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ESTIMATION OF THE VELOCITIES OF WEATHERED AND CONSOLIDATED LAYERS USING SEISMIC REFRACTION METHOD

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Abstract

Seismic refraction tomography was carried out in four different sites within University of Port Harcourt to determine the seismic velocities of the weathered and consolidated layers. A total of twenty points were made for both forward and reverse shots using ABEM terralog with 12- channel geophones. The data processing was carried out using ReflexW seismic data processing software. The first arrival times recorded at shot points were plotted against the geophone separations from the shot point to obtain the time distance graphs using Microsoft Excel. The velocities of the different layers were calculated from these plots. The weathered layer velocities range from 900 m/ s to 1300 m/s with an average of 1118.3 m/s for the forward down velocities while the velocities range from 867 m/s to 1200 m/s with an average of 1062.3 m/s for the reverse down velocities. The consolidated layer velocities range from 1592 m/s to 1715 m/s with an average of 11680.5 m/s for the forward up velocities while the velocities range from 1333 m/s to 1964 m/s with an average of 1683.5 m/s for the reverse up velocities. It was observed that these consolidated layers across the study area were sufficiently competent for civil engineering applications judging from their recorded high seismic velocity values.

Keywords: *Geophone; Refraction; Velocity; Tomography; Weathered Layer.*

1. Introduction

Seismic refraction survey is used extensively in engineering geological and geotechnical investigations to determine the overburden and weathered zone thickness, to identify geological anomalies and highly cracked zone, to determine the boundary between rocks of different lithological composition. It is also used to locate aquifers, to search for building materials, to contribute to assess liquefaction and landslides of layers near the surface [1].

Seismic exploration involves the generation, detection, analysis and interpretation of elastic waves in the earth to study the sub-surface properties of the earth. When the seismic wave reaches the interface having higher velocity, it is refracted and travel along the refracted surface. Energy is transmitted back to the surface when the angle of incidence equals the critical angle. At this point, the refracted wave moves along the interface between the two materials. The refracted angle is dependent on layer composition and structure [2].

When the seismic wave is back to the surface, it is discovered by a series of geophones and recorded by a seismograph as shown in Figure 1.

The weathered layer is the shallow subsurface layer composed of unconsolidated materials such as soil, sand and gravel. The delay in travel time experienced during seismic refraction acquisition is as a result of the heterogeneous composition of the subsurface and characterized by low seismic velocity [4].

Characteristics of the weathered layer include low pressure and bulk modulus, lack of cementation and high porosity. These characteristics are responsible for the very low compressional and shear wave velocities occurring in the layer. The interface between the weathered layer and the consolidated layer represents the base of the weathered layer [5].

Investigation of properties of the subsurface could be carried out downhole survey of seismic refraction method. Seismic refraction survey is carried out by recording arrival time and off distance which will be used to determine depth and velocity of the subsurface. This is based on the fact that rays are refracted at boundaries of different properties of formation; the lines of geophone will detect refracted signals which have traveled down the different layers before returning back to the surface [6]. Two most important and commonly used methods of determining the features of low velocity layer are the uphole and downhole seismic refraction methods. The methods can be used to determine thicknesses of layers in vertical direction, depth and near surface velocities. Geology and seismic refraction response of a particular site could be determined once the velocity information is known.

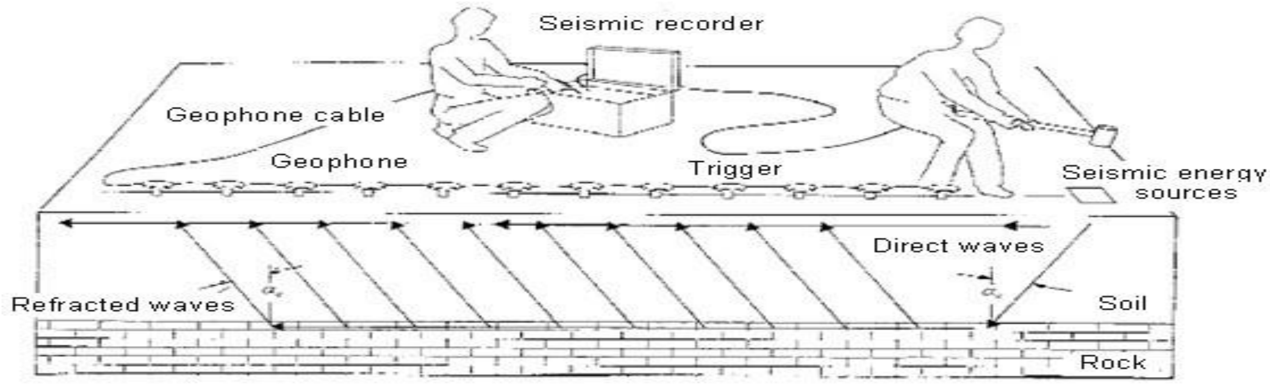

Figure 1: Field layout of seismic refraction [3]

