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

3-5-6

MULTIPLE REFLECTION OF SEISMIC WAVES IN SEDIMENTARY LAYERS DURING EXPLOSION AND EARTHQUAKE IN THE SOUTHWESTERN KANTO PLAIN, JAPAN

Hiroaki YAMANAKA, Kazuoh SEO and Takanori SAMANO

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

SUMMARY

Major later phases observed during explosion and earthquake in the southwestern Kanto plain, Japan, were interpreted to be caused by two-dimensional multiple reflections in sedimentary layers. Calculations based on the ray theory show that the amplitude of these phases depends on the incident angle to sedimentary layers and basement topography. Some earthquake records obtained at a station show the azimuthal variation on the amplitudes of the multiple reflected phases according to the difference of focal depth.

INTRODUCTION

The duration of ground motion is one of the important factors for evaluating responses of structures during earthquakes. An earthquake ground motion consists of many phases and the sequence of the later phases determine the duration. Some of the problems on characteristics of ground motions can be reduced by proper identifying natures of the different phases. This kind of investigations, however, could not be carried with ease, because of complexity of rupture at source and uncertainty of underground structure.

In the southwestern Kanto plain, Japan, the underground structure down to the top layer of the earth's crust with P-wave velocity of 5.5 km/s has been clarified by seismic refraction prospectings. It was found that the Kanto plain has sedimentary layers having P-wave velocities of 2-3 km/s with the thickness of several kilometers (Ref. 1). Later phases in seismograms obtained at such a large plain are affected not only by local shallow underground structure, but also by the thick sedimentary layers overlying basement rock. In this study, later phases in seismograms observed during explosion and earthquakes in the southwestern Kanto plain are interpreted with respect to propagation mechanism of body wave by taking into consideration the deep sedimentary layers structure.

LATER PHASES IN SEISMOGRAMS OBSERVED DURING EXPLOSION

At first, we notice distinct later phases seen in the explosion seismograms. When they are compared with earthquake ground motions at the surface, explosion seismograms give a key to understand propagation mechanism of seismic waves, because of the well-defined source parameters. In the area, earthquake observation have been carried out at the bottom of the Fuchu deep bore hole (-2.75 km) by the National Research Center for Disaster Prevention as shown in Fig. 1. The profiles for P- and S-wave velocities were obtained and the bottom layer has P-wave velocity of 4.8 km/s, in which the seismometers are installed (Ref. 2). There is a layer with P-wave velocity of 5.3 to 5.6 km/s can exist beneath the bottom layer of the bore hole. Some explosion seismograms were observed at the bottom during the seismic prospectings in the area as shown in Fig. 2. All traces indicate the radial velocities at the bottom. Distinct later phases can be seen only in the seimograms from the Yumenoshima explosion. We, therefore, pay out attention to the records of the Yumenoshima explosion.

The observation of the explosion at Yumenoshima was also done at the surface of the bore hole. Fig. 3 shows the velocity seismograms obtained at the bottom and the surface of the bore hole during the Yumenoshima explosion. The lower and upper traces display the radial component at the bottom and the vertical one at the surface, respectively. Since the explosion seismograms consist of dilatational phases, the propagation direction at the bottom is slightly oblique and it becomes almost vertical near the surface. Therefore such components are compared. The particle motions at the bottom are also indicated in the figure. The particle motion of the initial P-wave arrival at the bottom shows an upward oblique polarization. This implies that the initial phase is a refracted phase which propagates in the layer with P-wave velocity of about 5.5 km/s and comes upward around the bore hole. The observed arrival time difference of the initial phase in the surface and the bottom traces, 0.9 sec. is in good agreement with the calculated one of 0.85. As for the distinct later phase in the bottom trace, the first part of the particle motion(A) shows downward oblique direction. The second part(B), however, indicates upward direction. All distinct later phases in the surface trace arrive between those in the surface trace. From these facts, the distinct later phases should be interpreted as multiple reflected ones between the surface and the top of the refractor; almost in the sedimentary layers. The schematic diagram of the propagation mechanism is depicted in Fig. 4.

