

## Toward the autojuggie: Planting 72 geophones in 2 sec

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**Abstract.** Shallow seismic reflection surveys require dense spatial wave-field sampling, contributing to their high cost. To assess the feasibility of planting geophones automatically, we planted 72 geophones in approximately 2 s in a test line, using an 11-m-wide farm tillage tool as a planting device. Geophones were attached rigidly, at 15 cm intervals, to five pieces of heavy-duty channel iron bolted to the tillage-tool frame. Conventional comparison-line data collected about 75 cm away, parallel to the test line, were visually comparable with the seismic source 12 m distant. When the sources were placed 1 m from the geophones, a surface-wave mode was excited by the channel iron and detected by geophones in both lines. This mode exhibited a different phase velocity than that of the desired seismic body-waves and could be attenuated by frequency-wavenumber filtering. These results suggest that automatic geophone placement is feasible and could decrease shallow seismic surveying costs.

### Introduction

Shallow seismic reflection methods sometimes can be applied to near-surface geological problems at depths of 10 m or less (Pakiser and Warrick 1956, Birkelo et al., 1987; Baker et al., 1999). However, when working with seismic reflections at such shallow depths, the cost of planting geophones becomes a significant factor because dense spatial sampling of the wavefield is required. If a cost-effective apparatus capable of rapidly and automatically planting large numbers of closely spaced geophones were to become available, shallow seismic reflection techniques could be used more often at depths of less than 10 m as a complement to ground-penetrating radar (GPR), particularly in situations in which GPR does not work well, such as those involving clay-rich soils, or when a broader range of depths is to be imaged.

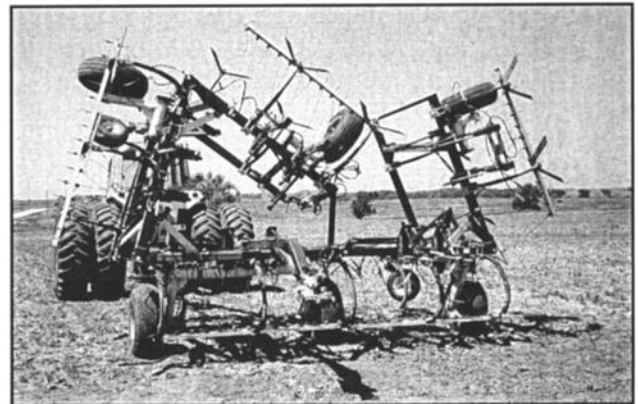
The experiments described here are a continuation of work first discussed in Steeples et al. (1998), in which geophones were rigidly attached at 5-cm intervals to a board 0.7 m long. Those experiments showed that attaching several geophones to a board was not significantly detrimental to the quality of the seismic data acquired.

In the present experiments, we examined the feasibility of developing a fast, cost-effective method of deploying dozens to hundreds of closely spaced geophones for use in shallow seismic surveys. For these tests, 72 geophones were bolted rigidly at 15-cm intervals to five pieces of heavy-duty ~9 cm by 3 cm channel iron each about 2.2 m long [Figure 1(a and b); Figure 2(a)]. These were bolted tightly to the frame of an 11-m-wide farm tillage tool referred to as a plow.

Tests were designed to determine whether 72 geophones could be planted in a matter of seconds while maintaining good coupling to the ground and ensuring minimal interference between the geophones. We found that the level of interference caused by connecting the geophones to a single rigid medium was dependent upon the distance from the seismic source to the geophones and, to some degree, upon the amount of energy produced by the source.

### Field Experiments

Experimental data were collected in a plowed field near Palco, Kansas, when the soil was relatively dry. A silty-loam soil derived from loess overlies the sandy, partially consolidated sediments of the Tertiary-aged Ogallala formation, which



(a)



(b)

**Figure 1.** (a) Folded plow, ready for transport. Channel iron welded to V-shaped blades can be seen at top right. (b) Plow ready for automatic geophone planting. Channel iron with geophones attached can be seen in foreground as a white line running from left to right.

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(a)



(b)

**Figure 2.** View (a) from one end of plow. Channel iron (white) with geophones and wiring attached runs from lower right to just above center of photo. (b) Plow with test-line geophones planted in the ground under the rear of the plow. Comparison-line geophones with normal plants are about 75 cm to the right of the test line.

is about 20 m thick in this area, overlying Cretaceous-aged Niobrara chalk bedrock.

Two parallel lines, referred to here as the "test line" and the "comparison line," were positioned about 75 cm apart, each consisting of 72 geophones with intervals of 15 cm [Figure 2(a) and (b)]. On the test line, all of the geophones were planted mechanically within approximately 2 s using the plow. The geophones in this experiment were attached rigidly to the channel iron, which was bolted tightly to the frame of the plow, as outlined in the next section. Comparison-line data were collected using traditional methods to plant 72 geophones in a line parallel to the test line [Figure 2(b)].

The comparison line served as an experimental control to ascertain the effects that bolting geophones to a long, rigid medium might have on the geophone plants and thus on the recorded data.

