Compressional and Shear-Wave Velocity Measurements in Unconsolidated Top-Soil in Eket, South-eastern Nigeria.

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ABSTRACT

Seismic compressional, P- and shear, S-wave measurements were done on the unconsolidated top-soil at the different locations of the study area. A 12-channel seismograph with signal stacking ability was used together with high frequency (100 Hz) geophones on the top-soil. The geophone intervals were set to 5 m at the all locations. In all the locations, the P-wave velocity ranged from 297.00 to 383.00 m/s for the top layer with a mean value of 355.10 m/s. The P-wave Velocity in the second layer ranged from 462.00 to 861.00 m/s with a mean value of 597.80 m/s. The S-wave Velocity for the first layer ranged from 250.00 to 363.00 m/s with a mean value of 309.60 m/s. For the second layer, the S-wave Velocity ranged from 325.0 to 552.5m/s with a mean value of 424.60 m/s. The $\frac{V_p}{V_s}$ ratios were generally less than $\sqrt{2}$ in layer one and were slightly greater than $\sqrt{2}$ in some locations in layer two.

(Keywords: seismic refraction, compressional wave, shear wave, Vp/Vs ratio, top-soil)

INTRODUCTION

Seismic refraction method utilizes seismic energy that returns to the surface after travelling through the ground along refracted ray path. This method is normally used to locate refracting interfaces (refractors) separating layers of the different seismic velocities (Keary and Brooks, 1991). Application of seismic refraction method ranges from engineering site investigation surveys to large scale experiments designed to study the structure of the earth, ground search, mineral exploration, and in petroleum exploration. Seismic refraction is employed in the determination of the dynamic elastic modulus of the subsurface layer to obtain information on the elastic properties of that layer.

Many studies have shown that compressional (P) wave velocity (Vp) is below the 330 m/s in the near surface soil. Bachrach *et al*. (1998) found that the P wave velocity of beach sand is lower than 100 m/s. Bachrach and Nur (1998) suggested a quantitative explanation for low P wave velocities for the near surface ground. Baker *et al*. (1999) also observed P wave velocities in the near surface ground lower than the velocity in the air. The seismic velocity ratio (compressional and shear wave velocity ratio, Vp/Vs) is especially sensitive to the fluid in the pores existing in the sedimentary rocks. Particularly, the Vp/Vs ratio in the gas saturated environments is much lower than liquid saturated environments (Tatham, 1982). Pickett (1963) studied on the porous environment for the Vp/Vs ratios, and found about 1.9, 1.8 and 1.6 to 1.75 for limestone, dolomite and sandstones, respectively. In this paper, seismic refraction is used to determine the elastic properties and lithological information as an aid to engineering foundation.

LOCATION AND GEOLOGY OF THE STUDY AREA

The study area, Eket lies between latitudes 4°37′ and 4°7′ N and longitudes 7°38′ and 8°00′ E. It has an estimated area of 214km^2 (Figure1). The study area belongs to the low-lying coastal deltaic plains of southern Nigeria (Emujakporue and Ekine, 2009). The terrain is virtually flat to gently undulating, sloping generally towards the Atlantic Ocean. Elevation varies from about 100 to 120m at the northern part of the study area to near sea level at the southern part (George *et al*, 2010). The surface drainage basin within the study area is mainly due to the Qua Iboe River which drains the western part (Tathan, 1982.).

Geologically, the study area falls within the Niger Delta area. The geologic formation in the Niger Delta area is made up of the Akata Formation (shales, intercalated sands and sandstones), the Agbada Formation (sands and sandstones intercalated with shales) in the middle and the Benin Formation (Coarse grained, gravelly sands with minor intercalations with clay) at the top (Okwueze, 1988). However, only the Benin Formation otherwise called the coastal plain sands is exposed in the study area where the investigation concentrates .The coastal plain sand covers 80 percent of the area and forms the major aquiferous and foundation zones of the study area. The area is generally porous and permeable and this is usually interrupted by clay-sand sequence at different depths (Okwueze, 1991, Ekwueme *et al*, 1985).

