

# Shallow Seismic Reflection Surveys: CDP or "Optimum Offset?"

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## SUMMARY

The last decade has seen the development and general acceptance of shallow seismic reflection methods as a viable geophysical tool for groundwater, engineering, urban, environmental, and surficial geological studies. During this period there have been two approaches to collecting and processing shallow seismic reflection data; one being the modification of traditional common-depth-point (CDP) methods for shallow applications, and the other being the collection of single channel data using the "optimum" source-receiver offset. The last decade has also brought a revolution in engineering seismographs and in personal computing and data storage capabilities. This paper examines the CDP and "optimum offset" approaches to shallow seismic surveys in the light of these developments, and attempts to clarify the potential, limitations, and general usefulness of each technique.

## INTRODUCTION

Seismic reflection techniques have been in widespread use in the petroleum industry for over 60 years. Except for a few isolated attempts (e.g. Pakiser and Warrick, 1956), refraction rather than reflection techniques were routinely applied to "shallow" (engineering, urban, groundwater) problems prior to about 1980. The microelectronic revolution of the last two decades, resulting in the development of digital engineering seismographs and powerful microcomputers, has now made the collection and processing of shallow seismic reflection data a viable and cost-effective alternative.

The pioneering work in the development and testing of shallow seismic reflection methods was carried out in the early 1980's, when the first digital engineering seismographs with enhancement and filtering capabilities became available. At this time, two different approaches to the collection and processing of shallow seismic reflection data evolved. One was the adaptation of conventional common-depth-point (CDP) data acquisition and processing techniques for shallow, high-resolution applications. Two groups were notable in this development: the Kansas Geological Survey (Steeple and Knapp, 1982; Knapp and Steeples, 1986), and the University of Utrecht in the Netherlands (Doornenbal and Helbig, 1983). Meanwhile, researchers at the Geological Survey of Canada developed a second approach to shallow seismic reflection surveying. The "optimum offset" technique was designed with the aim of keeping equipment and computing requirements to a minimum, and providing a reflection technique that could be applied by small geophysical contracting companies (Hunter et al., 1984).

Over the last decade the Kansas Geological Survey and the Geological Survey of Canada have gained a great deal of experience in the application of shallow seismic techniques, as well as an appreciation for their pitfalls and limitations (Steeple and Miller, 1990; Pullan and Hunter, 1990). The purpose of this paper is to examine the CDP and optimum offset approaches to shallow seismic reflection surveying in light of this experience and of the hardware and software developments of the last decade.

## FIELD PROCEDURES

The optimum offset technique is the simplest form of shallow seismic reflection profiling possible. Each trace of the final section is obtained by recording the output of a single geophone separated from the source by a given offset. The "optimum" offset is chosen after examination of a number of multichannel records shot at test sites around the survey area. The test records are also used to identify the target reflection and other events on the seismic record (such as possible groundroll and airwave interference), and to determine recording parameters such as filter settings, amplifier gains, and record length. The optimum offset section is then produced trace-by-trace by moving the position of the source and recording geophone progressively down the line in equal increments. Multichannel records are required, at least intermittently along the line, for velocity analysis. In most cases, it is recommended that these data be recorded along with the optimum offset data.

The choice of the optimum offset is critical to the success of an optimum offset survey. The greatest resolution of the shallow subsurface is obtained by using as small an offset as possible, but the offset must be large enough that the target reflection is not lost in airwave or groundroll interference at any point along the survey line. As a rule of thumb, the source-receiver offset should not exceed the depth to the target of interest.

Once the choice of the optimum offset is made, any geophone spacing can be used depending on the desired subsurface coverage (on an optimum offset section, the spacing of subsurface data points is equal to the spacing between geophones chosen for the field survey), and on the object of the survey. Geophone spacings of 1-5 m will provide detailed subsurface information, while larger spacings may be used when the object of the survey is to obtain regional coverage with limited time and resources.

As each trace that is recorded becomes a trace on the final optimum offset section, the ground coupling at every shot point and receiver position has a direct effect on the quality of the final result. Therefore, it is important that

consideration be given to each and every source position and geophone plant.

