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Characteristics of long-period ground motions in Tokyo Bay area, Japan

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ABSTRACT: Predominant periods and wave propagation characteristics in Tokyo Bay area have been investigated in the period from about 3 to 12 sec. From the comparison of the predominant periods obtained from the microtremor measurement, earthquake observation, and S-wave structure, it was found that these periods almost agree with one another. The snapshots of wavefronts, which were produced by considering both arrival times and particle motions of several wave packets in the band-pass filtered records of the 1990 Izu-Ohshima Kinkai earthquake, show that the wave packets at the period of about 8 sec propagate through the different paths in Tokyo Bay area.

1 INTRODUCTION

In 1964 Niigata earthquake, the great fire in oil tanks broke out by the liquid sloshing, and spreaded to the private houses. As there are many oil storage tanks in Tokyo Bay area, this region could be heavily damaged when the large sloshing occurs in a future earthquake.

The mechanism of generation of liquid sloshing is explained by the resonance between liquid in a tank and ground motions. The natural period of liquid sloshing of an oil tank is in the period from about 3 to 12 sec, which depends on both the diameter of a tank and the height of liquid. Thus, it is very important to clarify the characteristics of the ground motions with this frequency band.

In this paper, first, predominant periods were examined through the measurement of microtremors, the observation of seismic ground motions, and the estimation of S-wave velocity structure in the coast of Tokyo Bay. Secondly, the long-period ground motions observed during the 1990 Izu-Ohshima Kinkai earthquake(M6.5) were investigated to clarify the wave propagation characterisitics.

2 PREDOMINANT PERIODS

2.1 Measurement of microtremors

We measured the microtremors at 23 points along the coast of Tokyo Bay, after checking the stability of predominat periods obtained from the spectra of microtremors at MTK shown in Fig.1. Frequency characteristic of the measurement system is flat in the period of 2 to 10 sec. Predominant periods were obtained from the average of Hanning windowed spectra of the data except the artificial noise.

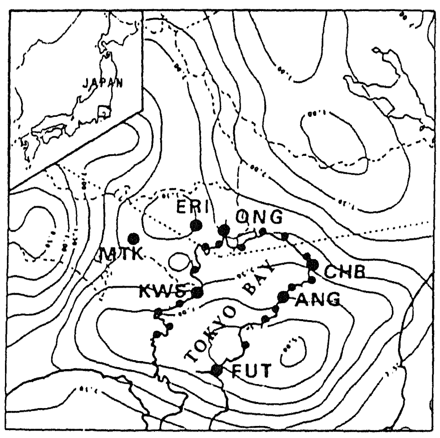

Fig.1 Location of observation points. Large circles show the earthquake observatories. Contour shows the depth(km) to the base rock after Higashi et al.(1989).

2.2 Earthquake observation

Digital earthquake observation has been carried out at 7 points in and around Tokyo Bay. Frequency characteristic of the velocity seismometer is flat up to 40 sec. Predominant periods are obtained by taking an average of the peak periods in Fourier spectra of several earthquakes.

2.3 Approximate S-wave velocity in a sedimentary layer

P-wave velocity structures in and around Tokyo Bay have become clear by many explosion experiments since 1975(eg. Shima et al. 1976), and the contour map of the depth to the base rock shown in Fig.1 was produced by Higashi et al.(1989) as one of these results However, a few S-wave structures have been obtained, which is very important to predict the strong ground motions. Then, approximate S-wave velocities were estimated from the seismograms whose example is shown in Fig.2. We can see X-phase in the radial component after P-wave arrival. This phase is interpreted as PS-wave from the following features.

1. Waveform of X-phase closely resembles that of P-phase.
2. Time difference between P and X-phase arrivals is independent of the source location, and is constant(about 1.5～2.3 sec) for each observation point.
3. Orbit of X-phase is mainly on the radial-z plane and perpendicular to that of P-phase.