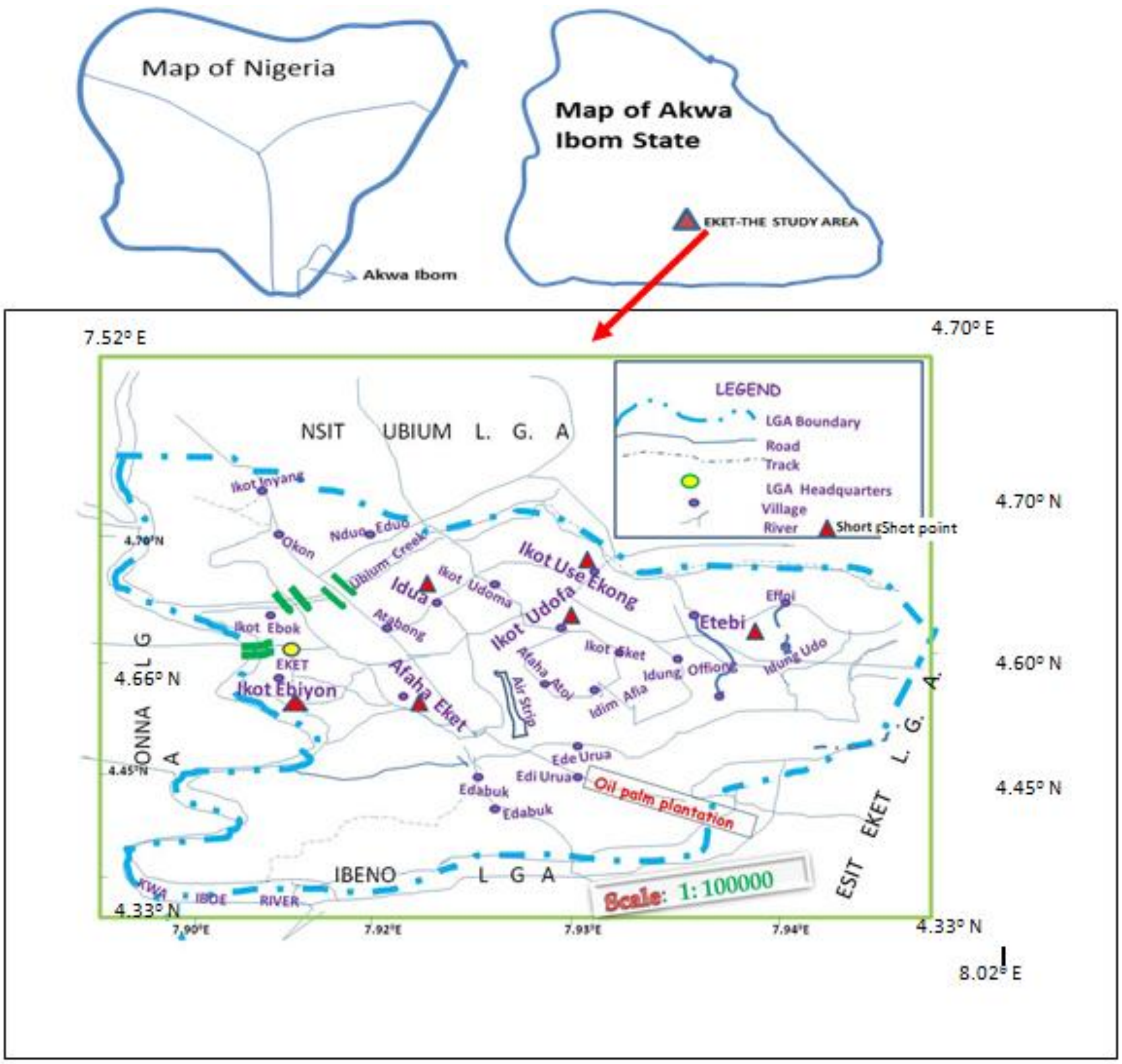

Figure 1: Location Map of Study Area.

METHODOLOGY

The seismic study was based on recording the travel time of an elastic wave traveled through the ground, refracted from a subsurface, and received via geophones on the surface. Seismic P- and S-waves were recorded using vertical and horizontal components geophones (100 Hz), laid along a line with 5 m spacing, and connected to a 12-channel digital recorder.

The required energy for P-wave measurement was created by a sledge hammer hitting the wooden cone at the shot points. The S-wave was created by hitting the ends of a flat-lying wooden timber loaded by a person, the weight of which increases the friction and the contact area of the timber with the ground surface.

The data obtained from the seismograph (seismogram) were processed using Pickwin software to obtain the arrival time for P-wave and S-wave. With the geophone separations of 5m interval, T-X graph were plotted for the different locations using IX Refrax software and the inverse of the slope were obtained as velocity for each of the layer penetrated. The Pick-win software helped in picking the arrival times while the IX Refrax directly converted the slope into Velocity for the different layers. The IX Refrax also gave the depth of each of the layers penetrated (Figures 1 to 12).

RESULTS AND DISCUSSION

Within this geological province, the deduced velocities of the first layer reflect loose soils which are porous and air-filled. In layer two, the geologic description according to the inferred velocities ranges from loose sand (Ikot Udofa) to dry and wet sands mixed with gravels (Idua, Afaha Eket, Ikot Ebiyon, Ikot Use Ekong and Etebi) Table 2. The velocity variations obtained from the T – X plots give the geological implications of the geomaterials.

These interpretations were added by the use of standard velocity values for different geomaterials in Table 2. Although dipping was not significant ($<10^0$), the forward and reverse velocities were averaged in some locations to obtain the mean Velocity in both the P-wave and S-wave velocities and the obtained values are recorded in Table 1.

To actually map the elastic constants which depend on lithology, the V_P/V_S ratio usually viewed as lithology discriminator were determined for each location (Table 1).

For compressional and shear waves, the velocity increases with depth. The underlain Velocities were all greater than the overlain velocities at all the locations. In all the locations, the velocity ranged from 297.00 to 383.00 m/s for the top layer, while the mean value of velocity for the top layer was 355.10 m/s in p-wave.

The range of the second layer P-wave Velocity was 462.00 to 861.00 m/s and the average was 597.80 m/s. The range of S-wave Velocity for the first layer was 250.00 to 363.00 m/s, while the mean value was determined as 309.60 m/s. For the second layer, the Velocity ranged from 325.0 to 552.5m/s and the mean value for S-wave Velocity in this layer was 424.60 m/s. In agreement with the theoretical foundation, the P-wave Velocity was greater than the S-Wave Velocity in all the locations. The elastic parameters are quite sensitive to the $\frac{V_p}{V_s}$ ratio and the variations in its values reflect a high degree of anisotropy.

The IX Refrax software does the determination of depth along with the velocity. Being a two layer case, the depth of the first layers alone was determined in all the locations. The porous and air filled geomaterials of the anisotropic medium seemed to be deepest in Etebi, followed by Ikot Udofa, Idua, Afaha Eket, Ikot Use Ekong and Ikot Ebiyon (Table 1).

