Weathering Structure of Southwestern Niger Delta, Nigeria.

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ABSTRACT

Seismic refraction survey was conducted in southwestern Niger delta to determine the weathering structure. The velocity and depth of the weathered layer and the velocity of the refractor in the area were calculated from critically refracted arrivals using flat layer models. Using the time-intercept method for interpretation, the thickness of the low velocity weathered layer in the area varies from 3.6 m to 46.2 m with a regional average of about 24.0 m. The weathered layer and the refractor beneath it have an average P wave velocity of about 600.0 m/s and 1842.0 m/s; respectively. The knowledge of the weathering structure is extremely valuable for oil and groundwater exploration in the area of study. The structure is also interest to those engaged in civil engineering practice.

(Keywords: seismic refraction, weathering structure, P wave velocity, refractor)

INTRODUCTION

A low velocity layer (LVL) refraction survey was conducted in the southwestern region of the Niger Delta from February to March in 2003. In this study, seismic refraction data were collected over the area (Figure 1) with the aim to determine the depth of the weathered layer and the shallow velocity structure required for petroleum and groundwater exploration.

Seismic refraction methods have been used in petroleum, mineral, engineering, coal investigations, and for hydrologic applications. While seismic reflection techniques have dominated the deep exploration works during recent years, shallow exploration works have used seismic refraction techniques extensively. To utilize the technique effectively, one must understand its principles, limitations, advantages, equipment, field procedures, interpretation procedures and potential uses.

LOCATION AND BRIEF GEOLOGY

The study area is enclosed by the geographical grids 6^0 10^1 to 6^0 42^1 N and 5^0 40^1 to 6^0 12^1 E (Figure 1). The area is part of the Niger Delta complex. The sediments are unconsolidated and have a highly variable thickness throughout the region. The Niger Delta is located between longitude 4^0 to 9^0 E and latitude 4^0 to 6^0 N (Figure 1). It is made up of fresh water swamps and mangrove swamps with relief that increases towards the north.

The Niger Delta is characterized by both marine and mixed continental depositional environments which is believed to have originated during the Eocene era (Aseez, 1976; Novelli, 1974). The Niger Delta is composed of three sedimentary formations, namely; the Benin, the Agbade, and Akata formations. The Benin Formation consists of coarse-grained, gravelly sandstones with minor intercalations of shales. It is a continental deposit of Miocene to younger age and has a thickness in excess of 1800 m. Typical outcrops of the Benin Formation can be seen around Benin, Onisha, and Oben where this survey was carried out (Figure 2).

The Agbada Formation consists of alternating sandstones and shales and is fluviomarine in origin. It is Eocene in age in the north and Pliocene in the south. These sands, sandstones and marine shales which make up the Agbada Formation has a maximum thickness of about 4600 m. The Akata Formation consists of shales with local interbedding of sands and siltstones.

