SHEAR-WAVE INVESTIGATIONS IN POORLY CONSOLIDATED MATERIALS

by

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I. ABSTRACT

Shear-wave (S-wave) refraction is a powerful tool for investigation of the shallow subsurface. Compressional-wave (P-wave) refraction, while very successful for bedrock mapping, is not successful at differentiating bedding within the alluvial section. In poorly consolidated and saturated materials P-wave velocities are determined by the speed of sound in water (about 5200 feet/second). S-wave propagation is not greatly affected by water content, thus layering within the alluvial section can often be mapped with S-wave refraction.

Travel-time curves for models illustrating these points include a P-wave model with two alluvial layers over bedrock. The P-wave velocities of 1000'/s, 3000'/s and 7000'/s are shown to be masked by saturation within the alluvial section. Modeled S-wave velocities for the same section predict clear detection of the S-wave first arrivals. The acoustic (through the air) arrival can complicate the S-wave results.

A landfill investigation case-history is an example of the use of S-wave refraction. A suite of geophysical tools were proposed to assist in the sitting of monitor wells. The geologic setting is 10-70 feet of loess over 20-100 feet of till over limestone bedrock. Water table was within the loess but the loess-till interface (a potential aquiclude) was the primary target. GPR, DC resistivity, EM-34, P-wave refraction, P-wave reflection, and S-wave refraction were tested. GPR penetration was less than 15 feet and the resistivity contrasts between the loess and till were less than 30% thus the electromagnetic methods were discarded. P-wave refraction mapped the top of the water table, a secondary target. P-wave reflection mapped the top of bedrock (also of secondary interest). S-wave refraction produced excellent data and mapped the horizon of interest.

Why? Favorable geometry, favorable surface conditions, good field practice, and correlative information. The conclusions are: 1) in-field tests are required and 2) S-wave refraction is a method to be used for mapping interalluvial bedding unless ruled out by suprageophysical considerations.

II. INTRODUCTION

This paper consists of two sections. The first is a theoretical section illustrating a common problem in obtaining data within an alluvial section. The second section gives the results of a case study which confirms, under favorable field conditions, the results of the first section.

III. MODELING

Figure 2 contains a geologic model and a P-wave travel time curve. Horizontal layering is used to model what might be soil weathered-layer over a gravel tightly-packed layer over a weak bedrock. For the geometry and the velocities shown in Figure 2, clear first arrivals are received from each layer and each layer can be mapped. Figure 2 postulates the introduction of saturation within layer 2. No specific depth is given for the top of the water layer-simply a 5000'/s arrival is slapped on the travel time curve. Two positions are shown - one where the two deeper layers do not produce first arrivals (lower curve labeled W) and one where water, if present, does not interfere with the mapping process.

This model is generated for illustrative purposes only. A specific model would be used to sort out all the possibilities of thicknesses and depths. However, it is clear that the velocity in the saturated sediments crimps layer discrimination within the alluvial section. Imagine a shallower water table - even the bottom of layer 1 disappears!

A similar model for S-wave refraction is shown in Figure 3. Note the change of vertical scale due to the lower S-wave velocities. The layering is easily detected on the travel-time curve. Of course, all is not rosy - Figure 3 shows how the sound wave (denoted S) can interfere with S-wave phase identification.

IV. CASE STUDY

A landfill closure problem illustrates the use of the above results. The landfill, more than one-quarter square mile in extent, is being prepared for closure. More than 25 drill holes on the periphery have defined the geologic problems. To assure

proper sampling and treatment of fugitive waters, if necessary, the additional holes must be optimally placed on the hydrogeologic drainages.

The geologic section includes 10-70 feet of loess, 20-100 feet of two formations of till and a limestone bedrock. Some alluvial sand and till detritus appears above and below the till in some holes. The hydrogeologic section includes a shallow water table (1-20 feet) and an identification of the top of the till as an aquiclude.

The geophysical objectives were to map the top of the aquiclude and the interformational sands. Secondary objectives were the top of the water table, the till-till boundary, and the top of bedrock. Geologic descriptions did not indicate a strong physical contrast at any boundary except the top of bedrock.

