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Engineering Geophysical Study of Unconsolidated Top Soil Using Shallow Seismic Refraction and Electrical Resistivity Techniques

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Abstract
A near-surface geophysical study was conducted at University of Peshawar (UOP), Khyber Pakhtunkhwa, Pakistan, using an integrated approach including seismic refraction and electrical resistivity survey (ERS) techniques in order to image the shallow subsurface in terms of main geological and geophysical properties covering the study area. Seismic longitudinal wave velocities (Vp) were determined within four meters beneath ground surface which indirectly provided us with critical subsurface information about depth of layers, morphology and stratigraphic sequence without borehole information. The results of the seismic refraction survey along profile AB, showed two-layers separated by a refractor having gentle slope and P-wave velocity values (223m/sec & 316 m/sec) for overlying and underlying layers respectively indicating loose soil filled in top four meters underneath the surveyed seismic profile. Seismic refraction data demonstrated shallow subsurface structure characterized by longitudinal wave velocities less than 330 m/s.Apparant resistivity data was acquired along two profiles (CD & DE) using four shlumberger vertical electrical soundings with maximum spread length of 10m. Electrical resistivity survey validated the results obtained from seismic refraction data analysis by detecting bi-layer near-surface geologic model at all VES stations with distinct characteristics. These geoelectric layers included top soil/dry unconsolidated surface material ranging in thickness from 1.11m to 1.3m with true resistivity values (38.08 - 52.70 Ωm) and less resistive (13.13-18.38 Ωm) clayey layer. Integrated geophysical approach showed that overburden terrain in the target zone is characterized by a relatively thin superficial layer (dry unconsolidated sediments) underlain by a clay layer having high porosity and saturation. Based on seismic velocities (223m/sec & 316 m/sec) and resistivity values (13.13 - 52.70 Ωm), it is derived that sub surface soil conditions within studied depth interval are poor and should be considered seriously as this may put the high rise buildings at risk.
Keywords: Shallow seismic refraction, Compressional wave velocity (Vp), time-term inversion, electrical resistivity survey (ERS), top soil.

1. Introduction

Seismic refraction method is one of the best tool for investigation of ground water, bedrock mapping, type and associated changes (lateral and vertical) in lithology. The compressional P-waves can be used to detect the cavities and resolve many other problems in shallow subsurface. Seismic refraction technique is also successfully used for several engineering problems such as dam sites as well as determination of the physical characteristics of ground, investigation of the deep earth layers and for geotechnical purposes ,demonstrated by (Tezcan *et al*., 2006; Budhu &Al-Karni 1993; Othman 2005; Dormieux & Pecker 1995.,Richards *et al*., 1993; Turker 2004; Paolucci & Pecker 1997).Seismic refraction method is used to study the physical properties of site presented by (Dutta 1984; Hatherly & Neville 1986).Several studies demonstrated that longitudinal velocity is less than 330 m/s in shallow sub-surface e.g. low compressional velocities were discussed quantitatively by Bachrach & Nur 1998. Similarly Bachrach *et al*. (1998) found low longitudinal wave velocity (<100 m/s) of beach sand. Baker et al. (1999) showed that compressional (P) wave velocities in the shallow sub-surface are lower than the velocity in the air.

Shallow electrical resistivity technique is used to address the geological ,hydro-geological and environmental problems. Some recent studies focused on the delineation of the geometry of the uppermost layers of shallow sub-surface (Lamotte *et al.* 1994; Robain *et al.* 1995, 1996).

2. Materials & Methods

The study was accomplished for each geophysical method, following the three steps given below

