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Application of Seismic Refraction Tomography in Delineating Subsurface Geology and Weathering Structures in Parts of Osubi Delta State

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Abstract: *Seismic refraction tomography have been carried out at a site located in Osubi area of Delta state,Nigeria, to establish a database on the subsurface geology and structural setting of the area for engineering purposes. A total of 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 results indicate the presence of three seismic refraction layers with the first layer having a velocity of 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 a velocity of 578-878m/s. The third refraction layer consists of sandy clay with a velocity of 1000-2500m/s. 2D geologic sections computed from transformed seismic velocities show 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 stations F to T showed discontinuities in velocities at about 7-15m of the subsurface. This correlates with the 2D geologic sections computed for these stations. Abrupt changes in velocity is diagnostic of 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). From this study, it is inferred 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. This method of refraction interpretation has improved on the existing literatures on quantitative seismic refraction data interpretation, and has helped to establish a database on the subsurface geology and structural setting of the study area.*

Keywords: *Seismic refraction, tomography, Seismic velocity, Geologic section.*

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I. Introduction

Geophysical data is an important parameter in contributing to the design and construction of Civil Engineering structures such as buildings, roads and dams. Geophysical methods are often used in site investigation to determine the overburden thickness and to map subsurface conditions prior to excavation and construction. 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 i:e resistivity sounding or resistivity imaging.

Seismic method is the geophysical method that gives the most detailed picture of subsurface geology because it gives the opportunity to view the subsurface layers in two-dimension (2D) or three-dimension (3D) and allows for greater depths penetration than that captured in resistivity method. Therefore, geologic sections computed from seismic method are more reliable since the earth is heterogeneous and 3D in geometry; the seismic method is often used to determine the characteristics of subsurface soils and rocks (Ugwu, 2008;Ayolabi et al., 2009; 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).

The Osubitownship around theEffurun metropolis, Warri, Delta state, is a new area opening to development, hence, varied constructions, dredging and engineering activities predominates in the area. Recently, there have been reports of the reports of building collapse due to structural failure. This have been attributed to the inadequate knowledge of the subsurface geology of thearea leading to abandonment of construction sites. 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

2.1 Accessibility, topography and Climate

The site under investigation is located at Osubi in Okpe local government area around the Effurun metropolis, 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 footpaths traverse the area.

