Shallow Reflection Seismics Using Firecracker as the Source, I: Firecracker

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ABSTRACT

We have designed a tool that uses firecrackers as the source for shallow seismic study. The performance of this instrument was evaluated by conducting noise test experiments comparing three different sources, at the NCU campus. Adequate high frequency, high quality signals were generated. Except for a slightly lower energy level, the firecracker source has many interesting features as distinct from other sources. It was found to be able to produce signals of high frequency and to be efficient, portable, cheap and safe. Especially, as firecrackers are obtained easily from local stores, the utilization of a firecracker source may circumvent complex government regulations and open opportunities for further development. All these benefits make the firecracker a convenient source worth introducing to the scientists in this country who are interested in the shallow seismic methods.

The firecracker is an explosive with a very small charge. In this paper, we will describe the detailed designation and operation procedures for this new tool and also examine its properties and application limitations. Finally, a CDP seismic section is presented as a demonstration. If the background noise is not too high, the firecracker will be a useful source for shallow seismic surveys including both the reflection and the refraction methods.

1. INTRODUCTION

Over the last decade there have been large improvements of seismic instruments which are used to study shallow structures. The new generation of engineering seismic seismographs have much lower prices, but more powerful functions than before due to the assistance of modern computers. The recording system of the new instruments is already able to accept a broad band of signals which gives data at higher frequencies and thus of higher resolution.

All these developments necessitate a powerful source able to generate high frequency signals.

Conventionally, the sledge hammer has been used as a cheap, portable, and nondestructive source, especially for refraction surveys (Singh, 1983). The signals produced by a sledge hammer, however, do not contain sufficient high frequencies for shallow seismic reflection purposes. Its repeatability and energy level are also too low. An explosive source is another alternative if large energy is desired, but explosive sources have many disadvantages such as environmental damages, the high cost of caps and dynamite, and the troublesomeness caused by strict laws for the purchase, transportation, and storage of dynamite. In Taiwan, the difficulties of application for permission to work with explosives may have discouraged the wide use of this dangerous source.

Some impact sources such as Dynasource or Primary source, could be a feasible choice if there are roads giving access to the survey area. However, transportation of this equipment over long distances or on inadequate road may become a nightmare. In the difficult areas where seismic methods are frequently applied, this kind of source has only limited use.

Another shallow seismic source widely used in the United States is a shotgun or rifle fired into the ground as described by Miller *et al.* (1986). There is much excellent research (Steeples and Knapp, 1982; Seeber and Steeples, 1986) done using guns as a source. But the use of shotguns has serious problems. They are difficult to purchase and to licence under the strict laws in many countries. Pullan and MacAulay (1987) have designed a buffalo gun (prototype of Batsy gun) used for shallow seismic study. This Batsy gun has been modified to be an instrument. However its use is still out of question in Taiwan.

When choosing alternate shallow seismic sources, we have to consider some special features the source should possess. These include its energy level, frequency content and wavelet signals as well as its portability, cost, availability to the site, repeatability, cycle time between shots, damage to environment, and safety. Miller *et al.* (1986) has tested 15 different shallow seismic sources in the field and made some interesting comparisons. For this paper, we could only afford three kinds of source: Dynasource, sledge hammer and firecracker. We conducted an experiment similar to Miller's. The study concentrated on comparisons of energy released, frequency content, cost, and signal quality. The purpose was to find out the properties of a firecracker source. These properties could then be given as the conditions under which the firecracker source works properly.

2. FIRECRACKER SOURCE

The firing rod design for a firecracker source is shown in Fig. 1. It is com-

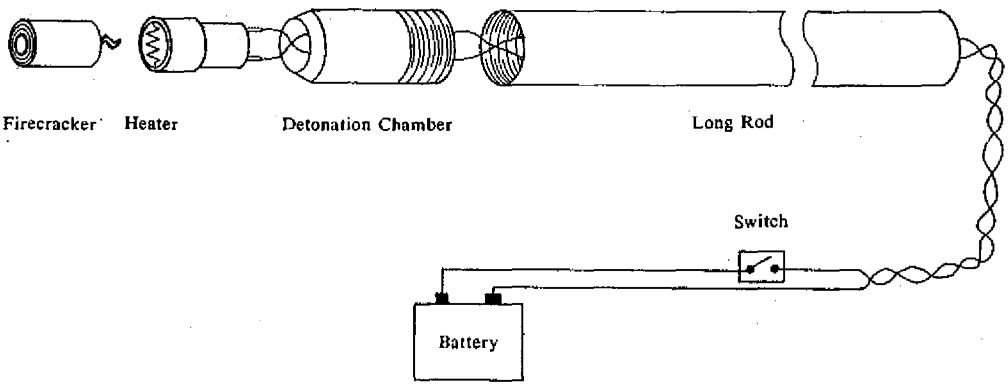


Fig. 1. Schematic diagram of the design of the firecracker source.