2.1 Data Acquisition/Field operations

Field study was performed at campus of university of Peshawar,Khyber pakhtunkhwa, Pakistan located between Latitudes 33˚56'0" N - 34˚40'0" N and Longitudes 71˚27'0" E - 71˚33'0" E (fig.1). In seismic-profiling method a seismic source and geophones planted at regular intervals across the ground surface is used for data acquisition (Beck 1981; Reynolds 1997; Sharma 1997). For seismic refraction data acquisition, profile-shooting technique is used to acquire the data which consists of all the common seismic refraction survey modes in a single profile. The refraction work was based on measuring the travel time of longitudinal wave passed through the subsurface, generated by striking sledge hammer of 7kg on aluminum plate as a source of seismic energy, refracted from an interface and detected via vertical component geophones (10 Hz) spaced at 1m interval on the surface. All these geophones are connected through seismic cable to a 24-channel Geometrics digital seismograph (Geode).Specific geophysical survey geometry is used based on five shots in appropriate fashion along the spread. At minimum there should be two shots located at either end of the seismic line. We planted the very first geophone at 0-m along the seismic line. First shot is fired at distance of 0.5m in start of seismic line before geophone (G1), the second one located at a 5.75 m, third at 11.5 m ,the fourth shot at a 17.25 m, and the last shot is at 23.5 m along profile AB while going from 0m towards end of spread length (23m) as shown in (fig.2). The total spread length of seismic refraction profile is 23 m containing an array of 24 geophones spaced evenly at 1 m. This specific physical layout of geophones and shots provides better coverage to generate an interpretable stacked profile.

Shallow electrical resistivity data is acquired along two resistivity profiles along profiles (CD & DE) based on four vertical electrical soundings using Shlumberger configuration. ABEM Terrameter (SAS 1000/4000) is used to for apparent resistivity readings on plain area with maximum electrode separation of 10m for each traverse in order to clearly image the target at very shallow depth within top four meters zone from ground surface. The primary acquisition parameters for both methods are given in table 1.

2.2 Data processing

Seismic refraction data is always processed to enhance the data quality by suppressing noises from different sources to generate final velocity model. The recorded seismic data saved in laptop PC were imported to one of the module (Pickwin95) of commercial software package, seisImager.All traces were normalized and clipped. Also some bad records were killed in order to extract meaningful information. Finally first breaks were carefully picked using Pickwin. The picked first-arrival time data were uploaded to another module (Plotrefa).Thereinafter inversion method (time-term inversion) was used to get the velocity structure (fig.6) with root mean square (RMS) error of 1.5%.

ERS data (apparent resistivity) obtained from each station was uploaded to ipiwin2 software and plotted against electrode spacing (AB/2) on double logarithmic scale to get the VES sounding curves. The sounding curves, models and their respective geoelectric sections are prepared for each profile (fig.4 & 5).

2.3 Interpretation/Conclusions

There are different techniques in use for refraction data analysis and interpretation e.g. ray-tracing method (Whiteley 2002, 2004), delay-time method (Wyrobek 1956; Palmer 1980; Sjogren 2000).Some other scientists (Hales 1958; Barton & Barker 2003) discussed the intercept−time method. Recently researchers have focused on inversion and tomography method (Zhang & Toksöz 1998;Watanabe *et al.* 1999; Hecht 2003).

There is no subsurface ground model available about the thickness, depth, velocity distribution in the top soil and weathering layer in the surveyed area. The Main purpose of the study was to determine shallow sub-surface structure using shallow seismic refraction method and its confirmation by another surface geophysical tool (ERS). Keeping in mind the objective, receiver interval of only 1m in case of refraction and maximum resistivity profile length of 10m was chosen during data acquisition to get the improved subsurface image. Although the delineated geologic strata has small variations in terms of geophysical properties like P-wave velocities and electrical resistivities but are being mapped in this research work because of special geophysical configurations. An integrated geophysical approach including electrical resistivity and seismic refraction is used to delineate shallow sub-surface. Each method responds to different geophysical property with varying resolution however interpreted results in both cases can be combined and correlated to get comprehensive geological information for site under investigation.

First compressional wave velocity (Vp) –depth model is derived from time-distance (T-D) plots after assigning layers by employing two-layer model to represent the shallow subsurface structure on the studied area. Taking the seismic profile AB, for example two layers are observed. A thin layer of loose sediments is noticed corresponding to the first arrivals (direct waves close to the seismic energy source) marking the superficial layer with very low velocity (223 m/sec) and thickness (0.2 to 1.7 m) approximately along the seismic line. The first layer is thinner on margins of the profile AB while gets thicker relatively in central part. Low acoustic impedance contrast and an undulating trend are shown by the contact between layers. Difference is observed in depth of the refractor along the seismic line. In general the refractor is gently dipping in study area. The deepest layer (layer2) in the geo-seismic section is appeared at depth of 1.7m exactly below the midpoint (11.5 m) of seismic profile, characterized by comparatively high P-wave velocity (316 m/sec).