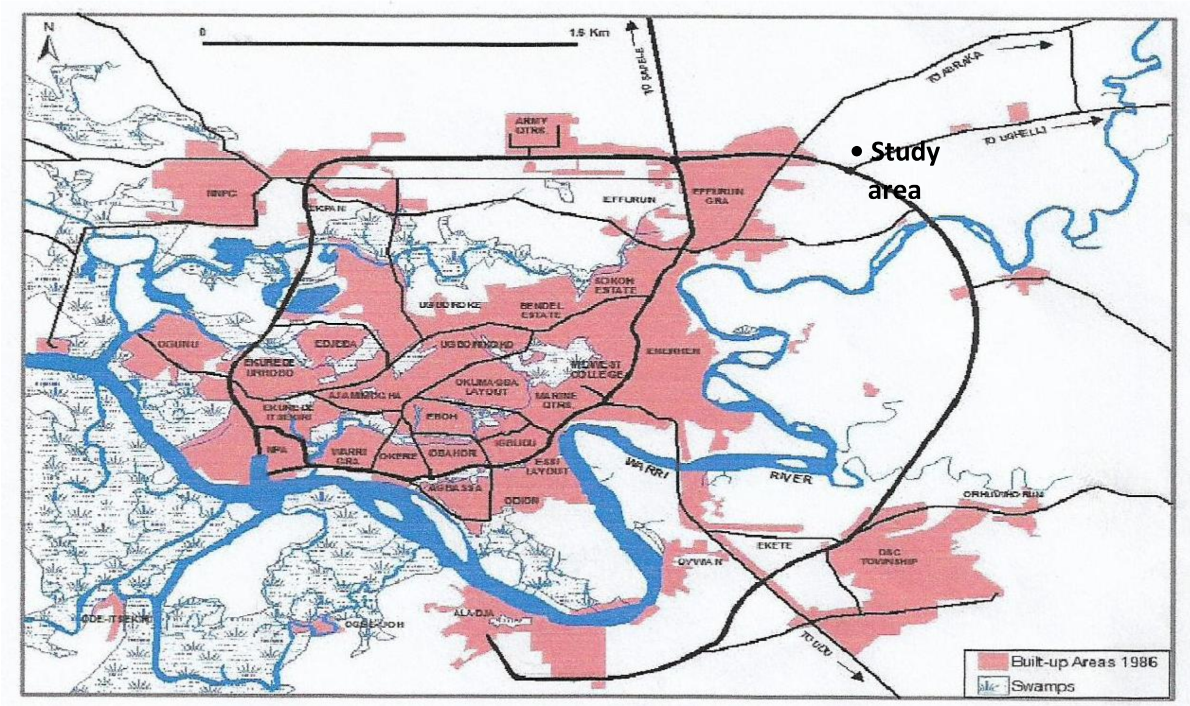


Figure 1: Map of Effurun-Warri Metropolitan Area (Odemerho, 1986), showing Study area.

The Osubi 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 topography is dissected by several rivers which cut and shape the terrain.

Basically, there are two distinct climatic seasons in this region namely,

- The Rainy season and
- The Dry season, respectively.

The climate is tropical equatorial with mean annual temperature of 32.8°C and high temperature of 36°C and 37°Cand mean annual rainfall gauge of 2673.8 mm (Meteorological Report of 1999-2015). The region encounters high humidity for most part of the year.

2.2 Geology of the Area

The Study Area is situated within the Niger Delta. The Niger Delta comprises of three litho-stratigraphic units; The Akata Formation which is the oldest (Paleocene), and is overlain by the Agbada Formation (Eocene). The topmost unit is the Benin Formation (Miocene to recent). (Short and Stauble(1967).

The sedimentary units of the Benin Formation (plate 1) 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 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 literatures 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 lateritic clay overburden with varying thicknesses at some locations (plate 2) but is massively exposed near the shorelines (Evamy et al., 1978). The major aquiferous unit in the area lies within the sands of the upper deltaic top lithofacies.

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

Plate 2: Exposed outcrop of lateritic clay in the study area.

III. Materials And Methodology

The research design used for this work is summarized in the flow chart below (figure 2). The data was acquired from twenty (20) locations within Osubi, Delta State using MACSEIS-160 VI.32 24-Channel Model Seismograph with a weight drop mechanism as the energy source.

