SITE INVESTIGATION

BY THE

SEISMIC REFRACTION METHOD

Special Application to Lebanon

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PREFACE

At present Lebanon is witnessing a boom in construction of buildings and highways. The majority of these projects are being designed based on no real study of the subsurface foundation conditions, and contractors are pricing many projects without knowing the real picture of the subsurface. This may be attributed to many factors, major among which are the high cost of borings, and the non-availability locally of a soil exploration method which would detect the subsoil formations at low price and without much delay.

There are however several geophysical methods that may be used for soil exploration. The seismic refraction method is probably the most rapid and effective for shallow prospecting especially when used in conjunction with borings. Soil exploration carried out in this way will reduce the number of boreholes required and will thus result in the saving of time and money.

ABSTRACT

This thesis presents an investigation of the possibility of using the seismic refraction method for the purpose of subsurface soil exploration in Lebanon.

An introduction to subsurface soil exploration together with a review of different geophysical methods used are given. This is followed by the theoretical considerations of the refraction method of subsoil exploration and the description of the instrument used as well as the field operations. In order to check the possibility of the application of this method in Lebanon, several sites were explored and the results and test analysis are presented.

It was found that both the method and the Terra-Scout seismograph which was used have some drawbacks. However in spite of these short comings, and if prior knowledge of the subsurface is available through boreholes or other means, reasonable estimates of subsoil conditions can be extended over wide areas.

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Chapter I

INTRODUCTION TO GEOPHYSICAL PROSPECTING

Considerable field and design practice is required to obtain proper exploratory data on a project and to give them an adequate engineering interpretation. Such ability cannot come from just a book or a paper, but from extensive practice and experimentation. This thesis should therefore be considered as merely an aid in gaining some background knowledge in the vast realm of subsurface explorations. Existing subsurface exploratory methods are not something final or rigid but are subject to development and improvement. To make the most efficient use of available exploratory methods in a given locality, the investigator should be acquainted with geology in general and with local geological conditions in particular.

Geophysical exploration is a form of field investigation in which physical measurements normally are made at the ground surface by using special instruments to secure subsurface information. It is a blend of physics and geology because the physical measurements are interpreted in terms of subsurface geological conditions.

Geophysical prospecting is one of the newest branches of applied science. Within the past three decades it has become a weapon of first-rank importance in man's incessant struggle to maintain and increase his yield of fuels and raw materials from the untapped stores hidden beneath the earth's surface. It has permitted the determination of data which bears directly on the cost of civil engineering projects. In fact, the thickness of soil and rock, the location and size of sand and gravel deposits, the profile and rippability of rock and the elevation and extend of water tables can all be determined, at relatively low cost, by the geophysical prospecting methods.

Geophysical prospecting differs from core boring and other standard engineering exploratory methods in that the information obtained is always indirect and not subject to direct visual verification.

The geophysical methods used in investigating the shallow features of the earth's crust vary in accordance with the physical properties of the rocks of which these features are composed, but broadly speaking they fall into four classes. On the one hand are the "static methods" in which the distortions of a static physical field are detected and measured accurately in order to delineate the features producing them. The static field may be a natural field like the geomagnetic, the gravitational or the thermal gradient field, or it may be an artificially applied field like an electric potential gradient. On the other hand are the "dynamic methods" in which signals are sent in the ground, the returning signals are detected and their strengths and times of arrival are measured at suitable points.. In the dynamic methods the dimension of time always appears. There is a small, as yet relatively unimportant, class of methods which falls in between the two just mentioned. These are called the "relaxation methods". Their feature is that the dimension of time appears in them as the time needed for a disturbed medium to return to its normal state. Finally there are what is called "integrated effect methods" in which the detected signals are statistical averages over a given area or within a given volume. The methods using radioactivity fall in this class.

The classification of geophysical methods into ground, airborne or borehole methods refers only to the operational procedure. It has no physical significance.

The following discussions are intended merely to acquaint the reader with some of the principal geophysical methods in use and their potentialities and limitations.

GRAVITY METHODS:-

These methods consist of measuring the gravitational field of the earth at various points on its surface. Due to the fact that earth is an oblate spheroid which rotates at a rate varying from about 1000 miles per hour at the equator to zero at the poles, and due to the fact that earth does not have a uniform density throughout all its mass, gravity forces are not the same at different points of the surface of the earth. By application of physical laws it is possible to correct for the above factors and arrive at a computed value of gravity for any point of the earth's surface. If, after these corrections have been made, the computed value of gravity does not equal the observed value, the difference between the two constitutes a gravity anomaly. Such anomalies must arise from irregularities in the distribution of mass in the earth's crust and can be interpreted as being due to geological features such as intrusions of light material like salt or heavy material such as basalt, or to faults or anticlinal or synclinal structures.

Instruments:- The difference in density between very light and very heavy rocks is not great enough to produce marked differences in gravity potentials. It follows that very sensitive instruments are necessary to measure the small differences in gravity potentials.

Various types of instruments are possible, but in practice pendulums and gravimeters are the devices most frequently employed. Both pendulums and gravimeters measure relative values of gravity.

Corrections applied:- All gravity measurements must be corrected for: 1) Latitude; 2) Elevation; 3) Material between station levels; 4) Tides.

Plotting of data:- In pendulum and gravimeter surveys, the corrected values of gravity are plotted beside the appropriate stations. Gravity anomalies are usually shown by contours drawn at a suitable interval through or around the observation points.

Interpretation of results:- The interpretation of gravity results is usually qualitative. In as much as gravity methods depend on measurements of density distribution in a gravitational field, no depth control is possible. In theory an infinite number of mass arrangements may cause any given anomaly, and it might appear that geologic interpretation of gravity measurements is impossible. However if the number of unknowns is reduced by making tentative and plausible assumptions (based upon the known geology), a qualitative interpretation can always be made. Thus knowledge of the geology of the area is very important. In civil engineering work it is usually possible to test these assumptions by a core drilling and with the data so obtained arrive at a reasonably reliable quantitative interpretation. Thus with a single drill hole at a considerably less expense than if borings had been used, a reasonably reliable estimate of subsurface conditions may be obtained.

Engineering applications:- Gravity methods do not appear to have been much used in civil engineering investigations so much as the seismic and resistivity methods. The main reason for this infrequent application is that gravity measurements are less easily interpreted in quantitative terms than are seismic layer velocities or the measured resistivity of rocks and soils. But because of their low cost a number of applications of the gravity methods seem possible; gravimeters can be used in searching for underground caverns which should produce recognizable negative anomalies, and, although the limits might still require detailing by core borings, application of gravity methods might entail less expense than exploring by core boring alone.

MAGNETIC METHODS:-

The magnetic methods are much like the gravity methods. The magnetic intensity of the earth's field is measured at a set of locations, and the values plotted and contoured in the same way as with gravity. Anomalies in the magnetic field are evidence of anomalies in the geological structure just as gravity anomalies are. Anomalies of the local geomagnetic field are produced by the variations in the intensity of magnetization in rock formations.

Instruments:- The ultimate cause of the earth's magnetism is unknown, but the intensity, direction, and variations have been measured with considerable accuracy. In practical work it is convenient to distinguish between the vertical and the horizontal fields, the former being the one more frequently measured. If a magnetic body is present, its existence will be disclosed by a change in the normal value of the magnetic fields for the area in question (magnetic anomaly).

Unlike the instruments used in gravity measurements, a great variety of commercial magnetometers are designed with relative ease. Those instruments compare intensities from point to point over the surface of the earth. Magnetometers are portable, and thus are easily adaptable to work in all types of terrain. Rapidly gaining in popularity is the airborne magnetometer which is used in aeromagnetic surveys offering thus a cheap and rapid reconnaissance method.

Corrections applied:- Strong anomalies are produced by wires, rails, pipes etc..causing the magnetic method to be best suited to poorly developed regions. However a number of corrections must be applied to magnetic observations:

1) Temperature corrections
2) Diurnal changes in the earth's magnetism must be taken into account
3) The influence of magnetic storms must also be considered
4) Rough terrains may give rise to anomalies.

Plotting of data:- The corrected results of magnetic surveys may be presented as lines of equal magnetic anomaly (isanomalic lines) or as curves along profiles at right angles to the assumed strike.

Interpretation of results:- Quantitative interpretation of the results of magnetic surveys is unusually difficult for the following reasons:

1) there is lack of depth control
2) magnetic anomalies in rocks are subject to great lateral and vertical variations, and are closely connected with their thermal history.

As a result, most quantitative interpretation is indirect, but in engineering work it is usually feasible to check the results by one or more core borings, thus greatly strengthening the interpretation. Thus the magnetic method should be used in cooperation with other subsurface exploration techniques.

Engineering Applications:- Magnetic measurements are useful wherever a body of magnetic rock (usually igneous) underlies the surface. Surveys of water supply potentials have been made in areas where the subsurface water is associated with magnetic anomalies. Concealed bodies of building stone (granite, basalt, etc..) may also be located magnetically. Magnetic surveys are used extensibely in military engineering for the location of mines, ammunition etc...

RADIOACTIVE METHODS (RADIOACTIVITY WELL LOGGING)

The object of radioactivity well logging is to measure the radiations emitted by radioactive substances in the rock formations adjacent to the walls of a drill hole and to plot the intensity of the radiations, in the form of a graph, versus depth. By proper interpretation of the results obtained the subsurface conditions can be known.

In radioactivity well logging (fig. I-1), an ionization chamber filled with an inert gas is lowered into the bore hole. There is a "source of neutrons" at the bottom of the ionization chamber (crosshatched in the figure).

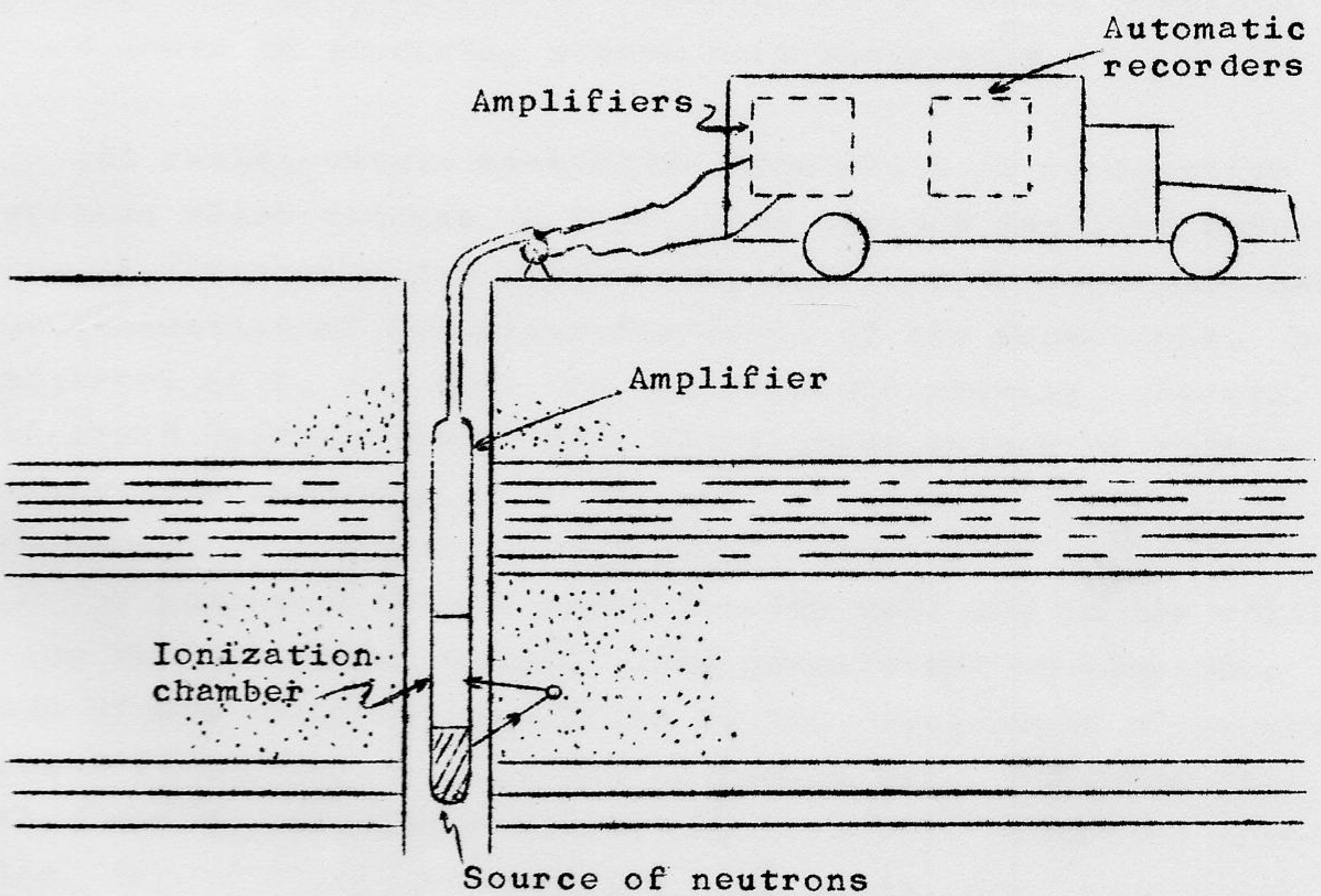

Fig. I-1. Radioactivity logging methods.

The fast neutrons leaving the chamber bombard the walls of the bore hole and, thus, release γ rays that ionize the gas in the ionization chamber. The electric current generated is amplified, and its voltage, which is proportional to the intensity of the γ rays, measured. An automatic recorder traces the log by plotting these measured values as horizontal ordinates from a vertical base line representing the hole. The mass of a neutron being nearly equal to that of hydrogen, the fast neutrons are slowed down by elastic collisions with hydrogen. Therefore in a formation containing a considerable amount of fluid (such as gas, oil or water) and thus porous, only a small percentage of neutrons actually bombards the formation thus resulting in a low γ ray value and hence a low voltage.

The neutron curve used in combination with the radio-activity well logging can be interpreted to locate possible porous zones in producing strata very accurately.

All rocks contain measurable quantities of radioactive materials which release γ rays, thus besides locating saturated zones in limestones and sandstones, the neutron logs also give some indication of the classifications of the formations. Sand, limestone, salt, and coal are low in radioactivity, whereas, shales and volcanic ashes have the highest values of radio-activity encountered.

The advantage of the radioactivity well log is its ability to log through steel casing. This permits the statigraphic study of old wells drilled prior to the development of geophy-sical well-logging methods now in common use. Moreover this method can be used under almost any bore-hole condition (cased holes, dry or filled with fluid; open holes, dry; open holes filled with mud or water; open holes filled with oil or gas).

Simplicity of interpretation of the results is one of the primary advantages of logging by radioactivity means. However, a limitation to the method is the fact that a drill hole or an old well needs to exist within the site to be explored. As a result, radioactivity well logging is being oriented towards ground water studies and soil moisture determinations rather than civil engineering exploratory work.

ELECTRICAL METHODS (RESISTIVITY METHOD)

The electrical conductivity and its reciprocal, the resistivity of rocks or soils, are a function of the amount of dissolved electrolyte and the volume of interstitial water; the first is chiefly a function of the chemical composition, whereas the latter depends on the porosity.

The electrical methods of geophysical exploration make use of several types of electric fields, therefore, the methods of observation are several and varied both as to technique and to properties measured. Certain of the methods utilize natural electrical currents that flow through the earth. Others use controlled current obtained from batteries or mobile generators. The resistivity method is the one most applicable to civil engineering problems, and is thus the only method which needs be treated in detail.

Four electrodes are set in the ground in a line, the two middle electrodes being equally spaced from the outer electrodes. A current is introduced between the outer two electrodes and the potential difference caused by this current between the inner two electrodes is measured, (fig. I-2).

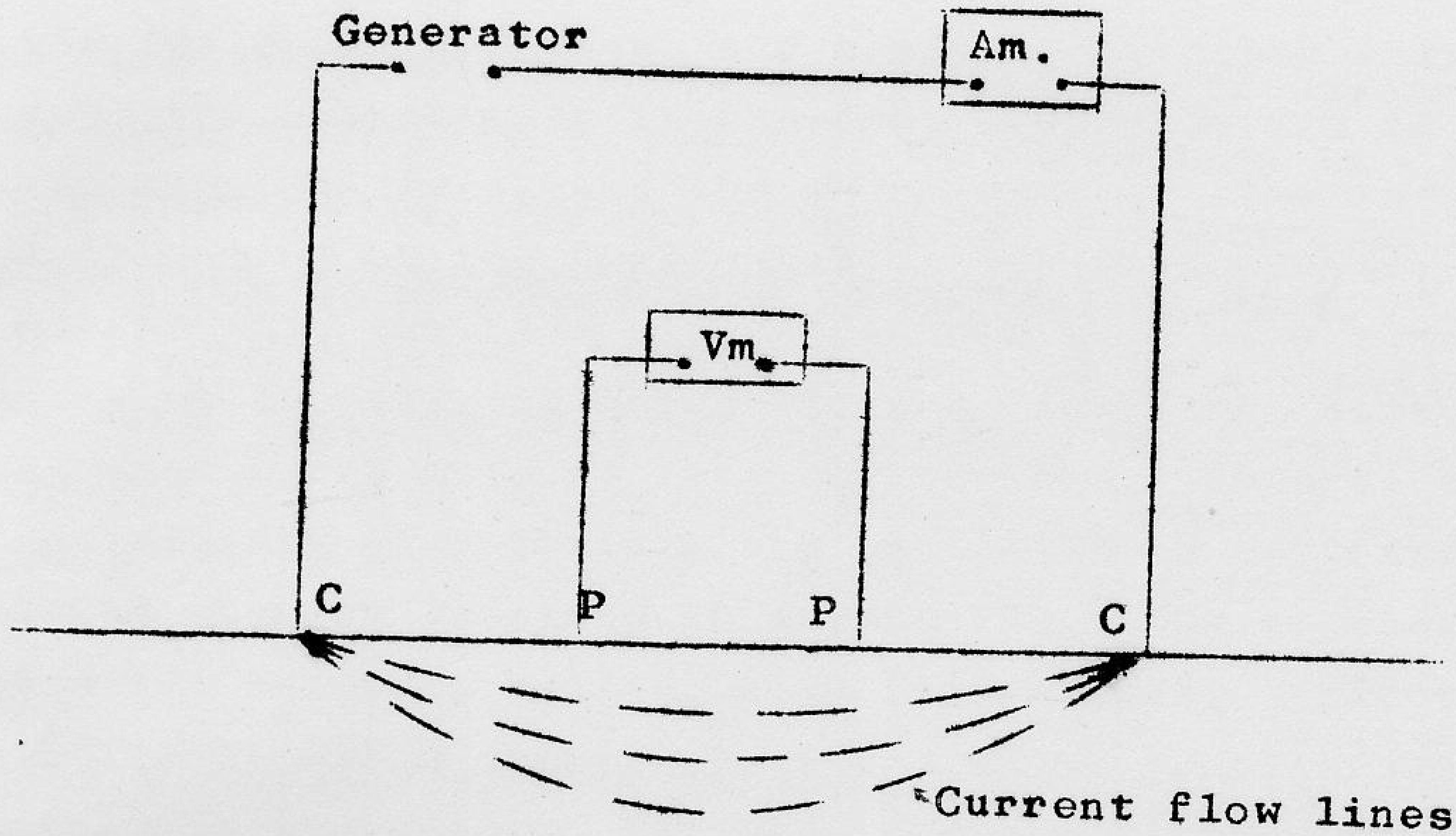

Fig. I-2. Electrical resistivity method. C indicate the current electrodes, and P the potential probes.

Knowing the current flowing, the potential difference and the geometry of the electrodes, the resistivity of the soil or rock between the current electrodes can be found. The resistivity thus measured constitutes an average of the resistivities of the ground, and is called the "apparent resistivity".

The resistivity method may be used to make 1) resistivity depth measurements at a selected point or 2) fixed depth resistivity measurements along a traverse line. In method (1), the electrode spacing is progressively increased to pick up changes in resistivity with depth. As the distance between the electrodes become greater, the current penetrates to a greater depth. Experience has shown that the average depth of penetration of the current is one fourth of the distance separating the two current electrodes. This procedure has been called, figuratively, "electrical drilling". On the basis

of the field measurements, the resistivity depth curves are traced, the resistivity in ohm-feet or ohm-meters is plotted on the vertical axis, and the separation of electrodes in feet or meters on the horizontal or separation axis.
In method (2), the four electrodes are kept at a constant spacing while they are moved along a line, and resistivity measurements are made at various stations. Lateral changes in resistivity of materials are indicated in contrast to the vertical changes obtained in method (1). The procedure of method (2) has been called, also figuratively, "electrical trenching". Field measurements are shown graphically as resistivity traverses. The stations are plotted on the horizontal axis, and the resistivity is plotted on the vertical axis. Also the results can be presented in the form of equi-resistivity curves plotted on a topographic map.

Corrections applied:- In practical work no corrections are made. The effect of topography cannot be estimated, and, because the theoretical curves of electrical measurements can be calculated only by assuming a horizontal surface and stratification, in uneven topography resistivity measurements lose most of their meaning. Depth of the water table also influences results, and in practice adds much to the difficulty of interpretation, unless some prior knowledge of subsurface conditions is obtained.

Interpretation of results:- Interpretation of resistivity maps is based on the assumption that the resistance of a given bed is constant over the area investigated. However, in the resistivity depth curves the lack of sharp discontinuities at rock contacts makes precise interpretation very difficult. Lack of sharply defined breaks results from the fact that average, rather than specific, resistivities are measured.

Knowing the geology of the area investigated and the results of the resistivity measurements, assumptions as to the subsurface formations can be made and checked by core boring: the resistivity method does not do away with the necessity of core boring, but it does serve to guide the location of borings and reduce the number of holes required.

Engineering applications:- The chief civil engineering applications of the resistivity method are in estimating the depth of overburden at dam sites (depth to bedrock, as resistance difference between overburden and rock is sharp), estimation of the physical characteristics of the rocks underlying construction sites, location of construction materials, and location of faults and water-bearing formations.

SEISMIC METHODS

Seismic methods depend on the properties of the elastic waves propagated in the earth's crust for the calculation of the depths and properties of the strata through which they have been transmitted. Elastic waves are generated from explosive charges or man-made shocks. The distance between the point of disturbance and the receiving station can be controlled, travel time measured, and the subsurface conditions can thus be estimated. In non-homogeneous earth, seismic waves are both reflected and refracted, Seismic exploration methods may therefore be classified as reflection and refraction, depending on the type of wave utilized.

I) THE SEISMIC REFLECTION METHOD:-

The most extensively used of all geophysical prospecting techniques, the seismic reflection method comes closer to giving a direct and detailed picture of subsurface geological structure than any other geophysical method. From the data it provides, one can map depths to subsurface horizons in the same way that they can be mapped from direct measurements in wells.

The depths are determined by measuring the travel times of elastic waves generated near the surface and reflected back to the surface from the formations below.

A unique advantage of the reflection method is that it permits mapping of many horizons from the same series of shots. When dynamite is exploded in a shot hole, the waves recorded by nearby detecting instruments will have taken a great variety of paths, each requiring a different time to travel from shot to detector. For several seconds after the first arrival of energy at the detector, the ground below it will be in continual motion under the impact of waves (e.g. refracted waves and scattered waves). To use the reflected energy on the record, one must distinguish it from ground motion due to other kinds of waves. It is not likely that this could be done if only a single detector were used. In actual practice, however, a number of detectors laid out with close spacing along a line pointing to the shot is used to receive the waves from each explosion. The ground movement at each instrument is recorded on a separate trace of the same record. The waves corresponding to a reflection will all line up across the record in such a way that the crests on adjacent traces will give the appearance of fitting into one another. The time differential in arrivals of a given peak at successive detector positions (the"step-out time") gives information on the dip of the reflecting bed while the absolute time indicates its depth below the surface. However in order to determine depths from reflection times by use of standard formulas, it is necessary to know the average velocity of the section down to the reflecting bed. This is done either by well shooting, or by analyzing differences in travel times for reflections from the same bed received at various distances. In well shooting the procedure is to explode a charge of dynamite in a shallow drill hole and to record the first-arrival time of waves received by a detector lowered in the hole to various depths, well distributed from top to bottom.

Reflection surveys give only the geometry of the subsurface formations; thus in an area where no information is available on the subsurface geology, reflection surveys can cast no light on the composition of the underlying rocks.

Corrections applied:-

1 - Elevation correction

2 - Weathering corrections

Engineering applications:- Because of their expense, reflection surveys are not ordinarily planned until cheaper but less definitive gravity, magnetic, or seismic refraction surveys, made on a reconnaissance basis, have isolated anomalous areas for detailed study by a more costly technique.

Reflection methods are used almost entirely for petroleum prospecting since they are not applicable at the shallow depths where engineering informations are ordinarily sought.

II) THE SEISMIC REFRACTION METHOD:-

See chapter 2.

Chapter II

THE SEISMIC REFRACTION METHOD

As a material can be classified by sieve analysis, so also can it be classified by its ability to transmit sound waves. A dense material, such as rock, will transmit waves much faster than a loose material such as sand. Therefore measuring the velocity of the wave in an unknown material will classify the material as to its probable nature and type.

Waves have the property of being refracted back to the surface of the earth when there is a high velocity material beneath a low velocity material. This property enables depth computations to be made.

The seismic refraction method involves the creation of a small shock at the earth's surface either by the impact of a heavy instrument or by exploding a small dynamite charge and measuring the time required for the resulting sound, or shock, wave to penetrate into the earth and return by refraction to the surface, all along minimum time paths, to a series of detectors laid out with close spacing along a line pointing to the shot. In commercial refraction work, only the first-arrival times of the waves are ordinarily used.

Wave Paths and Time-distance Relations for Horizontal Layers

Mechanism for Transmission of Refracted Waves.

Consider a hypothetical case where the subsurface consists of two media each with uniform eleastic properties, the upper separated from the lower by a horizontal interface at depth z (Fig. 2-1). The velocity of seismic waves in the upper is V_0

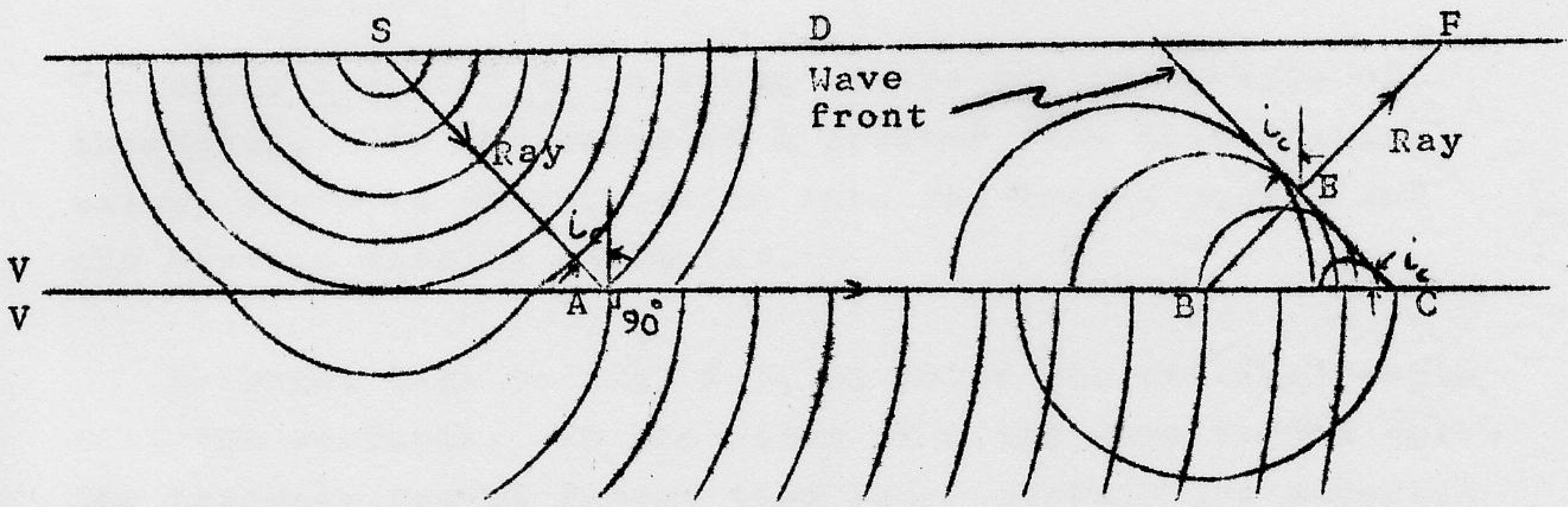

Fig. 2-1. Mechanism for transmission of refracted waves in two-layered earth. (After Dix, Geophysics, 1939).

and in the lower V_1 , with $V_1 > V_0$. If a seismic wave is generated at point S on the surface, the energy travels out from it in hemispherical wave fronts.* If a detecting instrument is at point D, a distance x from S, the wave SD traveling horizontally through the upper medium will be first to reach D provided that $x < x_c$ (x_c soon to be defined). For values of $x > x_c$ the wave traveling along the top of the lower medium will overtake the direct wave as the time for the ray path SABF will be shorter than the time for the path SF.

