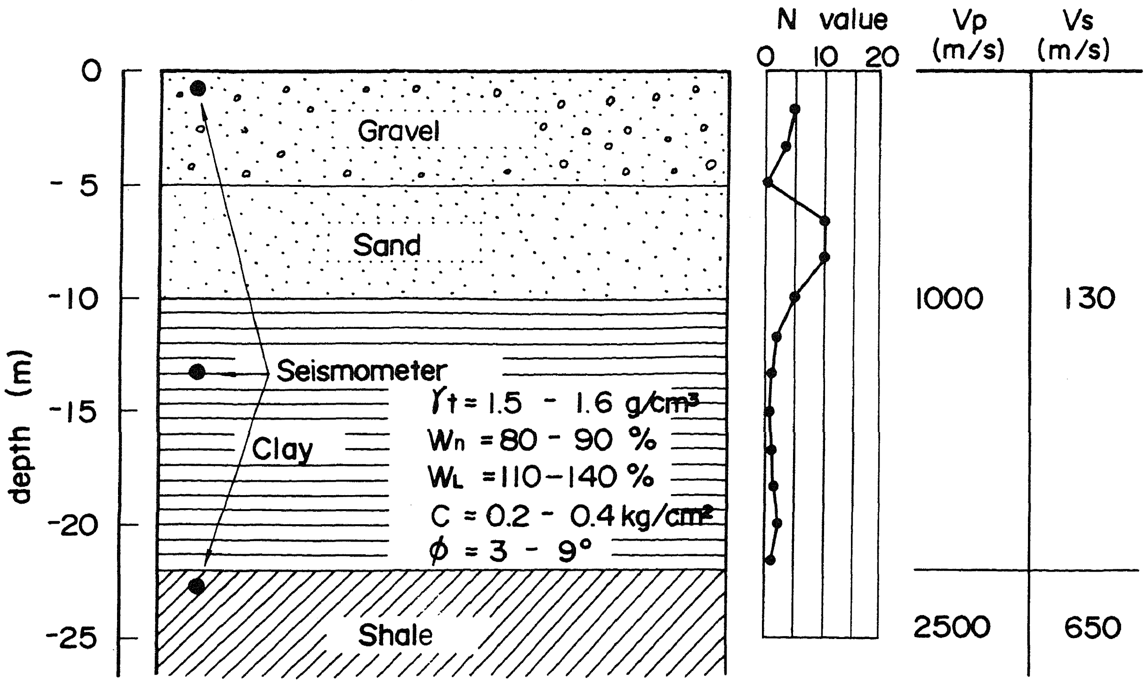
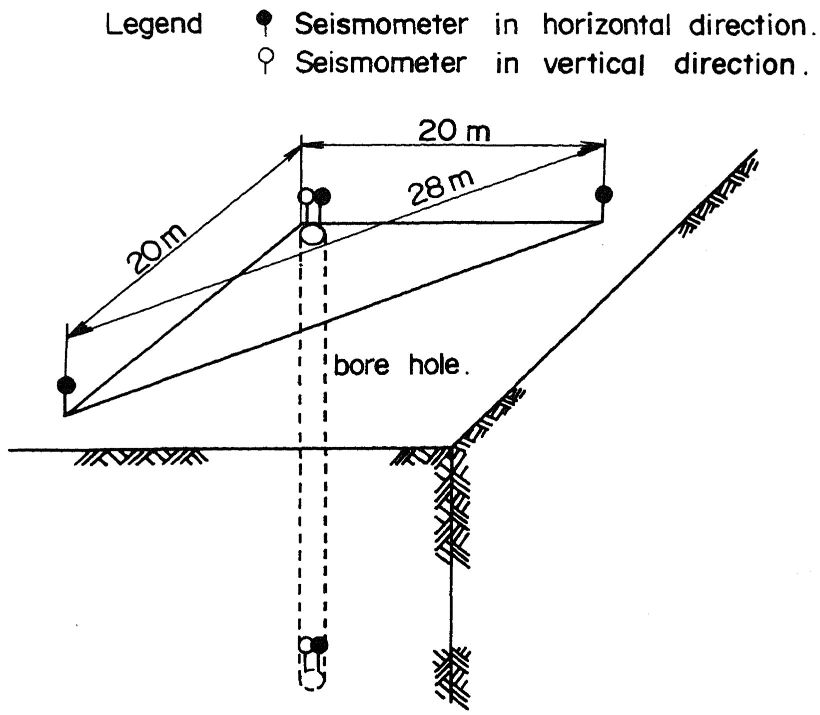
