On the Base Rock of Tokyo Metropolis

by

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SYNOPSIS

Through the observations of seismic waves generated from 4 large explosions, the thickness of subsurface layers down to the base rock of Tokyo was found to be 2.3 km. The base rock of Tokyo having Vp=5.6 km/sec and Vs=3.0 km/sec corresponds to the uppermost layer of the earth's crust. Dispersion characteristics for both Love and Rayleigh waves were computed assuming the derived underground structure. Seismic waves having the period of 8 sec in case of Love and 4.5 sec in case of Rayleigh waves may predominate in Tokyo during the large earthquakes.

INTRODUCTION

Recent theory associated with the occurence of earthquakes tells us that the earthquakes will occur repeatedly in the same region where historical earthquakes once originated. Because of this, scientists and engineers have growing interest in predicting the next coming earthquake, the location of its origin, time of occurence, magnitude and the disaster due to the earthquake. To prevent the structure as well as the city from the damage due to the earthquake, it has been demanded to estimate the earthquake force or waveform impinging upon the base rock of the area we are concerned. The meaning of base rock mentioned above, however, is not clear. One may imagine the base rock as the soil layer which support the structure. From the engineering point of view, the sand and gravel layer of diluvial deposits in Tokyo are often called the Tokyo Gravel Bed in the sense of base rock. In such a case, we can explain the modifications of seismic waves due to the surface layers in the period range of less than about 2 sec. Tall buildings and long span constructions, consequently having the long natural periods around 2-10 sec, are being constructed and the need for understanding the physical properties of deeper geological formations is inevitable. So that, we have to assign the base rock in the deeper geological formation. We now suggest that we had better assign the formation having the shear wave velocity higher than around 3 km/sec as the base rock. This formation corresponds to uppermost layer of the earth's crust. If we do so, it is convenient to apply the seismological derivings, essentially long period characteristics, to the engineering problem. From this view, to clarify the base rock of Tokyo Metropolis, we conducted the explosions three times in Yumenoshima, the reclaimed land which is located in the south of downtown Tokyo, and once in Yoshikawa, Saitama Prefecture north of Tokyo, and the resulting seismic waves were observed at 15-17 temporary stations along the line connecting Yumenoshima and Yoshikawa. In the following, we will introduce the result of observations. The thickness of the soft layers down to the base rock was clarified for the first time through these experiments. Comments deduced from the surface wave dispersion characteristics estimated from the derived underground structure were also given.

OBSERVATIONS OF ARTIFICIAL EARTHQUAKES

Fig. 1 shows the locations of shot and observation points for 3rd Yumenoshima and Yoshikawa explosions. The distance between both shot points was 35 km. First and 2nd Yumenoshima explosions were set off at the places

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close to and around 1 km north of the location of 3rd Yumenoshima shot point. 495 kg of dynamite was fired simultaneously in each case at the bottom of 100 -110 m deep bore holes. The velocity type seismometers (vertical and horizontal) were used at most of the observation points. For recording seismic signals together with the JJY time signals magnetic tape recorder was utilized. We had to be anxious about the traffic noises because of the observation points being located in busy area. Generally, in day time, the noise level exceed 10 m kine. In midnight, however, the noise level go down appreciably. The noise level at the quietest temporary station in our experiments was well over 200μkine. That is why we had to fire a large amount of explosives in midnight to overcome high noises. The maximum amplitude at the furthest station was about 2 m kine. It is noted that we could reduce the noise some extent by installing the seismometers on the firm foundation of the structure. Fig. 2 shows the sample records, showing P arrivals, for 3rd Yumenoshima explosion. First arrivals, identified as refracted P waves from the base rock, can be seen almost all through the spread. Second large phases show the same phase velocity with that of the first arrivals. As far as the arrival times of these phases are concerned, we can explain them as the ones due to the reverborations of Pwaves associated with the subsurface layers. Intermediate velocity phases are not so clear from the sample records. Direct waves can be seen through the spread. Fig. 3 is the travel time graph for P waves obtained from Fig. 2. In Fig. 3, we can see clearly the abrupt decrease of arrival time at $\Delta=20$ km, although the phase velocities both nearer and further points from this distance are the same. This kind of time gap can not be found in direct wave arrivals. Therefore, the time gap of 1st arrivals can be explained by assuming the upheaval of base rock beneath the further points than $\Delta = 20$ km. In the same way, Fig. 4 shows the S wave arrivals. Horizontally sensitive seismometers were used to detect the S wave arrivals. Note the paper speed in Fig. 4 is slow compared with Fig. 2. Fig. 5 is the travel time graph for S waves. From Fig. 6 through Fig. 9, P wave records, P travel time graph, S wave records and S travel time graph are given. Fig. 6 shows clear direct wave arrivals. But, P 1st arrivals are not so clear because of noises, since far points from the Yoshikawa shot point are located in noisy Tokyo Metropolis. Readings of such arrival times are shown in Fig. 7 and Fig. 9 with parenthesis.