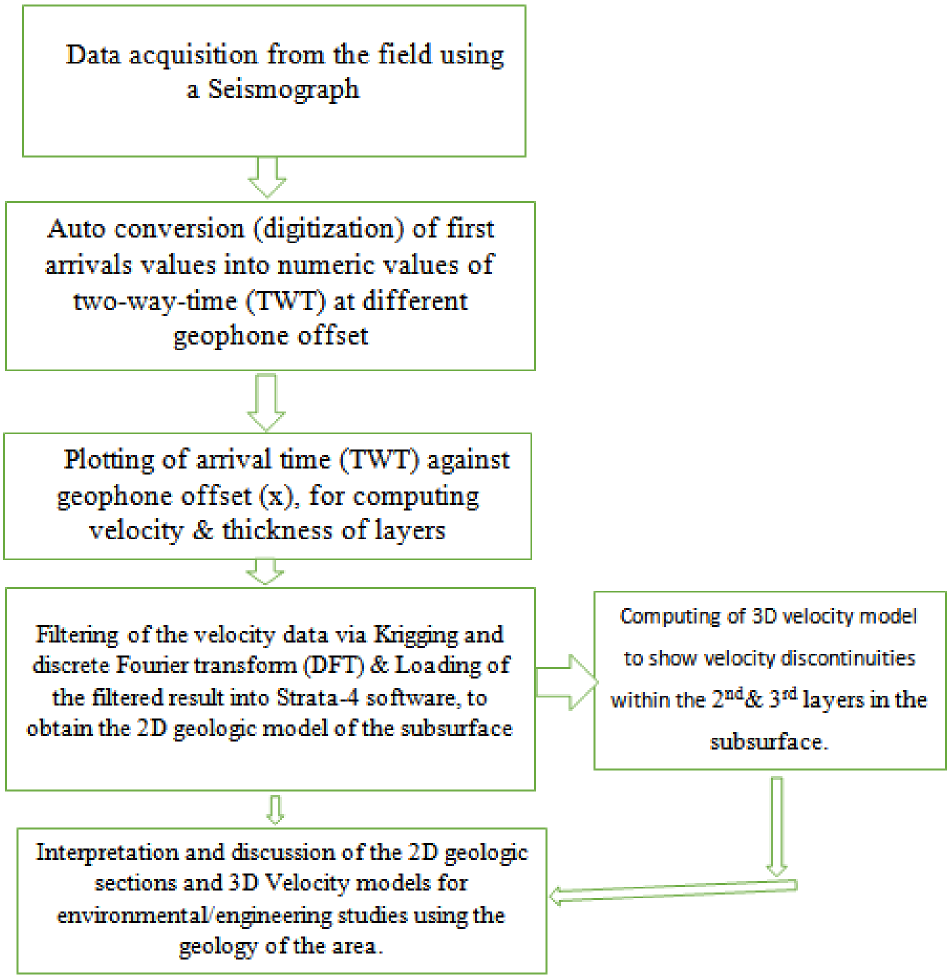


Figure 2: Research workflow.

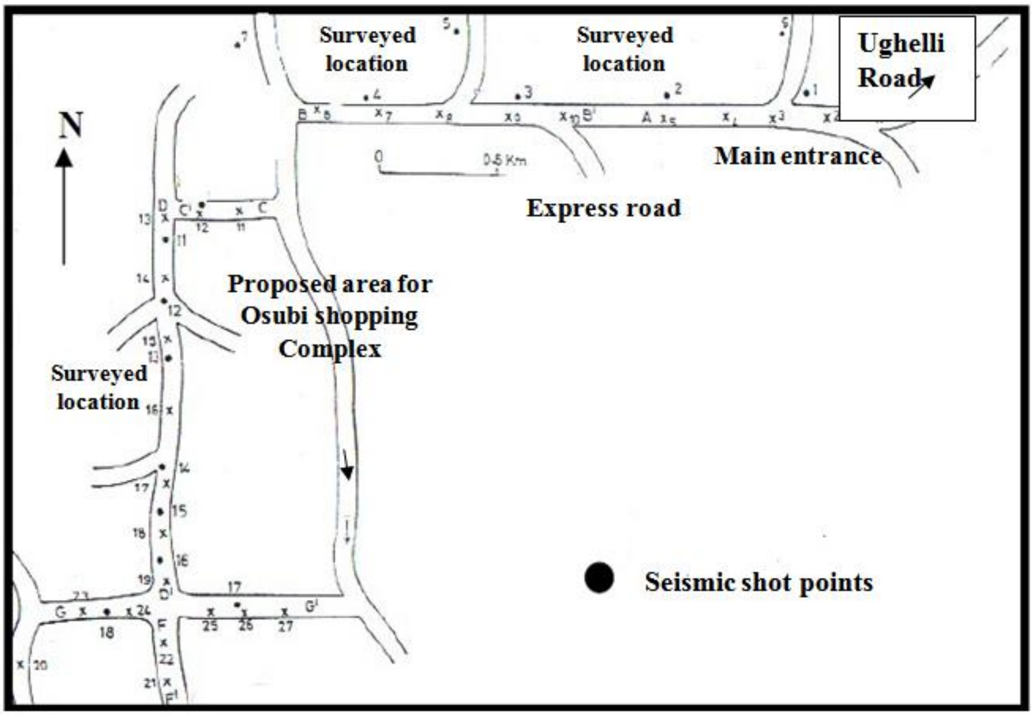


Figure 3: Schematic map of location showing data acquisition profiles.

The data used consists of the two-way-time (TWT) for a 200ft spread of geophone offsets. Twenty (20) Shot points were acquired along twenty (20) stations (A-T) in the area. A shot point 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 filtered by taking the discrete Fourier transform (DFT) magnitude of the various velocities within MATLAB software. 2D Seismic geologic sections were computed using the filtered velocity, 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. Geologic discontinuities, such as faults and fracturespresent 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

In this section, the results of the seismic refraction data interpretation is presented and discussed. Interpretation of seismic record involves determining the arrival times, plotting the time-distance graphs, calculating the velocity of each layer and computing of the geologic structural model from seismic velocities to agree with the subsurface layers and its geologic significance. The time distance graph for only stations A, B, C, D is shown in Figure 4 below.

