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Case History

In-situ, high-frequency *P*-wave velocity measurements within 1 m of the earth's surface

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ABSTRACT

Seismic *P*-wave velocities in near-surface materials can be much slower than the speed of sound waves in air (normally 335 m/s or 1100 ft/s). Difficulties often arise when measuring these low-velocity *P*-waves because of interference by the air wave and the air-coupled waves near the seismic source, at least when gathering data with the more commonly used shallow *P*-wave sources. Additional problems in separating the direct and refracted arrivals within ~2 m of the source arise from source-generated nonlinear displacement, even when small energy sources such as sledgehammers, small-caliber rifles, and seismic blasting caps are used. Using an automotive spark plug as an energy source allowed us to measure seismic *P*-wave velocities accurately, in situ, from a few decimeters to a few meters from the shotpoint. We were able to observe three distinct *P*-wave velocities at our test site: ~130 m/s, 180 m/s, and 300 m/s. Even the third layer, which would normally constitute the first detected layer in a shallow-seismic–refraction survey, had a *P*-wave velocity lower than the speed of sound in air.

DISCUSSION

Bachrach et al. (1998) reported observing seismic *P*-wave velocities of less than 100 m/s in beach sands, and Bachrach and Nur (1998) presented a quantitative rationale for the presence of such low seismic velocities in the near-surface. We present here similar, repeatable subsonic *P*-wave results, along with a description of a low-cost seismic source that can be used to measure *P*-wave velocities within 2–3 m of the shotpoint.

The seismic source we refer to is an ordinary automotive spark plug connected to the distributor of an automobile. In our experiment, the vehicle was parked about 25 m from the shotpoint, a spark-plug wire from the distributor was disconnected, and a spark-plug wire ~30 m long was attached in its place (spark-plug wires of this length are available from automotive-parts distributors). After the equipment was hooked up and all personnel were clear of the wire, the engine of the automobile was started and left running to provide a spark source. We grounded the chassis of the vehicle to the soil with a wire.

Photos of the spark plug (Figure 1) show it both in and out of the ground, with geophones planted at 5-cm intervals on either side to sample densely the near-source wavefield. The spark plug was placed between the geophones in a hole ~1 cm in diameter and 2 cm deep. We achieved better coupling to the soil when we moistened the hole with ~1 ml of water before inserting the spark plug, being careful at the same time not to place the electrode of the spark plug below the water level.

The total energy output of a spark plug is very small and does not cause measurable nonlinear displacements in the immediate vicinity of the shotpoint—a major advantage when obtaining accurate velocity measurements near the shotpoint. Nonetheless, the spark plug provided sufficient energy for us to pick *P*-wave first arrivals to a distance of a few meters from the shotpoint. The spark-plug source also provided high-frequency, broad-band seismic energy. Figure 2 presents a spectrum of data gathered at our first test site, along with a noise spectrum taken several seconds before the data were collected. Note that the spectrum is relatively flat from about 200 Hz to about 1.3 kHz, at which point the high frequencies began to attenuate. The loss of high frequencies may have occurred partly as a result of the effects of the antialias filters in the seismograph.

In some instances, a spark plug might not provide enough energy to overcome noise from wind or nearby cultural sources such as traffic. In such cases, several spark signals can be stacked to enhance the S/N ratio. The data in Figure 3, for example, were collected by allowing the engine of the automobile to idle for a

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few seconds. In the laboratory the data were stacked vertically (Figure 4), and the time break for each spark-plug pulse was fixed at the time of the first arrival at the nearest geophone, which was only 2 cm from the spark plug.