When the spherical wave fronts from S strike the interface just below the source, the energy will be refracted into the lower medium in accordance with Snell's law which states that:

$$\frac{\sin i}{\sin R} = \frac{V_0}{V_1},$$ where i is the angle of incidence and R is the angle of refraction

At some point A the wave front in the lower medium becomes perpendicular to the boundary. The ray, which is always normal to the wave front, here begins to travel along the boundary with the speed of the lower medium. At point A, $R = 90^\circ$, hence $\sin R = 1$ and $\sin i = \frac{V_0}{V_1}$.

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* Seismic Prospecting for Oil - Dix, 1952.

The angle $i_c = \sin^{-1} \frac{V_0}{V_1}$ is known as the critical angle of incidence. For any value of i greater than this critical value, there is no refraction into the second medium and the wave is totally reflected.

Refering back to fig. 2-1, SA makes the critical angle with the vertical. To the right of A the wave fronts below the boundary travel faster than those above. The material at the interface is subjected to oscillating stress from below, and this generates continuous new disturbances along the boundary which spread out in the upper medium with a speed of V_0. The spherical wave spreading outward from point B in the lower medium will travel a distance BC while the sphere spreading out in the upper medium will have attained a radius of BE. The resultant wave front above the interface will follow the line CE, which makes an angle i_c with the boundary. The angle which the wave front makes with the horizontal is the same as that which the ray makes with the vertical so that the wave will return to the surface at the critical angle ($\sin^{-1} \frac{V_0}{V_1}$) with the vertical. For values of x greater than a critical distance soon to be defined, it can be shown that the wave requiring the smallest travel time from S to D will approach the interface at the critical angle, will propagate along the boundary with a speed of V_1, and will return to the surface at the critical angle through the upper layer. The trajectory is demonstrated in fig. 2-2. The most convenient as well as useful way of representing refraction data is to plot the first-arrival time T vs, the shot-detector distance x. Such a plot, known as a time-distance curve, is quite simple to interpret.

Two-layer Case. Refering to fig. 2-2, where there are two media, with respective speeds of V_0 and V_1, separated by a plane discontinuity at depth z; the time-distance relations can be determined.

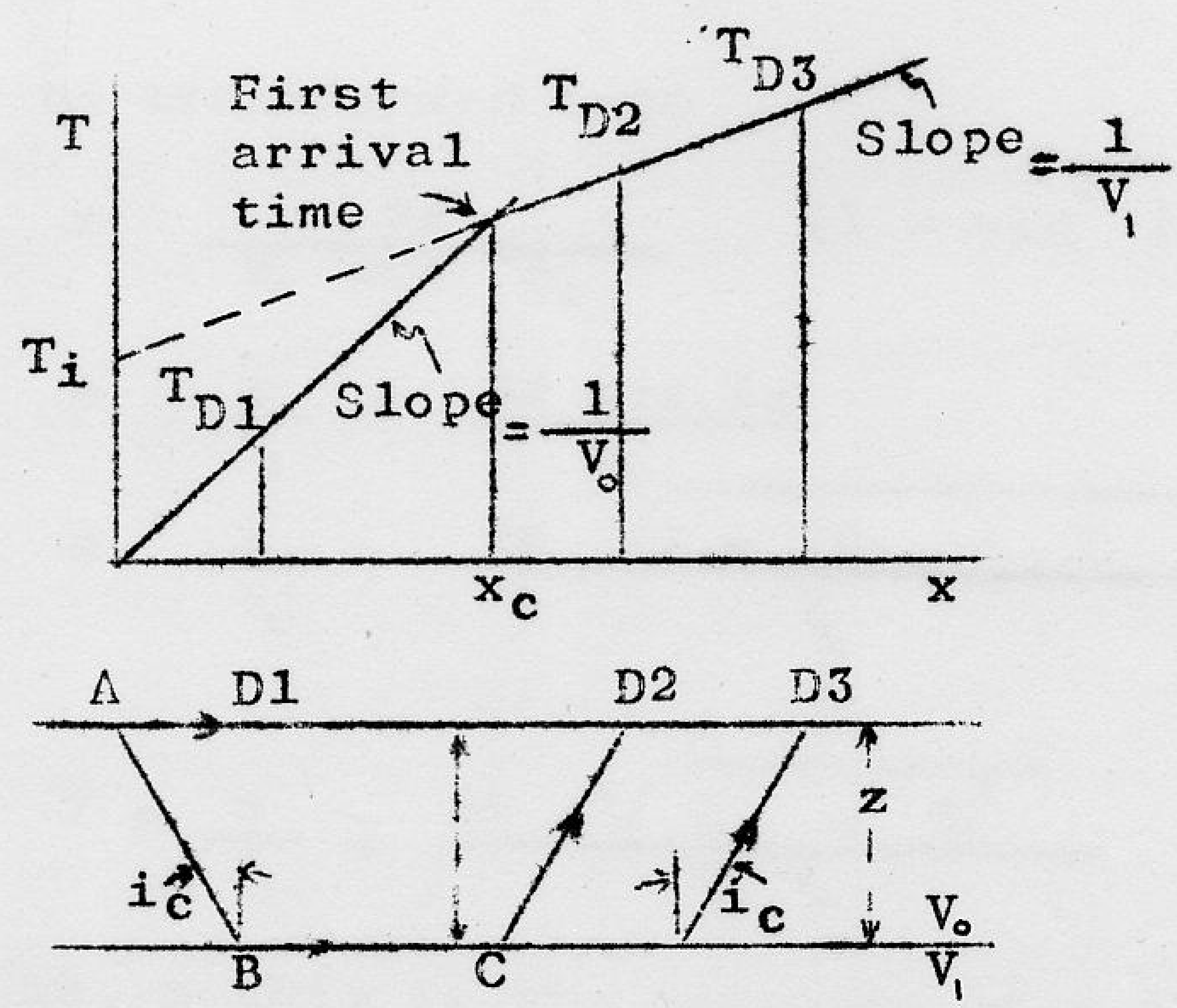


Fig. 2-2. Ray paths of least time and time-distance curve for two layers separated by horizontal interface.

Intercept Time: The direct wave travels from shot to detector near the earth's surface at a speed of V_0 , so that $T = x/V_0$. This is represented on the plot of T vs. x as a straight line which passes through the origin and has a slope of $1/V_0$. The wave refracted along the interface at depth z, reaching it and leaving it at the critical angle i_c, takes a path consisting of three legs, AB, BC, and CD. In the derivation that follows we make use of the following three relations:

$$\sin i_c = \frac{V_0}{V_1}$$

$$\cos i_c = \left(1 - \frac{V_0^2}{V_1^2}\right)^{\frac{1}{2}}$$

$$\tan i_c = \frac{\sin i_c}{\cos i_c} = \frac{V_0}{\sqrt{V_1^2 - V_0^2}}$$

The total time along the refraction path ABCD is

$$T = T_{AB} + T_{BC} + T_{CD}$$

which can be written in the form

$$T = \frac{z}{V_0 \cos i_c} + \frac{x - 2z \tan i_c}{V_1} + \frac{z}{V_0 \cos i_c}$$

$$= \frac{2z}{V_0 \cos i_c} - \frac{2z \sin i_c}{V_1 \cos i_c} + \frac{x}{V_1}$$

This can readily be transformed into

$$T = \frac{2z}{V_o \cos i_c} (1 - \sin^2 i_c) + \frac{x}{V_1}$$

$$= \frac{x}{V_1} + \frac{2z \cos ic}{V_o}$$

$$= \frac{x}{V_1} + \frac{2z \sqrt{1 - (V_o / V_1)^2}}{V_o}$$

so that finally

$$T = \frac{x}{V_1} + \frac{2z \sqrt{V_1^2 - V_o^2}}{V_1 V_o}$$

On the plot of T vs. x this is the equation of a straight line which has a slope of $1/V_1$ and which intercepts the T axis ($x = 0$) at a time

$$T_i = 2z \frac{\sqrt{V_1^2 - V_o^2}}{V_1 V_o}$$

T_i is known as the intercept time.

Critical Distance: At a distance x_c (see Fig. 2-2), the two linear segments cross. At distance less than this, the direct wave traveling along the top of the V_o layer reaches the detector first. At greater distances, the wave refracted by the interface arrives before the direct wave. For this reason, x_c is called the critical distance. The depth z to the interface can be calculated from the intercept time of the second segment or from the critical distance.

Depth Calculation: In term of T_i and the velocities V_o and V_1, Eq. (2-1) can be solved for the depth z to obtain

$$z = \frac{T_i}{2} \frac{V_1 V_o}{\sqrt{V_1^2 - V_o^2}}$$

T_i can be obtained graphically as shown in Fig. 2-2 or numerically from the relation $T_i = T - (x/V_1)$.

The depth can be solved for in terms of x_c, the critical distance, making use of the fact that at $x_c, T_o = T_1$, hence

$$\frac{x_c}{V_o} = \frac{x_c}{V_1} + \frac{2z\sqrt{V_1^2 - V_o^2}}{V_1 V_o}$$

$$z = \frac{1}{2} \frac{V_o V_1 x_c}{\sqrt{V_1^2 - V_o^2}} \left(\frac{1}{V_o} - \frac{1}{V_1}\right)$$

This simplifies to

$$z = \frac{1}{2}\sqrt{\frac{V_1 - V_o}{V_1 + V_o}}\; x_c$$

if $K_1 = \frac{1}{2}\sqrt{\frac{V_1 - V_o}{V_1 + V_o}}$

then $z = K_1 \cdot x_c$

<u>Three-layer Case</u>: For three layers with velocities V_o, V_1, and V_2 ($V_2 > V_1 > V_o$), the treatment is similar but somewhat more complicated. Fig 2-3 shows the wave paths and the time-distance curve.

Depths' computations are similar to the two-layer case, the results are:

$$z_1 = K_1 \cdot x_{c_1}$$

and $$z_2 = K_2 \cdot x_{c_2} + z_1 \cdot Q$$

where,

z_1 = Depth of the first layer

z_2 = Total depth of first and second layers

x_{c_1} = First critical distance

x_{c_2} = Second critical distance

$$K_1 = \frac{1}{2}\sqrt{\frac{V_1 - V_o}{V_1 + V_o}}$$

$$K_2 = \frac{1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

$$Q = 1 - \frac{V_1\sqrt{V_2^2 - V_o^2} - V_2\sqrt{V_1^2 - V_o^2}}{V_o\sqrt{V_2^2 - V_1^2}}$$

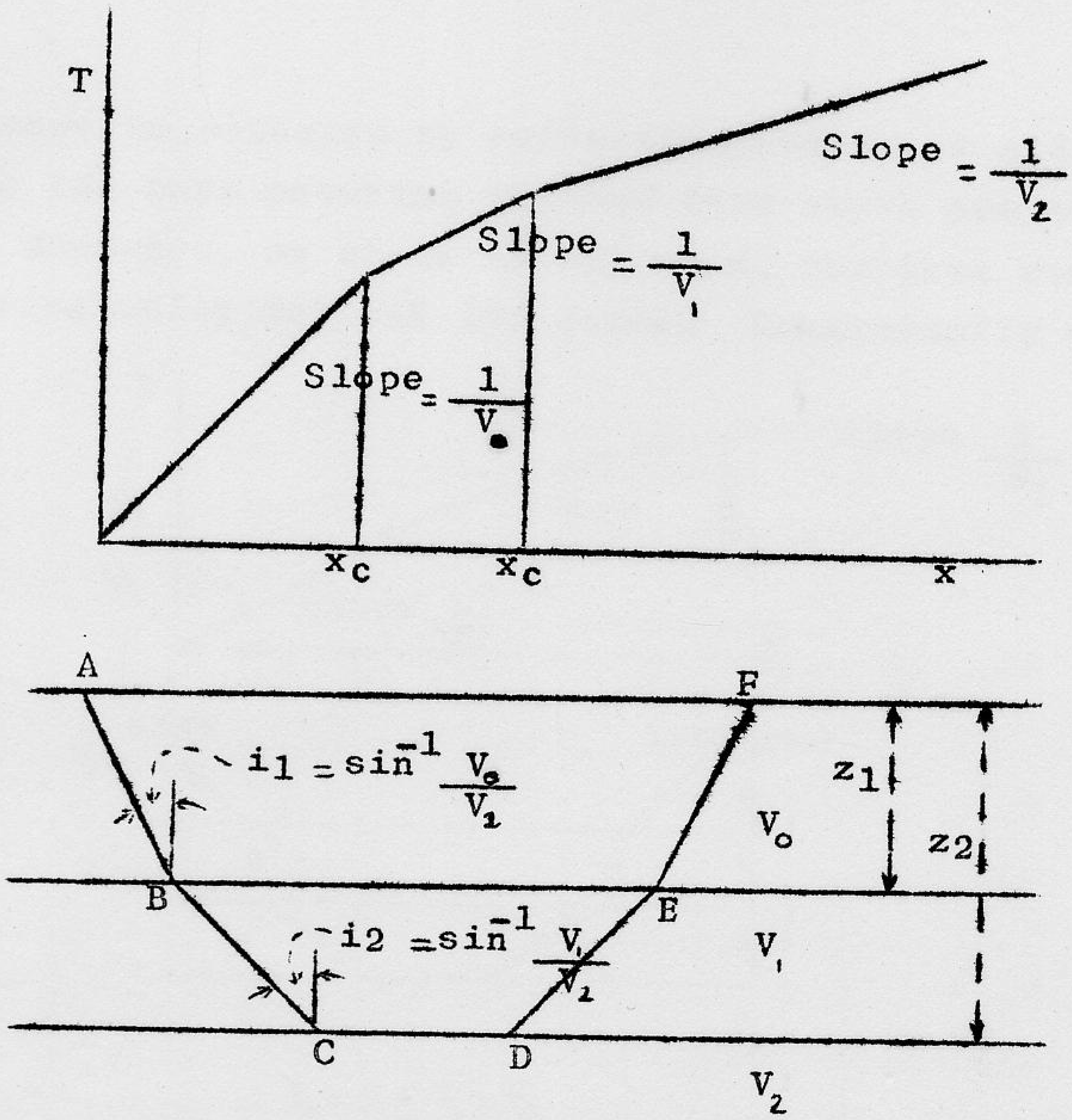


Fig. 2-3 Ray paths of least time and time-distance curve for three layers separated by horizontal interfaces.

Multilayer Case. The time-depth relations just derived for the two- and three-layer cases can be extended to allow calculation of depth for a larger number of layers as long as the speed in each layer is higher than the one just above it. A method which simplifies computations consists in peeling off successive layers by use of the two- and, or, three-layer relations. In this case, travel times are reduced by the delay in the upper group of two- or three-layers, and the datum line for depth computations is taken to be the lower interface of the layers overlying the group studied.

Low-speed Layer:- The analysis thus far is valid only in cases where successively deeper layers have successively higher speeds. If any bed in the sequence has a lower speed than the one above it, it cannot be detected by refraction method at all. This is because the rays entering the bed from above are always deflected downward, as shown in Fig. 2-4, and thus can never travel horizontally through the layer. Consequently there

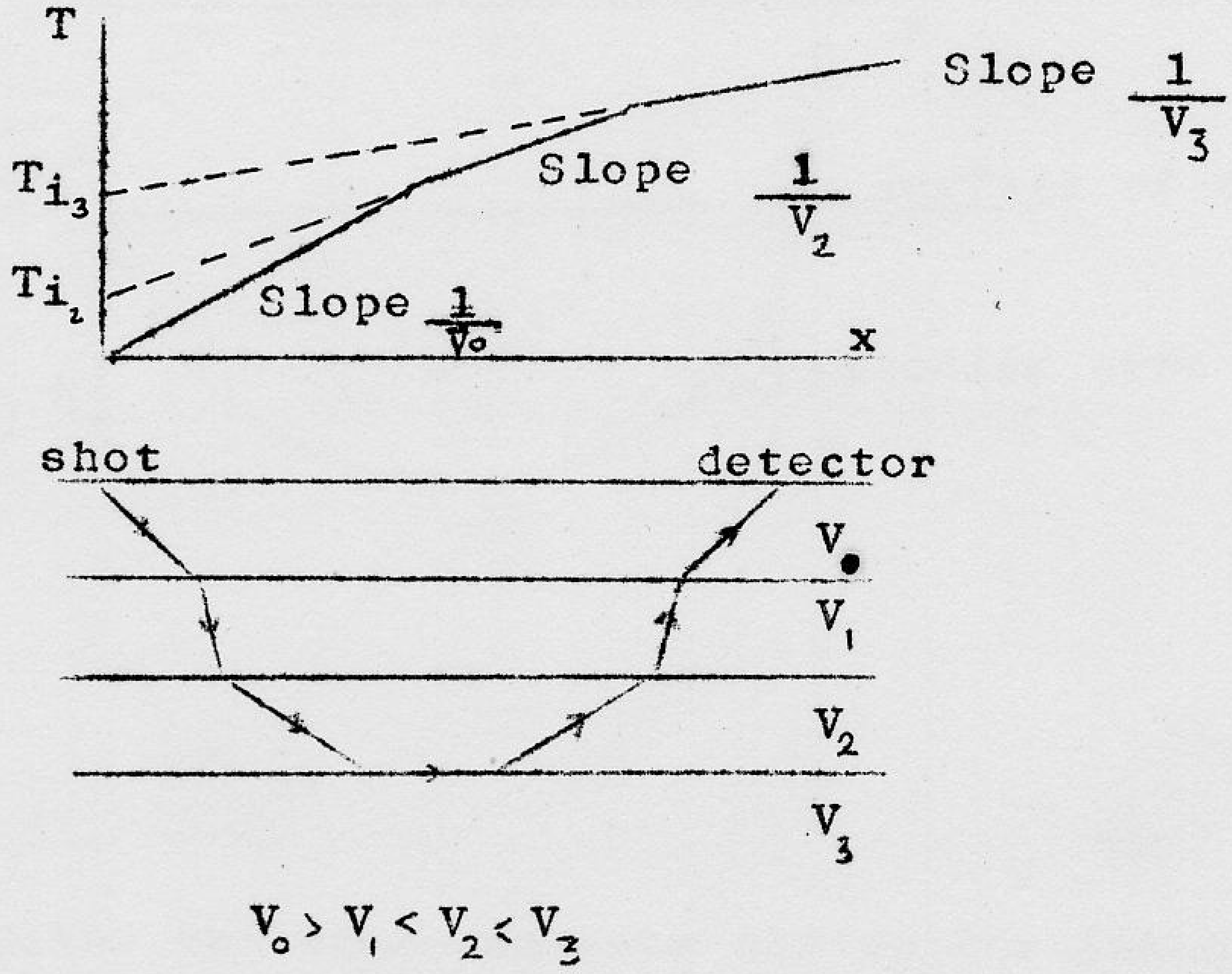


Fig. 2-4 Ray paths of least time and time-distance curve where low-speed layer (V_1) lies below high speed layer (V_0).

will be no segment of inverse slope V_1 on the time-distance curve. The presence of such a layer, moreover, will lead to an error in the computation of depths to all lower interfaces, since its thickness will not be taken into account in the calculations.

Continuous change of speed with depth:- In many areas the formations do not consist of discrete layers, each of constant velocity, but occur in thick sections where there is a gradual increase of velocity with depth. The ray paths in this case approach a smooth curve which is convex downward, while the time-distance curve becomes smooth and convex upward (Fig. 2-5). The shape of the ray paths as well as the form of the time-distance curve depends on the manner in which velocity varies with depth.

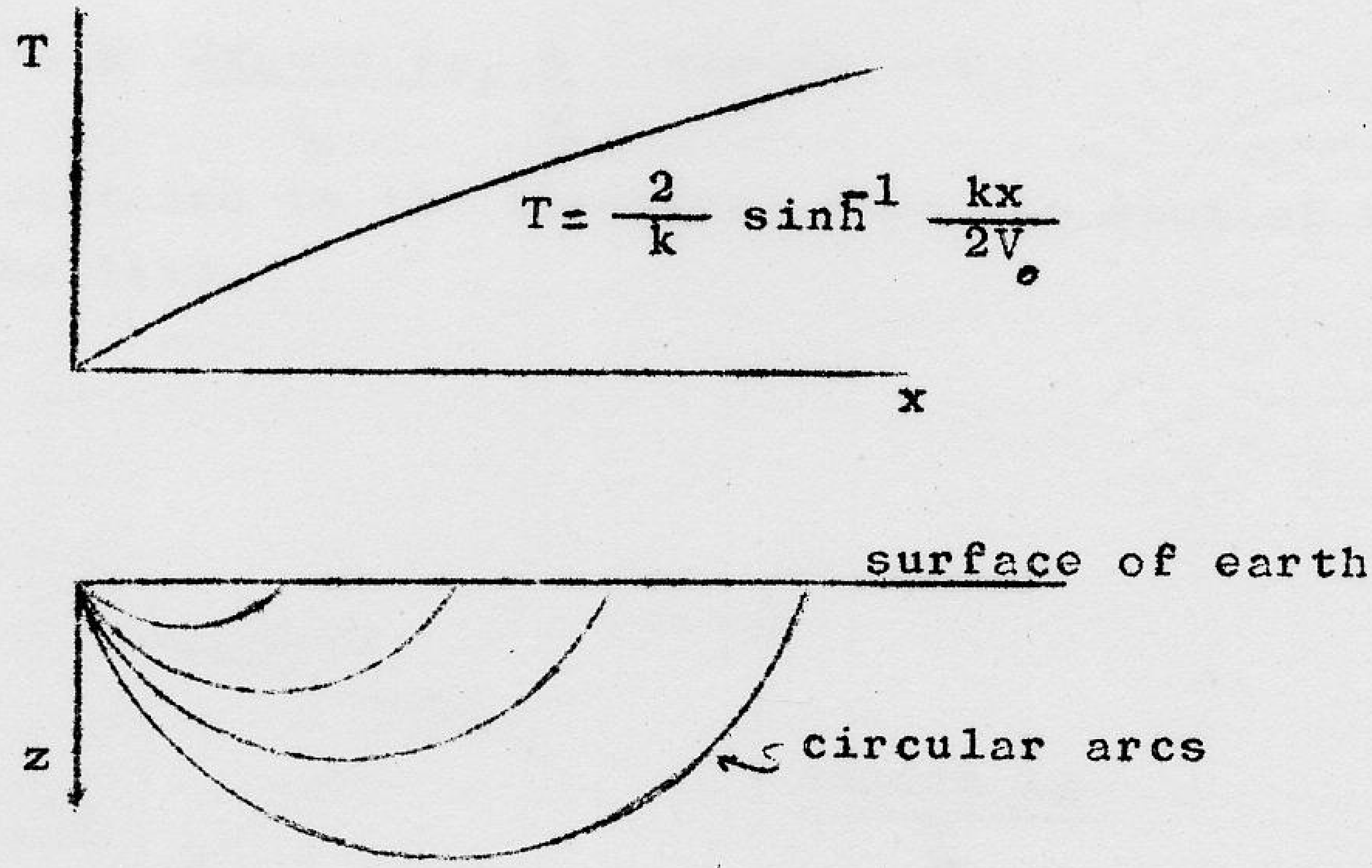


Fig. 2-5 Ray paths and time-distance curves for linear increase of speed with depth, as demonstrated by Ewing and Leet.

Ewing and Leet have derived the expression for the travel time for this case. For any distance x from the detector, the travel time is

$$T = \frac{2}{k} \sinh^{-1} \frac{kx}{2v_0}$$

where k is a constant depending upon variation of velocity with depth, and v_0 is the speed at zero depth.

Dipping Beds:- In the case where the interfaces between beds are not horizontal (fig. 2-6), the angle of dip can often be determined from refraction data. Shooting down dip, the travel time is given by

$$T_d = \frac{2z_d \cos i_c}{V_0} + \frac{x}{V_0} \sin (\alpha + i_c)$$

where α is the angle of dip, and z_d the perpendicular distance from the shot to the interface at the updip end of the line.

Similarly, the updip time can be shown to be

$$T_u = \frac{2z_u \cos i_c}{V_o} + \frac{x}{V_o} \sin(\alpha - i_c)$$

where z_u is the distance to the interface from the shot at the downdip end of the line.