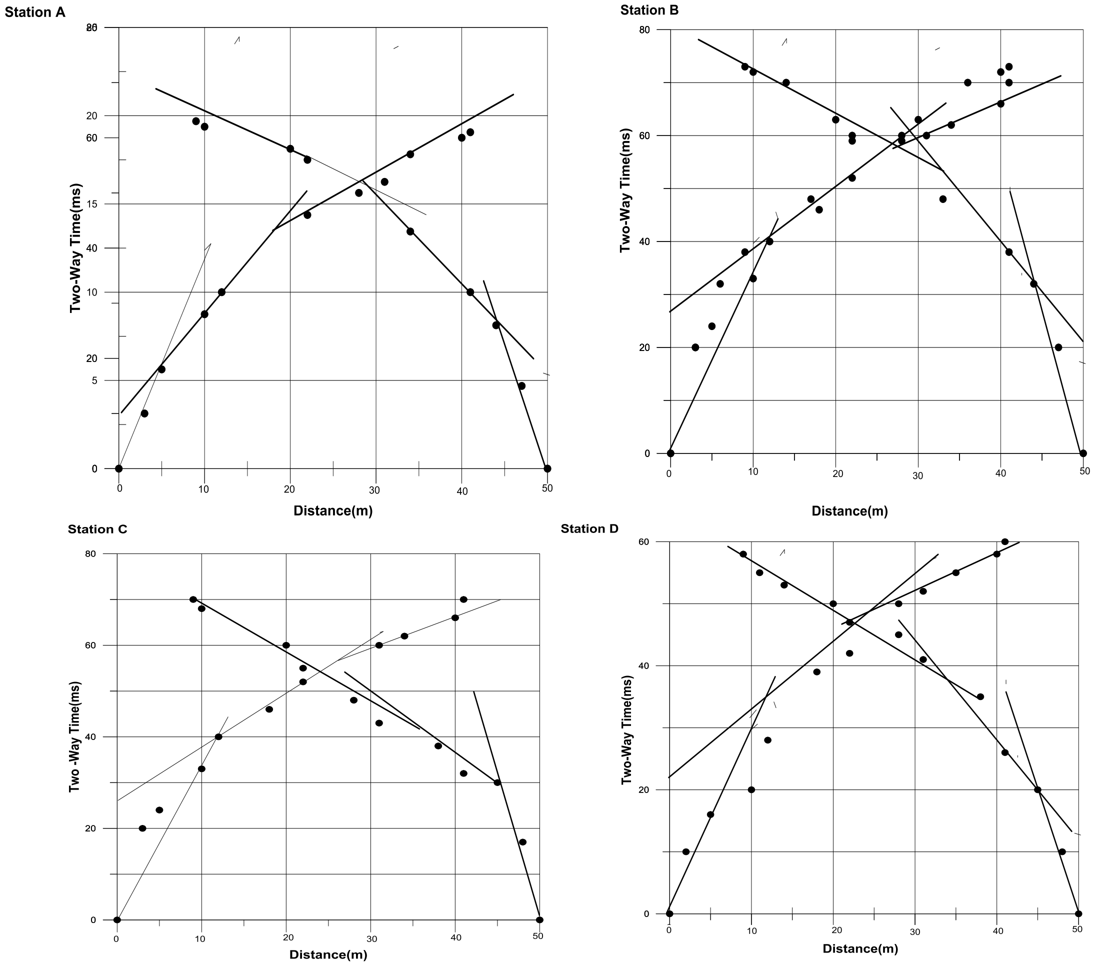


Figure 4: Time distance graph for Shot points 1-20 for stations A, B, C, D in the study area.

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

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

Table 1: Summary of Seismic Refraction parameters for shot points A-T station

Geophone station	V_1(m/s)	V_2(m/s)	V_3(m/s)	Z_1(m)	Z_2(m)
A	282	696	1404	3.0	8.6
B	150	732	1207	1.6	8.7
C	207	709	1945	2.0	9.5
D	167	639	1364	1.8	8.3
E	152	578	1250	1.3	7.0
F	237	690	1714	2.9	10.1
G	173	725	-	1.9	-
H	208	750	1573	2.2	9.2
I	191	635	1867	1.5	10.5
J	238	732	1220	1.4	11.5
K	366	878	-	3.4	-
L	253	766	1000	2.3	7.5
M	241	667	-	2.0	-
N	252	709	2000	2.1	12.2
O	193	643	1976	1.9	10.2
P	213	771	-	2.0	-
Q	250	628	1776	1.2	8.1
R	287	659	1404	1.5	8.5
S	201	625	1936	1.5	9.8
T	295	746	-	2.5	-

4.1 2D Geologic Section

Three geologic sections were computed for this study. 2D geologic sections were computed using the filtered layer velocity data to show the subsurface geologic characteristics of the area, and its subsurface structural setting (Figs. 5, 6 and 7). In Figure 5, the first layer is the topsoil which is trending east-west and underlain by laterite as the second layer, laterite is underlain by sandy clay deposit as third layer. In Figures 6and 7 below, the first layer is also trending East-West while the second layer breaks and intrudes into the third layer.