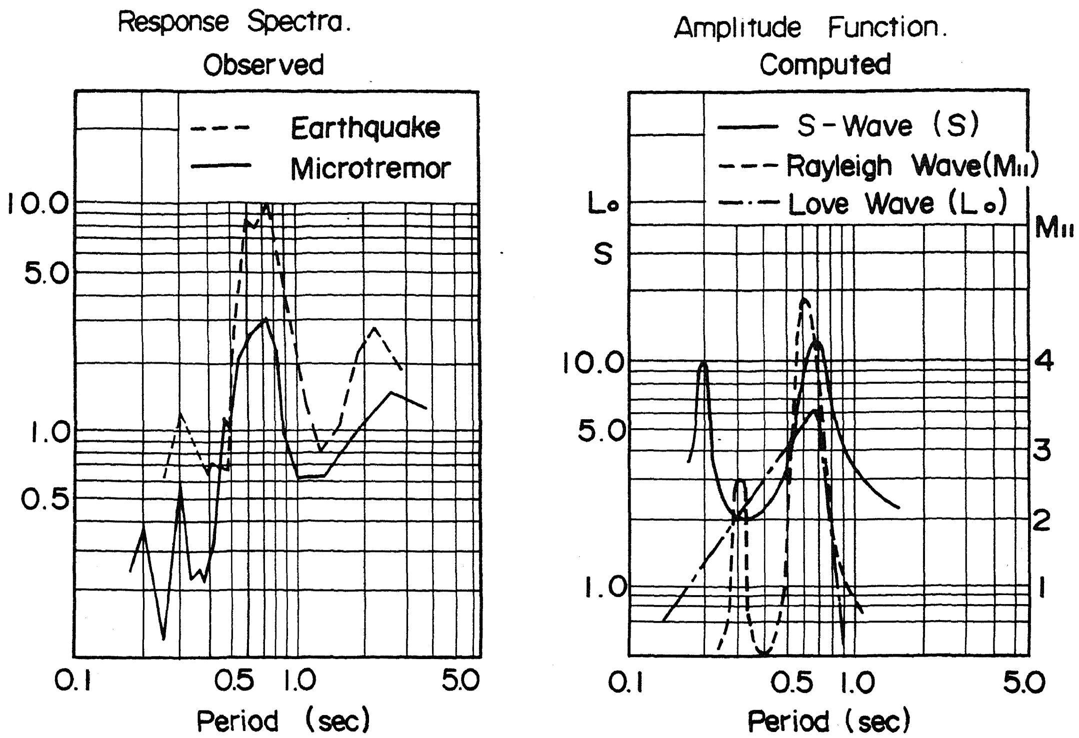