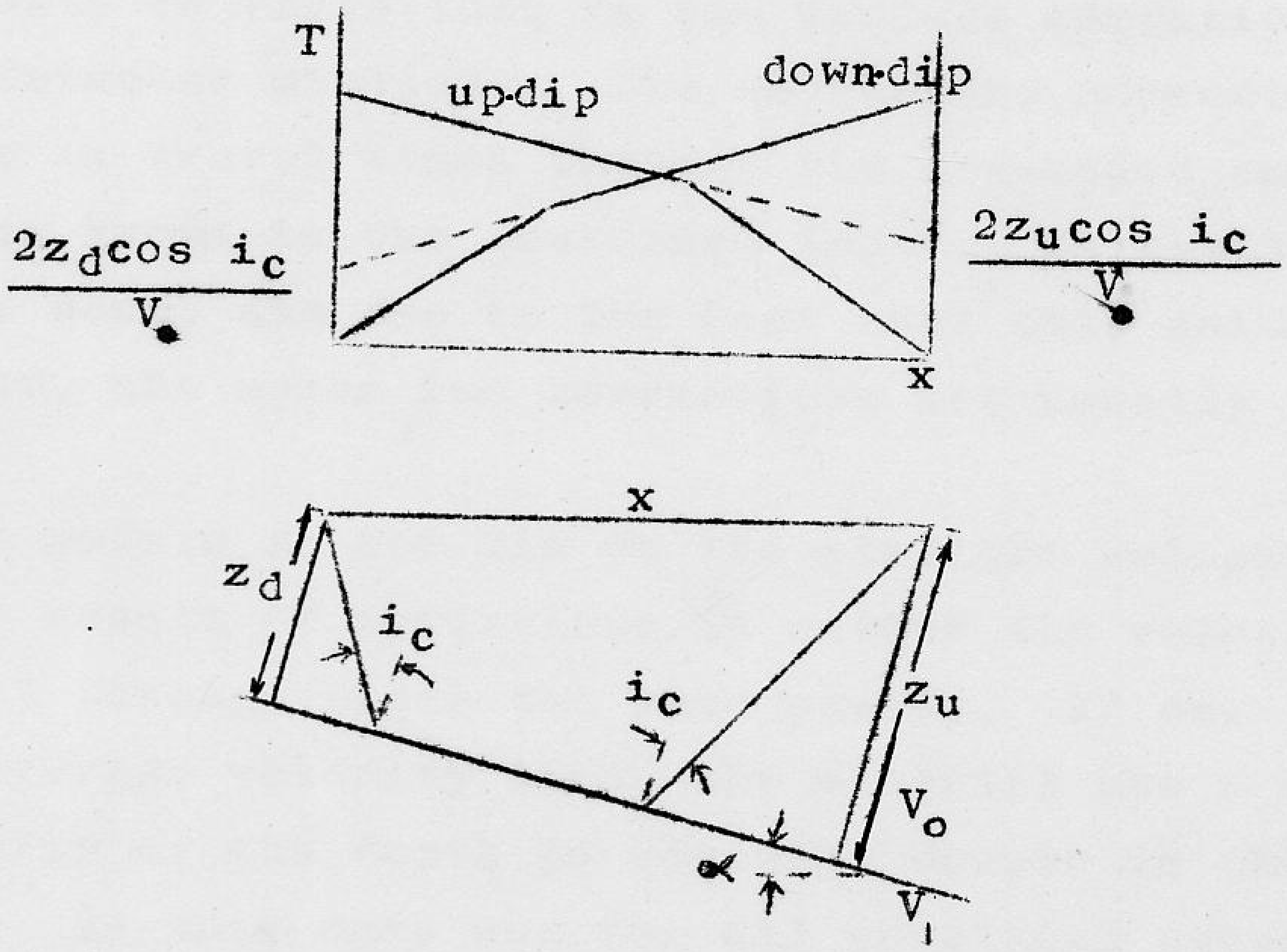


Fig. 2-6 Refraction along an interface dipping at an angle α. Respective shots are at updip and downdip ends of profile.

Both relations are represented graphically on the time-distance plot (fig. 2-6). The inverse slope of either time-distance curve cannot give the true velocity V_1 of the lower bed, but the average of the updip and downdip inverse slopes will give a close approximation if the angle of dip is not large. Thus in order to check for sloping layers and to get accurate depths and velocities if there are sloping layers, two field layouts are used:

Reversed Course. After measurements are taken in one direction, another set of measurements is taken in the reversed direction covering the same ground.

Connecting Course. After measurements are taken in one direction, another set of measurements is taken in the direction opposite to the first one.

Corrections Used in Refraction Interpretation:- Refraction times must be corrected for elevation and changes in weathering thickness. The former correction removes differences in travel times due only to variations in the surface elevation of the shots and detector stations. The weathering correction removes differences in travel times through the low-speed unconsolidated surface zone known as the weathered layer. In civil engineering exploratory work, and due to the fact that only guiding informations are required, the upper two corrections are usually neglected.

Often points do not lie on the straight velocity lines. This is the result of variations in either the velocity, and or the material through which the wave passes. If one point is above the average velocity line, the material has a somewhat lower velocity or the depth is somewhat deeper in the area of that point. In this case and for all practical purposes no corrections are applied in civil engineering exploratory work.

Chapter III

INSTRUMENT AND FIELD OPERATIONS

Because of the high cost of multi channel instruments and recorders, single channel instruments have been developed for shallow prospection. In this case one fixed detector is used and the shock source is moved along a line at close intervals. For every position of the shock source, the travel time to the detector is measured.

Instrument:- The instrument used was the TERRA-SCOUT portable refraction seismograph model R-150, developed by SOILTEST INC. and actually available at the soil testing laboratory of the American University of Beirut.

The Terra-Scout is basically made up of three parts: (1) the hammer, which strikes the ground, creating a sound wave; (2) the geophone, which picks up the wave created by the hammer; and (3) the instrument, which records the wave from the geophone on a cathode ray tube screen and measures the travel time of the wave between the hammer and the geophone. The block diagram is shown in fig. 3-1

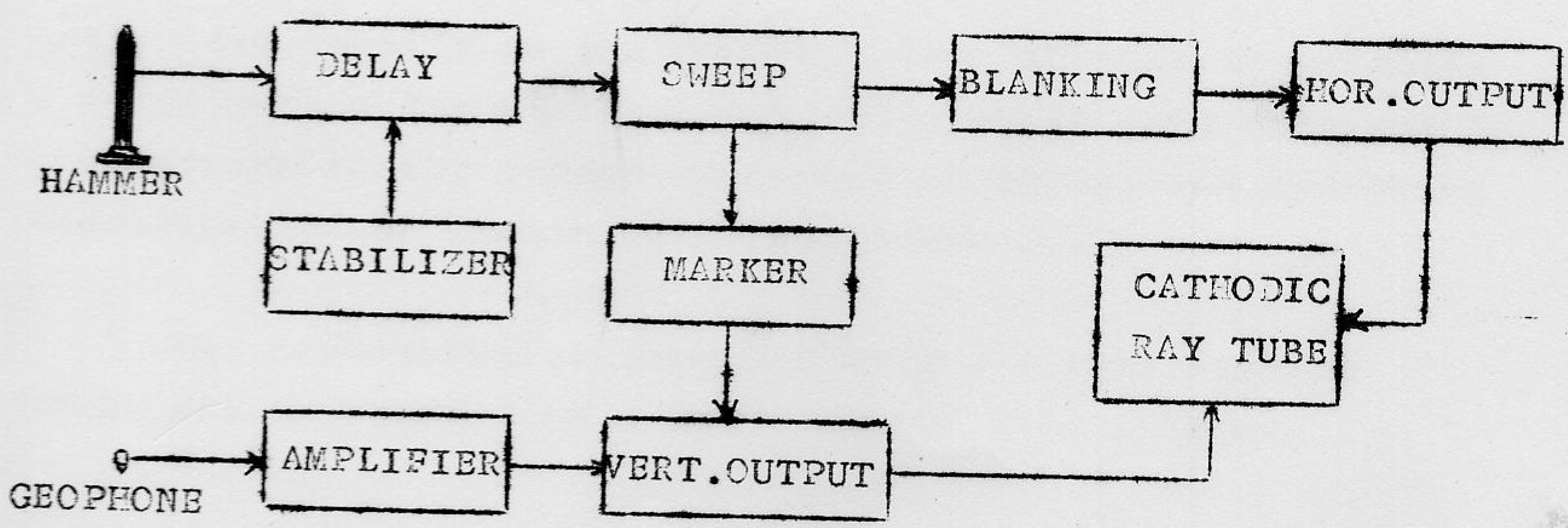


Fig. 3-1. Block Diagram.

The instrument has many controls some of which are the following:

Gain: Serves to adjust the size of the wave seen on the screen. At each new distance from the geophone, the Gain must be adjusted. Fig. 3.2 illustrates the size that is required.

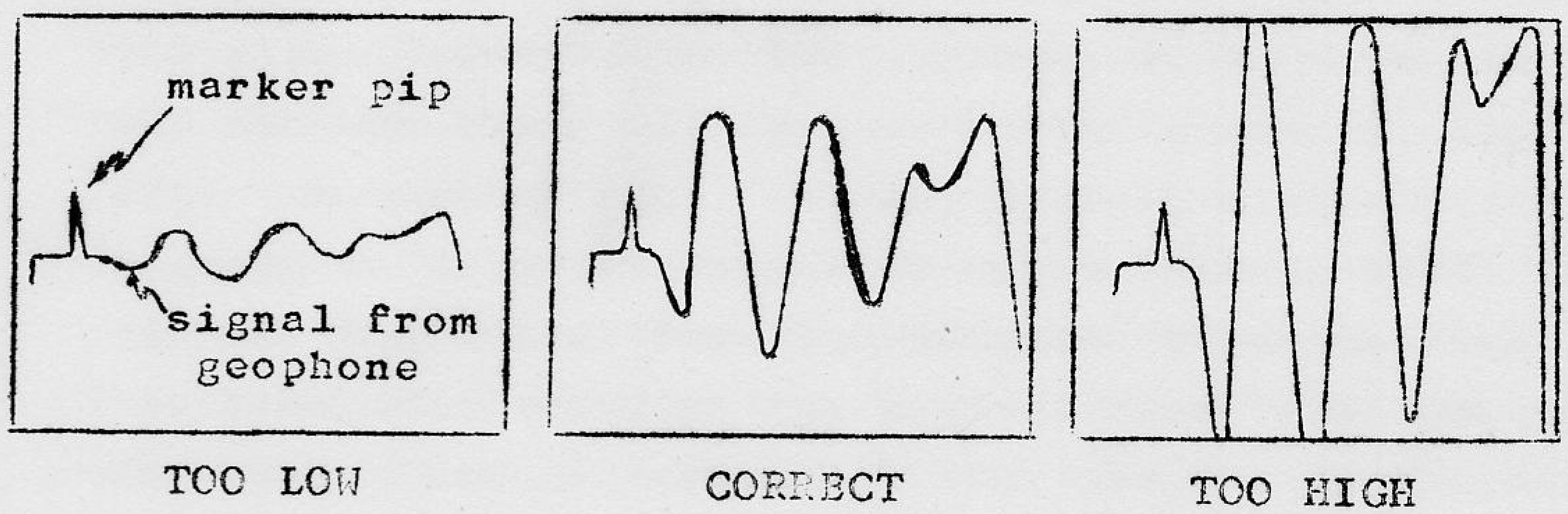


Fig. 3-2. Adjusting GAIN for wave size.

Delay: Varies the interval of the time between the hammer blow and the start of the sweep across the screen.

Range: Provides two ranges by acting as a multiplier of the Delay dial reading.

Test: Acts exactly as the hammer switch in that it produces a sweep across the screen. Normally, it is used to check on the outside noise; proper centering of sweep; and operating conditions after turning the instrument on.

The instrument is provided with a 6 volt battery which can be charged by a built-in 110 volt charger.

Operational procedure:- In order to measure the times of the first arrivals from the hammer to the geophone the following technique is used with this particular instrument: the hammer is fitted with an inertia switch which closes when the hammer hits the ground. In this way a sweep is initiated on the screen of the cathode ray tube which incorporates a marker pip as a reference for time measurements. The marker pip represents the instant at which the shock is initiated. The signal received by the geophone is fed into the sweep and its wave form will appear on the screen at some time after the marker pip. A delay circuit with a digital timer is used to delay the signal from the hammer until the marker pip and the signal from the geophone coincide (fig. 3.3). The time delay read on the digital timer will now represent the actual time of arrival of the wave to the geophone.

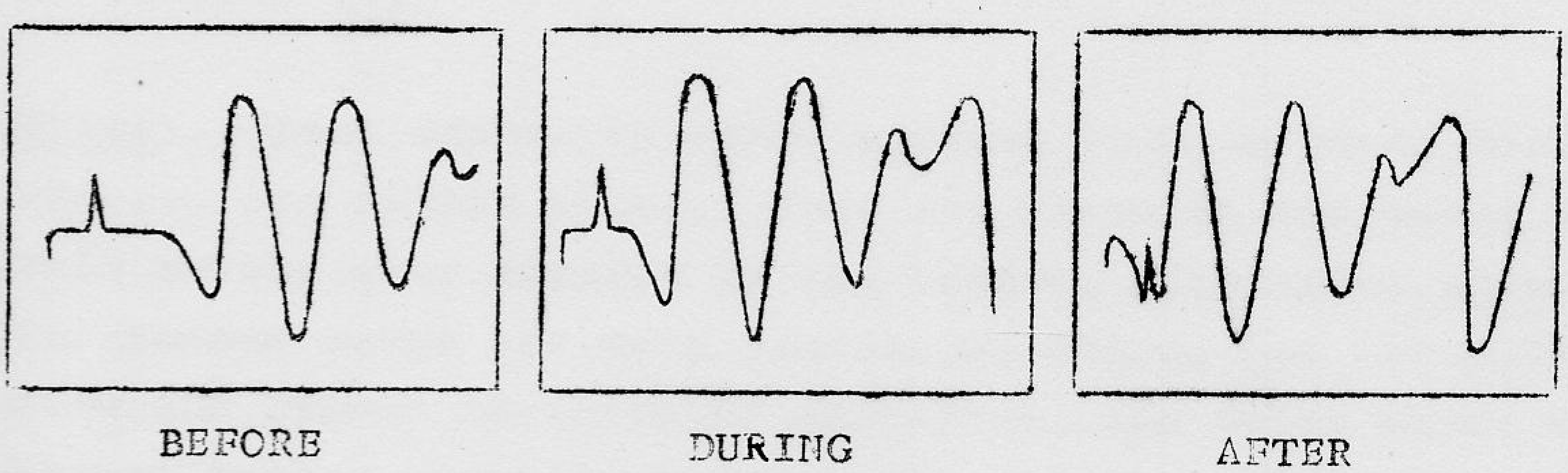


Fig. 3-3. Adjusting DELAY for time reading

Abbreviated Field Operation:- The course along which the measurements are to be made is chosen. The choice of the course is of great importance: hard surfaces such as concrete, blacktop and dense gravel roads are avoided as they give erratic results.

The geophone is planted firmly into the ground or preferably burried to avoid wind noise.

After checking the operating conditions (by use of the test control), hammering begins: the spacing of the hammering points depend on the accuracy required and the geologic conditions present. The course length is determined by the depth required.
The hammer distance, delay dial reading and any variation in shape of wave are recorded. Changes in wave shape and amplitude indicate changes in material.
The time-distance graph is plotted while field work is carried to check erratic results,

In order to check for sloping subsurface layers and to get an accurate depth if there are sloping layers, a reversed course or a connecting course is run as described in chapter II.

Noise: Waves caused by other sources such as wind, traffic, etc..., are called noise. They are shown on the sweep as well as the wave created by the hammer. The noise waves and the hammer waves are very similar in shape. As the distance from the hammer to geophone increases, the noise waves may become larger than the hammer wave and it will be impossible to distinguish between the two and consequently, to probe any deeper.

Chapter IV

ANALYSIS OF TEST RESULTS

Seismic Velocities:- The velocities of various materials differ considerably but generally the higher the velocity, the more compact the material. It is difficult to pin-point a specific velocity for a certain material since the material itself may vary with depth or geographic location. The following table shows the range of values that may be expected, and illustrates the wide overlap of velocities that can be found for different materials.

VELOCITY TABLE*

Sand and Topsoil	600 - 1,200 ft/sec.
Sandy Clay	1,200 - 1,900 ft/sec.
Gravel	1,600 - 2,600 ft/sec.
Glacial Till	1,800 - 7,000 ft/sec.
Rock Talus	1,300 - 2,500 ft/sec.
Water in Loose Materials†	4,600 - 6,000 ft/sec.
Shale	2,600 -11,000 ft/sec.
Sandstone	3,000 - 9,000 ft/sec.
Granite	10,000 -20,000 ft/sec.
Limestone	6,000 -20,000 ft/sec.

Rock velocities can show the rippability of rock: the higher the velocity is, the less it is rippable.

In general the velocities obtained by the tests agreed with the values shown in the above table.

---

* From Soiltest Inc.

† Wave travelling mainly through the water

Computations:- In order to reduce computation time, the chart shown in Fig. 4-1, developed by SOILTEST INC. was used for the determination of depths for two- and three-layer cases. Knowing the velocities of the different subsoil formations, the constants K_1 , K_2 , and Q, necessary for the computation of depths, are found directly from the chart.

Choice of sites:- The choice of sites was mainly governed by the availability of borehole records as well as the conditions of the sites (whether any construction had taken place). However, consideration as to the number of layers and type of soil was given to every site before making the choice. One-, two-, three-, and four-layer cases were chosen in order to check the performance of the Terra-Scout refraction seismograph under each of the above mentioned cases. Sites in the city of Beirut, in the suburbs of the city, and in the South of Lebanon (Awali River) were chosen.

The description of the sites and the analysis of test results are found in the coming pages.

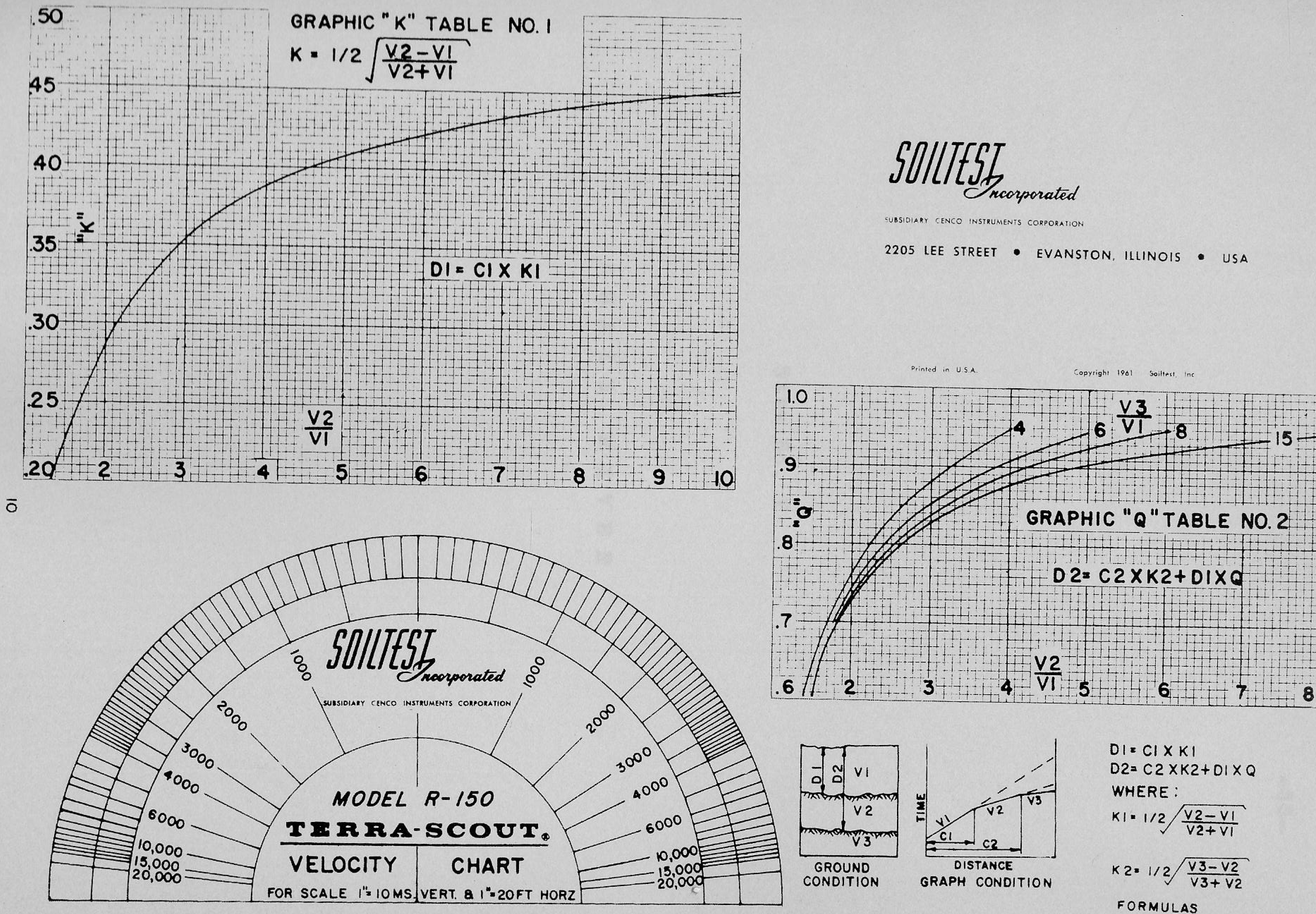
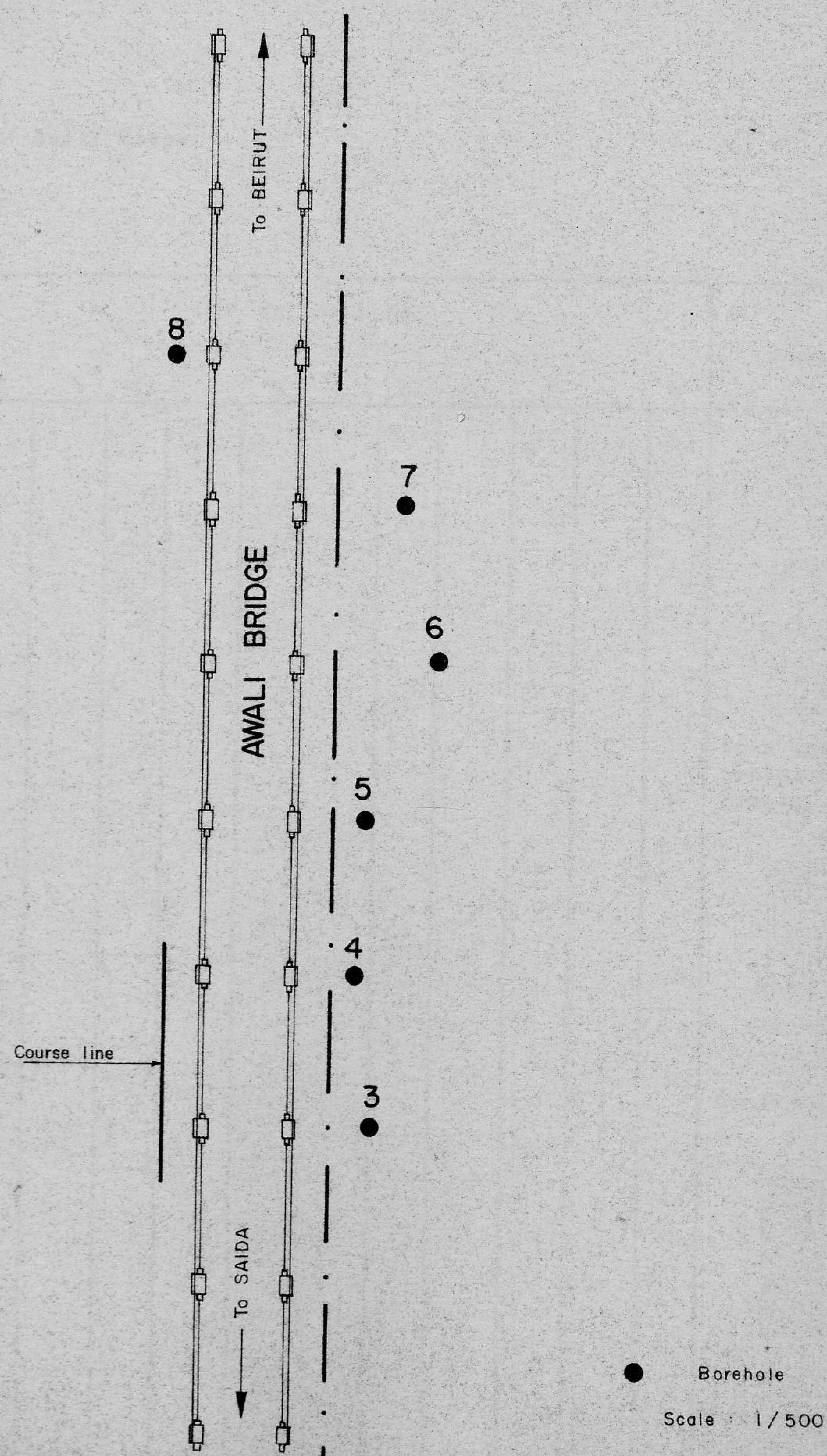

GRAPHIC "K" TABLE NO. 1
K = 1/2 √((V2−V1)/(V2+V1))
"K"
D1 = C1 X K1
V2/V1
.20
.25
.30
.35
.40
.45
.50
2
3
4
5
6
7
8
9
10
SOILTEST Incorporated
SUBSIDIARY CENCO INSTRUMENTS CORPORATION
2205 LEE STREET • EVANSTON, ILLINOIS • USA
Printed in U.S.A.
Copyright 1961 Soiltest, Inc
GRAPHIC "Q" TABLE NO. 2
D2 = C2 X K2 + D1 X Q
"Q"
V3/V1
V2/V1
4
6
8
15
.6
.7
.8
.9
1.0
2
3
4
5
6
7
8
SOILTEST Incorporated
SUBSIDIARY CENCO INSTRUMENTS CORPORATION
MODEL R-150
TERRA-SCOUT®
VELOCITY
CHART
FOR SCALE 1" = 10MS. VERT. & 1" = 20FT HORZ
1000
2000
3000
4000
6000
10,000
15,000
20,000
D1
D2
V1
V2
V3
GROUND CONDITION
TIME
C1
C2
DISTANCE
GRAPH CONDITION
D1 = C1 X K1
D2 = C2 X K2 + D1 X Q
WHERE:
K1 = 1/2 √((V2−V1)/(V2+V1))
K2 = 1/2 √((V3−V2)/(V3+V2))
FORMULAS
10

Fig. 4-1

Site No. I

A W A L I   R I V E R

KEY PLAN - AWALI RIVER

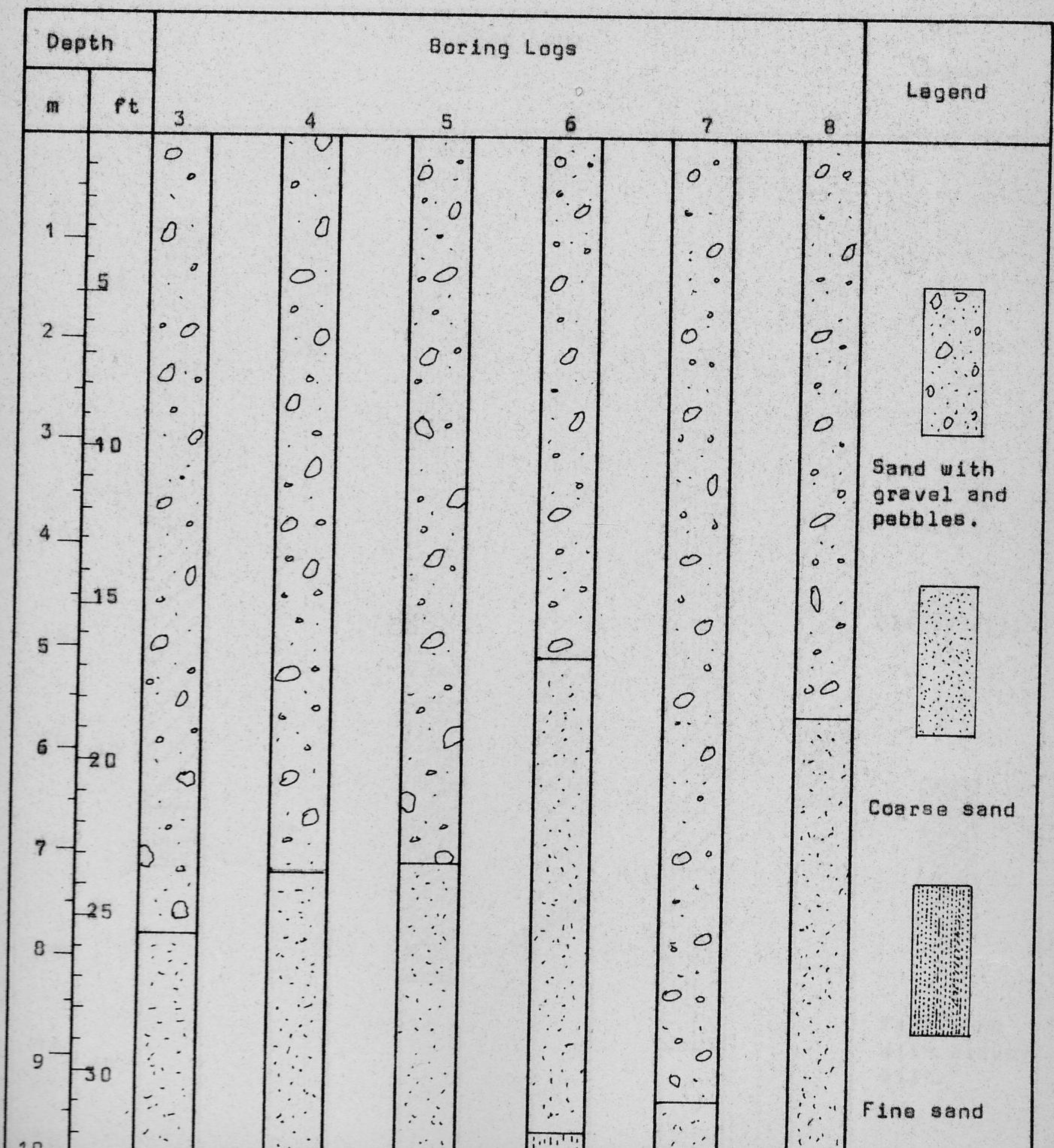


Information given by

ROAD LABORATORY - MINISTRY OF PUBLIC WORKS

Boring Logs - Subsurface Exploration

Project: Awali River.