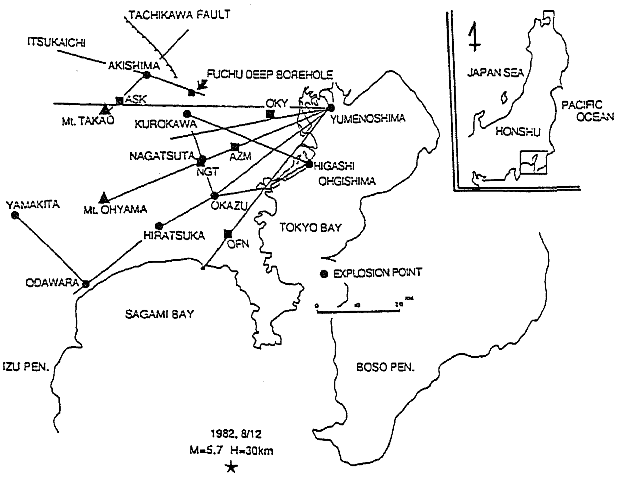

Fig. 1 Map of the studied field; the south-western Kanto District, Japan. Location of explosion points (solid circles) and surveying lines for refraction prospectings, and earthquake observation stations (squares).

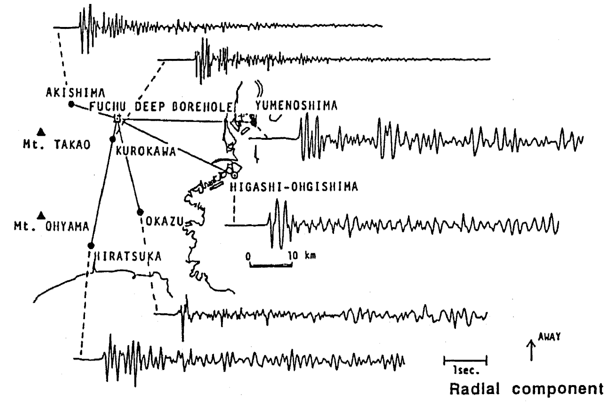

Fig. 2 Radial components of explosion seismograms observed at the bottom of the Fuchu deep bore hole.

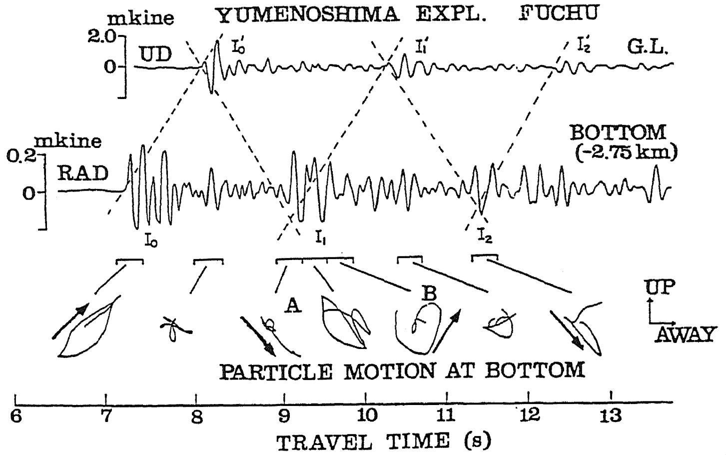

Fig. 3 Seismograms observed during Yumenoshima explsion at the surface (upper trace) and the bottom (lower trace) of the Fuchu deep bore hole, and the particle motions at the bottom.

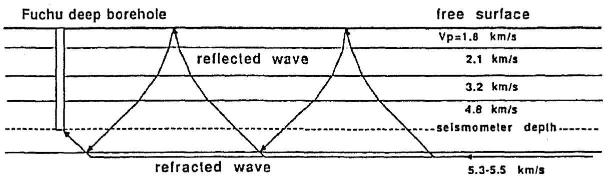

Fig. 4 Schematic diagram for propagation of multiple reflections of the refracted wave.