posed of two parts: the detonation chamber and a long rod. The rod is made of stainless steel which has a diameter of 2.54 *cm* and a length of 1 *m*. Its total weight is about 1.5 *kg*. The detonation chamber is screwed onto one end of the rod. Inside the detonation chamber, there is a heater based on an isolator. The heater is composed of an electric-resistance wire which is connected to a 12v battery, and the isolator is made of synthetic electric wood which can withstand explosions for over 50 times. The 12v battery is used to warm up the heater which then ignites the firecracker in the chamber. A hammer switch is attached directly to the rod to trigger the seismograph when the firecracker explodes. The weight of the whole device including the battery is less than 5 *kg*. It is quite easy to operate.

During the field work, we first need to prepare a small hole in the ground for the firing rod to plug into. In most cases, it is about 50 *cm* in depth. If the hole is filled with water to increase the efficiency of explosion energy release, a PE bag is used to wrap the detonation chamber to prevent it from getting wet. The ignition is set by closing the electric circuit to heat the detonation chamber. Only a very small sound escaped during the explosion due to the burial of the firecracker. This is also useful to reduce groundroll generation. A cooling process is necessary after each firecracker ignition or failed shot. It needs to clean and cool down the detonation chamber completely before the next firecracker is put in. Flushing the detonation chamber with compressed air is frequently used for this purpose. We also designed a firecracker insertion device which helps to insert the firecracker directly into the chamber without touching by hand. This is done for security. The recycle time for each firecracker detonation is about 40 *seconds*. On the average, 3 to 5 *fires* are taken at each shot location.

The most attractive features of this device are its light weight, compactness and portability. It works almost anywhere regardless of the topography, traffic or human interference. Another important benefit of the firecracker is its ease to build and to purchase in Taiwan. It can also be a very convenient source to use in urban areas where the use of a large source is prohibited.

3. FIELD PROCEDURES

We selected a test site at the National Central University campus to do the field experiment. The study area is quite flat and only with limited traffic. A Geometric ES-2401 digital-enhanced recording system was used to collect the seismic data. The seismograph is set for a recording length of 512 *msec* at intervals of 0.5 *msec*. None of filters was applied during recording. This recording system has an instantaneous floating A/D converter with 15 significant bits (including the sign bit), hence it has enough dynamic range for the test with a large noise-to-signal ratio. The job was carried out using twenty-four OYO 100 *Hz* geophones. They were firmly planted in the ground at 2 *metre* geophone intervals and were not disturbed during the test. The geophone set was moved a spread length once, which makes a total profile having 48 channels ranging from 2 *m* up to 96 *m*.

The sources used in the experiment were

(1) A Dynasource with a vacuum pressure of 30 $ib\ inch^{-2}$.

(2) A 9.125 *kg* sledge hammer with a steel plate.

(3) A firecracker source which is placed in a hole filled with water.

The Dynasource was stacked 3 times while the firecracker source as well as the hammer were stacked 6 times for each test. The data which were originally stored on 3.5 *inch* floppy disk were later transferred to a HP9000/835S workstation for data processing and display. A CDP data processing software called the Shallow Seismic System (SSS) has been set up recently by our research group at this HP workstation (Wang, *et al.*, 1991a). We can modify the program to treat any kind of seismic data without much difficulty. Another accompanied paper (Wang, *et al.*, 1991b) will describe the processing functions of this system for data collected using firecracker sources.