UNDERGROUND STRUCTURE

Fig. 10 shows the travel time graph of P 1st arrivals including 1st, 2nd and 3rd Yumenoshima data. The travel time graph is shown by reducing the amount of time $\Delta/5.5$ km/sec from the original travel time to exaggerate the time scale of the graph. This type of graph is convenient to determine the phase velocity accurately. From this figure, we may safely conclude that the apparent velocity is very close to 5.5 km/sec up to the distance around 20 km. After the abrupt travel time decrease which can be seen between 20-22 km, the phase velocity becomes again 5.5 km/sec up to the distance 30 km. Faster phase velocity can be seen farther than 30 km (near Yoshikawa shot point). Fig. 11 shows the reduced travel time graph for Yoshikawa explosion. If the time gap seen in Fig. 10 was due to the upheaval of base rock in the north side of the spread, we would expect the same amount of time gap (delay in this time) in Fig. 11. This would be expected at the distance around 10-15 km from the Yoshikawa shot point. Unfortunately, we could not confirm this from our experiment because of the interference of noises, and this was left for the future study. From the figure, the apparent velocity associated with the base rock was found to be faster than 5.5 km/sec but only a little. From this finding, we could conclude that the inclination of base rock was small and consequently that the true velocity in base rock was close to 5.5 km/sec. Fig. 12 shows the underground structures calculated from the intercept times at the shot points. These solutions are said to be the mean underground structures beneath the shot points. The discrepancy was found between P and S profiles associated with the depth of intermediate layer. The boundary between surface and intermediate layers may not be sharp. The thickness of the subsurface layers down to base rock, however,agreed well. If we combine both structures shown in Fig. 12, we may have the approximate underground structure through the spread. Thus in Fig. 13 the proposed profile taking 1st and 2nd Yumenoshima data into consideration is shown. The travel times from Yoshikawa shot point were computed using the proposed model and shown in Fig. 7 by open circles for the check.

SURFACE WAVE CHARACTERISTICS

Utilizing the derived underground structure, we have studied the characteristics of surface waves following the Harkrider's theory[1] (1964) if the vibration characteristics of subsurface layers due to the surface waves play an important role associated with the engineering problem. Fig. 14 shows the phase and group velocities of Love waves expected from the derived underground structure together with the energy function $\mathcal{A}\kappa^{-\frac{1}{2}}$. $\mathcal{A}\kappa^{-\frac{1}{2}}$ is shown in arbitrary scale. $\mathcal{A}$ and κ are the amplitude function and the wavenumber respectively. The predominant period due to the Love waves in Tokyo can be estimated if the information on source mechanism of future earthquake is available. Many seismologists are now working on this matter. So, we will only give an approximation here, that we could expect the large amplitude near the period where the group velocity is minimum (Airy phase). From the figure we may notice that the energy associated with the fundamental mode of Love waves is much higher than those of the higher modes. Therefore, we may conclude that the Love waves having the period of 8 sec may predominate during the large earthquake. In the same way, the phase and group velocities of Rayleigh waves were computed and shown in Fig. 15. In the figure ε is the amplitude ratio between horizontal and vertical components. From the figure, we may conclude that M_{11} mode is the most important one associated with the engineering problem. We may expect the large amplitude of Rayleigh waves, mainly of vertical component, having the period of around 4.5 sec during the large earthquake. To confirm the abovementioned derivings, we have to observe large earthquakes. Fig. 16 shows the seismograms of Off Izu-Peninsula Earthquake ($M=6.9$, 37°11′N, 137°27′E, $H=10$ km) observed at Hongo, Tokyo (Iwata et al.[2], 1974). The record was taken on the smoked paper by means of Omori-type long period mechanical seismograph (EW-comp: $T=19.9$ sec, $V=1.34$, $h=0.23$. NS-comp: $T=31.0$ sec, $V=1.44$, $h=0.18$). Since we do not have the vertical component, we could not prove the Rayleigh wave characteristics. Kudo and Tanaka[3] (1976) rearranged the above seismograms into the radial and transverse components. Then they measured the group velocities and compared them with those estimated from the underground structure we have studied. The mechanism of the abovementioned earthquake was studied by many reserchers. Using their data, Kudo and Tanaka also studied the amplitude spectra expected in Tokyo. Through the study, they found that the estimation from our model explained the observation well.