Field data from downhole seismic refraction gives information on travel times of compressional and shear waves from the distance between source and geophone and from source to geophone. In downhole seismic refraction survey, seismic signals are generated from seismic source placed at or near the ground [7].

Lots of civil engineering construction works are going on in the study area which is located within the Niger Delta basin, a prolific oil bearing region. Poor knowledge of weathered layer properties of the study area is responsible for most of the failures recorded in engineering structures [8].

Seismic refraction survey can be used to determine/estimate the velocities of the strata with a view to ascertaining the suitability of these layers for seismic reflection data acquisition and other engineering applications.

The aim of this study was to determine the velocities of weathered and consolidated layers in parts of University of Port Harcourt, Nigeria using a tomography model of seismic refraction method.

1.1. Study area

University of Port Harcourt is located in Choba community in Obio-Akpor local government which is bounded by Port Harcourt (local government area) to the south, Oyigbo to the east, Ikwerre to the north, and Emohua to the west. It is located between latitudes 4°45'N and 4°60'N and longitudes 6°50'E and 8°00'E.

The study area is characterized by high rainfall with little dry season and lies in the tropical wet climate zone. The raining season occurs between April and October, with rainfall ranging between 2000 and 2500 mm with temperature of about 25^0C and consistent humidity. Figure 2 shows the map of the study area.

1.2. Geology and relief

University of Port Harcourt has an average elevation generally below 30 metres above sea level and it’s regarded as a lowland area. Basement complex and alluvial sedimentary basin characterized the geology of the study area. The vegetation in the area includes raffia palms, light rainforest and thick mangrove forest. The soil in the area is generally sandy or sandy loamy as a result of the high rainfall prevalent in the area. Leaching of soil in the area is a common occurrence and underlain by a layer of impervious pan.

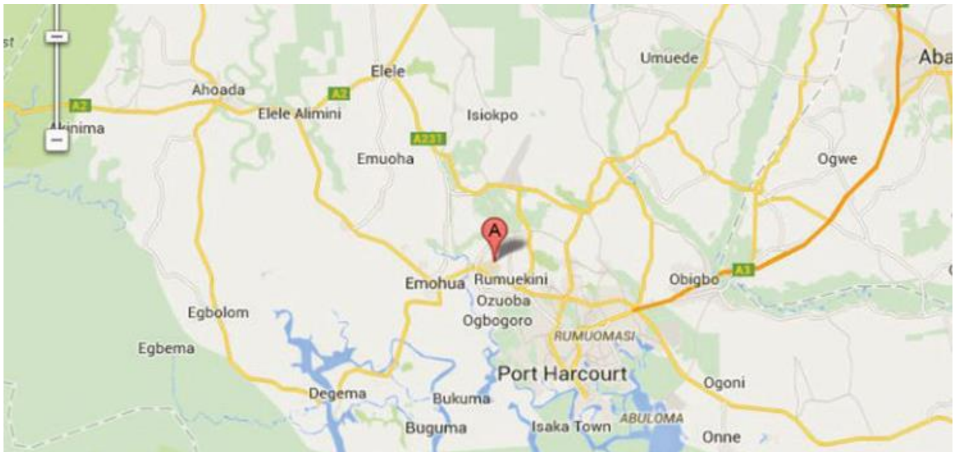

Figure 2. Map of the study area

2. Methodology

A wide variety of seismic geophysical equipment is available and the choice of equipment for a seismic refraction survey should be made in order to meet the objectives of the survey. geophysical equipment used for this seismic refraction measurement includes the seismograph, geophones, geophone cable, and energy source and a trigger cable or radio link.

The data for this work were acquired in four different locations with the University Park, University of port Harcourt, Nigeria. The locations are behind the Faculty of Social Sciences (first profile), in the front of the Faculty of Humanities (second profile), behind Faculty of Gas Engineering (third profile), and adjacent to the Faculty of Gas Engineering (fourth profile).