Due to the lack of contrast based on a priori knowledge, a test phase was recommended. GPR, DC resistivity, EM-34, P-wave refraction, P-wave reflection, and S-wave refraction were considered. Deep penetration by GPR and shallow results from the reflection were not anticipated.

Figure 4 gives the results of the electrical methods. Though some differentiation is apparent on the Schlumberger sounding and the EM-profile, modeling of the potential quantitative results using these methods indicated insufficient resolution for the objectives of the survey.

The reflection results (not shown) gave a clear reflector identified as the bedrock. Cost of mapping this secondary objective was to high for the results attained. The P-wave refraction, as anticipated, mapped the water table (see Figure 7). Again, the results were of some interest, but not particularly germane to the primary objectives. GPR (not shown) was not effective in detecting buried objects at 10-15 feet.

S-wave refraction produced records of excellent quality (see Figure 5). This quality is due to a combination of the following factors:

1. Low S-wave velocities minimize acoustic interference.

2. Fine grained sediments on surface improve source coupling and improve geophone plants.

3. Grass and weeds minimize acoustic interference.

4. Factor of 1.5 contrast of S-wave velocities at interface.

Results of a <u>TYPICAL</u> line are shown as Figure 6. The depth in the hole is the loess-till boundary.

Figures 8 and 9 show the utility of the geophysics. Figure 8 is the cross-section hypothesized from the drill holes. Note that the formation boundaries between drill holes are extrapolations. Figure 9 contains the results of the shear-wave refraction. The cutout into the Kansan Till and the edge of the sand-loess material is now well located and its geometry defined.

The sub-till sands were too thin (3-7 feet) to detect. A test of refraction mapping of the bedrock was not done (explosives were not allowed). The geophysical boundary exhibits a large S-wave velocity change and is interpreted as the aquiclude.

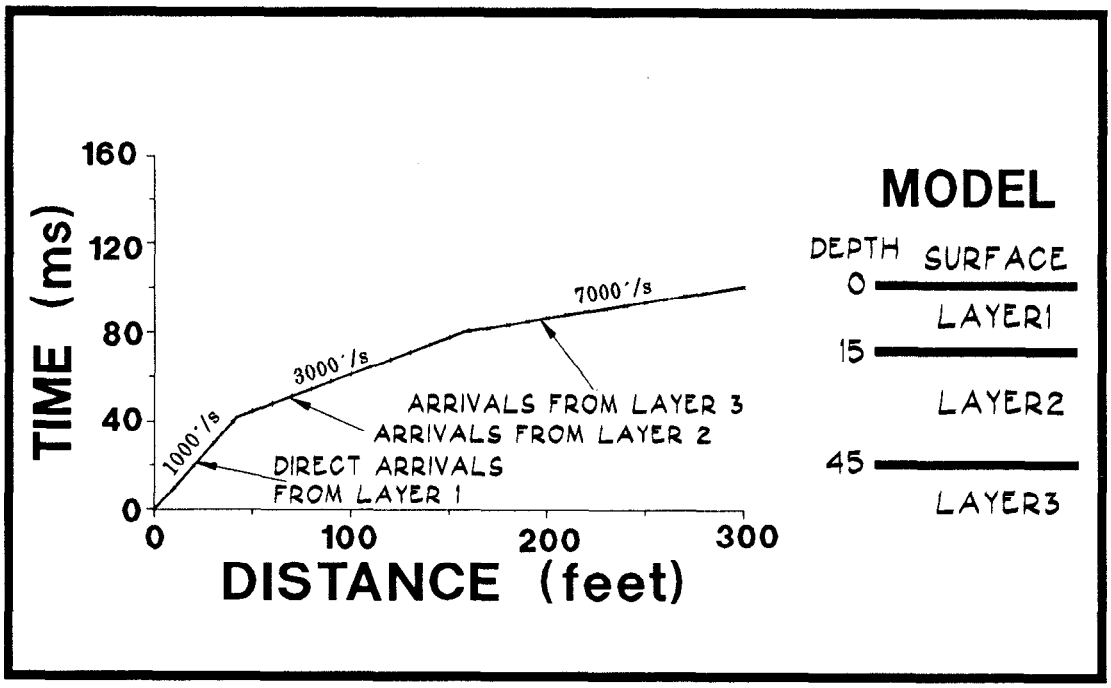
V. DISCUSSION

Where the geophysical properties are poorly known, a test phase may be required. S-wave refraction was the only tool to achieve the primary objective of mapping the loess/till boundary on this project.

