

Repeatability observations from a time-lapse seismic survey

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Summary

Time-lapse seismic surveys have proven extremely valuable in recent years, having numerous economical and environmental applications. To fully utilize this monitoring technique, problems associated with recording repeatability must be minimized. Much work has been done to equalize data from one survey to the next via processing techniques (Huang et al., 1998). The purpose of this study is to investigate the potential for minimized processing, allowing study of extremely small changes in subsurface characteristics. The goal is to evaluate source and receiver terrain combination to optimize signal repeatability, and to improve deconvolution with the ground force to suppress different types of noise and increase repeatability.

Introduction

Repeatability of seismic data acquisition is hindered by a number of factors, including ambient and variable noise conditions, source and receiver consistency, etc. Such problems are many times considered too difficult to overcome during data acquisition, and must be corrected during processing (Zhang and Schmitt, 2004). However, there are certain sources of variability that could be prevented during acquisition.

Large land surveys often span a variety of terrain types. Changes in terrain between a receiver and/or source station can affect the repeatability of a survey through time. Roads, pastures, tilled fields, and sand dunes are uniquely different near-surface settings that effect recorded data differently as a function of surface noise and/or seasonal changes. Roads will likely remain the same from one survey to the next. Tilled fields, on the other hand, change substantially between seasons; they are loosely tilled prior to planting, and vegetated prior to harvest. Pastures also change seasonally, but only due to precipitation, temperature, and vegetation. Sand dunes can certainly change throughout the course of time, but in general they are consistently very loose and change with contact. Signals recorded from a geophone in these terrains are all affected differently with seasonal and surface noise conditions.

Noise in each terrain possesses different spectral and amplitude characteristics. Noise from a passing vehicle will manifest itself differently between the signal picked up by a geophone in a road than in a sand dune. This study aims to distinguish a source and receiver terrain combination that may help optimize repeatability, and to experiment with

different approaches to pre-correlation, which might be useful attenuating different types of noise.

Geologic Setting

The data used for this study was part of a 4D monitoring survey of the enhanced oil recovery program in the Hall-Gurney field near Russell, Kansas. The target was a thin, oomoldic limestone member (Plattsburg) "C zone" of the Lansing-Kansas City in central Kansas, deposited on a shallow marine shelf as part of a sequence of Upper Pennsylvanian depositional cyclothems. Reservoir rocks were deposited as coarse-grained ooid sands. Exposure to subaerial conditions and meteoric waters has caused ooid dissolution, resulting in oomoldic grainstones. Development of these carbonate-dominated cyclothems was predominantly controlled by the eustatic sea level (Raef et al., 2004).

Several different terrain types are present in the acquisition area. There are roads, sand dunes, tilled fields, and pastures. A uniform grid of shot and receiver stations were located in each of these types of terrain.

Seismic Data Acquisition

A baseline survey was acquired in November 2003, followed by seven monitor surveys approximately one every four months. The surveys were single-patch, modified brick style surveys with a source area of approximately 3.6 km². An IVI Minivib II generated 10-s linear upsweeps with a frequency range of 20-250 Hz.

Each of five receiver lines was located with a Trimble DGPS to ensure straight grid lines, with deviations in line-to-line spacing not exceeding 0.2 m and to insure precise re-deployment. Three Mark Products U2 10-Hz geophones with 14-cm spikes were placed at the point of a half-meter equilateral triangle centered on the receiver station. Each receiver was planted at the base of a hole dug down through the sod and into firm soil in order to ensure good coupling and reduce the effects of wind noise.

Nineteen shot lines and 240 receiver stations on a five-line layout constitute a single patch. Both shot and receiver station spacing was 20 m. Shot lines were separated by 100 m; receiver lines were separated by 200 m. Source progression through this spread was along shot lines when possible, but vibrators were GPS guided to insure safe operation and optimized repeatability. At each shot station, five

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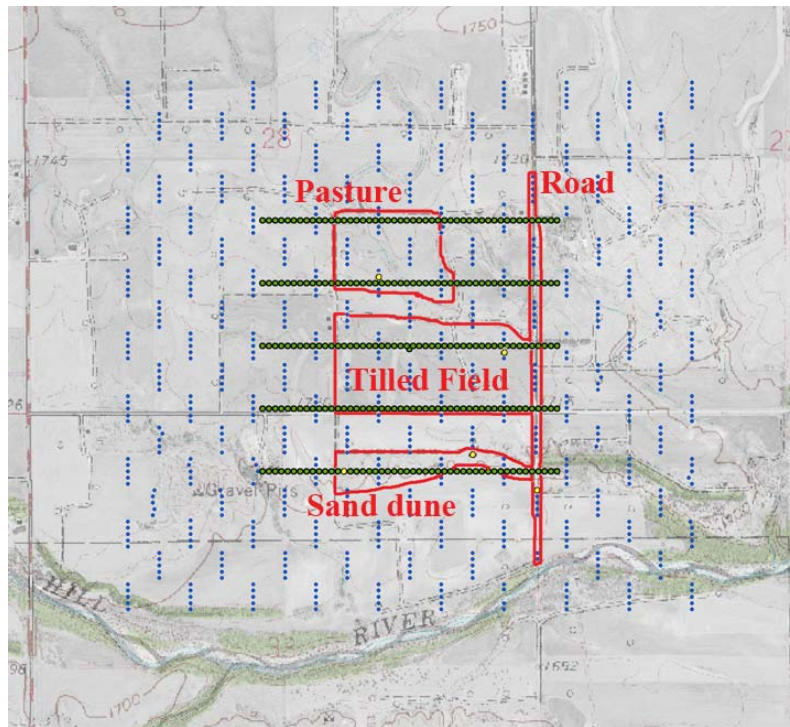