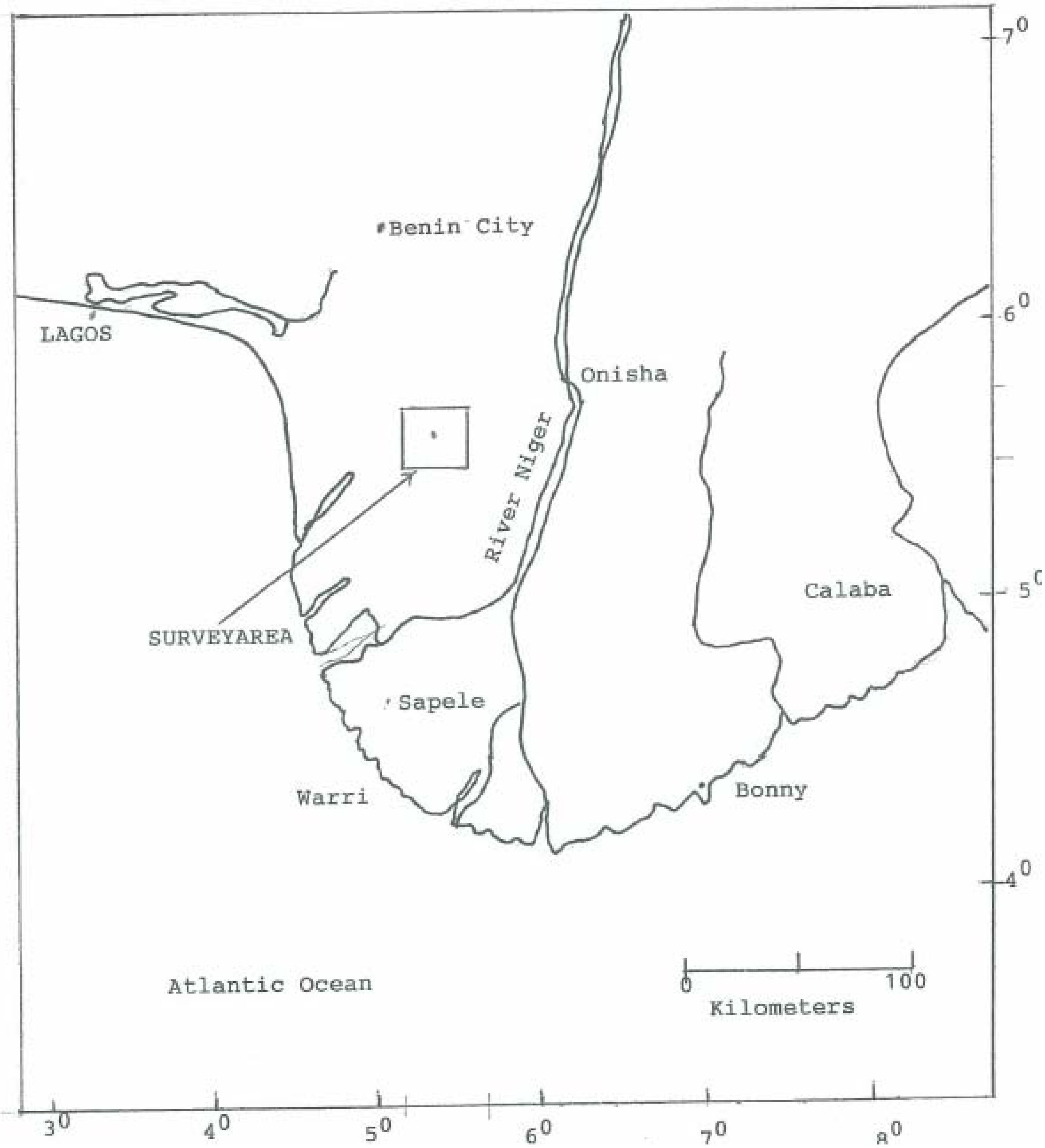

Figure 1: Southern Nigeria showing the Niger Delta Region and the Study Area.

It was deposited in a marine environment and has a maximum thickness of about 6500 m (Hospers, 1965; Short and Stauble, Kogbe, 1976).

THEORY

Many textbooks and numerous journal articles present details of seismic refraction theory (Dobrin, 1976; Mooney, 1984; Slotnick, 1959; Musgrove, 1967; Telford, 1976; Parasins, 1979; Grant and West, 1965). Therefore the following discussion only reviews the very basic principles of the seismic refraction method.

The foundation of seismic refraction theory is Snell's law, which governs the refraction of a sound or light ray across the boundary between layers of different physical properties.