A CDP shallow seismic reflection survey also requires a number of test records (walkaway-noise tests) to be shot in the survey area in order to determine recording parameters such as filter settings, amplifier gains, record length and source and geophone spacings. Once these parameters have been set, the survey is carried out by moving the source progressively down the line and "rolling" through the series of planted geophones, so as to record a multichannel (usually 12 or 24 channel) record with the chosen offset and receiver geometry at each shot point. The "fold" of the final section depends on the relationship between the source and receiver positions, but if a shot position corresponds to each geophone position, the fold will be half the number of channels on each record.

The criteria for choosing the source offset and geophone spacings used in a CDP survey differs from those described above for optimum offset surveys. Since accurate velocity analyses are critical to the quality of the final CDP stack, the target reflection should show significant moveout on the field records. In general, at least 4 geophones should be closer to the shotpoint than the shallowest depth of interest, while the most distant geophones should not be farther from the shotpoint than the maximum depth of interest. Geophone spacings of about 1 m have been used routinely during shallow CDP production surveys.

The stacking procedure is the essence of the CDP technique. By combining traces with the same source-receiver midpoint but different source and receiver locations, some traces with marginal data quality (resulting from anything from a bad takeout to environmental noise) can be overlooked during acquisition. As a result, data acquired using the CDP method does not require the same level of concern for the quality of individual traces as that acquired using the optimum offset method.

#### DATA PROCESSING

The data processing required to produce a final optimum offset reflection section is shown in diagram form in Figure 1. The processing is largely cosmetic, and a preliminary section can easily be produced on a microcomputer in the field office within hours of collecting the data. Static corrections are usually simply a matter of aligning first arrivals, to remove the effect of variations in the low velocity layer immediately below ground surface. The depth scale is produced independently from a velocity-depth function determined from velocity analyses of the multichannel records.

The data processing required to produce a final CDP shallow reflection section is shown in diagram form in Figure 2. Before even a preliminary section can be produced the data must be sorted into CDP gathers, velocity analyses performed and normal moveout corrections made.

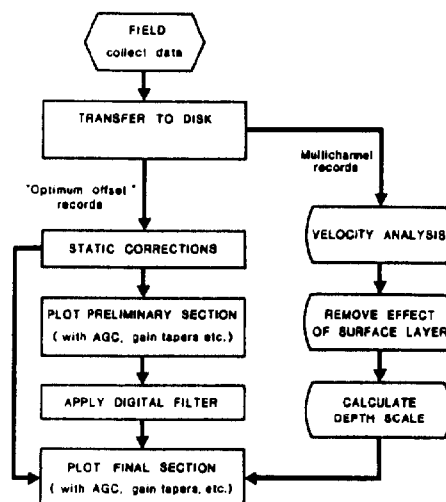


Fig.1 Block diagram of optimum offset processing sequence.

These operations require the manipulation of large amounts of data, and in the early 1980's could only be practically carried out on a mainframe computer. The introduction of increasingly powerful personal computers, now available with large capacity, fast access hard drives, has made CDP processing on a microcomputer a viable option (Somanas et al., 1987). There are now several reasonably-priced CDP data processing software packages available for personal computers.

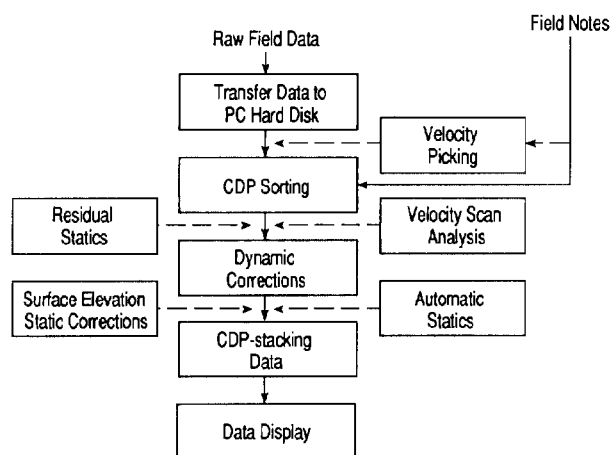


Fig.2 Block diagram of standard CDP processing sequence.