The variations in V_p/V_s ratios really have significant effects on the elastic constants that determine the building foundation. Table 1 indicates a significant depth of layers with anisotropic materials. It also shows that the ratio of average V_p and V_s is about 1.5 in the second layers at Idua, Afaha Eket and Ikot Udofia. This result indicates that even up to the second layer the ground has an air-filled porous structure. Additionally, the almost 1.5 V_p/V_s ratio observed in the above locations point to the fact that the ratio of incompressibility is almost unity.

Table 1: Summary of Layer Parameters and Elastic Properties in the Study Area.

Location/ Name	Lat°	Long°	Layer	V_pMean	V_sMean	V_p/V_s	X_{mean}(m)
Idua	4.6760	7.9256	L_1	357.5	303.0	1.1799	9.550
			L_2	563.5	325.0	1.5492	
Afaha Eket	4.6800	7.9145	L_1	350.0	333.5	1.0495	8.050
			L_2	650.0	410.5	1.5834	
Ikot Ebiyon	4.6667	7.9147	L_1	369.5	338.0	1.0932	6.225
			L_2	462.0	439.5	1.0512	
Ikot Use Ekong	4.6636	7.9156	L_1	383.0	270.0	1.4185	7.525
			L_2	509.0	430.5	1.1823	
Ikot Udofa	4.6206	7.9325	L_1	373.5	363.0	1.0289	12.025
			L_2	861.0	552.5	1.5584	
Etebi	4.6125	7.9419	L_1	297.0	250.0	1.1880	13.550
			L_2	541.0	389.5	1.3890	

Table 2: Velocity of Standard Values of Geomaterials
(After Dobrin, 1976; Schephers, 1973 and Mota *et al*, 2006).

Material	V_p (m/s)	V_s(m/s)
+ Loose sand	1800	500
Δ Sand with gravel (dry)	430 – 690	-
Sand with gravel (wet)	690 – 1150	-
∇ Loose soils	180 – 750	-

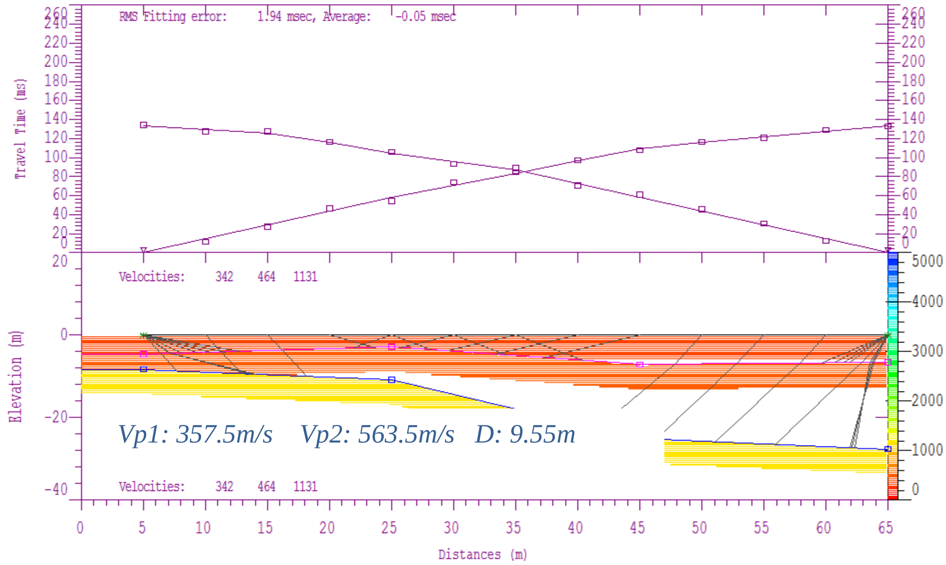

Figure 1: T-X plot of Velocity and Depth Variation for P-wave at Idua (Elevation 12.45m).

