UNDERGROUND EARTHQUAKE MOTIONS
IN PORTS AND HARBOURS OF JAPAN

by

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SYNOPSIS

The earthquake motions in the soil layers were observed by the bore-hole seismometers at the observation stations in five ports and harbours of Japan. The effects of the characteristics of earthquakes and the vibrational properties of soil layers on the ground motions are investigated by the analysis of the Fourier amplitude spectra of the observed earthquake motions.

INTRODUCTION

It has been known for a long time that the degree of damage caused by the earthquake is influenced on the properties of ground. To explain this fact, the theory of the multiple reflections of traveling seismic waves in the soil layers has been proposed, and according to the development of the bore-hole seismometer the earthquake motions in the various grounds have been observed.

Most port facilities in Japan are constructed on the thick soil layers. In order to make basic data on the earthquake resistance of port facilities, the underground earthquake motions at five observation stations in ports harbours of Japan (Tokyo, Funabashi, Nagoya, Osaka, Kurihama) were observed by the bore-hole seismometers. The locations of the observation stations are shown in Fig.1. The seismometer (natural frequency = 5 Hz, damping constant = 10 - 20) is connected directly to the galvanometer of electromagnetic oscillograph (natural frequency = 100 Hz, damping constant = 0.7), and the recorded amplitudes of the seismometer are proportional to the accelerations of ground motions. Among the observed motions, the records with relatively large amplitude which accelerations are from 4.1 to 60.9 gals at the top of the layers are analyzed. The locations of the epicenters of earthquake used in the analysis are shown in Fig.1.

SPECTRA OF EARTHQUAKE MOTIONS

A example of the recorded earthquake motions and the wave forms computed by the theory of the multiple reflections of vertically traveling S-wave is shown in Fig.2. As shown in the figure, the main motions travel vertically in the soil layer and are amplified particularly in the upper part of the layer. It is seen that the computed shapes of motions are considerably similar to the recorded shapes of motions.

To investigate the frequency characteristics of the underground motions, the Fourier amplitude spectra of the recorded earthquake motions are computed. The spectra for the different earthquakes (Ear.

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No.9; Magnitude = 6.9, Depth = 10 km, Epicentral Distance = 161 km, Ear. No.14; Magnitude = 7.25 - 7.5, Depth = 350 km, Epicentral Distance = 573 km, Ear. No.15; Magnitude = - , Depth = - , Epicentral Distance = 31 km) observed at the same observation station are shown in Fig.3. It is found that the spectra of underground motions differ with the magnitude, depth and location of the earthquake.

The spectra for the same earthquake observed at the different observation stations are shown in Fig.4. It is found that the spectra of underground motions also differ with the ground conditions of the observation station.

The ratios of the spectra between the observation point and the deepest observation point are shown in Fig.5. It is seen that there are many dominant peaks of spectra in the figure. The vertical distributions of S-wave velocity in the observation stations are shown in the right of Fig.6. From the figure, it is estimated that the thicknesses of alluvial layer in the observation stations are 50 m in Tokyo, 34 m in Funabashi, 21 m in Nagoya, 35 m in Osaka, 30 m in Kurihama approximately. The predominant frequency of the alluvial layer is computed by the values of the thickness of layer and the S-wave velocity. The computed values are 0.92 Hz in Tokyo, 1.8 Hz in Funabashi, 2.1 Hz in Nagoya, 1.2 Hz in Osaka and 0.64 Hz in Kurihama respectively. These computed predominant frequencies correspond to the frequencies for the peak of the spectra in the low range of frequency in Fig.5.

VERTICAL DISTRIBUTION OF MAXIMUM UNDERGROUND EARTHQUAKE MOTIONS

The mean value of the maximum amplitudes recorded by the seismometers is plotted to the depth in the left of Fig.6. In the figure, the mean value of the maximum amplitudes computed by the theory of the multiple reflections is also shown by the broken line. It is seen that the computed values approximately agree with the observed values in the figure.

It is concluded that the main part of the earthquake motions can be estimated to a certain degree by the theory of the multiple reflections of vertically traveling S-wave, if the vertical distribution of S-wave velocity could be determined in detail.