We found that X-phase is converted at the top of base rock(Vp～5km/sec), from the comparison between observed and theoretical travel times and amplitudes. Thus, the mean S-wave velocities in a sedimentary layer under the stations can be estimated, using the P-wave structure in Fig.1. Predominant periods are calculated by one-dimensional wave propagation theory.

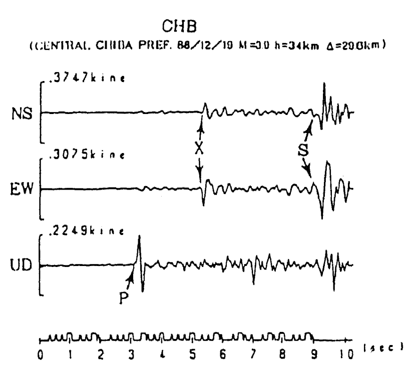

Fig.2 An example of the record showing the X-phase at CHB. P and S indicate P-wave and S-wave arrivals, respectively.

2.4 Comparison of predominant periods

Fig.3 shows the comparison of the predominant periods obtained from the analyses of microtremors, seismic ground motions, and S-wave velocity structures, respectively, and also shows the depth to the base rock along the coast of Tokyo Bay. Predominant periods by three methods almost agree with one another at the most of observation points, and correspond with the depth to the base rock.

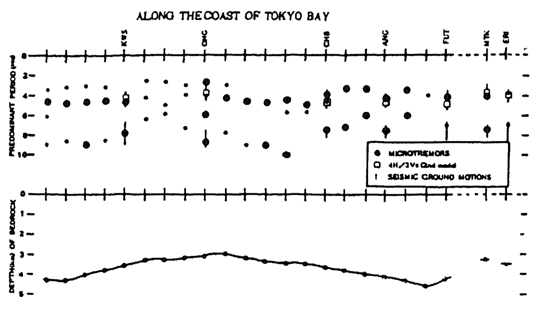

Fig.3 (Upper) Predominant period of microtremors, seismic ground motions, and the one estimated from underground structure.
(Lower) Depth to the base rock.

3 THE 1990 IZU-OHSHIMA KINKAI EARTHQUAKE

Long-period ground motions were eminent in and around Tokyo Bay during the 1990 Izu-Ohshima Kinkai earthquake(M=6.5, focal depth =6.5km). Here, we investigate some features of seismograms and wave propagation characteristics, using the records at observatories shown in Fig.4.

3.1 Features of seismic records

Fig.5 shows the transverse velocity records. S-wave is prominent at ABR, TAT, and ENS not far off the epicenter and at FCN, ASK, NGT, and MTK located in the western Kanto Plain. At KWS, OHK, and TKY etc., near the west coast of Tokyo Bay, the long-period phases have larger amplitudes than S-wave, and have long duration of about 100 sec. On the other hand, at FUT, ANG, and CHB along the east coast Tokyo Bay, later phases are also predominant, and become larger as the epicentral distance increases from about 80 to 120 km, but their duration time become shorter.

From Fig.6 showing the Fourier spectra, in which the thick line indicates the resultant of the spectra of three components, it is found that the predominant periods are about 7 to 8.5 sec at the most of stations, and

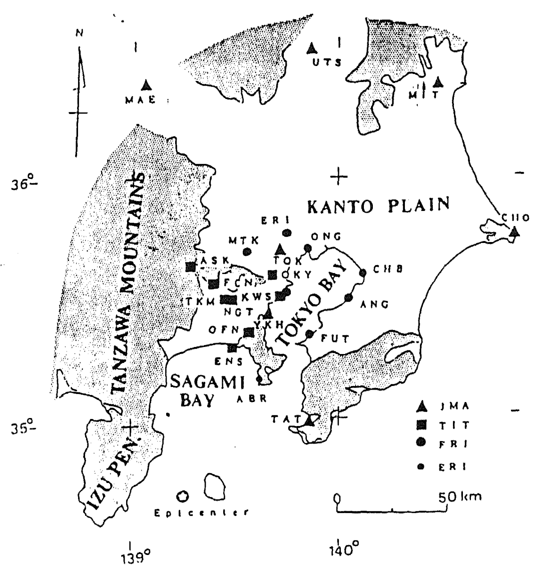

Fig.4 Location of seismic observation points and the epicenter of the 1990 Izu-Ohshima Kinkai earthquake.