S-wave refraction is a powerful, but not infallible, tool for mapping boundaries within poorly consolidated sediments.

VI. ACKNOWLEDGEMENTS

Norm Hanson of Douglas County Nebraska Special Services furnished the landfill. Roger Helgoth of Jacobson Helgoth Consultants assisted in the development of the QA/QC plan for the work. Don Hansen of MGC swung the hammer.



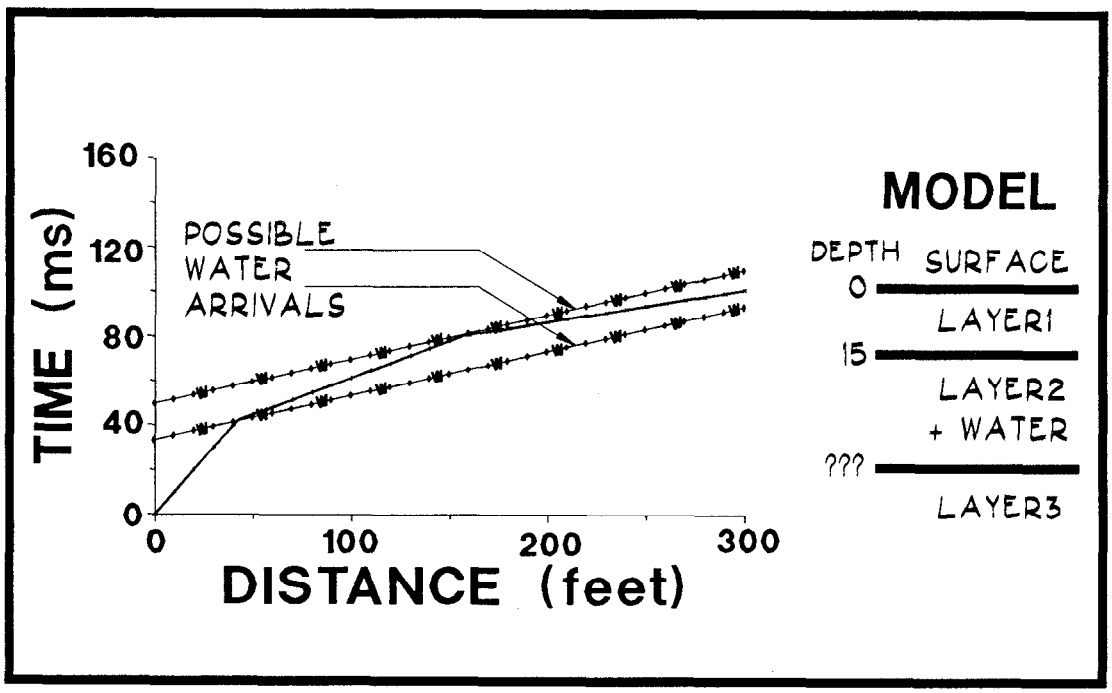
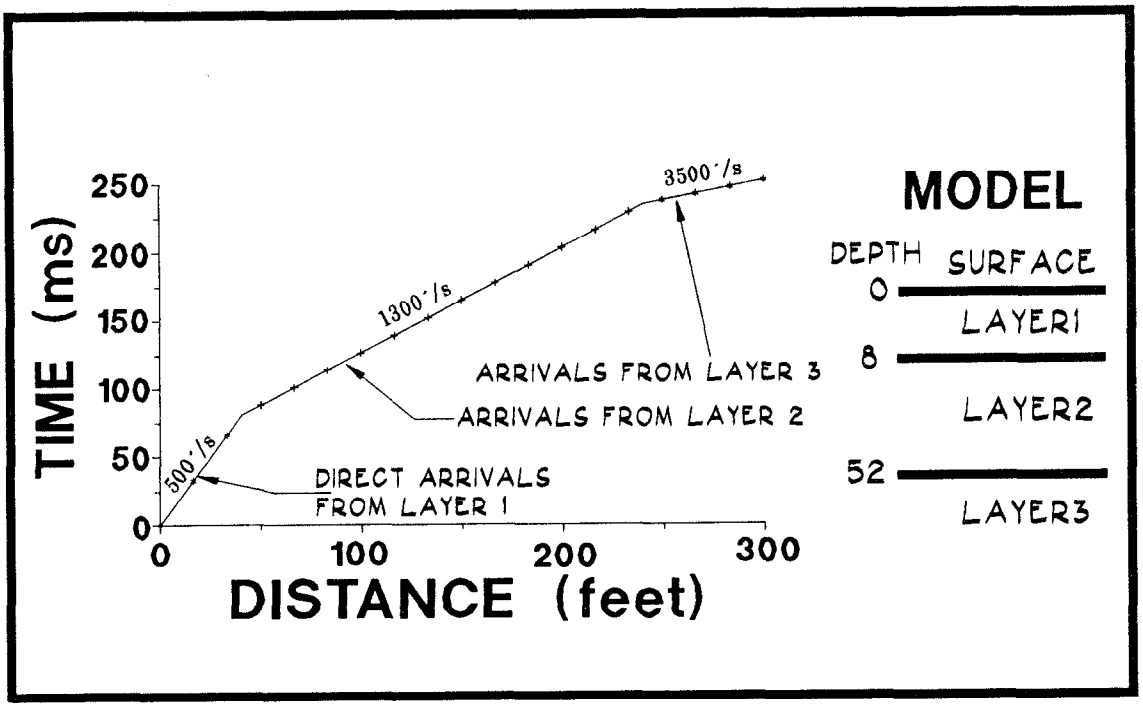


