Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.II)

3-4-14

INFLUENCE OF DEEP UNDERGROUND STRUCTURE ON CHARACTERISTICS OF RATHER LONG-PERIOD GROUND MOTIONS

Takanori SAMANO and Kazuoh SEO

The Graduate School at Nagatsuta, Tokyo Institute of Technology,
Midori-ku, Yokohama, Japan

SUMMARY

From the viewpoint of deep underground structure effects, the characteristics of earthquake ground motions in the rather long-period range (1 to 10 or more seconds) on thick deposit are discussed. Comparing seismograms on thick deposit with those on firm rock obtained by an array earthquake observation, which has been being carried out in the southwestern part of the Kanto district, Japan, it can be recognized that in cases of shallow earthquakes, rather long-period ground motions with large amplitude and long duration appear frequently in the seismograms on thick deposit, while they can't be seen in those on hard rock. Such rather long-period ground motions are elucidated by SH-waves trapped and performing multiple total reflections within the deposit.

INTRODUCTION

The Kanto district is one of the most densely populated area in Japan. And major part of the district is covered with thick Tertiary and Quaternary deposit. At sites of such underground structure, in cases of shallow earthquakes, rather long-period ground motions tend to be predominant (Ref. 1). Moreover, a number of huge structures having fundamental natural period in the same period range have been increasing recently. Therefore, for the purpose of earthquake disaster prevention, it should be eagerly desired to understand the characteristics of rather long-period earthquake ground motions.

Deep underground structure in the southwestern part of the Kanto district is being made clear gradually by means of seismic prospecting with explosions (e.g., Ref. 2). To investigate the influence of underground structure on characteristics of ground motions and propagation of seismic waves, authors have been carrying out an array observation of earthquake ground motions in the same area using wide-band velocity type seismographs. The array observation consists of twelve stations as indicated by solid squares in Fig. 1. In the figure, geological conditions (Ref. 3) and epicenters of earthquakes used in this study are also shown. Among these stations, ASK is located on Pre-Neogene firm rock and ENS almost directly on Neogene rock. The other stations are located on Tertiary and Quaternary deposit with thickness of several kilometers, but their underground structures are considered to be quite different from each other.

In this paper, using seismograms obtained by the array observation, the characteristics of rather long-period earthquake ground motions on thick deposit are discussed from the viewpoint of deep underground structure effects. Hereat,

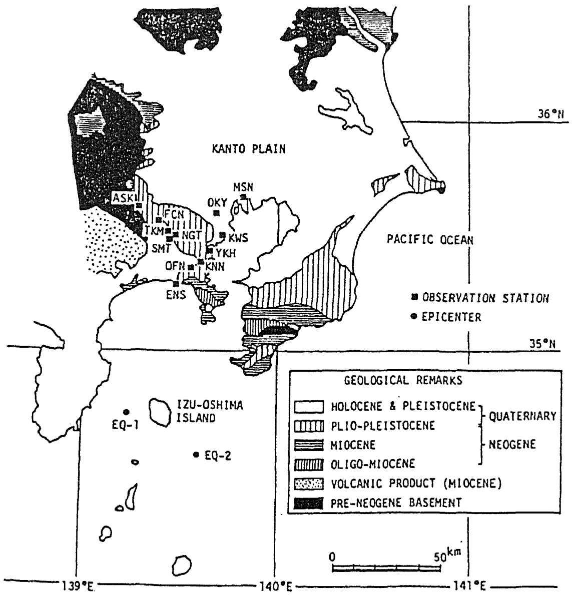

Fig. 1 Map of the Kanto district. Observation stations for earthquakes and epicenters used in this study are indicated with geological conditions.

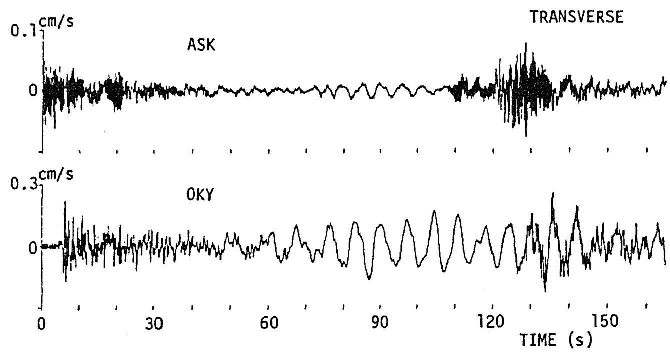

Fig. 2 Transverse velocities observed at ASK and OKY during EQ-1.

we pay our attention to transverse component which can be considered to be mostly composed by SH-wave and Love wave.

