ENVIRONMENTAL / ENGINEERING-SCALE SEISMIC EXPLORATION

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Introduction

Due to the rapid technical developments over the past two decades sophisticated seismic exploration techniques have become available to a broad community of users in academia and industry. This is indicated by the significant number of associated articles published in relevant journals (e.g., Geophysics, 1998, 2000; The Leading Edge, 1999, 2002). Based on developments in software, powerful computer facilities and multi-channel engineering seismographs shallow investigation techniques have improved markedly, also by adapting acquisition, processing and interpretation techniques established for deep seismic surveying in the hydrocarbon industry. This article provides a brief overview of typical applications of shallow seismic investigations and summarizes the most critical issues in engineering-scale exploration.

Typical applications of shallow seismic exploration techniques

Main targets in environmental / engineering-scale seismic exploration are natural resources - like groundwater or industrial minerals - situated in the shallow (~200 m) subsurface. The extensive exploitation of these valuable resources requires techniques that provide a detailed image of their complex near-surface structures. Sparse networks of boreholes and outcrops are often the only source of information but the costs and required data interpolation restricts this approach to only a limited number of locations.

An alternative approach involves the application of appropriate geophysical methods and targeted drilling that together may provide detailed images of the complex shallow subsurface. The 2-D reflection and refraction methods have proved to be reliable and valuable tools for non-destructive mapping of the shallow subsurface for groundwater studies and mineral exploration and exploitation. Shallow 3-D seismic reflection techniques have also recently been developed for mineral exploration, where most of the surveyed areas were characterized by highly complex unconsolidated sedimentary sequences. As an example, Büker et al. (2000) reported the results of a 3-D high-resolution seismic reflection survey across glacial deposits overlying bedrock at shallow depths of ~85 m. Near-surface data were acquired across a 357 x 432 m area with a subsurface bin size of 1.5 x 1.5 m. Shallowest reflections resolved occurred at ~20 ms (~15 m) (Figure 1). Thus, 3-D seismic reflection methods are reliable and valuable tools for the detailed mapping of near-surface targets and for target depths of > 30 m, the resolution provided by this technique is unrivaled by any surface-based method.

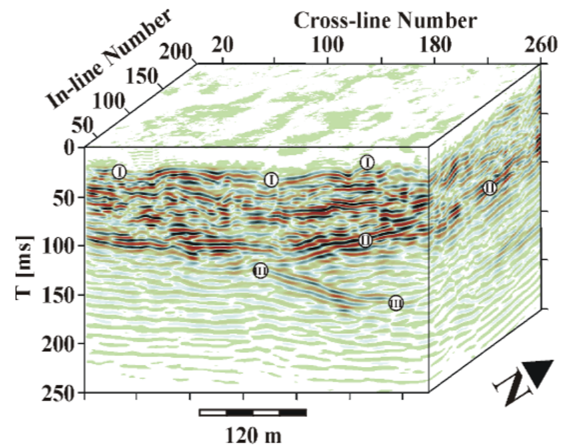

__Figure 1:__ 3-D high-resolution seismic reflection data set adapted from Büker et al. (2000). I - shallowest detectable reflection from top of shallow glacial sediments; II - outlines boundary within glacial sediments; III - delineates bedrock boundary.

Another important approach to map near-surface structures is the tomographic inversion of first-arrival times obtained from surface seismic profiles or recordings between boreholes. Strong heterogeneity with low-and high-velocity anomalies and pronounced topographic variations often cause significant imaging problems for conventional seismic investigations. However, small shot and receiver separations allow the recording of densely sampled data sets, which can be used for robust high-resolution seismic tomography. Musil et al. (2002) show the tomographic results of an experiment conducted over a rock glacier, which poses a serious natural hazard for the region due to its potential instabilities, possibly caused by global warming.

The aforementioned techniques and applications represent only a very limited selection out of a range of valuable tools for the mapping of near-surface targets in a broad variety of environments. Among others, near-surface structural investigations, mapping the depth to bedrock, the delineation of shallow faults, mapping suitable formations for potential construction and waste disposal sites and detecting fracture zones and intrusions in crystalline rocks are also potential targets of engineering-scale exploration.

Shallow seismic data acquisition

More geophones and more source points increase markedly the logistical complexity of a typical shallow seismic survey, which result in increases in the time-consuming and costly aspects of shallow seismic data acquisition. Therefore, to record such high-resolution data sets it is essential to apply fast and efficient acquisition techniques and systems.