FIGURE 2: Upper graph shows a model and the resulting travel time curve for typical P-wave velocities. Lower graph show a similar model with a saturated layer of variable thickness introduced.



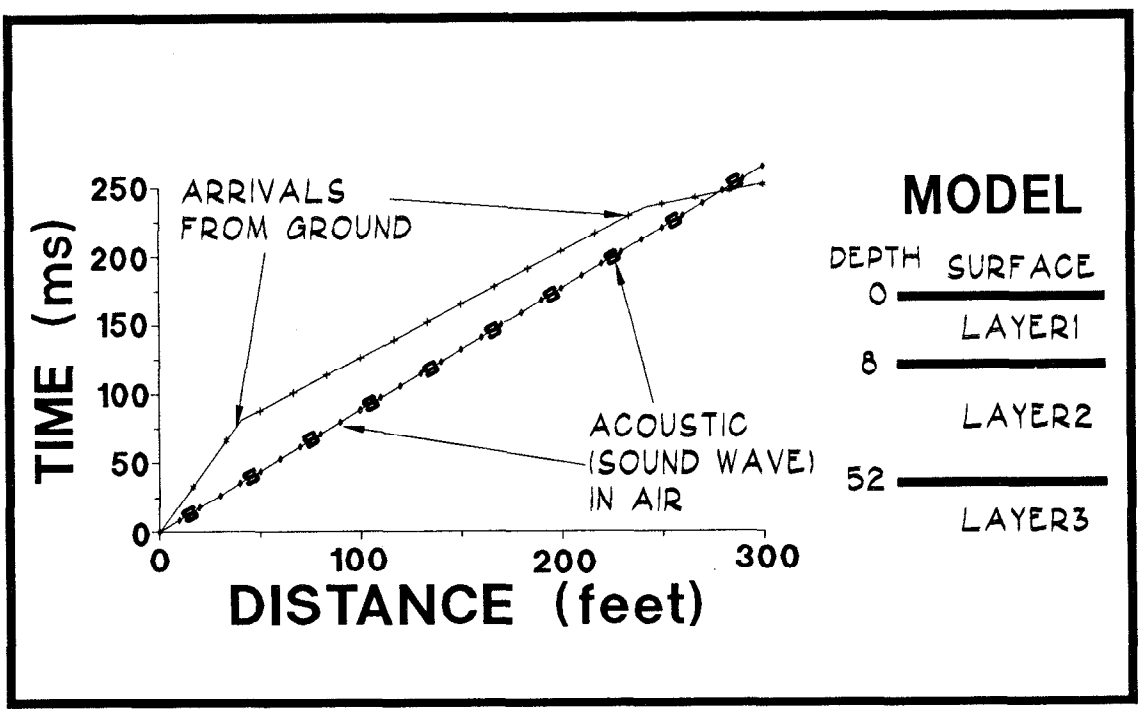


FIGURE 3: Upper graph is model and travel time curve for S-wave example. Lower graph indicates the location of the acoustic wave on the travel time curve.

