AN INVESTIGATION OF TWO SEISMIC TECHNIQUES: REFRACTION AND REFLECTION IN THE SHALLOW SUBSURFACE OF THE CONNECTICUT RIVER VALLEY, MASSACHUSETTS

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The techniques of seismic refraction and seismic reflection have long been used to determine subsurface structure of geologically significant areas. Most of these surveys, however, have concentrated on deep lithified layers and have largely ignored the shallow subsurface (the uppermost 500 meters), which usually consists of unconsolidated, undeformed sediments. Recently though, interest in these sediments has grown as people have become more concerned about groundwater, especially in relation to potential buried aquifers. This interest has encouraged many geologists and geophysicists to begin profiling the geometries of these shallow layers in the hope that significant reservoirs will be found (Hansen, 1980; Warrick and Winslow, 1960).

Surprisingly, despite all of this activity, relatively little research (except Hunter, et. al., 1984) has been conducted concerning the effectiveness of refraction and reflection in determining discrete layers in the shallow subsurface. It has been assumed that these methods are the equivalents of their counterparts in deep seismic profiling when, in fact, the overlapping of compressional wave velocities of unconsolidated sediments suggests that it may be much more difficult than imagined to determine such layers. With this in mind, then, I worked with Rowlamd Cromwell of Carleton College to challenge these assumptions. Using well logs as a control, we investigated how accurate refraction and reflection are in discerning layers of known depth and velocity.

The Connecticut River valley of central Massachussetts is ideal for conducting such investigations because of an abundance of well logs and a fairly simple stratigraphy of glacial clays and sands overlying bedrock. Velocity contrasts between the sands and clays can be correlated with well logs with little difficulty by running seismic lines near well sites.

Field research was conducted at four sites in the vicinity of Northampton, Massachussetts and was augmented by data collected in 1985 by students of Robert Burger, the faculty sponsor of the current project. At each site we collected both types of data in order to compare the results of each method. All types of seismic data are collected using three basic tools: an energy source, which is any device that channels energy into the ground (in our case, a sledgehammer or a shotgun); geophones, which register the disturbances in the ground caused by seismic waves; and a seismograph, which displays the information received at each geophone. In addition, we used a digital recorder to save all the data for computer processing.

We commonly ran one or two refraction lines at each site to determine the depth to the water table and the depth to bedrock there. It was impossible to rely on refraction for more detailed information because refracted waves can reach the surface only if a bed has a greater velocity than the bed overlying it (Dix, 1966). Thus, sand, which has a slower velocity than clay (200-1500 m/sec and 1100-2500 m/sec, respectively (Burger 1988a)), is in most cases "invisible" beneath the first clay layer. However, the bedrock-overburden interface and the water table are quite distinct in refraction records because the velocity of consolidated material is in general greater than the velocity of saturated, unconsolidated material, which is in turn greater than the velocity of unsaturated, unconsolidated material (Burger, 1988b).

To create a record, we used a 120m cable to connect 12 35-Hz geophone clusters, spaced at ten meter intervals, to the seismograph. The geophones were connected to the ground by means of spikes which were pushed into the surface. We would then stand a certain distance away (usually five meters) and strike the hammer against an aluminum or steel plate on the ground until a first arrival (the first downdip in the seismic trace) was visible at all twelve geophones. Then, in the lab, we would plot the first arrivals on a time-distance graph. Changes in slope of the time-distance curve are the result of changes in velocity (calculated as the inverse of the slope) in the subsurface and are thus indicative of different layers (Dix, 1966). However, because velocity calculations assume a horizontal interface, any dip in the interface causes incorrect calculations of velocity and depth; therefore, we always ran a second line in the reverse direction to compensate for any dip that an interface might have (Burger, 1988b).

