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24. Experimental Study on Generation and Propagation of S-Waves: IV

S-Wave Prospecting by Means of Well Shooting.

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1. Introduction

Determination of the physical properties of the subsoil layers in situ is of essential importance in studying the modifications of seismic waves at the surface. These properties are also important in the design of earthquake resistant structures. Such properties can be known by studying P- and S-wave velocities in the subsoil layers. In general, the longer the spread the deeper we can acquire such information at the depths. Since it is usually necessary to make such an exploration in heavily populated areas, where the available space is limited, it is important to search for a method in which one can make the lateral distance from the borehole to the seismometers as short as possible. Because we are accumulating S-information in various kinds of soils, it would be convenient if a method which is easier and faster than the other conventional S-wave prospecting could be found, taking the aforementioned condition into consideration[1].

The main purpose of this study is to try and apply the well shooting method in the determination of SH-waves in the different media at depths. Efforts have been made to determine how closely the cal-

1) H. KAWASUMI, E. SHIMA, Y. OHTA, M. YANAGISAWA, A. ALLAM and K. MIYAKAWA, *Bull. Earthq. Res. Inst.*, **44** (1966), 731–747, (in Japanese).
Y. OHTA and E. SHIMA, *Bull. Earthq. Res. Inst.*, **45** (1967), 33–42.
Y. OHTA, *Bull. Earthq. Res. Inst.*, **45** (1967), 727–738.
N. KOBAYASHI, *Zisin*, [ii], **12** (1959), 19–24, (in Japanese).
E. SHIMA and Y. OHTA, *Bull. Earthq. Res. Inst.*, **45** (1967), 19–31.

culation of the interval velocity, within the shortest possible lateral distance from the borehole, could give an accurate interpretation of the underground structure.

It is possible to generate SV-waves by dynamite explosion in a borehole[2]. However, this type of source is not appropriate for our purpose, because of the radiation pattern, and also, difficulty arises in observing clear S-arrivals, due to the interference of P-waves. On the other hand, SH-waves can be generated easily by hitting a wooden plate horizontally[3]. In such a case there would be no P-waves and one could observe clear SH-arrivals.

Another point of importance is the detection of low velocity layers at depths. Such information is not available from the recordings which are made only at the surface of the ground. The method used for the calculation in this study, however, is very convenient to determine the low velocity layers at depths.

2. Experiments

This experiment was done in the Tokyo Metropolitan area in Minato-ku, Aoyama, Takagi-cho. A borehole 24 m. deep was dug in the area as shown in Fig. 1. Two spreads were arranged, Spread I and Spread II. A hole having the dimensions of 3 m. long, 50 cm. wide and 50 cm. deep was dug at each of the source points and the geophones. In Spread II, a borehole-seismometer was placed at a depth of 3 m. A wooden plate, 2 m. long, 30 cm. wide and 4 cm. thick, was placed at each of the source points. In order to improve the contact between the plate and the ground surface, lime and water were scattered at these points. Several persons

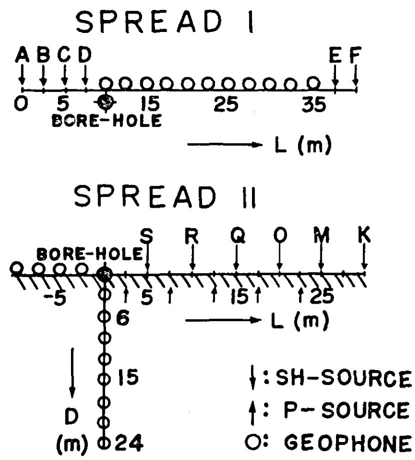

Fig. 1. Schematic diagram showing the borehole and the spreads.

2) *loc. cit.*, 1).
C. KITSUNEZAKI, *Butsuri-Tanko*, **20** (1967), 1-15, (in Japanese).
J.E. WHITE and R.L. SENGBUSH, *Goephysics*, **28** (1963), 1001-1019.
J.E. WHITE, *Seismic Waves: Radiation, Transmission and Attenuation* (McGraw-Hill, 1965).