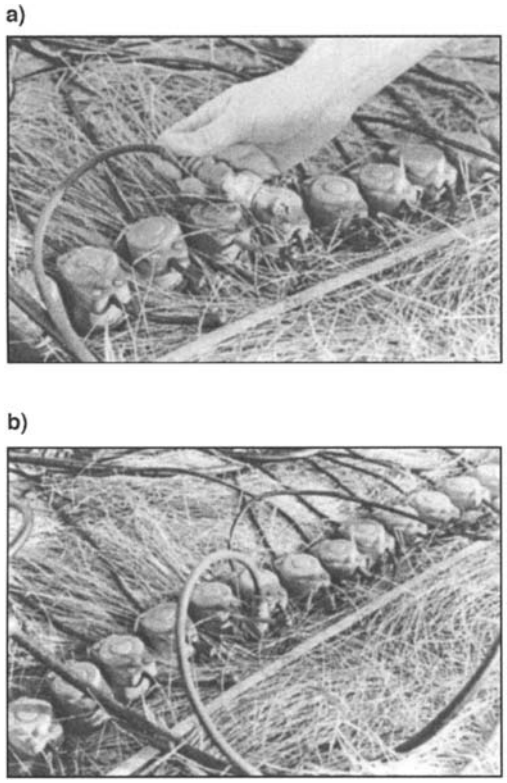

FIG. 1. The spark-plug source before (a) and after (b) positioning in the ground.

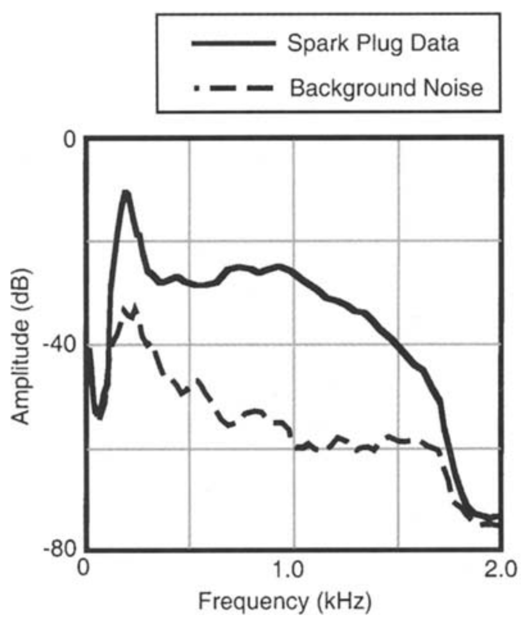

FIG. 2. Amplitude spectra from the test site. The solid line is an eight-trace averaged amplitude spectrum from a representative field file of the spark-plug data. The dashed line is an eight-trace averaged amplitude spectrum of a noise-test field file recorded without the spark plug firing.

We were able to identify three distinct P-wave velocities at this test site (Figure 5). The first and shallowest layer, a mixture of silty-clay soil and grass roots, appears to be only a fraction of a meter thick and has a P-wave velocity of about 130 m/s. The second layer is presumably soil judged to be ~0.5-m thick; it exhibits a P-wave velocity of about 180 m/s. The third layer, which under normal circumstances would be the first layer detectable by a shallow-seismic-refraction survey, has a P-wave velocity of about 300 m/s—which is still below the speed of sound traveling in air.