BIBLIOGRAPHY

(1) E. SHIMA: Modifications of Seismic Waves in Superficial Soil Layers as Verified by Comparative Observations on and beneath the Surface., Bull. Earthq. Res. Inst., 40 (1962), pp. 187 - 259.

(2) S. YOSHIZAWA, T. TANAKA, K. KANAI: Some Features of Strong Underground Earthquake Motions Computed from Observed Surface Records., Bull. Earthq. Res. Inst., 46 (1968), pp. 667 - 686.

(3) N. C. TSAI, G. W. HOUSNER: Calculation of Surface Motions of a Layered Half-Space., Bull. Seism. Soc. Am., 60 (1970), pp. 1625 - 1651.

(4) H. TSUCHIDA, T. UWABE: Characteristics of Base- Rock Motios Calculated from Strong-Motion Accelerograms at Ground Surface., Rep. of Port and Harbour Res. Inst., Vol. 11, No. 4, (1972), pp. 191-270.

(5) H. ARAI, M. IWABUCHI: Studies on the Vertical Distributions of the Earthquake Motions in the Superficial Soil Layers (1st Report)., Rep. of Port and Harbour Res. Inst., Vol. 12, No. 2, (1973), pp. 63 - 83.

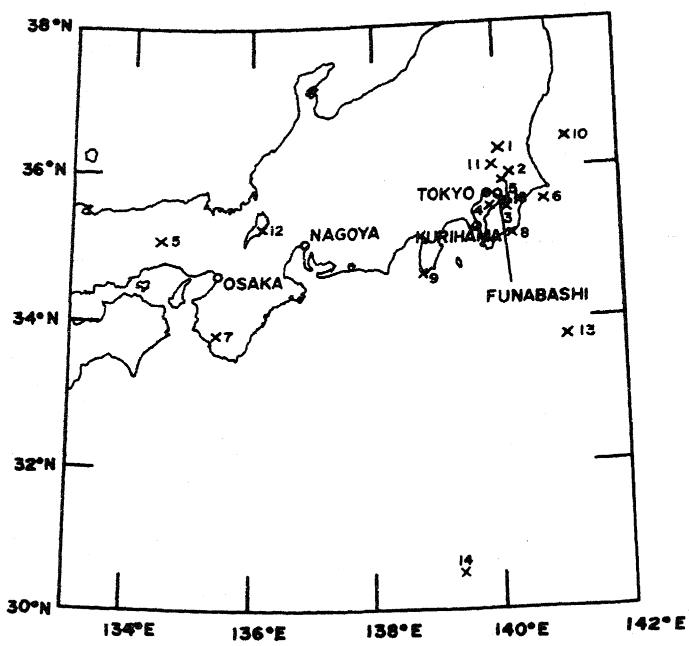

Fig. 1 Location of the observation stations and the epcenters of the earthquakes.

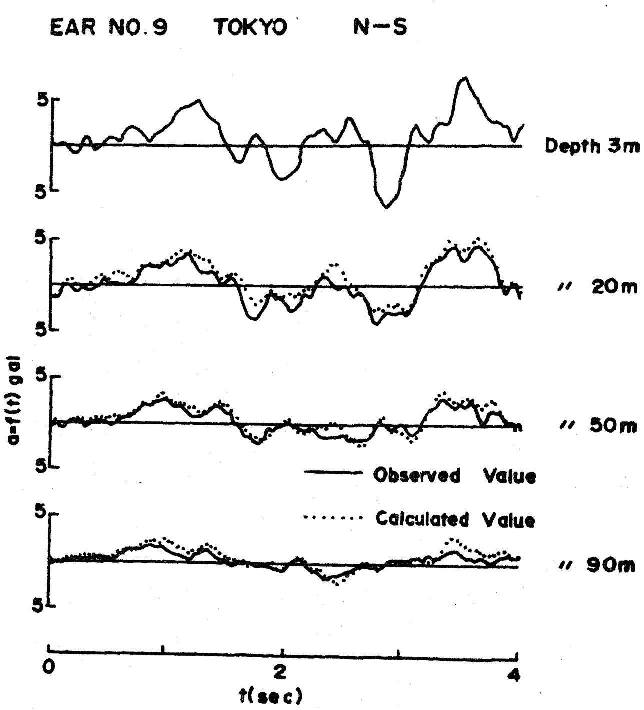

Fig. 2. Example of the observed waveforms and computed waveforms.