4. EXPERIMENTAL RESULTS

The original data for the source comparison experiment are shown in Fig. 2. The sections in this figure have been trace balanced using an automatic gain control (AGC) with a window length of 100 *msec*. The weak reflection events have been magnified sufficiently. Figs. 2a, 2b and 2c correspond to the signals generated by the Dynasource, the sledge hammer and the firecracker,

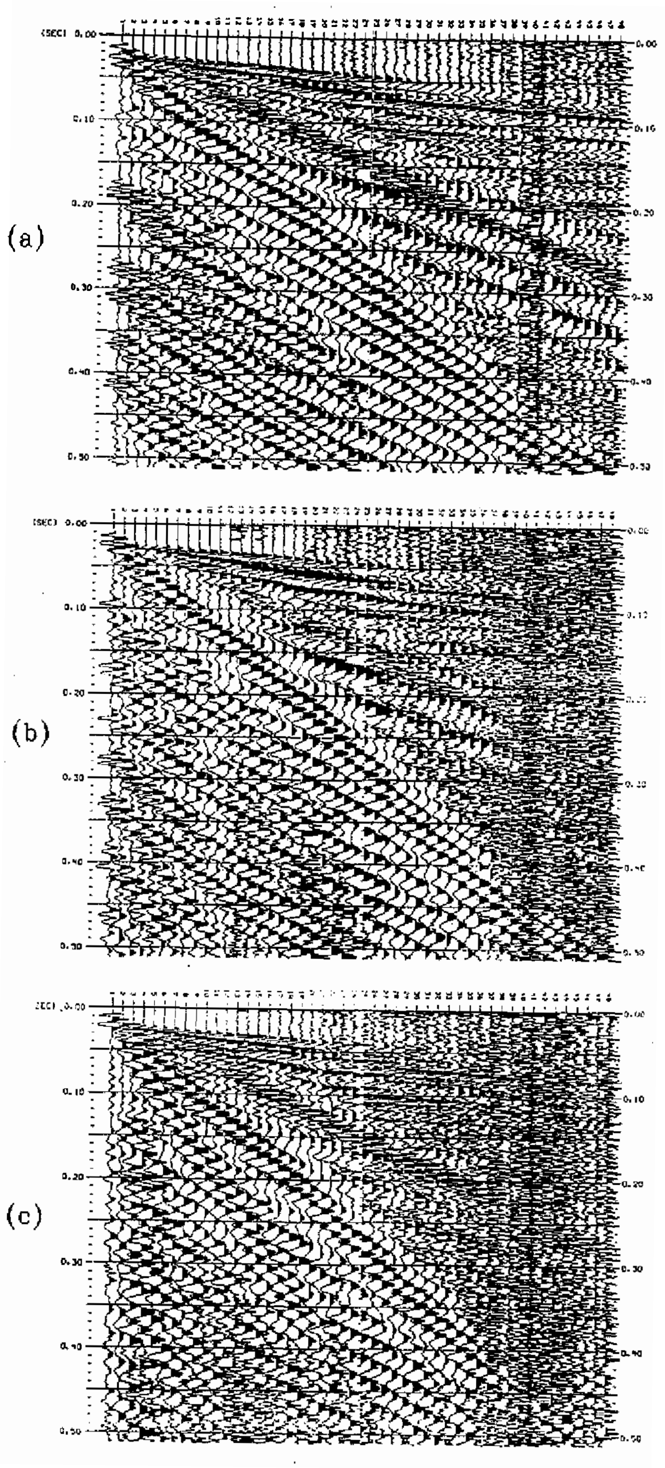


Fig. 2. Original seismic records of noise tests which are displayed after 100 milliseconds AGC. The seismic data were produced by (a) Dynasource, (b) sledge hammer, (c) firecracker source.

respectively. We can see different types of strong noises sweeping across most parts of the section. The noises include air-coupled waves (apparent velocity 350 $m\ sec^{-1}$), air-wave generated groundroll (just below air-coupled wave), source generated groundroll (apparent velocity smaller than 250 $m\ sec^{-1}$) and diffractions(visible at the near-source traces). Some high frequency random noises are obvious on the far traces. The reflection events are restricted to the upper right-hand corner just before the air-coupled wave arrivals, as seen in Fig. 2. This corner has been defined as the 'optimum window' by Hunter *et al.* (1984).