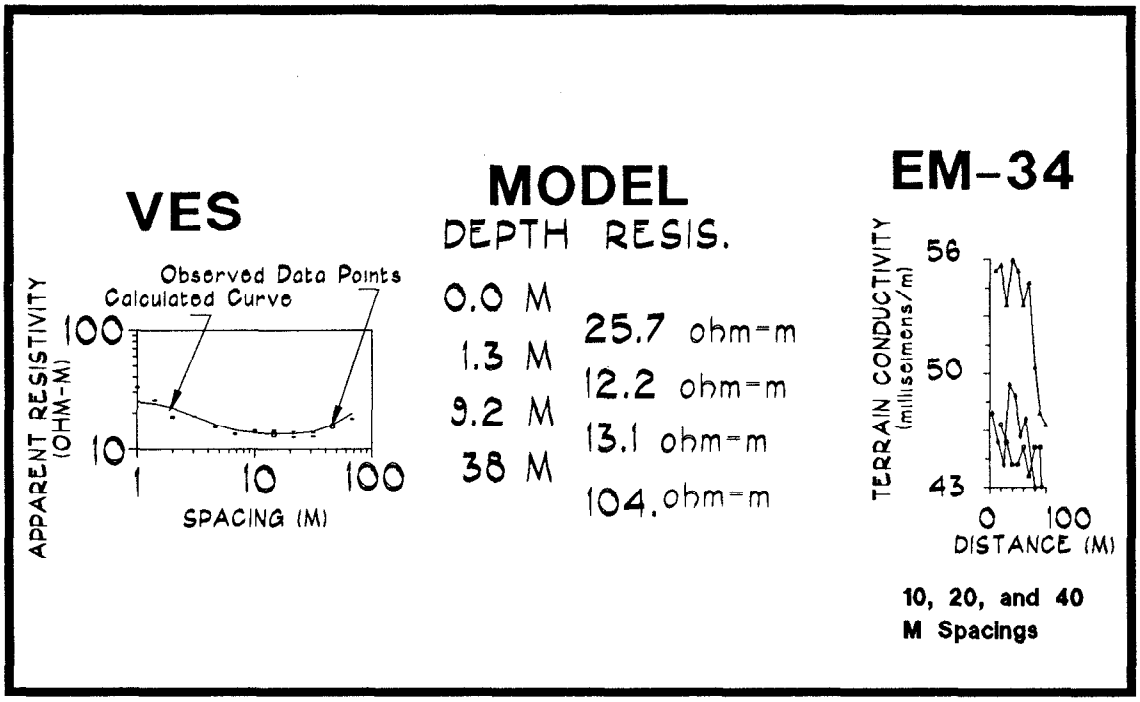


FIGURE 4: DC resistivity results, DC model results, and EM-34 Profile.

