HIGH FREQUENCY SEISMIC PROSPECTING

BY

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1. Introduction

At first, seismic prospecting was developed for oil explorations in America in 1920's. Since then it has contributed mainly to the oil exploration in many countries. In Japan the situation is somewhat different. The fields of mining and civil engineering have been also important for its application as well as the oil exploration, since the beginning of this technique in Japan in the 1930's. After the War seismic prospecting have extrodinarily developed, and has prevailed to be applied in many fields. Especially its recent spread in the fields of civil engineering is very remarkable.

However, there are severe restrictions regarding the application of conventional seismic prospecting for the new fields. Commonly, the place where it can be performed is on the surface of the earth, and the structure which can be explored is relatively simple and of large scale. Recently, with the development of civil and mining engineering fields, it has been expected for geophysicists to explore more minute and complicated structures, which can not be treated by the conventional conception. And then the places where the survey is required are not always on the surface of the earth.

The scale of the structures which may be explored by the seismic waves depends upon their wave length. In the case of conventional seismic prospecting, the frequency range of the waves is commonly 10~100 cps and the scale of the structures (usually, depth or thickness of the layer) which can be explored is more than ten meters in ordinary cases. If the exploration of more minute structures is required, the waves of the shorter wave length (high frequency) must be treated. In this study, "high frequency seismic prospecting", the waves of 100~3000 cps are treated.

The author has studied on this subject since 1956, suggested by Prof. K. Sassa. Two factors should be pointed out as the historical background of this study. In our laboratory conducted by Prof. K. Sassa, seismic prospecting has been studied as experiments of seismology since the beginning in our country and main efforts have been concentrated to exploration of special structures. Another factor is the experiment on explosion in rocks, carried out by S. Yoshikawa. In this experiment it was remarked that frequency of seismic waves generated by small explosion is very high and application of this waves for exploration of minute structures was tried by F. Toba before my study.

In this paper the outline of high frequency seismic prospecting is explained.

2. Generation of high frequency seismic waves and their attenuation

In rock areas, high frequency seismic waves can be easily generated by a small explosion. The attenuation of seismic waves grows with the increase of their frequency. The attenuation constant, however, is relatively low in rock, different from in soil. So the rock areas are adequate for practice of the high frequency seismic work. In this meaning, it is natural for this to be applied for the surveys under the ground.

Some remarkable characters can be pointed out regarding the feature of waves on the records obtained with careful technique under the ground. That is, surface waves are not commonly predominant and so S waves are distinctly observed as well as P waves. An example of the records is shown on Fig. 1.

The frequency of P wave generated by a small explosion, a single cap~100 g dynamite, is predominant in the range from 500 to 3000 cps on common rocks, and it depends upon the kinds and existing condition of the rock and upon the charge. The predominant frequency of S wave is lower than that of P wave, but it should be noted that they are nearly equal so far as wave length is concerned.

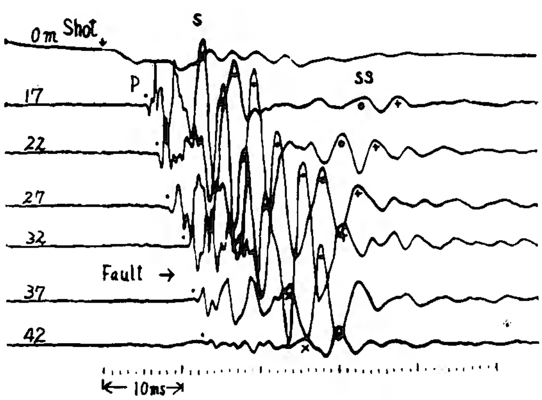

Fig. 1 An example of the records obtained at the seismic work in the drifts. The geophones and the shot hole were set in the same drift. The geophone spread (direct line) was crossed by a shear zone (fault) of 0.5~0.7 m thick at the position ca. 33 m far from the shot position. On this record S wave reflected from the shear zone (SS) is demonstrated together with direct waves (P and S).