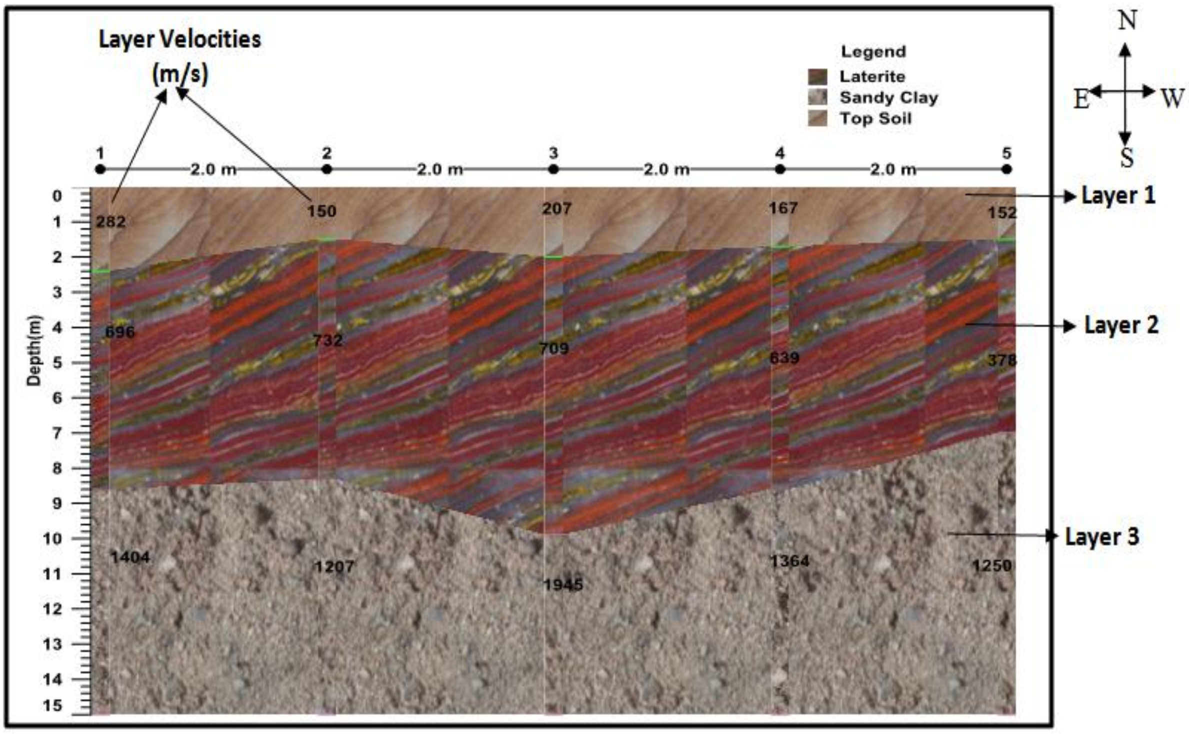


Figure 5: 2D geologic section for shot points 1-5 station A, showing subsurface geology of the area.