A resistivity survey was also conducted on warm and sunny day of May 14, 2013. The ERS data results are displayed in form of table 2 and corresponding resistivity - cross sections under depth sounding curves (fig.4 & 5), which confirmed the two layer geologic structure. Interpretation of both resistivity lines showed the heterogeneous nature of studied part of vadose zone. For example; location 1 consists of two layers with resistivity values of 18.40 Ωm &13.13 Ωm while location 2 is characterized by 19.50 Ωm & 15.0 Ωm for first and second layer respectively. First layer is more thicker (1.28m) and deeper at location1 than at location 2 where its thickness is 1.11m.VES curves of Location 3 showed the same sub-surface geologic sequence having resistivity values (52.70 Ωm & 20.72 Ωm) for overlying and underlying geologic layers respectively. At Location 4 top most geo-electric layer has 38.08 Ωm resistivity while lower layer is characterized by 18.38 Ωm.It is deduced from the interpreted sounding curves of location 3 & 4 that first geologic layer is 1.259m & 1.059m thick respectively. Here both stations have almost same thickness value of layer 1.

Both types of geophysical traverses revealed approximately same thickness of first layer and depth of interface appeared across the studied site but low resistivity contrast is observed along profile line CD as compared to profile EF.

It is concluded that top overburden material within four meters is divided in two sub-layers, a superficial layer composed of unconsolidated sediments with high resistivity because of dry nature underlain by a thicker, slightly compact but more conductive indicating relatively high moisture content and clay component concentrated in this part of geological model.

There is good correlation between seismic refraction and electrical resistivity as both methods mapped the same stratigraphic sequence with the equal number of layers but a depth variation still detected, due to the different physical properties measured by the two geophysical tools ,employed while field operations. From resistivity cross sections it is clear that an interface is appeared at 1.28 m from the surface. On average an interface is appeared slightly below 1m along depth axis on resistivity cross section as well as in case of velocity structure.

It is deduced from the interpretation of geophysical data (seismic refraction & ERS),that the subsurface geologic sequence beneath the study area up to 4m depth is composed of material having clayey sand content with high porosity and high degree of saturation which are indications of poor sub-soil conditions due to its low load-bearing capacity. In geotechnical applications all these factors are of great importance which must be taken into account seriously during construction of massive engineering structures.

Joint interpretation of both types of data provided us with more accurate geotechnical model with high confidence where both methods seem to be in good agreement and areas of some doubtful information, which could then be confirmed via drilling as several feet's uncertainty in depth of interface is of great importance in very near sub-surface studies. Combined geophysical approach helped us in making the interpretation easier by adding to spatial resolution than separate approach traditionally used in engineering and hydrogeology.

In future the study will be extended to weathering layer by an integrated geophysical approach using both the seismic refraction and electrical resistivity techniques with new physical layouts for greater depth of penetration. Also geophysical properties will be correlated with geotechnical parameters in order to better understand the sub-soil conditions.

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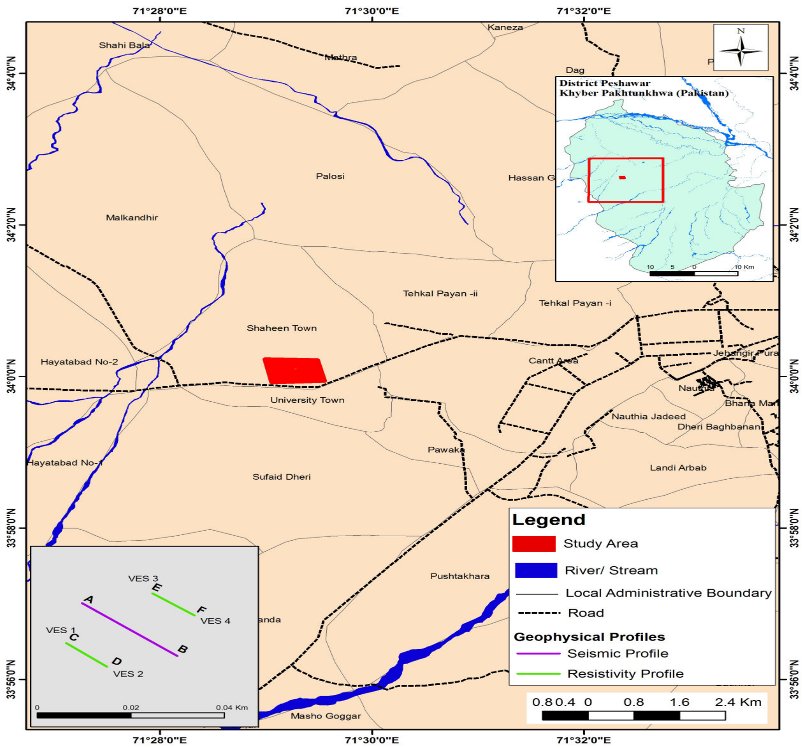