In general, the predominant frequency of the waves (P and S) becomes higher, with the decrease of the charge and with the increase of the wave velocities of the rock. It is an interesting fact that their wave length, however, is not so considerably affected by the kinds and the condition of the rock on the same shot condition. The predominant wave length of the P wave is 2~1 m for a single cap, 3~6 m for dynamite of 10g, whose seismic effect (defined as the vibration amplitude on particle velocity record) is about 10 times of that of a single cap. There are not essentially difficult problems on the generation of the seismic waves. Usually, a single cap or a little quantum of dynamite is charged at the bottom of a hole (about 1 m deep), being tamped by clay or water.

The problem on the attenuation of the waves is serious for this work. The exact measurement of the attenuation is not so easy, because troublesome technique are required to observe the true wave form and to measure the vibration amplitude. Such technical difficulty increases especially in high frequency region. However, it is convenient that the measurement in this region can be done in short geophone spread. To discuss the matter physically, the attenuation of the waves must be determined as a function of the frequency. Such strict measurement is difficult to be done with the present technique in this region.

For convenience, attenuation constant is calculated as to the amplitude of the waves on seismic record (roughly particle velocity), on such assumption as $A=K(1/r^n)\ e^{-\alpha r}$, where A is amplitude at a position whose distance from the source is r; α is attenuation constant; K is a constant relating to the condition of the source; n is a constant ($=1$; experimentally determined).

The degree of attenuation is considerably affected by the kind and the condition of the rock. It is low in old and hard rocks having fine and tight texture. It seems that the values of the attenuation constant exists in the range 0.01~0.1/m for the P wave of 2~5 m wave length, in the case of common rocks, which contain a palaeozoic schist (0.01/m) and a tertiary sand stone (0.8/m).

It is an interesting problem for the application to civil engineering fields how the attenuation characters are affected by special structures, for example, shear zone. This subject is now being studied.

3. Instruments

The whole apparutus for this work consists of geophones, an amplifier unit, an electromagnetic recorder, a magnetic recorder (used some times), a power supplier, and connecting cables. The apparatus for the conventional seismic prospectings are designed mainly so as to record the waves of 10~100 cps. In some cases they are available for the observation up to ca. 300 cps by slight modifications on some characteristics, mainly on the speed of recording-paper. In order to conduct the work completely, essential modifications are necessary on the design of each instrument of the apparatus.

The problem on the geophone is the severest among them. Generally, geophones are used in the frequency range in which the mechanical motion can be analised as oscillation system having lumped elements. In this range there is a natural frequency. In the frequency range higher than that, there are many resonances of higher order, which obstruct normal observation of the waves. Natural frequency of the conventional geophones (commonly, moving coil type) is generally 7~30 cps. For example, in the case of commercial geophones, 14 cps, the secondary resonance appeared at the frequency of 700~1500 cps. The conventional geophone is not commonly adequate to be used for this work.

Generally speaking, it is desirable for the geophones of this work that their natural frequency is high and their internal mechanical construction are rigid. Piezoelectric type geophone is adequate as to these points, but it is not convenient for field works because its output impedance is too high. Moving coil type one is suitable for field works, but problems exist in its mechanical constructions and damping system. Electromagnetic system, which is commonly adopted conventionally, is not effective for high natural frequency. And hence oil damping system was adopted to the geophones (100 cps), which were designed by K. Koseki (Nihon Electric Company) specially for this study. There has never been any trouble as to resonances of higher order in field experiments in which these geophones are used, though more improvement is necessary for some characteristics.

It is not so difficult to design an amplifier unit for this work, because usual audio frequency techniques are available for this purpose. Strict caution must be given to avoid the noise induced by other channels, because the noise level becomes higher with the increase of the frequency.

The electromagnetic oscillograph is the most convenient of many recorders for this work, as in the case of conventional one. However, for this work it must be designed so as to have some special characteristics. That is, its paper speed should be fast and natural frequency of galvanometers should be high. Specifications of the electromagnetic oscillograph now being used is as follows: maximum paper speed, 6m; natural frequency of galvanometer, 5000 cps (oil damping); number of elements, 8 (of which 2 elements are used as time marker and shot marker). This is not so convenient for field work as to some points (operation, size and number of elements), and hence a more convenient recorder should be designed for this work.