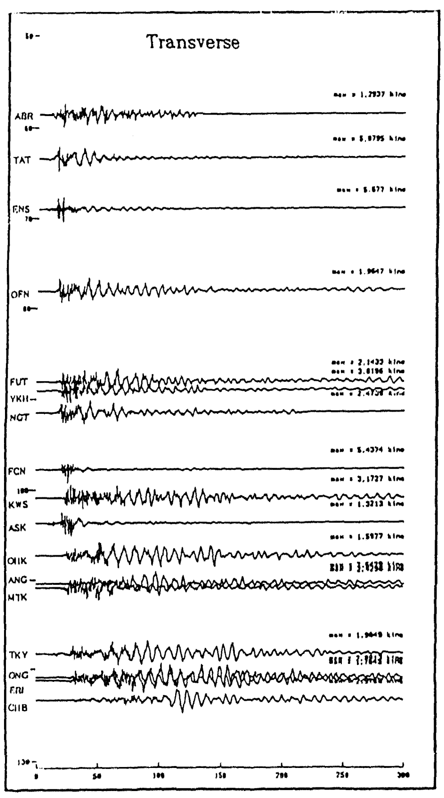

Fig.5 Transverse velocity records. Abscissa is the travel time(sec) measured from 10.2 sec after the origin time, and ordinate is the epicentral distance(km).

that the spectral shape, in general, becomes sharp at the period of about 8 sec as the epicentral distance increases. Especially, it is surprised that the Fourier amplitude at the period of 8 sec of CHB is about two times that of FUT, althogh CHB lies further from the epicenter than FUT.

3.2 Wave propagation characteristics

Here, we pay attention to the waves at the period of about 8 sec on the basis of the spectral analyses. Fig.7 shows the long axis of the particle motions on the horizontal plane, obtained from the band-pass(8 sec) filtered record. Since the dominant wave at the period of about 8 sec in Tokyo is considered as Love wave(eg. Tanaka et al., 1979), this wave doesn't propagate from the epicenter, but propagate from about south-west direction.

Then, the record section applied to the band-pass(7~8 sec) filter in the NW-SE component is produced as shown in Fig.8, in which the ordinate is the distance(km) projected on the NE-SW direction from the arbitrary point. Seven propagating wave packets are found, that is, the wave packet(①), indicated by the very thick line, propagating through the east coast(ABR, FUT, ANG, CHB), two wave packets(②,③), indicated by the thick line, through the west coast(ENS, OFN, YKH, KWS', KWS, ONG), three wave packets(④ ⑤,⑥), indicated by the thin line, from the western to the central Kanto Plain(NGT, MTK, OHK, TKY, ERI), and the one(①') from CHB to FUT. Accordingly, the wave propagation paths are broadly classified into three paths, that is, along the east and west coast, and from the western to central Kanto Plain.

The wave packet(①') is identified from the multiple filter analysis shown in Fig.9a. The wave packet(①') propagates reversely with the same group velocity as the one of ①, as if ①' were the reflected Love wave.

In order to confirm this, the simulation of Love wave propagation by FEM was carried out by using the model produced from the contour map shown in Fig.1. The reflected waves can be seen in the upper trace in Fig. 10, which are generated at the area of about 30km north-east of CHB, where the base rock is very shallow. Thus, we concluded that the wave packet(①') is the reflected Love wave.