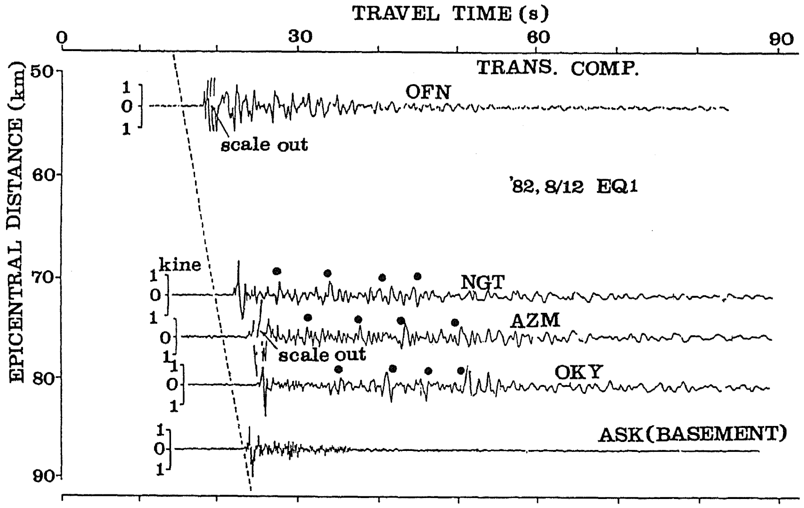

Fig. 5 Transverse velocities observed during earthquake of August 12, 1982.

LATER PHASES IN SEISMOGRAMS OBSERVED DURING EARTHQUAKE

In the area, array observation of earthquake ground motion has been carried out on the free surface at the stations indicated by squares in Fig. 1. One of the stations called "ASK" is located on firm rock with P-wave velocity of about 5 km/s. The others are set on the sedimentary layers. Some seismograms observed on the sediments exhibit distinct later phases. We, here, pay our attention to seismograms having simple wave forms, because of clear understanding.

Fig. 5 shows nearly transverse oriented velocities observed during the earthquake of August 12, 1982 with magnitude of 5.7. The seismograms obtained at the station ASK has relatively simple and impulsive wave form. The initial motions of S-wave observed at the other stations are also impulsive ones. Moreover, some impulsive later phases can be found every 5 to 6 sec. These arrival time differences between later phases are almost equal to the two way-time of the S-wave in the stack of the sedimentary layers. In the case of P-wave, the corresponding time interval would be 2 to 3 sec. Therefore, it is reasonable to assume that these later phases are also caused by multiple reflections within the sedimentary layers as discussed earlier. However, some differences should be noted with respect to propagation mechanism. Since the hypocentral depth is 30 km, the initial S-wave travels in the upper mantle as a refracted wave (Sn); the initial phase in the explosion seismograms travels along the top of the basement rock which is located considerably shallower than the mantle. This difference leads the different incident angle into the sedimentary layers. The incident angle to the sedimentary layers is somewhat oblique in the case of the earthquakes.

CHARACTERISTICS OF MULTIPLE REFLECTIONS

To investigate the characteristics of multiple reflection, a simple computation based on ray theory (Ref. 3) is carried out. The model consist of a layer overlying half-space with a dipping interface as depicted in Fig. 6. The response of the model is represented as the superposition of multiply reflected phases within the surface layer due to the plane SH-wave incidence from the half-space. Since to understand the propagation mechanism of multiple reflection is of our major interest, diffracted wave which may contribute considerably is not included in the computation. In the calculation, S-wave velocities for surface layer and the basement are 1.0 and 2.5 km/s, and densities are 1.9 and 2.3 g/cm**3, respectively. A Ricker wavelet (to=1 sec.) is used as an input wave. The calculated points are set at the free surface of a layer which has a depth of 3km to the half-space.

Fig. 7 shows the result of the case for the down-dip propagation; wave propagates in the direction, to which a layer becomes thicker (cf. Fig. 6). The incident angle is set constant as 125 deg. considering the ray path of the seismic wave during the earthquake discussed before. The dip angle changes from 2 to 10 deg. The initial phases are the same for each case. However, the multiple reflected phases with large amplitudes can be seen only when the dip angle is equal or greater than 7 deg. This means that the first down-going wave reflects over-critically at the interface. On the other hand, the traces for dip angle less than 6 deg. have no distinct later phases, because of under-critical reflection of the down-going wave at the interface. To explain the large later phases in the observed seismograms, the basement topography would have a downwards dip angle of several degrees from the south to the north for the over-critical reflection.

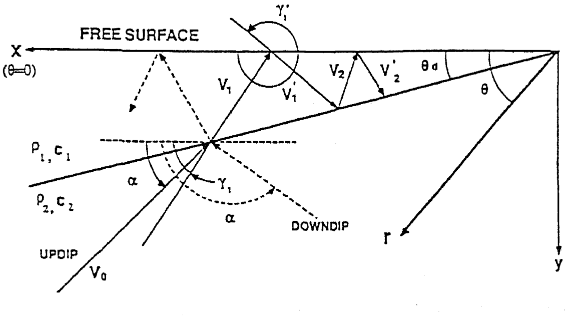

Fig. 6 Computational model with a dipping interface to interpret multiple reflections. Parameters for calculaton are $\rho_1=1.9\ g/cm^3$; $\rho_2=2.3\ g/cm^3$; $C_1=1.0\ km/s$; $C_2=3.0\ km/s$.

