Field Comparison of Shallow Seismic Sources near Chino, California

Richard D. Miller, Kansas Geological Survey (KGS); Susan E. Pullan, Geological Survey of Canada (GSC); Don W. Steeples, KGS; and James A. Hunter, GSC

SUMMARY

Choosing a seismic source can be the most pivotal decision for a shallow-reflection survey. The intent of this paper is to summarize preliminary results of a shallow seismic source comparison conducted in an area with a water table depth in excess of 30 m and near-surface velocities less than 330 m/s. Data were acquired from 13 different sources in November, 1988, at a single site in California. The unique characteristics of each source can be deduced from the data. A possible reflecting event can be interpreted at about 70 ms. The geologic unit responsible for this event is not known. Our previous work and that of our colleagues suggests that, given a specific set of site characteristics, any source could dominate the comparison categories addressed here.

INTRODUCTION

During November, 1988, a group of shallow-seismic source owners, in cooperation with the Geological Survey of Canada, California Division of Mines and Geology, Kansas Geological Survey, and U.S. Geological Survey, gathered at a site approximately 40 km east of Los Angeles near Chino, California, to compare their sources. The preliminary results from those tests are summarized in this paper. Application of seismic-reflection methods to engineering, ground water, mining, and environmental problems has become increasingly popular over the last 10 years (Jongerius and Helbig, 1988; Steeples and Miller, 1988; Pullan and MacAulay, 1987; Hunter et al., 1984; Ruskey, 1981; Schepers, 1975). With the extreme site-dependent nature of shallow reflections, any source in a specific geologic setting can generate higher quality and more usable seismic energy than any other. To assist investigators with selection of the optimum seismic sources for particular applications, geologic conditions, and site logistics, a representative group of sources needs to be compared in a variety of settings with consistent testing procedures and equipment.

In an attempt to quantify significant characteristics of some of the more popular shallow-seismic sources, a simple source comparison was conducted in New Jersey during 1985 (Miller et al., 1986). This comparison was orchestrated by the Geologic Survey of Canada, Kansas Geological Survey, New Jersey Geological Survey, and U. S. Geological Survey. Under the geologic conditions at that particular site the main distinction between the 26 different sources and variations of sources tested was related to the total energy recorded for each source. Very little diversity in recorded seismic characteristics could be deduced from analysis of the data generated during that extensive series of tests. These data suggest that at an excellent seismic-data site source selection is critical only in relation to total energy necessary to image the geologic target.

The geologic conditions at the site near Chino, California, were less conducive for the propagation of high-frequency seismic energy than at the New Jersey site. Previous studies in 1985 by the Kansas Geological Survey and the U.S. Geological Survey identified the Chino site as fair-to-poor with respect to recording of shallow-seismic reflections. Some reflection information seems to be present, however, on unprocessed field files around 65 to 85 ms at offsets of between 8 and 15 m (Fig. 2).

There are many factors to consider in a source evaluation. This experiment was designed to be as consistent as possible with the 1985 New Jersey tests, primarily addressing the questions of energy, frequency content, and signal-to-noise ratio. Other factors significant to the selection of the optimum source relate to source wavelet, portability, cost (both initial and per shotpoint), site preparation requirements, source cycle time and repeatability, environmental damage, and safety requirements.

The shallow subsurface geology at the site is not well known. The near-surface velocity at the site is unknown. The depth to the water table is more than 30 m. The observed surface and very shallow near-surface material consisted of a thin layer of dust overlying loosely compacted unsorted material with grains ranging in size from clay particles to pebbles. The cultural noise was limited to an occasional car or light plane passing within a predesignated unacceptable distance from live geophones. In cases involving excessive noise, the recording of data was halted until traffic cleared. The site was unobstructed by surface barriers that could possibly act as reflecting interfaces for source-generated air waves. The site was easily accessible to vehicles.

FIELD PROCEDURES

An Input/Output, Inc. DHR 2400 seismograph recorded the data digitally on half-inch magnetic tape in modified SEG-Y format and also on paper. The record length was 250 ms with a sample interval of 1/4 ms. Analog-to-digital (A/D) conversion is 11 bits plus sign. The amplifiers have a factory noise specification of 120 nV root-mean-square (rms), providing a fixed gain instantaneous dynamic range of 72 dB.

