Quantitative Analysis of Seismic Refraction Data to Delineate the Weathering Structures in Parts of Delta State

Uwadiegwu Promise[#1], Nwankwo C.N[*2], Eze S.U.[#3]
[#1,2]Department of Physics, University of Port Harcourt, PMB 5323, Choba, Port Harcourt, Nigeria
[3]Department of Physics, Nigeria Maritime University Warri South-West Delta State, Nigeria

Abstract

Seismic refraction shooting have been carried out at a site located in Osubi Township within Effurun metropolis Delta state Nigeria, to establish a database on the subsurface geology and weathering structures in the area for engineering studies. Twenty (20) seismic refraction data using forward and reverse shooting methods of lateral distance 2m along each shot points were acquired within the study area. The data was analyzed using Microsoft Excel and Strata-4 software; and the results indicate the presence of three seismic refraction layers with the first layer having velocity 150-366m/s and thickness 1.0-3.3m, representing topsoil. The second refraction layer is composed of lateritic clay with thickness 4.5-10.5m and velocity 578-878m/s. The third refraction layer consists of sandy clay with velocity 1000-2500m/s. 2D geologic sections were drawn from seismic velocities showed that within the subsurface exists low permeable material (sandy clay) within the third layer. Clay is expansive with respect to moisture content, and this causes differential settlement which results in structural failure. 3D velocity model computed within the second and third layers for shot points 6 to 20 showed discontinuities in velocities at about 7-15m of the subsurface. Abrupt changes in velocity is diagnostic to presence of faults or fault like structures within the subsurface. Faults are plains of weakness where the subsurface geologic materials have lost cohesion (shear strength), therefore the study area has the existence of near surface weak materials (sandy clay) for foundation and engineering structures. Thus it is recommended that further geophysical investigation should be carried out such as resistivity tomography (2D or 3D) to quantify the vertical and lateral extent of the weak zones, so that further geotechnical decisions can be taken.

Keywords: *Seismic refraction, Seismic velocity, Geologic section, Velocity model.*

I. INTRODUCTION

Geophysical methods are often used in site investigation to determine the overburden thickness and to map subsurface conditions prior to excavation and construction. Geophysical data is an important parameter in contributing to the design and construction of Civil Engineering structures such as buildings, roads and dams. Electrical resistivity and seismic refraction methods are the most common geophysical techniques used for this purpose (Kurthenecker, 1934; Drake, 1962; Early and Dyer, 1964; Burton, 1976; Nun, 1979; Keary and Brooks, 1984; Olorunfemi and Meshida, 1987). However, in resistivity method, the depth of investigation and subsurface sections captured is limited to the array techniques employed during data acquisition that is resistivity sounding or resistivity imaging.

Seismic method is the geophysical method that gives the most detailed picture of subsurface geology because it gives us the opportunity to view the subsurface layers in two-dimensions (2D) or three-dimensions (3D) and to greater depths than that captured in resistivity method. Therefore geologic sections computed from seismic method is a more reliable model of the subsurface since the earth is heterogeneous and 3D in geometry. This is why seismic method is often used to determine the characteristics of subsurface soils and rocks (Ugwu, 2008; Ayolabi, 2004; Gabr *et al*., 2012), and structural setting of an area. The technique (seismic refraction) finds application in the determination of rock competence for engineering application, depth to bedrock, groundwater exploration, crustal structure and tectonics (Kilner *et al*., 2005; Asokhai *et al*., 2008; Chiemeke and Aboh, 2012).

Osubi township within Effurun metropolis Warri Delta state, before now is known for the various construction, dredging and engineering activities going on there. Recently there have been evidences to believe that the abandoning of the engineering sites in the area is as a result of the inadequate knowledge of the subsurface geology of the area which has given rise to collapse of some structures in time past. Therefore, there is need to develop a geological database of the area that will help in deducing suitable sites for engineering structures and general development in the area; hence the need for this study.

II. GEOLOGIC SETTING

The site under investigation is located at Osubi in Okpe local government area Effurun Delta State at

Longitude N005034'52" and Latitude E005048'32" with an Elevation of about 12 m above sea level. Several major and minor roads and footpath traverse the area see (fig. 1).

