BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 45 (1967) pp. 33-42

4. *Experimental Study on Generation and Propagation of S-waves: II. Preliminary Experiments on Generation of SV-waves.*

By Yutaka OHTA and Etsuzo SHIMA,

Earthquake Research Institute.

(Read May 24, 1966.—Received Oct. 28, 1966.)

1. Introduction

It is well known that the insitu measurements of the shear wave velocities play an important role in the investigation of the physical properties of the subsoil layers. Along this line, the designing of an SH-wave generator and the field experiments by means of the generator were accomplished successfully, and were reported in our previous paper.[1] As a continuation of this kind of study, some efforts to generate the other type of S-waves, that is SV-waves, are herein reported.

Until recently, picking up SV-phases in the seismograms obtained from the conventional explosive seismic sources was believed to be a very difficult matter. From the theoretical point of view, we expect that the radiation patterns in such a case are spherically symmetrical with respect to the origin so that no shear waves can be expected. However, if there exists a slight unsymmetry in radiation patterns, which is not so optimistic in field experiments, then we can expect the SV-waves. For instance, White and Sengbush[2] took up the problem and demonstrated that for small explosive charges, when fired in a shot hole, the hole is not permanently enlarged, and radiation is due to the pressure acting on the wall of a cylindrical cavity and strong pressure pulses travel away in both directions in the bore hole fluid. Kitsunezaki[3] also proved from his experiment carried out at a metalliferous mine that the unsymmetrical radiation pattern generated the SV-waves. In their experiments, charges were fired in relatively hard rocks so that the hole itself contributed to produce the directivity of force and hence SV-waves.

1) E. SHIMA and Y. OHTA, *Bull. Earthq. Res. Inst.*, **45** (1966), 19-31.
2) J. E. WHITE and R. L. SENGBUSH, *Geophysics*, **28** (1963), 1001-1019.
3) C. KITSUNEZAKI, *Bull. Disast. Prev. Res. Inst.*, **15** (1965), 19-41.

The media we are now going to study are very soft ones, mostly of alluvial deposits, so that we can't apply their methods directly. First of all, we have to use casing pipes to keep the shot hole in good shape from collapsing due to static pressure as well as explosion pressure. Therefore special consideration should be made with regard to the seismic sources. As is well known, the generation of SV-waves is inherently related with that of P-waves, it being difficult to get rid of P-waves which obscure the arrivals of SV-waves. So that to improve the amplitude ratio between S- and P-waves from the view-point of instrumentation as well as from the way of observations is essential.

In response to the above-mentioned requirements preliminary experiments by means of two types of SV seismic sources were carried out at the river beach of Tone River in Narita City, Chiba Prefecture: the same site as described in our previous paper.[4] For recording the events a 24-channel tape recorder system and seismometers, having their natural frequencies 4.5 cps and 30 cps, favourable for conventional seismic prospecting, were used.

2. Field experiments

i) *Case* 1. This experiment was somewhat similar to White and Sengbush's experiment, which stands on Heelan's theoretical basis[5]. However, the media we were interested in were so soft that without the casing pipes a collapsing of the bore hole was certain. Consequently, plastic casing pipes were used for this purpose. As shown schematically in Fig. 1, an iron pipe was used to regulate the directivity of the force, because we were afraid that a strong directivity of the force not be expected from the conventional shot. The iron pipe used was 150 cm in length, 7.5 cm in diameter and 0.3 cm in thickness. The required charge was fixed in the center of the pipe, the latter being lowered down slowly into the bore hole by a wire rope. It was then fired at the prescribed depth. The pipe not only regulates the explosive pressure pattern but is also a protection against the breakage of the casing pipes due to direct radial pressure applied to the bore hole wall. Subsequently the strong pressure pulses will travel away in both up and down directions. As a result, the seismic source polarized in a vertical direction would be expected.

4) *loc. cit.*, 1).
5) P. A. HEELAN, *Geophysics*, **18** (1953), 685-696.