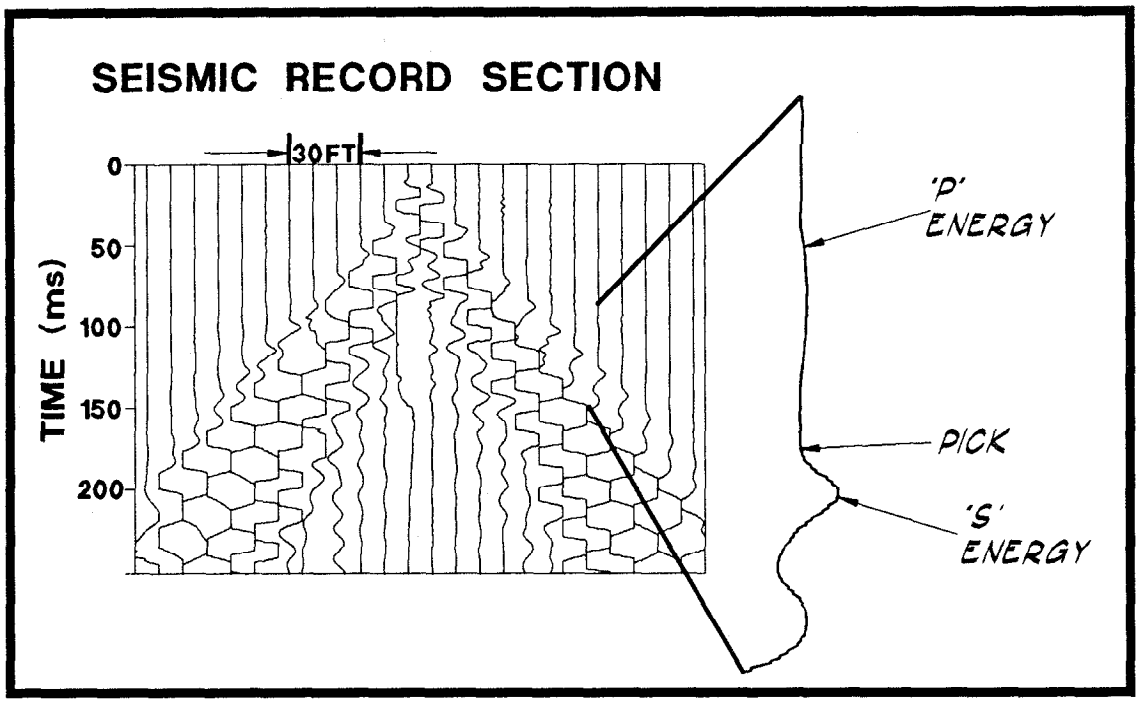


FIGURE 5: Example of Shear-wave record. Expanded trace identifies "S" and "P" energy confirmed by dual trace plots.

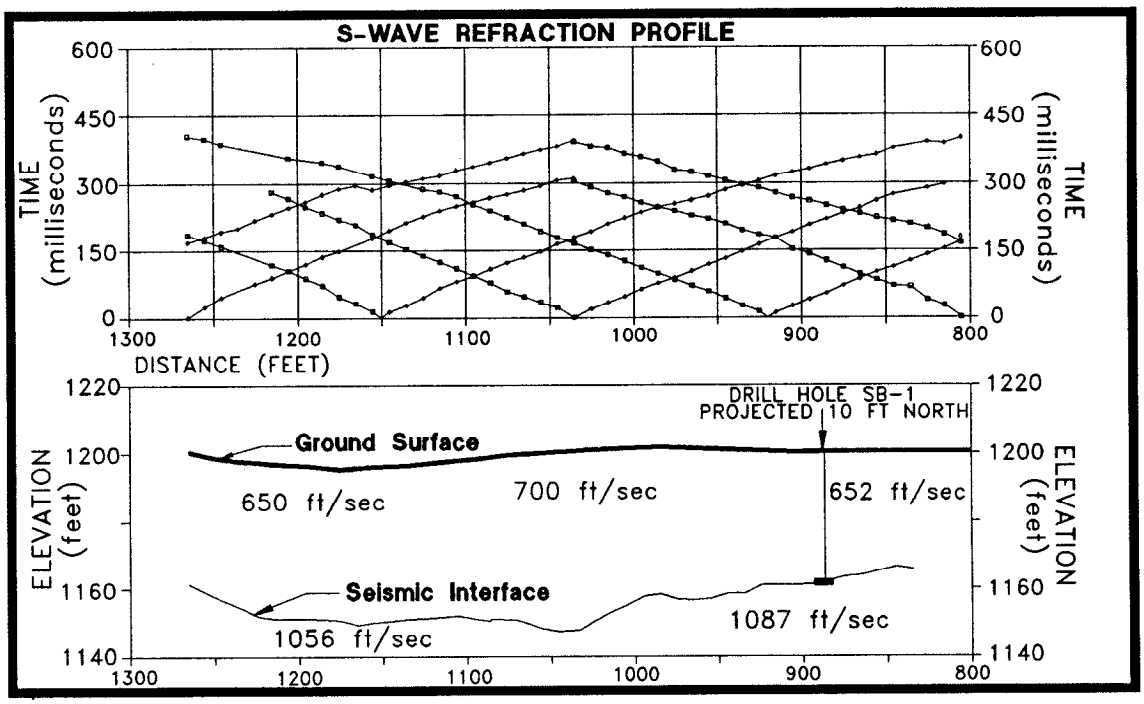


FIGURE 6: Typical interpreted seismic section. Drill hole results show loess/till boundary. Note minor 'leg jumping' on travel-time curves.