Receiver offsets and spacings were determined after a series of walkaway noise tests conducted the first day of the comparison. The nearest geophone to the source area was 8.5 m and the receiver interval was 0.5 m. The receivers were 3- 40 Hz L28E Mark Products geophones damped to 0.65 of critical, on 0.14 m spikes, wired in series, and spaced 0.25 m apart perpendicular to the survey line. The geophones were firmly planted and left in place throughout the tests.

Each source was fired on, into, or within previously undisturbed ground. All field parameters were held constant for each source except for analog low-cut (high pass) filters and amplifier gains. Each source was fired three times, recording with no low-cut filtering, 110 Hz low-cut filtering, or 220 Hz low-cut filtering, each with a 24 dB per octave roll-off from the selected -3 dB point of 110 or 220 Hz. The fixed gains were adjusted with each shot to nearly maximize the 12-bit A/D converters. The intent of the amplification process was to maintain a minimum of at least one 8-bit digital word on all traces with no word using the full 11 bits (relative plots in the field were used to verify no signal was clipped). The total surface area disturbed during the 2 days of testing was less than 6 m^2.

RESULTS

The participants brought and tested a total of 23 sources or variations of sources (Table 1). Thirteen primary types of sources were tested with variations including wet holes, dry holes, types of gun powder, amounts of gun powder, type of projectile, weight of projectile, and drawback on rubber band.

This preliminary report on the results of the Chino source comparison only includes variable area plots of the 7.3-kg sledge hammer, 8-gauge buffalo gun, downhole .50-caliber rifle, and the EWG (accelerated weight drop) recorded with no analog low-cut filters and 220 Hz low-cut filters (Figs. 3, 4, 5, and 6). The data are plotted here trace-by-trace normalized. This negates any relative comparison of sources with respect to amplitude or energy. The final report to be submitted to *Geophysics* for publication will contain all the data plotted with true amplitude, frequency spectra, power spectra, photographs, and physical information.

Reflections are interpretable on the raw field data at approximately 65 ms (Figs. 3, 4, 5, and 6). The reflection can best be observed on data acquired with 220-Hz analog low-cut filters. The first-arrival information on all the field data at this offset is interpreted as source-generated air coupled wave. This suggests the velocity of the material in the very-near surface is less than the speed of sound in air. The field files displayed here are representative examples from the data set.

DISCUSSION

Choosing the seismic source for a shallow-reflection survey can be a pivotal decision for the engineering geophysicist. The intent of this report is to present the preliminary results from an area with a relatively deep water table and very slow near-surface velocity and to allow comparison with data acquired in an area with a water table very near the surface and a much higher near-surface velocity. We hope the final results of this comparison (to be submitted to *Geophysics* for publication) will prove useful to the engineering geophysic community.

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FIG. 1. Site map indicating approximate location of Chino, CA.

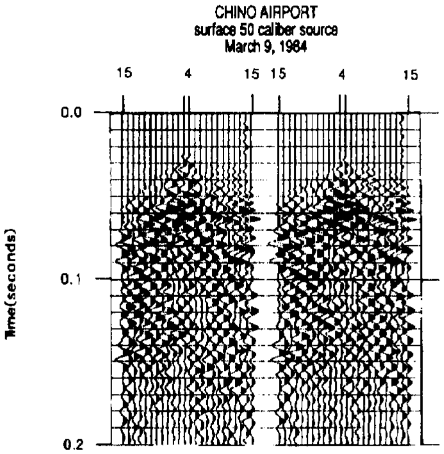

FIG. 2. Split-spread field files from survey conducted in 1984 by KGS.

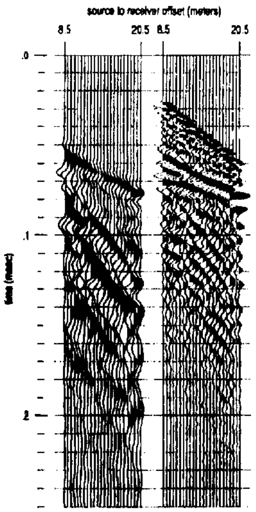

FIG. 3. 7.3 kg sledge analog low cut out and 220 Hz (trace-by-trace normalized).

