Shallow Seismic Reflection as applied to Ground Water Surveys

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Introduction

The shallow seismic reflection method measures the velocity and depth of every different velocity layer regardless of any velocity inversions in the stratigraphy and, thus, unlike seismic refraction surveys, results in a more complete picture of the subsurface. In theory, this approach can give accurate and precise information on the composition, shape and size of an aquifer, however, problems reduce the effectiveness of this method. This project involved conducting seismic surveys at four locations in the Connecticut River valley, and interpreting and evaluating the results.

Field Methods, Procedures and Equipment

The seismograph used in this project was an EG & G Geometrics ES-1210F 12-channel seismograph. Energy sources were 10-gauge blank load shotgun shells and occasionally a 10 or 20-lb sledge hammer. Geophones were 50-hertz Mark (marsh) for the reflection surveys and standard 35-hertz (six in series per takeout) for the refraction method.

Results from surveys done in 1984 were used to supplement the surveys completed during August, 1988.

In the field, three types of seismic surveys were used. These were the seismic reflection methods of normal moveout (NMO) and common offset (CO) as well as the standard refraction method. The last was used in conjunction with well log information to provide a better standard with which to compare the seismic reflection results.

The NMO method is used to obtain layer velocities and depths to the reflecting interface. This method involves arranging the geophones in a line and recording simultaneously the passing compression waves whose energy source is offset some distance from the first geophone. The shape of the recorded reflection and its arrival times at each geophone provide the information needed for velocity and depth calculations.

The common offset method produces a more graphic vertical profile of the subsurface. A reflection is recorded individually at each geophone with a common offset from the energy source. The result of this common offset is that any changes in the arrival time of a reflection is related to a change of the depth of the reflector. Thus the reflections mimic the actual vertical profile of the subsurface.

Data were processed using computer programs to obtain the calculated structures. The CO profile with the depths and velocity values for each layer from the NMO method were then compared with the well log and the refraction survey from each site. The success of the seismic reflection surveys was judged by the ability to identify the bedrock and other prominent structures as well as by other information it produced which can not be determined by the well log and refraction surveys.

Results and Interpretations

Site 4 (2.5 km north of Whately, Massachusetts, on North Street)

Site 4 seismic lines were run from a grassy pasture of a tree orchard to a maintenance road in a mature marsh. As would be expected, the water level was near the surface and, in fact, most of the shotgun blasts were discharged below the water table.

Figure 1 is the common offset profile for Site 4 shown with the well log information. The two strongest events arrive around 35 ms and 80-100 ms. That first event (A) arrives at the same time as does the refracted wave from the water table on the Site 4 refraction results. Thus the event is obviously not a reflection but the water table refraction.

The strong event (D) between 80-100 ms is the bedrock reflection. This is supported by its strength (i.e. the size of the waveforms) and as its NMO value for depth (52m) is very similar to the nearby well log data for bedrock (65m).

The CO reflection of the bedrock in Figure 1 suggests that it is a buried valley. This finding is supported by other surveyors who place a paleo-river bed directly underneath Site 4 (Whately Water Study, 1985).

The intermediate reflections between the bedrock and water table refraction are not significant in where they are, rather where they're not. The large band that is virtually absent of reflections (50-70ms) correlates with the dominate blue clay layer seen in the well log. Throughout the profile the clay layer retains its thickness with little variation. The intermediate reflection (B) above the clay "void" is interpreted to be the top of the clay layer with the strength of the reflection possibly corresponding to a sharp or gradual transition from the silt, sand and gravel layer to the clay layer.

The lower reflector (C) appears about 15 meters too shallow to correspond directly to the bottom of the clay layer in the well log. The strength and length of the reflection must be due to a definite velocity (i.e. facies) change. This can be explained either by a shallowing of the bottom contact of the clay layer or a completely new layer within the blue clay which has thinned completely before it reaches the well site. Since the latter lacks any other supporting evidence, C is interpreted as the lower boundary of the clay layer.

The minor reflections between the clay layer bottom and bedrock reveal the frequent facies changes in the clay, silt and sand deposit.

Site 17 (1 km south of Sunderland, Massachusetts, on route 47)

Site 17 is one of three surveys that was selected from 1984 results. The data from this site included the necessary NMO and common offset information but unfortunately the refraction survey didn't reveal the bedrock interface. Also, the closest well is 500 meters away. Other wells in the area, however, provide good reason to assume that the bedrock is around 70 meters below the surface at Site 17.

In the common offset profile (see Fig. 2) there are three reflections A, B' and B. The B reflection is the strongest and deepest of the three and its respective NMO value places it at a depth of 60-70 meters. The strength of the reflection and the depth which is near the expected bedrock depth supports the interpretation that it is, in fact, the bedrock reflection.

An interesting feature at this site is a reflection in some NMO surveys that arrived later (i.e. it is deeper) than the bedrock (see Fig. 3). This event (D) exhibits NMO and for all practical purposes possesses the qualities of a good reflection. This, however, was determined not to be an actual reflection from beneath the bedrock, rather it is a reflection which is from the bedrock then is reflected back down by the A layer and finally reflected to the surface by the bedrock; a BAB reflection. This is supported by the fact that D arrives at the calculated time for such a reflection as well as that many of the waveforms of D mimic the waveforms of B.