Figure 1: Topographic map of Hall-Gurney Field, central Kansas. Source locations are in blue, receiver locations are green. One example of each terrain type is outlined in red. One set of receiver and corresponding source locations is given; the receiver is in a road, and there is one source in each terrain type.

sweeps were recorded uncorrelated and separately. The first sweep was designed to compact the ground so that subsequent sweeps were as consistent as possible.

Methodology

One receiver station was selected from each of the four terrain types. For each receiver station, four corresponding shot stations were selected in each terrain type (Figure 1). These four shot stations were chosen such that they were approximately the same distance from the receiver station to minimize any difference in wavelet associated with long-offset effects. In all, there were sixteen shot and receiver station combinations, and seven total traces for each of those combinations (one trace per monitor survey).

Traces corresponding to the same shot and receiver stations for each survey were cut from the raw shot gathers of the final sweep. An autocorrelation technique was used to determine the appropriate amount of shift needed to be applied to each trace so that they each had the same t_0 time, thus maximizing the correlation coefficient (predictability).

After the appropriate shift was applied to each trace of raw data, the correlation coefficient was calculated for each trace relative to the first trace. These raw traces were then cross-correlated with a synthetic sweep (Figure 2), and the

correlation coefficients were again determined, listed in the table in Figure 3.

Results and Discussion

Ideally, data recorded for a specific shot and receiver pair would be identical every time. However, changes in noise, equipment, and near-surface conditions have the most profound effects on recorded data. Changes in wavelet characteristics associated with subsurface changes are generally extremely small. A trace from one monitoring survey should theoretically have a correlation coefficient of 1.0 when compared to the corresponding trace (with the same shot and receiver stations) of subsequent surveys if no change occurs between the surveys. In practice, however, the correlation coefficients for traces of raw data were small; average correlation coefficients for data at all shot and receiver terrain combinations is 0.11. That means 11% similarity; conceptually, it is difficult to consider them to be the same wavelet.

Overall, it does not appear as though the magnitude of the correlation coefficient is strongly associated with source terrain. However, there does appear to be a correlation with receiver terrain. This is not particularly surprising; the vibrator is an efficient and relatively consistent means of putting signal into the ground, regardless of environmental

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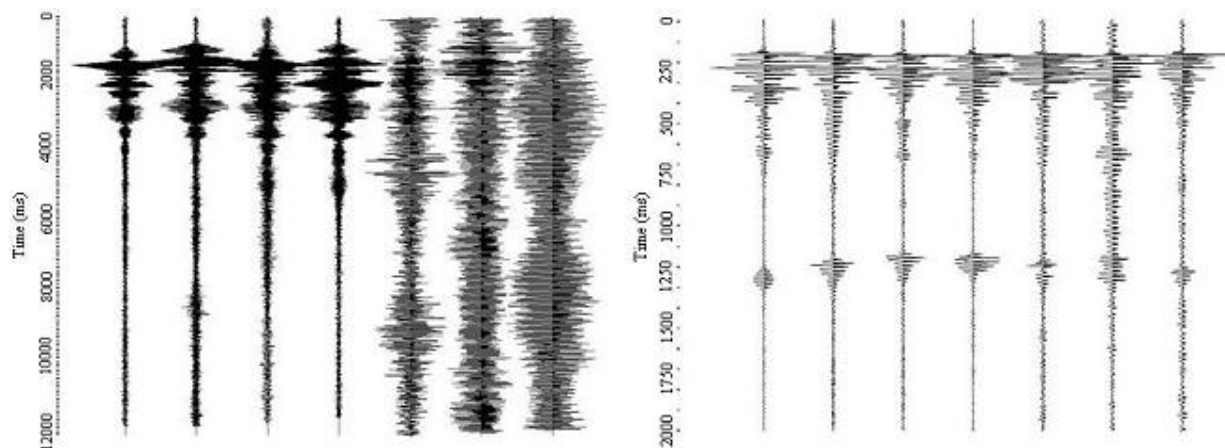


Figure 2: *Uncorrelated (left) and Correlated Data (right).* These are the seven traces, one from each monitoring survey, for a source and receiver located in a sand dune.

factors. Receivers, on the other hand, are affected significantly by wind noise and other environmental, in addition to ground coupling issues. It stands to reason that correlation coefficients would be more sensitive to receiver terrain than source terrain.