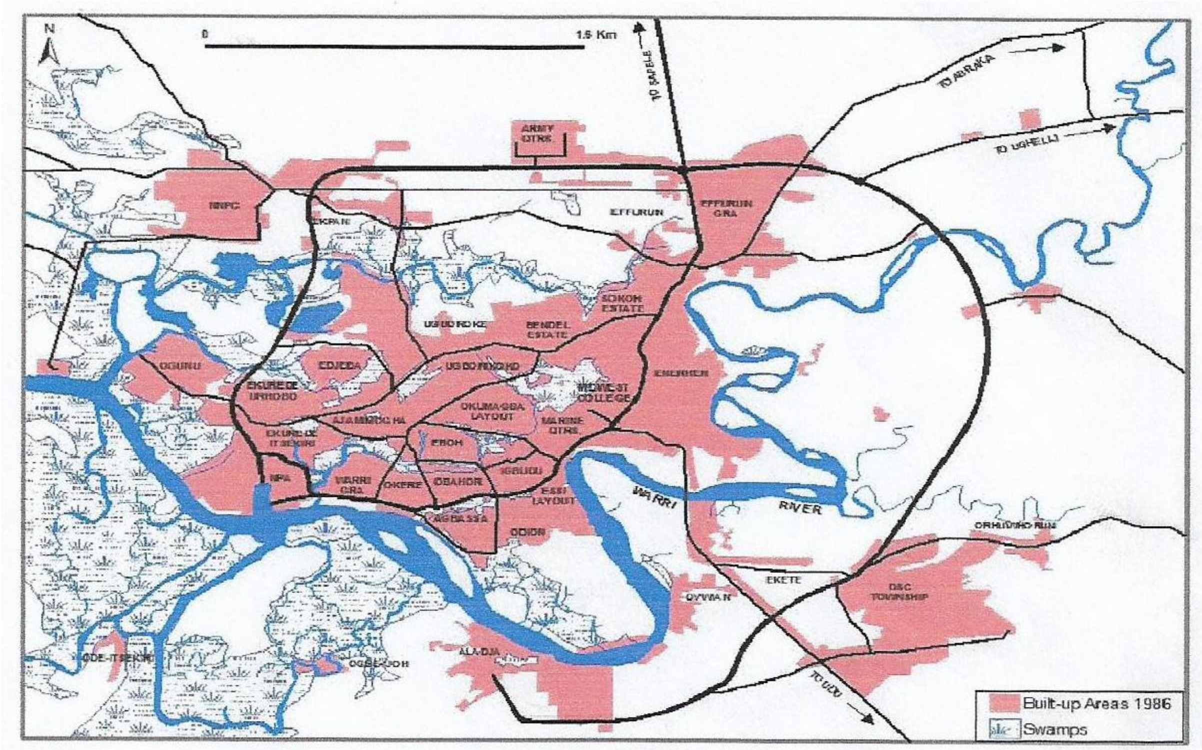


Figure 1: Map of Effurun-Warri with Co-ordinates Long N005034'52" and Lat E005048'32" (Odemerho, 1986).

The Effurun Area is a low-lying, slightly undulating deltaic plain. The plain is generally flat and rises only very gently towards the north and northeast with gradient of about 1:960. The Ugbomro Creek drain the area. The area is part of the Niger Delta and has a network of streams that are typical in a Deltaic setting. The amount of water drained in and out from the region is a function of the total rainfall, evaporation and losses because of absorption. The topography is dissected by several rivers which cut and shape out the path along which they flow to form fluvial channels. The Geology of Effurun region, some part of the Niger Delta comprises of three litho-stratigraphic units: The Akata Formation which is the oldest (Paleocene), is overlain by the Agbada Formation (Eocene) which is overlain by the Benin Formation (Miocene to recent). This is based on the works of Short and Stauble (1967). The Benin Formation covers 80 % of the rocks seen on the surface in the study area. It is underlain by the paralic Agbada Formation. The sedimentary units of the Benin Formation is comprised of inter fingering units of lacustrine and fluvial loose sands, pebbles, clays, and lignite streaks of varying thicknesses while the alluvial units is comprised of tidal and lagoon sediments and beach sands which are mostly found along the river banks. The reservoirs comprises the aquifer units found in the Agbada Formation (Plate 1).

