AN EASY-CAPABLE AND HIGH-PRECISE SHEAR WAVE MEASUREMENT BY MEANS OF THE STANDARD PENETRATION TEST

by

Noritoshi GOTO,[I)] Hiroshi KAGAMI,[II)] Keishi SHIONO[III)] and Yutaka OHTA[IV)]

ABSTRACT

An experiment was carried out to develop a new technique to measure shear wave velocity simultaneously with the standard penetration test. A three-component geophone was set on the ground surface near the borehole mouth and the generated waves were recorded for succesive depths of the penetration test. Signal amplitudes decrease with depths and go under the noise level at a certain depth. Sō, a simple process of stacking was employed by use of the advantage that the waveforms of signal events by N blows of the penetration at a depth are very similar. Shear wave velocities by this new method, N values by the standard penetration test and other soil indexes were compared. By this experiment it was clarified that an easy-capable and high-precise shear wave measurement can be introduced without any expert knowledge into the routine work together with the standard penetration test.

INTRODUCTION

The shear(S) wave velocity is one of the important characteristic indexes of soils. Especially in earthquake engineering it is indispensable because of its essential relationship to the dynamic behaviour of soil deposits during an earthquake. Many influential problems as design earthquake motions, soil-structure interaction, wave amplification and so on are next to impossible to be solved without knowledges about the S wave velocity of soils.

Recently studies of the in situ S wave velocity measurement have remarkably progressed and a lot of techniques have been presented [for example; Ohta(1968), Duke(1969), Murphy(1972)]. Nevertheless, the measurement itself is not widely spreaded. In the usual S wave measurement professional judgements are requested to carry out the field operation. If a handy field operation to which no specialist is needed is introduced to the S wave field survey, a wide popularization of the measurement will be surely expected.

In this study a new method for the in situ measurement by which the S wave velocity is obtained simultaneously with a standard penetration test is proposed. The standard penetration test is widely employed today in soil engineering and is usually performed together with boring survey for constructions.

METHOD AND MEASUREMENT

On the occasion of the standard penetration test, elastic waves are generated at the bottom of a borehole by an impact to drive a sampler. If they are recorded at the ground surface, S wave velocities in depths can

---

I),II) Research associate, Faculty of Engineering, Hokkaido University, Sapporo, 060 Japan, III) Graduate student, ditto, IV) Professor, ditto.

be obtained through a travel time analysis between the bottom and surface. A schematic view of the field measurement is shown in Fig.1.

The standard penetration test, which is widely employed in soil engineering because of its simplicity but of its usefulness is performed by a drop of a weight [for detail; Terzaghi and Peck (1967)]. The weight blows the knocking head that is fixed at the rod in order to receive the falling weight, and the sampler is driven into the borehole bottom. The weight is of 63.5 kg and falls freely 76 cm to the knocking head. The number of blows that is required to drive the sampler into the ground by 30 cm, is called N value and is known as a useful index to bearing characteristics of soil. The penetration test is usually carried out with a certain interval, for example each 1 m in depth.

The impact acting to the bottom of the borehole by the weight dropping generates several types of waves. Characteristics of the waves generated by this test are not self-evident, since the mechanism of the penetration seems very complicated. But a simplified interpretation of the event as a vertically acting point force in an unbounded elastic material may provide a fairly good approximation to wave generation.

The waves generated at the bottom of the borehole are detected by a geophone set at the ground surface. For travel time analysis the geophone is better to be located as close to the borehole mouth as possible. But in contrast with this, in order to avoid the engine noise from a drill rig and to make observations in the direction in which the SV wave radiates sufficiently, it is desired to set the geophone reasonably apart from the borehole mouth.

An experiment was carried out in the suburbs of Sapporo City, Japan, in December 1974. The S wave measurement was conducted simultaneously with the N value measurement which was performed down to the depth of 40 m at a 1 m interval. The whole observation system was composed of the conventional instruments. A set of three-component moving coil type geophones with a natural frequency of 28 cps, was installed on the ground surface with a distance of several meters from the borehole mouth. The damping constant of the geophone was 0.6 and the sensitivity was 0.06 volts/kine. A high frequency (100cps) geophone as a shot mark detector was attached to the guide rod for weight dropping at just below the knocking head. The outputs of the geophones were amplified by ready-made DC amplifiers, and then led to a four channels magnetic tape recorder. Gain adjustment of the amplifiers was easily made during the preparatory penetrations. The maximum amplification employed was about 1000.

For better recordings an attention to ambient noises should be paid. The most troublesome noise was one from the drill rig. The engine noise was a little more than twice of the microtremors at the experimental field. At the source depth of 10 m the signal was six times as large as the engine noise at the source depth of 20 m (Fig.2).