The predominant period of each wave packet is determined from the multiple filter analysis shown in Fig.9. It is found from Fig.9 that the predominant periods differ with each wave packet. For example, 8.5 sec at ENS and OFN, but 8 sec from YKH to ONG for ②, and 7 sec from ENS to ONG for ③. It is difficult to explain the travel time differ-

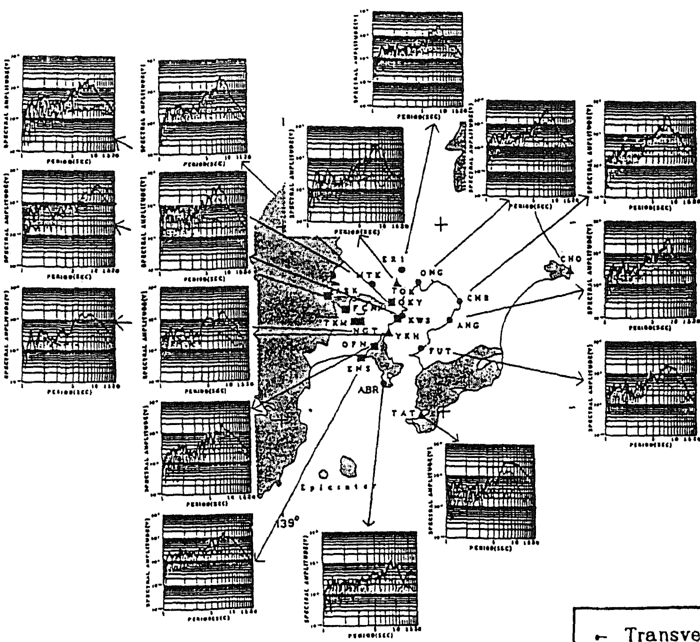

Fig.6 Fourier spectra of the velocity seismograms. Thick line shows the resultant of the spectra of three components. Horizontal thick line is spectral amplitude of 1(kine・sec).

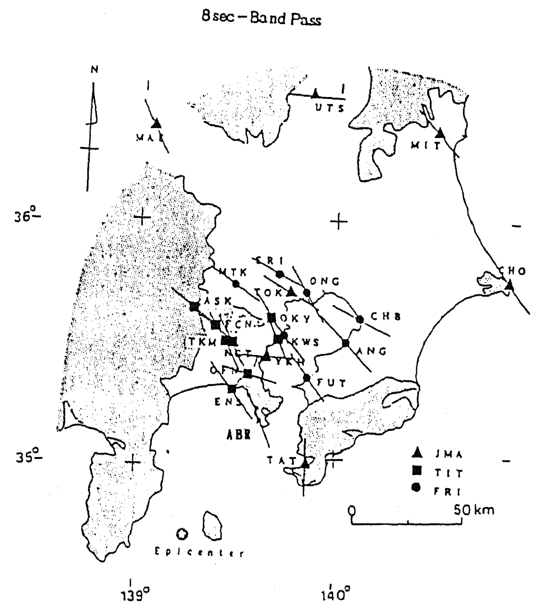

Fig.7 Principal direction of band-pass(8 sec) filtered particle motions of wave packet with large amplitude.

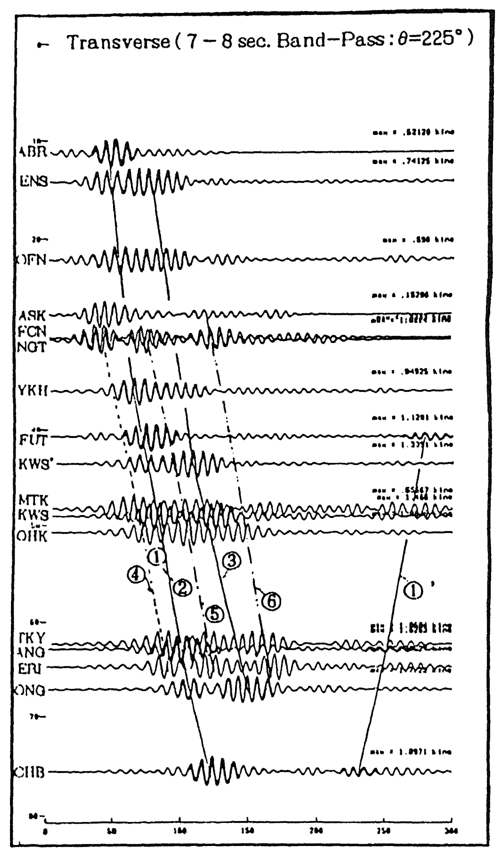

Fig.8 Band pass(7∼8 sec) filtered velocity records in the NW-SE component. Ordinate is the distance(km) projected on the NE-SW direction from the arbitrary point. Numerals indicate the propagating transmitted and reflected wave packets.