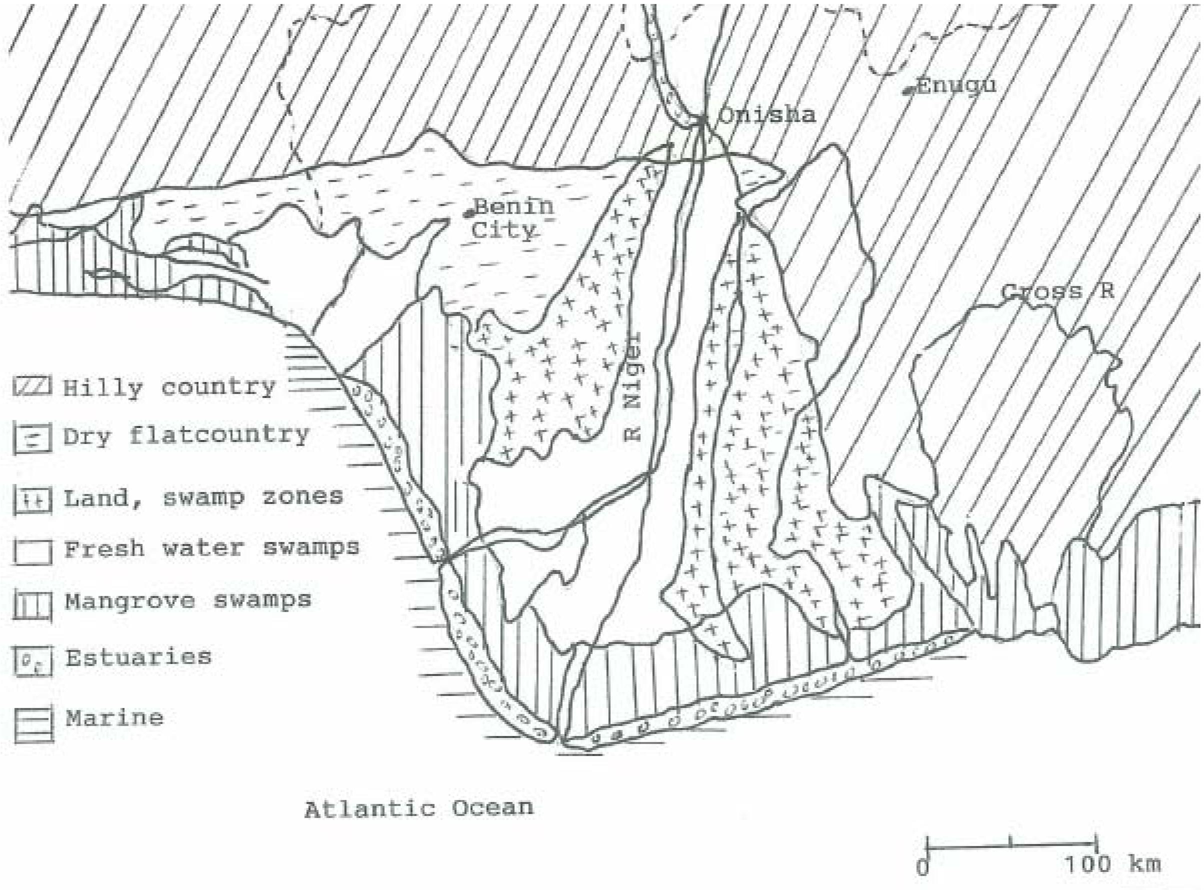

Figure 2: Geological Features and Sedimentary Environment of the Niger Delta (after Short and Stauble 1967).

As sound waves travel from a medium of low seismic velocity into a medium of higher seismic velocity, some are refracted toward the lower velocity medium and some are reflected back into the first medium. As the angle of incidence of the sound ray approaches the critical angle (an angle where the refracted ray grazes the surface of the contact between the two media), most of the compressional energy is transmitted along the surface of the second layer, at the velocity of sound in the second layer.

As this energy propagates along the surface, it generates new sound waves in the upper medium (Huygens' principle; every point on an advancing wavefront can be regarded as the source of a new sound wave) that in turn propagate back to the surface at the critical angle and at the seismic velocity of layer one. For seismic refraction to work, therefore, the velocity of sound in each deeper layer must be greater than in the layer above it. When this condition is met, the refracted wave arrives at the Earth's surface where it can be detected by geophone which generates an electrical signal and sends the signal to a seismograph.

From a series of geophones placed on the ground, the seismic arrival time versus the shot-to–detector distances (Figure 3) can be plotted to give a time–distance curve. Examples of time-distance curves for a wide variety of geologic sections are shown in Zohdy et al. (1974) and Mooney (1984).