CONCLUSION

Through the observations of seismic waves generated from 4 large explosions, the deep underground structure of Tokyo Metropolis was clarified. The result are summarized as follows. 1) The thickness of the surface soft layer having $V_p=1.8$ km/sec and $V_s=0.68$ km/sec is 1.5 km.

ii) The thickness of the intermediate layer having Vp = 2.8 km/sec and Vs = 1.5 km/sec is 0.8 km. iii) The depth of the base rock was found to be 2.3 km. Vp and Vs in the base rock are 5.6 km/sec and 3.0 km/sec respectively. These values correspond to the ones of the uppermost layer of the earth's crust. iv) A suspected fault was found at a depth near the boundary of Tokyo Metropolis and Saitama Prefecture. The upheaval of the base rock in the northern part of the suspected fault was found to be around 300 m. v) Love waves having the period of 8 sec and Rayleigh waves having the period of 4.5 sec, mostly of vertical amplitude at this period, may predominate in Tokyo during the large earthquake.

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3. Kudo, K. and T. Tanaka (1976). On the Long Period Seismic Waves Observed in Tokyo (In Japanese), 4th Symposium on Subsoil Vibrations, Architectural Institute of Japan.

Fig. 1. Shot and observation points for 3rd Yumenoshima and Yoshikawa explosions.

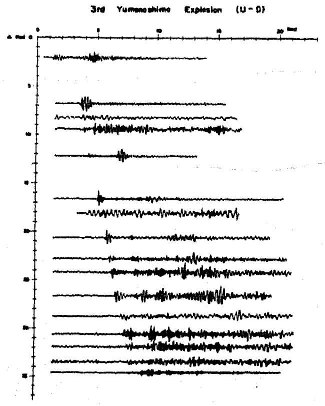

Fig. 2. P arrivals for 3rd Yumenoshima explosion.

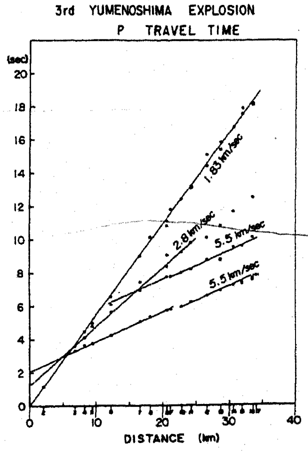

Fig. 3. P travel time graph for 3rd Yumenoshima explosion.

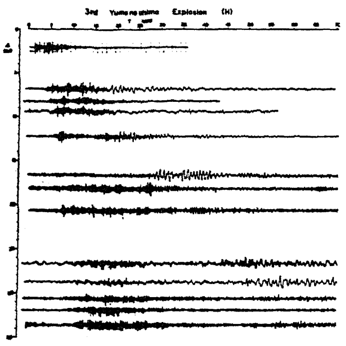

Fig. 4. S arrivals for 3rd Yumenoshima explosion.

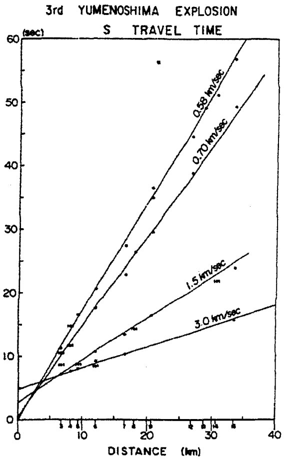

Fig. 5. S travel time graph for 3rd Yumenoshima explosion.

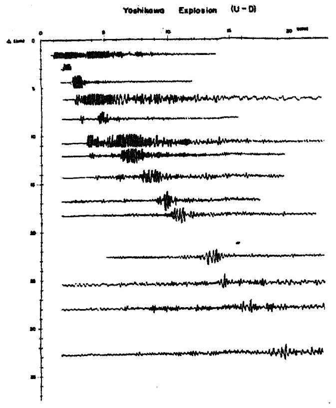

Fig. 6. P arrivals for Yoshikawa explosion.

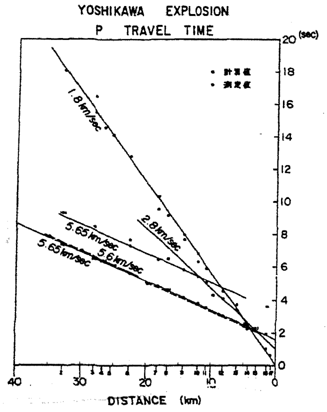

Fig. 7. P travel time graph for Yoshikawa explosion.

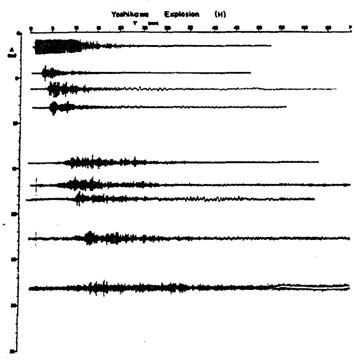

Fig. 8. S arrivals for Yoshikawa explosion.