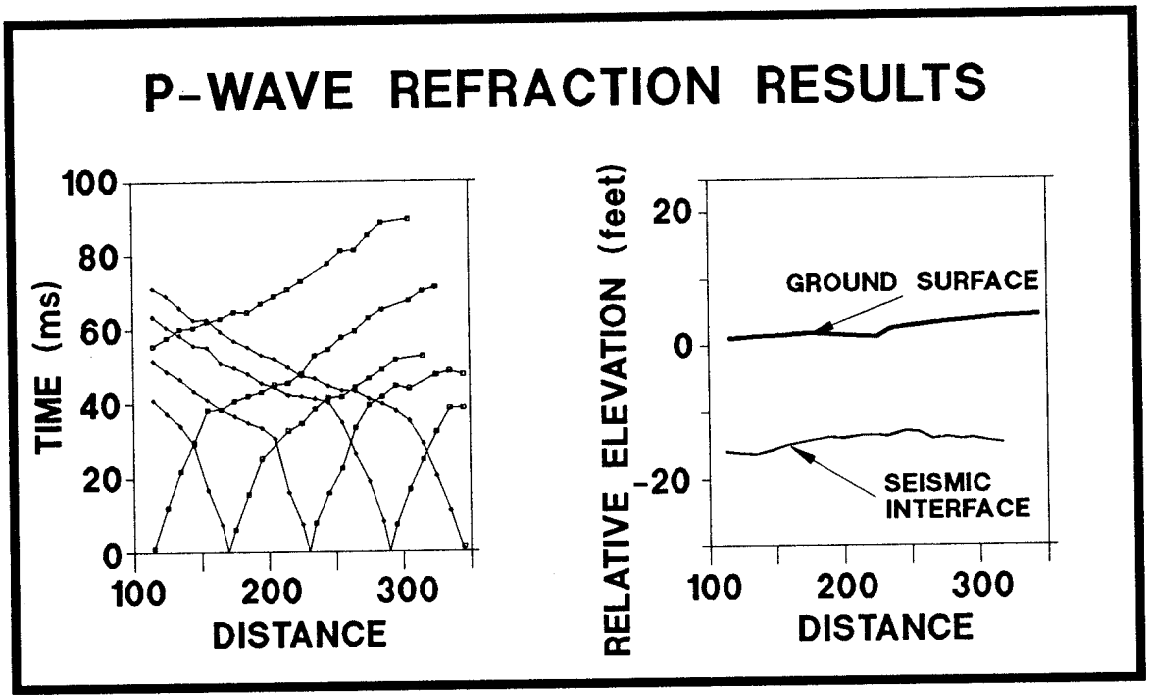


FIGURE 7: P-wave refraction travel-time curves and interpreted cross-section.

