Extensive testing of sled-mounted geophone arrays for near-surface (0-4m) layers in floodplain sedimentary facies: Atchafalaya Basin, Indian Bayou, Louisiana

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Summary

During November 2003 through June 2004 we conduct extensive seismic tests with traditional geophones mounted on low-cost "channel" steel and wooden sleds. We target human habitation surfaces within the upper few meters (4-5m) of Holocene floodplain deposits in the Atchafalaya Basin, Indian Bayou Wildlife Management Area, Louisiana, U.S. One 5-m-long sediment core is run through a multi-sensor tool to compare magnetic susceptibility, bulk sediment density and electrical resistivity properties.

We rank the quality of 24-channel seismic data, collected using multiple P-wave and SH-wave sources. Receivers include 100-Hz vertical-, and 14-Hz-horizontal-component geophones. P-wave sources comprise (1) a commercial downhole 12-gauge pipe-gun, (2) a 0.22 caliber-powered piston gun striking a ~5 cm-square steel plate, (3) a commercial elastomer-band-accelerated weight (36 kg) drop striking a 30 cm-square aluminum plate and (4) a ~1.5-kg claw hammer striking a 15-cm-square aluminum plate. We compare both ground-planted and geophones screwed to long (1.2 m, 22 kg) wooden and shorter (0.25 m., 9 kg) steel sleds. SH waves are generated striking the sides of a planted 15-cm-wide I-beam.

Geophones screwed to steel sleds collect adequate but noisier data than geophones planted in ground. Because of the high seismic attenuation of reflected P-waves in this sedimentary environment, horizontal-component geophones mounted on heavy (9-kg) steel sleds provide more useful data (refractions) for forward modeling the velocity structure. The shallowest observed shear wave reflected arrival appears from a boundary at ~19 m depth, below the target depth of 4-5 m. When time and cost efficiency are considered, steel, sled-mounted, horizontal component geophone arrays are recommended for these types of sediments.

Introduction

Land-streamer (or "sled-mounted" herein) systems have the potential to increase markedly the efficiency (van der Veen et al., 2001) for collecting near-surface (0-100m) seismic data but viable cases are few and have been limited to a narrow range of near-surface low-attenuation facies (Van der Veen and Green, 1998) and snow (Eiken et al., 1989). Although Pugin et al. (2004) show that soil gas content can affect P-wave attenuation, the use of these techniques for extremely shallow (0-5 m) imaging in a large variety of facies remains unclear.

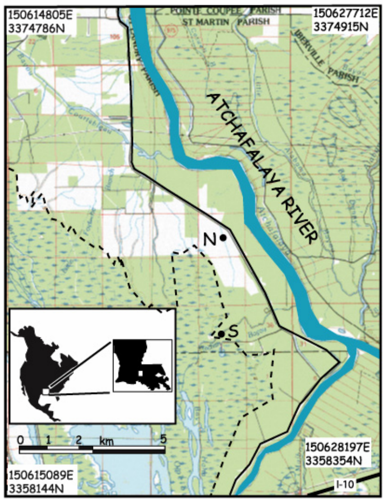


Figure 1: USGS BATON ROUGE map (1984) 1:100000. Corner Universal Transverse Mercator (UTM) co-ordinates (+/- 10 m), Z=15, use WGS 84 geoid. Two insets locate map within North America and state of Louisiana. Northern (**N**) site is located near core site C-1 used in this study (Weinstein and Wells, 2004), at UTM co-ordinates 3367040 m N and 150622386 m E and within sight of the Atchafalaya River western artificial levee (continuous black line). Southern (**S**) site is located at UTM coordinates 3363708 m N and 150622223 m E. Dashed line marks ~5m contour with marsh and lower land to south and west..

Our area of study is located ~80 km west of Baton Rouge, Louisiana, ~5.5- ~8.5 km north of US Interstate 10 (Figure 1). The study area lies within Holocene natural levee deposits of the Atchafalaya River and crevasse splay deposits less than 500 years old (Weinstein and Wells, 2004) and aims to provide best-practice recommendations specific to these modern sediments.

In order to establish an appropriate technique for seismically detecting human habitation surfaces within these modern fluvial facies, we collect and analyze seismic refraction and reflection SH- (horizontally polarized shear) and P-(compressional) wave data in pseudo-walkaway tests for the shallow (4-5m) geological structure. We employ one SH seismic source (15-cm wide, steel I-beam), and four different types of P-wave sources (claw-hammer, 12-gauge pipe-gun, 0.22 caliber piston and 36 kg accelerated weight drop). For each SH test we generate two data sets of opposite polarities, by hitting the I-beam on opposing sides. Differencing the data helps enhance true SH-wave while attenuating P-wave arrivals. We also compare and rank data collected using geophones placed in the ground versus data collected by the same geophones mounted on steel or wooden sleds (Table 1, Figure 2).

24 horizontal -component 14-Hz geophone.

24 vertical-component 100-Hz geophone.

24-channel , 24-bit seismograph, 0.5-s record lengths.

32.5-microsecond sampling rate.