3) *loc. cit.*, 1).

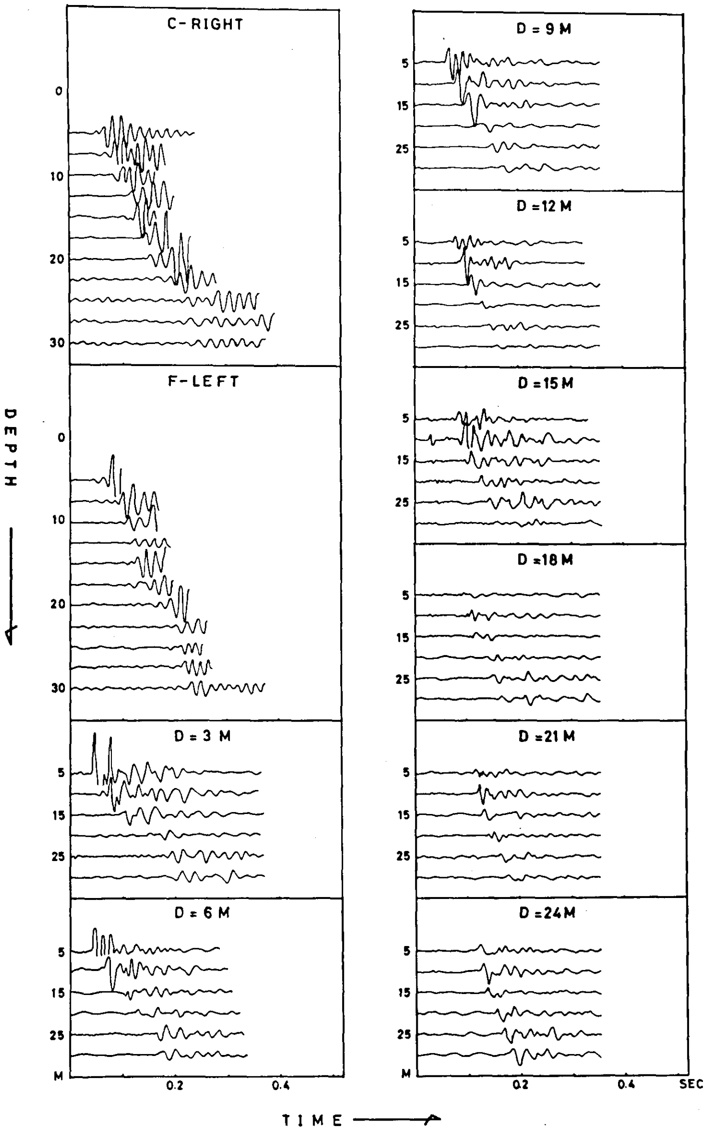

Fig. 2. Examples of the recorded SH- waves.

stood on the plate as a weight. SH-waves were then generated by hitting either end of the wooden plate horizontally at the points shown by the arrows pointing downwards, using a wooden sledge hammer. P-waves were generated by hitting the ground vertically at the points represented by the arrows pointing upwards, using the wooden sledge hammer. In both cases the source points were at 5 meter intervals. The procedure was repeated, moving the borehole-seismometer downwards every 3 m. to a depth of 24 m. In Spread I, eleven geophones were placed as represented in the figure by hollow circles. On the left side, there are source points A, B, C and D at intervals of 2.5 m. On the right side there are points E and F with the same interval. SH- and P-waves were generated as described before. This spread was an auxiliary one to determine the characteristics of the surface layers.

Fig. 2 shows examples of the recordings of SH- waves. On the upper left of the figure are SH-waves generated at point C. The next recordings are those generated at point F. The other recordings were obtained at the points S, R, Q, O, M and K with respect to different depths.