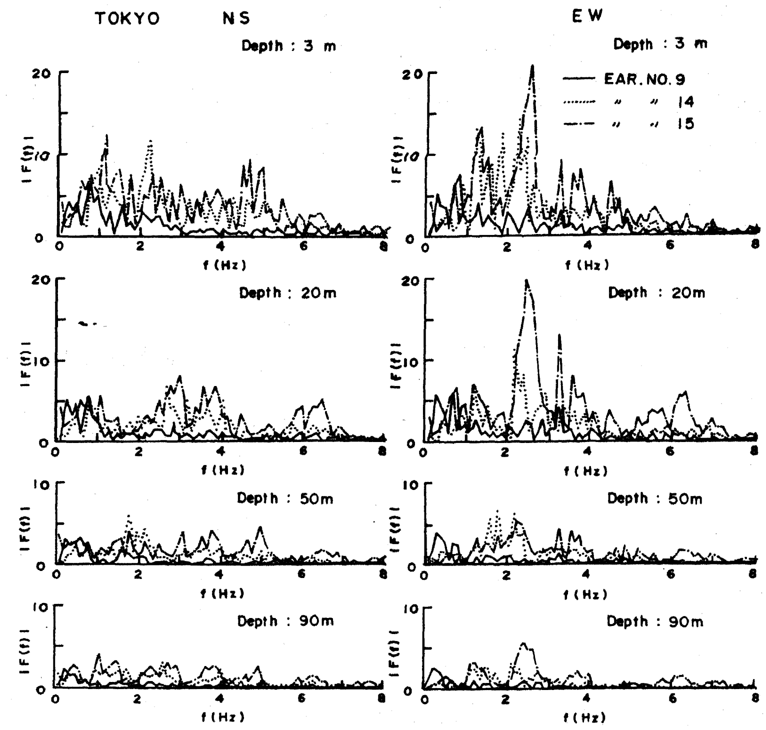

Fig. 3 Fourier amplitude spectra for the different earthquakes observed at the same observation station.

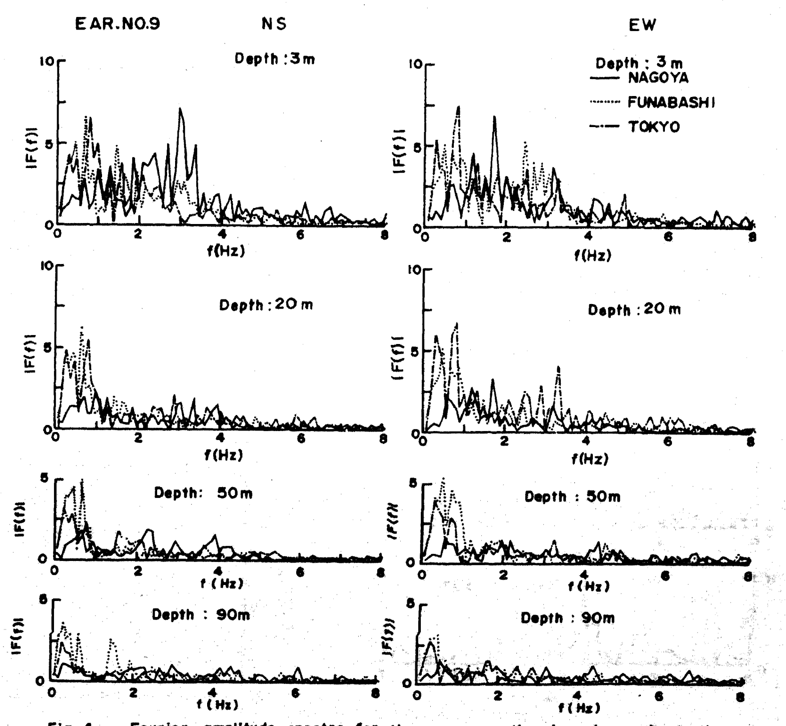

Fig. 4. Fourier amplitude spectra for the same earthquake observed at the different observation stations.