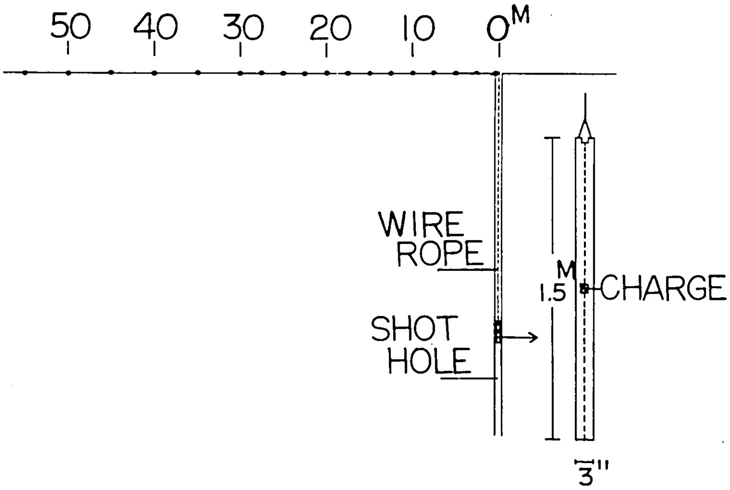

Fig. 1. Spread of seismometers and the iron pipe used to regulate the seismic source.

The seismometer's interval was taken 2.5 m apart from each other from the bore hole ($\Delta=0$ m) to 30 m, and 5 m from 30 m to 55 m respectively (Fig. 1). Both vertical and radial components of the events were observed. The natural frequencies of the seismometers were 30 cps. Auxiliary observations were made by seven 4.5 cps vertical seismometers, installed at the bottom of the bore holes along the circle having its center at 30 m depth, so that they could detect the radiation patterns of the events. However, seismograms from the surface spread were mainly used for the interpretation.

For the first time, we tried to compare the seismograms obtained when there was the iron pipe and without it in different charge sizes. This would provide us with information as to how effectively the iron pipe affected the pattern of radiation. We failed, however, because we could not withdraw the pipe when the charge amount of 100 g$\times$1/16 was fired in it at the depth of 29.9 m. Casing pipes might be broken, because the iron pipe was not strong enough to protect the casing pipes from the explosive pressure. So we were forced to use the smaller charge. For safety, a cap was fired at the depths 14.3 m and 7.0 m with and without the pipe respectively.

Fig. 2 shows comparative records from both kinds of seismic sources. Comparing them, two predominant wave groups are easily seen in both cases. For example, let us compare the middle ones (shot depth 14.3 m), The first coming wave groups in both records are P-waves having apparent velocities of approximately 1500 m/s, and next ones are the somewhat solitary wave groups having slightly lower frequencies compared with the P-waves and apparent velocities of approximately 250 m/s. Arrivals of these wave groups are marked by "." in the figure. The special feature of these wave groups is the change in their apparent velocities according to the variation of shot depths suggesting that they