On each of the lines, Mark Products L-40A, 100-Hz geophones were positioned at intervals of 15 cm and equipped with spikes 12.5 cm long. Data on the comparison line were recorded with a Bison 24096 seismograph, whereas data on the test line were recorded with a Geometrics Strataview seismograph. Both seismographs have 24-bit A/D conversion, and our previous (unpublished) tests have demonstrated that the difference in recorded data between the two is negligible.

**Attachment of test-line geophones.** In the test line, each of the 72 geophones was screwed into a 9.5-mm (3/8-in) NF-threaded nut welded to the head of an NF-threaded bolt 3 cm long and 9.5 mm in diameter. The bolts were inserted downward into the channel iron through 9.5-mm drillholes and fastened with 9.5-mm NF-threaded nuts. Geophone spikes 12.5 cm long then were screwed onto the ends of the bolts. The channel iron was welded to tillage shovels bolted to the framework of the plow, and the plow was towed by a large farm tractor that provided the hydraulic power necessary to raise and lower the apparatus. When a single hydraulic-control lever in the tractor cab was depressed for about 2 s, all 72 geophones were planted in the test line simultaneously.

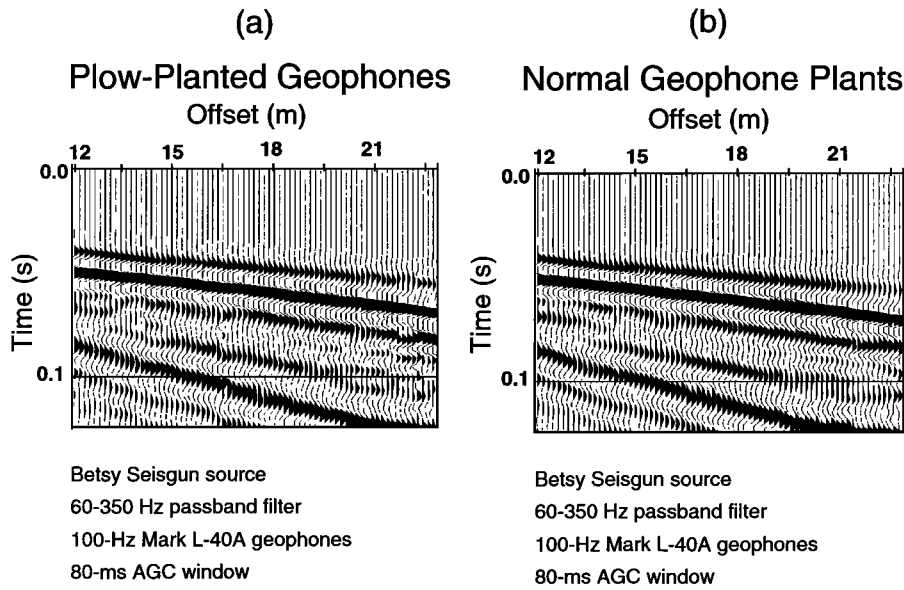
## Experimental Data

Having constructed the geophone-planting device, we then designed a simple experiment to determine the measurable effects of planting the geophones automatically. A series of tests was performed simultaneously on the test line and the comparison line to compare the recorded wave fields for the two geophone lines. The data contained direct waves, refractions, surface waves, and noise (no reflections were visible).

Sources tested included a 1-kg sledge hammer and an 8-gauge Betsy Seisgun™ with 3-oz lead slugs (further described in Miller et al., 1986). The geophone configuration depicted in Figure 2(b) remained fixed as each source was moved away progressively, in 10.8-m increments, from one end of each geophone line. Data were recorded simultaneously on the two lines to remove source variations from our data comparisons.

Figure 3 presents Betsy Seisgun™ data showing the relative equivalence of the two data sets. In this figure, the effect on the first-arrival body waves of bolting the geophones rigidly to the channel iron is negligible. In fact, even subtle changes in the first-arrival amplitude and waveform are preserved, such as that visible at 15-m offset in both parts of Figure 3. Some minor differences in the waveforms that appear at later times may be related to the interference phenomena discussed next.

When the hammer source was placed within 1 m of the geophones, the stronger ground motion that developed near the geophones appears to have stimulated at least one wave mode in the channel iron. This interference was then picked up by the attached geophones [Figure 4(a)]. A wave mode with the same velocity characteristics also was found in the geophones at the far offsets on the comparison line [Figure 4(b)]. Although the source of the interfering mode remains unknown, it has a phase velocity very near that of ground roll, and it couples through the ground from the test line to the comparison line. The velocity of this unidentified wave mode is at least an order of magnitude too small to be a *P*-wave traveling horizontally within the channel iron. That this



**Figure 3.** Seismogram from (a) test line (plow-planted geophones) and (b) comparison line (normal geophone plants), recorded from the same shot from an 8-gauge Betsy Seisgun. Even subtle, offset-dependent changes in the first-arrival *P*-waves are similar in the two records, as can be seen at offsets of about 15 m.