The A reflection is probably produced by the prominent clay sequence observed throughout the area. A's exact identity can not be established due to the distance of the wells from the seismic line. The B' reflection is not very strong but its close proximity to the bedrock suggests that it comes from the sand and silt or gravel layers found at the bottom of all the well logs in the area.

The high frequency waves and the large amplitude waves arriving after 130 ms on the CO profile are the airwave and ground roll respectively.

The results of the survey are that three detectable horizontal interfaces exist at 28, 44 and 70 meters beneath the surface. The strongest reflections are interpreted to be a clay and bedrock interface which show little lateral variation. This correlates well with the local sequence of even lake deposits on top of a level bedrock surface.

Things to consider: time delays and reflecting surfaces

There are two factors which must be considered when interpreting the seismic data. First, an inherent time delay is present when the shot gun shells are used as an energy source. The timing device in the seismograph starts when the firing pin makes contact with the primer of the shell, but the shock wave isn't produced until the black powder charge reaches peak pressure. For 10-gauge shells the delay is 2.4 to 3 ms (D. Cruz, personal communication, 1989). As a rule, one can expect the NMO depth values to be adjusted by 1 to 2 meters when correcting for this delay.

The delay affects the refraction results as well but the only detectable error was in the top layer. A thin layer could be calculated to exist at the surface by the refraction method which is caused solely by the delay.

The error produced by this delay in the reflection and refraction surveys are minor, systematic, and would not misdirect conclusions about the structure if the surveyor is aware of the delay.

Another important factor is the actual area of the interface that contributes to a single reflection impulse (the Fresnel zone). The size of the Fresnel zone, which is shaped like a thin ellipse with the long axis along the seismic line, depends upon the depth of the reflector, the offset between the energy source and the geophone, and the wavelength of the compression waves (Waters, 1987, p. 28). The long axis of the Fresnel zone for an offset of 36 meters, wavelengths from 6.6 to 13.3 meters (frequencies from 90 to 180 hertz), and depths at 30 and 60 meters was calculated to range from 17 to 30 meters in diameter. This is the absolute maximum size and assumes a perfectly horizontal reflector. When the slope and irregularities are taken into account the Fresnel zone shrinks.

This demonstrates that each reflection is not from a single point, rather from a discrete area, the length of which could be almost as long as the 36 meter offset. The resolution of shallow seismic reflection can not guarantee the detection of any structure smaller than 30 meters.

Discussion

The shallow seismic reflection method does provide much detail about the subsurface which is not revealed by refraction surveys. However, since thin, quaternary deposits may possess a great deal of lateral variation, they can not be reliably identified without the knowledge of the sequence of deposits (e.g. a log from a nearby well), and a strong marker bed (e.g. bedrock) to reveal the relative position of all reflections in the sequence. Once the reflections are identified at one end of the seismic line, the survey can continue for quite a distance without the need for more wells if there isn't too much lateral variation in the deposits. Site 4 is a good example of this type of extrapolation. The benefits of the reflection method are drastically reduced when these criteria aren't met as seen in Site 17.

Also, when working with unconsolidated sediments it is never certain that a thick layer will always produce a reflection at its boundaries. The reflection depends completely upon the degree of velocity variation for the layers on either side of the contact. Since the velocity ranges for all saturated, unconsolidated sediments overlap one another, none of these sediments would be expected to always reflect seismic waves at its boundaries. For Site 4, the top and bottom of the thick clay layer did provide good reflections but even in this relatively short CO profile the top reflection (A) began to diminished at the ends of the profile.

The possibility of multiple reflections must always be assumed. The BAB reflection in the NMO survey of Site 17 demonstrates that seismic waves can be multiply reflected even in unconsolidated sediment and appear to be reflections of layers beneath bedrock. Another source of false reflections are side reflections which come from the walls of buried valleys.

Overall the shallow seismic reflection method does well when used in appropriate areas. This method would be valuable when researching specific local trends in unconsolidated layers or if the local bedrock surface has variations in its surface relief which are too small to be detected by a seismic refraction survey.

References Cited

Whately Water Study, 1985, prepared for Town of Whately, Board of Selectmen, Whately, MA, Franklin County, prepared by Coffin and Richardson, Inc., Boston, MA.

Waters, Kenneth H., 1987, Reflection Seismology, 3rd ed.: New York, John Wiley and Sons, 538 p.