SEISMOGRAMS OBTAINED BY ARRAY OBSERVATION

During one of foreshocks of the Near Izu-Oshima Earthquake of 1978 (EQ-1 in Fig. 1, M=4.9, D=0km), ground motions were observed at ASK, OKY and some other stations. Transverse components of the ground motions at ASK and OKY are compared in Fig. 2. Short-period components seen in the latter part of both traces are due to the succeeding earthquake. The significant difference between the ground motions at two stations is that rather long-period components with large amplitude and long duration can be recognized remarkably in the trace of OKY, while such components can be seen seldom or never in that of ASK. This fact suggests that rather long-period earthquake ground motions are amplified during the propagation in thick deposit.

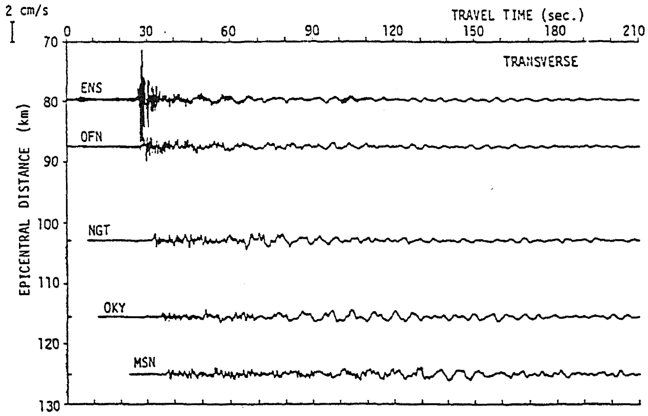

Fig. 3 Transverse velocities observed during EQ-2.

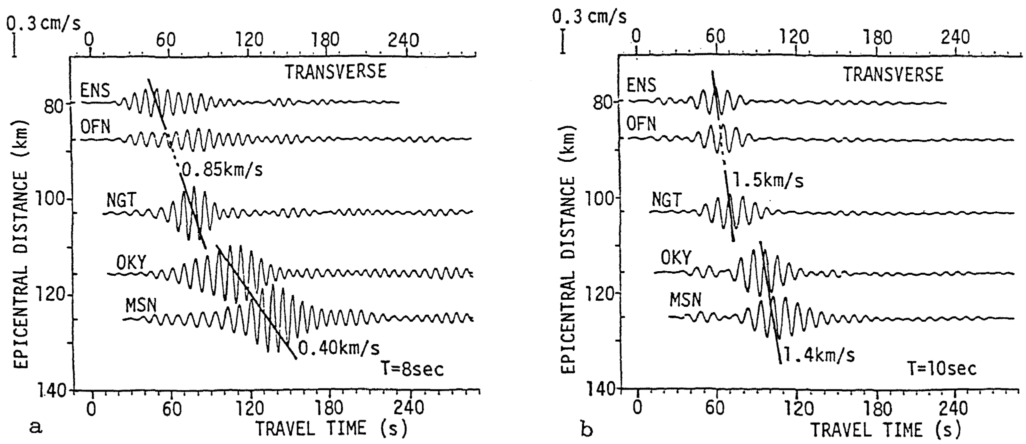

Fig. 4 Transverse velocities of EQ-2 calculated through band-pass filters with center period of 8 seconds (a) and 10 seconds (b).

Besides, Fig. 3 shows transverse components of ground motions at ENS, OFN, NGT, OKY and MSN during the earthquake of Nov. 22, 1986 (EQ-2 in Fig. 1, M=6.0, D=15km), in a form of propagation diagram. In this case also, the amplitude of rather long-period ground motions at deposit sites, i.e., NGT, OKY and MSN, are increased, compared with that at rock site ENS in spite of larger epicentral distances. Moreover, the propagation velocity of such rather long-period components seems to be much lower than that of the initial S-wave.

INFLUENCE OF DEEP UNDERGROUND STRUCTURE ON RATHER LONG-PERIOD GROUND MOTIONS

Calculating the seismograms of EQ-2 through the band-pass filter, the influence of underground structure on the propagation velocity of rather long-period components was examined in detail. Filtering periods were selected as 8 and 10 sec., those were predominant periods of the seismogram observed at each station. The results are shown in Fig. 4. In case of 10 sec. (see Fig. 4b), the propagation velocity from ENS to NGT and that between OKY and MSN are almost the same of about 1.5km/s. On the contrary, in case of 8 sec., they are evidently different from one another as shown in Fig. 4a.