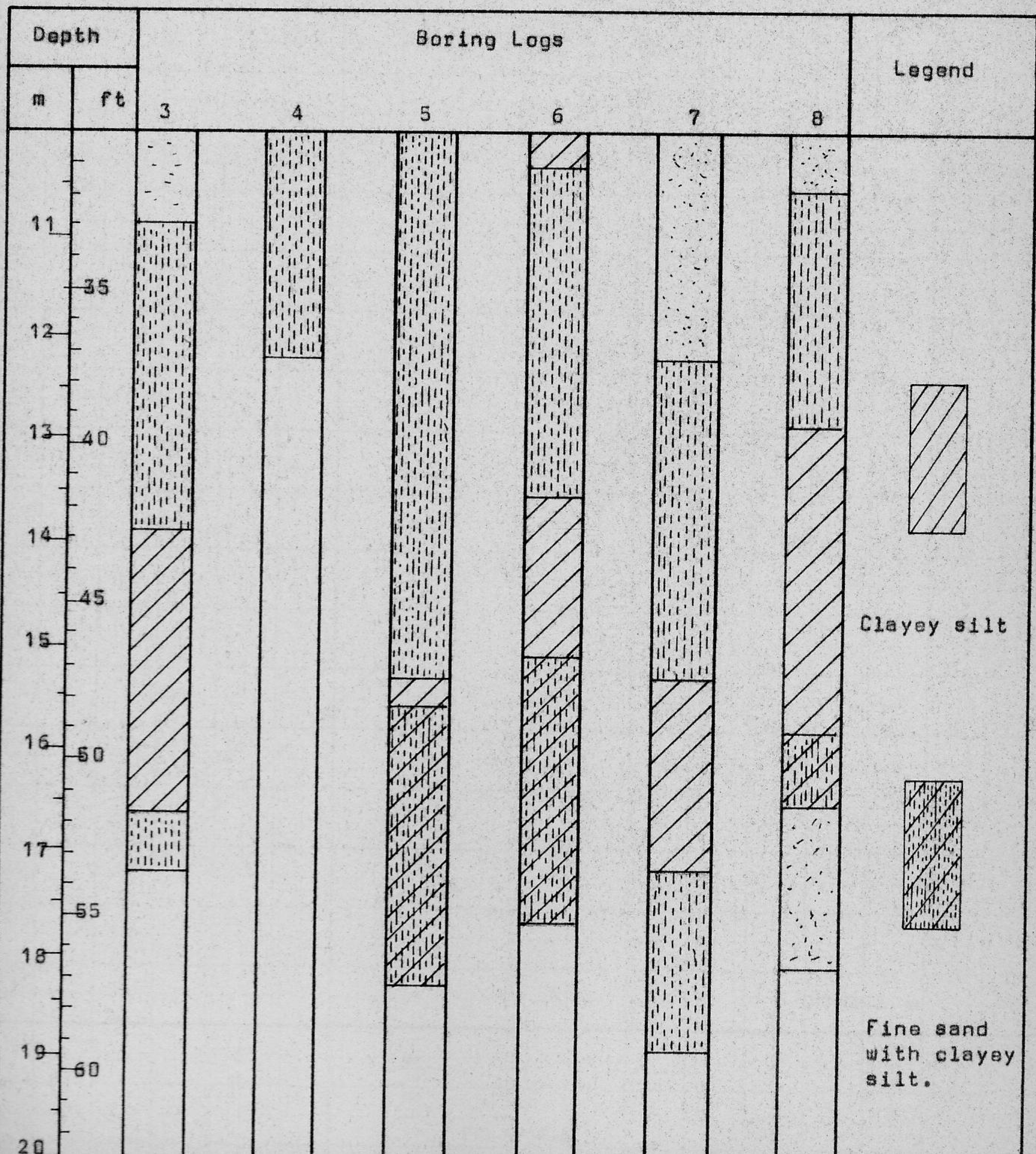


Information given by

ROAD LABORATORY - MINISTRY OF PUBLIC WORKS

Boribg Logs - Subsurface Exploration

Project: Awali River (continued).



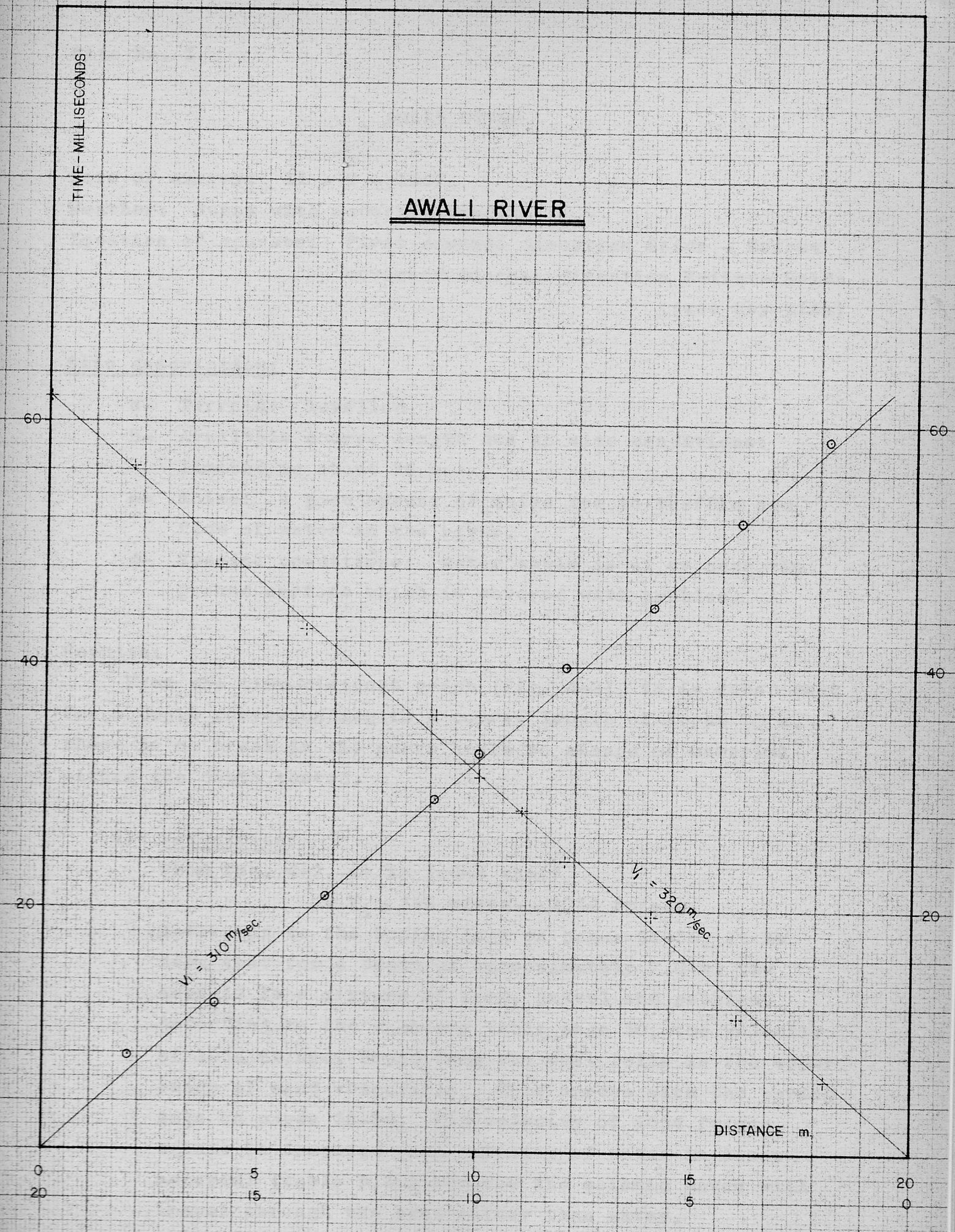

TIME - MILLISECONDS
AWALI RIVER
60
40
20
60
40
20
V_1 = 310 m/sec.
V_1 = 320 m/sec
DISTANCE m.
0
5
10
15
20
20
15
10
5
0

FIG. Nº 4-2

Site No. I

AWALI RIVER

Date of survey: 11 - 2 - 1967

Weather: Sunny with moderate wind.

Location of courses: first course: direction Saida - Beirut
reversed course: direction Beirut- Saida
(see key plan)

<u>Site description:</u>

a- Terrain: levelled

b- Available course length due to site conditions: limited to about 25 m.

c- Noise: a good amount of noise due to traffic and flow of water in the river.

d- Special conditions: water table is at, or near, the ground surface which is covered with pebbles.

<u>Results:</u>

From the time-distance graph (fig. 4-2), it is found that for a depth corresponding to a course length of about 20 m. there is no break in the curve hence no change of material within the depth tested.

a) <u>Velocities:</u>

From fig. 4-2, it is found that:

$$av.V_1 = 315 \text{ m/sec.} = 1034 \text{ ft/sec.}$$

Referring to the boring logs on pages 35-36, it is seen that for a depth of approximately 7.0 m. the subsoil is a mixture of sand, gravel and pebbles. According to the velocity table page 30, the velocity of 1034 ft/sec. found from the test falls in the upper range of sand velocities. This agrees with the boring logs on pages 35-36. The velocity of 1034 ft/sec. cannot be compared with velocity of water in loose material (table p.30) because the seismic waves will travel through the sand rather than water.

b) Depths:

Although only one velocity line is shown on the time-distance graph, it is possible to compute a depth of penetration either by (i): assuming a low velocity $V_2 > V_1$ and assuming the critical point at the last hammering distance, or (ii): taking the depth to be roughly equal to one fourth of the course length. In both cases the calculated depth will be on the conservative or shallow side.

As an illustration the depth shall be computed by both methods (i) and (ii):

(i): Assuming a velocity $V_2 = 400$ m/sec. and a critical distance $C_1 = 18$ m. we get:

$$K_1 = \frac{1}{2}\sqrt{\frac{400 - 315}{400 + 315}} = 0.172$$

hence $D_1 = K_1 \cdot C_1 = 0.172 \times 18 = \underline{3.10 \text{ m}}$

(ii): $D_1 = \frac{C_1}{4} = \frac{18}{4} = \underline{4.50 \text{ m}}$

Hence for a minimum depth of about 4.00 m. there is no change of material with depth.

Comments:

Although the results obtained do confirm with the borings, the readings could be taken only with great difficulty. This was due to the fact that the waves were very often dispersed or distorted by the pebbles. At every hammering station, a large number of blows was necessary before the well-shaped wave could be seen and the delay time recorded.

At about 20 m. from the geophone, the readings could no more be taken as it became impossible to distinguish between the noise and the hammer waves. Had it been that no disturbance was caused by noise, still no deeper probing could be done due to the limited available course length by the site conditions.

Site No. 2

T H E E A S T E N T R A N C E
O F T H E C I T Y O F B E I R U T

Information given by

INDUSTRY INSTITUTE

Boring Log-Subsurface Exploration

Project: East Entrance of the City of Beirut

Boring No. 3

Depth to Ground water: 200 cm on 5-5-66

Depth m.	Depth ft.	Visual Identification of Materials	Legend	Remarks
1		Fill materials consisting of rock fragments and clay.		
2	5	Silty sand, reddish in color, with some roots.		Standard Penetration= 5
3, 4	10, 15	Medium to fine beach sand, loose, with gravel broken glass and bricks.		Standard Penetration= 11
5, 6, 7, 8	20, 25	Porous weathered limestone creamy white in color, changing into greyish limestone, varying between soft to hard, interbeded with clayey marls.		End of drilling
9, 10	30			

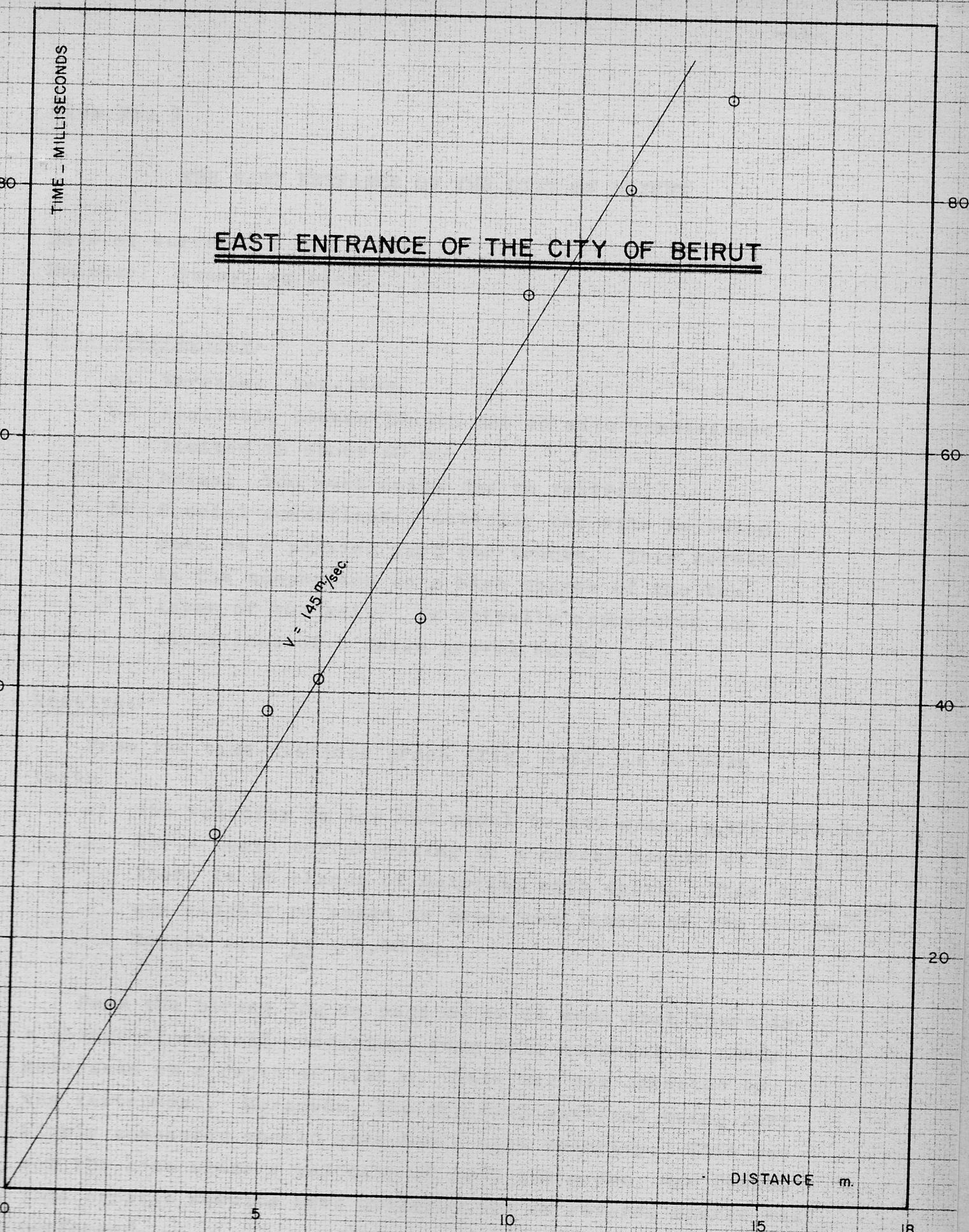

EAST ENTRANCE OF THE CITY OF BEIRUT
TIME _ MILLISECONDS
V = 145 m/sec.
DISTANCE m.
0
5
10
15
18
20
40
60
80

FIG. Nº 4-3

Site No. 2

THE EAST ENTRANCE OF THE CITY OF BEIRUT

Date of survey: 2 - 4 - 1967

Weather: Sunny, no wind.

Site description:

a- Terrain: levelled

b- Available course length due to site conditions: limited to about 60 m.

c- Noise: too much noise due to traffic.

d- Special conditions: Actually the site is being used as a parking yard for trucks. This resulted in the compaction to a high degree of the top layer of the soil. It actually approaches the conditions of a dense gravel road.

Results:

From the time-distance graph (fig. 4-3), it is seen that:

a) the velocity is low and equal to 145 m/sec. ≈ 475 ft/sec.

b) for a depth corresponding to a course length of 14 m. there is no change of material with depth. This depth can roughly be taken as being one fourth of the course length i.e. $\frac{14}{4} = 3.50$ m.

From the boring log on page 41 it is seen that there is a change of subsoil conditions from fill material to sandy materials at a depth of 1.25 m. This was not detected by the instrument. Moreover, the top fill material being very highly compacted should have had a high velocity. This was not the case since a velocity of only 145 m/sec. was found. Thus erratic results were obtained and no reverse course was performed.

<u>Comments</u>:

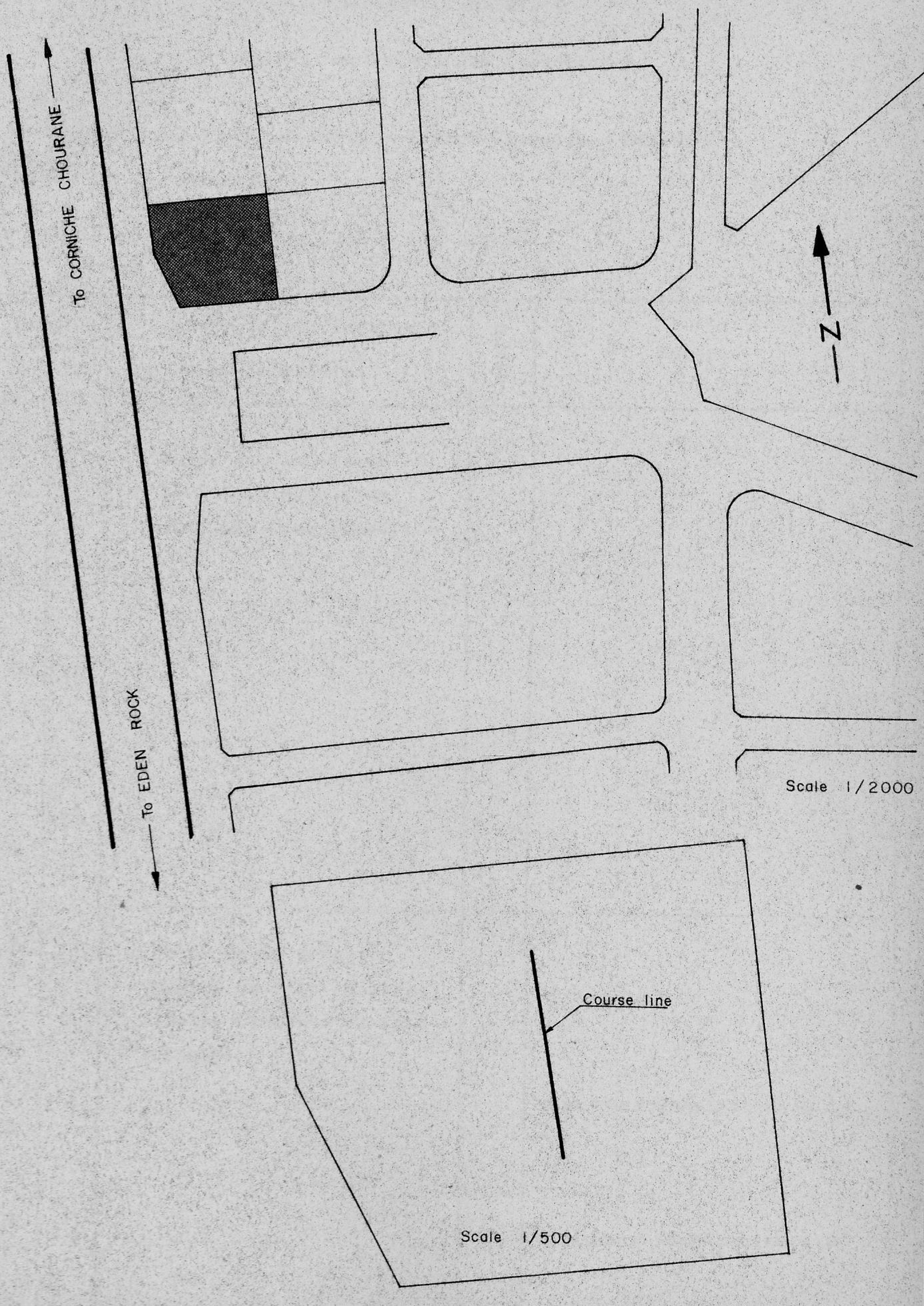
The erratic results obtained were mainly due to the fact that the site conditions approached those of a dense gravel road, a condition which should had been avoided upon choice of the course, but which in our case could not be because of the fact that all the site was highly compacted since it is being used as a parking yard as already mentioned. The highly compacted fill top materials are undoubtly overlying formations that have lower velocities. The velocity obtained from the test was probably an average velocity from the two upper layers. The erratic readings were probably the result of the compacted condition and non-uniformity of the top layer causing dispersion of the energy and restricting penetration.

The level of noise due to traffic was very high even though the time of the survey was chosen on purpose to be the early hours of a sunday morning. At about 15 m. from the geophone, the hammer waves were completely undistinguishable from the noise waves.

Site No. 3

S T R A N D B E A C H H O T E L L O T

KEY PLAN - STRAND BEACH HOTEL



Information given by

INDUSTRY INSTITUTE

Boring Log-Subsurface Exploration

Project: Strand Beach Hotel - Ramleh El-Beida - Beirut

Boring No. Typical

Depth to Ground Water: 12.5 m on 7-11-66

Depth m	Depth ft	Visual Identification of Materials	Legend	Remarks
0 – 5.6	0 – 18.5	Sand, reddish brown in color, with some clay and some gravel.		
5.6 – 10	18.5 – 33	Beach sand, clean, medium to fine in size, weakly cemented in some places.		Standard Penetration = 49 (at 7.7 m / 25 ft) Standard Penetration = 99 (at 9.2 m / 30 ft)

Information given by

INDUSTRY INSTITUTE

Boring Log-Subsurface Exploration

Project: Strand Beach Hotel - Ramleh El-Beida - Beirut

Boring No. Typical (continued).

Depth m	Depth ft	Visual Identification of Materials		Remarks
	35			
11				Standard Penetration = 55
12	40			Standard Penetration = 30
13				
	45			Standard Penetration = 37
14				
15				
	50			Standard Penetration = 62
16				
	55			Standard Penetration = 55
17				
18				
	60			Standard Penetration = 46
19				
	65			Standard Penetration = 24
20				

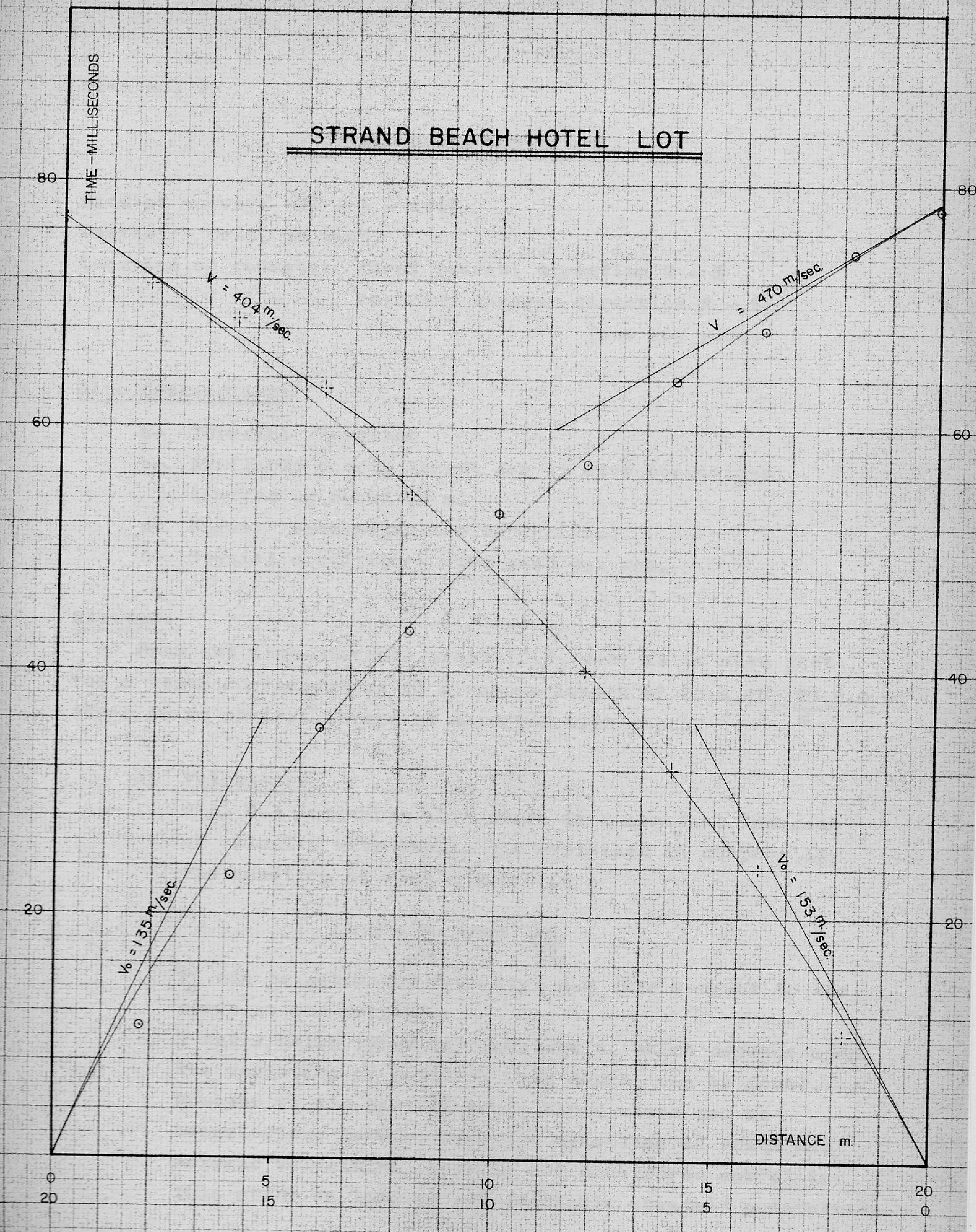

STRAND BEACH HOTEL LOT
TIME-MILLISECONDS
80
60
40
20
V = 404 m/sec.
V = 470 m/sec.
V0 = 135 m/sec.
V0 = 153 m/sec.
DISTANCE m.
0
5
10
15
20
20
15
10
5
0

FIG. Nº 4-4

Site No. 3

STRAND BEACH HOTEL LOT

Date of survey: 21 - 1 - 1967

Weather: Cold, no wind.