The receivers with the largest correlation coefficients prior to cross-correlation (0.16, on average) were those in a road or sand dune; the largest average pre-cross-correlation coefficient (0.37) was from a trace with the receiver in a road and the source in a dune. It is peculiar that regardless of whether receivers were in a road or dune they appear to produce the most repeatable raw, unprocessed signal. The road is solid with good coupling and minimal compaction, while the sand is unconsolidated and has poor coupling with significant compaction potential. The receivers in the road have a more repeatable signal. It is possible that this result is merely coincidence, and it needs to be verified or disproved with further data. The smallest pre-cross-correlation coefficients (0.06) were from receivers in a pasture; the smallest (0.02) was from both receiver and source in a pasture. Poor correlation coefficients from a receiver in a pasture is likely due to environmental factors (wind noise, seasonal change in vegetation, etc) that are amplified by surface exposure and ground shaking through root systems.

After cross-correlation with a synthetic sweep, there is again no apparent pattern associated with source terrain, but there is with receiver terrain. The largest correlation coefficients (0.52) are associated with receivers in a pasture or road; the largest average correlation coefficient (0.72) is from a receiver located in a road and source in a pasture. Tilled fields tend to change significantly with the seasons.

Roads change very little, and pastures do not change as much as tilled fields; therefore, this result agrees with intuition. The smallest correlation coefficients (0.32) are associated with receivers located in a dune; the smallest coefficient (0.21) is from a receiver in a dune and source in a road.

Comparison of cross-correlation versus deconvolution is a good measure of how ideally the source produces the designed signal. Data from certain terrains responded better to cross-correlation. Traces associated with receivers in a pasture or tilled field responded the best; the average correlation coefficients for these traces increased by approximately 42% (from 0.07 uncorrelated to 0.49 correlated). The receiver and source combination that resulted in the largest average increase in correlation coefficient (59%, from 0.07 to 0.65) was for a receiver in a pasture and a source in a dune. Traces associated with receivers in a dune did not respond nearly as well; these correlation coefficients increased by approximately 19% (from 0.13 to 0.32). The smallest average increase in correlation coefficient (14%, from 0.07 to 0.21) was for a receiver in a dune and the source in a road. These results indicate that cross-correlation best diminishes effects associated with seasonal changes, and has little effect on data associated with changing near surface conditions in unconsolidated materials.

Future Work

Using cross-correlation and deconvolution as a quality control tool still remains to be explored. A larger, more diverse data set would assist determining the relationship between source and receiver terrains and correlation coefficients more accurately.

Time-lapse repeatability observations

Receiver Terrain	Source Terrain	Uncorrelated CC	Cross-Correlated CC	CC Improvement
Road	Dune	0.37	0.69	0.32
Road	Road	0.05	0.40	0.35
Road	Tilled Field	0.08	0.30	0.22
Road	Pasture	0.28	0.72	0.44
Dune	Dune	0.21	0.35	0.14
Dune	Road	0.07	0.21	0.14
Dune	Tilled Field	0.10	0.31	0.21
Dune	Pasture	0.14	0.40	0.26
Tilled Field	Dune	0.12	0.39	0.27
Tilled Field	Road	0.07	0.42	0.35
Tilled Field	Tilled Field	0.07	0.56	0.49
Tilled Field	Pasture	0.06	0.48	0.42
Pasture	Dune	0.07	0.66	0.59
Pasture	Road	0.07	0.59	0.52
Pasture	Tilled Field	0.07	0.41	0.34
Pasture	Pasture	0.02	0.41	0.39

Figure 3: Correlation Coefficients. Average correlation coefficients for each source and receiver location combination before and after the seven traces with each combination were cross-correlated with a synthetic sweep and the percentage improvement after cross-correlation.

Conclusions

Raw, uncorrelated vibroseis data has very little similarity from different surveys, with a predictability of only approximately 11%. After cross-correlation with a synthetic sweep, predictability is significantly improved. Some source and receiver terrains improved more than others. It does not appear as though improvement is as dependent upon source terrain as receiver terrain. Receivers in a road have the greatest predictability prior to cross-correlation; receivers in a pasture had the poorest. Subsequent to cross-correlation, receivers in a pasture or road had the greatest predictability; receivers in a dune had the poorest. The receiver terrains that saw the greatest increase in predictability were those in a pasture or tilled field. Receivers in a dune saw the smallest increase in predictability.

To optimize repeatability during acquisition, this study found that a survey should be designed with receivers located in a road, wherever possible. This minimizes change in recorded signal between surveys associated with change in terrain.

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Acknowledgements

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2006 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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