Supposing that the amplitude of the random noise were equivalent during the test, we found that the largest magnitude of energy is produced by the Dynasource, and the minimum from the sledge hammer. The firecracker source generates the least groundroll among the three. This might reflect the fact that the firecracker is placed under the ground. It was also found by examining the reflection event at about 100 *msec* that the wavelet created by the firecracker source was sharpest among the three sources. Fig. 3 describes the frequency-wavenumber (f-k) analysis and the frequency response of the sections in Fig. 2. The f-k analysis provides another way to examine the data distribution. The straight lines plotted on the f-k diagrams are constant velocity lines which have velocities from 500 $m\ sec^{-1}$ to 4000 $m\ sec^{-1}$ increasing by 500 $m\ sec^{-1}$ The stronger energy is represented by the darker gray scale in each diagram. In this figure, a low velocity (about 250 $m\ sec^{-1}$), low frequency (about 50 Hz), but high amplitude groundroll is extremely obvious. The air-wave which has an apparent velocity of about 350 $m\ sec^{-1}$ lines up across the whole f-k diagram (the negative wavenumber part should move to the right side of the positive wavenumber due to the folding of Fourier transform). This stands for the wide frequency band that the air-coupled wave possesses (Knapp, 1986). The reflection energy is mainly located between velocity lines of 1000 $m\ sec^{-1}$ and 2000 $m\ sec^{-1}$. The firecracker source has a broader frequency band content of reflection energy than the other sources.

To express the reflection signals more clearly, we further performed a series processing to the data collected in the field. For consistency, we have used the same parameters and the same sequences for all three cases in Fig. 2. These processing procedures include air-wave suppression, 80 Hz to 250 Hz bandpass filtering, dip filtering with a pass band from 500 $m\ sec^{-1}$ to infinity, 80 Hz to 250 Hz bandpass filtering again, and finally a 100 *msec* AGC. The results are shown in Fig. 4. The reflection waveforms become apparent after processing for all three sections. There are strong events aligned in the upper portion of Fig. 4a generated by the Dynasource. However, a deep event around 350 *msec* stands out in Fig. 4c which is from the firecracker source. Some residual groundroll effect is still left in Fig. 4b which is the one with the lowest signal-