ANALYSIS

First, to examine the wave type the recorded traces at the source depth of 10 m was used. A particle orbit was made from the radial and vertical components and is shown in Fig.3. At the clear onset of the wave packet in the radial component, indicated by a thick arrow head, the particle motion dominant in the horizontal component. So, admitting that the wave path in nearly vertical, the main wave packet in the radial component can be identified as a phase of the primary S(SV) wave. A paste-up was made of the radial component traces, and is shown in Fig.4. The phase of the S wave is clear in the traces at the source depths of from 10 to 20 m, and no difficulty could be found in the interpretation of the S wave velocities. But in the traces at the source larger than 20 m in depth, the identification of the signals gradually becomes difficult and even impossible in cases of very deep sources. So, some technique of signal enhancement is preferable to be introduced for an accurate estimation of the velocity. In the field measurement described here, the number of the seismic records at one source depth are naturally the same to the N value there , since the S wave and N value are simultaneously measured. The easiest way of signal enhancement is to employ this advantage.

Seismic disturbances other than the signal in the traces may be composed of noises, that is, one derived from the engine of the drill rig, one generated during the falling down of the weight and the background noise(microtremors). The engine noise and the microtremors may possibly be as steady events, and the rest as a transient one. It is known that if N traces including steady noises are stacked the signal to noise ratio in the resultant trace is expected to be increased as $\sqrt{N}$ times of that of each individual trace [Klipsch(1936), Ishii(1974)]. This simple stack was applied to our records. The process for the signal enhancement was performed by making use of a digital stacker(8824,MARK RAND Ltd.,Japan). An outline of the flows is illustrated in Fig.5.

Fig.6 shows a process of the stack how the engine noise gradually reduces as the stack goes on. In the lower part the result of stacking for the records at the source depth of 35 m, in which the signal is very weak because of noises, is shown. As stack goes on, the S wave signal is enhanced gradually. The traces at every source depth were stacked and then a new paste-up was made as shown in Fig.7. In the paste-up shown in Fig.4 where no enhancement was done, the signals are not self-evident in general and are uneasy to be identified in the traces at sources deeper than 20 m. But in contrast with this there is no much difficulty in the new paste-up for identification of the S wave signals. The signal positions are indicated by solid circles in the figure.

An S wave velocity distribution was obtained through a travel time analysis of the paste-up made of the enhanced signal traces. S wave velocities of 165 m/sec at 6-9 m in depth, 341 m/sec at 9-19 m, 187 m/sec at 19-23 m, 252 m/sec at 23-32 m, and 542 m/sec at 32-40 m were obtained. In Fig.8 the S wave velocities are shown in columnar forms together with a geologic log, N values and specific resistivities measured in the concerned borehole. It is significant that the data obtained by independent methods are mutually very consistent. For example, there are low velocity strata with the S wave velocities of 187 m/sec and 252 m/sec, which are silt strata sandwitched in between upper and lower sands. Corresponding to this matter, N values in the low velocity strata are smaller than those in the upper and lower strata. The correspondency of N value to S wave velocity is a fairly established evidence in soil engineering [Ohta and Goto (1976)]. And still more the low specific resistivity suggests an existence of the clayey soils thus the low velocity strata. These could be seen as powerful evidences of preciseness of the S wave velocity measurement by the new method.

CONCLUDING REMARKS

In this paper an easy-capable and high-precise S wave velocity measurement is proposed. Through an experimental measurement it was confirmed that the newly developed method has a high possibility to practical uses.

Field operations of the new method are performed while accompanying with the standard penetration test. The operations are so simple that no special technique is necessary. All the preparations preceeding the test are; first, to put a suitable set of geophones on the ground surface near the borehole mouth and to attach a shot mark detector to the guide rod, and then to connect the outputs from two kinds of detectors to the data recorder. The field measurement of S wave is automatically followed if the standard penetration test is done under this consideration. This is why a wide popularization of the new method is expected.

Sometimes we may have the records disturbed by various kinds of noises, which will require to introduce some signal enhancement technique. The new method has a remarkable merit that the number of traces obtainable at each penetration depth is naturally the same to the N value. So, a superposition of these traces is preferable as a technique of signal enhancement, that is, for diminishing the steady noises as those produced by the drill rig and microtremors. But for transient noises as seismic waves inevitably generated at the penetration, no special effort is considered yet. Then the final paste-up is not necessarily perfect. Further refinements of data processing are desired.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks to Dr.S.Koyanagi for his devoted assistance in the experimental field. The authors are also greatly indebted to Miss R.Tsugawa for drafting and typing the manuscript.

REFERENCES

Duke,C.M.(1969), "Techniques for Field Measurement of Shear Wave Velocity in Soils", 4th World Conf. Earthq. Engg., Santiago, Chile, A-5, 39-54.