The Agbada Formation consists of the sands intercalated by clays and shales while the Akata Formation occurs beneath comprising predominantly of shales rich in organic matter. Existing literature on the geology of the area are well documented from the exploration activities of oil and gas companies in the area.

The Benin Formation is overlain by thin laterites overburden with varying thicknesses at some locations but is massively exposed near the shorelines. The major aquiferous unit in the area lies within the sands of the upper deltaic top lithofacies. The Benin Formation is comprised of poorly-sorted continental (fine, medium and coarse) sands and gravels which alternate with streaks of lignite, thin clay lenses and horizons at some locations.

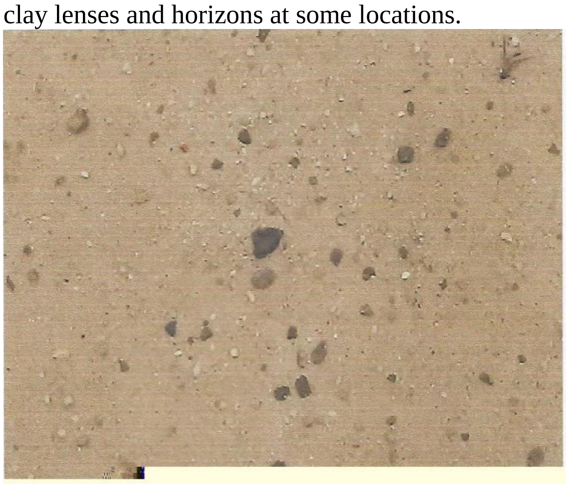


Plate 1: Top lithology in the study area comprising of unconsolidated sand, pebbles and gravels of the Benin Formation.

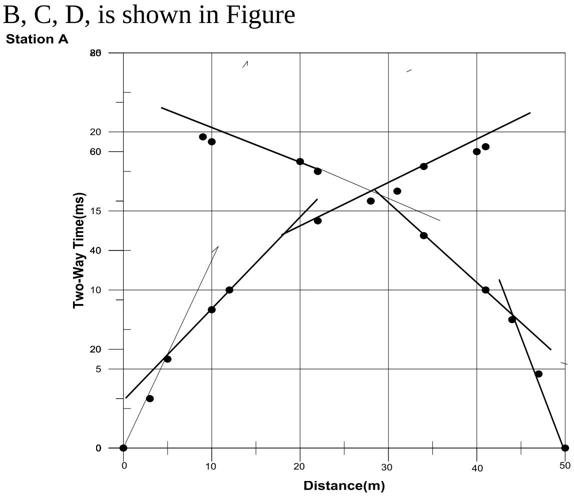
III. MATERIALS AND METHODS

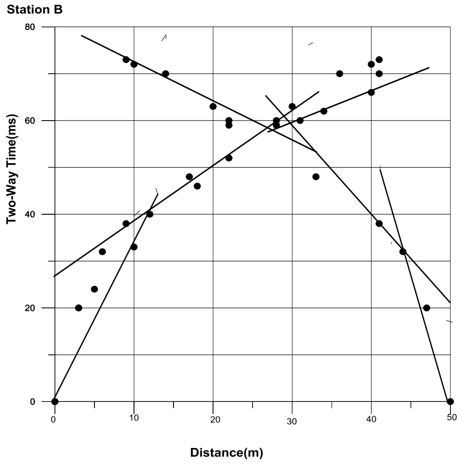
The research design used for this work is summarized in the flow chart in figure 2. The data was acquired from a site location in Osubi, Effurun Delta State using MACSEIS-160 VI.32 24-Channel Model Seismograph. The data used consists of two-way-time (TWT) for a 200ft spread of geophone offsets. Twenty (20) Shot points were acquired along four stations (A, B, C, D) in the area. A shot point's interval of 2m was maintained along each traverse. Time-distance (T-X) graph for each station was plotted using the arrival time, and from the T-X graphs, layer velocities and thicknesses were calculated using the intercept time method. The true velocities of the first and second refraction layers were obtained using their arithmetic mean since the dip is very small (Sharma, 1997), while the harmonic mean of the forward and reversed velocities was used to determine the true velocities of the third refraction layer.