By the way, the deep underground structure in the array earthquake observation area is, as above-mentioned, being investigated by means of seismic prospecting with explosions. After the investigation, the underground structure consists of 4 layers in the southwestern part of the area (around NGT, see Fig. 1). P-wave velocities of these layers represent 1.8, 2.8, 4.8 and 5.5km/s, up to down. On the other hand, in the northeastern part of the area (around OKY and MSN in Fig. 1), it consists of 3 layers lacking 4.8km/s layer. Furthermore, the notable difference between the underground structures in these two parts is that the thickness of 1.8km/s layer is much larger than that of 2.8km/s layer in the northeastern part, while the tendency is reverse in the southwestern part. Based on the results of seismic prospecting, S-wave profiles at NGT, OKY and MSN were presumed as shown in Fig. 5. Then, theoretical dispersion curve (group velocity) of Love wave due to each profile was calculated to be compared with observed propagation velocity. As shown in Fig. 6, the theoretical dispersion curve gives fairly good elucidation to observed velocities in each area. Consequently, the rather long-period earthquake ground motions on thick deposit are mainly composed Love wave under the influence of deep underground structure around the site.

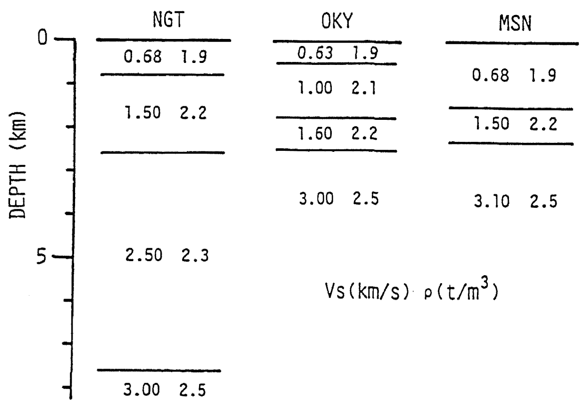

Fig. 5 S-wave profile models at NGT, OKY and MSN presumed from the results of seismic prospecting.

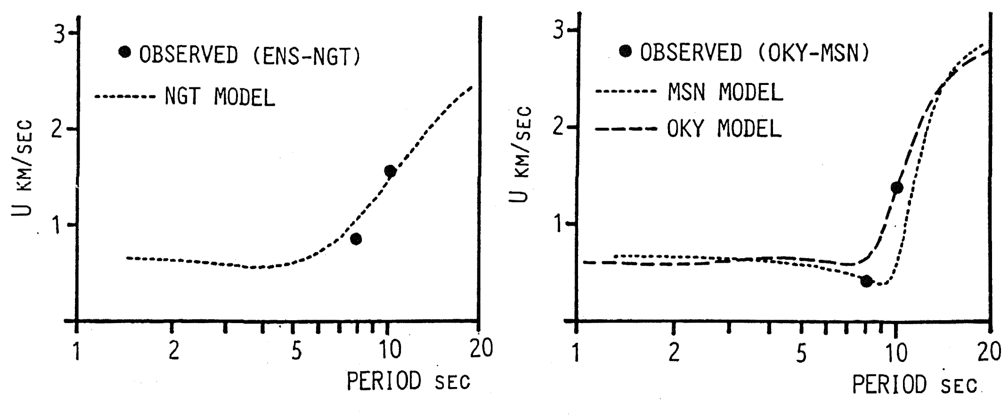

Fig. 6 Comparison of propagation velocities from the band-pass filtered records (Fig. 4) and group velocities of Love wave due to S-wave profile models at NGT, OKY and MSN (Fig. 5).

ESTIMATION OF RATHER LONG-PERIOD GROUND MOTIONS ON THICK DEPOSIT

The rather long-period earthquake ground motion at OKY on thick deposit during EQ-1 was estimated based on the simultaneous seismogram at ASK on hard rock in the following manner. The underground structure model is determined as shown by Fig. 7 after the results of seismic prospectings mentioned above. It consists of a basin deposit with 2.5 km thickness over a half-space basement. The S-wave velocities in the deposit and the basement layers are presumed as 0.7 km/s and 2.5 km/s, respectively. The density of soil and the Q-value of each layer are assumed as shown in the figure. The ground motion at a station on the deposit is evaluated by the following two kinds of SH-wave components. The one is due to ordinary SH-wave components coming up the deposit from the bottom calculated by the Haskell's method. The other is caused by SH-wave components which radiate into the deposit from an imaginary focus assumed at the edge of the deposit and arrive at the station with performing total reflections between the free surface and the bottom of the deposit layer. These components are superposed in consideration of delay time during the propagation. Then, the incident SH-waves into the deposit from the bottom and the imaginary focus are presumed to be equivalent to the ground motions on hard rock but are performed through the distance correction. As for the SH-wave components from the imaginary focus, attenuation due to the propagation in the deposit layer is also taken into consideration according to the Q-value. And since it is hardly possible at present to anticipate the transmission coefficient into the deposit, which is considered to be related to various conditions of actual underground structure such as shape of the interface and impedance ratio between the deposit and the basement layers, the coefficient is determined so that the amplitude of estimated ground motion may be nearly equal to that of observed motion.