Figure 3 shows that at distances less than the crossover distance, the sound has traveled directly from the sound source to the detectors. Because the compressional waves has traveled a known distance in a known time, the velocity of layer one can be calculated. In the time-distance curve, v_1 is equal to the inverse slope of the plotted line, or:

$$V_1 = \frac{\Delta x \quad (m)}{\Delta t \quad (ms)}$$

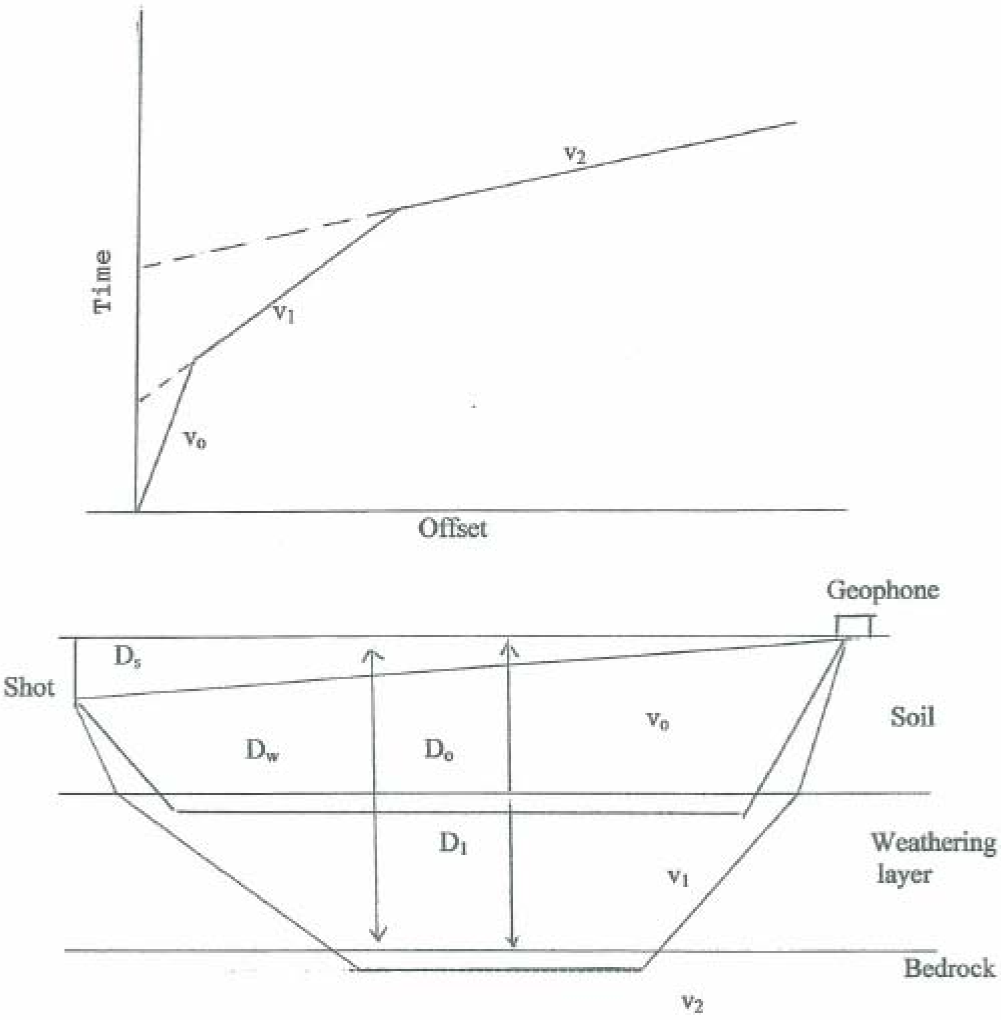

Figure 3: Theoretical Ray Paths and Travel Time Graph for a Two Layer Model.

where v_1 is the velocity of sound in layer one,

Δx is the change in distance,

and Δt is the change in time.

At the crossover distance and beyond, the sound wave that has traveled through layer one, then along the interface of the high-speed layer (layer two), then back up to the surface through layer one, arrives before the wave that has been in the slow layer all the time. All first compressional wave arrives at geophones with distances larger than the crossover distance will therefore be refracted waves from the high speed layer.