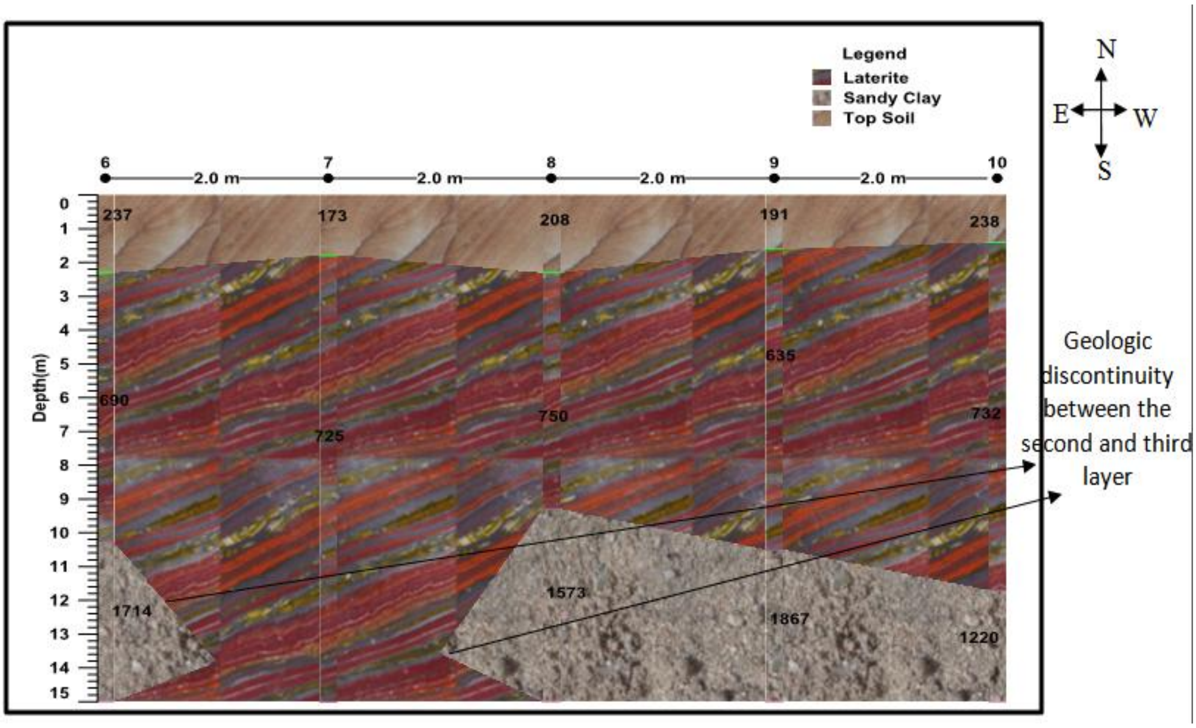


Figure 6: 2D geologic section for shot points 6-10 station B, showing subsurface geology of the study area.