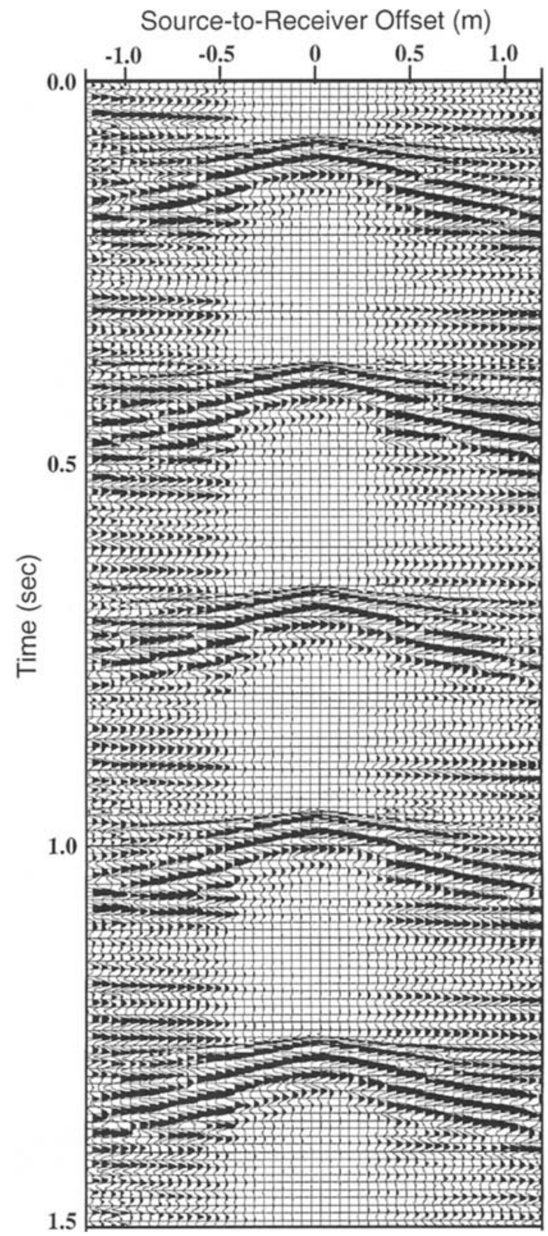

FIG. 3. A field file using a spark-plug source and 100-Hz geophones with an interval of 5 cm. Each field file was collected by recording for 1.5 s while the automobile was idling, thus causing the periodic firing of the spark-plug source. The linear noise that dips slightly from left to right is generated by the automobile, which is located off line. Note the high-frequency direct-wave (>1 kHz) recorded at the near-offset traces.

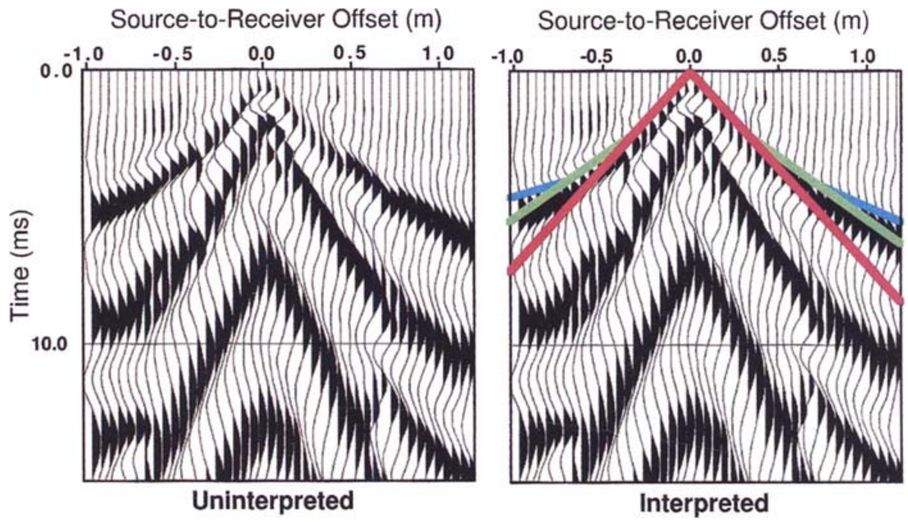

FIG. 4. Uninterpreted and interpreted field file generated by stacking the five spark-plug-generated events seen in Figure 3. Note the time scale and that the near-source first arrivals have a dominant frequency >1 kHz.

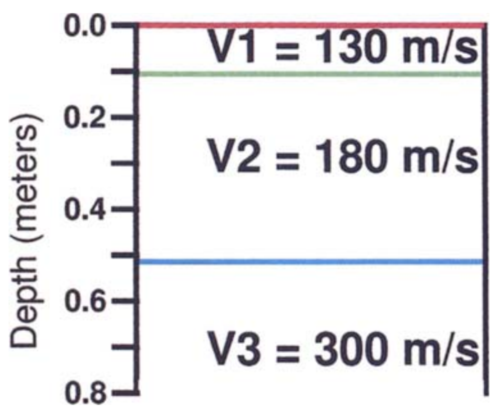

FIG. 5. 1-D solution to the three-layer problem from the first arrivals picked in Figure 4.

CONCLUSIONS

We found that using an automotive spark plug as a seismic source holds promise as a simple, cost-effective method of determining the *P*-wave velocity structure within 1 m of the earth's surface. The spark-plug source is highly repeatable and does not induce nonlinear displacements when geophones are within a few centimeters of the shotpoint. We propose that because of these favorable characteristics, the spark-plug source would be amenable to the use of the MiniSOSIE technique (Barbier et al., 1976) as well as to other pulse-coded linear stacking processes for reflection-survey targets within a few meters of the earth's surface.

REFERENCES

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