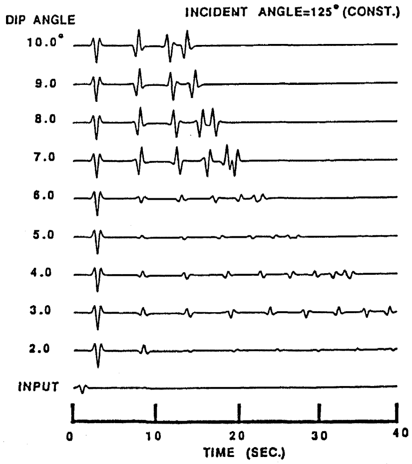

Fig. 7 Computed seismograms (SH-waves) at points on the surface. Amplitudes are normalized to the maximum in all traces. The dip angle are varied from 2 deg. to 10 deg. and the incident angle is constant as 125 deg.

The effect of the incident angle (α) is shown in Fig. 8 with a constant dip angle (θ_d) of 7 deg. The cases with incident angle less than 90 deg. correspond to up-dip propagation, the others show the down-dip propagation. The wave forms with incident angle equal or greater than 130 deg. are very different from those with the case less than 120 deg. with respect to later phases. These results clearly show that the amplitude of the multiply reflected phases depend considerably on the dip angle and propagation angle.

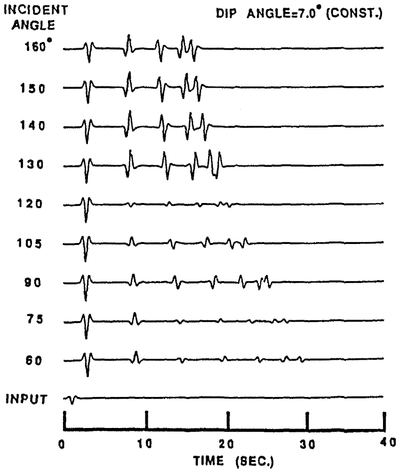

Fig. 8 Computed seismograms (SH-waves) at points on the surface. Amplitudes are normalized to the maximum in all traces. The incident angle are varied from 60 deg. to 160 deg. and the dip angle is constant as 7 deg.

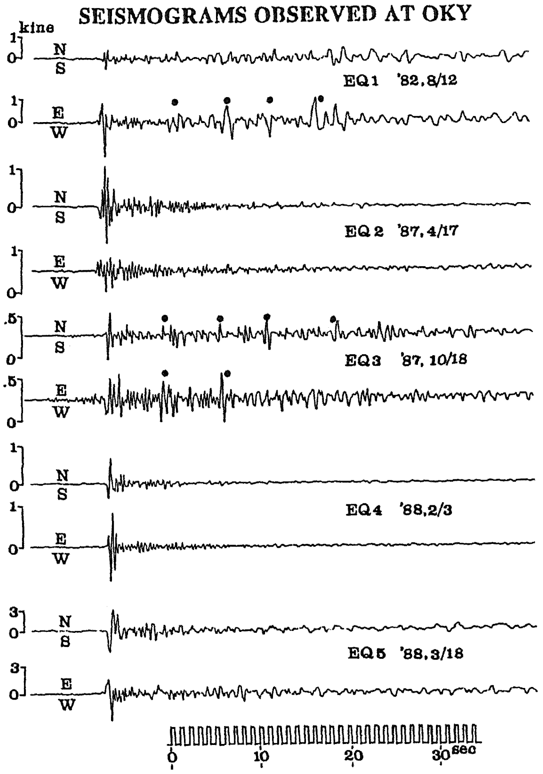

Fig. 9 Seismograms observed at OKY. Each trace indicates horizontal velocity.