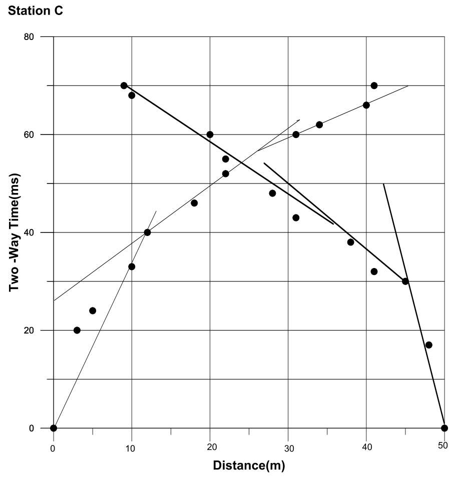
After obtaining the velocities and thicknesses of the various layers along each station, the velocities were used to draw 2D geologic sections to demonstrate the subsurface geologic characteristics of the area, and its structural setting. Strata-4 software application was used for the 2D geological section drawing. Also since geologic discontinuities, such as faults and fractures in the subsurface manifest themselves as abrupt, gradual and subtle changes of amplitudes and velocities (Partyka *et al.*, 1999), 3D velocity model was computed to show this discontinuity within the subsurface.

IV. PRESENTATION OF RESULTS

The results of the seismic refraction data interpretation is presented and discussed. Interpretation of seismic record involves determining the arrival times, plotting a time-distance graph, calculating the velocity of each layer and computing of geologic structural model from seismic velocities to agree with the subsurface layers and its geologic significance. The time distance graph for stations A, B, C, D, is shown in Figure







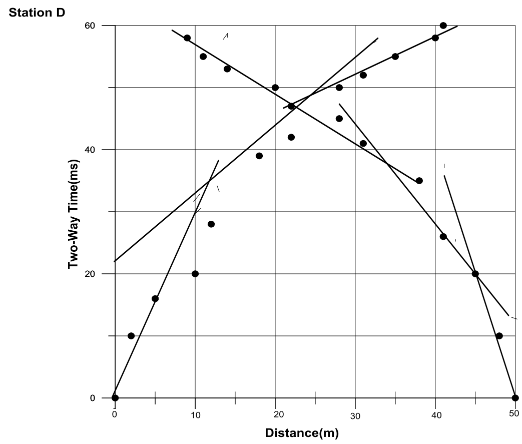


Figure 2: Time distance graph for Shot points 1-20 station A, B, C, D in the study area.

From the time distance graph, an estimate of the second layer velocities was done using their harmonic mean. The harmonic mean of V_{2U} V_{2D} for the Up dip and down dip shot for the second layer (V_2) is;

$$V_2 = \frac{2V_{2U}V_{2D}}{V_{2U} + V_{2D}} \cos\gamma$$

Where γ is the dip angle. The refraction parameters obtained in the study is shown in Table 1.

Table 1: Summary of Seismic Refraction parameters for shot points 1-20 station.

Geoph one station	V_1 (m/s)	V_2 (m/s)	V_3 (m/s)	Z_1 (m)	Z_2 (m)
1	282	696	1404	3.0	8.6
2	150	732	1207	1.6	8.7
3	207	709	1945	2.0	9.5
4	167	639	1364	1.8	8.3
5	152	578	1250	1.3	7.0
6	237	690	1714	2.9	10.1
7	173	725	-	1.9	-
8	208	750	1573	2.2	9.2
9	191	635	1867	1.5	10.5
10	238	732	1220	1.4	11.5
11	366	878	-	3.4	-
12	253	766	1000	2.3	7.5
13	241	667	-	2.0	-
14	252	709	2000	2.1	12.2
15	193	643	1976	1.9	10.2
16	213	771	-	2.0	-
17	250	628	1776	1.2	8.1
18	287	659	1404	1.5	8.5
19	201	625	1936	1.5	9.8
20	295	746	-	2.5	-

A. 2D Geologic Section

Three geologic sections were computed for this study. 2D geologic sections were computed to show the subsurface geologic characteristics of the area, and its subsurface structural setting (Figs. 3, 4 and 5).