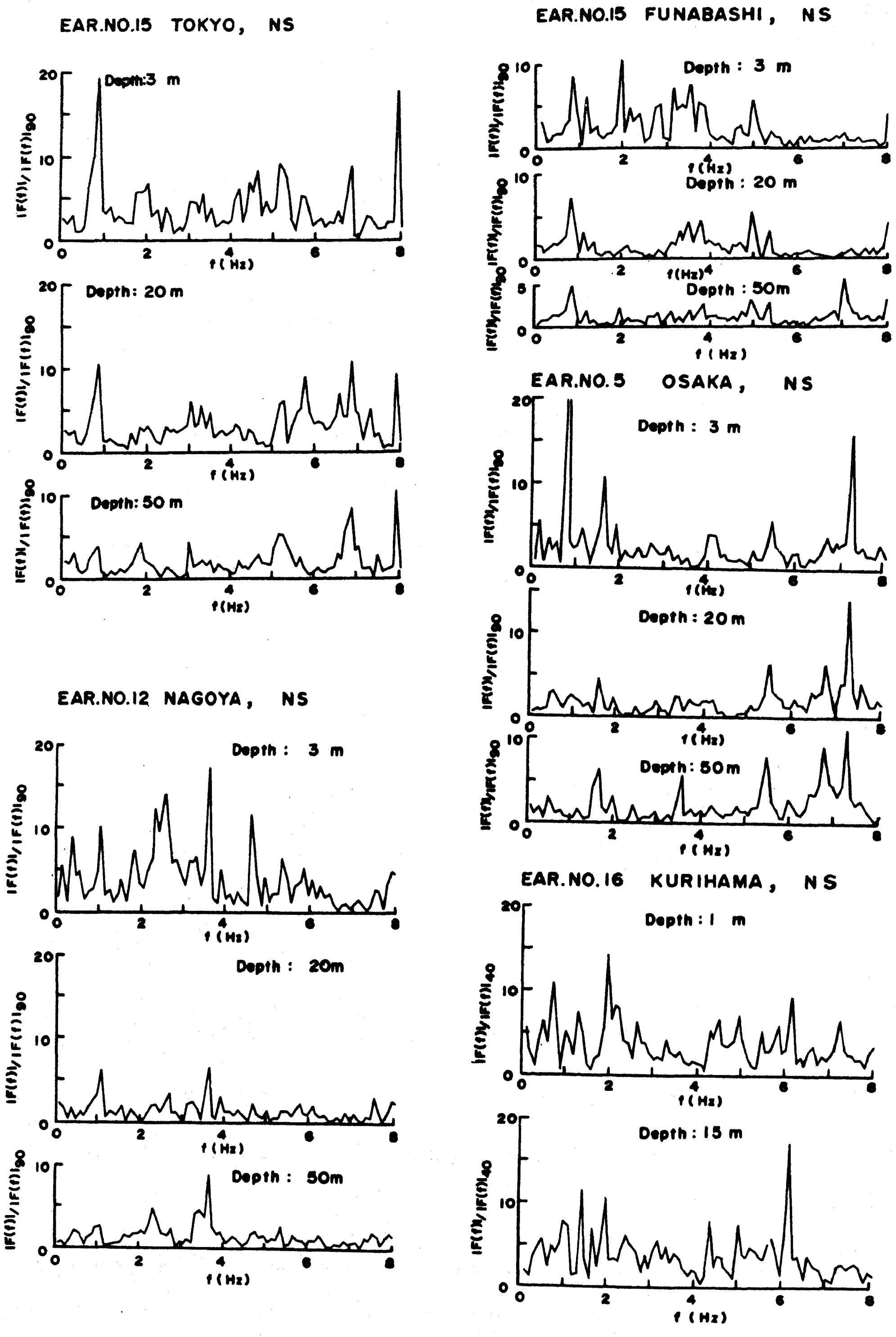

Fig.5 Ratios of the Fourier amplitude spectra between the observation points and the deepest observation point.