Magnetic recorders have been tested in fields, together with the electromagnetic oscillograph, and some useful results were got, though they are not complete. The direct recording system, which consists of simple circuits and is used in the audio recorders, is adopted for them. Unstability of reproduced output level (short period) is the severest problem in this system. The modification systems, which are adopted in the conventional seismic prospecting, are excellent as to this problem, but its circuits are very complicated and the size of the recorder becomes too large to be used in drifts. A complete reproducible recorder should be designed for this work, since it is essentially useful for the exploration of structures that many features of wave propagation can be simultaneously discussed.

4. Fundamental problems on the field technique

Generally, the higher the frequency of the waves being treated are, the severer the noise problems become. Cautions should be taken against the noise induced in the cables, geophone-amplifier, by other channels or disturbing source. When the works are carried out on such humid places as drifts, noise generated by leakage of the cable is most troublesome.

Fix condition of geophones is essential problem for observation of the high frequency vibration. Geophone should be cemented to the rock to ensure the same vibration. Commonly there are many fissures on the surface rocks (or walls of drifts). The vibration on the surface rocks bounded by fissures is apt to be distorted, because the rocks have such a particular vibration mode as resonance. The such places should be avoided as geophone positions. Sometimes, in order to discuss especially on high frequency waves precisely, geophones were fixed in the bottom of drill holes, which were deep enough to avoid the effect of the surface rocks (1~2 m commonly). In connection with them, attention should be paid to the fact that elastic resonances generated by coupling of solid parts (for example; a geophone and the rock, a rock block bounded by fissures and other rock blocks) generally exist in the high frequency range treated in this work, and that elastic resonance of finite dimensional body itself, (for example, a rock block bounded by fissures) is also apt to exist in this range because the dimension is usually correspond to the wave length treated.

The cementation of geophones is so troublesome as to make this work difficult in some cases. Hence, special hydrophones (barium titanate ceramic) were used on some experiments instead of geophones. They were set in drill holes or bore holes, filled with water. The author believes that this is one of the useful and simple methods to detect the high frequency waves.

5. Some examples of the field experiments

The reflection method is important also in this technique for the exploration of the structures having relatively plane boundaries. Reflection wave *PP* (predominant frequency=1500 cps) from a pyrite vein of 50 cm thick was detected in the drift of the Makimine mine (mother rock; phyllite, $V_p=5$ km/s). Reflection wave

SS from a shear zone was detected in some cases. Exploration of shear zone by this wave may be useful in mine and civil engineering fields.

The high frequency seismic technique can be applied to determine velocity distribution in minute structures. In the Sazare mine, distribution and anisotropic character of wave velocities in rocks (schist) are measured by this technique.

It is an interesting problem in application of this technique to utilize bore holes positively as geophone spreads or shot positions. The bore holes filled with liquid are adequate for this work, because hydrophones can be used and waves are effectively generated by explosions in this condition. By surveys of such type useful informations may be got on the region where the bore holes have never reached. Some fundamental experiments on this problem were carried out by the author. Water waves (tube waves) are very predominant in bore holes and sometimes mask useful phases later than first kick. In order to push forward this study, the obstructive effect of these waves should be rejected. It was revealed that some predominant phases of them are generated at shear zone (filled with water) when *P* waves reach there. This phenomenon may be utilized to detect the zones filled with water and their physical properties.

6. Result

" High frequency seismic prospecting " is the new field of the seismic prospecting. By this technique, the special structures (more minute and complex) can be explored. The fundamental studies on the high frequency seismic waves have been carried out by the author. The particular experimental techniques are required for this purpose and the new instruments have been developed by the author.

The utility of this technique is proved by those studies. The more improvements of the instruments are an important problem for the development in the practical fields (the mine and civil engineering fields). This work is commonly carried out under the ground (in the drift). For this reason, the practical application of the wave theory may be more advanced than in the case of the conventional method.

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