Fig 1: Map showing location of study area and layout for ERS (CD & EF) & seismic refraction (AB) profiles

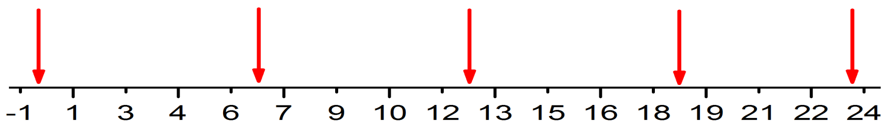

Fig 2: Seismic refraction profile AB, arrows highlighted in red are indicating shot points

Table 1: Summary of geophysical acquisition parameters

Acquisition parameters for seismic refraction data	
Recording system	Geode (24-channel seismograph)
Source Sledgehammer	7 kg
Sampling interval	0.125 ms
Record length	256 ms
Geophones	10 Hz (vertical)
Recording format	SEG-2
Geophone interval	1 m
Acquisition parameters for electrical resistivity data	
Recording system	ABEM Terrameter (SAS 1000/4000)
Configuration type	Shlumberger
Mode of survey	VES (vertical electrical sounding)
Maximum electrode separation	10m
Profile interval	20m

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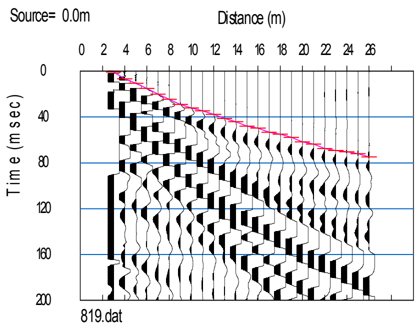
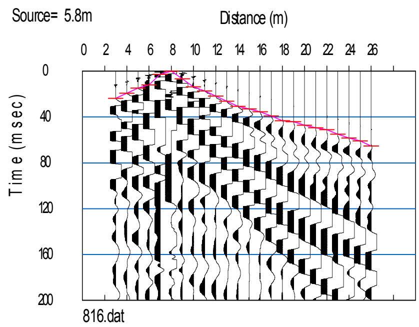
Table 2: Summary of the interpreted VES curves

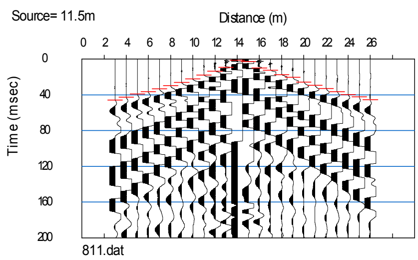
# VES /Location	N (# layers)		ρ (Ωm)	h (m)	d (m)
1	2	1	18.40	1.28	1.28
		2	13.13	-	-
2	2	1	19.50	1.11	1.11
		2	15.00	-	-
3	2	1	52.70	1.059	1.059
		2	20.72	-	-
4	2	1	38.08	1.259	1.259
		2	18.38	-	-