**EXAMPLE CASE HISTORIES**

1) Casselman, Ontario

The seismic survey at Casselman, Ontario, was conducted to map the bedrock topography and overlying stratigraphy to investigate the possible cause of large-scale slumping in the area. The surface material was fine-grained and water table was within 1 m of the ground surface. The data were collected using a 12-gauge in-hole shotgun as the seismic source, and groups of three accelerometers, closely spaced, as receivers. Six-fold CDP data were recorded, using a source-to-closest-receiver distance of 6 m, and a 1.5 m shot and group station interval.

This site proved to be an excellent one for shallow seismic reflection surveying. The dominant reflection frequency observed on the raw field files is on the order of 350 Hz. The bedrock reflection is a large-amplitude event, and several reflections from shallower horizons within the overburden are visible.

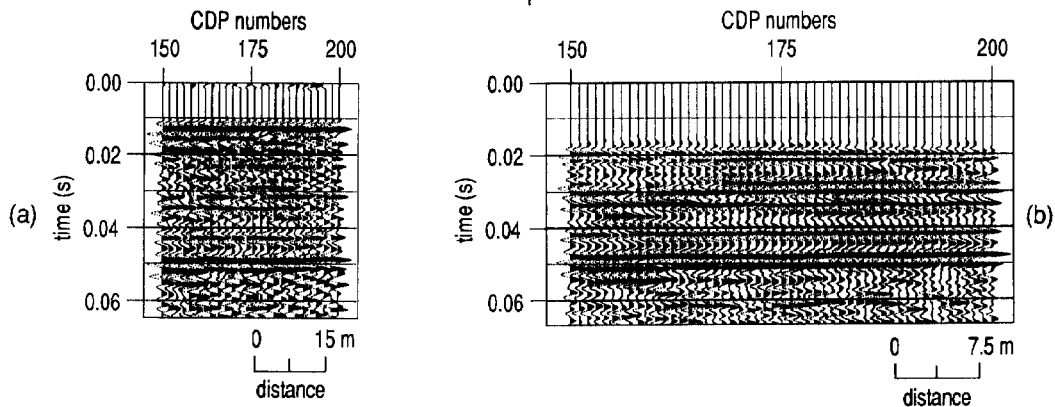
A comparison of the optimum offset and CDP processed sections from these data (Figure 3) shows that the

CDP processing results in a decrease in the dominant frequency of the reflection events, even when great care was taken over the velocity analyses and static corrections. At this site, the optimum offset section provides higher resolution of the bedrock surface and the overlying stratigraphy than can be obtained from a CDP stack.