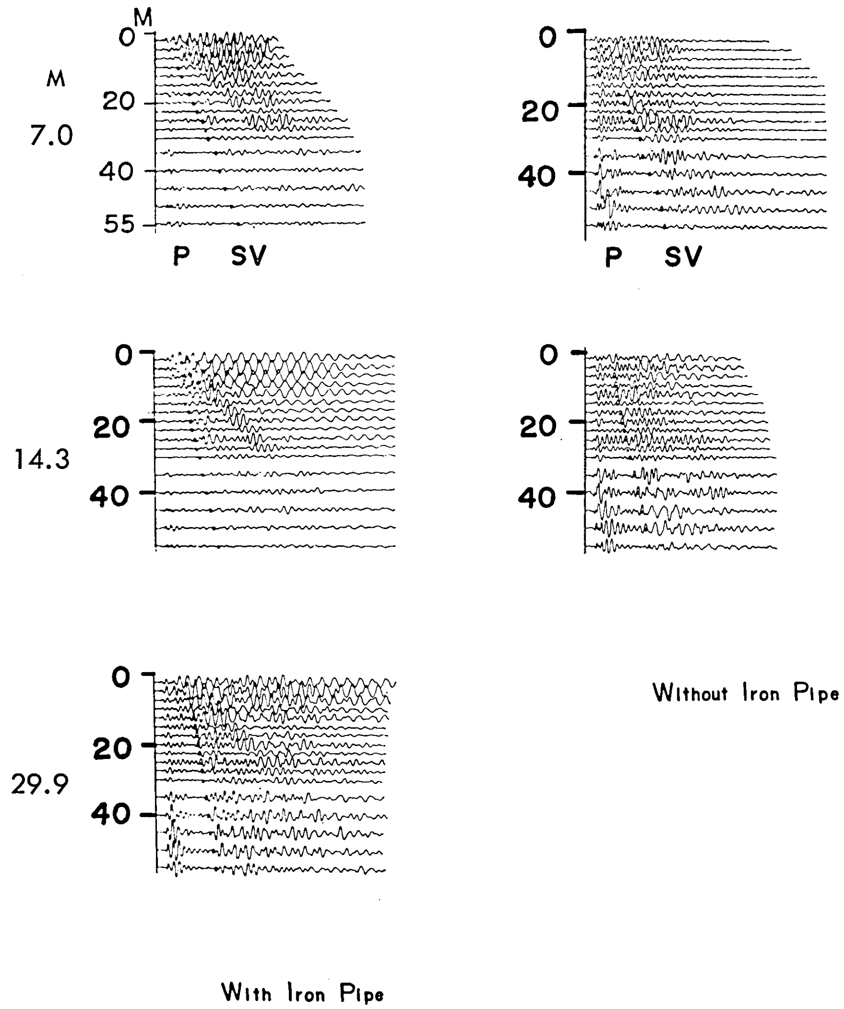

Fig. 2. Comparison of seismograms from seismic sources with and without the iron pipe.

are body waves (SV-waves). The above-mentioned wave groups appear in all cases. The 3 rd wave groups, however, were predominate only when the seismic source was regulated by the iron pipe. It is noted that these waves have no relation with shot depths. Velocities obtained from different shot depths were the same and the intercept times were also almost the same. These waves were believed to be secondary generated SV-waves near the surface due to the arrivals of strong pressure pulses from the source. Examining the figure, one will notice that the above-mentioned phases were clear even when the shot depth was as deep as 29.9 m. Usually from such a small explosion at the depth the surface waves would not be observed. Actually, no such wave groups were found in the seismograms obtained from the conventional shot at the depth of 7 m. The 4th wave groups were the surface waves in relation to the surface SV-waves thus generated.

Comparing both kinds of source, the smaller P-wave amplitudes were found in the case of the source with pipe, although SV-wave amplitudes were also reduced. This was a good indication showing that the energy partition to S- and P-waves could be largely improved by this simple device. However, the quantitative amplitude study was left for a future study.

ii) *Case* 2. The second experiment was the test to determine whether we could obtain the SV-waves by hitting the casing pipe vertically dowards with a hammer. This was because we expected that a strong shearing force would be applied to the wall of the bore hole. As far as the authors know this type of study has been attempted by quite a few investigators by observing the waves due to pile driving often seen at construction sites. However, no appreciable report has been published so far. Sample seismograms obtained by this method are shown in Fig. 3 (A(1) and A(2)). A(1) was derived right after the charge at 29.9 m depth was fired. Because this explosion broke the casing pipes near the shot depth the total length of the casing pipes was expected to be less than that. First arrivals having the apparent velocity of 120 m/s up to about 17 m and 240 m/s further than 17 m were very clear proving that the waves were bodily waves. In the same way A(2) was derived after the 7 m shot. The apparent velocity of the waves was 120 m/s in this case. These derived data were quite similar to the ones we obtained by the former method. For comparison, a record obtained by hitting the ground surface with a hammer is also shown in Fig. 3. SV-phases were also clear. These observations were