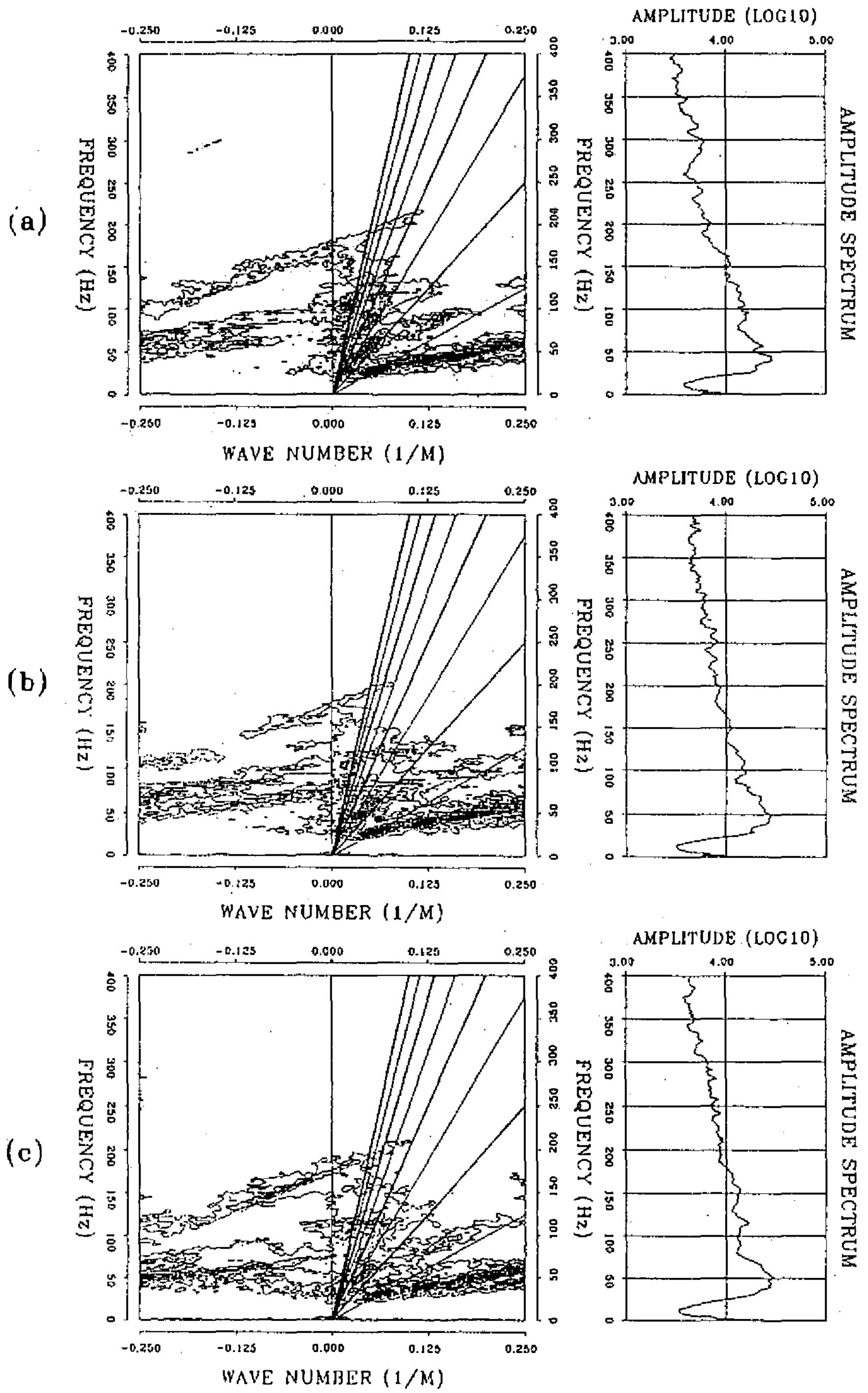


Fig. 3. The f-k analysis of the records shown in *Fig.* 2 . (a) is for signals generated by Dynasource, (b) hammer, (c) firecracker. The left-hand parts are f-k diagrams. The right-hand parts are their amplitude spectra. The lines drawn on the f-k diagram indicate the apparent velocities from 500 $m\ sec^{-1}$ to 4000 $m\ sec^{-1}$ with an increment of 500 $m\ sec^{-1}$ each time.

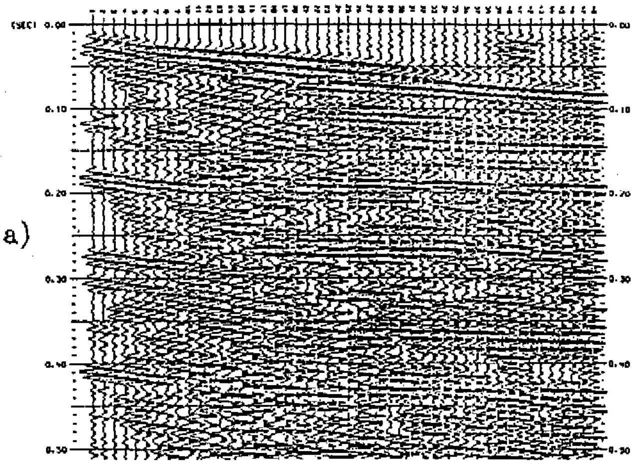
to-noise ratio. The f-k analysis of these sections is illustrated in Fig. 5. More detailed information for data distribution can be obtained after comparing this figure with that before the data processing shown in Fig. 3. Most groundrolls are removed, but the air-coupled waves are still there especially as seen in Figs. 5a and 5b which happen to be of high frequencies (above 200 Hz). An examination of frequency response curves reveals that the firecracker source has the flattest amplitude spectrum between 100 Hz and 200 Hz (Fig. 5c). This gave the records produced by the firecracker source more resolution power.

An especially interesting characteristic of the test records is that there are some unknown coherent signals in the first 10 traces (see Fig. 2 and also Fig. 4). They have lower apparent velocities than the reflection signals. We have scanned the whole figure and found that these signals have some relationship to the reflection events. They are probably reflection signals trapped in the top low-velocity layer. If this is true, the use of near offsets to detect shallow reflectors could be an error. They have the wrong moveout velocities. However, this supposition needs to be verified by further study.

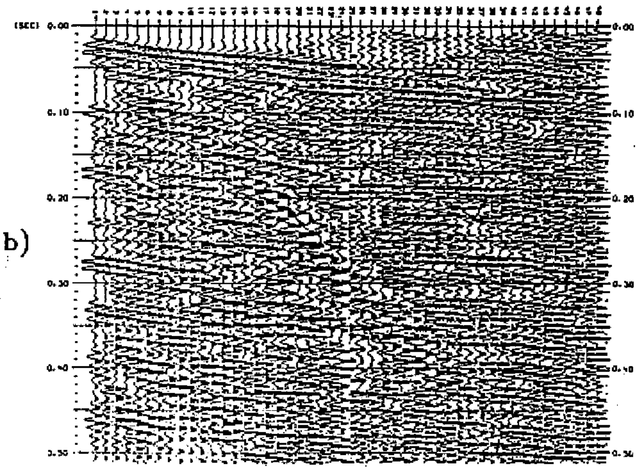
Table 1: Field Parameters Used for NCU Seismic Line.

layout	end-on spread, station interval = 2 m, near-trace-offset = 30 m, far-trace-offset = 76 m, fold = 12.
receiver	OYO 100Hz geophone, one geophone per station.
source	firecracker in 40 cm hole, filled with water, avg. 4 shots/station.
recording	pre-emphasis low cut filter = 100 Hz, sampling interval = 0.2 ms, recording length = 204.8 ms.

