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SEISMIC PROSPECTING OF DEEP UNDERGROUND STRUCTURE WITH EXPLOSIONS IN THE SOUTHWESTERN PART OF THE TOKYO METROPOLITAN AREA, JAPAN

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SUMMARY

Deep underground structure down to firm basement rock is clarified by seismic refraction prospectings in the southwestern part of the Tokyo Metropolitan Area, Japan. Underground structure of several kilometers in thickness consists of four layers, they are two kinds of Neogene sediments and two types of pre-Neogene basements. It should be noticed that each interface between layers is very clear with high impedance ratio. Therefore, it is expected that each region in the area possesses its own ground motion characteristics during earthquake. Moreover, it will be pointed out that site effect is more effective than source effect in prediction of earthquake ground motions.

INTRODUCTION

A number of huge structures, such as high-rise buildings, oil storage tanks and long-spanned bridges, have been constructed with industrial and economic enlargement until now. Such structures have their fundamental natural periods in so-called "longer period" range from one to 20 seconds. Because of small damping coefficient of the structure, the behavior during an earthquake is considerably dependent on characteristics of ground motions acting to them. Therefore, it is required for reasonable anti-seismic design of these structures to estimate earthquake ground motion accurately in the longer period range.

In the last two decades, observational and theoretical investigations on this subject have been carried out (e.g., Refs. 1,2,3). These results show that earthquake ground motions in the longer period range are affected by deep underground structure of several kilometers in depth. In particular, deep underground structure for propagation path must be clarified, when we consider amplification of surface wave which propagates with in thick Tertiary deposit horizontally.

Accordingly, seismic refraction prospectings using explosion as artificial source have been carried out in the Tokyo Metropolitan area including Tokyo and Yokohama since 1975. The configuration of sedimentary layers was made clear down to the firm basement rock with P-wave velocity of about 5.6km/s (Refs. 4,5). Although the resultant underground structures provide us a number of keys to understand characteristics of earthquake ground motions, they are more or less approximated ones, because some profiles were unreversed ones. Therefore, it is difficult to deduce the underground structure at any construction sites with accuracy for engineering use.

Recently, some seismic prospectings conducted to refine the underground structure in the Kanto plain, to which most of the Tokyo Metropolitan Area belong. In this study, the results of recent seismic prospectings in the southwestern part of the Tokyo Metropolitan area are summarized and compared with the other geophysical data.

DEEP UNDERGROUND STRUCTURE IN THE SOUTHWESTERN PART OF THE TOKYO METROPOLITAN AREA

The field of the investigation is shown in Fig. 1. The Kanto plain forms a tectonic basin and there is the Kanto Mountainous district at the western side of the area. We can find outcrops of basement rock having a P-wave velocity of about 5 km/s at the foot of Mt. Takao. Explosions with 100 to 500 kg dynamite were detonated at 9 sites in the area. Explosion seismic waves were observed at temporary stations indicated by solid circles. The travel time analysis by means of refraction method was carried out to obtain P-wave velocity profile of the underground structure for each surveying line in Fig. 1, so that the disagreement at the cross points between surveying lines becomes as small as possible.

Example of the seismograms is shown in Fig. 2. They indicate vertical velocities observed during the Hiratsuka explosion at the stations along line B in Fig. 1. Travel time diagram for P-wave initial onsets and P-wave velocity profile obtained from the travel time diagrams along the line are shown in Figs. 3 and 4, respectively. The same analyses were performed for all of the lines.

The P-wave velocity profiles derived at every explosion site are depicted in Fig. 5. S-wave velocities in the figure are deduced from those of P-wave, empirically. Several features can be pointed out as follows;

1) The bottom layer with P-wave velocity of 5.5 km/s can be found in the most of the area. It can be regarded as so-called "seismic bedrock" in the area.

2) Although the layer with 4.8 km/s in velocity does not exist or is very thin in the northeastern half of the area(around Tokyo), it becomes considerably thick as 4 km in the southwestern half of the area(around Yokohama).

3) The thickness of the upper sedimentary layer with P-wave velocity of 1.8 km/s is smaller than that of the second one with velocity of 2.8 km/s in the southwestern part; however the tendency is opposite in the northeastern part.