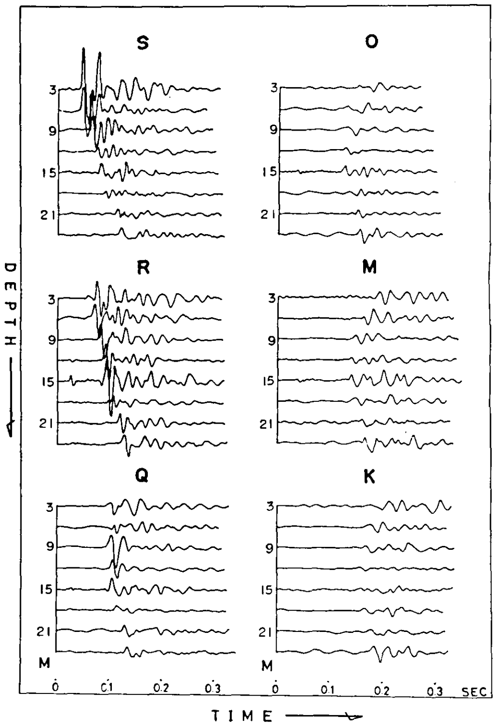

Fig. 3. Examples of the recorded SH-waves for different points when the seismometer is at different depths.

Fig. 3 shows SH-waves obtained from the point e.g. S to the seismometer at different depths. Clear SH-arrivals are seen on these seismograms.

Fig. 4 shows examples of the recordings obtained by hitting the ground vertically at a point 2.5 m. from the borehole. They are the vertical, the radial and transverse components. Each has a three meters interval depth from 9 to 24 meters. The initial motion of P-waves can be seen in this figure. It is interesting to note that other definite phases appear later, as shown in Fig. 4. Such phases will be examined later on.

Fig. 5 shows the travel times of SH-waves. The circles represent the travel times at different depths where the source point is at 5, 10, 15, 20, 25 and 30m. distance from the borehole. From the

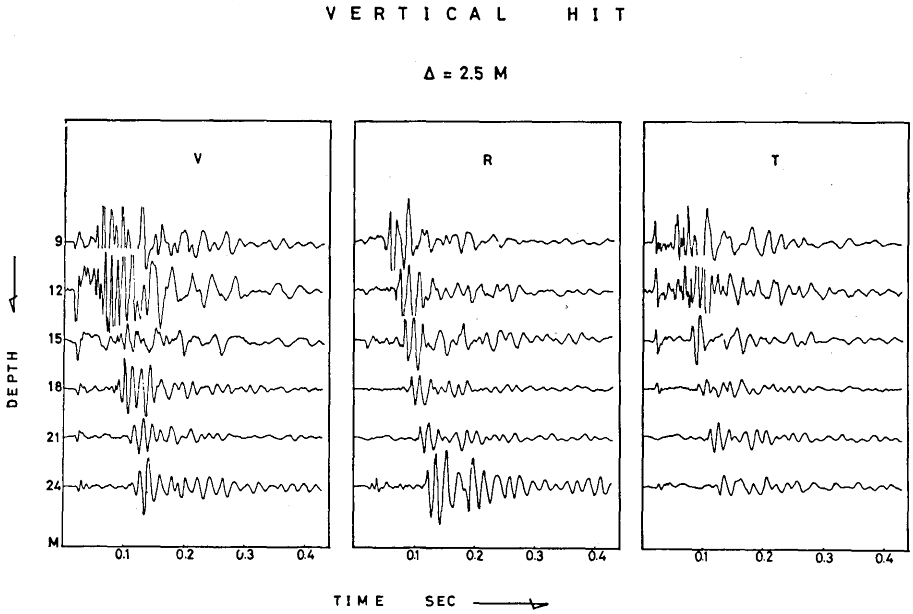

Fig. 4. Examples of vertical hit records.

figure we can observe the possibility of the existence of a low velocity layer between 18 and 21 meters.

Fig. 6 shows the travel times of SH-waves. The circles represent the travel times of different source points from the borehole where the seismometer is at a depth of 3, 6, 9, 12, 15, 18, 21 and 24 meters. The cross marks represent the travel times from the different sources to the observed points on the surface of the ground.