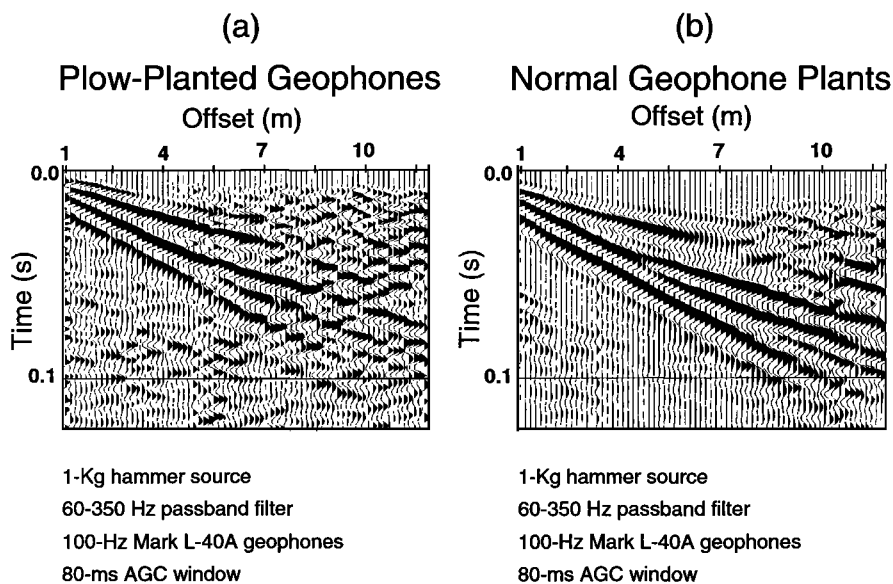
interfering mode couples to the geophones on the comparison line 75 cm away suggests that the plow may be rocking in response to the hammer blow. Whatever its source, the presence of this mode may not necessarily preclude the use of rigidly mounted geophones because its phase velocity is significantly different from that of the desired body wave.

**Discussion**

Conventional thought suggests either that the 72 plow-mounted geophones used in these experiments would interfere with each other as a result of their firm connection to the

channel iron or that the data acquired would be seriously contaminated by waves traveling within the channel iron. In fact, we found little intergeophone interference in response to the use of small, near-surface seismic sources at offsets of more than 10 m, and we were able to extract usable data despite the presence of an unidentified wave mode in the channel iron.

When we placed sources at offsets between 1 and 10 m, discernible, slow-moving waves were excited in the channel iron. Some of these interfering waves were reflected back toward the seismic source from the ends of the sections of channel iron and could be attenuated by *f-k* filtering. However,



**Figure 4.** Seismograms from (a) test line (plow-planted geophones) and (b) comparison line (normal geophone plants). Note the similarity between the seismograms at offsets less than 5 m. The plow-planted geophones between offsets of 5 m and 12 m show a mode related to the presence of the channel iron. That same mode is noticeable between 8 m and 12 m offsets on the normal-plant geophones, suggesting that the mode is generated by the rocking of the plow and that it couples to geophones about 0.7 m away on the comparison line. Both seismograms were recorded from a single 1-kg hammer impact.

others propagated away from the source with a velocity near that of the surface waves; thus, the interfering waves were not easily separable from the surface waves.

The firm attachment of the geophones to the channel iron did not affect their performance as detectors of shallow seismic body waves (in this case *P*-wave refractions). These findings were consistent with data shown in Steeples et al. (1998) in which geophones were mounted on a rigid 70-cm-long board at intervals of 5 cm.

These results and their ramifications may be of interest to those performing shallow seismic surveys requiring small geophone intervals. For example, we were able to move the geophones smoothly from one site to another by lifting them out of the ground using the tractor's hydraulic system; hence, the time required to plant, move, and reposition geophones was reduced significantly. In addition, we were able to leave the cable connections in place, thus eliminating the need to reconnect cables to geophones.

Other uses for these results may evolve. For example, small arrays could be deployed quickly and used as listening devices in military applications. An array of geophones could be attached to a vibroseis truck, and a near-surface tomographic velocity image of the area immediately beneath the truck could be generated to assist in the calculation of the static corrections used in deeper seismic surveys.

## Conclusions

We examined the feasibility of planting large numbers of geophones quickly and effectively by bolting geophones to long pieces of channel iron at 15-cm intervals. Shallow seismic body-wave data were nearly equivalent to control-test data gathered using classic, single-geophone plants with identical intervals. Our results indicate that planting many closely spaced geophones simultaneously and automatically is feasible. With geophones attached securely to a rigid medium, the necessary electrical wiring could be connected permanently, thus helping to create a device that would be robust, efficient,

and cost-effective in the field with respect to maintenance and labor requirements. Another practical advantage of using a forceful device such as a plow to plant geophones is that the geophones are likely to be coupled more firmly to the ground, thus making them more sensitive to ground motion.

Despite these advantages, the mechanical planting of geophones may not be applicable to all sites or situations. For example, the use of larger energy sources may induce undesirable modes of motion within the rigid medium. Furthermore, attempting to plant large numbers of geophones in rough terrain or dense forest would present a formidable challenge. Nevertheless, automatic geophone placement may offer a way of increasing the cost-effectiveness of many 2-D and 3-D shallow seismic surveys.

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