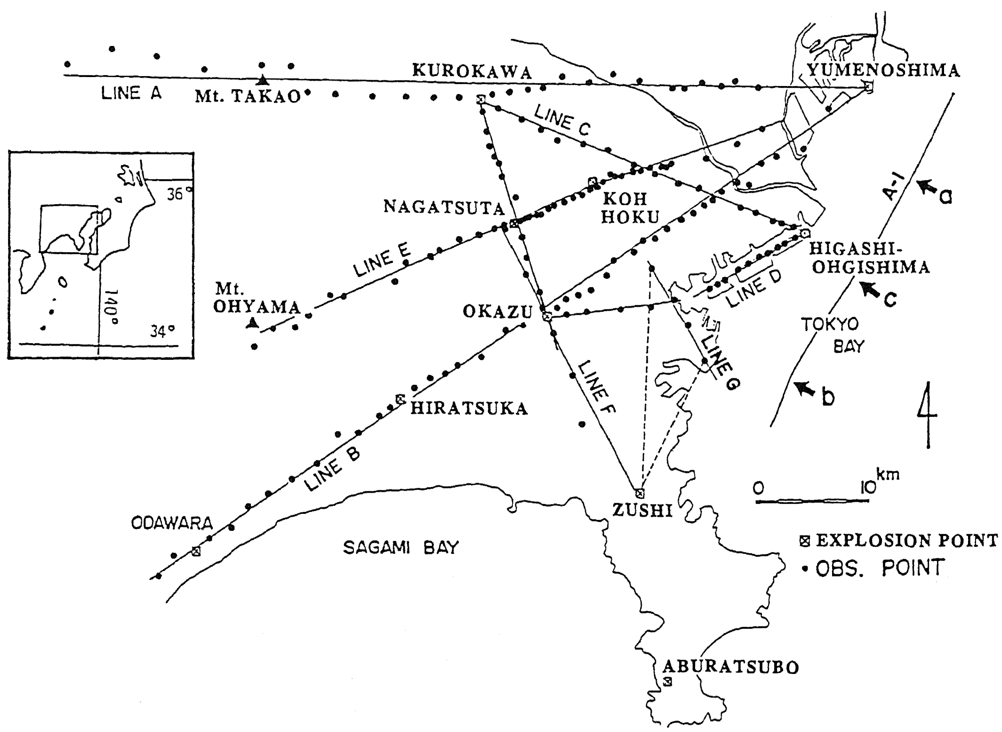

Fig. 1 Map of the studied field; the south-western Kanto District, Japan. Solid circles and solid lines show temporary observation stations and surveying lines, respectively. Explosion points are indicated by squares.

An attempt to represent the underground structure was performed three dimensionally, in spite of some ambiguities still remained . The contour maps showing significant interfaces are obtained by compiling all the profiles revealed. The contour map for the upper boundary of the layer with P-wave velocity of 4.8 km/s is shown in Fig. 6a. The maximum depth of more than 4 km can be seen near Yokohama habour. The depth becomes shallower towards the west side in the area. The 5.5 km/s contour is depicted in Fig. 6b. The depth is almost the same as 2.5 km between Yumenoshima and Kurokawa. It becomes drastically shallower towards the west from Kurokawa and appears at the ground surface around Mt. Takao. A vertical discontinuity can be found on this basement layer. In the western side beyond the step-like structure, the depth of the layer with velocity of 5.5 km/s is more than 6 km and becomes shallower toward the west. Near the Higashi-Ohgishima explosion site, the vertical discontinuity inclines somewhat gentle. It should be noted that the Tachikawa active fault is located on the northwestern extension from the vertical discontinuity. By means of geological survey, the Tachikawa fault is already confirmed. It, however, has not been found in the locations where the vertical discontinuity is recognized in this study.

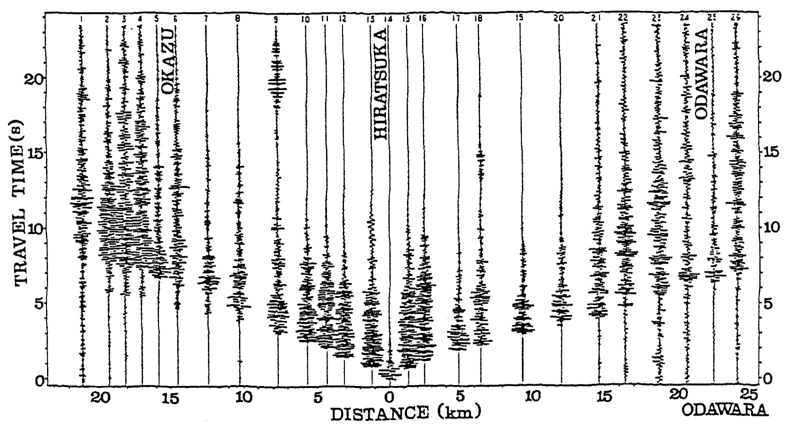

Fig. 2 Example of observed seismograms during explosion. Traces indicate vertical velocity obtained at the stations along the Yumenoshima-Odawara line (Line B in Fig.1) during the Hiratsuka explosion.