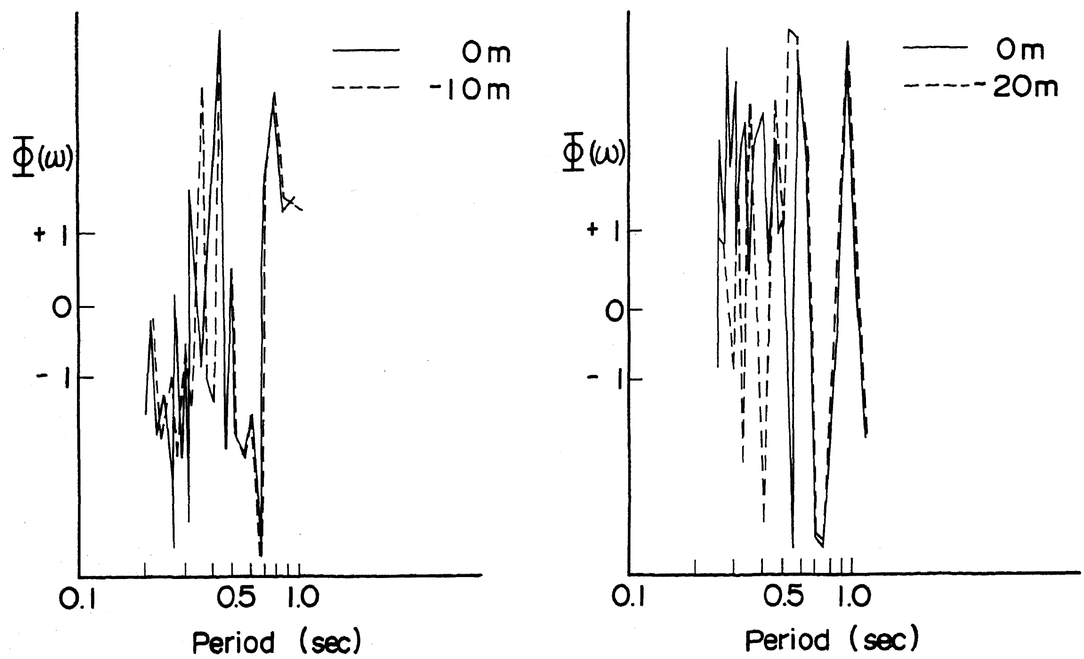
Fig·1 Soil Profile



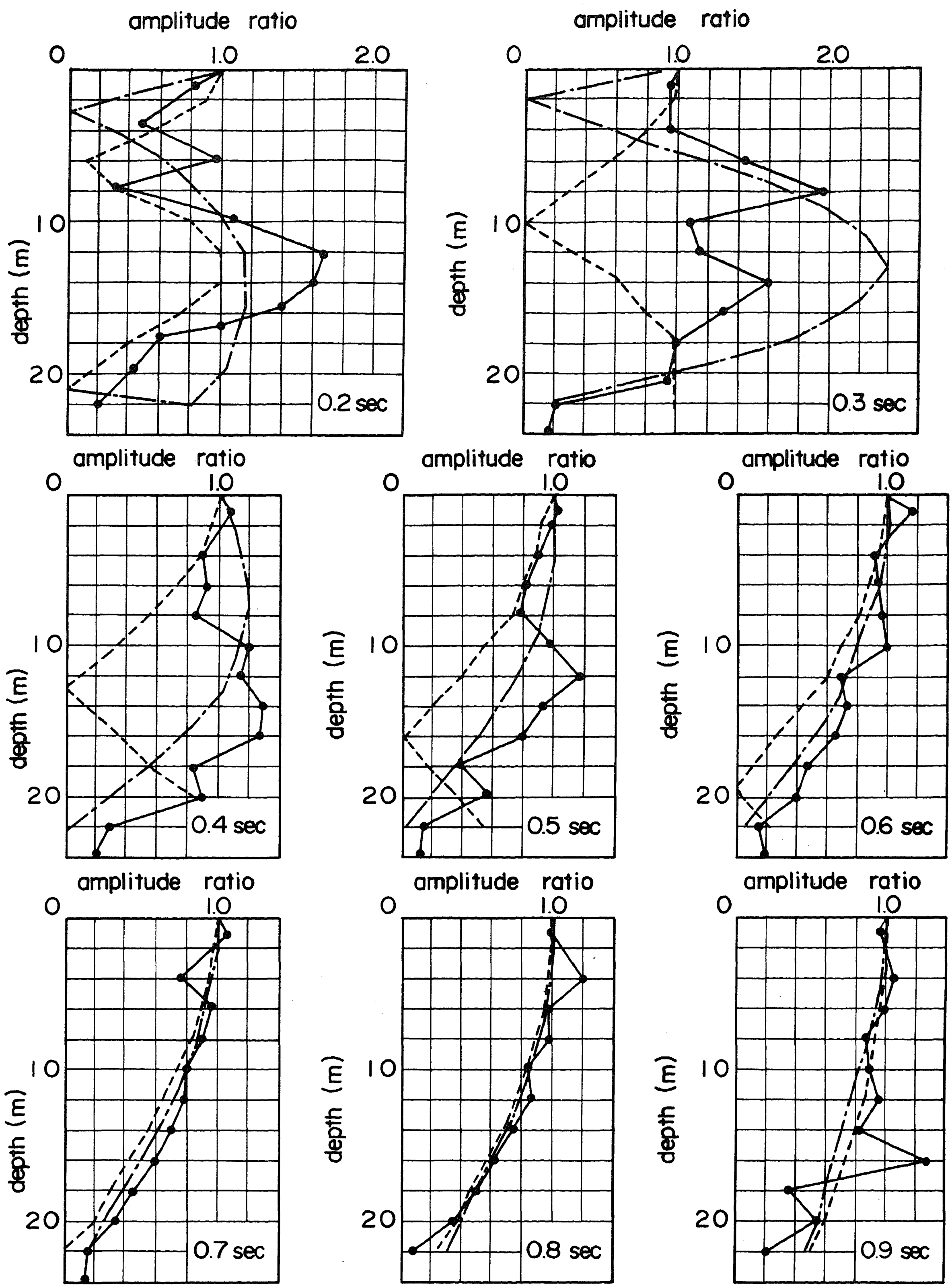
Fig·2 Observation on Microtremors.