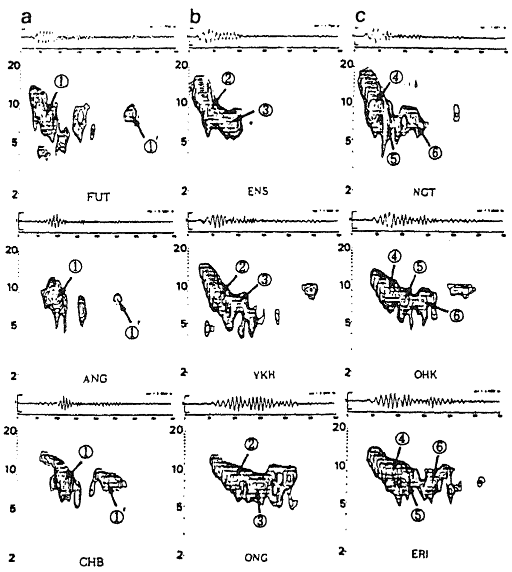

Fig. 9 Multiple filtered records for the displacement seismograms in the NW-SE component. Numerals correspond to the ones in Fig. 8.

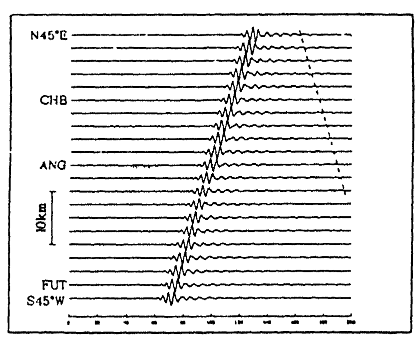

Fig. 10 Synthetic seismograms. Each trace is low-pass(4 sec) filtered. Reflected waves(dashed line) can be seen in the upper traces

ence of about 30 sec between the wave packets of ② and ③ at ENS for the standard undeground structure, and also difficult for ⑤ and ⑥ with the same predominant period at NGT.

Considering both the arrival time and the particle motion of each wave packet, the wavefronts are obtained as shown in Fig. 10. The wave packet of ④ near ASK～NGT at T(travel time)=45 sec, propagates clockwise toward TKY～ERI up to T=95 sec. The wave packets of ① and ② near ENS～ABR propagate through Tokyo Bay, and reach near CHB at T=130 sec. At T=95 sec, the wave packet(③) at the period of 7 sec appears near ENS, and propagates toward ONG up to T=150 sec, but cannot be seen in the east coast. Second(⑤) and third(⑥) wave packet at NGT appear at T=80 and 130 sec, and propagate toward NE and NNE, respectively.

In the west interior of Tokyo Bay, the duration time of ground motions at the period of about 8 sec becomes very long, because the several wave packets propagating through the different paths succesively arrive here. On the other hand, the time duration is very short in the east coast because of the only one wave packet like a standing wave. It is considered that these phenomena may be explained by the effects of Tanzawa mountain system and the source region in Fig. 4.

CONCLUSIONS

The predominant periods along the coast of Tokyo Bay, which are determined from the measurement of microtremors, earthquake observarions, and S-wave velocity structure, almost agree with one another. This suggests that the measurement of microtremors is helpful in estimating the perdominant period at an arbitrary point.

The seismic ground motion at the period of about 8 sec is eminent at the most of observation points, which mainly consists of Love wave, for the 1990 Izu-Ohshima Kinkai earthquake. Several distinguished wave packets are found in the band-pass(7～8) filtered records. These wave packets do not propagate from the epicentral direction, but from the southwest or west.