Location of courses: first course: direction S - N
reversed course: direction N - S
(see key plan)

Site description:

a- Terrain: levelled

b- Available course length due to site conditions: limited to about 25 m.

c- Noise: some noise due to traffic.

d- Special conditions: the sand was wet.

Results:

From the time-distance graph (fig. 4-4) it is seen that for a depth corresponding to a course length of 20 m. ($D_1 = \frac{20}{4} = 5.0$ m) there is no obvious change of material with depth.

a) **Velocities:**

Fig. 4-4 indicates that there is a constant increase of velocity with depth. As explained in chapter II, the equation of such a curve is :

$$T = \frac{2}{k} \sinh^{-1} \frac{kx}{2V_o}$$

V_o can be estimated from fig. 4-4 (the tangent to the curve at the origin).

T and x being known the constant k, which depends upon the variation of velocity with depth, can be found. However at the present time, since there are no correlations between relative densities of sands and seismic velocities, this is not considered useful in this study as long as the available standard penetration results are erratic (see boring log p. 47-48). It was therefore considered more useful to estimate the range of velocities encountered within the depth of penetration by drawing tangents to the travel time curve at the two ends of the courses. The following velocities were obtained:

$$\text{av.}V_o' = \frac{135+153}{2} = 144 \text{ m/sec.} = 472 \text{ ft/sec.}$$

$$\text{av.}V' = \frac{470+404}{2} = 437 \text{ m/sec.} = 1433 \text{ ft/sec.}$$

$$\text{av.}\frac{V_o+V'}{2} = \frac{144+437}{2} = 290 \text{ m/sec.} = 952 \text{ ft/sec.}$$

The velocity of 952 ft/sec. is typical of that of sands; moreover the range of test velocities (472 ft/sec. 1433 ft/sec.) falls within the expected range for sand under site conditions, i.e. the top is loose and weathered (hence low velocities) and the lower region compact and wet (hence higher velocities).

b) Depth:

As previously explained, an approximate depth of penetration of $D_1 = \frac{20}{4} = 5.0$ m. can be assumed.

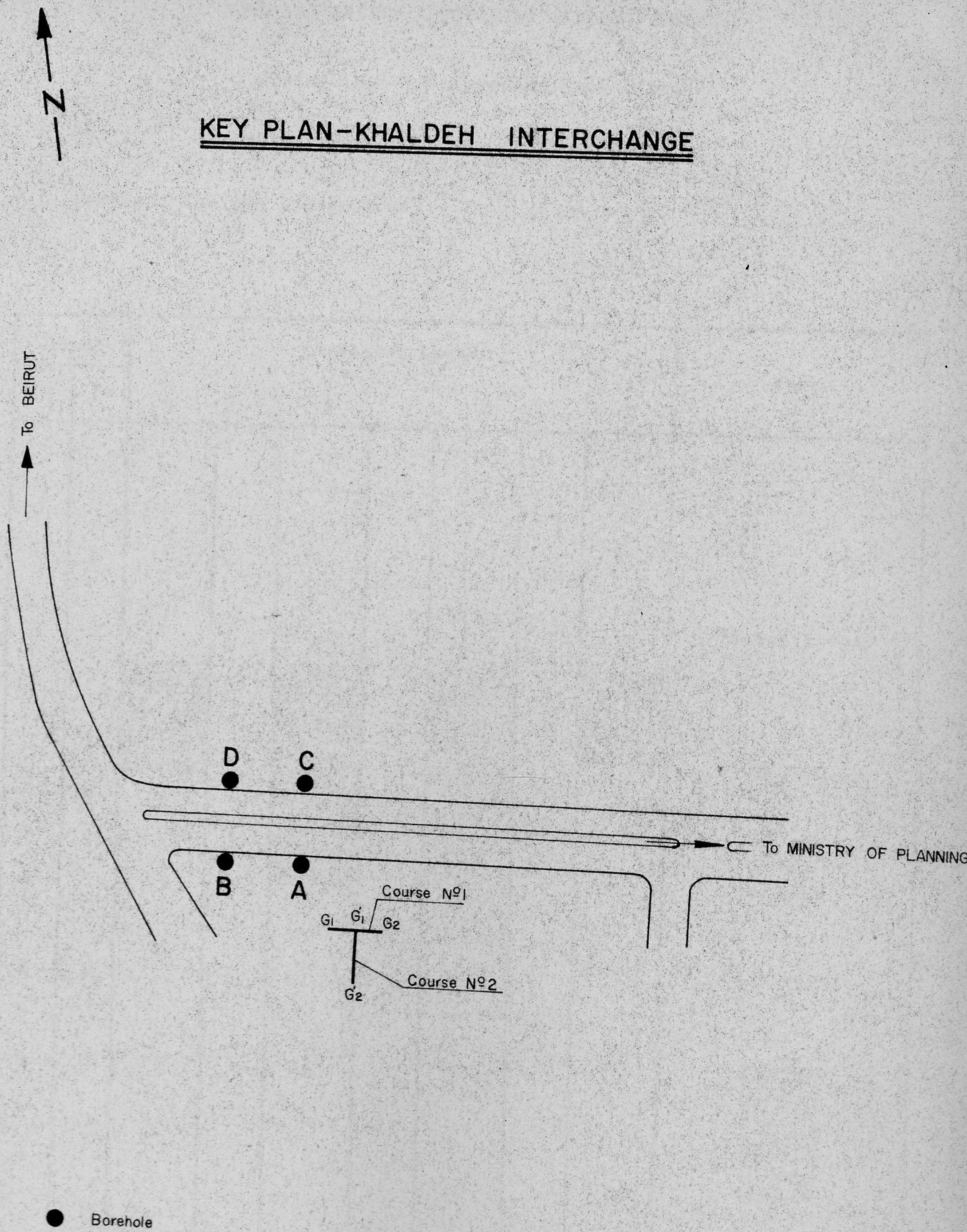
Comments:

The wave was very clear and well determined. Readings could be taken with ease up to a distance of 20 m. Beyond which it became impossible to distinguish between the hammer waves and the noise waves.

Site No. 4

K H A L D E H   I N T E R C H A N G E

KEY PLAN-KHALDEH INTERCHANGE



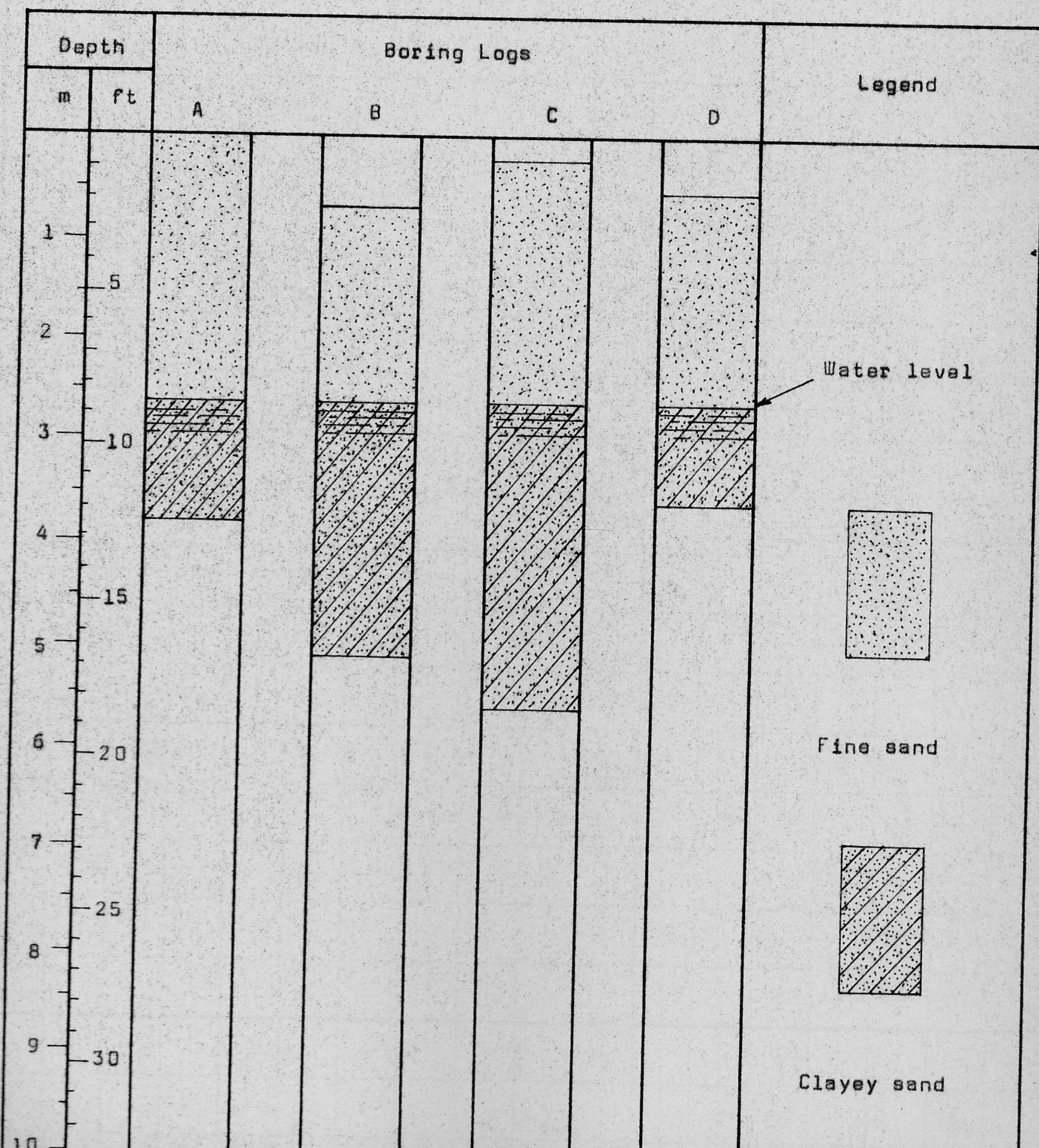
Scale 1/2000

Information given by

ROAD LABORATORY - MINISTRY OF PUBLIC WORKS

Boring Logs - Subsurface Exploration

Project: Khaldeh Interchange.



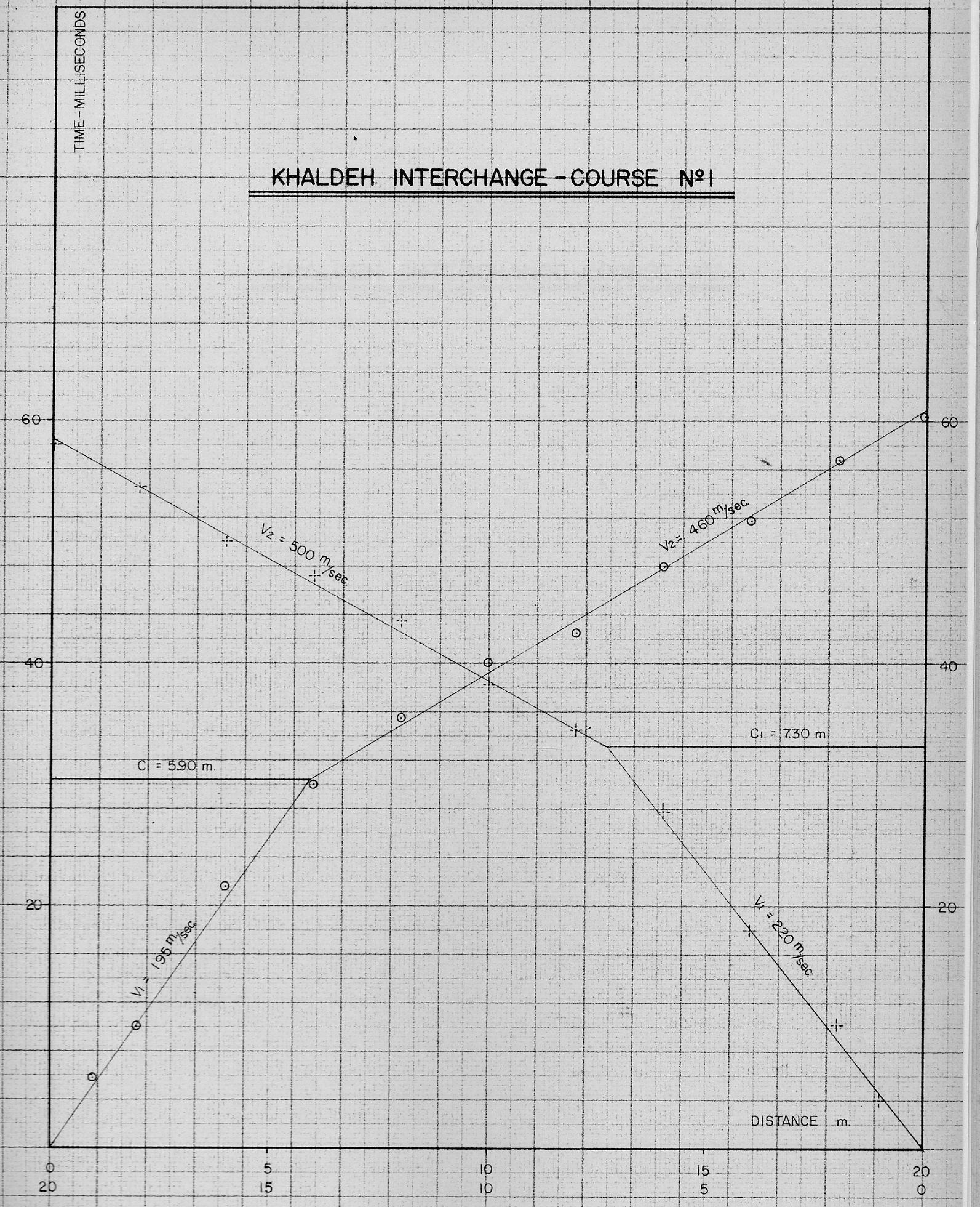

TIME - MILLISECONDS
KHALDEH INTERCHANGE - COURSE №1
V2 = 500 m/sec.
V2 = 460 m/sec.
C1 = 7.30 m.
C1 = 5.90 m.
V1 = 195 m/sec
V1 = 220 m/sec.
DISTANCE m.
60
40
20
0
5
10
15
20
20
15
10
5
0

FIG. № 4-5

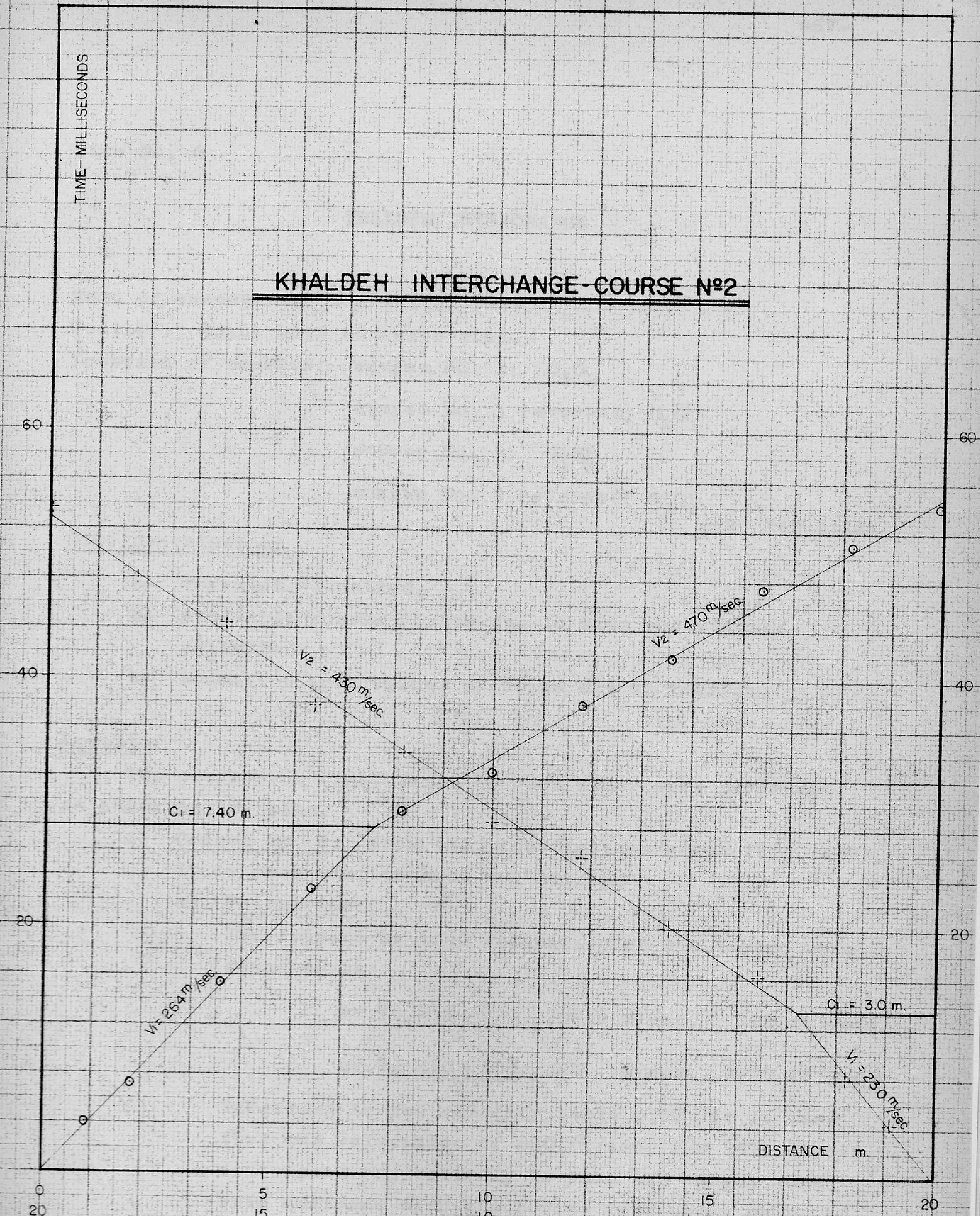

TIME-MILLISECONDS
KHALDEH INTERCHANGE-COURSE №2
60
40
20
60
40
20
V2 = 430 m/sec
V2 = 470 m/sec
C1 = 7.40 m.
C1 = 3.0 m.
V1 = 264 m/sec
V1 = 230 m/sec
DISTANCE m.
0
5
10
15
20
20
15
10
5
0

FIG. № 4-6

Site No. 4

KHALDEH INTERCHANGE

Date of survey: 19 - 3 - 1967

Weather: Sunny with moderate wind.

Location of courses: course No. 1: G_1G_2

course No. 1 reversed: G_2G_1

course No. 2: $G'_1G'_2$

course No. 2 reversed: $G'_2G'_1$

(see key plan)

Site description:

a- Terrain: levelled.

b- Available course length due to site conditions: unlimited.

c- Noise: a good amount of noise due to traffic.

Results:

Two courses at right angle to each other were performed as shown in key plan.

A) Course No. 1: From the time-distance graph (fig. 4-5), it is seen that we have two layers.

a) Velocities:

The average or true velocities of the layers were found to be:

$$av.V_1 = \frac{195 + 220}{2} = 207.5 \text{ m/sec.} = 680 \text{ ft/sec.}$$

$$av.V_2 = \frac{460 + 500}{2} = 480 \text{ m/sec.} = 1575 \text{ ft/sec.}$$

Referring to the velocity table p.30, it is seen that the velocities of 680 ft/sec. and 1575 ft/sec. correspond respectively to sand and clayey sand. This conforms with the boring logs shown on p. 54.

b) <u>Depths</u>:

Course G_1G_2:

$$K_1 = \frac{1}{2}\sqrt{\frac{480.0 - 207.5}{480.0 + 207.5}} = 0.314$$

$C_1 = 5.90$ m.

hence $D_1 = 0.314 \times 5.90 = \underline{1.85}$ m.

Course G_2G_1:

$K_1 = 0.314$

$C_1 = 7.30$ m.

hence $D_1 = 0.314 \times 7.30 = \underline{2.30}$ m.

The interface is therefore dipping in the direction G_1G_2. From the boring logs p. 54, it is seen that the interface is at a depth of 3.0 m. from the ground surface. This conforms reasonably with the results obtained by the refraction seismograph specially that the exact location of the points at which the borings were made is not known (key plan shows estimated locations).

B) <u>Course No. 2</u>: From the time-distance graph (fig. 4-6), it is seen that we have two layers as in the previous course.

a) <u>Velocities</u>:

The average or true velocities of the layers are:

$$av.V_1 = \frac{264 + 230}{2} = 247 \text{ m/sec.} = 810 \text{ ft/sec.}$$

$$av.V_2 = \frac{470 + 430}{2} = 450 \text{ m/sec.} = 1475 \text{ ft/sec.}$$

These velocities correspond respectively to sand and clayey sand as given by the boring logs on p. 54

b) Depths:

Course $G_1'G_2'$:

$$K_1 = \frac{1}{2}\sqrt{\frac{450 - 247}{450 + 247}} = 0.270$$

$C_1 = 7.40$ m.

hence $D_1 = 0.270 \times 7.40 = \underline{2.00}$ m.

Course $G_2'G_1'$:

$K_1 = 0.270$

$C_1 = 3.0$ m.

hence $D_1 = 0.270 \times 3.0 = \underline{0.81}$ m.

The interface is therefore dipping in the direction $G_2'G_1'$. This conforms with the conditions of the site as at an approximate distance of 20 m. from G_2' in the up-dip direction, the clayey sand reaches the surface.

From course No. 1 and at midpoint between G_1 and G_2 (point G_1') the depth is $\approx \frac{1.85 + 2.30}{2} = \underline{2.20}$ m. This compares very closely with the depth found from course No. 2, namely $D_1 = \underline{2.00}$ m.

Comments:

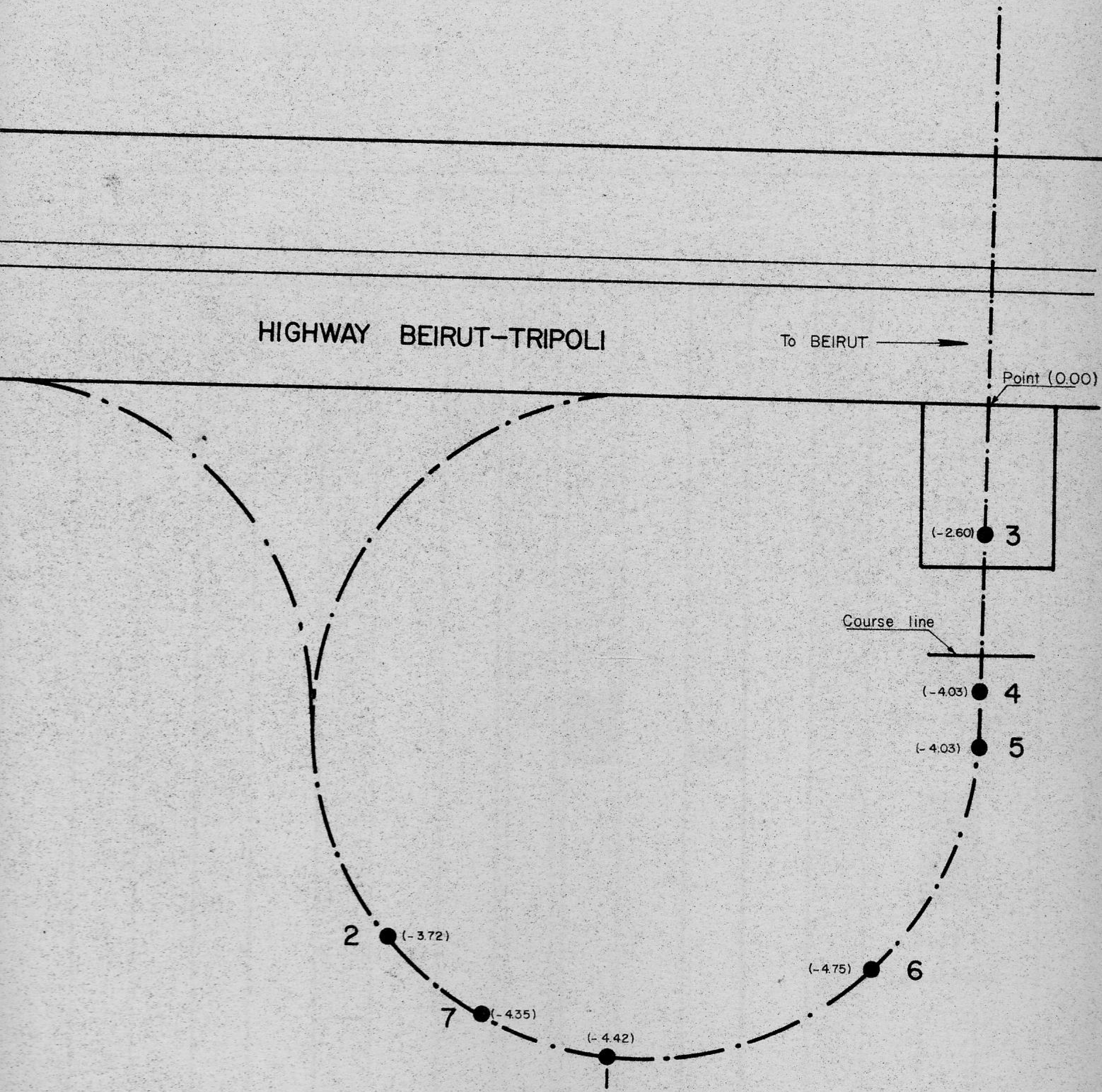
The results obtained with the refraction seismograph conform with the boring logs except for the fact that the water table which is at three meters below the ground surface was not detected. This may be due to the fact that the soil was saturated by the heavy rain which preceded the date of the survey, and no sharp velocity change would be expected.

Noise created by traffic was very disturbing, and at about 20 m. from the geophone, the hammer waves could no more be distinguished from the noise waves.