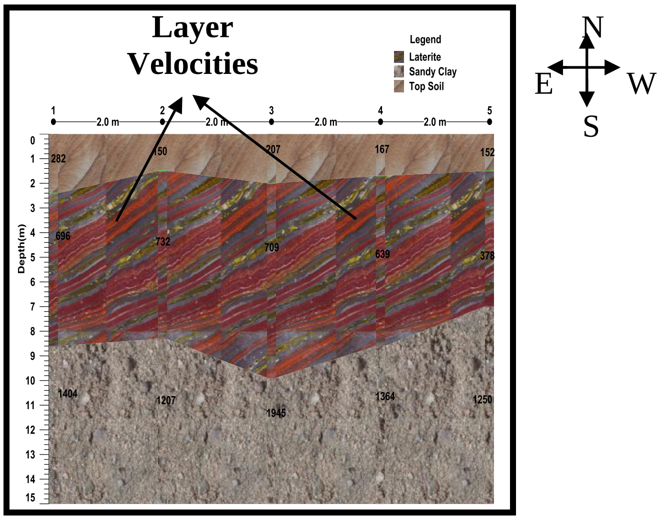


Figure 3: 2D geologic section for shot points 1-5 station A, showing subsurface geology of the area.

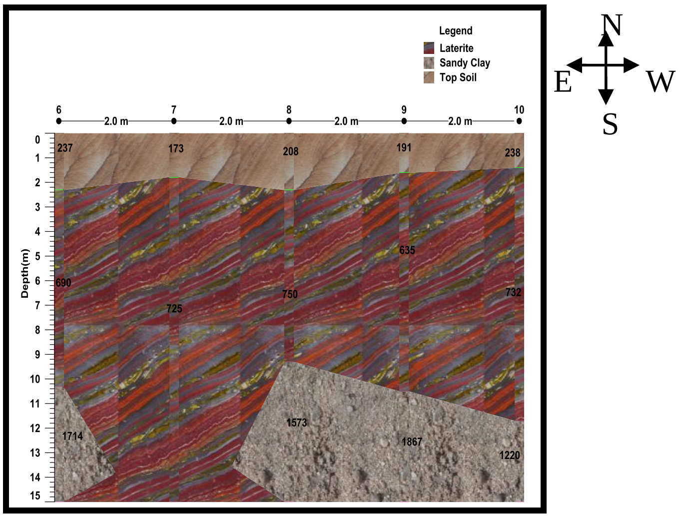


Figure 4: 2D geologic section for shot points 6-10 station B, showing subsurface geology of the study area.

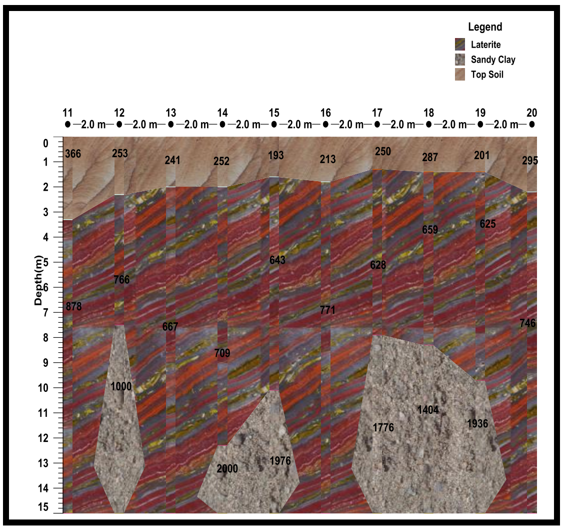


Figure 5: 2D geologic section for shot points 11-20 station C and D, showing subsurface geology of the study area.

B. 3D Velocity modelled section

3D velocity modelled sections was computed to show the geologic discontinuities which were evident in the 2D geologic section.