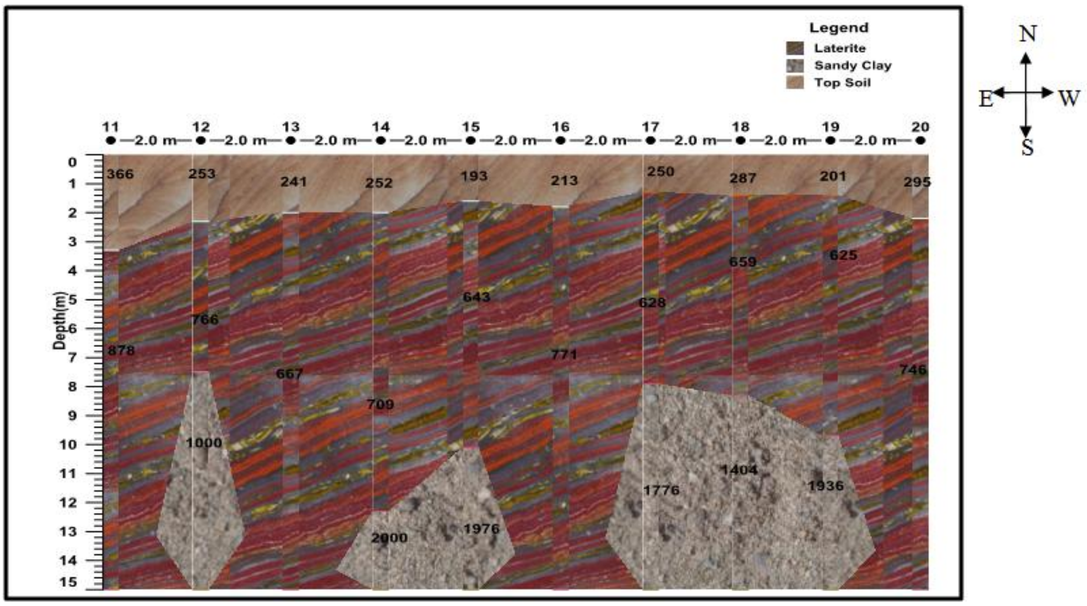
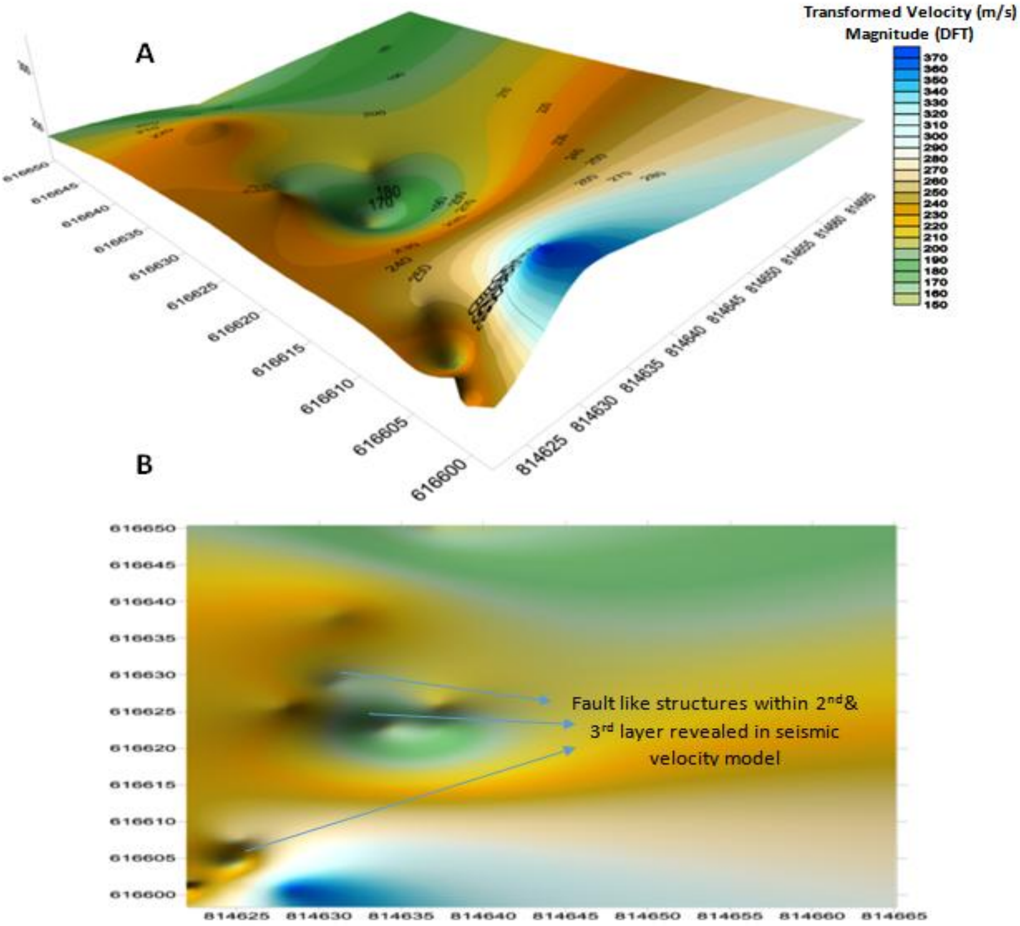


Figure 7: 2D geologic section for shot points 11-20 station C and D, showing subsurface geology of the study area.

4.2 3D Velocity modelled section

3D velocity modelled sections was computed using the transformed (filtered) seismic velocity to show the geologic discontinuities which were evident in the 2D geologic section.



Fault like structures within 2nd& 3rd layer revealed in seismic velocity model

Figure 8: (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 station A – T (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. 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 because the impact of energy source terminated within this zones. The third refractor layer denotes sandy clay having velocity variation of 1000-2500m/sec (Gabr et al., 2012; Early and Dyer, 1964). Clay is expansive with respect to moisture content and this causes differential settlement which can bring about structural failure. These results agree with the qualitative interpretation results of refraction data obtained by Ogagarue (2007), within the Niger delta basin where 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 was obtained within the consolidated shallow layer thickness between 2.9-4.5m.

3D velocity model computed within the second and third layers for shot points 6 to 20 (Fig 8 A&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 of 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 Effurunis 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 & competence of the geo-material and finally lead to structural failure. From this study, it shows that the study area has the existence of near surface weak and non-competent geo-materials (sandy clay) which are not suitable for high impact 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 claydelineated within the third layer which will poses a potential threat to buildings and foundation when laid in the area; so that further geo-technical decisions can be made with minimal error.