Site No. 5

J E I T A   O V E R P A S S

KEY PLAN- JEITA OVERPASS



● Borehole

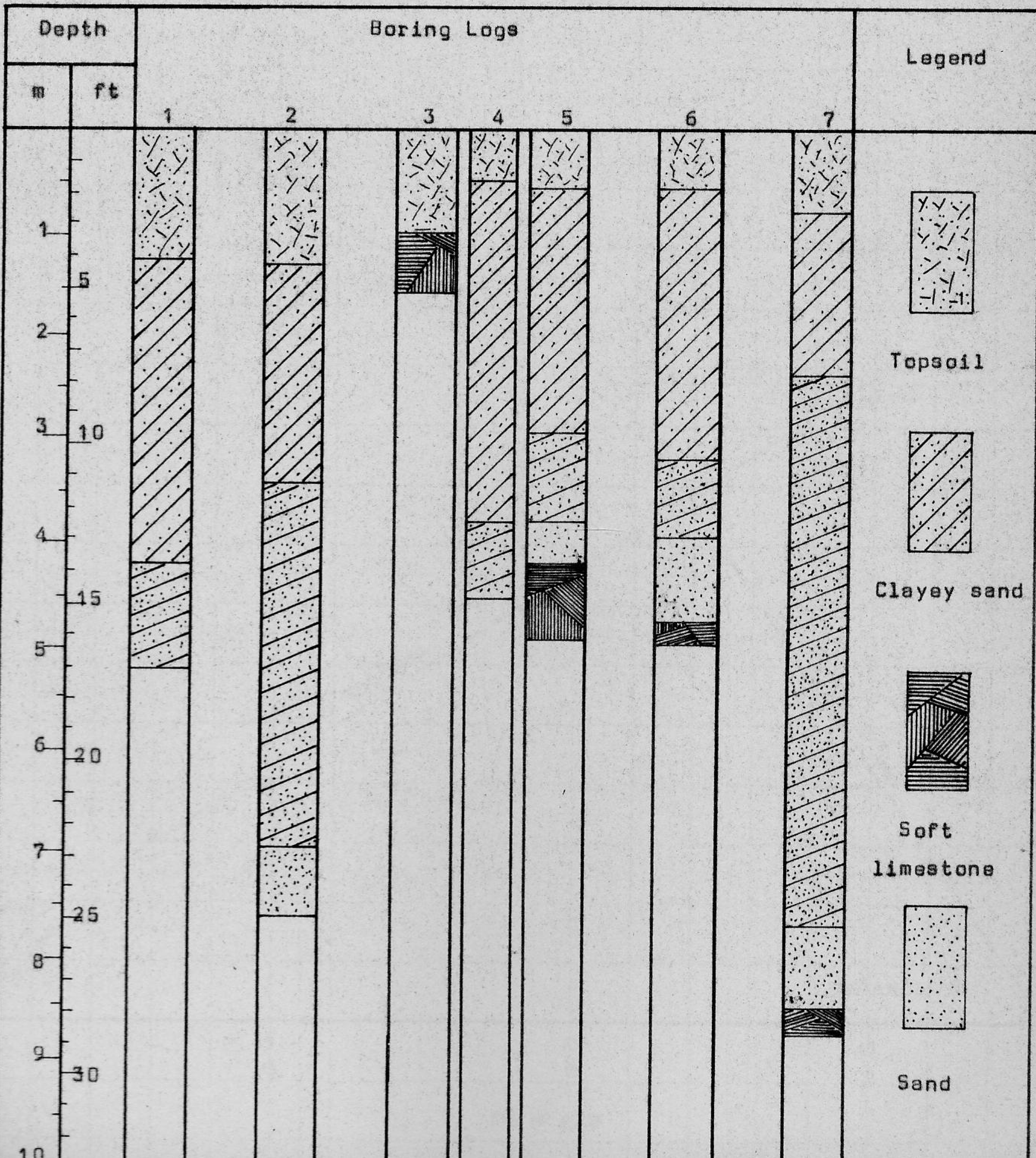
Scale 1/1000

Information given by

ROAD LABORATORY - MINISTRY OF PUBLIC WORKS

Boring Logs - Subsurface Exploration

Project: Jaita Overpass.



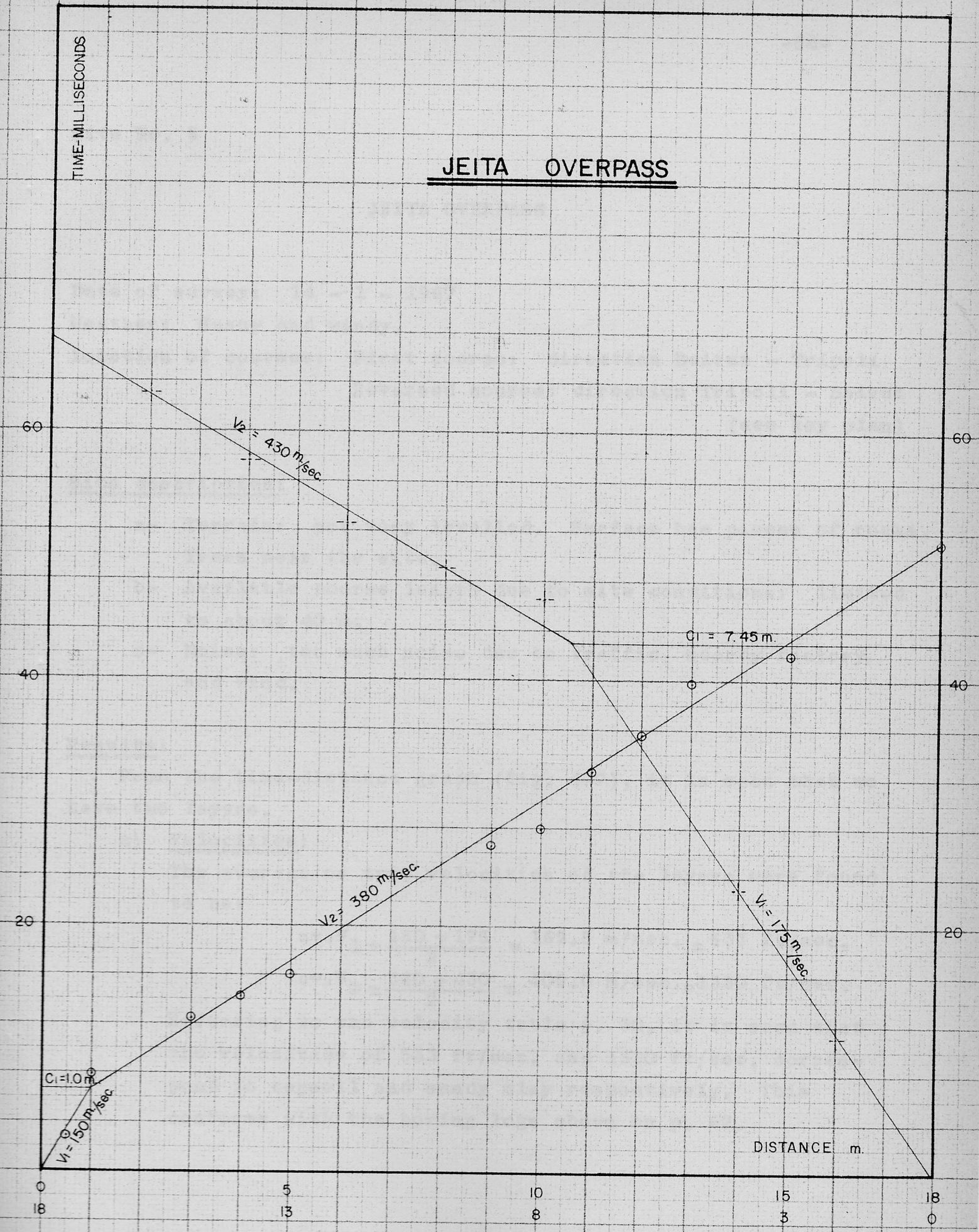

TIME-MILLISECONDS
JEITA OVERPASS
V2 = 430 m/sec.
C1 = 7.45 m.
V2 = 380 m/sec.
V1 = 175 m/sec.
C1 = 1.0 m.
V1 = 150 m/sec.
DISTANCE m.
60
40
20
0
5
10
15
18
18
13
8
3
0

FIG. Nº 4-7

Site No. 5

JEITA OVERPASS

Date of survey: 14 - 1 - 1967

Weather: Sunny and windy.

Location of courses: First course: direction Beirut - Tripoli
Reversed course: direction Tripoli - Beirut
(see key plan)

Site description:

a- Terrain: not very levelled. Surface has pieces of rocks. Trees near the site.

b- Available course length due to site conditions: limited to about 40 m.

c- Noise: too much noise due to traffic, nearby factory, and wind.

Results:

From the time-distance graph (fig. 4-7), it is seen that we have two layers.

a) **Velocities:**

The average or true velocities of the layers were found to be:

$$av.V_1 = \frac{150 + 175}{2} = 162.5 \text{ m/sec.} = 533 \text{ ft/sec.}$$

$$av.V_2 = \frac{380 + 430}{2} = 405.0 \text{ m/sec.} = 1330 \text{ ft/sec.}$$

Referring to the velocity table p. 30, it is seen that the velocities of 533 ft/sec. and 1330 ft/sec. correspond to topsoil and sandy clay respectively. This conforms with the boring logs shown on p. 62.

b) **Depths:**

First course:

$$K_1 = \frac{1}{2}\sqrt{\frac{405.0 - 162.5}{405.0 + 162.5}} = 0.326$$

$$C_1 = 1.0 \text{ m.}$$

hence $D_1 = 0.326 \times 1.0 = \underline{0.326}$ m.

Reversed course:

$$K_1 = 0.326$$

$$C_1 = 7.45 \text{ m.}$$

hence $D_1 = 0.326 \times 7.45 = \underline{2.44}$ m.

Referring to the boring logs p. 62, it is seen that the thickness of the topsoil varies between 0.50 m. and 1.25 m. The direction and location of the course were imposed by the site conditions i.e. presence of water on the surface and existance of supporting columns of the overpass. Consequently the test results cannot be correlated with any particular available borehole records which show variable subsurface conditions.

The results obtained can be considered as reasonable especially that the borehole records refer to conditions before construction of the overpass.

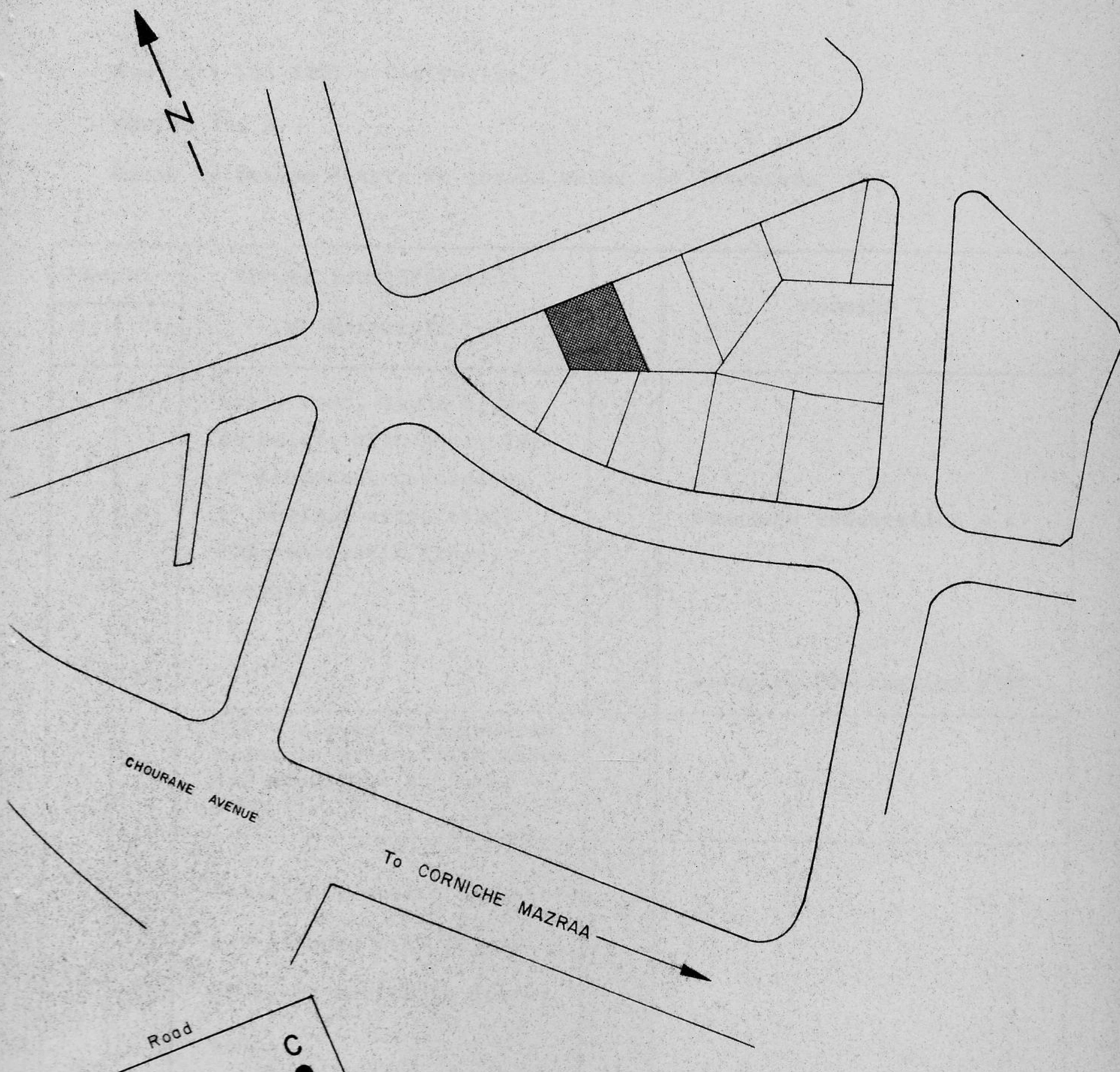
Comments:

The readings could be taken only with great difficulty especially when the distance between the hammer and the geophone became in the order of 10 m. This was due mainly to the outside noise (particularly due to factory), and partly to the fact that the waves were dispersed and distorted by the pieces of rocks scattered all over the site.

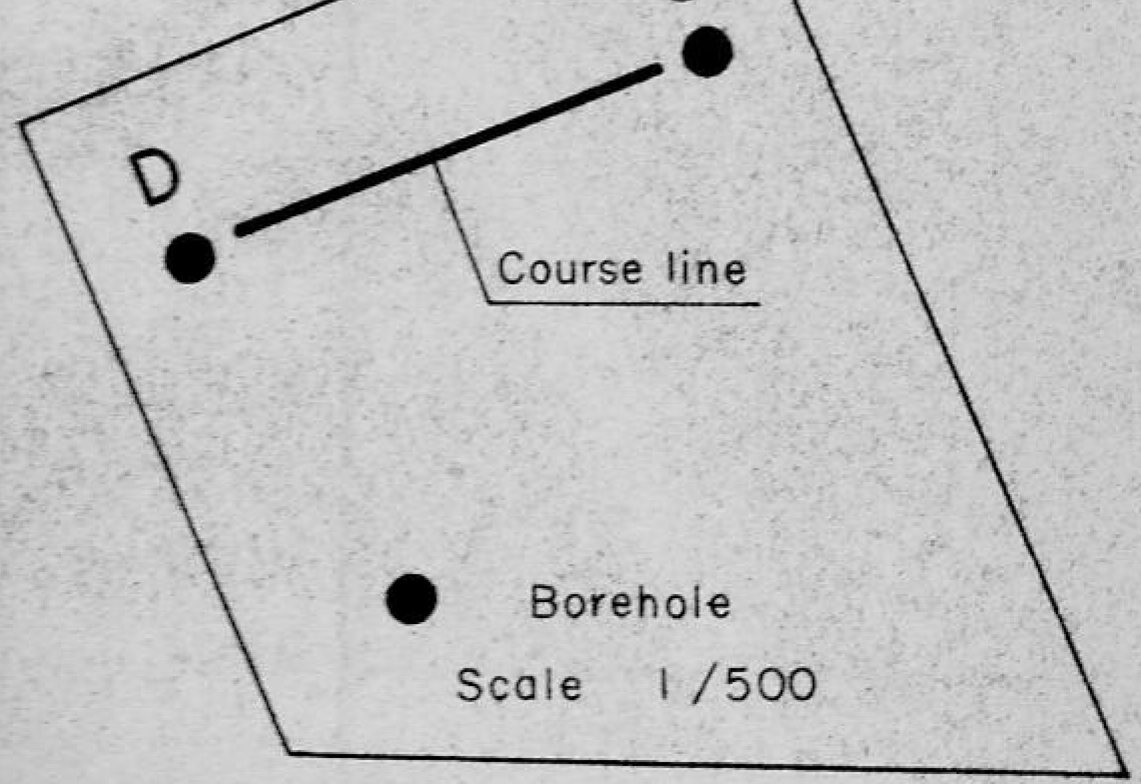
Site No. 6

LOT 3301 - RAS BEIRUT

KEY PLAN PLOT 3301- RAS BEIRUT



Scale : 1/2000



Information given by

INDUSTRY INSTITUTE

Boring Log-Subsurface Exploration

Project: Lot 3301 - Ras Beirut.

Boring No. C

Depth to Ground Water: No ground water was detected.

Depth m	Depth ft	Visual Identification of Materials	Legend	Remarks
1, 2, 3	5, 10	Silty sand, light brown in color, with about 20% of sandstone particles, 1" maximum size, about 20% nonplastic fines, compact.		Standard Penetration = 27 Standard Penetration = 40
4	15	Silty clayey sand, reddish brown in color, with about 25% nonplasti c fines, compact.		
5, 6, 7, 8, 9	20, 25, 30	Sandstone, weakly cemented, int erbeded with layers of clean medium to coarse sand.		End of drilling.
10				

Information given by

INDUSTRY INSTITUTE

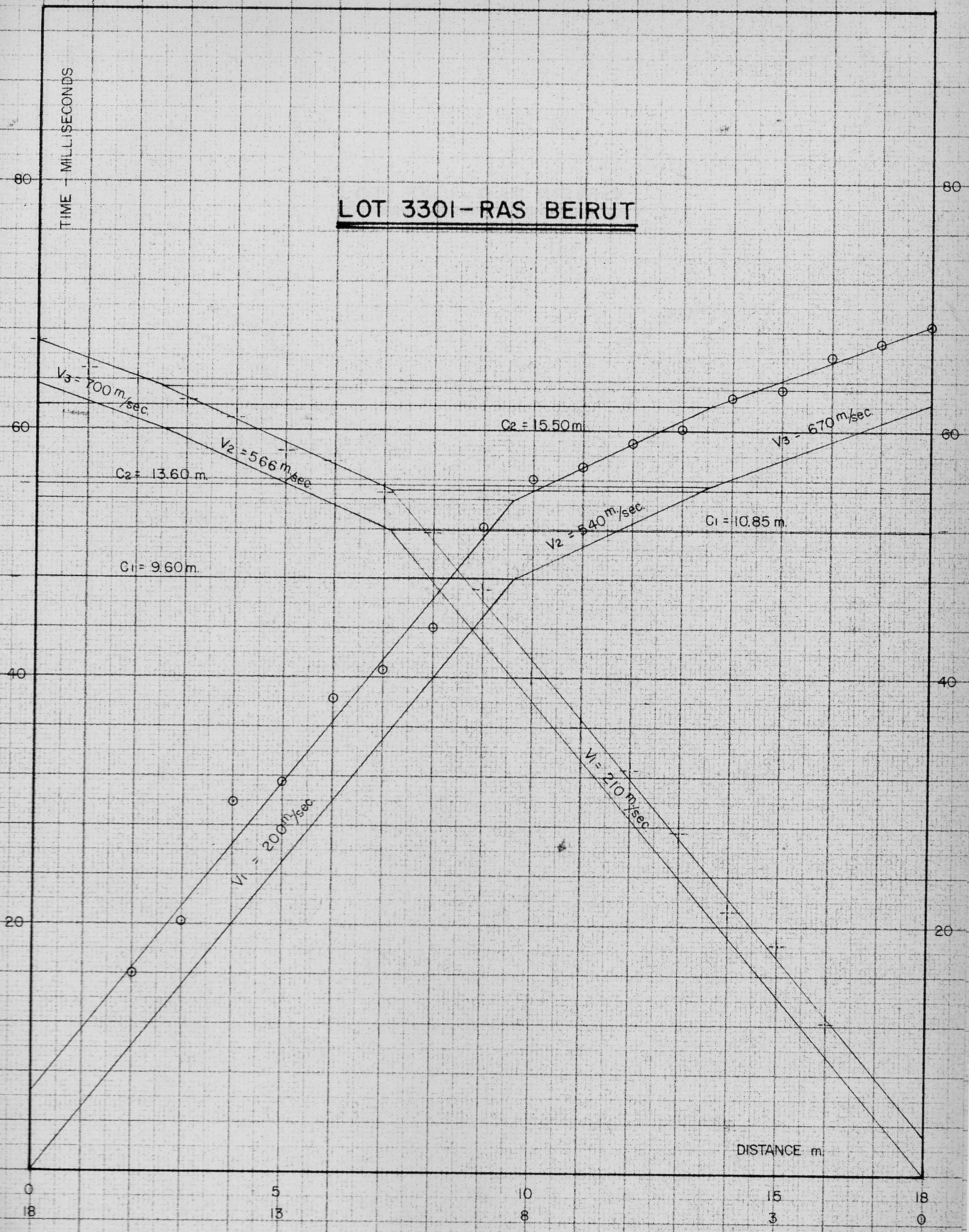
Boring Log-Subsurface Exploration

Project: Lot 3301 - Ras Beirut.

Boring No. D

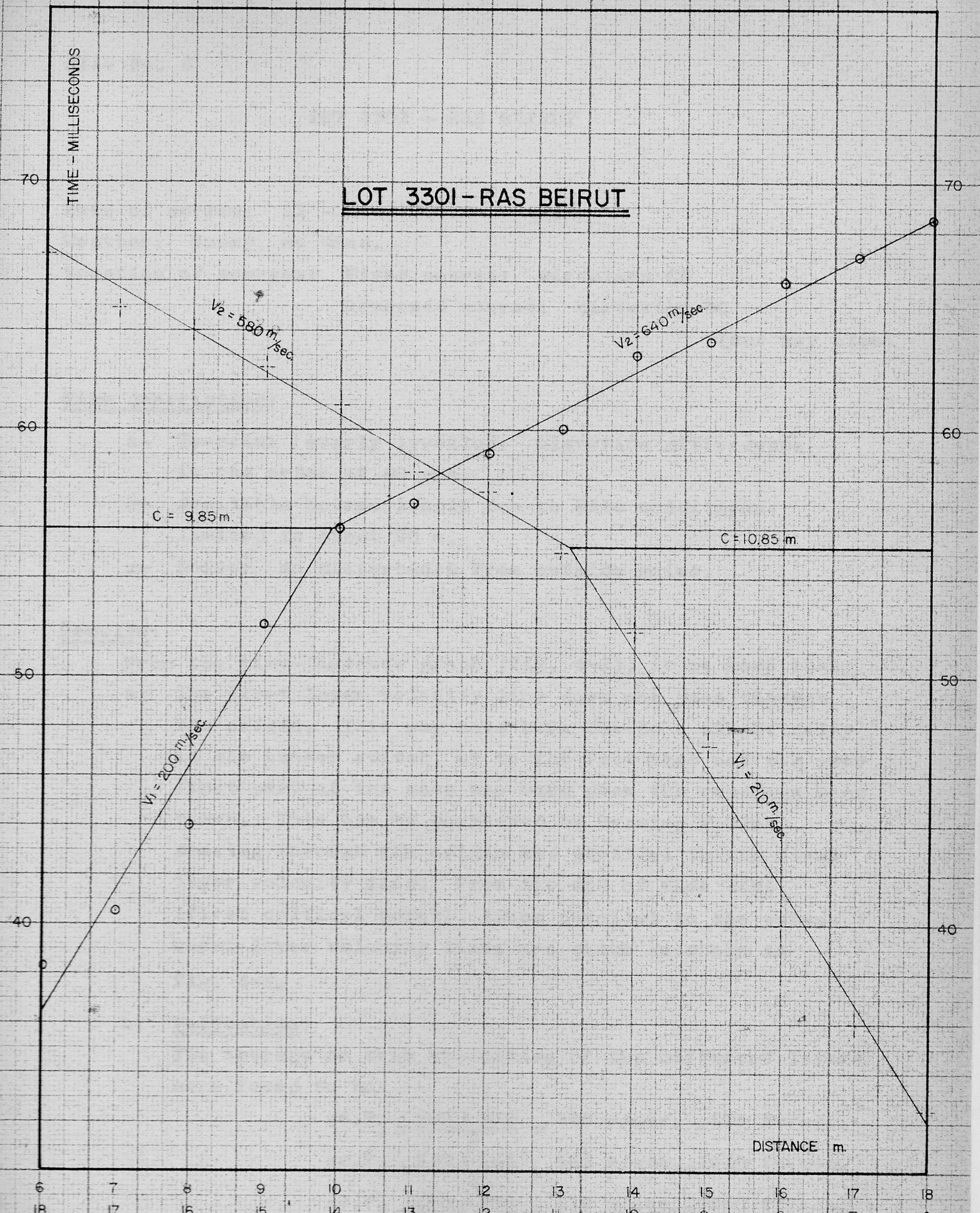
Depth to Ground Water: No ground water was detected.

Depth m	Depth ft	Visual Identification of Materials	Legend	Remarks
1 2 3	5 10	Silty sand, light brown in color, with about 20% of sandstone particles, 1" maximum size, about 20% non-plastic fines, compact.		Standard Penetration = 9 Standard Penetration = 10
4 5	15	Silty clayey sand, reddish brown in color, wiyh about 25% plastic fines, compact.		Standard Penetration = 62
6 7 8 9 10	20 25 30	Sandstone, weakly cemented, interbeded with layers of clean medium to coarse sand.		End of drilling at 10.5 m. No change in material.



LOT 3301-RAS BEIRUT
TIME - MILLISECONDS
80
60
40
20
V3 = 700 m/sec.
V2 = 566 m/sec.
C2 = 15.50 m.
C2 = 13.60 m.
C1 = 10.85 m.
C1 = 9.60 m.
V3 - 670 m/sec.
V2 = 540 m/sec.
V1 = 200 m/sec.
V1 = 210 m/sec.
DISTANCE m.
0
5
10
15
18
18
13
8
3
0

FIG. Nº 4-8



TIME - MILLISECONDS
LOT 3301-RAS BEIRUT
70
60
50
40
V_2 = 580 m/sec.
V_2 = 640 m/sec.
C = 9.85 m.
C = 10.85 m.
V_1 = 200 m/sec.
V_1 = 210 m/sec.
DISTANCE m.
6 7 8 9 10 11 12 13 14 15 16 17 18
18 17 16 15 14 13 12 11 10 9 8 7 6

FIG. Nº 4-9

Site No. 6

LOT 3301 - RAS BEIRUT

Date of survey: 12 - 1 - 1967

Weather: Sunny, no wind.

Location of courses: First course: direction CD

Reversed course: direction DC

(see key plan)

Site description:

a- Terrain: nearly levelled: elevation differences in the order of 40 cms.

b- Available course length due to site conditions: limited to about 20 m.

c- Noise: no disturbance from outside noise.

Results:

From the time-distance graph (fig. 4-8), it is seen that:

a) The first layer velocity line does not pass through the origin. This may have been due to a slight delay in the hammer switch, or to the fact that not the very first part of the wave was used when the readings were taken. This can be corrected by drawing a line passing through the origin and parallel to the first layer velocity line. From the end of this line (first critical point), lines parallel to the subsequent layer velocity lines are drawn as shown in fig. 4-8.

b) Velocities:

The average or true velocities of the different layers were found to be:

$$av.V_1 = \frac{200 + 210}{2} = 205 \text{ m/sec.} = 675 \text{ ft/sec.}$$

$$av.V_2 = \frac{540 + 566}{2} = 553 \text{ m/sec.} = 1810 \text{ ft/sec.}$$

$$av.V_3 = \frac{670 + 700}{2} = 685 \text{ m/sec.} = 2250 \text{ ft/sec.}$$

Referring to the velocity table on p. 30, it is seen that the velocities of 675 ft/sec., 1810 ft/sec. and 2250 ft/sec. correspond respectively to silty sand, silty clayey sand and weakly cemented sandstone. Therefore, the results as far as velocities and materials do check with the borings shown on p. 68 - 69.

c) <u>Depths</u>:

$$K_1 = \frac{1}{2}\sqrt{\frac{553 - 205}{553 + 205}} = 0.339$$

$$K_2 = \frac{1}{2}\sqrt{\frac{685 - 553}{685 + 553}} = 0.163$$

$$\frac{V_2}{V_1} = \frac{553}{205} = 2.70$$

$$\frac{V_3}{V_1} = \frac{685}{205} = 3.34$$

$\therefore$ $Q = 0.886$ (from fig. 4-1)

First course:

$C_1 = 9.60$ m. , $C_2 = 13.60$ m.

hence $D_1 = 0.339 \times 9.60 = \underline{3.26}$ m.