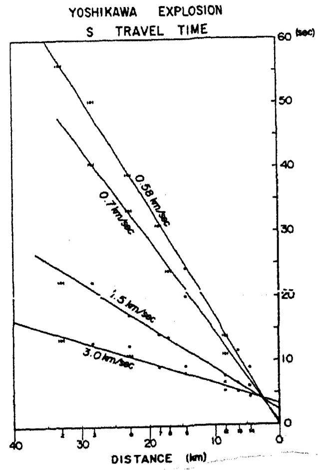

Fig. 9. S travel time graph for Yoshikawa explosion.

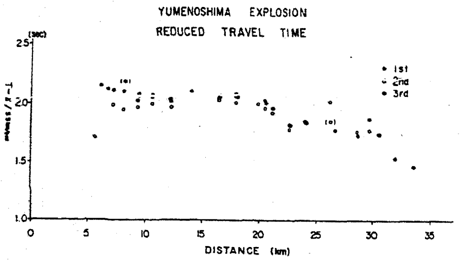

Fig. 10. Reduced travel time graph of first P arrivals for 1st, 2nd and 3rd Yumenoshima explosions.

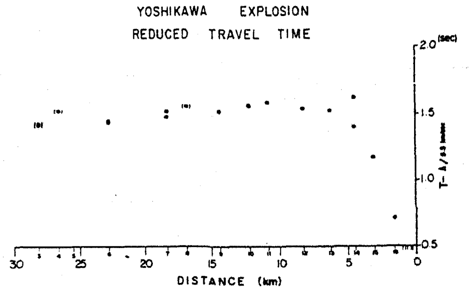

Fig. 11. Reduced travel time graph of first P arrivals for Yoshikawa explosion.

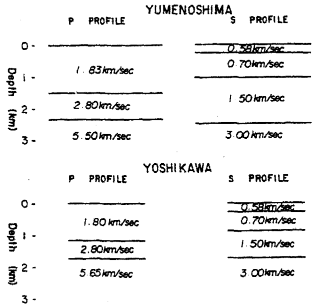

Fig. 12. P and S profiles beneath the shot points.

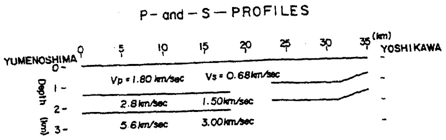

Fig. 13. Proposed underground structure.

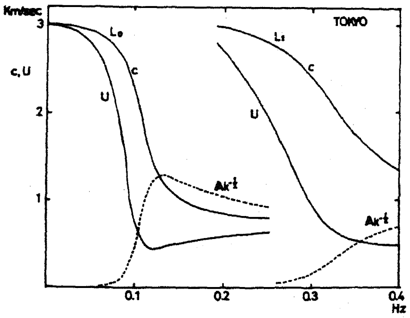

Fig. 14. Love wave characteristics.

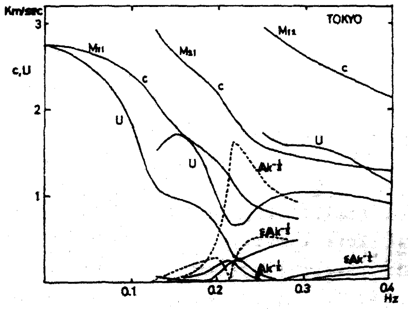

Fig. 15. Rayleigh wave characteristics.

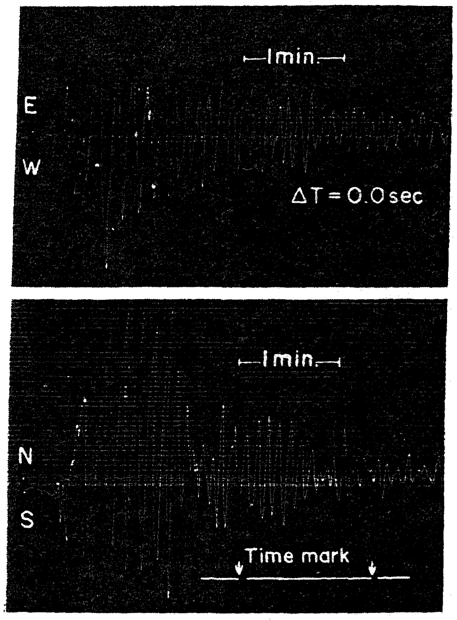

Fig. 16. Seismograms of 1974 Off Izu-Peninsula Earthquake observed at Hongo, Tokyo (after Iwata et al.).