The wavefronts of these wave packets show that the several wave packets propagating through the different paths succesively arrive at northwestern Tokyo Bay. This fact leads to the long duration of groud motions. On the other hand, the time duration is very short in the east coast because the only one wave packet propagates.

Thus, the analyses considering the effects of the three dimensional underground structure including the source region are required in order to understand the whole wave field in Tokyo Bay area.

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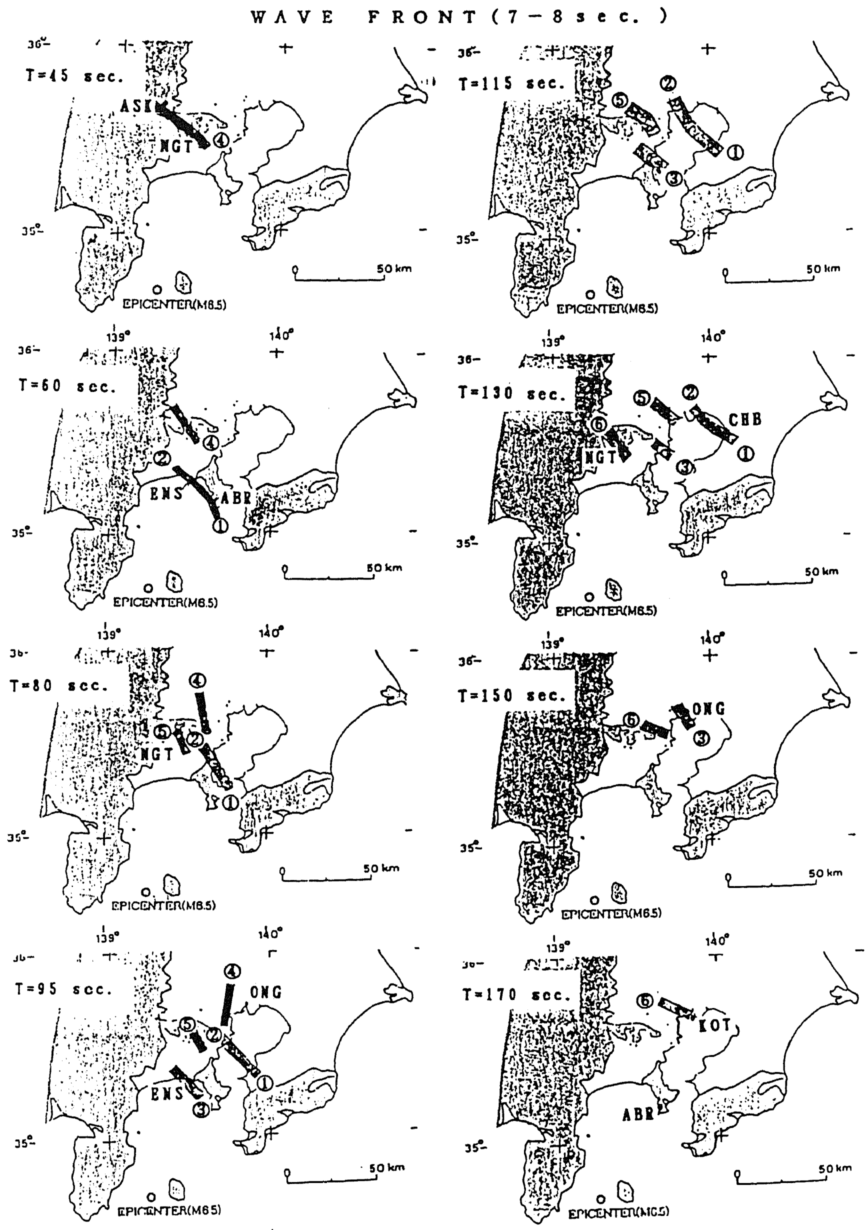

Fig.11 Snapshots of the wavefront of main wave packets at the periods of about 7 to 8 sec. Numerals correspond to the ones in Fig.8.

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