A total of twenty points were made for both forward and reverse shots with a total length of 95 m used for each profile line. In order to reduce random noise, five stacks were made, and the averages were recorded by the seismometer on each shot point.

3. Results and discussion

3.1. Results

The data processing was carried out using ReflexW 2D-data analysis processor software. The data used in this work was acquired from a seismic investigation field for velocity variation of weathered layers (using a 2D Tomography of a seismic refracted method), the signal is a single shot type and the first geophone started from zero point, in Reflex-w software the type of output received is called SEG.

Figure 3 shows the traces of signals at each geophones as received from the refracted incident ray from a single shot point and the signals are accompanied by random noise. For the data to be well processed it will first undergo a filtering process.

Figure 4 shows the data after it has undergone a filtering process which was carried out using a Band pass frequency 1D Filter, but the amplitudes is small and this create troublesome for the data to be well analyse, so the data need to undergo a gaining process.

Figure 5 shows the data after it has undergone a gaining process, now the amplitudes are large and very easy to differentiate. At this point we pick out our various arrival time of signals at each geophone, we do this by picking the point with `x' sign. Gaining means to enlarge our amplitude, and we use the Y gain manual a unit in ReflexW data analysis seismic software, the main objective in gaining data is to pick the 1st arrival time and the reflected ray.

Figure 6 shows that the arrival times have been marked out and the data is set to draw its model (the path of differences). The first arrival times recorded at shot points were plotted against the geophone separations from the shot point to obtain the time distance graphs using Microsoft Excel to obtain Tables 1 - 4 and Figures 8 – 11.