Twenty-three 9-kg "channel" steel sleds, 0.25 m x 0.30 m x 0.08 m in size with single geophone screw mounts; 0.30-m geophone spacing; the remaining geophone is planted in the ground (Figure 2)

Two 22-kg, ~1.2-m x 0.25-m x 0.15-m southern yellow pine sleds with a total of 24 geophone screw mounts; geophone separation is ~0.1 m.

Display with automatic gain control width of 0.05 s, minimum phase bandpass filter with corner frequencies at 20, 40, 1000 and 1250 Hz.

SH-source

Steel I-beam 76 cm-wide on its side, seated with 2 blows of a ~1.5 k hammer and then struck from each side.

P-wave sources

(1) ~1.5-kg-claw-hammer vertically striking a ~0.15 m x 0.15 m x 0.025 m aluminum striker plate.

(2) A 5-cm-square, ~12-mm-thick steel plate seated with four blows of a ~.1.5-kg hammer and struck by commercial 0.22-caliber-powered hammer piston.

(3) A commercial 12-gauge seismic firing rod within a water-filled ~30-cm-deep hole used to detonate (1) a commercial blank shell and shells loaded with (2) only primer or (3) 2 g FFF (fine-ground) black powder.

(4) P-waves using a commercial 36-kg weight accelerated by an elastomer band to strike a flat-lying ~0.3-m x 0.3 -m x 0.025-m aluminum plate.

Table 1: Description of acquisition equipment, seismic recording and display parameters. Note that sled dimensions are in order of length, width and height with respect to the line of geophones.

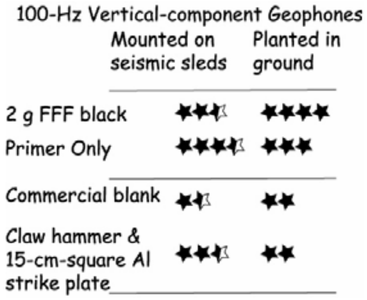
Data Acquisition

For all the above cases while maintaining the location of the source and receivers we vary the number of impacts on the striker plates and the steel I-beam, using 1, 3, 5 and 7 blows, although eventually 3 blows appear to be the optimum number in most cases. Each additional blow provides data that are added to data recorded from previous blows. In this manner the signal-to-noise ratio usually improves and we determine the minimum number of blows needed to collect good quality data. Because the accelerated weight drop (36 kg) provides such a heavy impact, only 1, 3 and 5 blows were struck, although 1 blow eventually proved sufficient.

Figure 2: Twenty-three (plus one planted in ground in foreground) 100-Hz vertical component geophones are screwed rigidly to "channel" steel sleds. The heavy weight of each sled (9 kg) assures suitable mechanical coupling with the ground. The line of geophones is oriented west (farthest point) to east. Geophones are placed ~ 0.30 m apart.

Seismic Data Quality

Both horizontal component (for SH-wave) and vertical component (for P-wave) data collected on steel sleds provide good and efficient refracted seismic returns that can be analyzed for velocity information for the upper ~ 4 m of buried sediment. We summarize the relative quality of these data sets in Table 2.



100-Hz Vertical-component Geophones	Mounted on seismic sleds	Planted in ground
2 g FFF black	★★★⯨	★★★★
Primer Only	★★★★⯨	★★★
Commercial blank	★⯨	★★
Claw hammer & 15-cm-square Al strike plate	★★⯨	★★

Table 2: Relatively better data quality for P-wave source data is indicated by the number of stars and their degree of infilling. Separate holes are dug for 12-gauge shotgun blanks, only-primer and black powder sources. These comparisons are available only for data are conducted at the southern site (Figure 1). Overall, data collected by conventionally planted geophones and geophones on sleds are qualitatively very similar.

In the case of P-wave data, slightly better seismic refraction data are obtained using ground-planted geophones with an accelerated weight drop source (Figure 3). However, a suitable model of the subsurface (Figure 4) is generated using refraction data collected by geophones on steel sleds. Data collected by carrying geophones on sleds is more than adequate for determining the velocity structure in the upper few meters of the subsurface.

Although we expect the commercial 0.22-caliber-powered hammer piston to be a low-cost (~$20) repeatable seismic source the data show cumbersome reverberations which we attribute to the internal piston spring mechanism of the source. P-wave data collected with geophones screwed to wooden sleds display unusually air-to-wood coupled waves and their internal multiples.

Multi-sensor Core Analyses

To complement the seismic data, we use a commercial multi-sensor core logger (Figure 4) to collect physical parameters such as magnetic susceptibility, bulk sediment density and electrical resistivity from one 5-m long core (7.6 cm diameter; core C-1; Weinstein and Wells, 2004). Spatial resolutions for sensor measurements are ~0.5 cm for bulk density, ~1 cm for P-wave speed, and 2-8 cm for magnetic susceptibility and resistivity. The precision and accuracy of the sensors (after calibration) are ~0.5-1% of the measured values.