Ishii,Y.(1974), "On the Signal Enhancement for Civil Engineering", Geophys. Explor., 27, 16-27 (in Japanese).

Klipsch,P.W.(1936), "Some Aspects of Multiple Recording in Seismic Prospecting", Geophys., 1, 365-377.

Murphy,V.J.(1972), "Geophysical Engineering Investigation Techniques for Microzonation", Proc., Internat. Conf. Microzonation, Washington Univ., 131-159.

Ohta,Y.(1968), "Generation of S Waves and Their Applications", Special Issue, 20th Aniversary, Soc. Explor. Geophysicists, Japan, Geophys. Explor., 20, 227-242 (in Japanese).

Ohta,Y and N.Goto(1976), "Estimation of Shear Wave Velocity in Terms of Characteristic Indices of Soil" (in preparation).

Terzaghi,K. and R.B.Peck(1967), "Soil Mechanics in Engineering Practice", 2nd Ed., John Wiley & Sons Inc., New York, 729.

White,J.E.(1965), "Seismic Waves", McGraw-Hill Inc., New York, 214-217.

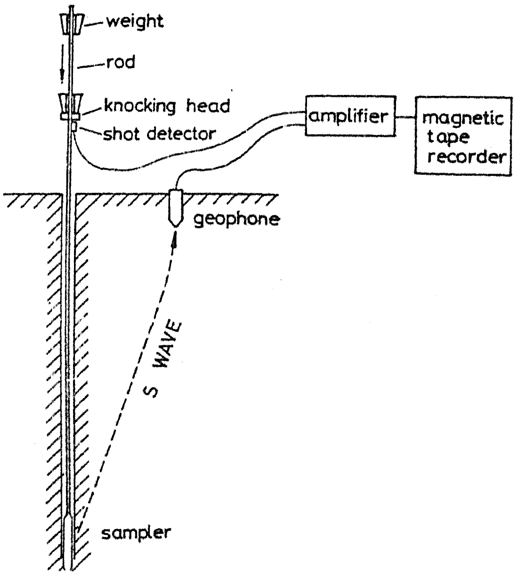

Fig.1 Schematic representation of simultaneous measurement of S wave velocity with standard penetration test. SV wave generated at the bottom of a borehole by a sampler penetration is detected on the ground surface near the borehole.

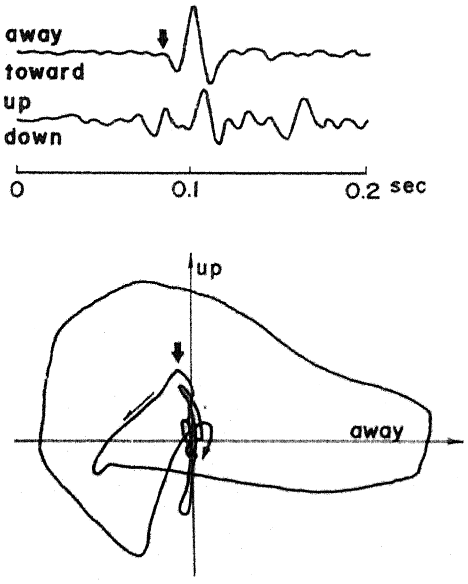

Fig.3 Onset of SV wave. At the clear onset of the wave packet in the radial component, indicated by a thick arrow head, the particle motion suddenly turnes its shape from the vertically polarized to the holizontally elongated.

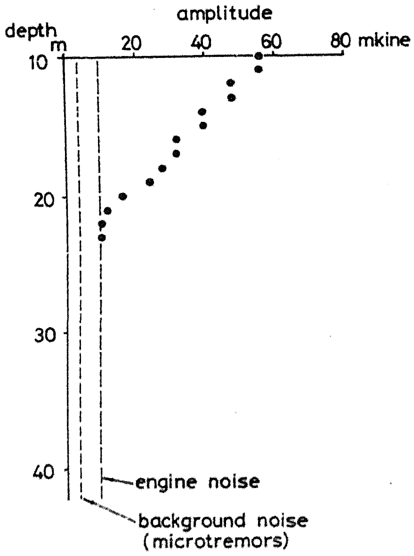

Fig.2 Change of signal amplitude with depth. Two broken lines show the average amplitudes of the engine noise from a drill rig and of background noise.