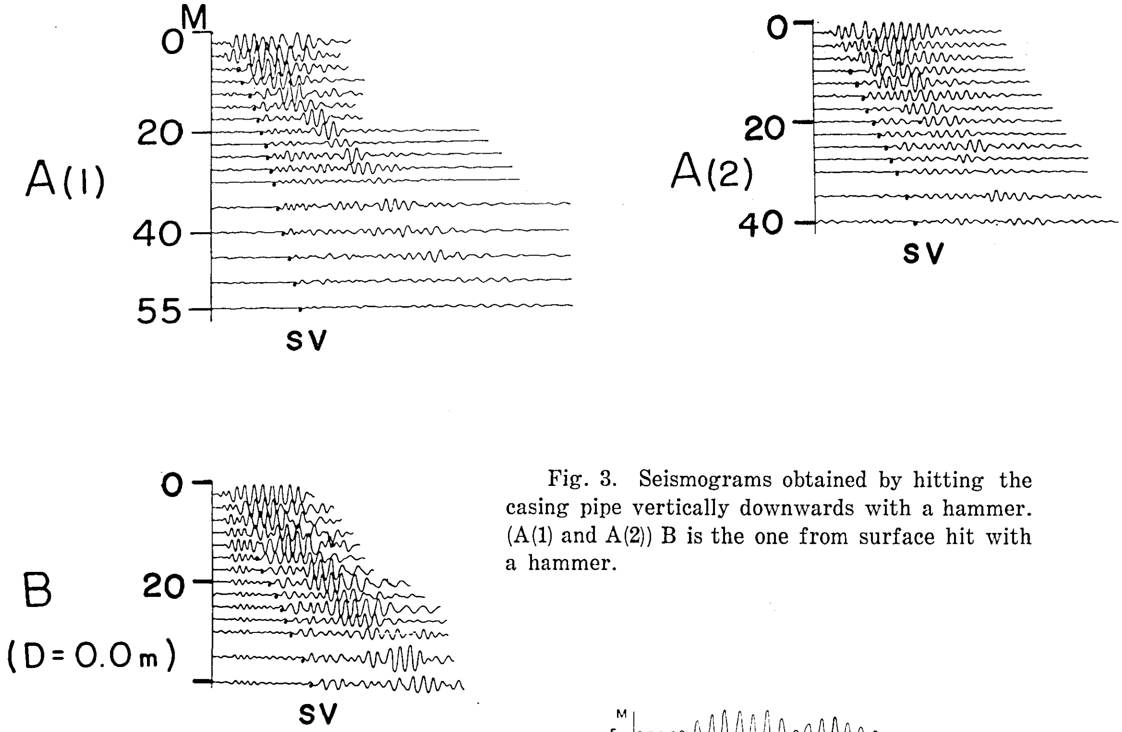

Fig. 3. Seismograms obtained by hitting the casing pipe vertically downwards with a hammer. (A(1) and A(2)) B is the one from surface hit with a hammer.

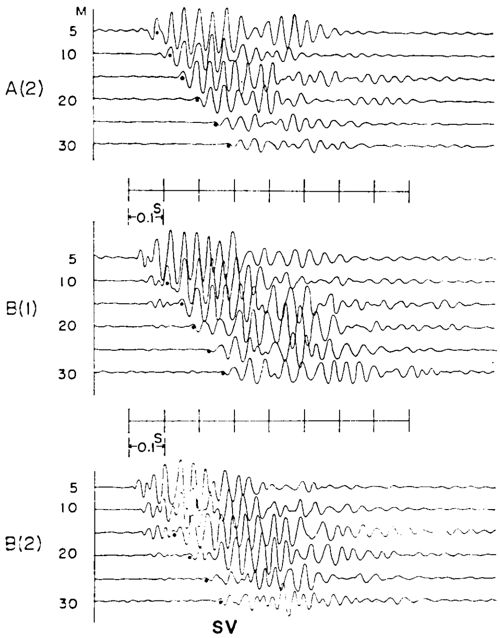

Fig. 4. Examples of records of radial components from various seismic sources.
A(2): hitting the casing pipe,
B(1): hitting the ground surface,
B(2): conventional shot of a cap at the depth of 30 cm.

made by the vertical components.