3. Interpretation

As was mentioned before, it would be of great use to make the spread as short as possible, therefore, we tried to find out if the data obtained at a point only 5 m. from the borehole could be sufficient to give us the same result as that of the longer spread. The observed travel times, the accuracy of which within one millisecond, were corrected to vertical travel times and the interval velocities were calculated, using the afore-mentioned data. These velocities are shown in Fig. 7. There are two low velocity layers, one is between 6 and 9 m., and the other is

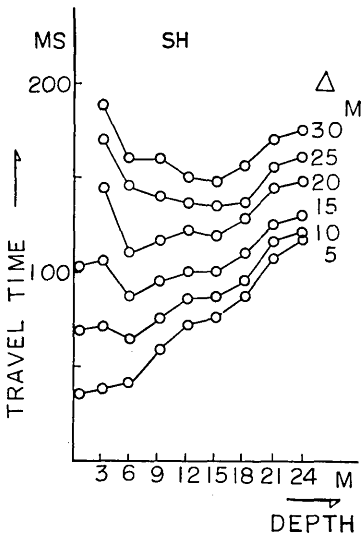

Fig. 5. Travel-times of SH-waves.

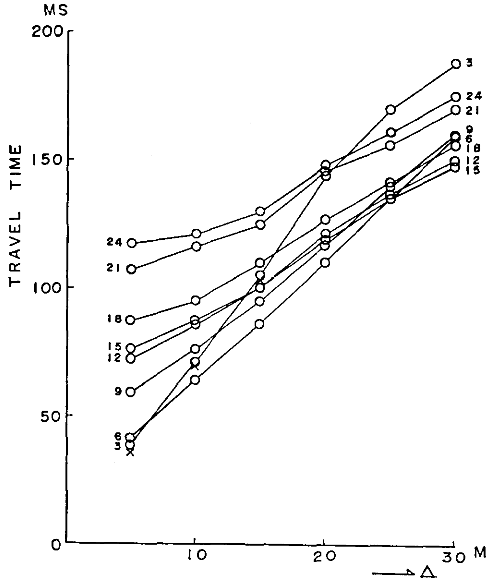

Fig. 6. Travel-times of SH-waves.

between 18 and 21 m. The velocity between 12 and 15 meters, which gives 525 m/s, appears to be out of the ordinary. However, the velocity calculated from the travel time curve of SH-waves between 12 and 18 meters is 340 m/s when the two points at 12 and 18 meters are connected. If the two points at 12 and 15 meters are connected, it will give a higher velocity, but if the two points at 15 and 18 meters are connected, it will give a lower velocity. It is not enough to depend on only two points, therefore, it is essential that closer readings should be made in such a case. We tried to make a model using the SH-velocities as shown on the left side of the figure by the dark lines, however, we could not explain the other observed data. Regarding the interval velocity between 3 and 6 meters, it is higher than that in the travel time curve. But if we look at the travel time of the point at 6 meters, in the travel time curve, we can notice that this point is a little faster than the line itself. Because of this, we can assume that the velocity at this depth is faster than 180 m/s. Actually, the travel times obtained from Spread I showed that the true velocities of SH-waves in the first two layers are 145 and 210 m/s. Also, if we average the total of the three interval velocities between 3 and 12 meters, as shown on the right of the figure, it will

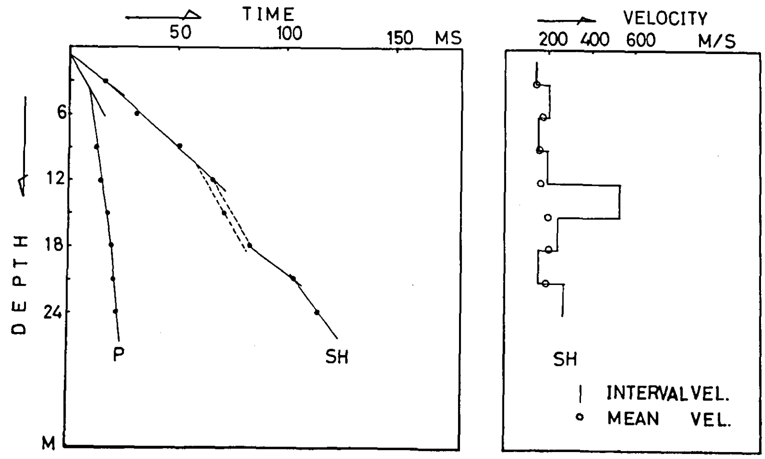

Fig. 7. Travel-times of SH-waves and P-waves, together with the interval velocities of SH-waves.

coincide with the velocity obtained from the travel time curve between 3 and 12 meters, as shown on the left of the figure.