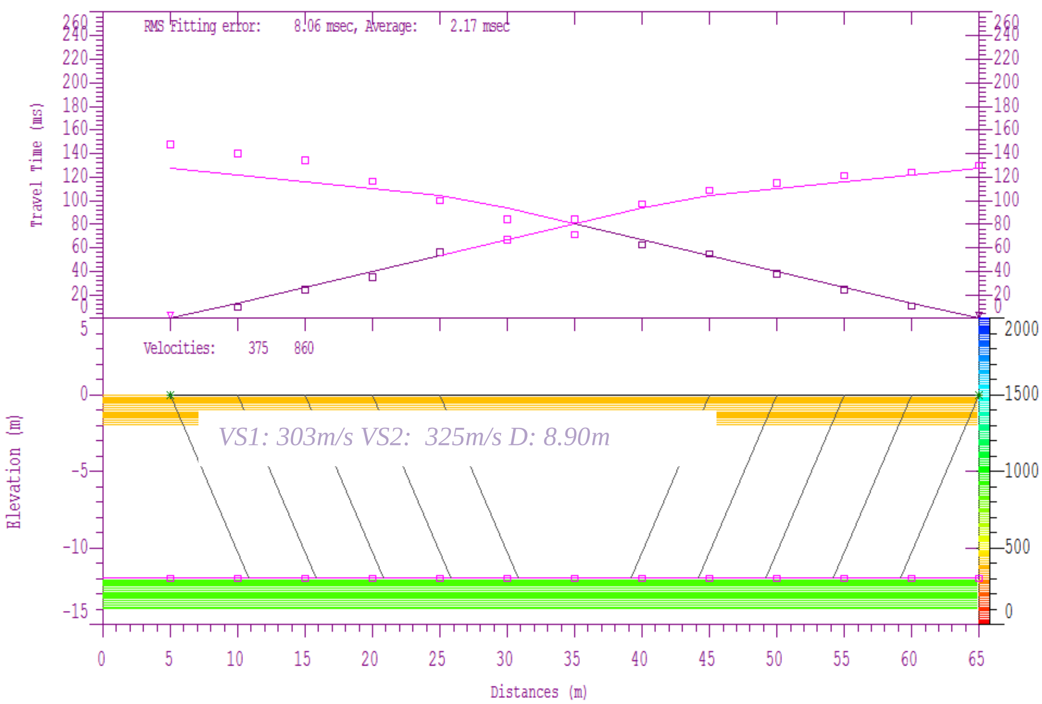

Figure 2: T-X plot of Velocity and Depth Variation for S-wave at Idua (Elevation 12.45m).

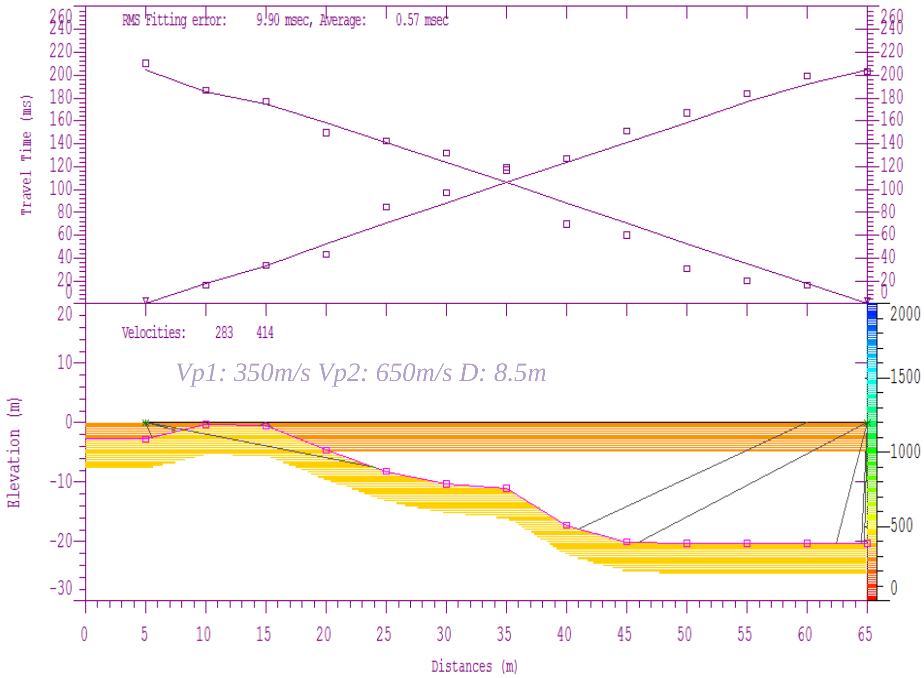

Figure 3: T-X plot of Velocity and Depth Variation for P-wave at Afaha Eket (Elevation 12.43m).

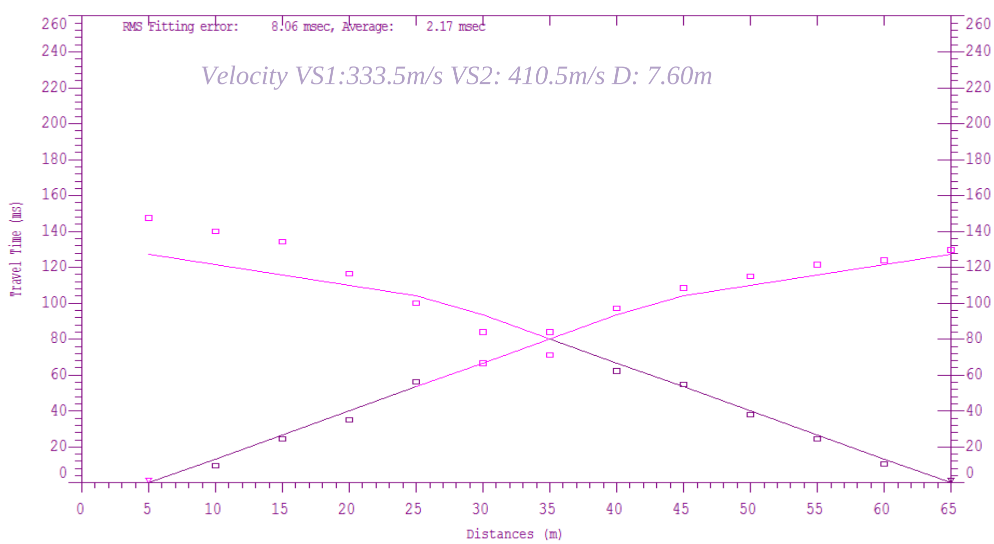

Figure 4: T-X Plot of Velocity and Depth Variation for S-wave at Afaha Eket (Elevation 10.33m).