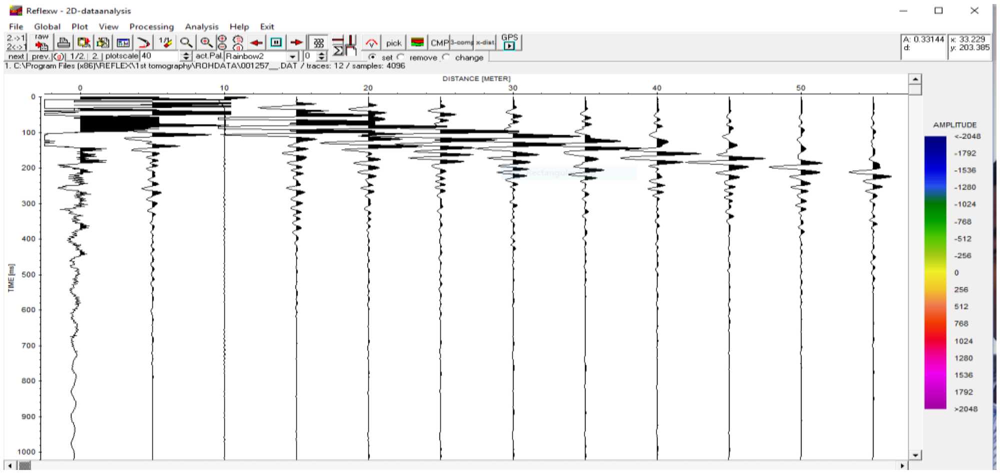

Figure 3. Kicking (traces) before filtering

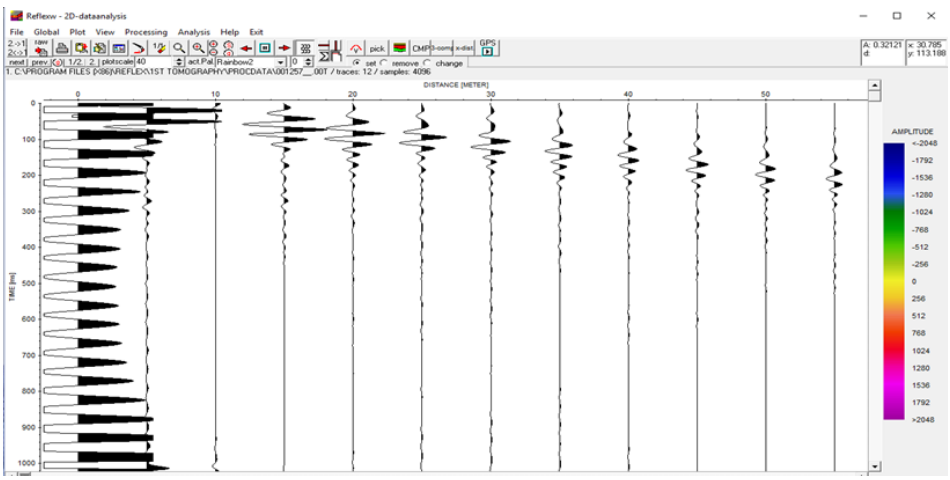

Figure 4. Kicking (traces) after filtering and before gaining

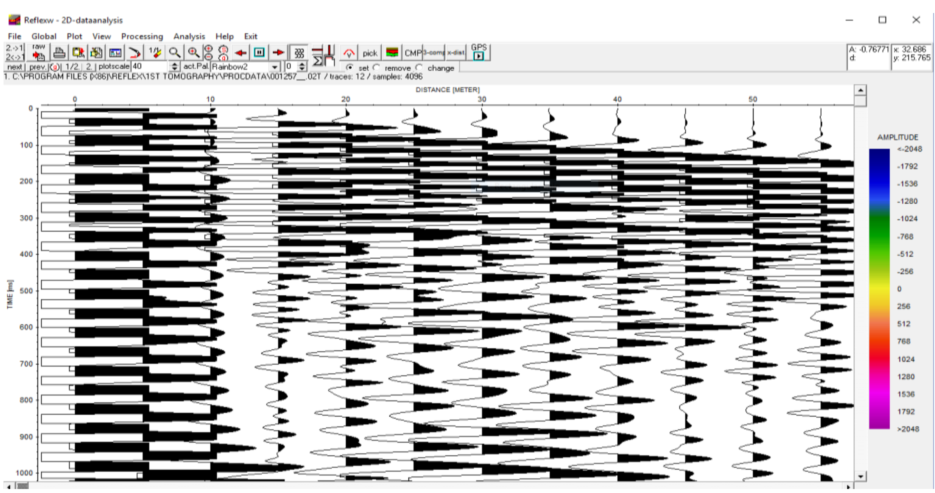

Figure 5. Kicking (traces) after gaining

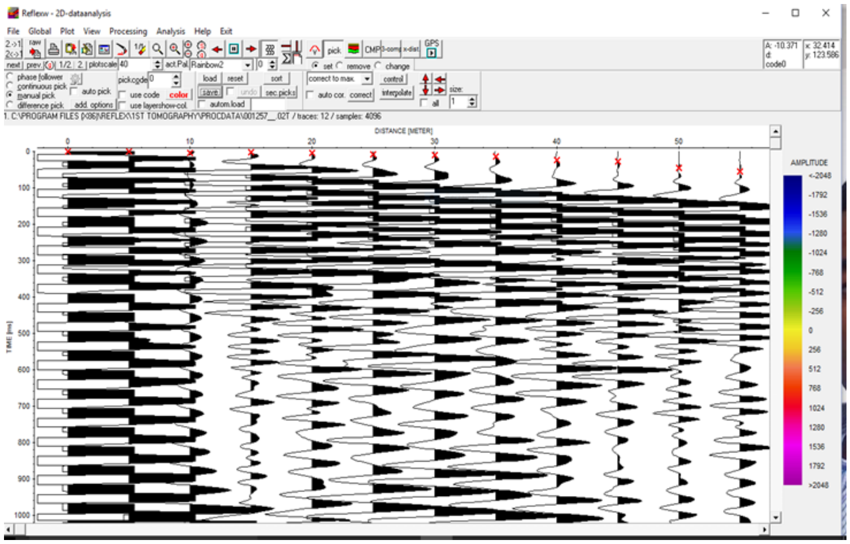

Figure 6. Picking of the first arrival

Table 1. Data for the first forward and reserve time

Distance (m)	Forward time (ms)	Reversed time (ms)
0	5.99	55.9
5	7.98	53.89
10	9.98	39.92
15	15.97	27.95
20	13.97	33.93
25	19.96	33.93
30	19.96	21.96
35	33.93	15.97
40	27.95	11.98
45	39.92	11.98
50	41.92	9.81
55	43.91	5.89