Using the interval velocities of SH- waves, we checked to see if the underground structure, thus obtained, could explain all the other data. We used the interval velocities of SH-waves and with slight modification of the model in the places away from the borehole, we obtained the underground structure shown in Fig. 8. It is noted here, that the velocities between 12 and 18 meters in the S-profile of Fig. 8 are different from those of Fig. 7. As mentioned before, since the velocity between 12 and 15 meters is faster than 340 m/s, it is calculated as 370 m/s, and since the velocity between 15 and 18 meters is slower, it is calculated as 300 m/s. The velocity between 21 and 24 meters is 400 m/s, as shown in the S-profile, while that in Fig. 7 is 300 m/s. This last velocity depends only on the observations made when the source point was at a 5 meters distance from the borehole. However, this velocity does not coincide with that obtained when the source point was at a 10, 15, 20, 25 and 30 meters distance from the borehole, in which case the velocity is 400 m/s. In that case, closer recordings of the borehole-seismometer are necessary to give an accurate result. The main purpose of this study, as mentioned before, is to try and determine how closely the calculation of the interval velocities, within the shortest possible lateral distance from the borehole, can give

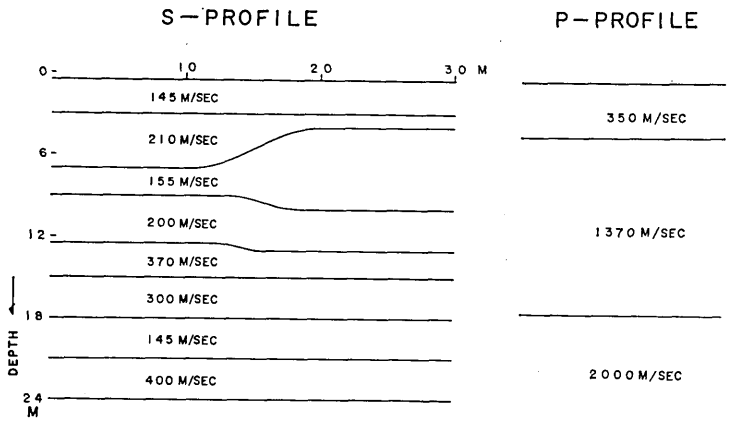

Fig. 8. Underground structures for both P- and S-profiles.

an accurate interpretation of the underground structure when we apply the well shooting method in the determination of SH-waves in the different media at depths. It is found that with slight modification of the model in the places away from the borehole, the travel time from the points at different depths to the surface, coincide within one millisecond with those of the actual observations obtained from the recordings, as can be seen in Fig. 9. It is noted, that the underground structure obtained from P-waves, is not entirely the same as that from S-wave observations, as shown in Fig. 8. This may be due to the fact that the thin structures of P-profile could not be determined because of the high speed of P-waves.

Fig. 10 shows the geological section near the spread. This section was drawn using the data obtained from three boreholes. One of the boreholes is located at the extreme left of the figure, which corresponds to the extreme left of the figure of the underground structure, as in Fig. 8. However, the boreholes are away from the spread. Considering this situation, we could say that there is a similarity between this section and the underground structure obtained by calculating the interval velocities of SH waves.