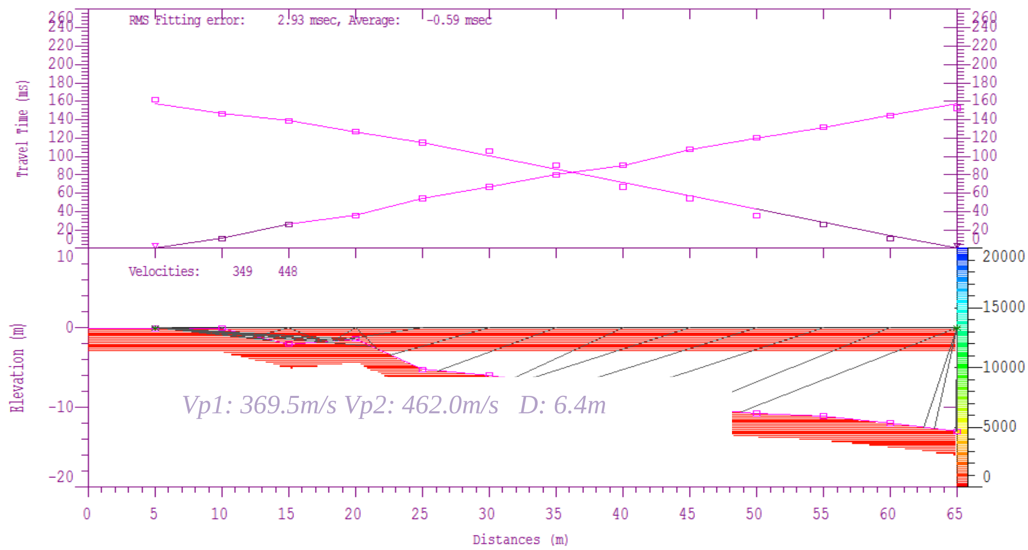

Figure 5: T-X Plot of Velocity and Depth Variation for P-wave at Ikot Ebiyon (Elevation 10.83m).

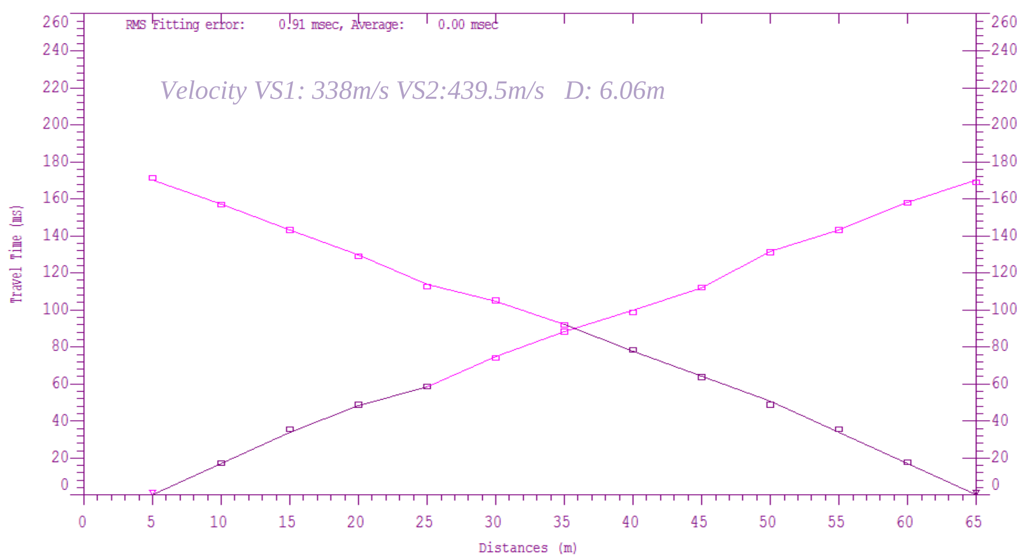

Figure 6: T-X Plot of Velocity and Depth Variation for S-wave at Ikot Ebiyon (Elevation 11.6m).

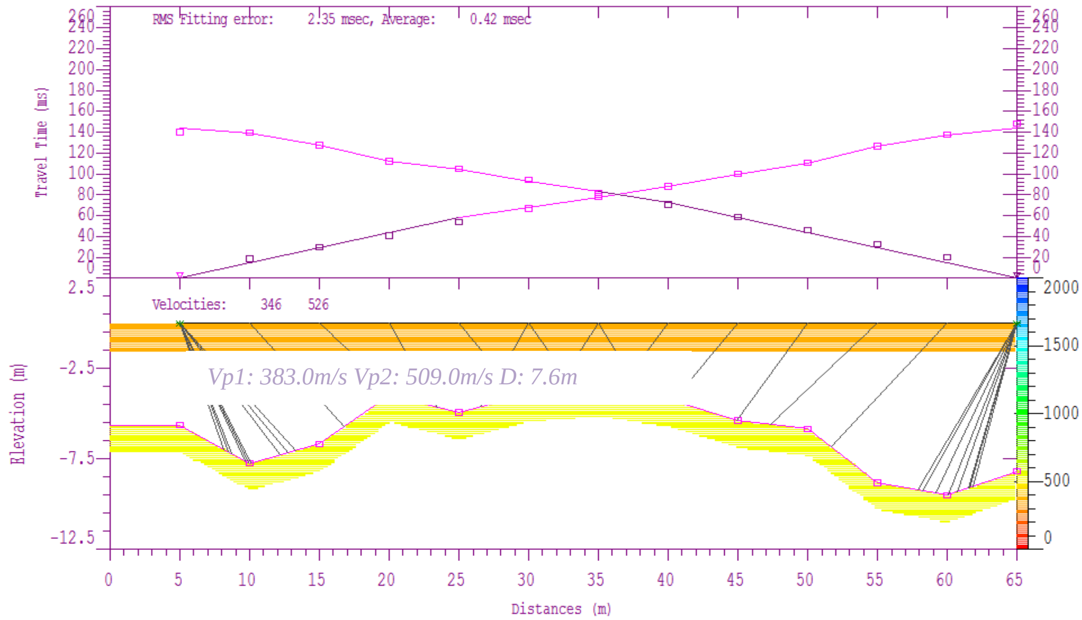

Figure 7: T-X Plot of Velocity and Depth Variation for P-wave at Ikot Use Ekong (Elevation: 13.5m).