Now if SV-waves were generated at the depth, refracted waves observed at the ground surface would have much the radial components. For that reason, radial components of the events were also observed and are shown in Fig. 4 (A(2)). B(1) and B(2) in Fig. 4 are the sample records derived from the surface hit by a hammer and the shot fired at 30 cm depth respectively. A(2) is excellent for SV-wave study compared with the others, seeing the smaller P-arrivals which will contaminate the SV-arrivals.

Fig. 5 shows the travel time graph from SV initial motions from different kinds of seismic sources. Travel times of all the events were plotted in one figure to see the correlation between the apparent velocities from different sources so that no depth correction for each event was made. One will notice the excellent correlation between them. The velocity of the uppermost layer was determined referring to the derived data of the SH-experiment and from the direct SV-wave measurement in this study. Heavy lines in Fig. 5 were drawn for reference using the values derived from the SH-experiment. Recently, discussions on the speed difference between SH- and SV- waves have been quite

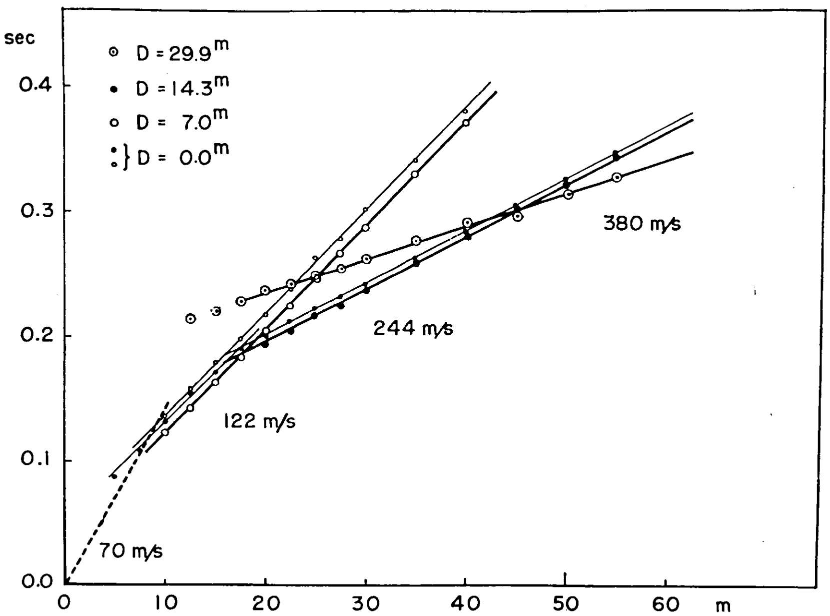

Fig. 5. Travel-time graph of initial motions of SV-waves.

popular. However, no such indication was found in this field.
iii) *Underground structure for SV-waves.* From Fig. 5, the underground structure for SV-waves was determined by means of the method of trial and errors and is tabulated in Table 1.

Table 1. Structure for SV-waves.

Layer	Velocity (m/s)	Thickness (m)
1	70	3.2
2	122	9.4
3	244	17.4
4	380	—

Fig. 6 shows the correlation between the above-mentioned derived data and other geological and geophysical findings. There is a slight difference between the SH- and SV- profiles. However, from the fact that both profiles were not reversed and both spreads were separated a