Table 2. Data for the 2nd forward and reserve time

Distance (m)	Forward time (ms)	Reversed time (ms)
0	1.96	43.91
5	2.73	37.93
10	5.99	33.93
15	7.98	43.91
20	11.98	25.95
25	11.96	21.96
30	17.96	13.97
35	19.96	15.79
40	25.95	7.98
45	35.93	7.98
50	37.93	5.99
55	47.91	3.99

Table 3. Data for the 3rd forward and reserve time

Distance (m)	Forward Time (ms)	Reversed Time (ms)
0	0.93	39.92
5	6.52	37.93
10	7.45	35.95
15	11.77	23.95
20	11.8	19.96
25	13.97	15.97
30	15.97	13.97
35	21.96	11.98
40	21.96	19.78
45	25.95	7.98
50	27.93	3.73
55	33.93	1.86

Table 4. Data for the 4th forward and reserve time

Distance (m)	Forward Time (ms)	Reversed Time (ms)
0	0	37.93
5	0.28	33.93
10	2.27	25.95
15	6.43	19.96
20	7.85	19.96
25	13.33	15.97
30	18.06	9.98
35	20.99	9.98
40	23.95	7.98
45	33.93	5.89
50	31.94	1.54
55	39.92	0.77

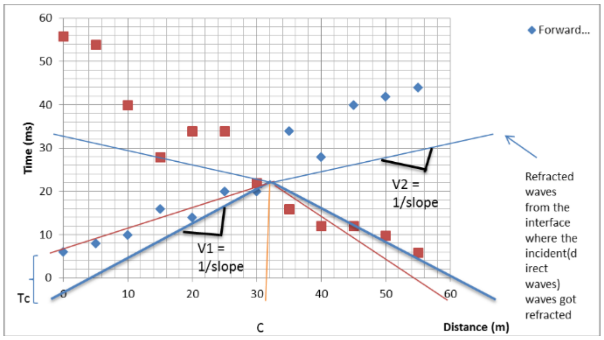

Figure 7. Graph for the first forward and reserve time

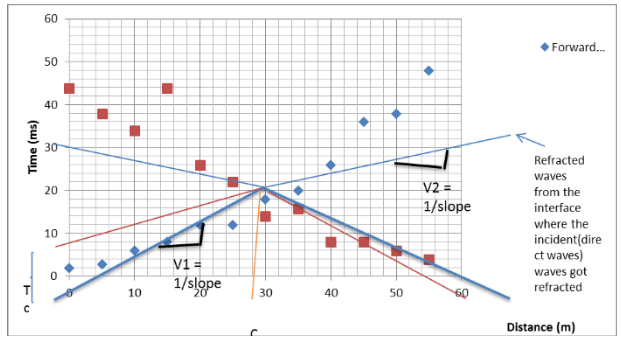

Figure 8. Graph for the 2nd forward and reserve time

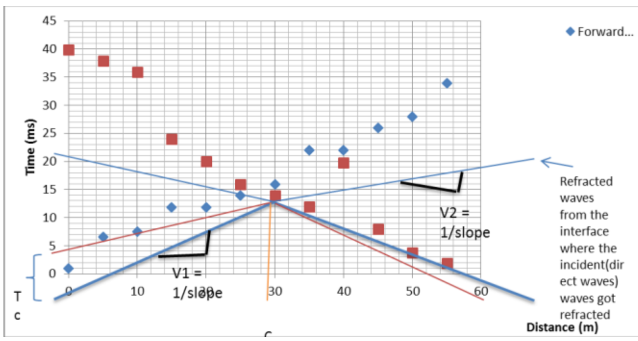

Figure 9 Graph for the 3rd forward and reverse time

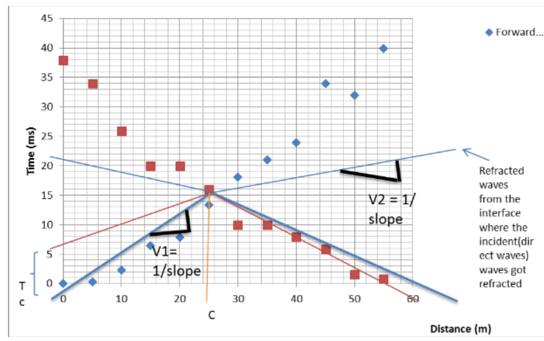

Figure 10. Graph for the 4th forward and reverse time

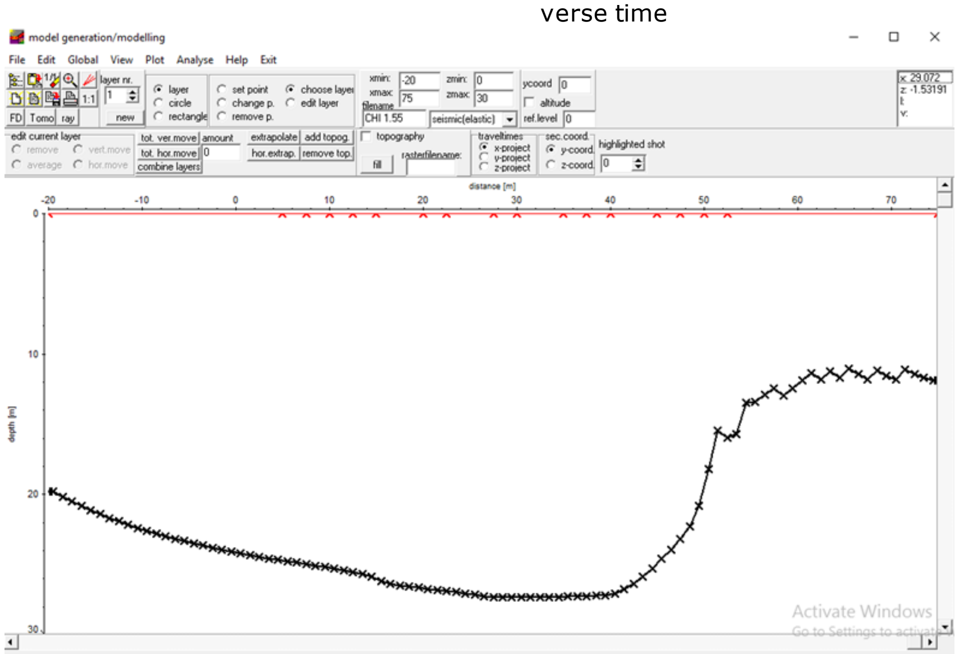

Figure 12. Model