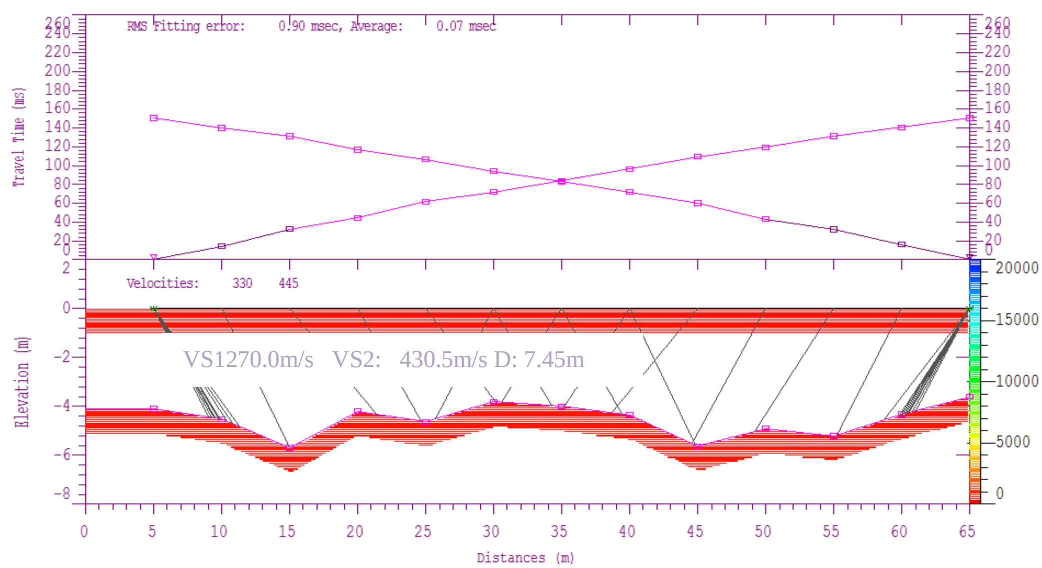

Figure 8: T-X Plot of Velocity and Depth Variation for S-wave at Ikot Use Ekong (Elevation: 14.7m).

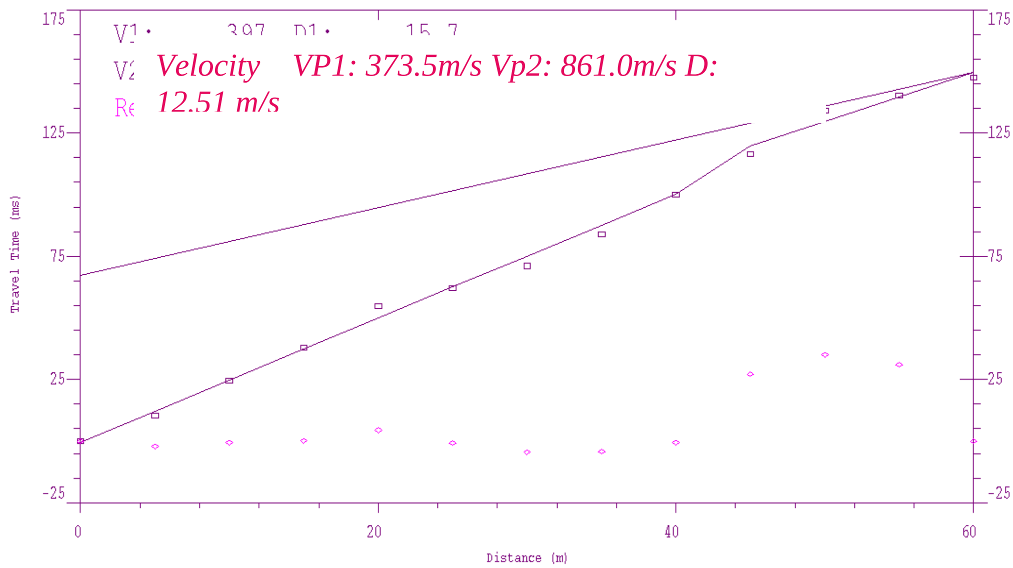

Figure 9: T-X Plot of Velocity and Depth Variation for P-wave at Ikot Udofa (Elevation 15.2m).

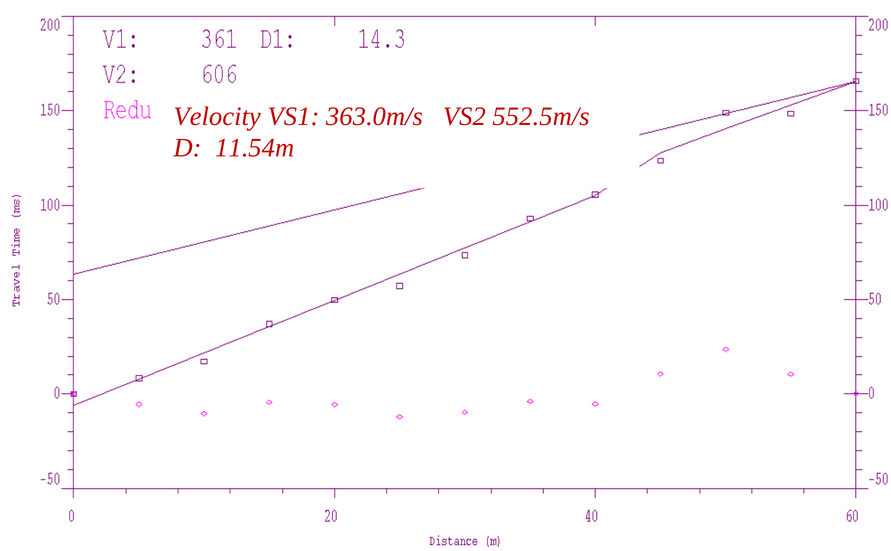

Figure 10: T-X Plot of Velocity and Depth Variation for S-wave at Ikot Udofa (Elevation 15.12m).