Regarding the vertical hitting, latter phases appear on the seismograms. Because the velocities of these phases are the same as those of SH-waves, they may be considered as SV-waves. The curves on the left of Fig. 11, are the travel times of the aforementioned phases. The radial and transverse data have been shifted upwards by 20 and

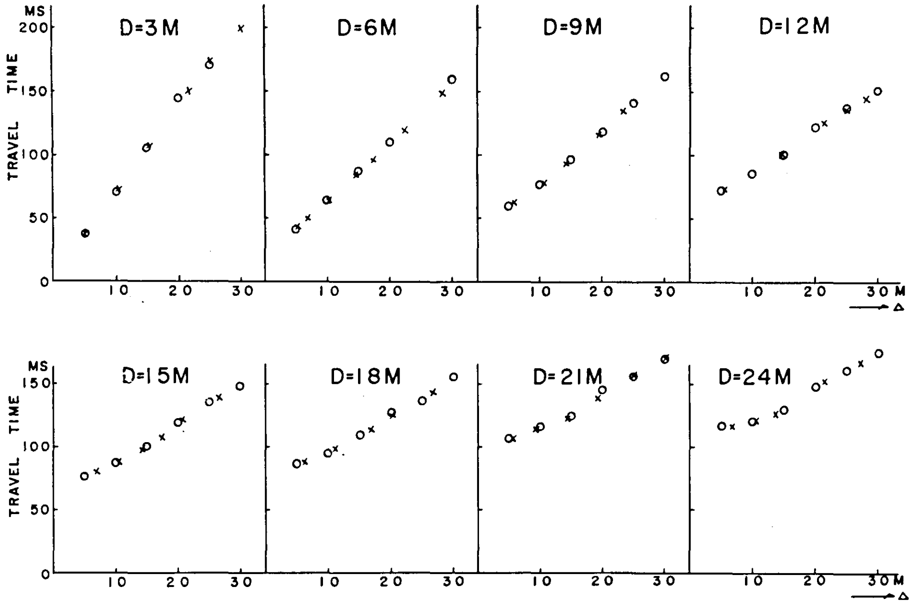

Fig. 9. Observed and calculated travel times of SH-waves.
o: Observed x: Calculated

40 ms respectively, so that their time-origins are at 20 ms and at 40 ms. The figure on the right shows the interval velocities of such phases. The solid lines represent the vertical component, the broken lines represent the radial component, and the dotted lines represent the transverse component. We can notice proximity of the interval velocities of the three components. However, the interval velocities of the three components, between 12 and 15 meters, are different. The vertical component shows an interval velocity of about 340 m/s.

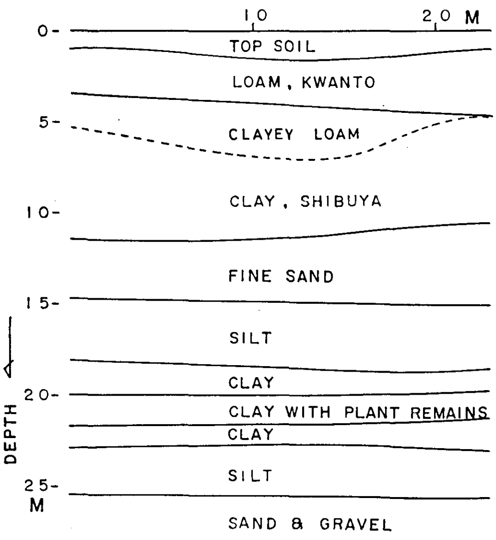

Fig. 10. Geological section near the spread.

The velocity of the radial component, however, is faster and that of the transverse component is slower than that of the vertical component. This coincides with the interpretation of the travel time curves of SH-waves, between 12 and 18 meters. Again, it is necessary that closer readings be made in such a case. For the other interval velocities, there is quite a similarity between these interval velocities and those of SH-waves, as shown in Fig. 7. It would be useful, if we could obtain S-information by hitting the ground vertically. Therefore, further studies of such phases are necessary, to give a clearer picture of this problem.

Concluding the previous study, one may use the well shooting method for conveniently obtaining S-information within a short lateral distance from the source point and the borehole. There are two main merits for this method. The first of which is that it is applicable in a limited area and it is safe and not noisy when used in heavily populated areas. The second is that it can be used for the exploration of low velocity layers at depths.