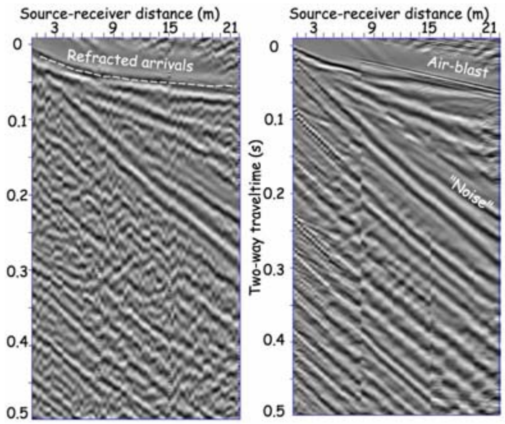


Figure 3: P-wave pseudo-walkaway seismic data sets, both collected with one blow of accelerated weight drop. Left data set uses spikeless geophones screwed to steel sleds. Right data uses geophones spiked into ground. Slight offsets within panel are result of juxtaposing shot data with different source-receiver offsets

We confirm a high degree of seismic signal attenuation in the upper 5 m of the subsurface. This tool is not able to provide any usable P-wave velocity values because transmitted signal values are considered too weak (250 to 500 kHz range) for picking traveltimes. Visual inspection of the cores after cutting does not reveal air gaps in the core that may also cause the attenuation. Thus, we conclude that the nature of the soils is responsible for this attenuation.

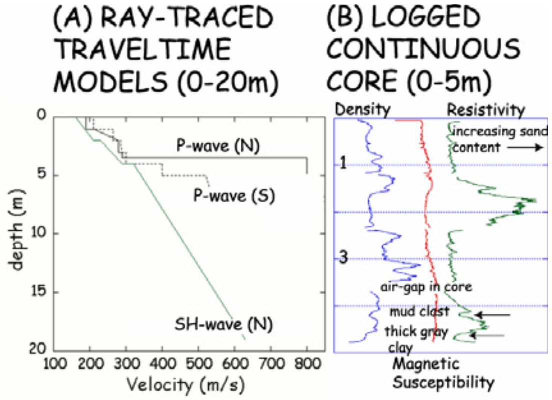


Figure 4: (A) Constant-velocity and gradient velocity approximations derived by forward-modeling traveltime of principal refracted arrivals (See Figure 3). Letters denote site location (Figure 1). (B) Multi-sensor core log values of continuous sampled core at northern test site (See Figure 1). Errors are +/- 10 m/s. For reference we note that P-wave velocity in air is ~ 330 m/s (Beranek, 1986). See Figure 1 for location of northern (**N**) and southern (**S**) sites.

Conclusions

Only SH-type seismic data sets show near-surface reflected arrivals (Figure 5). The absence of reflections can be caused by the attenuation of high frequency components or absence of suitable sediment contrasts. However, the core analyses (Figure 4) show marked changes in sediment type (Weinstein and Wells, 2004) and physical properties. The shallow subsurface consists of partially saturated soils with many visible and microscopic voids that may attenuate seismic waves. SH waves are less affected because they can not travel in the fluid pores. By comparison then, air proves to be a more rigid medium than the loose soil of the study area.

An advantage of the use of steel sleds is that it allows use of legacy geophones that are not gimbaled and especially high-frequency-response phones which are able to maintain a good response under small deviations from near-verticality.

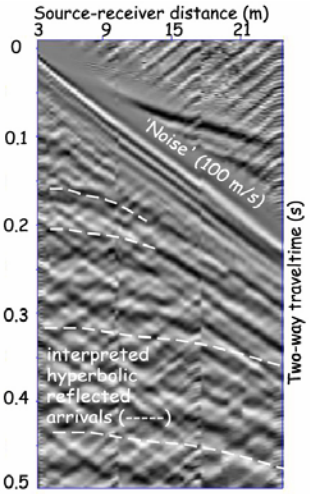


Figure 5 SH pseudo-walkaway seismic data set at northern site (Figure 1) stacked from 3-blows to I-beam and collected by geophones screwed to steel sleds. Reflected arrivals are shown dashed starting at ~0.15s.

Of the four types of seismic sources we use, only shear wave data show any detectable reflections from the subsurface. The shallowest reflection occurs from a boundary at about 19 m below the surface.

We suggest an empirical correlation between the absence of P-wave reflected arrivals and subsonic P-wave (Baker et al., 1999) refracted arrival velocities. We suggest too that low ground roll (Rayleigh waves) velocities correlate with poor P-wave reflections and that in these cases shear wave data be collected instead. We find that when ground roll arrivals show velocities in the low range of 80 m/s, attenuation of P waves is detrimental, and shear waves are the only type of seismic energy that can provide reflections in the shallow subsurface.

From forward modeling of the shallowest refraction arrivals we derive the layer model shown in Figure 4A. We used a ray-tracing approach to best-match the arrival times of refracted arrivals assuming constant and gradient-velocity layers. Shear wave velocities are lower than the acoustic-wave velocities at the same depths. From the combination of both P-wave and SH-wave velocities, useful engineering properties such as the shear modulus and bulk modulus of the soils may be easily calculated.

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