$D_2 = 0.163 \times 13.60 + 0.886 \times 3.26 = \underline{5.10}$ m.

Reversed course:

$C_1 = 10.85$ m. , $C_2 = 15.50$ m.

hence $D_1 = 0.339 \times 10.85 = \underline{3.68}$ m.

$D_2 = 0.163 \times 15.50 + 0.886 \times 3.68 = \underline{5.78}$ m.

From the above results it is seen that both interfaces dip in the direction CD.
According to the boring log p. 68, it is seen that at boring C the depth to the first interface is 3.40 m. and that to the second interface is 4.60 m. These results compare favourably with the results found by the test (3.26 m. and 5.10 m. respectively).

Boring log on p. 69 shows that at point D the depth to the first interface is 3.40 m. and that to the second interface is 5.50 m. Again these results compare closely with the results obtained by the test (3.68 m. and 5.78 m. respectively).

Thus the results obtained with the refraction seismograph check with the borings as far as materials, velocities, and depth values.

Comments:

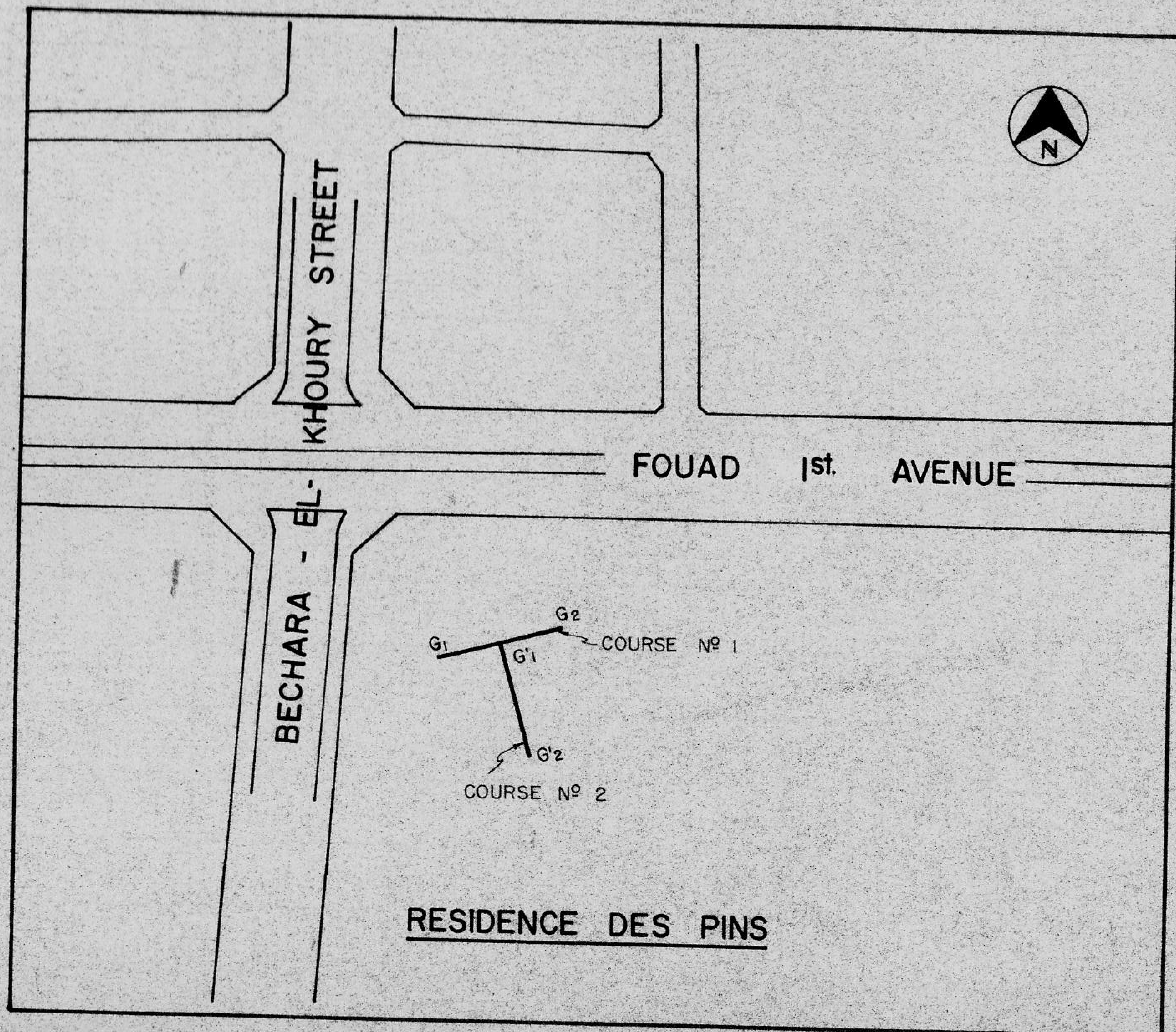
From the time-distance graph (fig. 4-8), it is seen that the breaks between the second and the third velocity lines are not sharp. This means that if the investigator had no previous knowledge of the subsurface conditions, only one line could have been fitted instead of the two lines corresponding to the second and third velocity lines. This is shown to a large scale in fig. 4-9. Knowledge of the subsurface conditions before the interpretation of the results is therefore of prime importance.

The limitation of the course length by surrounding buildings and abrupt differences in elevation did not allow probing deeper than 5.78 m.

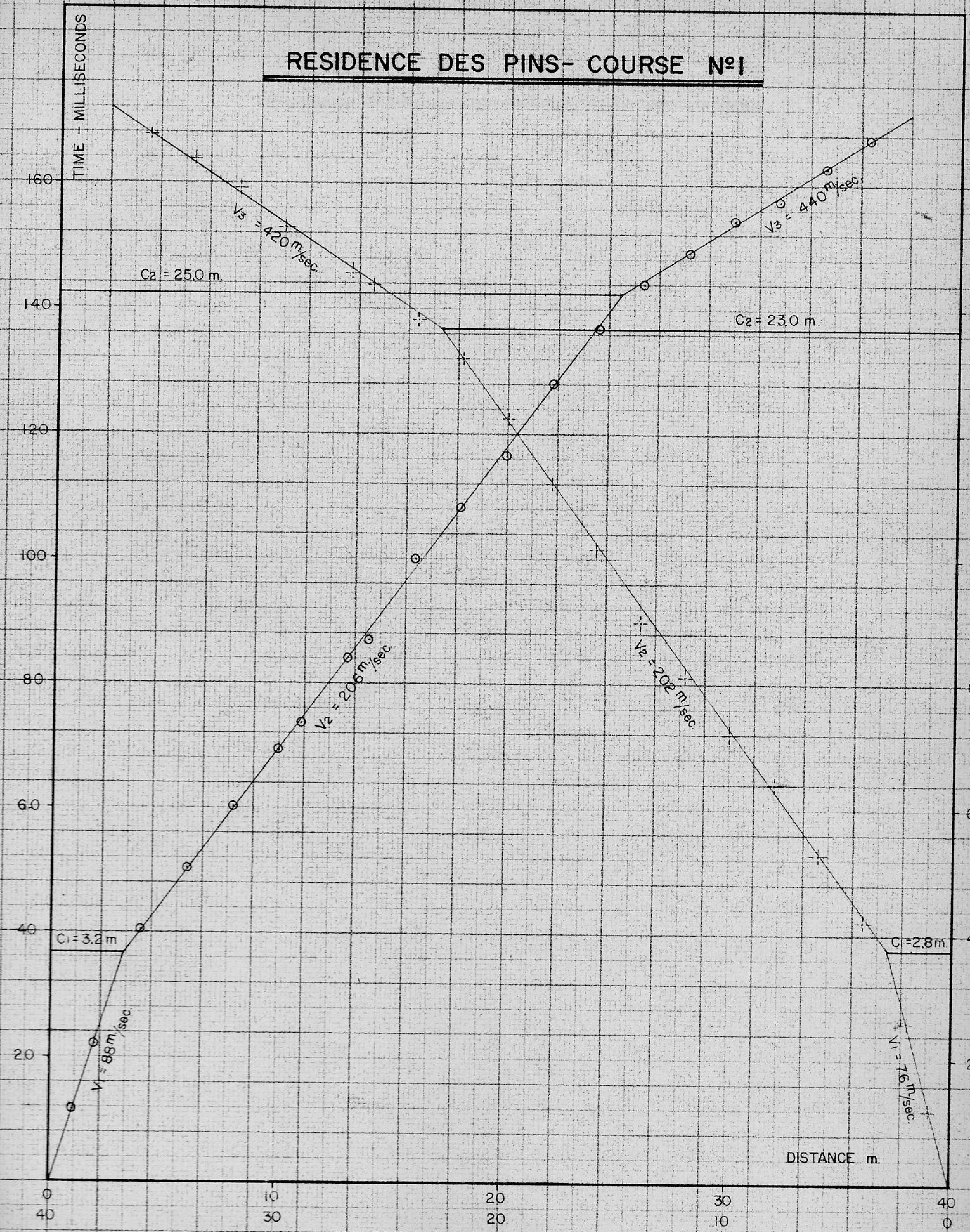
Site No. 7

R E S I D E N C E   D E S   P I N S

KEY PLAN - RESIDENCE DES PINS



SCALE 1: 2000



RESIDENCE DES PINS- COURSE Nº1
TIME - MILLISECONDS
DISTANCE m.
C2 = 25.0 m.
C2 = 23.0 m.
C1 = 3.2 m
C1 = 2.8 m.
V3 = 420 m/sec.
V3 = 440 m/sec.
V2 = 206 m/sec.
V2 = 202 m/sec.
V1 = 88 m/sec.
V1 = 76 m/sec.
160
140
120
100
80
60
40
20
0
10
20
30
40

FIG. Nº 4-10

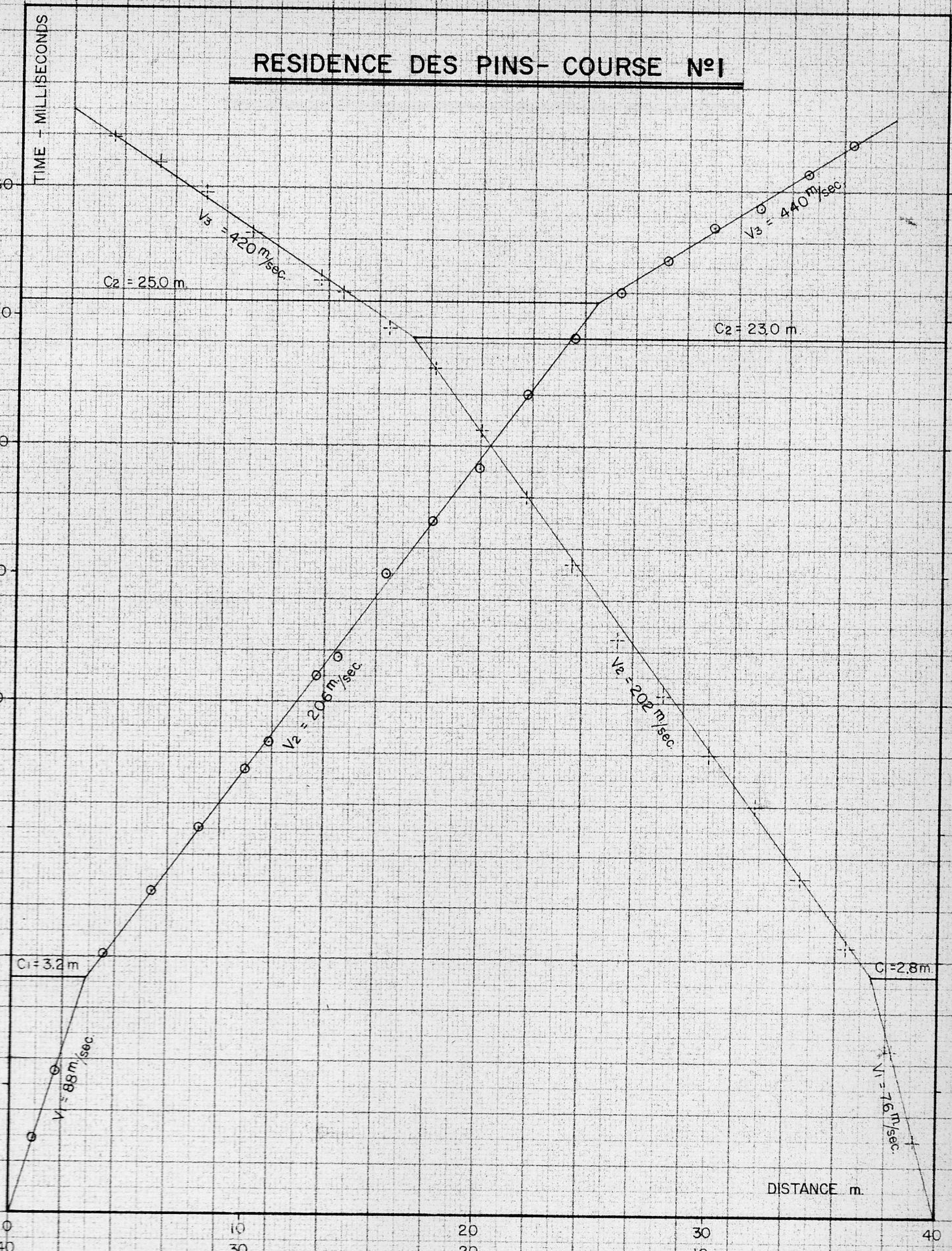

RESIDENCE DES PINS- COURSE Nº1
TIME - MILLISECONDS
DISTANCE m.
V3 = 420 m/sec.
V3 = 440 m/sec.
C2 = 25,0 m.
C2 = 23,0 m.
V2 = 206 m/sec.
V2 = 202 m/sec.
C1 = 3,2 m
C1 = 2,8 m.
V1 = 88 m/sec.
V1 = 76 m/sec.
160
140
120
100
80
60
40
20
0
10
20
30
40
40
30
20
10
0

FIG. Nº 4-10

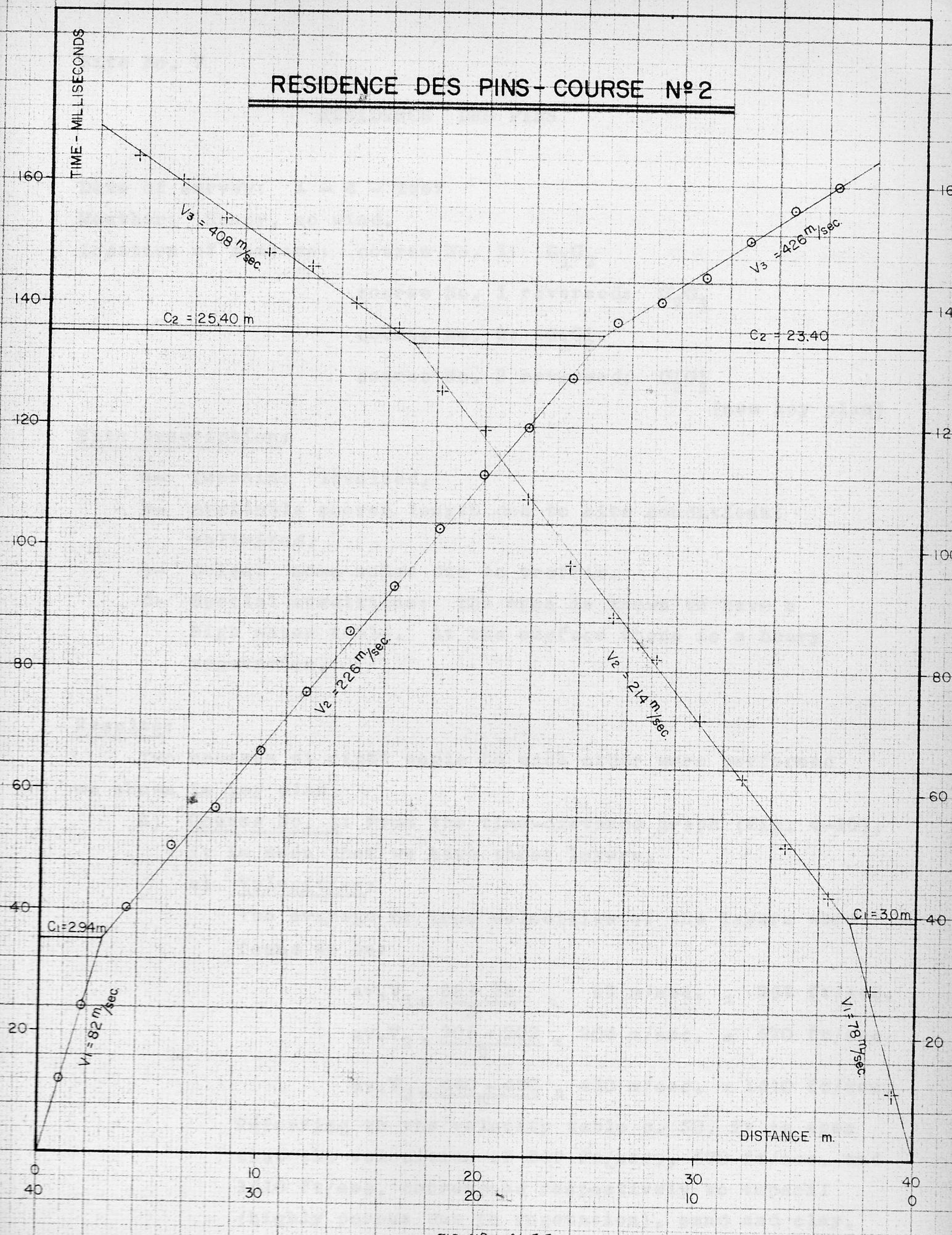

RESIDENCE DES PINS - COURSE Nº 2
TIME - MILLISECONDS
DISTANCE m.
V3 = 408 m/sec.
V3 = 426 m/sec.
C2 = 25.40 m
C2 = 23.40
V2 = 226 m/sec.
V2 = 214 m/sec.
C1 = 2.94 m
C1 = 3.0 m
V1 = 82 m/sec
V1 = 78 m/sec.
160
140
120
100
80
60
40
20
0
40
10
30
20
20
30
10
40
0

FIG. Nº 4-11

Site No. 7

RESIDENCE DES PINS

Date of survey: 1 - 4 - 1967

Weather: Sunny, no wind.

Location of courses: course No. 1: G_1G_2

course No. 1 reversed: G_2G_1

course No. 2: $G'_1G'_2$

course No. 2 reversed: $G'_2G'_1$

(see key plan)

Site description:

a- Terrain: levelled.

b- Available course length due to site conditions: unlimited.

c- Noise: some noise due to traffic.

d- Special conditions: the area is known to have a high water table. At the surface there is a heavy vegetation.

Results:

Two courses at right angle to each other were performed as shown in key plan.

A) Course No. 1: From the time-distance graph (fig. 4-10), it is seen that we have three layers.

a) Velocities:

The average or true velocities of the layers were found to be:

$$av.V_1 = \frac{88 + 76}{2} = 82 \text{ m/sec.} = 269 \text{ ft/sec.}$$

$$av.V_2 = \frac{206 + 202}{2} = 204 \text{ m/sec.} = 670 \text{ ft/sec.}$$

$$av.V_3 = \frac{440 + 420}{2} = 430 \text{ m/sec.} = 1410 \text{ ft/sec.}$$

Referring to the velocity table p. 30, it is seen that the velocities of 269 ft/sec., 670 ft/sec. and 1410 ft/sec. correspond respectively to topsoil (highly porous due to vegetation), sand and clay.

From information obtained from the "Conseil Executif Des Grands Projets de la Ville de Beyrouth". who built the underpass Bechara El Khoury Av. - Fouad 1st Av. the profile of the subsoil in this area is as follows: weathered topsoil for about one meter and reddish sand to a depth of 7.0 m. to 8.0 m. from the ground surface. Below the sand a deep layer of a very plastic blue clay exists; the thickness of this layer is not known. Ground water is at an approximate depth of 4.0 m.

b) Depths:

$$K_1 = \frac{1}{2}\sqrt{\frac{204 - 82}{204 + 82}} = 0.327$$

$$K_2 = \frac{1}{2}\sqrt{\frac{430 - 204}{430 + 204}} = 0.299$$

$$\frac{V_2}{V_1} = \frac{204}{82} = 2.49 \quad , \quad \frac{V_3}{V_1} = \frac{430}{82} = 5.25$$

$\therefore \quad Q = 0.819$ (from fig. 4-1)

Course G_1G_2:

$C_1 = 3.20$ m. , $C_2 = 25.00$ m.

hence $D_1 = 0.327 \times 3.20 = \underline{1.04}$ m.

$D_2 = 0.299 \times 25.00 + 0.819 \times 1.04 = \underline{8.33}$ m.

Course G_2G_1:

$C_1 = 2.80$ m. , $C_2 = 23.00$ m.

hence $D_1 = 0.327 \times 2.80 = \underline{0.90}$ m.

$D_2 = 0.299 \times 23.00 + 0.819 \times 0.90 = \underline{7.60}$ m.

These results compare favourably with the actual conditions of the site.

From the results of the survey it is seen that both interfaces dip in the direction G_2G_1.

B) Course No. 2: From the time-distance graph (fig. 4-11), it is seen that we have three layers.

a) Velocities:

The average or true velocities of the layers were found to be:

$$av.V_1 = \frac{82 + 78}{2} = 80 \text{ m/sec.} = 262 \text{ ft/sec.}$$

$$av.V_2 = \frac{226+214}{2} = 220 \text{ m/sec.} = 722 \text{ ft/sec.}$$

$$av.V_3 = \frac{426+408}{2} = 417 \text{ m/sec.} = 1370 \text{ ft/sec.}$$

Again these velocities correspond to highly weathered topsoil, sand, and clay respectively. Thus these results compare with the actual conditions of the site.

b) Depths:

$$K_1 = \frac{1}{2}\sqrt{\frac{220 - 80}{220 + 80}} = 0.341$$

$$K_2 = \frac{1}{2}\sqrt{\frac{417 - 220}{417 + 220}} = 0.278$$

$$\frac{V_2}{V_1} = \frac{220}{80} = 2.75 \ , \quad \frac{V_3}{V_1} = \frac{417}{80} = 5.21$$

$\therefore$ $Q = 0.840$ (from fig. 4-1)

Course $G_1'G_2'$:

$C_1 = 2.94$ m. , $C_2 = 25.40$ m.

hence $D_1 = 0.341 \times 2.94 = \underline{1.00}$ m.

$D_2 = 0.278 \times 25.40 + 0.840 \times 1.00 = \underline{7.90}$ m.

Course $G_2'G_1'$:

$C_1 = 3.00$ m. , $C_2 = 23.40$ m.

hence $D_1 = 0.341 \times 3.00 = \underline{1.00}$ m.

$D_2 = 0.278 \times 23.40 + 0.840 \times 1.00 = \underline{7.35}$ m.

These results are in agreement with the previous ones. Moreover it is seen that the lower interface dips in the direction $G_2'G_1'$.

At midpoint between G_1 and G_2 (point G_1') the depths are $D_1 = \frac{1.04 + 0.90}{2} = 0.97$ m. and $D_2 = \frac{8.33 + 7.60}{2} = 7.96$ m. These results compare closely with the depths found with course No. 2, namely $D_1 = 1.00$ m. and $D_2 = 7.90$ m.

Comments:

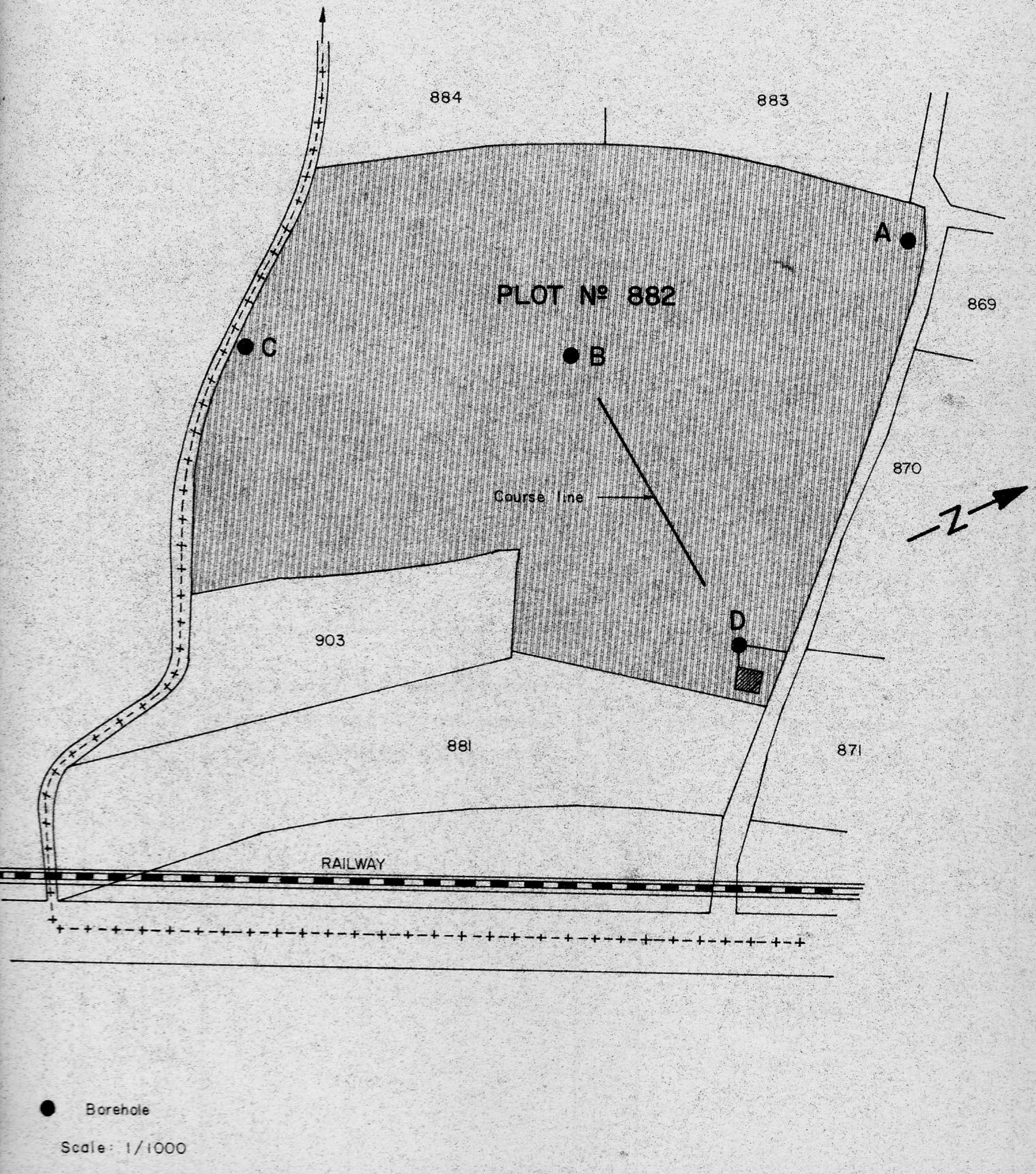
No special difficulty was encountered; however at a distance between hammer and geophone of 38 m. it became impossible to distinguish between the hammer waves and the noise waves.