When these points are plotted on the time–distance curve, the inverse slope of this segment equals the apparent velocity of layer two, which is the true velocity of layer two if it is parallel to the land surface. To determine the true velocity of layer two when it is dipping, the shot point will have to be placed at the opposite end of the geophone line, a reversed time- distance curve will have to be plotted and the true velocity will have to be calculated.

The intercept time and crossover distance (Figure 3) are dependent upon the velocity of the two materials and the thickness of the first layer and can be used to determine the thickness of the first layer.

For a two layer medium in which the energy source is located at a depth of D_s in the weathered zone (Figure 3), the thickness of the weathered layer is given by (Knox, 1967 and Dobrin, 1976):

$$D_0 = \frac{t_1}{2} \frac{v_1 v_0}{\sqrt{(v_1^2 - v_0^2)}} + \frac{D_s}{2} \qquad \textbf{(1)}$$

$$D_1 = \left\{ t_2 - \frac{2 D_0 \sqrt{(v_2^2 - v_0^2}}{V_2 v_0} \right\} \frac{v_2 v_1}{2\sqrt{(v_2^2 - v_1^2)}} \qquad \textbf{(2)}$$

where t_1 and t_2 are the intercept times on the time-distance graph and v_0 is the velocity of the first layer. The velocities of the second and third layers are v_1 and v_2, respectively and the sum of D_0 and D_1 is the total thickness of the weathered layer D_w. Several assumptions were made in the derivation of these equations. The seismic wave travels along straight ray paths with velocities that are constant within each layer. The layers are assumed to be homogeneous and isotropic. This is equivalent to the layer cake model used in refraction seismology.

FIELD TECHNIQUES

The data were acquired at fifty locations in the study area (Figure 4). We tried in most cases to closely follow horizontal or near horizontal ground surfaces in our survey setup so as to approximate the horizontal bedding assumption. Minimum and maximum source-receiver distances of 5.0 m and 200.0 m, respectively, were found to reduce noise and to reach expected depths of interest. This geometry was chosen after some preliminary tests were conducted in the survey area.

The geophone interval was 5.0 m and this provided adequate resolution for the survey. At each location, two overlapping reversed profiles were shot using a total of 24 geophones. Each shot was located in a shot hole at a depth of about 1.0 m and was 0.25 kg dynamite. Travel times were recorded manually in the field after each shot.

DATA ANALYSIS AND INTERPRETATION

The recorded travel times were plotted against the source-receiver distance. Figure 5 shows a typical travel time curve obtained at one of the sites. One can observe the low scatter of the plotted data points in this figure. The travel times were used to calculate both the thickness and the velocity of the underlying half-space. The data points were divided into segments. Each segment was fitted to a straight line whose slope represents the inverse of the velocity of the medium. The intercept time is related to the thickness of the medium. The layer thicknesses and velocities were calculated separately for each shot using Equations (1) and (2). The average thicknesses and velocities for various receivers were computed and plotted them at the shot location at the end of the line of profile and were used for the interpretation.

The interpreted data show a substantial variation of the weathered thickness in the survey area; varying between 3.6 m and 54.2 m. This indicates the necessity of correcting for this layer during seismic reflection exploration. The average thickness of the weathered layer in the survey area is about 25.0 m. It has an average velocity of about 600 m/s, while the velocity of the underlying consolidated layer has an average velocity of about 1842.0 m/s. The velocity of the consolidated layer tends to be lower than the average towards the south and considerably higher towards the north indicating a general increase in the velocity with the amount of consolidation of the bedrock. The first measured velocity of about 350 m/s is due to the air wave. A vertical velocity gradient of 7.5 s^{-1} was computed for the area. This velocity gradient can be used to determine the velocity at the depth of the weathered layer in the absence of any other information before exploration in the area.

The characteristics of the southwestern region of the Niger Delta can be deduced from the results of the study as follows:

The weathering layer has an average thickness of 24.0 m for the area. The thickness increases from about 18.0 m in the south to about 30.0 m in the north as the elevation increases , there is an anomalous thickening of the weathered layer to the northeast of the survey area where it reaches a thickness of about 46.2 m. The weathered thickness follows the general trend of the elevation, decreasing southwards toward the coast.