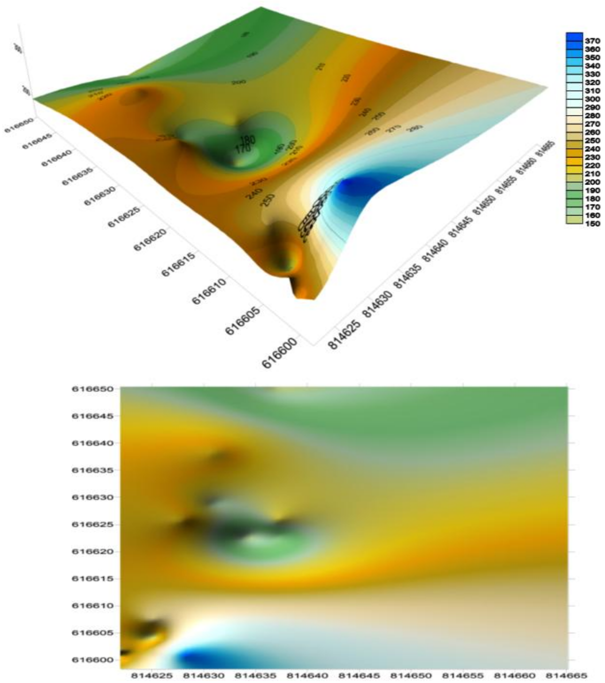


Figure 6: (A) 3D Velocity model within layers 2 and 3 for shot points 6-20, computed from transformed velocities; (B) 2D view of the model. The model shows the geologic discontinuities (faults and fractures) in the subsurface.

V. DISCUSSION OF RESULTS

Results from the summary of seismic refraction parameters for shot points 1-20 (Table 1), show that the first layer velocity ranges from 150 m/s-366 m/s, with a refractor thickness of 1.3 m-3.4 m, indicative of topsoil which are loosed and unconsolidated materials. The second refractor layer denotes laterite with its velocity ranging from 578 m/s-878 m/s and layer thickness between 7.0 m-12.2 m except beneath shot points 7, 11, 13, 16 and 20 where the impact of energy source terminated within this zone. The third refractor layer denotes sandy clay having velocity variation 1000-2500m/sec (Dobrin, 1988), its layer thickness could not be ascertained due to the weak energy source used. These results agree with the qualitative interpretation results of refraction data obtained by Ogagarue (2007) within the Niger delta basin were velocity ranging from 500m/sec-517m/sec were obtained within the unconsolidated/weathering layer (topsoil) at an average depth between 13.4-13.8m thereby confirming the depth of weathering. These likewise agree with the interpretation results of refraction data gotten by (Uko *et al*., 1992) within the Niger Delta where velocity ranging from 500.0 m/s-1732.0 m/s that was obtained within the consolidated shallow layer at a thickness between 2.9-4.5m. Also within the subsurface in the area exists loosed unconsolidated and low permeable sandy clay material which is overlain by laterite within the second layer. Clay is expansive with respect to moisture content and this causes differential settlement which brings about structural failure. 3D velocity model computed within the second and third layers for shot points 6 to 20 (Fig 6, A and B) showed discontinuities in velocities at about 7-15m of the subsurface. This correlates with the 2D geologic section computed for these shot points in figures 6 and 7. Abrupt changes in velocity is diagnostic to presence of faults or fault like structures within the subsurface. Faults are plains of weakness were the subsurface geologic materials have lost cohesion (shear strength). Furthermore, considering the mean annual rainfall gauge in Effurun 2673.8mm (Meteorological Report of 1999- 2015), Lee (2002) says that intense rainfall will raise groundwater level rapidly to the ground surface and this would result in a sudden increase in pore pressure which would reduce the shear resistance and competence of the geo-material and finally lead to structural failure. In this light, it is clear that the study area has the existence of near surface weak and non-competent geo-materials (sandy clay) for foundation and engineering structures as delineated within the third layer. Thus it is recommended that further geophysical investigation should be carried out such as high resolution resistivity tomography (2D or 3D) to quantify the vertical and lateral extent of sandy clay and shear zones already delineated in the third layer which is a a potential threat to buildings foundation when laid in the area.

VI. CONCLUSIONS

The results of the study area have been used to delineate the subsurface geologic setting of the area, and its suitability for engineering works. Layers with good engineering properties and competent to engineering structures are delineated within the second layer (laterite). The velocity of the subsurface layer increases with depth. However the presence of near surface weak zones (sandy clay) deposits within the third layer has been identified underlying laterite in the area from shot points 1-20. Deeper layers couldn't be delineated because of the energy source used. To delineate deeper layers, electrical resistivity sounding (VES) and 2D/3D resistivity tomography is recommended to probe deeper and quantify the extent of the sandy clay and shear zones already delineated by the 3D velocity model computed from seismic velocities. Also this work has improved on the existing literatures on quantitative seismic refraction data interpretation from the structural models (2D and 3D) computed from the seismic refraction parameters. This has helped to establish a database on the subsurface geology and structural setting of the study area, for environmental studies.