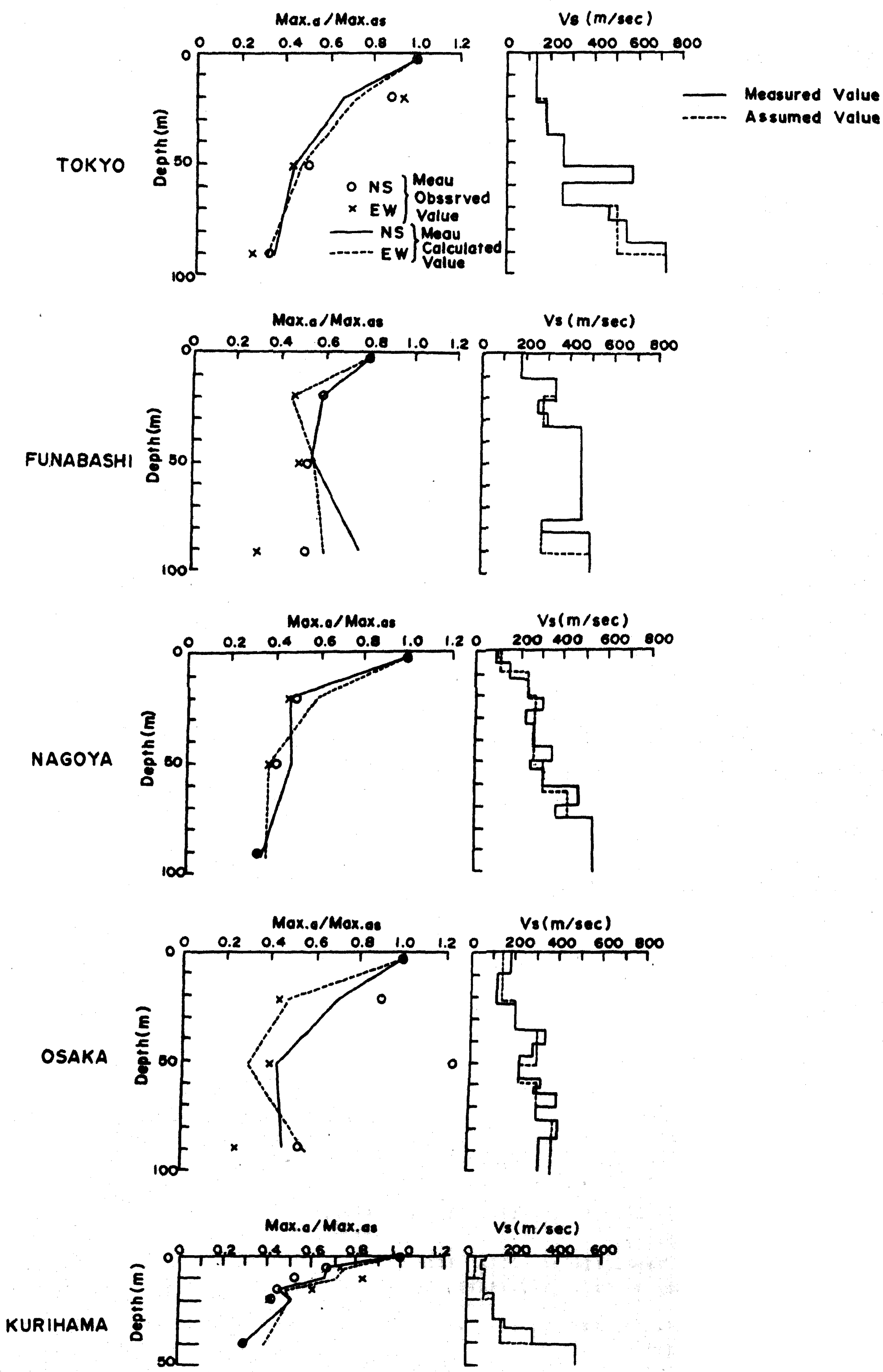

Fig. 6 Vertical distributions of the mean maximum amplitude and the S-Wave velocity

DISCUSSION

D.J. Dowrick (U.K.)

What was the maximum ground acceleration considered in the study ? How strong was the ground motion ?

D. Costes (France)

You said that the observed motions may be interpreted by the ascending shear wave scheme. It is the only scheme which would be satisfying ?

Author's Closure

Reply to D.J. Dowrick :

The maximum acceleration among the motions which we observed is 60.9 gals of the earthquake record No. 15 observed at 3 m depth of Funabashi observation station. We think that the soil layer behaves elastically within such a intensity of motion.

Reply to D. Costes :

The most effective earthquake motion for the earthquake resistance of port facilities is the shear wave and the general theory on the multiple reflections of seismic wave is very complex.

To simplify the problem, we adopted the ascending shear wave scheme.