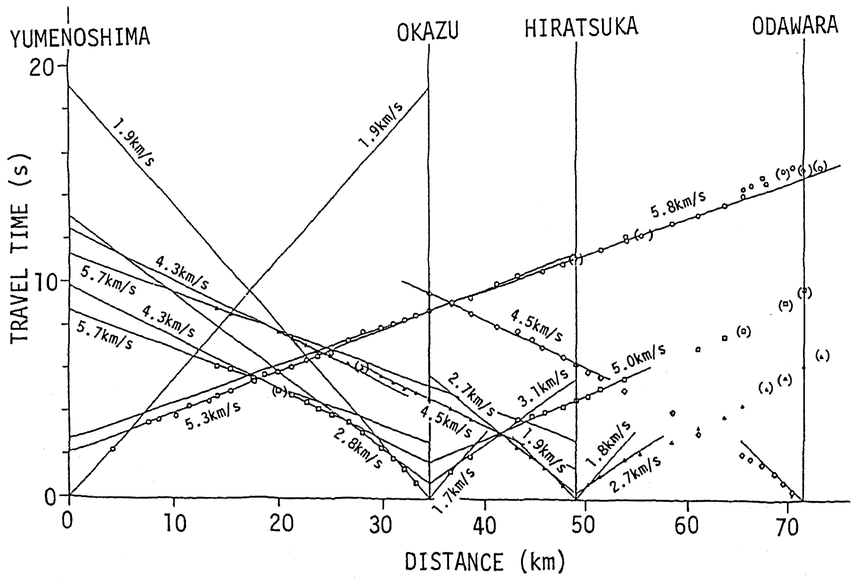

Fig. 3 Travel time diagram for the Yumenoshima-Odawara line (Line B in Fig.1).

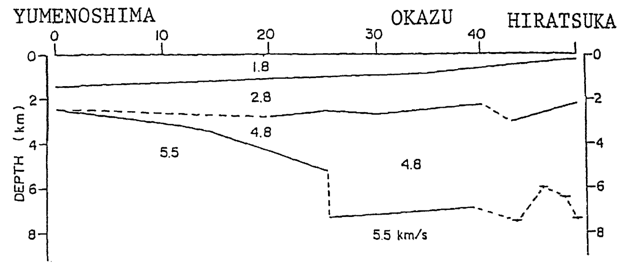

Fig. 4 Underground structure for the Yumenoshima-Odawara line (line B). Underground structure between Hiratsuka and Odawara is not estimated because of uncertainty of the travel time data.

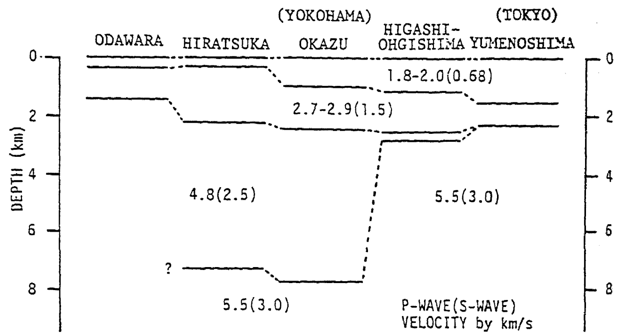

Fig. 5 Profiles of P-wave velocity derived at the explosion sites. S-wave velocities are deduced empirically from P-wave ones.

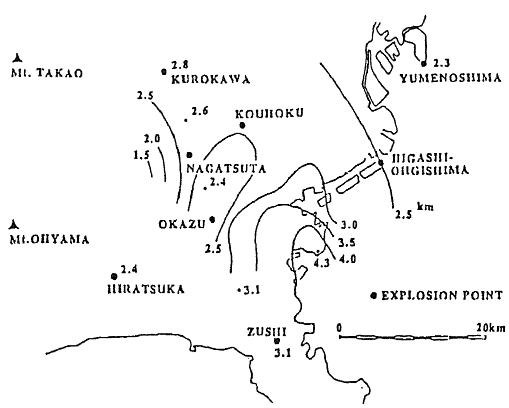

Fig. 6a Contours of depth to the layer with P-wave velocity of 4.8 km/s. Numbers in the figure indicate the depth in kilometer.