REFERENCES

[1] E.A.Ayolabi, Seismic refraction survey of University of Lagos, Nigeria and its implication. Journal of Applied Sciences. 7(3): 4319-4327, 2004.

[2] A.N. Burton, The use of geophysical methods in engineering geology, part 1; Seismic techniques, ground Engineering, 1976.

[3] C.C.Chiemeke and H.O. Aboh, "Delineation of aquiferous layers within the basement complex using joint inversion of Seismic refraction and high resolution 3D seismic reflection survey". Arch. Applied Sci, Res; Vol 4, 400-405, 2012..

[4] C.L.Drake, "Geophysics and engineering Geophysics", Vol 27, 193-197, 1962.

[5] M.B.Dobrin and C. H. Savit, "Introduction to geophysical prospecting," 4th edition, New York, Mc Graw-Hill, 72-84, 1988.

[6] K.R.Early and K.R. Dyer, "The use of resistivity and Seismic refraction survey in foundation site underlain by Karst dolomite. Geo-technique", Vol 14, 341-348, 1964.

[7] A.Gabr, A. Murad, H. Baker, K. Bloushi and H. Arman, The use of Seismic refraction and electrical techniques to investigate groundwater aquifers, Wadi Al-am, United Arab Emirates (UAE). Proceedings of the conference on Water Resources and Wetlands, Sept 14th-16th, 64-99, 2012.

[8] M.Kilner, L.J. West and T. Murray, "Characterization of glacial sediments using geophysical methods for groundwater source protection. Journal of Applied Geophys, Vlo 57, 293-305, 2005.

[9] P.Keary and M. Brooks, "An introduction to geophysical exploration" Blackwell Scientific Publication, Oxford, 198-217, 1984.

[10] K.S.Kurtenacker, "Some practical applications of resistivity measurements to highway problem," Transaction of American Institute of Mining and Metallurgical Engineers 110, 193-205, 1934.M.

[11] T.S.Lee, "Shallow Failure in Slope Stability Methods", 2nd Ed. John Wiley & sons, Inc, New York. Meteorological and Climate Report of Effurun between 1999-2015, 2002.

[12] K.R.Nun, "Geophysical surveys at two landfill sites in the West Midlands Symposium on the engineering behaviour of industrial and urban fill, 57-66, 1979.

[13] F.O.Odemerho and A.G. Onokerhoraye, "Physical Geography-Handbook for the Tropics: The Benin Social Sciences Series for Africa, University of Benin, Benin City, Nigeria". Pacific Journal of Scientific and Technology, Vol 8, 49-58, 1986.

[14] D.O.Ogagarue, "Comparative study of the Offset-Geophone and Down-deep hydrophone in Seismic refraction survey with applications to the Niger Delta Basin". Pacific Jorunal of Science and Technology, Vol 1, 49-58, 2007.

[15] M.O.Olorunfemi and E.A. Meshida,"Engineering geophysics and its application in engineering site investigation (Case study from Ile-Ife area)". The Nigerian Engineer, Vol 22, 57-66, 1987.

[16] G.Partyka, G.J. Gridley and J. Lopez, "Interpretational applications of Spectral decomposition in reservoir characterization", 353-360, 1999.

[17] P.V.Sharma, "Environmental and Engineering Geophysics". Cambridge- University Press, United Kingdom 475, 1997.

[18] K.C.Short and J. Stauble,"Outline Geology of the Niger Delta".American Association of Petroleum Geologist Bulletin, 51, 761-779, 1967.

[19] S.A.Ugwu," Determination of depth to bedrock in Afikpo Syncline of the Benue Trough Nigeria, using seismic refraction methods. Scientific Africana, 7(2), 73-80, 2008.

[20] E.D.Uko, A.S. Ekine, J.O. Ebeniro and C.O. Ofoegbu, "Weathering structure of the east-central Niger Delta Nigeria, Geophysics, 57, 1228-1233, 1992.