In contrast to refraction, reflection does not require that deeper layers have greater velocities (Burger, 1988b). As a result, it is much more useful in recognizing a sequence of layers of greater and lesser velocities. To create a reflection record, we placed 12 50-Hz geophones (which are more sensitive to the higher frequencies of reflected waves) at three meter intervals along a 36m cable. The geophones were usually buried in holes about two feet deep in order to minimize the effect of the air wave. Then, using either a sledgehammer or a shotgun as the energy source, we would move far enough away from the first geophone that the air wave would not interfere with the record, and would detonate the shotgun shell or strike the hammer on the plate until a satisfactory record was produced. This type of record, which shows the arrival of each seismic event (reflections and, to a lesser extent, refractions) at each geophone, is known as a normal move out (NMO) record. On such a record, reflections exhibit curved patterns while refractions exhibit straight-line patterns (Lankston and Lankston, 1983). This distinction is important when analyzing common offset (CO) records. To determine whether a certain event is a refraction or reflection, we plotted the square of the arrival time (T^2) of the event at each geophone against the square of the distance (X^2) of the geophone from the energy source on a log-log graph (X2T2 method). If the points plot as a straight line after squaring and plotting on log-log paper, then the event in question is a reflection. If not, then it is a refraction. As with refraction, the inverse of the slope of the line is the velocity of the layer that is being reflected.

Using the information provided by refraction and NMO, we also analysed the data using a method called common offset. This method attempts to profile the subsurface topography in such a way that it is able to be "seen" in the traces of the record. To obtain a common offset record, we would shoot an original NMO record until we were satisfied with the record for the first geophone. Then we would save the record of the first geophone, erase the others, and move the energy source so that the second geophone was the same distance away as the first one had been. By continuing this process for twelve geophones, we were able to determine how far beneath the geophone in question each layer was. The result is a readout that approximates a geologic cross-section. In the lab we were able to process the data so that some of the extraneous noise was de-emphasized, giving us a cleaner record than the field printout. Also, the program we used enabled us to link several CO records together, thereby extending our "cross-section" to as many records as we had been able to shoot at a given site.

Initial correlation of the refraction and NMO data with the well logs has been encouraging. As anticipated, the refraction data is not very consistent in recognizing interfaces besides the water table and the bedrock-overburden interface. This is not to say, however, that it was unable to recognize any of these interfaces. At several sites it picked up the interface between the fill on the surface and the underlying glacial sediments. At another location which, unfortunately, had no well control, it predicted several layers which were also seen in CO data. The composition of these layers, though, was unclear, since a given velocity can be indicative of a variety of materials. Refraction data also suffered from its need for long shot lines. We were only able to run a maximum of two lines at any site because energy loss was too severe beyond about 300 meters. As a result, bedrock often remained "unseen" to us.

Normal moveout was much more consistent in recognizing most of the major interfaces in the overburden. Correlation with well logs has shown that it may be relied on as being fairly accurate in surveying an area. However, it was fairly unsuccesful at identifying beds less than several meters thick. The thinnest bed it succeeded in recognizing was 4.5 meters thick. Also, because of velocity overlap, NMO is ineffective at identifying the composition of a given layer. This is not true in all cases, though. For instance, a pocket of sand between a clay layer and till was identified quite easily at the first site. One interesting result of the NMO data was that very few refractions showed up in the X2T2 record. This indicates that use of 50 Hz geophones and filters which eliminate low wavelength events are effective in restricting NMO and CO records to reflections. Unfortunately, as Miller and others (1986) discovered, and as our data support, high frequency filters often result in a record which is difficult to interpret because of excess noise which appears on the record.

Noisy records make common offset both the most rewarding and most frustrating of the methods. At all the sites it identified major units and subsurface structures quite effectively, but the noise which pervades most of these records obscures many of the finer details of the method. Individual reflections are in many cases difficult to follow from record to record, although their general trend may be discerned. Furthermore, because there is a high ratio of energy loss to distance, this method, much like refraction, is quite limited in terms of how far into the subsurface it can "see." It is to be presumed that greater energy sources (vibraphones or explosive charges) will propogate energy deeper into the subsurface; however, in our investigation both sources (sledgehammer and 12-gauge shotgun) reached bedrock and so did not provide conclusive proof for that assumption within the Connecticut valley. One other drawback to CO, noted by Lankston and Lankston (1983) and this author, is that with relatively low-energy sources it is difficult to obtain more than four significant reflectors in the record. In no site investigated were more than six observed.

Shallow seismic methods, especially reflection, are seen here to be helpful as well as accurate in determining subsurface interfaces and structures. There are, however, definite limits to each of the methods investigated. In particular, it is difficult to interpret the composition of layers when there is no control provided by by well logs. Thus, while seismic methods are helpful, they must be used in conjunction with other data to be fully effective.

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