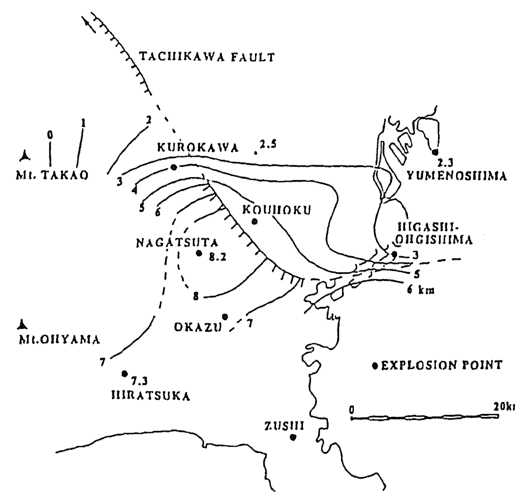

Fig. 6b Contours of depth to the layer with P-wave velocity of 5.5 km/s. Numbers in the figure indicate the depth in kilometer.

COMPARISONS WITH THE OTHER GEOPHYSICAL INVESTIGATIONS

It would be important and useful to compare the resultant underground structure with the results of the other geophysical investigations, because we can check the results and extrapolate them to the other area where the underground structures are still unknown.

In the area, a deep bore hole down to the layer with P-wave velocity of 4.8 km/s is made to observe the activity of the crust by the Research Center for Disaster Prevention. The P- and S-wave velocity profiles have been clarified by the down hole measurements; the bottom layer of the bore hole with P-wave velocity of 4.8 km/s is located at the depth of about 2 km (Ref. 6). In our results, the layer can be found at 2.8 km in depth at the Kurokawa explosion site. As the Kurokawa explosion site is 5 km apart to the south from the bore hole, the contour map for 4.8 km/s layer can be reasonable enough with the results at the bore hole.

Reflection prospectings along surveying lines area were carried out in the Tokyo Bay. The underground structure beneath one of the lines (A-1 in Fig. 1) was interpreted as shown in Fig. 7 (Ref. 7). The underground structure consists of 6 layers named as TA to TF in the figure. As compared with our results, some agreements can be pointed out as follows;

1) The depth to the top of TD layer is analyzed as about 1.3 km off Yumenoshima and 0.5 km off Yokohama. P-wave velocities for the layers overlying on TD layer are estimated as 1.5-2.2 km/s. Therefore, they correspond well to the first layer in our results.

2) P-wave velocity for TD layer is 2.1-3.3 km/s and its thickness distributes from 1 to 1.6 km. This layer is considered to be the same as the second one in our results.

3) TE layer begins to appear at off Haneda toward the south (loc. a in Fig. 7) and the thickness is considerably large at off Yokohama (loc. b in Fig. 7). This distribution pattern is similar to that of the 4.8 km/s layer. The velocity for TE layer, however, is estimated as 3.1-4.1 km/s and the thickness is also smaller as 1.3 km around off Yokohama.

4) The depth to TF layer is 2.3 km at off Yumenoshima. This layer corresponds to the layer with velocity of 5.5 km/s.

5) At off Ohgishima (loc. c in Fig. 7), the depth to TF layer becomes drastically large toward the south. This structural feature corresponds very well with the step-like structure found in this study.

Gravity data in this area are compiled by the Hydrographic Dept., Maritime Safety Agency (Ref. 8) as shown in Fig. 8. The gravity anomaly shows the negative extreme value in the northern part of Yokohama. By comparing Fig.8 with Fig.6, the distribution of the negative gravity anomaly seems to be harmonic with the depth contour of the layer having velocity of 5.5 km/s.

As compared with geological data, the top two layers belong to the Pleistocene and Miocene age, respectively. Although it is clear that the third and bottom layers belong to Pre-Neogene basement, the more detail classification is difficult only from the results of this study.