VI. Conclusion

The results of the refraction survey carried out in the study area have been used to delineate the subsurface geologic setting of the area, and its suitability for engineering work and to establish a database of the area. Layers with good competent and engineering properties and suitable for 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 A - T.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 which has helped to establish a database on the subsurface geology and structural setting of the study area, for environmental studies.

References

[1]. Ayolabi, E.A. (2004). Seismic refraction survey of University of Lagos, Nigeria and its implication. Journal of Applied Sciences. Vol.7, No.3, pp 4319-4327.

[2]. Ayolabi**.** E.A.; Adeoti. L, Oshilaja, N.A., Adeosun, I.O., and Idowu, (2009): Seismic refraction and Resistivity Studies of part of Igbogbo Township, South-West Nigeria. Journal of scientific research and Development. Vol. 11. Pp42 – 61.

[3]. Burton, A.N. (1976). The use of geophysical methods in engineering geology, Part 1: Seismic techniques. Ground Engineering.

[4]. Chiemeke, C.C. and H.O. Aboh, 2012. Delineation of aquiferous layers within the basement complex using joint inversion of seismic refraction tomography and high resolution 3D seismic reflection survey. Arch. Applied Sci. Res., 4: pp400-405.

[5]. Drake, C.L. (1962). Geophysics and engineering. Geophysics 27: 193-197.

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

[7]. Gabr, A., A. Murad, H. Baker, K. Bloushi and H. Arman et al., 2012. The use of seismic refraction and electrical techniques to investigate groundwater aquifer, Wadi Al-ain, United Arab Emirates (UAE). Proceedings of the International Conference on Water Resources and Wetlands Sept. 14-16, Tulcea-Romania, pp: 94-99.

[8]. Kilner, M., L.J. West and T. Murray, 2005. Characterization of glacial sediments using geophysical methods for groundwater source protection. J. Applied Geophys., 57: 293-305. DOI: 10.1016/j.jappgeo.

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

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

[11]. Lee, T.S. (2002). Shallow Failure in Slope Stability and Stabilization Methods, 2nd Ed. John Wiley & Sons, Inc New York.

[12]. Meteorological and Climate Report of Effurun between 1999-2015., http://homepage.ufp/Wiki/climate/page 10.html.
[13]. Nun, K.R. (1979). Geophysical surveys at two landfill sites in the West Midlands. Symposium on the engineering behaviour of industrial and urban fill. 57-66.
[14]. Odemerho, F.O. and Onokerhoraye, A.G. (1986). Physical Geography- Handbook for the Tropics: The Benin Social Sciences Series for Africa, University of Benin, Benin City, Nigeria, 16-25
[15]. Ogagarue, D.O. (2007). "Comparative Study of the Offset-Geophone and Down-deep Hydrophone Seismic Refraction Survey with Application to the Niger Delta Basin, Nigeria". Pacific Journal of Science and Technology. 8(1):49-58.
[16]. Olorunfemi, M.O. and Meshida, E.A. (1987). Engineering geophysics and its application in engineering site investigations (Case study from Ile-Ife area). The Nigerian Engineer 22: 57-66. 2005.02.002
[17]. Partyka, G., Gridley, G.J. and Lopez .J. (1999): Interpretational applications of Spectral decomposition in reservoir characterization. 353-360.
[18]. Sharma, P.V. (1997). Environmental and Engineering Geophysics. Cambridge. University Press, United Kingdom. 475.
[19]. Short KC, Stauble J (1967). Outline geology of the Niger Delta. American Association of petroleum geologist Bulletin. 51, 761-779.
[20]. Ugwu, S.A., (2008). Determination of depth to bedrock in Afikpo syncline of the Benue Trough, Nigeria, using seismic refraction methods. Scientific Africana. 7(2); 73-80.
[21]. Uko E.D, Ekine A.S, Ebeniro J.O and Ofoegbu C.O (1992). Weathering structure of the east-central Niger delta, Nigeria, 57, 1228-1233.

Orji Omafume." Application of Seismic Refraction Tomography in Delineating Subsurface Geology and Weathering Structures in Parts of Osubi Delta State.IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) 6.4 (2018): 11-20.