ON THE DEEP UNDERGROUND STRUCTURE OF TOKYO METROPOLITAN AREA

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SUMMARY

Through the observations of seismic waves generated from 15 large explosions, the three dimensional feature of the base rock of Tokyo Metropolitan area was investigated by utilizing the time term method. Since the time term at the site is approximately proportional to the thickness of the surface layer, we may deduce the thickness of the surface layer as well as the predominant periods of seismic waves at the other sites. The distribution of maximum acceleration amplitudes during the 1923 Kanto earthquake was also estimated taking the underground structure of Tokyo into consideration.

INTRODUCTION

We have many structures which have long natural periods from the engineering point of view. These structures are such as high rise buildings, long span bridges, huge oil tanks and so on. Natural periods of such structures are sometimes more than 5 seconds. We are expecting more and more of these kinds of structures in the future because of economic demands. In view of the antiseismic designing of such structures, it is necessary to clarify the deep underground structure down to the so called uppermost layer of earth crust ($Vp \fallingdotseq 5$-6 km/sec, $Vs \fallingdotseq 3$ km/sec) at the construction sites, because the underground structure down to this depth plays an important role associated with the modifications of seismic waves which will be dangerous to the abovementioned structures. For convenience' sake, we will define the medium deeper than this depth be the base rock from the engineering point of view.

For this reason, a new project to clarify the deep underground structure of Metropolitan area by means of the seismic refraction method has been started in 1975. A part of the research associated with this project was reported at the New Delhi meeting (Shima, 1977). He reported the predominant periods in Tokyo expected from Love and Rayleigh waves which would be generated from the future earthquakes. Utilizing the underground structure, Tanaka et al. (1978) also estimated the predominant periods of seismic waves during the earthquakes and compared them with the spectra of former large earthquakes observed in Tokyo. Their conclusion was that the estimated values agreed well with the observations. While, Kudo (1978) synthesized the Love waves expected in Tokyo from 1974 Izu-hanto-Oki and 1931 Nishi-Saitama earthquakes, using the published data on fault parameters and employing the normal mode theory. For simplicity, he assumed the parallel layering structure which was the slight modification of our derivings. He could explain the observed waveforms of Love waves of both earthquakes successfully not only the frequency contents but also amplitudes. Since the characteristics of Love waves depend on the mean underground structure from the source to the site, he had to employ the different underground structure for each earthquake. Such studies implied that the study on the three dimensional underground structure of

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Tokyo Metropolis is inevitable. In the following, the progress of our project will be reported.

THREE DIMENSIONAL UNDERGROUND STRUCTURE OF THE TOKYO METROPOLIS

We now have the data of the observations of 15 large explosions set off in Tokyo Metropolitan area. The time term method is employed to obtain the three dimensional underground structure. Let Ai, Bj and Δij are the shot point, observation point and distance between Ai and Bj. Then the travel time of refracted seismic waves Tij between Ai and Bj can be written in the following form,

$$Tij = ai + bj + \Delta ij/V \qquad (1)$$

where V is the seismic wave velocity of the base rock and ai and bj are called the time terms at points Ai and Bj.

$$ai,bj = Hi,Hj \cos i/Vo, \ \sin i = Vo/V \qquad (2)$$

where Hi and Hj are the thicknesses of the surface layer at the points Ai and Bj. The time term at the point is proportional to the thickness of the surface layer. Provided that we know the wave velocity of the surface layer Vo, we may obtain the thickness of the surface layer. Tij and Δij can be given through the observations, so that the unknown factors are ai, bj and V respectively. When we have many shots as well as observation points, we can determine the abovementioned unknown factors through the method of least squares. In our case, however, the true velocity of the base rock and the time term at the Yumenoshima shot point were determined by using the data of NS spread which was reversed. Therefore, bj associated with the other observation points of the other spread are unknowns to be determined. The underground structure at Yumenoshima consists of two surface layers. So, the time term at Yumenoshima is associated with two surface layers. It is difficult to obtain the thickness of two surface layers at every station, since the other spreads were not reversed and also almost all the shot points were located in the limited region. Consulting the relation between the time term and the depth down to the base rock at Yumenoshima, we assumed that the time term is approximately proportional to the depth to the base rock. Through the observations, the time term at Yumenoshima and the seismic wave velocities of top layer and base rock were determined accurately. But, the accuracy of intermediate layer velocity was not so high compared with the other derivings, since the phases associated with the intermediate layer were observed as later phases and they were contaminated by refracted phases. If we stick on the first arrivals of seismic waves and neglect the later phases, we may analyse the underground structure as two-layer case. If this is the case, the thickness of the surface layer at Yumenoshima becomes 2.1 km. Fortunately, we could read off the phases from the intermediate layer in the later phases. So, we analysed the underground structure as the three-layer case from the start. Shima (1957) discussed the errors involved in the depth calculation when we analyse the actual three-layer case as the two-layer case. In the case of Tokyo Metropolis, we might estimate the depth 20 % shallower than the actual one in the worst case. Since, we analysed the underground structure as the three-layer case from the begining, the estimation errors may be less than the above. To check this, fixing the velocities of the top layer and the base rock, we calculated the depths H1 and H2 changing the velocity of the intermediate layer little by little. When we reduce the velocity of the intermediate layer, the thickness of the top layer H1 becomes smaller. On the other hand, the thickness of the intermediate layer increases. Converses are true. So, if we pay the attention to the depth down to the base rock, that is H=H1+H2, it does not change much because of the cancellation. Assuming the 10 % variation of the intermediate layer velocity, the error estimated for the depth down to the base rock will be 3 % at most. This result emphasizes that we had better discuss the distribution of H, namely, the time terms at the sites, rather than those of H1 and H2. The P-wave time term map of Tokyo Metropolis thus derived is shown in the figure. The thickness of the surface layer in km can be obtained multiplying by 2.4 to the time term.