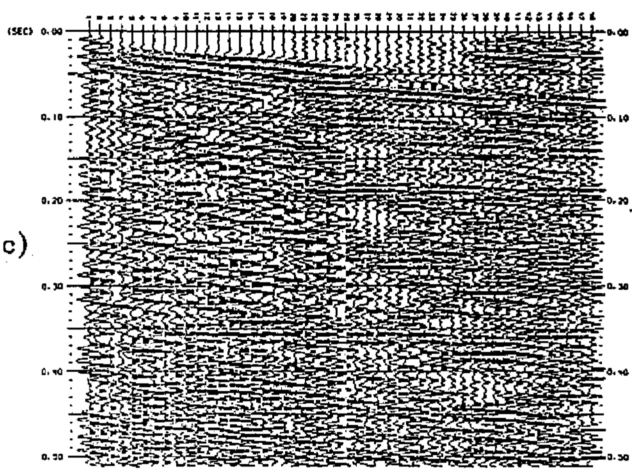
A complete CDP profiling has also been conducted along the same line that the noise test experiment took. Fig. 6 shows the final result. This job was carried out by using a firecracker source, 100 Hz geophones, and 12 fold survey geometry. This test served to check the field data acquisition parameters determined from the above noise test. These acquisition parameters are listed in Table 1. Several strong reflection events are delineated in the stacked section as those predicted from the noise test. The three parts of Fig. 6 present the results from different stacking processes. Fig. 6a is produced by conventional stacking, 6b by weighted stacking with an enhancement mode, and 6c by weighted stacking with an extraction mode. The weighted stacking uses



(a)



(b)



(c)

Fig. 4. The seismic section corresponds to *Fig.* 2 after data processing. Seismic traces were produced by (a) Dynasource, (b) sledge hammer, (c) firecracker source.