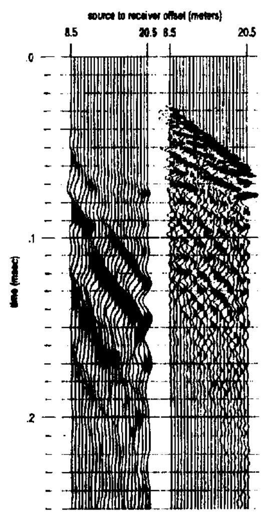

FIG. 4. .50-cal. rifle analog low cut out and 220 Hz (normalized Figure 3).

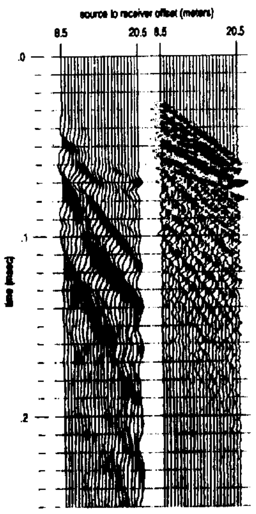

FIG. 5. 8-ga. Buffalo gun analog low cut out and 220 Hz (normalized as Figure 3).

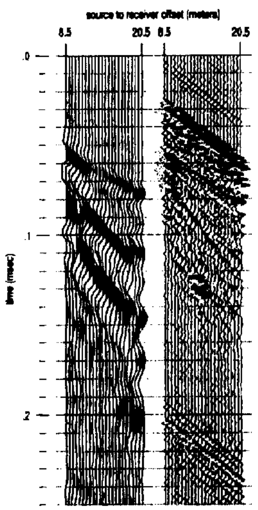

FIG. 6. EWG weight-drop analog low cut out and 220 Hz (normalized as Figure 3).

Table 1. Description and variation of sources and site preparation requirements.

	Source	Variation	Site Preparation
1)	7.3 kg hammer onto steel plate		Seated steel plate with several impacts.
2)	surface .30-06-cal. rifle silenced	a) shot into undisturbed ground 180-grain bullet. b) shot into water-filled hole 180-grain bullet.	none Poured water into bullet hole from previous shot.
3)	downhole .30-06-cal. rifle	shot into wet hole 180 grain projectile.	Poked 1/3 m deep hole with 2.3 cm shaft and poured in water.
4)	10 kj spark pak		Dug hole 0.5-m deep and 0.3 m in diameter lined with trash bag and poured in water and salt.
5)	Betsy Seisgun M3 8-ga.	a) undisturbed dry area 3 oz lead slug. b) shot 3 oz into wet hole.	Fired into undisturbed ground. Poured water into hole from dry shot of Betsy.
6)	.50-cal. rifle downhole	a) dry hole b) wet hole	Auger drilled 0.05 m hole 0.66 m deep. Poured water in previous dry shot hole; placed condom on end of barrel.
7)	8-ga. downhole capsules	a) 500-grain high voltage electric detonation. b) 220-grain high voltage electric detonation.	Auger drilled 0.05-m hole 0.66-m deep, loaded capsule, tamped water, and dirt on capsule.
8)	8-ga. Buffalo Gun / wet hole	a) powder only (blank) 250-grain REM R8BL. b) 3 oz lead slug REM 3 oz Pb. c) powder only (blank) w/PVC liner 250-grain REM R8BL.	Auger drilled 0.05 m hole 0.66 m deep, load gun in hole, pour in water, held in place by ATV*, compression detonation rubber mallet.
9)	12-ga. Buffalo Gun / wet hole	a) 1 oz lead slug REM SP12-Mag. b) black powder only (blank) WIN VW12BL, 165 grain. c) black powder only (blank) w/PVC liner WIN VW12BL, 165 grain.	Same as source 8, except ATV not used to hold gun down in hole, one-person secured gun.
10)	.410 Buffalo Gun / wet hole	1/5-oz lead slug FED F412-RS	Same as source 9.
11)	8-ga. Betsy Cage Gun downhole	powder only (blank) 250 grain REM R8BL	Same as source 9.
12)	Bison EWG Generator (accelerated weight drop)	a) full extension of rubber band before release. b) extend rubber band 0.5 m before release. c) extend rubber band 0.25 m before release.	Seat 2.6 cm steel plate with several impacts.
13)	Explosives	1.25 m det. cord 200 grains PETN.	Same as source 7.

* All terrain vehicle (ATV).