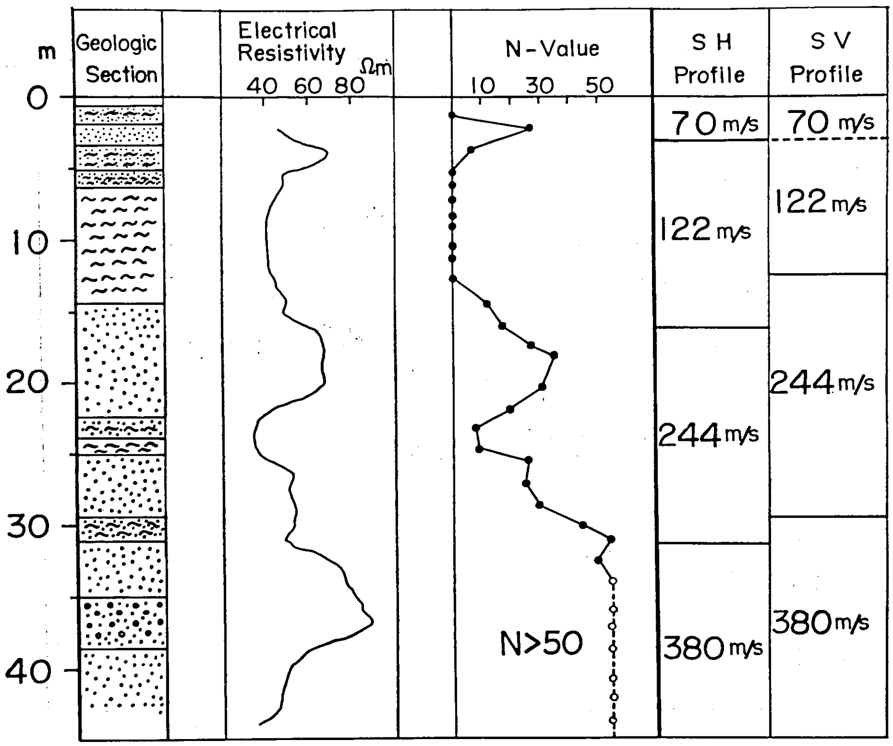

Fig. 6. Underground structure for S-waves.

little less than 100 m, we could say the correlation between them is rather good. The correlation between electrical resistivity and N-value of the standard penetration test is also excellent. Comparing these with the geological section we found that the values were higher in the case of a sand layer and lower in the case of a clay layer, such tests being very sensitive to changes in geology. Now those who attempt to obtain a simple relation between N-values and S velocities may imagine that the clay layer from 4 m to 14 m is a low velocity layer, because of a sudden decrease of N-values in this layer. However, no such indication was found from the insitu measurements. This suggests that the relations between these values are not so simple.

The discontinuity of N-values at 30 m depth stands for the plane of unconformity between alluvial and diluvial deposits. This boundary is also clearly indicated from our measurements.

3. Concluding remarks

Through these preliminary experiments, the seismic source with the iron pipe is proved to be effective for producing the directivity of the force and hence for generating the SV-waves. We found, however, the strength of the iron pipe used in this experiment was insufficient for bigger charges. Stronger pipes should be used in future studies and through the experiments for various amounts of charges and improving observation methods we may possibly arrive at the optimum charge size providing the maximum amplitude ratio between S- and P-waves.

It is surprising that the SV-waves can so easily be generated by hitting the casing pipe vertically downwards with a hammer. Because the method is simple and practical a more quantitative study on this matter is indispensable.

4. Acknowledgements

The authors express their sincere thanks to Messrs Shibato, Hirasawa and Ito of the Geological Survey Institute for valuable suggestions and help during the study. The authors' thanks are also due Mr. Tanaka and his crew of Ube Industries Ltd. who helped the authors in the field. Finally, the authors acknowledge the assistance of Misses Hidaka and Uematsu in preparing this paper.

4. S 波の発生と伝播に関する実験的研究 II

SV 波発生の 2, 3 の試み

地震研究所 {太田　裕 / 嶋　悦三}

SV 波発生の 1 つの試みとして，孔井中に長さ 150 cm，直径 7.5 cm の鉄製パイプを挿入し，この中で少量の火薬爆発を行なった．地震計は地上展開を主とした．また鉄パイプを利用しない単純火薬爆発の結果との比較も行ない，両者の P:SV のエネルギー配分の違いを調べた．これらの結果から，この方式による SV 波発生方法は今後十分に検討する価値のあることが推察された．

一方，地表で簡単に SV 波を発生させる他の試みとして孔井保護に用いてあるケーシングパイプをカケヤ打ちし，これに伴なう波動を観測した．この際も SV 波は明瞭に観測された。

以上の結果によって得られた S 波速度分布は，前論文 SH 波からのものとよく一致した．

また各種物性試験の結果とも矛盾しない．