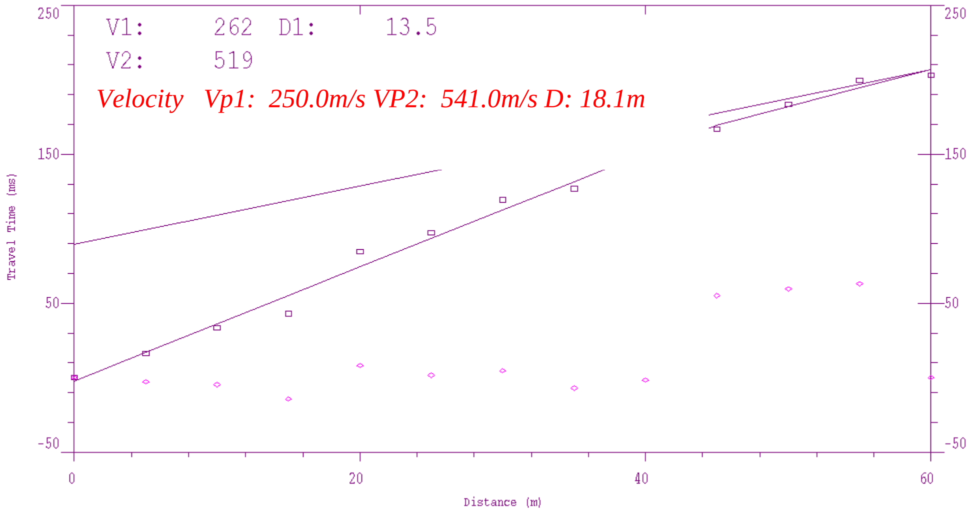

Figure 11: T-X Plot of Velocity and Depth Variation for P-wave at Etebi (Elevation 21.8m).

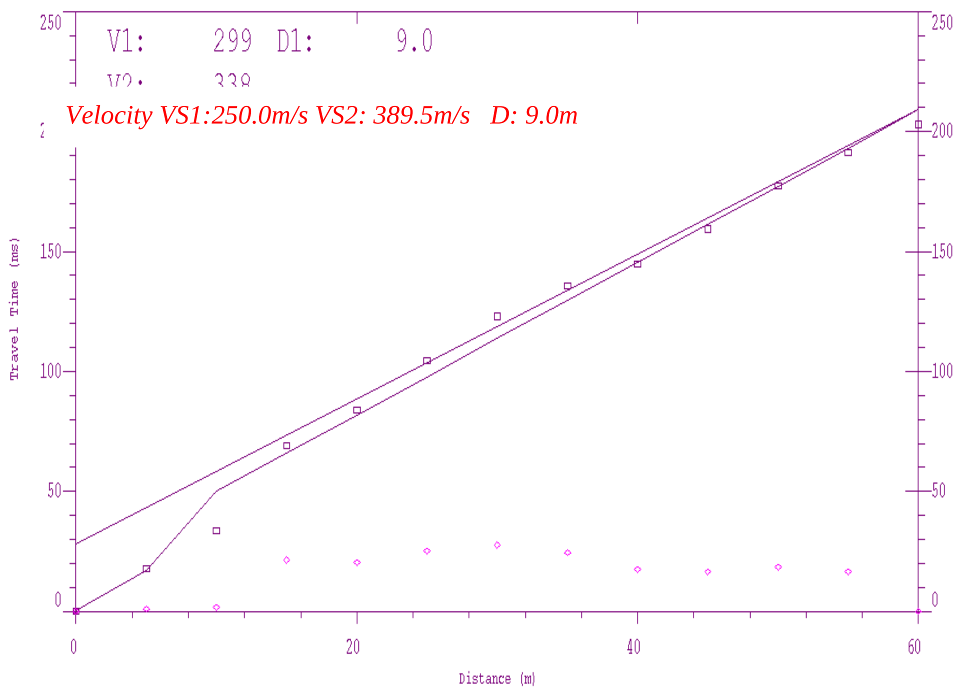

Figure12: T-X Plot of Velocity and Depth Variation for S-wave at Etebi (Elevation: 12.83m).

The parameters in Table 1 were contoured to display the distribution of the geomaterials of the top soil at the indicated depths. The results are displayed in Figures 13 and 14. Specifically, Figs. 13 and 14 are displays of V_s contours for first and second layers respectively. The V_s values seem to be highest at the Southern part of the considered area to both the first and second layers.

These areas correspond to Ikot Ebiyon and Ikot Udofa (Figures 13 and 14). In the Western part of the study area, the V_p values seem to be higher in the first layer. The values of V_p increase from East to West in the first layer (Figure 15). In layer two (Figure 16), the V_p values increase from North to South. The high values in the South are due to the presence of water, the river in this zone (Figure 17).