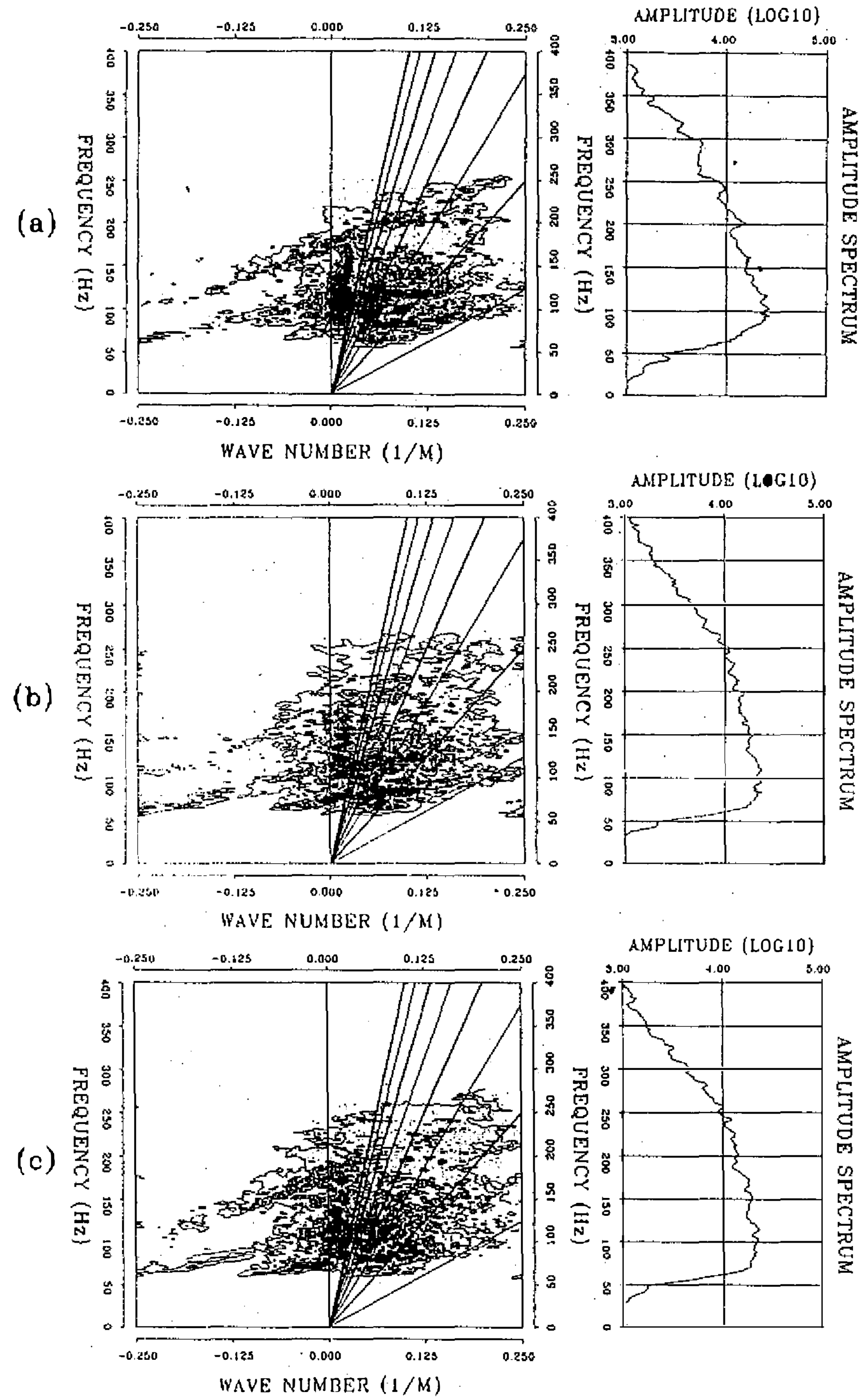


Fig. 5. The f-k analysis of the records shown in *Fig.* 4 . The signals are generated by (a) Dynasource, (b) sledge hammer, (c) firecracker. The left-hand parts are f-k diagrams. The right-hand parts are their amplitude spectra.