The average air wave velocity for the area was determined to be 342.0 m/s and that of the weathered layer is 520.0 m/s.

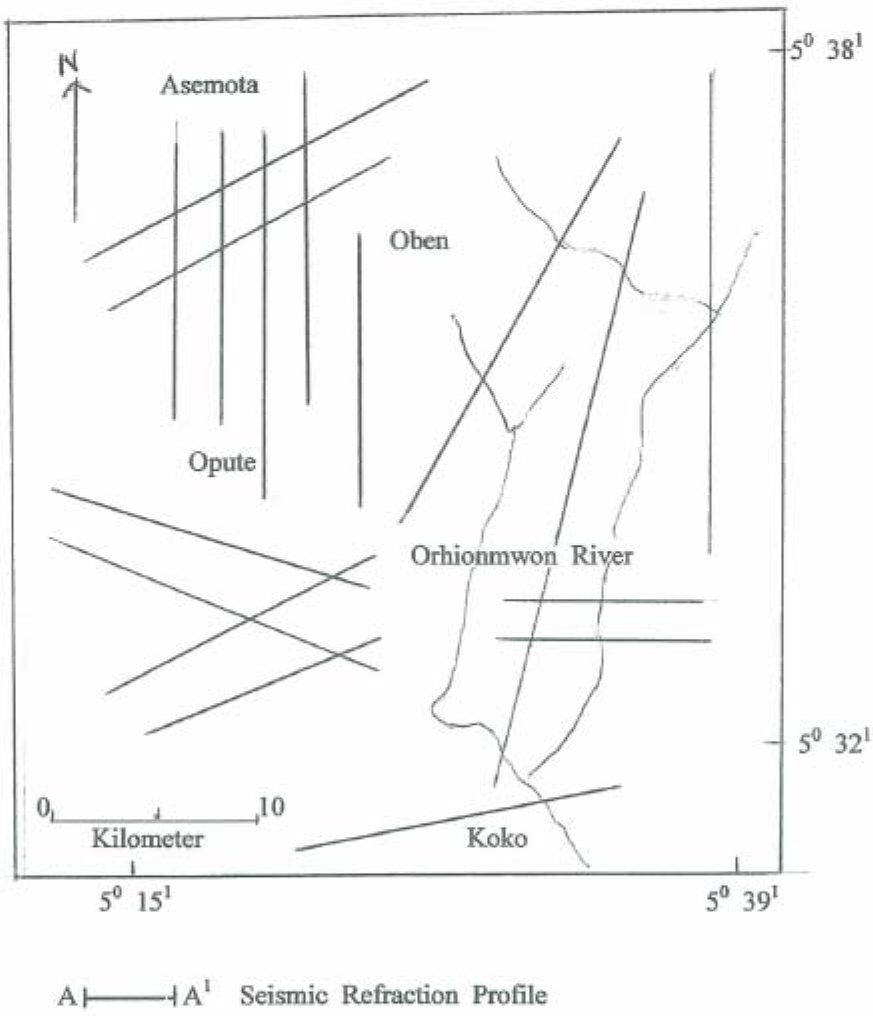

Figure 4: Location of Seismic Refraction Profiles shown on the Base Map of the Area.

A vertical velocity gradient of 7.5 s^{-1} was determined for the area. The velocity of the subweathered layer is 1842 m/s.

CONCLUSIONS

The information obtained from this study is extremely important to determine the time delays needed for static corrections during seismic reflection data processing. It is important to know the depth to the base of the weathered layer before a seismic survey. The knowledge of the thickness of the weathered layer is needed in order to locate the energy source at appropriate depths so as to reduce the ground roll that will interfere with the reflection data. Besides reducing the ground roll, the energy transmitted into the surface can be maximized by placing sources below the weathered zone.

The base of the weathered layer usually coincides with the depth of the water table (Haeni, 1986). This is consistent with the observed decrease in thickness of the weathered layer southwards towards the coast where the water table becomes shallower.

Because of the large regional variation in the thickness of the weathered layer, prior information of the character of the weathered layer is required for exploration purposes. The information obtained in this study would be of interest to those involved in civil engineering projects.