APPLICATION OF THE TIME TERM

From the seismicity of Kanto area, we have some idea about the foci of future earthquakes which will be hazardous to the Tokyo Metropolis. First, we establish the path from the origin to the site and estimate the time term for the mean underground structure. Multiplying by 8 to the time term, we may approximately infer the predominant periods of Love waves. Characteristics of Love waves are important, since Love waves were supposed to be predominated in Tokyo during the former large earthquakes. When the fault parameter of the earthquake is presumable, we may synthesize the waveforms in the longer period range, say longer than 5 sec, since the fault model at present is high cut source model. While, Sato et al. (1979) suggested the empirical formula which enable us to estimate the acceleration amplitude of short period range from the theoretical seismogram deduced from the fault model. Employing the fault model of 1923 Kanto earthquake suggested by Kanamori (1974), we computed the theoretical seismogram expected in Tokyo. The effect of the underground structure of Tokyo was taken into consideration. Following the method of Sato et al., the maximum acceleration amplitude at Hongo was estimated to be 410 gal at 3 Hz. Combining this result with the seismic microzoning map of Tokyo (Shima, 1978), we could estimate the maximum acceleration amplitudes at any places in Tokyo.

CONCLUSION

Through the observations of 15 large explosions set off in Tokyo Metropolitan area, the deep underground structure down to the so called uppermost layer of earth crust (Vp≒5-6 km/sec, Vs≒3 km/sec) was investigated. We defined the abovementioned layer as base rock from the engineering point of view. Three dimensional feature of the base rock was obtained utilizing the time term method. From the time term map thus derived, we may deduce the thickness of the surface layer in km multiplying by 2.4 and the predominant periods of seismic waves in sec multiplying by 8 to the time term. When the fault parameter of the future earthquake is presumable, we may synthesize the seismogram of long period surface waves. The maximum acceleration amplitude at the site can be also estimated taking the effect of underground structure into consideration. The distribution of maximum acceleration amplitudes during the 1923 Kanto earthquake was estimated combining above with the seismic microzoning map of Tokyo.

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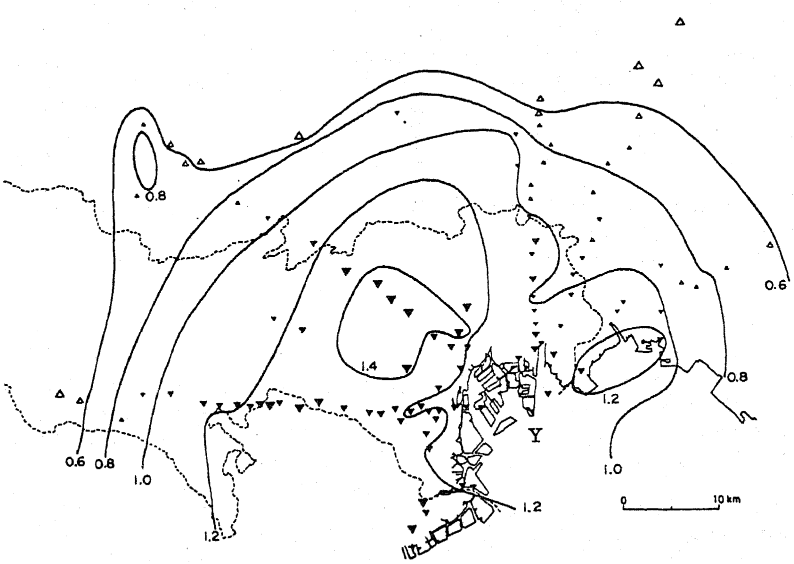

The P-wave time term map of Tokyo Metropolitan area. The thickness of the surface layer can be obtained multiplying by 2.4 to the time term (in km). " Y " in the figure denotes Yumenoshima, reclaimed land of Tokyo.