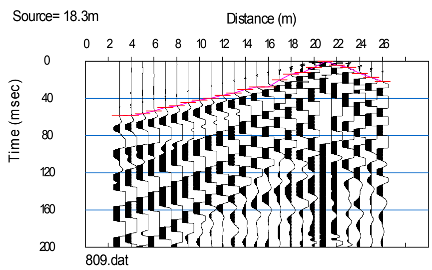
A-Normal shooting at 0.0 m



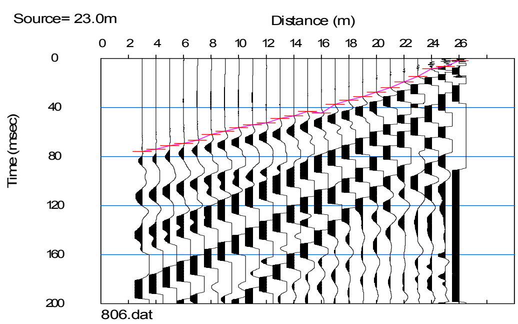
B-Shooting at 5.75m between G6 &G7



C-Mid-point Shooting at 11.5 m



D-Shooting at 18.25 m between G18& G19C-Mid-point



E-Reverse shooting at 23.0 m

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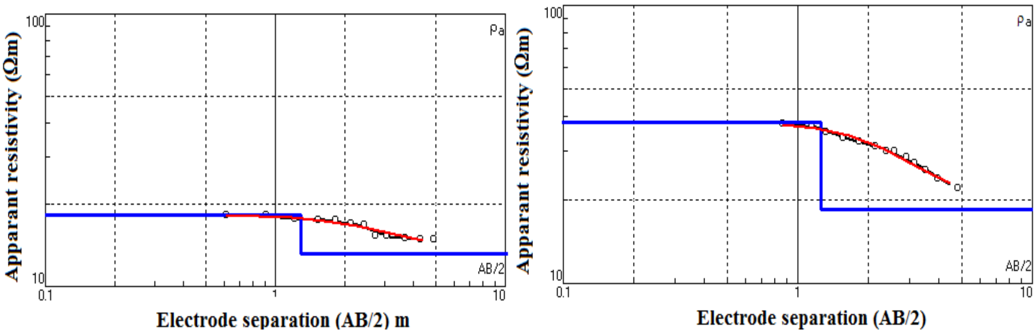
Figure 3: Seismograms with picked primary arrivals at study area along traverse AB



N	ρ	h	d
1	18.4	1.28	1.28
2	13.13		

N	ρ	h	d
1	38.08	1.259	1.259
2	18.38		

VES 1 **VES 4**

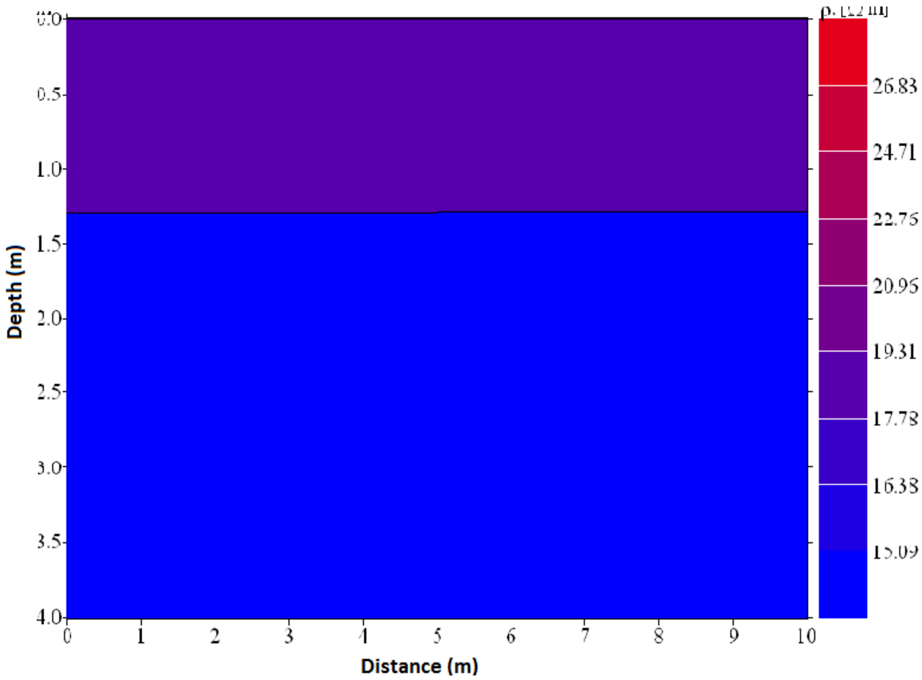


Figure 4: Interpreted VES curves & Resistivity cross section underneath VES1 & VES 2.