Fig. 8 shows the estimated and observed motions at OKY and the input motion at the imaginary focus. In the calculation, assuming the edge of the deposit to be located around ENS on the propagation path from the epicenter to OKY, the distance from the edge to OKY was defined as 32.5 km. The initial portion of the seismogram at ASK, where the body wave components were considered to be effective, was adopted as the input motion. And the transmission coefficient from the imaginary focus into the deposit layer was selected to be 6.6. Comparing the synthetic motion with the observed one, short-period components in the former part of the synthetic motion, which correspond to the components coming up the deposit from the bottom, are quite smaller than that of the observed one because of simple modeling of underground structure. Nevertheless, the synthetic motion is in good agreement with the observed one with respect to the arrival time and the duration of rather long-period components with large amplitude.

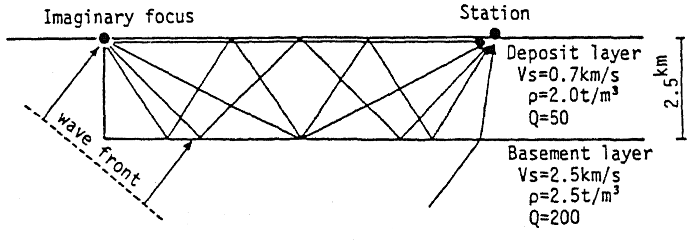

Fig. 7 Schematic diagram showing the manner for estimating the ground motions on thick deposit. Indicated values were used in this study.

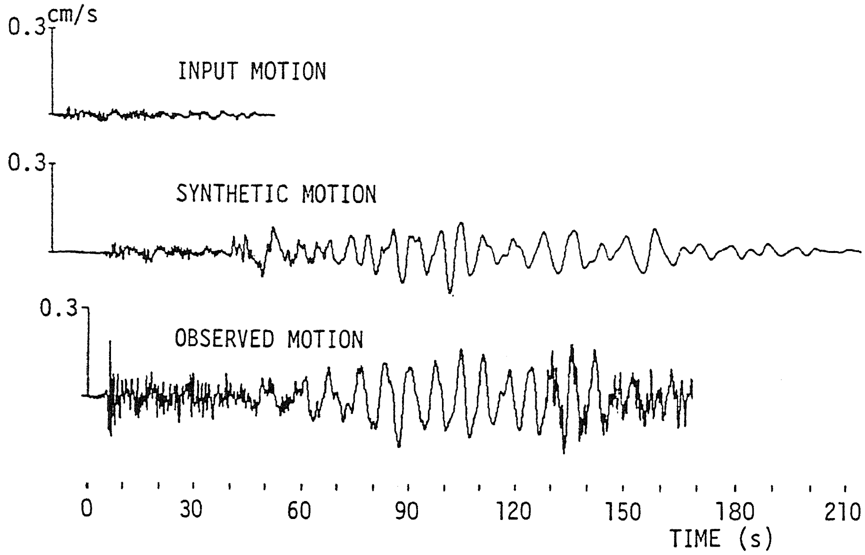

Fig. 8 Comparison of synthetic and observed ground motions at OKY with input motion. The distance from the edge of deposit to OKY was assumed as 32.5 km.

CONCLUSION

After the array earthquake observation in the southwestern part of the Kanto district, Japan, in cases of shallow earthquakes, even if they were not so large ones, the rather long-period ground motions with large amplitudes and long duration were often found out in the seismograms on thick deposit, but seldom or never in those on hard rock. Such ground motions on thick deposit were considered to be mainly caused by Love wave under the influence of deep underground structure. And they could be approximately elucidated by superposing SH-waves trapped and performing multiple total reflections within the deposit. However, some problems how to estimate the transmission coefficient still remain.

ACKNOWLEDGMENTS

The authors are most grateful to Emeritus Prof. H. Kobayashi, Prof. T. Ohmachi and Dr. S. Midorikawa, Tokyo Inst. of Tech. for their valuable advices. Observation of earthquake motions used in this study was owing to the cooperation of Dr. K. Kobayashi, Takenaka Corp., and the kindness of many persons. The ausors also wish to express sincere gratitude to all of them.

REFERENCES

1. Samano, T., et al., "Ground Motions Excited by Deep Tertiary Deposit," Proc. 8th World Conf. on Earthquake Eng., San Francisco, 2, 745-752, (1984).
2. Seo, K., et al., "Seismic Prospecting of Deep Underground Structure in the South-Western Kanto District, Japan," Proc. 23rd General Assembly of IASPEI, Tokyo, 2, 484, (1985).
3. Kakimi, T. et al., "Neotectonic Map Tokyo," Geological Survey of Japan, (1973)