REGIONAL VARIATION OF AMPLITUDE OF MULTIPLE REFLECTED PHASES

As investigated through simple calculation in the previous session, the amplitude of multiple reflected phase can vary according to the propagation path. This implies that there would be spatial distribution of earthquakes which generate multiple reflected phase with large amplitude. For this investigation, the seismic wave in source is required to be impulsive. Such records, however, are not enough. We, here, notice several recent earthquake records observed at one station, OKY, which occurred in various azimuthes. The traces in Fig. 9 show the observed horizontal velocities with impulsive initial phase. The seismograms of EQ1 are observed during the same as discussed previously in Fig. 5. Some distinct later phases with arrival time differences of around 6 sec. can be clearly seen in the seismograms of EQ1 and 3. Although we can find the later phases at about 6 sec. after the arrival of the initial phases in the record of EQ2 and 5, the amplitudes are small. The epicenter and focal depth of the earthquake are shown in Fig. 10. The epicenter of the earthquake which generates multiple reflected phases with large amplitude is located in south and west direction from the station with shallow focal depth. The focal depth of the earthquake with no distinct later phases are relatively deep. It is considered that the incident directions to the sedimentary layers are almost vertical during EQ2, 4 and 5, because of deep focal depth. Therefore, later phase can not have large amplitude as demonstrated in Fig. 8.

DISCUSSION AND CONCLUDING REMARKS

It is presented in this study that the major later phases in the seismograms obtained during explosions and earthquakes were interpreted and understood as phase reflected multiply within the sedimentary layers. From the calculation based on ray theory, it can be shown that the amplitudes of the multiple reflected phases depend on the incident angle into the layer overlying the basement rock and topogray of the basement rock. Some earthquake records obtained at a station show the variation of the amplitudes of the multiple reflected phases according to the focal depth. The observational fact is coincident with calculated results.

In this study, we discussed using seismic waves with simple wave forms, which allow us to understand clearly propagation mechanism. A number of records from earthquakes locating in various azimuthes should be compared for the further precise investigation on the generation of large multiple reflected phases. For this purpose, reasonable procedure and criteria to identify multiple reflected phases even in complex seismograms would be required.

From an engineering point of view, the existence of large multiple reflected phases can be expected to make duration of ground motion longer. In particular, surface wave with long duration and large amplitude would generated within the sedimentary layers by constructive interference of each multiple reflected phases, if incident wave into sedimentary layers has long duration and long period component during large earthquakes.

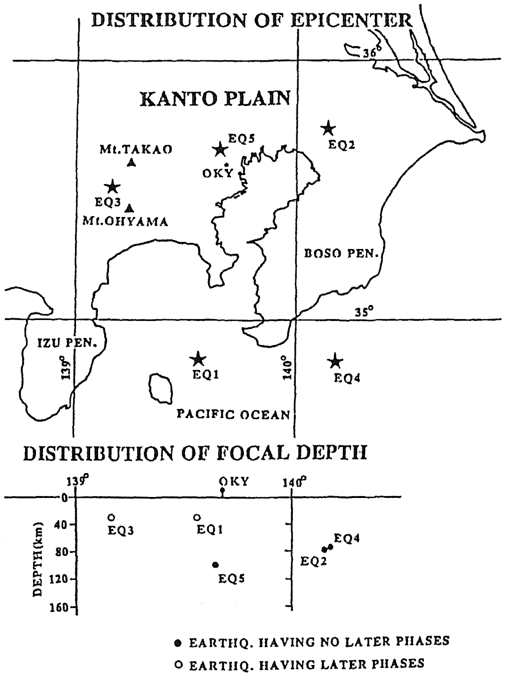

Fig. 10 Distribution of hypocenters.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to Emeritus Prof. H. Kobayashi and Dr. S. Midorikawa, Tokyo Inst. of Tech. for helpful suggestions. Mr. K. Itoh, National Research Center for Disaster Prevention, is acknowledged for making the explosion seismograms available. Some part of this study were carried out during stay of one of the authors (H.Y) at Inst. of Geophysics, the Swiss Federal Inst. of Tech. Zurich.

REFERENCES

1. Seo, K., H. Yamanaka, T. Samano and S. Midorikawa, Seismic prospecting of deep underground structure with explosions in the southwestern part of the Tokyo Metropolitan area, Japan, in Proc. of this Conf., (1988).
2. Yamamizu, F., H. Takahashi, N. Goto and Y. Ohta, Shear wave velocities in deep soil deposits. Part 3, Zisin (J. Seism. Soc. Japan), Ser.2, vol.34, 465-479, (1981; in Japanese).
3. Ishii H. and R. M. Ellis, Multiple reflection of plane SH waves by a dipping layer, Bull. Seis. Soc. Am., vol.60, 15-28, (1970)