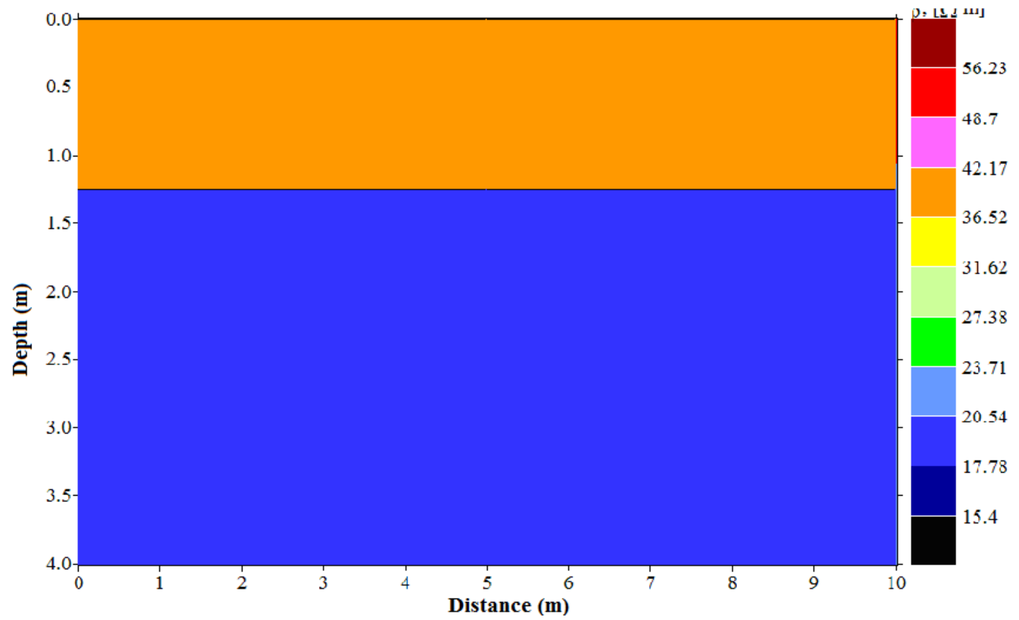


Figure 5: Interpreted VES curves & Resistivity cross section underneath VES3 & VES 4.

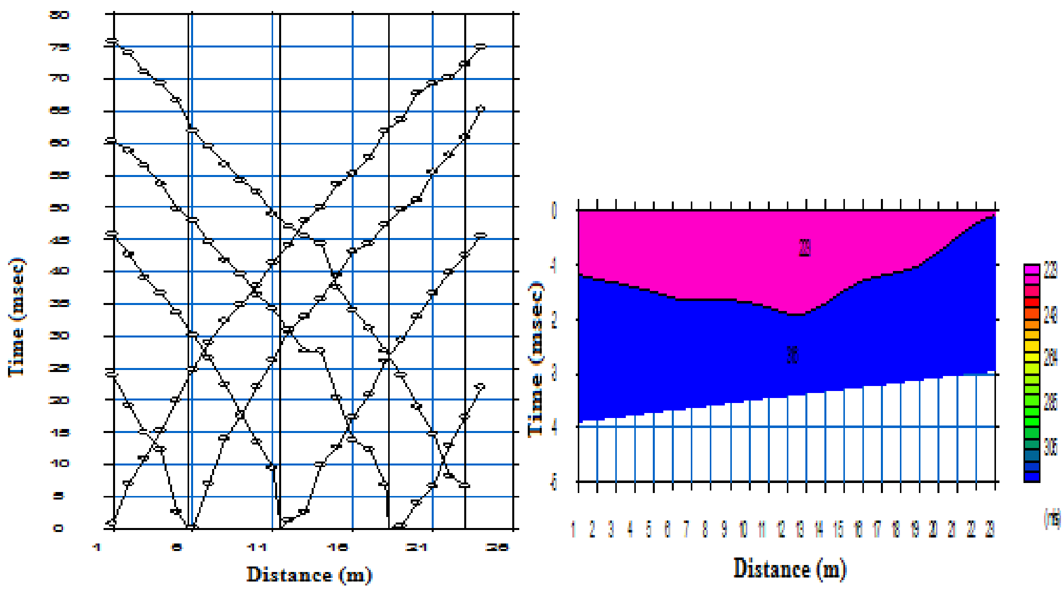


Figure 6: Time-distance (T-D) plot and Velocity-depth model of profile AB.