As an example, Van der Veen and Green (1998) have introduced a land-streamer concept with the principal goal of decreasing the number of field personnel, time, and costs. Self-rotating gimbal-mounted geophones have been attached to a long mobile (towed by a car) rubber mat. Test showed that the signal quality obtained with the land-streamer operating under most surface recording conditions (e.g., meadow, gravel road, asphalt) is comparable to the results from conventional spiking geophones.

In general, the application of appropriate acquisition parameters is an essential prerequisite for successful high-resolution seismic surveying. Conceptual computer modeling may provide guidelines to help choose the optimum recording parameters for a set of defined survey objectives. Nevertheless, initial experiments comprising walkaway noise and parameter tests should be performed prior to every shallow seismic investigation in order to match the field geometry to the site characteristics and the intended targets.

Shallow seismic data processing

Shallow seismic reflections are only observable within a relatively narrow reflection window, hence, the processing can be different from processing seismic data collected for hydrocarbon exploration. Elimination or significant reduction of source-generated noise (e.g., direct and refracted waves, airwaves, ground-roll, and guided waves) that delineates this window is critical for obtaining reliable information about the very shallow subsurface. A major difficulty is the differentiation between very shallow reflections and guided waves. Since very shallow reflections and guided waves may have similar dominant frequencies it may not be easy to separate them by simple frequency filtering and, therefore, advanced processing techniques have to be applied (Figure 2).

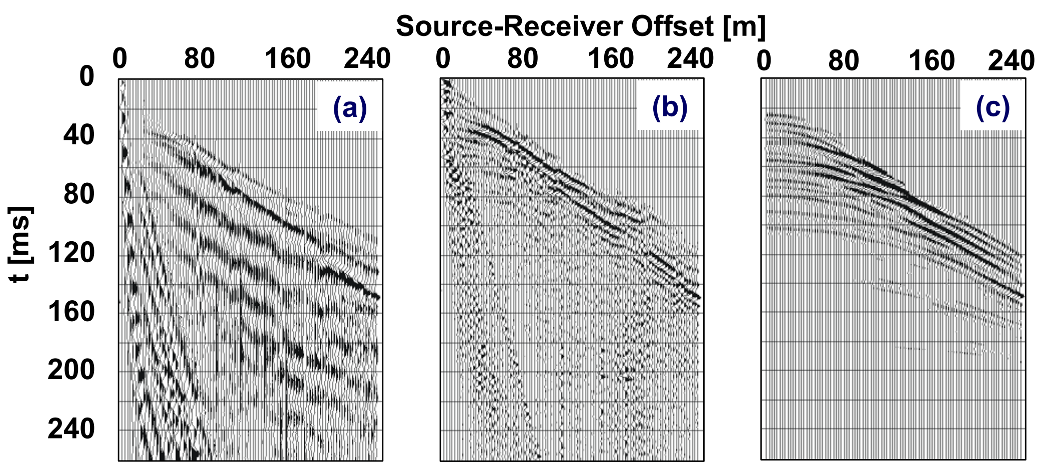

Figure 2: *(a) Typical shot gather recorded along a 2-D line over unconsolidated sediments. Note the dominance of guided waves and ground roll (i.e., source-generated noise). (b) As for (a) after conventional processing applied (i.e., deconvolution, bandpass filter and time-variant gain function). (c) The result of advanced processing applied to (b) including wavefield separation in the linear and hyperbolic tau-p domains (for details see Spitzer et al., 2001).*

Other difficulties in shallow seismic data processing are: (i) determination and application of static corrections - shallow reflections are generally less continuous and frequencies are much higher than for deep investigations and great accuracy is required in deriving static corrections. (ii) coherency filters - *f-k*, *K-L* or *tau-p* filter are often appropriate for targeted processing but can generate events that have no geological basis).

In general, employing standard processing sequences may lead to spurious coherent events and horizontal alignment of source-generated noise on CMP gathers, which can be misinterpreted as true reflections on final stacked sections. The seismic data processor should be absolutely certain that events on the stacked sections can be correlated with reflections on the original shot or CMP gathers, before accepting the results of any data processing (Steeples et al., 1997).

Outlook

Although shallow seismic surveying is now fairly common in academia and industry, field effort and costs continue to limit the application in commercial engineering projects. Therefore, a principal objective of the near future is to develop more efficient acquisition strategies to help minimize costs, such that more companies will eventually apply powerful geophysical tools to resolve diverse engineering and environmental problems.

Furthermore, most processing operations employed routinely in deep seismic exploration can be applied to shallow seismic data. However, a specific problem for high-resolution seismic data is the inevitable interference of source-generated noise with reflections from the shallow subsurface. A second objective is to overcome this difficulty by introducing new processing strategies that reduce coherent and incoherent noise and / or make use of the information contained in this source-generated noise.

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