Fig·3 Horizontal Response Spectra and Amplitude Function.



Fig·4 Phase Spectra at the Surface and under the Ground.



Fig·5 Amplitude Distribution

—●—●— Observed
- - - - Computed (S)
—·— Computed (M_{II})

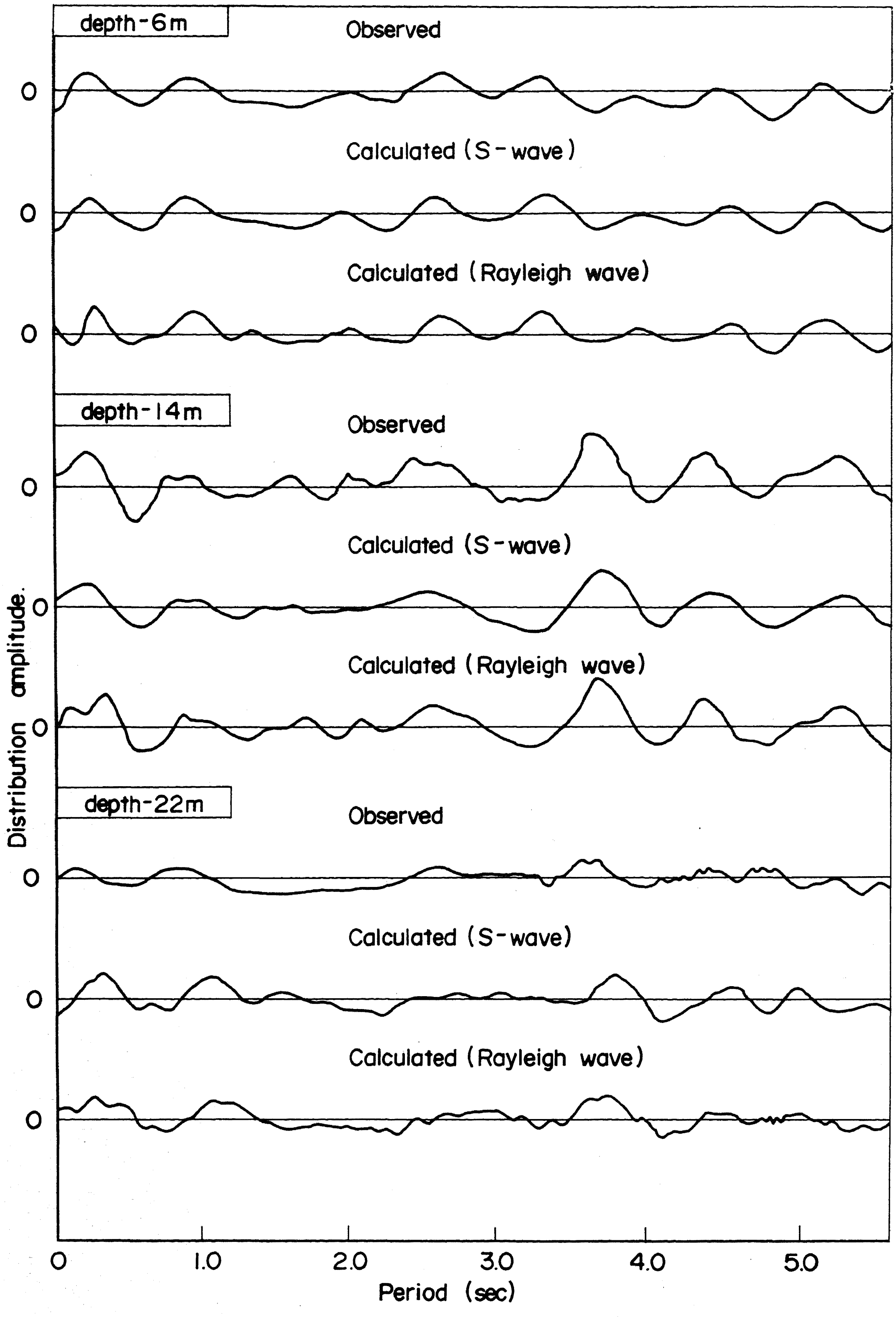
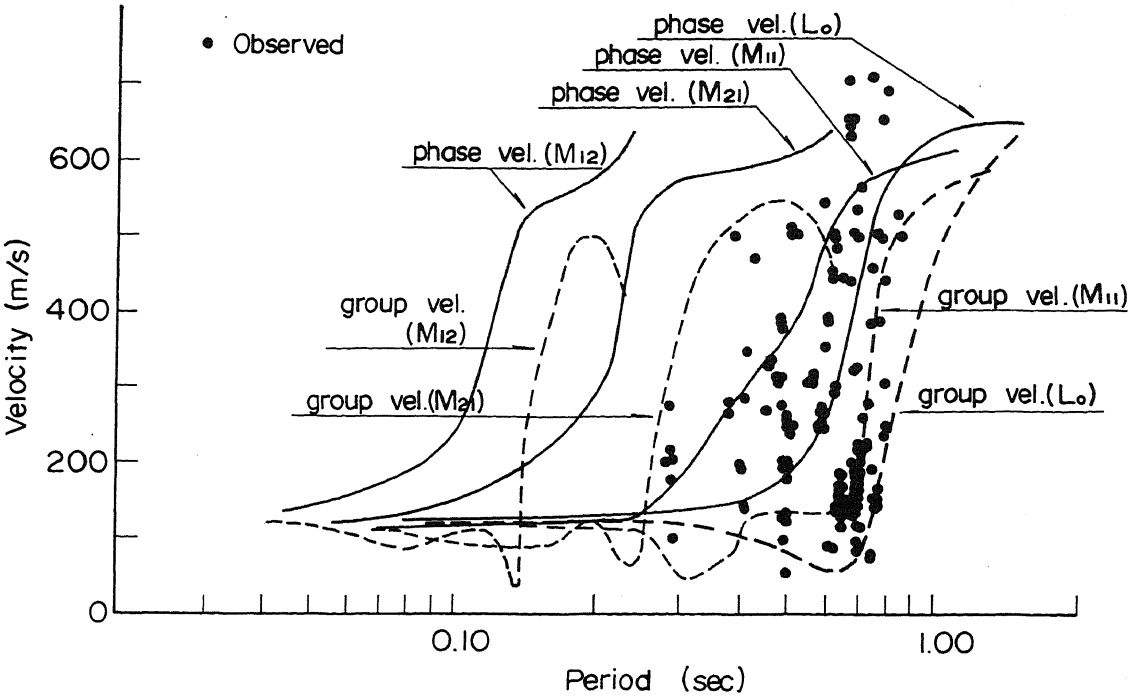
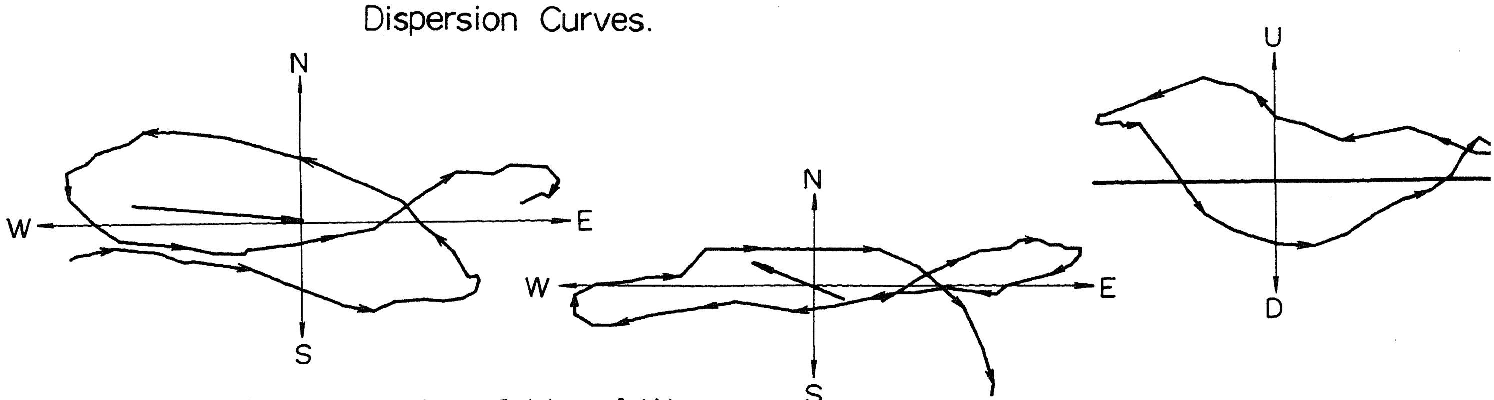