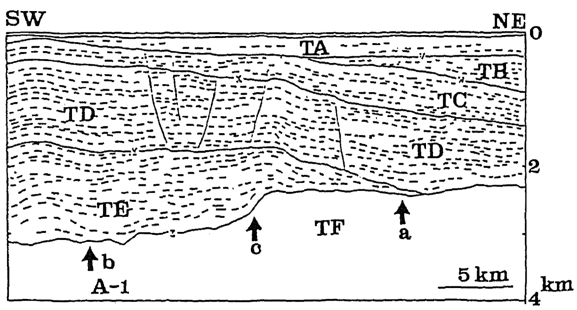

Fig. 7 Depth section of one of the seismic reflection profiles (A-1 in Fig.1) carried out in Tokyo Bay (Kato, 1984).

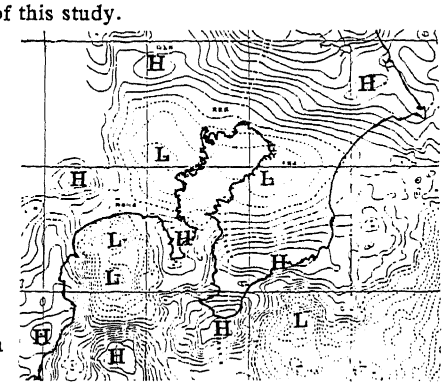

Fig. 8 Free-air gravity anomalies in the vicinity of southern Kanto district (Hydrographic Department, Maritime Safety Agency, 1987).

DISCUSSION AND CONCLUDING REMARKS

Travel time data obtained during explosions in the Tokyo Metropolitan area, Japan, are compiled to make clear underground structure down to firm basement rock. In the area, it consists of four layers with P-wave velocities of 1.8, 2.8, 4.8 and 5.5 km/s, respectively. Revealed underground structure is in agreement with the reflection profile in the Tokyo Bay area and distribution of gravity anomaly. The vertical discontinuity on the southwestern extension of the Tachikawa active fault can be found and deduced to continue to the Tokyo Bay area.

It is found that underground structure around Yokohama shows several features which differ from that around Tokyo. The differences can be expected to have influences on earthquake ground motions. Although the effects of the underground structure on ground motions should be discussed two- or three-dimensionally, the amplification due to SH-wave is going to be examined for two kinds of underground structures as shown in Fig. 9, because of simplicity. The amplification factors are shown in Fig. 10, Those for Yokohama and Tokyo models show their own clear fundamental period from 6 to 10 sec according to the underground structures. Moreover, the second and third peaks can be found in the shorter period range.

The amplification factor for the underground structure with gradient velocity increase with depth is also shown in the figure for the comparison. The S-wave velocity profile in Fig. 9 was deduced from the results of seismic prospectings in Imperial valley, USA (Ref. 9). This kind of structure can be regarded as a typical one in USA. The amplification factor seems to be relatively flat, as be compared with those for Japanese case. This spectral feature can be interpreted to be caused by no existence of interfaces with high impedance ratios in the profile for Imperial valley. These comparisons imply that source effects can be recognized easier than site effects in spectrum of ground motions observed at the site which has a structure with velocity gradient, on the other hands, the site effects can be predominant in seismograms observed at the site which has a velocity structure with clear interfaces. Therefore, site effect is more effective than source effect in prediction of ground motions in Japan.

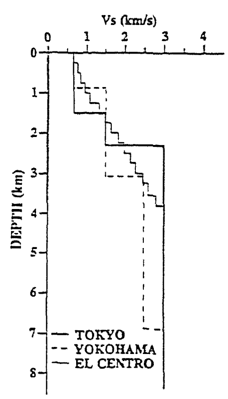

Fig. 9 S-wave velocity profiles

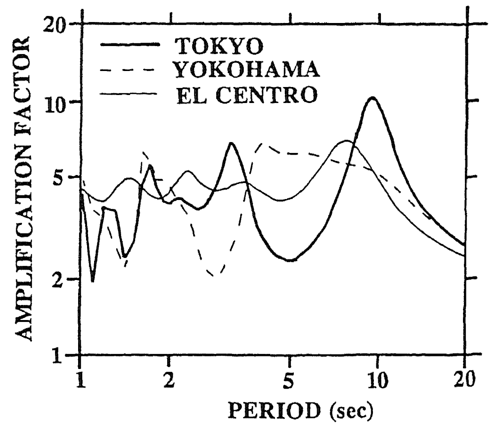

Fig. 10 Amplification factor due to SH-wave for the profiles shown in Fig. 9.

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