The graphs that were plotted were used to assign layers with the aid of the average travel time from the four charts i.e. Figures 11-12. Figure 11 shows that the model is unparabolic and shows a variation of layers and sign of unconformity. Figure 12 shows the tomographic look of the data, and from it we can predict the various velocities and their variations for each soil layer or soil type.

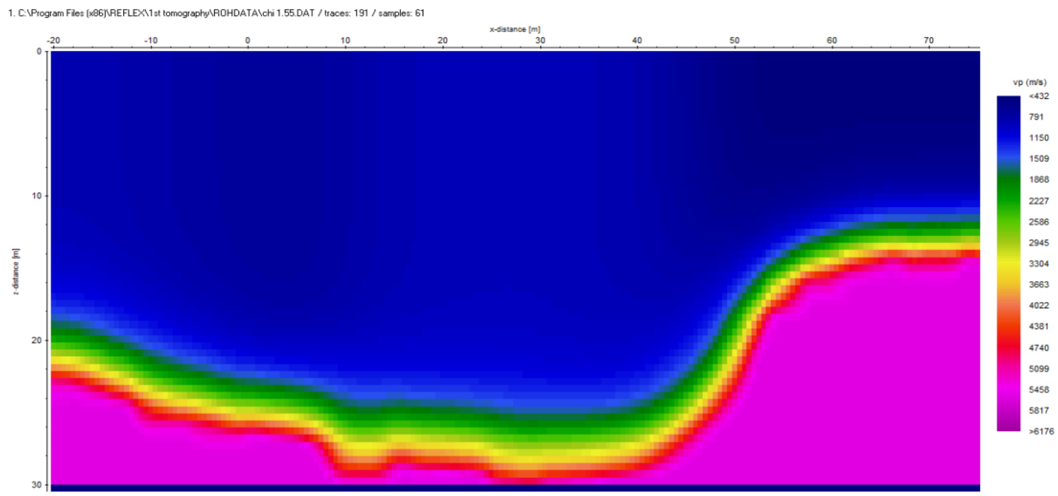

Figure 12. Seismic refraction tomography

The weathered layer velocity can be derived indirectly from surface seismic data and is very essential to geoscientists and environmental engineers [4]. Measurements of arrival times of the seismic pulses to the geophones at various depths give the velocity of the propagation of pulse in the ground. Since the elastic properties of the layer are assumed homogenous generally, the velocity of the ground motion will therefore vary both with depth and horizontal distance. For a source depth of h, an offset of X, the vertical velocity t_v corrected for the source depth is:

$$t_v = \frac{t_s(h-z)}{\left\{\left(\frac{hX-ZX}{h}\right)^2 + (h-Z)^2\right\}^{1/2}} \qquad 1$$

where Z is the respective receiver depths, h is the source depth, X is the offset, t_s is travel time for slant path (the raw time picked from the seismogram). The velocities were computed from the reciprocals of the slopes of the straight-line segments based on the thickness equation 1 [9].