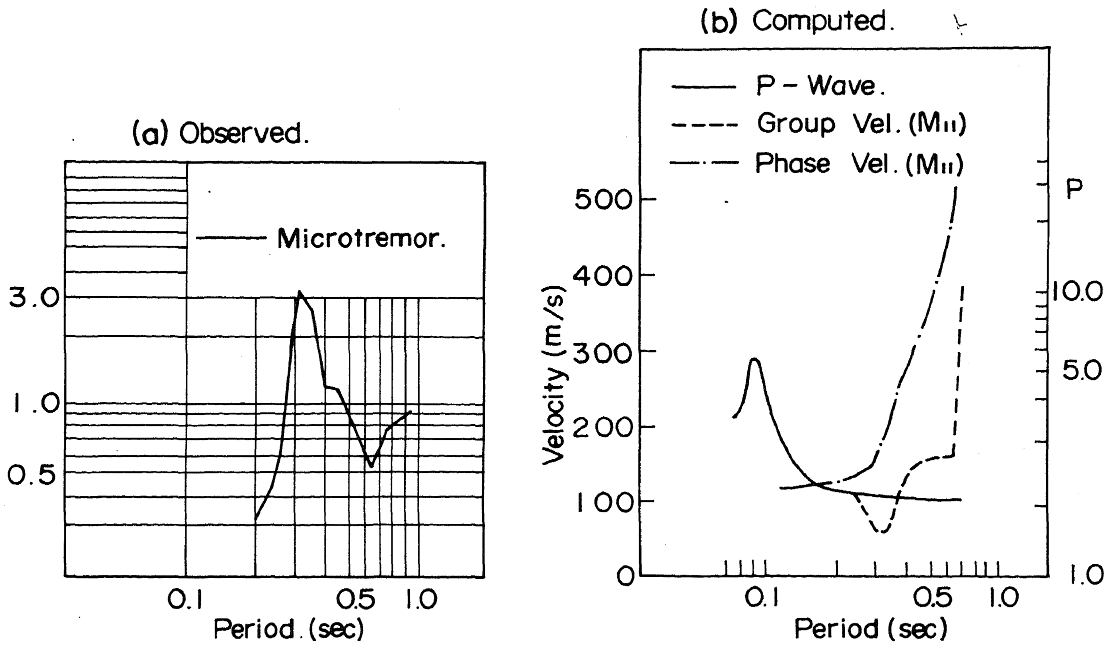
Fig 6 Comparison between Observed and Calculated Wave Forms.



Fig·7 Observed Dispersive Velocity and Theoretical Dispersion Curves.



Fig·8 Particle Orbits of Wave.



Fig·9 Vertical Response Spectra and Dispersive Curves.