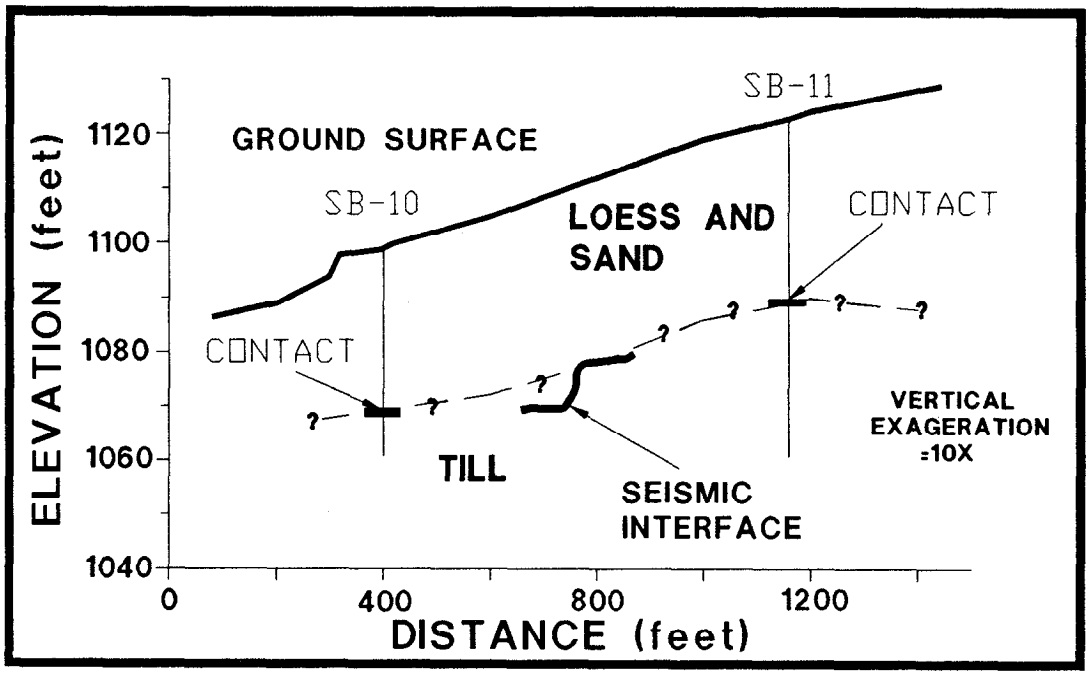


FIGURE 9: Cross-section between soil borings nos 10 and 11 after seismic work.

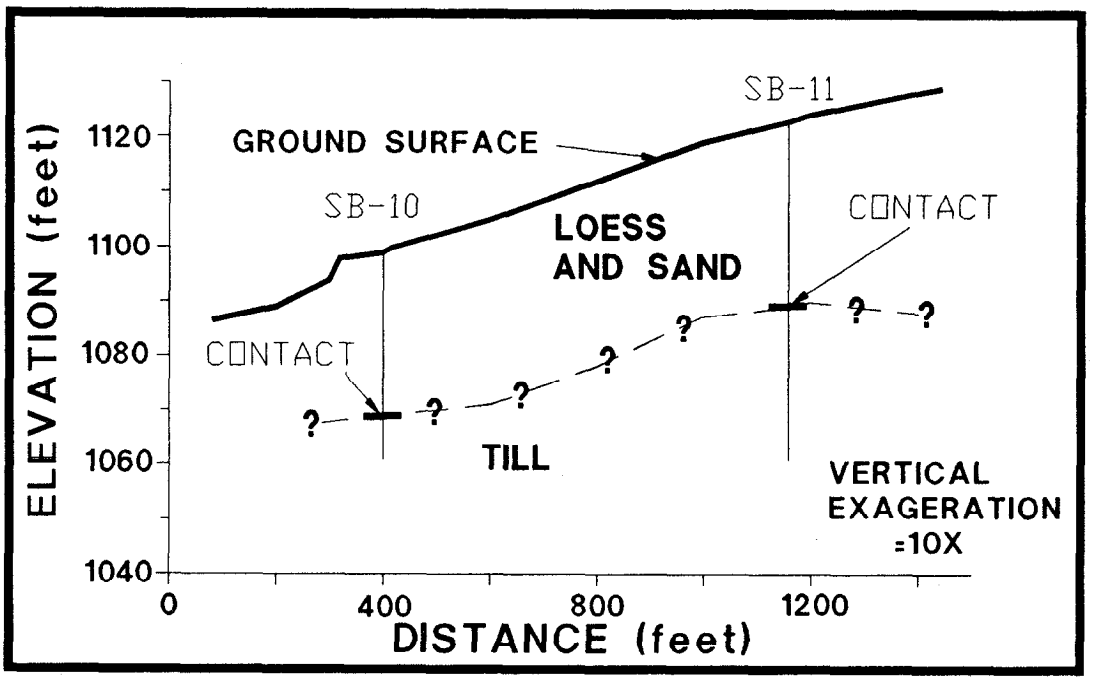


FIGURE 8: Cross-section between soil borings nos 10 and 11 before seismic work.