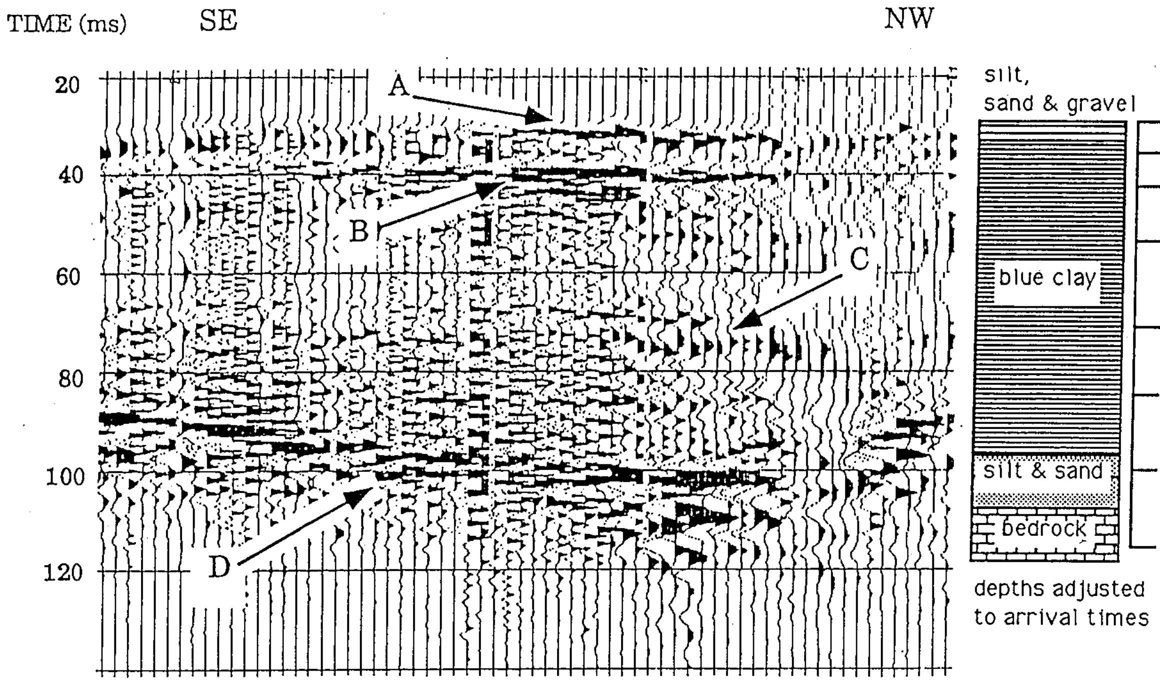

Figure 1. Site 4 Common Offset Profile.
A, refraction. Reflections: B, clay (top); C, clay (bottom); D, bedrock.

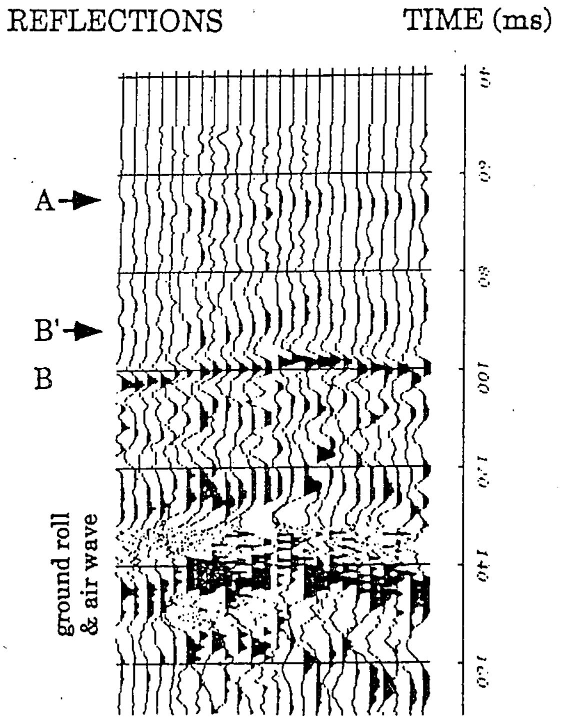

Figure 2. Site 17
Common Offset Profile

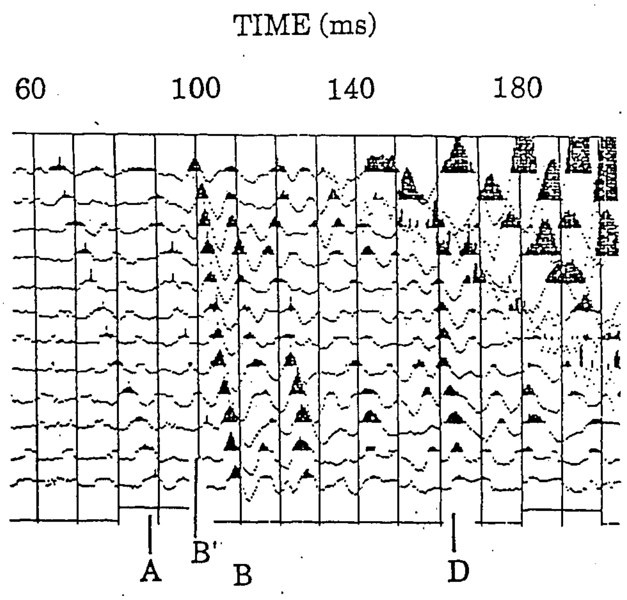

Figure 3. Site 17 NMO

A, clay; B', till(?); B, bedrock; D, multiple reflection.