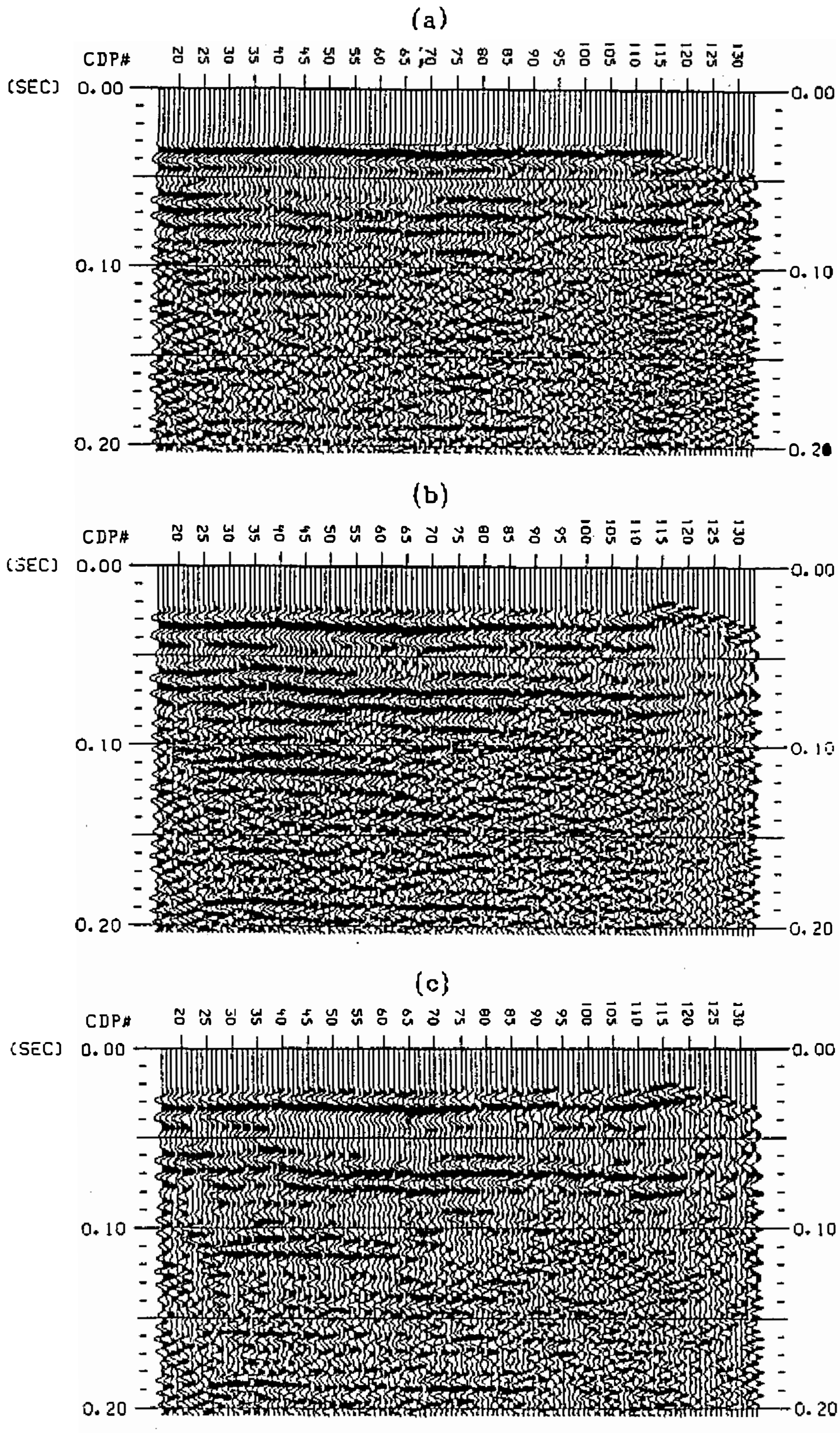


Fig. 6. The CDP seismic section along the same profile where the noise tests in *Fig.* 2 through *Fig.* 5 were carried out. The section is generated by using the firecracker as the source. (a), (b), and (c) are sections due to different processing steps. See the detailed explanation in the text.

Simpson's algorithm to measure the signal-to-noise ratio in each CDP gather which is then converted to a weighting number to increase (enhancement mode) or reject (extraction mode) the data in the stacked trace (Quincy and Tomich, 1987). The contrast of the event's presentation increases from 6a to 6c. Fig. 6c is actually the section in which only the signals having great coherency are reserved. We obtain different degrees of confidence concerning continuity of the events after comparing the three sections of Fig. 6. Nevertheless, the quality of these sections is quite good and may provide as an indication of the feasibility of firecracker as a source.

5. DISCUSSION

The firecracker source is very low priced as compared to other sources. The firing device costs about NT$ 2000 (US$ 70) and the firecracker, which is much cheaper than a gun shell, is about NT$1 each. Besides this, its portability and operational convenience make the source extremely useful for most shallow reflection purposes. But there are still some problems. We have found that the amount of explosive in each firecracker varies from 0.2 *gm* to 0.8 *gm* unless the quality is controlled. We ought to be careful during field work that each shot record is examined before putting it into the buffer. Since the energy of a firecracker is small, the background noise from the environment should be lower compared to that for the Dynasource. However, these restrictions are not too serious. The stacked section presented in Fig. 6 gives us confidence to continue using the firecracker as a shallow seismic source.

We have found that one reason for the good performance of a firecracker is that it is fired below the surface. The energy is easier to transmit into the ground instead of wasting its force in the air, especially when using a hole filled with water. Hunter *et al.* (1984) has pointed out that water helps generate high frequency and high quality seismic data. We have come to the same conclusion from our own field tests. As a small explosive, the firecracker behaves quite similarly to those used for large scale oil exploration. The shothole is always dampened in regular seismic surveys as it should be when using firecrackers. This 'small source' conception may indicate that firecracker's use should be improved in the same manner as larger explosives had ever used in oil exploration.

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爆竹震源淺層反射震測
第一部分　爆竹震源

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摘　　要

本研究主要討論以爆竹震源做爲淺層震源的問題。經比較三種不同震源在雜波測試中之結果，我們發現爆竹震源具有許多優越的特性，包括能產生高頻信號、效率高、容易攜帶、價廉及安全。尤其重要的，爆竹震源很容易製造，使用也在法律許可的範圍內。

爆竹震源可視爲一種小型炸藥。本文中，我們將詳細介紹此震源之設計及操作程序。並且討論其特性限制，以做爲使用時的參考。爆竹震源是一極佳的震源，不管反射或折射震測，都可加以應用。