The velocities of the weathered layers for this work were computed from the slopes of four profiles shown in Figures 7 – 10 and presented in Table 5.

Table 5. Table of seismic velocities

	Forward Up Velocity (m/s)	Forward Down Velocity (m/s)	Reverse Up Velocity (m/s)	Reverse Down Velocity (m/s)	Average (m/s)
Profile 1	1645	900	1333	1000	1219.5
Profile 2	1770	1000	1964	867	1400.3
Profile 3	1715	1273	1645	1200	1458.3
Profile 4	1592	1300	1792	1182	1466.5
Average	1680.5	1118.3	1683.5	1062.3	

3.2. Discussion

The velocity determination of weathered layer is bedrock of possibilities in predicting the nature of the earth, in terms of minerals and sustainability. Seismic refraction method in its simplest form had brought a way and easy take in evaluating the content of the Earth's crust, its thickness and permeability conditions. Seismic refraction methods of evaluating the crust (weathered layer) have given a room and possibilities for geoscientist to be fast and accurate to determine or predicting earthquakes and other similar tectonic related hazards.

The near surface geology is comparatively stable and inhomogeneous with moderate velocity contrast. The weathered layer velocities range from 900 m/s to 1300 m/s with an average of 1118.3 m/s for the forward down velocities while the velocities range from 867 m/s to 1200 m/s with an average of 1062.3 m/s for the reverse down velocities. The consolidated layer velocities range from 1592 m/s to 1715 m/s with an average of 11680.5 m/s for the forward up velocities while the velocities range from 1333 m/s to 1964 m/s with an average of 1683.5 m/s for the reverse up velocities. It was observed that these consolidated layers across the study area were sufficiently competent for civil engineering applications judging from their recorded high seismic velocity values.

The values of seismic velocities obtained in this study are in agreement with the results/values obtained by other researchers in the study area [4, 9-11].

Near surface seismic velocity variation gives rise to great chances of encountering inhomogeneity of the weathered zone and poses a problem for a smooth static behavior if seismic reflection survey is to be carried out in the area.

The average consolidated layer velocity of 1680 m/s found in this work falls within the range used for static correction in a reflection survey which is capable of removing it is effect on arrival time. The weathered layers are to a large extent heterogeneous and loose as indicated by the velocities of the layer. Results obtained from this study indicated that static correction will be required in the study area before seismic reflection work is carried out, owing to the high variations in weathered layer seismic velocity.

Results obtained from this study are very important in determining time delays required for static corrections during the processing of seismic reflection data [10-11]. The knowledge of the velocity of the low velocity layer is extremely important in civil engineering works as well as, in groundwater exploration. Civil engineers and construction experts can use the result among other fundamental soil parameters to determine the soil type and position of foundation for structures to be erected [12].

4. Conclusion

Seismic exploration involves the generation, detection, analysis and interpretation of elastic waves in the earth to study the sub-surface properties of the earth. Seismic refraction tomography was carried out in four different sites within the study area to determine the seismic velocities of the weathered and consolidated layers.

Results from the study area revealed that the weathered layer velocities range from 900 m/s to 1300 m/s with an average of 1118.3 m/s for the forward down velocities while the velocities range from 867 m/s to 1200 m/s with an average of 1062.3 m/s for the reverse down velocities. The consolidated layer velocities range from 1592 m/s to 1715 m/s with an average of 11680.5 m/s for the forward up velocities while the velocities range from 1333 m/s to 1964 m/s with an average of 1683.5 m/s for the reverse up velocities.

The values of velocities of weathered and consolidated layers obtained in this work are in agreement with the results obtained by others researchers that have worked in the Niger Delta region of Nigeria where this work was carried out. The high values of seismic velocities of the consolidated layers obtained from this work were adequately sufficient for civil engineering applications.

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