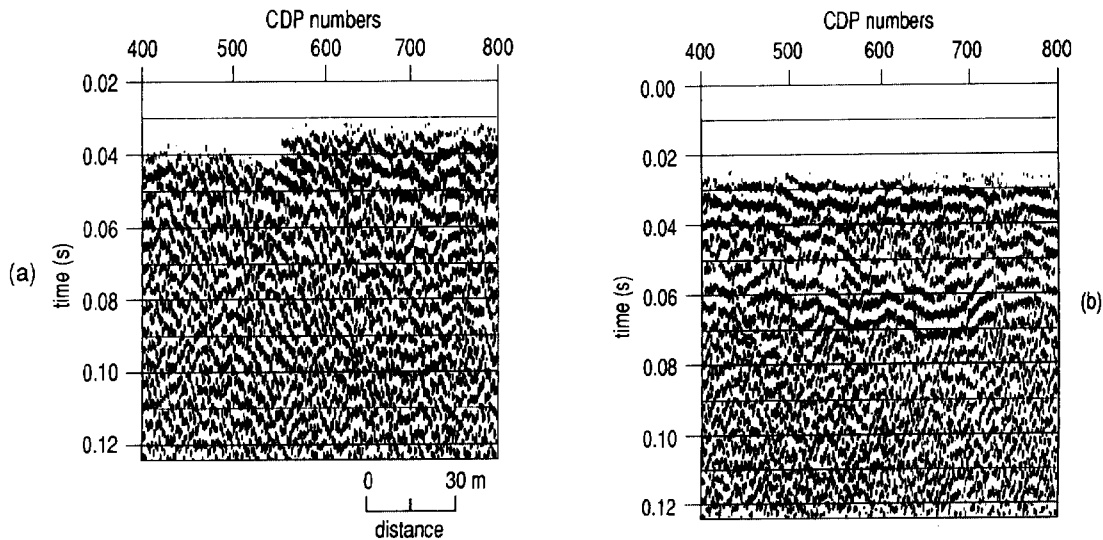
2) Pittman Lateral, Henderson, Nevada

The Pittman transect in Henderson, Nevada, is a site where polluted waters from an unknown source are moving laterally toward the intake facilities for the Las Vegas water supply. A 260 m long 12-fold CDP line was acquired to determine the location of topographic lows in the bedrock surface. The data were collected using a silenced .30-06 hunting rifle as the seismic source and single 100 Hz geophones as receivers. An end-on source/receiver configuration with a source-to-closest-receiver distance of 3.7 m and a 0.6 m shot and receiver station interval were used to collect the data.

Reflection events were not obvious on the raw field files, but could be identified on the filtered and scaled shot gathers. The dominant reflection frequency on these



**Fig.3** Comparison of (a) optimum offset and (b) CDP sections from Casselman, Ontario.



**Fig.4** Comparison of (a) optimum offset and (b) CDP sections from Henderson, Nevada.

records is in excess of 150 Hz. The stacking velocity ranges from 500 to 650 m/s for reflections identified from depths of 8 to 22 m below ground surface.

A comparison of the optimum offset and CDP sections derived from these data (Figure 4) clearly shows the necessity of CDP processing at this site. There are simply no confidently interpretable seismic reflections on the optimum offset section. Reflections interpretable on the filtered field files can be correlated to the events on the CDP stacked section. The signal enhancement capabilities of the CDP method are essential to produce a useable shallow seismic reflection profile at this site.

## DISCUSSION

The optimum offset technique is a very simple form of seismic reflection profiling that requires a minimum amount of data storage, handling and processing. It was developed at a time when the hardware costs (for the seismograph, data storage capabilities, and the computing hardware necessary for data processing) involved in these operations were substantial. The minimal data processing required significantly decreases the total cost of the survey. However, the technique is really only applicable in "good" areas where the target reflection is clearly visible on the field records, since there are no processing options that can potentially improve the signal-to-noise ratio. In contrast, the efficiency of the field operations is not greatly different from that of a shallow CDP survey.

CDP techniques require the storage and handling of a large amount of data, the processing of which is an integral, critical, time-consuming and costly part of the procedure. Experience in the processing of CDP data is essential to avoid potential pitfalls such as excessive deterioration of the high frequencies during the stacking procedure and incorrect identification of coherent arrivals. The great power of CDP techniques, however, is that the signal-to-noise ratio of the data can be improved to provide subsurface information that was not visible on an optimum offset section.

## CONCLUSION

The tremendous developments in engineering seismograph technology, in microcomputing capabilities, and in the cost and accessibility of data storage that have taken place over the last decade have greatly expanded the potential and cost-effectiveness of shallow seismic reflection methods. The constraints on data storage and microcomputer processing that originally led to the development of the optimum offset technique are now largely non-existent. However, there is still a place for both the optimum offset and CDP techniques of shallow seismic reflection profiling depending on the site conditions and the problem to be solved.

The added cost of conducting CDP surveys is primarily incurred in the processing of the data, while recording parameters (source offsets and geophone spacings) can often be chosen to be suitable for both CDP and optimum offset processing. Where logistics and the objectives of the survey permit, it is recommended that CDP data be collected in the field, allowing common offset panels to be pulled from the data set and examined before a final decision about the requirement for CDP processing be made. This procedure gives the interpreter the flexibility to use the optimum offset sections if they are sufficient to answer the geological problem at hand, while maintaining the option to produce the CDP sections if they could provide valuable additional information.

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