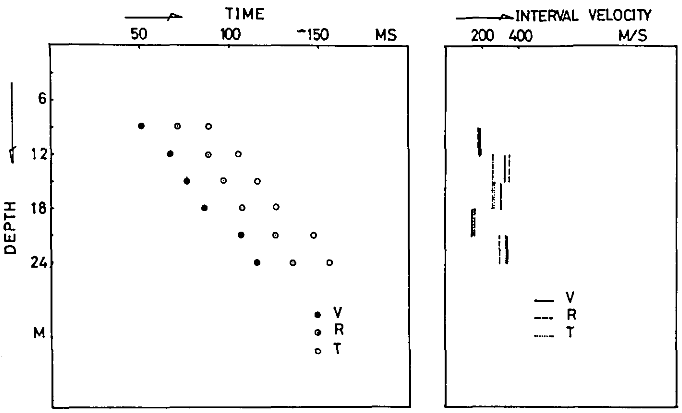

Fig. 11. Travel-time curves of the later phase of the vertical hit, together with the interval velocities of the three components.

4. Summary

The principle of the well shooting method, which is quite popular in reflection prospecting for oil, is used to obtain S-information. Seismic sources are generated by hitting a wooden plate horizontally. The main purpose of this study is to determine how closely the calculations of the interval velocity, within the shortest possible lateral distance from the borehole, can give an accurate interpretation of the underground structure. Travel times of waves travelling from a source point 5 meters away from the borehole, to a seismometer placed at a depth of 3 meters in the borehole, were recorded. The procedure was repeated, moving the borehole seismometer downwards every 3 meters, to a depth of 24 meters. These travel times were corrected to vertical travel times and the interval velocities were calculated. Using this velocity distribution with respect to depth, travel times from every surface source point to the seismometer placed at the different depths were calculated and were compared with the observations. Finally, with slight modification of the model in the places away from the borehole, we could determine the underground structure in situ. Therefore, S-prospecting can be carried out conveniently by means of the well shooting method using SH-source. This method is easier and faster than any other conventional method. Other merits are as follows: the first is that it can be applied in a limited area. The second is that it can be used for the detection of low velocity layers at depths, which are not easily available from the conventional method.

From the vertical hitting, later phases appear on the seismograms. There is quite a similarity between these interval velocities and those of SH-waves. Further studies of such phases are necessary to see if we could obtain S-information from the well shooting method by hitting the ground vertically.

5. Acknowledgements

The authors wish to express their thanks to Dr. Hirosi Kawasumi, Emeritus Professor of the University of Tokyo, who gave us the chance to do the experiments. Dr. Ohta's discussions were quite valuable. Special thanks are due to him. Mr. S. Noguchi helped the authors in the field. Author's appreciation is due to him. Thanks are also due to Miss S. Watanabe for helping in the drafting of the illustrations of this study.

24. S 波の発生と伝播に関する実験的研究 IV
SH 波による Well shooting

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S 波による小規模な地震探査が可能になり，軟弱地盤を構成する種々の地層内を伝わる S 波速度に関する情報も次第に数をましてきた．

いまゝでに開発されてきた探査法は，板叩き法 (SH 震源) と，ボーリング孔を利用する火薬震源操作法 (SV 震源) の 2 つに大別される．これ等の方法では，地盤深部における S 波の情報を得たい場合，地表に長い測線をとって観測しなければならない．これは都会地などでこの種調査を実施するためには致命的な欠点である．そこでこれ等の方法にとってかわる，場所をとらない，かつ容易な探査法の開発がのぞまれる．これは，S 波の data をふやす意味でも大切なことである．

今回上記両法の長所を生かした板叩き震源による Well shooting を実施する機会を得たので，これのみによって得られた地下構造が，他の地上展開による観測結果をどの程度までうまく説明出来るかをしらべることにより Well shooting の有用性を調べた．

この結果，板叩き法による Well shooting が充分に実用に供しうることがわかった．この方法の長所は，大変簡単であること，場所をとらないこと，低速度層の検出が容易であることなどである．