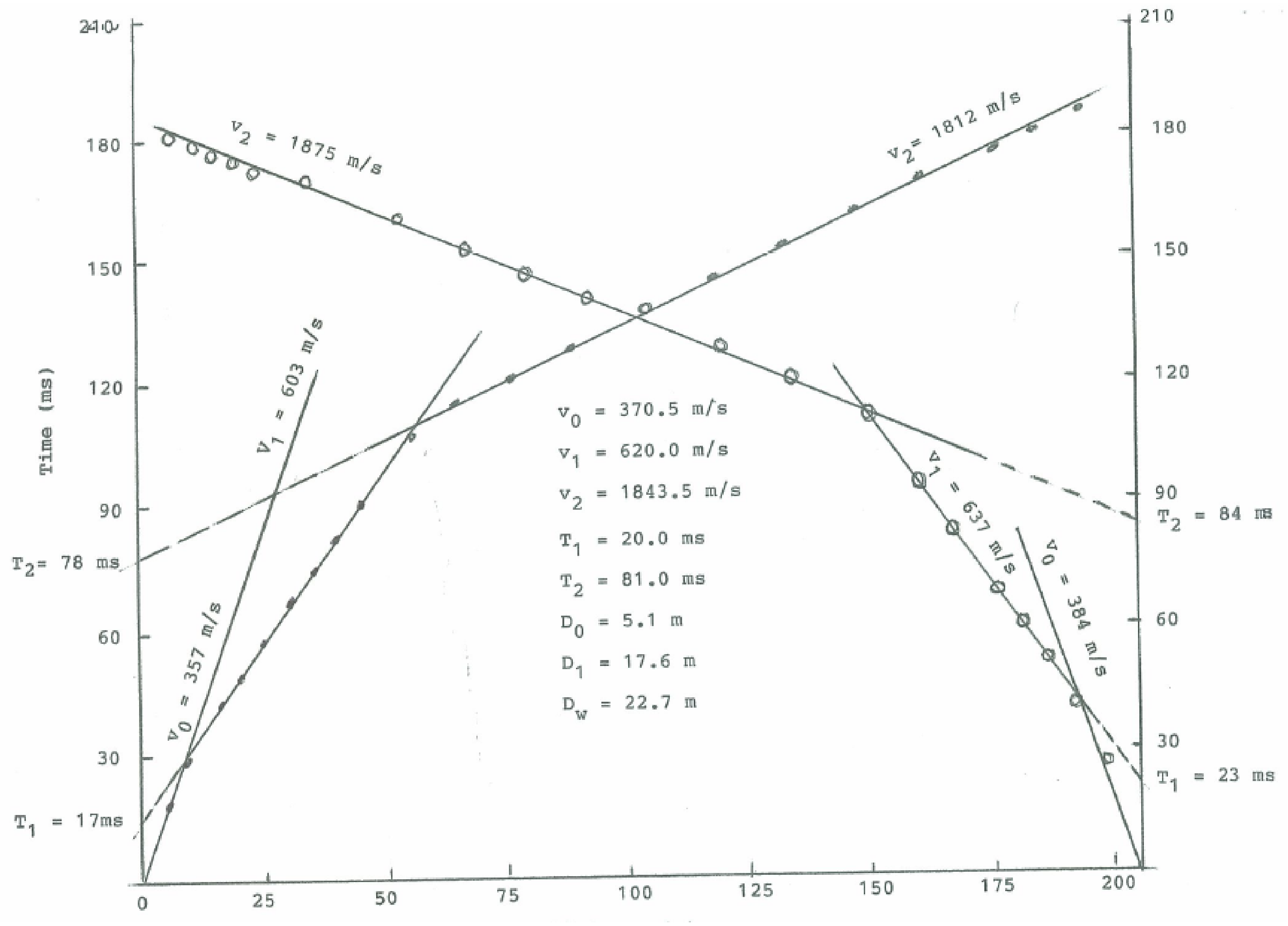

Figure 5: Typical Time-Distance Plot Recorded During the Study.

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