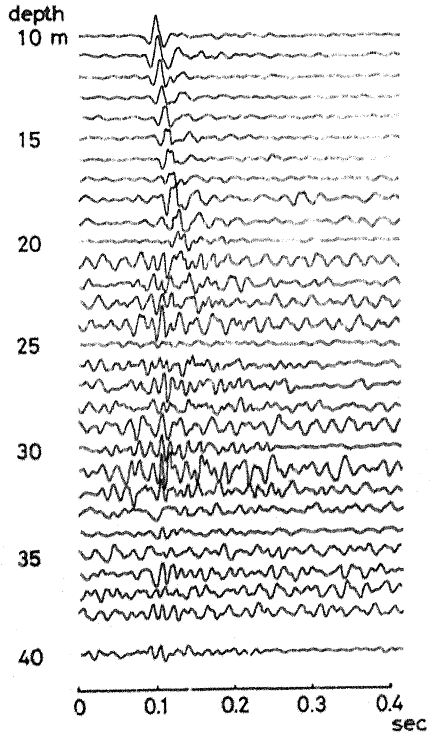

Fig.4 Paste-up of recorded traces with no refinement.

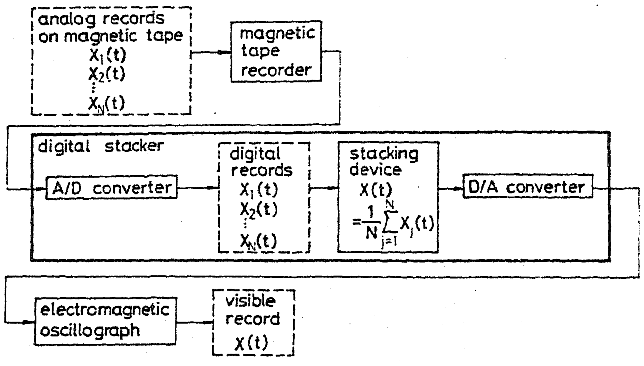

Fig.5 Flow chart of signal enhancement. A digital stacker is employed.

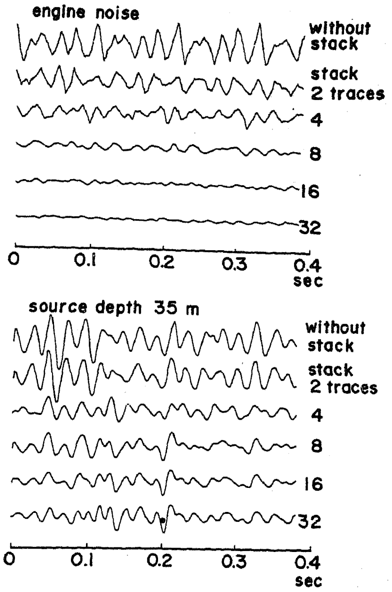

Fig.6 Effect of stacking on signal enhancement. Records of only engine noise are stacked (upper part). Records at the source depth of 35 m are stacked (lower part). The enhanced signal is indicated by solid circle.

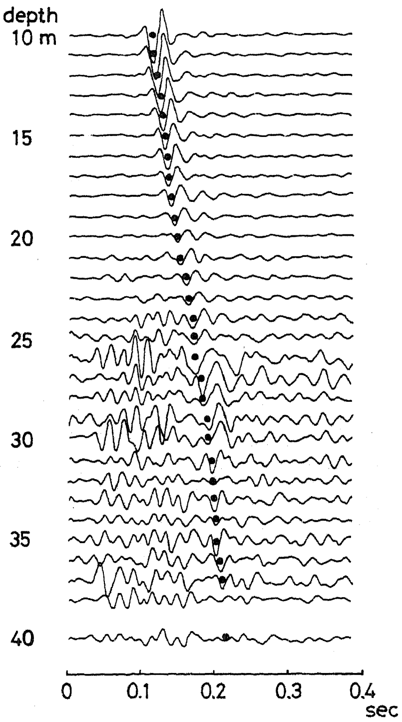

Fig.7 Paste-up of recorded traces with a simple stack. S wave signals are indicated by solid circles.

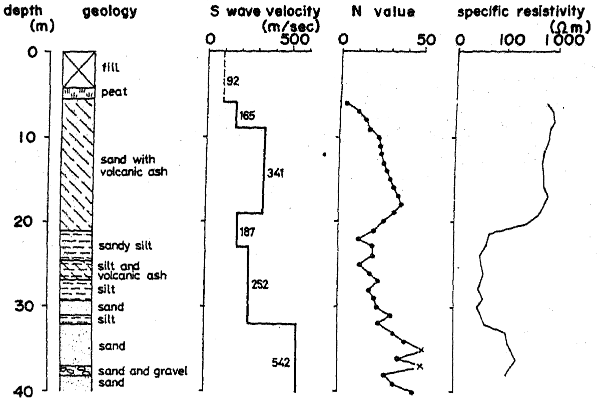

Fig.8 Distribution of S wave velocity together with geological log, N value, and specific resistivity. All the data obtained are mutually consistent.