Despite the fact that the water table is shallow, it was not detected by the instrument. This may be due again to the fact that the soil was saturated by the heavy rainfall which took place prior to the surveying of the site.

Site No. 8

PLOT 882 - ZOUK MIKHAYEL

KEY PLAN - ZOUK MIKHAYEL



Information given by
INDUSTRY INSTITUTE

Boring Log-Subsurface Exploration

Project: Plot 882 - Zouk Mikhayel.

Boring No. 8

Depth m	Depth ft	Visual Identification of Materials	Legend	Remarks
	1	Topsoil		
1	2, 3, 4	Dark-grey stiff silty-clay.		
2, 3	5, 6, 7, 8, 9, 10, 11, 12, 13	Reddish-brown stiff clayey sand.		Standard Penetration = 31 Standard Penetration = 21
4, 5, 6, 7, 8, 9, 10	14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33	White clayey marl eroded on the surface, becoming stronger with depth.		Standard Penetration = 64 End of drilling.

Information given by

INDUSTRY INSTITUTE

Boring Log - Subsurface Exploration

Project: Plot 882 - Zouk Mikhayel.

Boring No. D

Depth m	Depth ft	Visual Identification of Materials	Legend	Remarks
	1	Topsoil		
1, 2	2, 3, 4, 5, 6	Dark grey uniform silty-clay		
3, 4, 5	7, 8, 9, 10, 11, 12, 13, 14, 15, 16	Reddish brown stiff clayey-sand		Standard Penetration = 55 Standard Penetration = 49
6, 7, 8, 9, 10	17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	White clayey marl badly eroded on its surface for a depth of about five feet rock-like underneath.		Standard Penetration = 73 End of drilling.

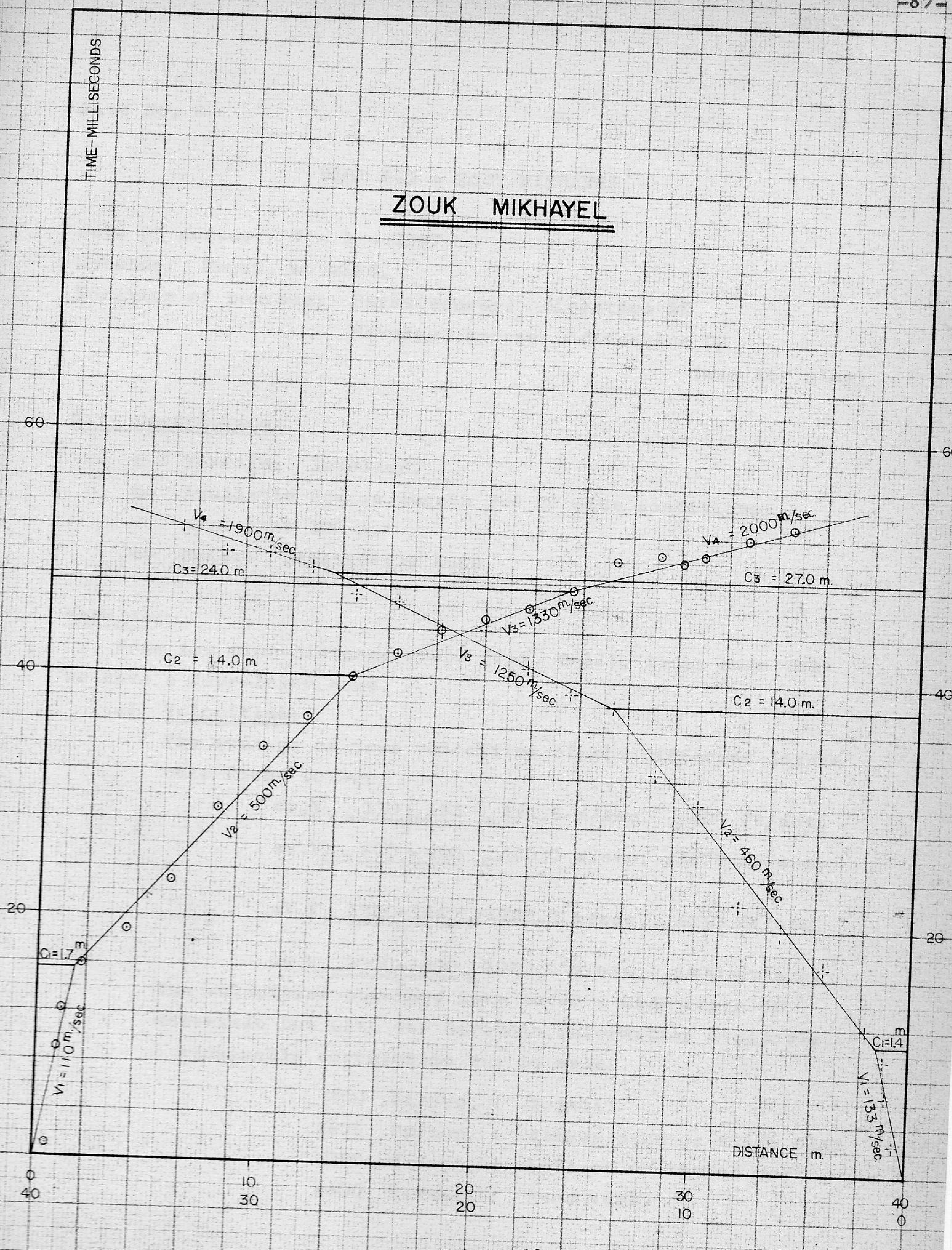

TIME-MILLISECONDS
ZOUK MIKHAYEL
V4 = 1900 m/sec
V4 = 2000 m/sec
C3 = 24.0 m
C3 = 27.0 m
V3 = 1330 m/sec
V3 = 1250 m/sec
C2 = 14.0 m
C2 = 14.0 m
V2 = 500 m/sec
V2 = 460 m/sec
C1 = 1.7 m
C1 = 1.4 m
V1 = 110 m/sec
V1 = 133 m/sec
DISTANCE m.
60
40
20
0
10
20
30
40

FIG. Nº 4-12

Site No. 8

PLOT 882 - ZOUK MIKHAYEL

Date of survey: 7 - 1 - 1967

Weather: Sunny, no wind.

Location of courses: First course: direction BD

Reversed course: direction DB

(see key plan)

Site description:

a- Terrain: levelled.

b- Available course length due to site conditions; more than 100 m.

c- Noise: practically none.

Results:

From the time-distance graph (fig. 4-12), it is seen that we have a four-layer case.

a) Velocities:

The average or true velocities of the different layers were found to be:

$$av.V_1 = \frac{110 + 133}{2} = 121.5 \text{ m/sec.} = 400 \text{ ft/sec.}$$

$$av.V_2 = \frac{500 + 460}{2} = 480.0 \text{ m/sec.} = 1575 \text{ ft/sec.}$$

$$av.V_3 = \frac{1330+1250}{2} = 1290.0 \text{ m/sec.} = 4230 \text{ ft/sec.}$$

$$av.V_4 = \frac{2000+1900}{2} = 1950.0 \text{ m/sec.} = 6400 \text{ ft/sec.}$$

The velocities obtained here cover a wide range of materials but with the borehole information available, a reasonable correlation can be made:

400	ft/sec. :	topsoil
1575	ft/sec. :	clayey sand or stiff clay
4230	ft/sec. :	soft or weathered rock
6400	ft/sec. :	hard rock.

b) **Depths:**

The method followed in the computation of depths was to peel off the topsoil layer and consider a three-layer case underneath it.

Course BD:

Taking the first two layers:

$$K_1 = \frac{1}{2}\sqrt{\frac{480.0 - 121.5}{480.0 + 121.5}} = 0.386$$

$$C_1 = 1.70 \text{ m.}$$

hence $D_1 = 0.386 \times 1.70 = \underline{0.65}$ m.

Taking the subsequent three layers:

$$K_1 = \frac{1}{2}\sqrt{\frac{1290 - 480}{1290 + 480}} = 0.338$$

$$K_2 = \frac{1}{2}\sqrt{\frac{1950 - 1290}{1950 + 1290}} = 0.226$$

$$\frac{V_2}{V_1} = \frac{1290}{480} = 2.68 \quad , \quad \frac{V_3}{V_1} = \frac{1950}{480} = 4.05$$

$\therefore$ $Q = 0.850$ (from fig. 4-1)

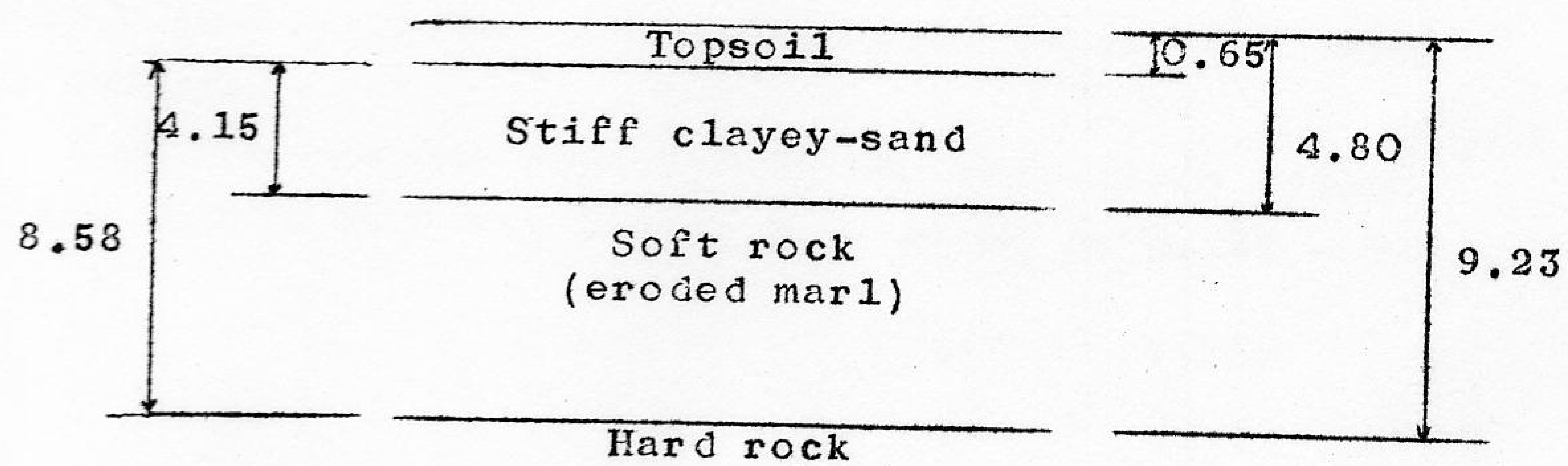
$C_1 = 14.0 - 1.7 = 12.3$ m.

$C_2 = 24.0 - 1.7 = 22.3$ m.

hence $D_1 = 0.338 \times 12.3 = \underline{4.15}$ m.

$D_2 = 0.226 \times 22.3 + 0.850 \times 4.15 = \underline{8.58}$ m.

hence the following subsoil profile is obtained; (sketch not to scale).



Course DB:

Repeating the same procedure:

$C_1 = 1.40$ m.

hence $D_1 = 0.386 \times 1.4 = \underline{0.54}$ m.

Taking the subsequent three layers:

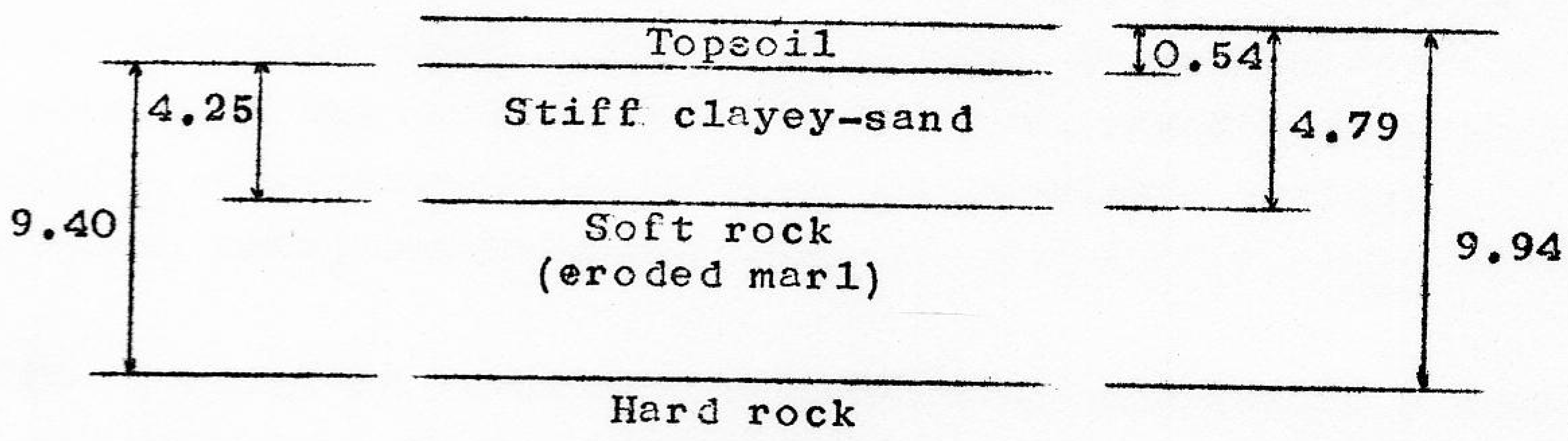
$C_1 = 14.0 - 1.4 = 12.6$ m.

$C_2 = 27.0 - 1.4 = 25.6$ m.

hence $D_1 = 0.338 \times 12.6 = \underline{4.25}$ m.

$D_2 = 0.226 \times 25.6 + 0.850 \times 4.25 = \underline{9.40}$ m.

and the subsoil profile is the following: (sketch not to scale).



Comments:

The depth of penetration from the refraction survey was greater than the borehole depths. The high velocity of 6400 ft/sec. detected at an approximate depth of 9.50 m. probably indicates the unweathered marl or another hard rock surface.

Thus the results obtained by the refraction method compare fairly with the boring logs shown on p. 85 - 86.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

Taking the borehole information as the basis for comparison, from the results presented in chapter IV it can be seen that fairly good correlation is obtained by the seismic refraction method used. A wide range of subsoil conditions was covered and with the exception of the East Entrance site, useful engineering information was obtained in all cases.

Computed depths to the various layers agreed fairly with the assumed depths within a range varying between 5% and 20%. This is acceptable for engineering exploratory work since errors in boring may be within these limits.

The identification of the subsoil material by velocity correlations is difficult due to the overlap of velocities within different soils. For this reason, an interpretation of the nature of the subsoil could well be in error unless prior knowledge of subsurface conditions is available through boreholes, cuts, excavations, etc.

The quality of results from refraction surveys is a function of how close the field conditions approach the theoretical model of discrete layers. If distinct layering is not present, i.e. a gradual change of material with depth, sharp breaks in the time-distance graph cannot be expected, thus leading to errors in interpretation. Moreover, non-homogeneity of the layers (e.g. sand mixed with pebbles and gravel), will lead to dispersion and distortion of the seismic energy such that erroneous recordings will be made. A similar effect would be obtained if the surface condition was such that seismic energy gets dispersed rather than penetrates into the ground, e.g. loose pebbles and boulders on the surface. A typical example of this phenomenon was found in the Awali River site where acceptable results were obtained only with great difficulty due to the constantly changing wave form as a result of the presence of pebbles and boulders in the section.

Despite the fact that good results were obtained, certain disadvantages of the method as well as the instrument should be outlined.

Disadvantages:-

a - Method:

- In shallow subsurface exploration which deals essencially with unconsolidated deposits, velocity changes tend to be gradual and thus sharp breaks in the time-distance graph are rarely obtained. Previous knowledge of the subsurface conditions is therefore an essential prerequisite to the interpretation of results.
- The presence of a thin high velocity layer may not be detected due to the small difference in travel time through that layer. In this case an verage velocity is usually recorded.
- The presence of a low velocity layer sandwiched between two higher velocities layers cannot be detected as the waves are not refracted on the interface of the layer but rather reflected through it as explained in chapter II. This results in a misleading interpretation for both depths and velocities.
- The depth of penetration is a function of the distance between source of energy and geophone (depth $\approx \frac{1}{4}$ to $\frac{1}{3}$ of distance), therefore in many cases it may be found that a restriction in depth penetration is imposed by the site conditions.

- The results given by this method cannot be subject to direct interpretation unless supplemented by precise subsoil information.

b - <u>Instrument</u>:-

- The source of energy is too weak to penetrate to a depth more than about a maximum of 10.0 m. under favourable conditions.
- The geophone used (number H/S 142) was very sensitive to high frequencies. This increased the possibility of picking up high frequency noise, e.g. traffic, microseisms, etc. . which frequently reduced the range of operation of the instrument. From the sites studied this optimum range was restricted mostly to about 20 m. equivalent to approximately 5.0 m. depth.
- The lack of a facility for permanent recording of signals eliminates the possibility of using a more powerful source of energy such as dynamite charges. This requires the plotting of the results directly during the survey so that any gross errors can be detected and corrected for. Later reappraisal of the data is therefore not possible.

This restriction in the depth of penetration is a serious drawback of the instrument used, but not for the validity of the refraction method. In fact, modifications with respect to the geophone, energy source, and method of recording, incorporated into the Terra-Scout R 150, could result in a more useful instrument of probable wider range of application in this field of study.

Advantages:-

The main advantages of the Terra-Scout refraction equipment are its portability, ease of operation and economy. Its principal application is for large scale surveys to detect major changes in subsurface conditions. This will lead to a more economical and useful siting of boreholes. A fair cost and result comparison of drilling and seismic work is difficult to make as many factors are involved. A fair example may be quoted (Welin, 1958)

	Number of depth determinations		Average depth m.	Cost $/m.
	Total	Per day		
Seismic	543	5	11.4	1.86
Drilling	12	0.13	11.0	35.63

Thus with intelligent use, time and money can be saved.

Recommendations:-

The application of the Terra-Scout Model R 150 is limited by the depth of penetration possible, and the surface and subsurface conditions of the area to be studied.

In the Lebanon the heterogeneity of the subsoil will restrict the use of this instrument to special cases where the conditions are suitable.

From the results of this study the use of the Terra-Scout is recommended for the following applications:

1) detection of bedrock at shallow depth (down to 10 m.) if soil and noise conditions are suitable.
2) checking the continuity of shallow high velocity layer over a large area

3) extending subsurface information from borehole logs over a wider area.

These applications may be found in projects relative to:

a) foundation studies for buildings, bridges, or other structures.
b) dam sites and reservoir surveys
c) irrigation projects
d) road and railway surveys
e) determination of excavation conditions.

APPENDIX "A"

RECORD OF TEST OBSERVATIONS

PROJECT:- AWALI RIVER

COURSE		REVERSED COURSE		REMARKS
Distance m	time millisec.	Distance m	time millisec.	
2.0	7.8	2.0	6.0	Date: 11-2-67
4.0	12.1	4.0	11.1	Weather: Sunny
6.5	21.0	6.0	19.5	Wind: Moderate
		8.0	24.0	Noise due to:
9.0	29.0	9.0	28.2	Water from the River Awali
10.0	32.9	10.0	30.1	Traffic on bridge
		11.0	36.0	- Water table at surface
12.0	40.0			- Shape of wave vary very much
14.0	45.0	14.0	42.9	- Wave is being dispersed by boulders - reading sometimes very difficult to take and sometimes needs a long time.
16.0	52.0	16.0	48.2	- course length limited
18.0	58.8	18.0	56.3	- from 14.0m on lots of vibration by using gain.
20.0	cannot read	20.0	62.0	- at 20m not able to read too much vibration from traffic and water

PROJECT:- THE EAST ENTRANCE OF THE CITY OF BEIRUT

COURSE		REMARKS
Distance m	time millisec.	
2.0	14.7	- Date:2-4-67
4.0	28.5	- Weather:- nice- sunny no wind
5.0	38.5	- lots of noise due to traffic
6.0	40.9	
8.0	46.0	
10.0	71.9	
12.0	80.4	
14.0	87.7	
16.0	cannot read	
18.0	cannot read	

PROJECT: STRAND BEACH HOTEL

COURSE		REVERSED COURSE		REMARKS
Distance m	time Millisec.	Distance m	time Millisec.	
2.0	12.6	2.0	10.5	Date:- 21-1-67
4.0	23.1	4.0	24.0	
6.0	35.3	6.0	32.0	Weather: cold no wind
8.0	43.3	8.0	40.2	- levelled terrain
10.0	52.8	10.0	49.1	- sand is wet
12.0	57.1	12.0	54.5	- traffic sometimes affects
14.0	64.0	14.0	63.1	- during reversed course lots of vibration were detected.
16.0	68.1	16.0	68.8	
18.0	74.5	18.0	71.6	
20.0	78.0	20.0	77.0	

PROJECT:- KHALDEH INTERCHANGE - COURSE NO. I

COURSE		REVERSED COURSE		REMARKS
Distance m	time millisec.	Distance m	time millisec.	
1.0	5.8	1.0	4.0	Date:- 19-3-67
2.0	10.0	2.0	10.2	Weather: sunny
4.0	21.2	4.0	18.0	with moderate wind
6.0	30.1	6.0	27.8	- noise due to
8.0	35.5	8.0	34.5	traffic
10.0	40.0	10.0	38.2	
12.0	42.5	12.0	43.5	
14.0	48.0	14.0	47.2	
16.0	51.8	16.0	50.1	
18.0	56.7	18.0	54.5	
20.0	60.4	20.0	58.0	

PROJECT:- KHALDEH INTERCHANGE - COURSE NO. 2

COURSE		REVERSED COURSE		REMARKS
Distance m	time millisec.	Distance m	time millisec.	
1.0	4.0	1.0	4.5	Date:- 19-3-67
2.0	7.2	2.0	8.0	Weather: sunny
4.0	15.7	4.0	16.2	with moderate wind
6.0	23.0	6.0	20.0	- noise due to
8.0	30.4	8.0	25.8	traffic
10.0	32.5	10.0	28.5	
12.0	38.0	12.0	34.0	
14.0	41.8	14.0	37.8	
16.0	47.5	16.0	44.3	
18.0	51.0	18.0	48.0	
20.0	54.1	20.0	53.6	

PROJECT:- JBITA OVERPASS

COURSE		REVERSED COURSE		REMARKS
Distance m	time millisec.	Distance m	time millisec.	
0.51	2.8			Date:- 14-1-67
1.00	7.9			Weather:- sunny
		2.00	11.0	with wind
3.00	12.4			- surface has
4.00	14.2	4.00	23.2	pieces of rocks
5.00	16.0			- too much traffic
		8.00	46.4	- factory creating
9.00	26.7			vibration regu-
10.00	27.9	10.00	49.0	larly
11.00	32.6			- wind noise
12.00	35.7	12.00	52.5	
13.00	39.8			
		14.00	57.6	
15.00	42.0			
		16.00	63.1	
18.00	51.0			

PROJECT:- PLCT 3301 - RAS BEIRUT

COURSE		REVERSED COURSE		REMARKS
Distance m	time millisec.	Distance m	time millisec.	
2.0	16.0	2.0	12.2	Date:- 12-1-67
3.0	20.2	3.0	18.5	Weather: Sunny,
4.0	29.9	4.0	21.1	no wind
5.0	31.6	5.0	27.5	- terrain not
6.0	38.3	6.0	32.5	levelled- dis-
7.0	40.5	7.0	36.0	levelling in the
8.0	44.0	8.0	40.0	order of 40 cms.
9.0	52.1	9.0	47.2	- horizontal dis-
10.0	56.0	10.0	51.8	tance limited by
11.0	57.0	11.0	55.0	surrounding
12.0	59.0	12.0	57.5	building and
13.0	60.0	13.0	58.3	dislevelled terrain
14.0	63.0	14.0	61.0	hence we cannot
15.0	63.6	15.0	62.5	go to great depths
16.0	66.0	16.0	64.0	- no disturbance
17.0	67.0	17.0	64.9	from outside noise
18.0	68.50	18.0	67.1	- 1st course from
				C to D
				reversed course
				from D to C

PROJECT:- RESIDENCE DES PINS - COURSE NO. I

COURSE		REVERSED COURSE		REMARKS
Distance m	time millisec.	Distance m	time millisec.	
1.0	11.8	1.0	12.0	Date:- 1-4-67
2.0	21.9	2.0	25.8	Weather: sunny,
4.0	40.6	4.0	42.0	no wind
6.0	50.5	6.0	52.8	- at 38.0m the
8.0	60.2	8.0	64.0	vibrations could
10.0	69.2	10.0	72.1	not allow reading
11.0	73.6			
		12.0	81.2	
13.0	84.1			
14.0	86.8	14.0	89.8	
16.0	100.0	16.0	101.6	
18.0	108.2	18.0	112.0	
20.0	116.6	20.0	122.5	
22.0	128.0	22.0	132.0	
24.0	136.6	24.0	138.2	
26.0	144.0	26.0	143.8	
		27.0	145.5	
28.0	149.3			
30.0	154.2	30.0	153.0	
32.0	157.1	32.0	158.9	
34.0	162.5	34.0	163.8	
36.0	167.2	36.0	167.6	

PROJECT:- RESIDENCE DES PINS - COURSE NO. 2

COURSE		REVERSED COURSE		REMARKS
Distance m	time Millisec.	Distance m	time Millisec.	
1.0	12.1	1.0	10.7	Date:- 1-4-67
2.0	24.0	2.0	27.9	Weather: Sunny, no wind
4.0	40.1	4.0	43.0	- beyond 36 m. too much noise thus unable to read.
6.0	50.5	6.0	51.2	
8.0	56.8	8.0	62.5	
10.0	65.9	10.0	72.0	
12.0	76.0	12.0	82.1	
14.0	86.2	14.0	88.6	
16.0	93.5	16.0	97.3	
18.0	103.4	18.0	108.0	
20.0	112.0	20.0	119.5	
22.0	119.8	22.0	125.8	
24.0	128.0	24.0	136.0	
26.0	137.5	26.0	140.1	
28.0	140.5	28.0	146.1	
30.0	144.8	30.0	148.2	
32.0	151.0	32.0	153.8	
34.0	156.1	34.0	160.0	
36.0	160.0	36.0	163.7	

PROJECT:- PLOT 882 - ZOUK MIKHAYEL

COURSE		REVERSED COURSE		REMARKS
Distance m	time Millisec.	Distance m	time Millisec.	
0.6	4.0	0.6	2.5	Date:- 7-1-67
1.0	9.0	1.0	6.5	Weather: Sunny,
1.2	12.1	1.2	9.5	no wind
2.0	15.9	2.0	12.0	
4.0	19.2	4.0	17.0	
6.0	23.0	6.0	20.0	
8.0	29.0	8.0	22.0	
10.0	34.0	10.0	30.1	
12.0	36.6	12.0	32.5	
14.0	40.0	14.0	38.0	
16.0	42.0	16.0	39.0	
18.0	44.0	18.0	41.0	
20.0	45.0	20.0	44.1	
22.0	45.9	22.0	44.0	
24.0	47.7	24.0	46.2	
26.0	48.0	26.0	46.7	
28.0	50.6	28.0	48.9	
29.0	50.0			
30.0	50.6	30.0	50.0	
32.0	52.0	32.0	50.1	
34.0	53.0	34.0	52.0	

APPENDIX "B"

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