In terms of the lithology discriminator, the $\frac{V_p}{V_s}$ ratio in the first layer is low in parts of the North and South. However, higher values are seen at the North West of the study area (Figure 18). In the second layer, higher values of the $\frac{V_p}{V_s}$ ratio is obtained in the Northeast and in the Southeastern region of the study area. Higher average depths are seen in the Southeastern region of the study area (Figure 19). This indicates that the region close to Kwa Iboe River should be deeply excavated and refilled with good engineering soil samples for effective engineering foundation.

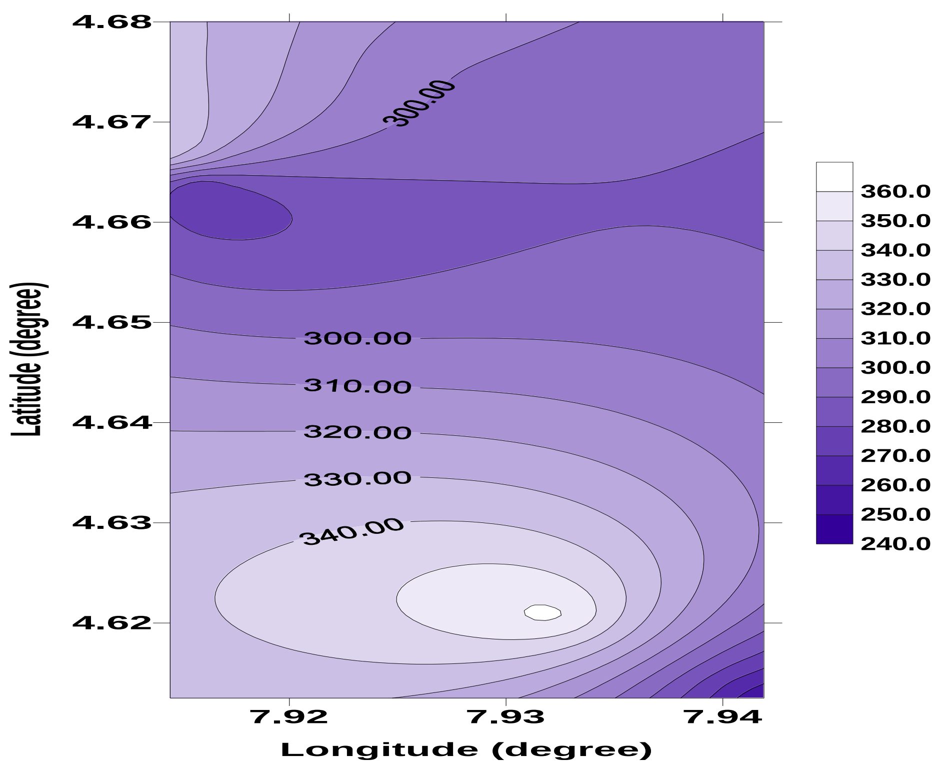

Figure 13: 2-D Contour Map of Layer One Vs in the Study Area.

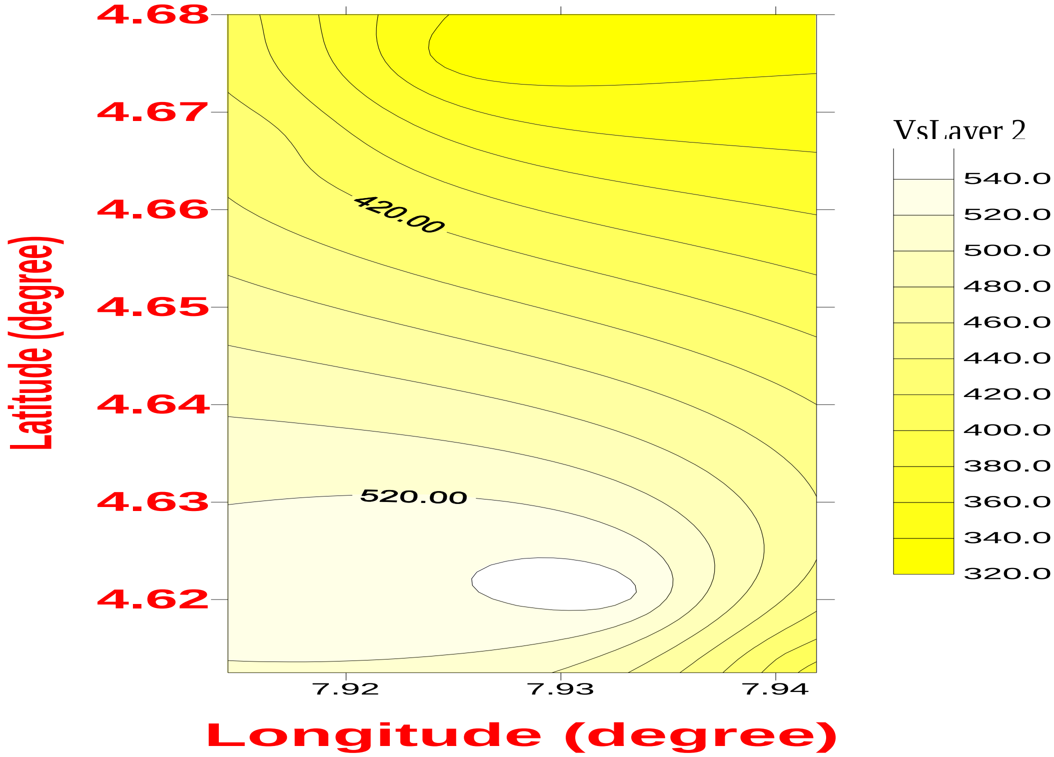

Figure 14: 2-D Contour Map of Layer Two Vs in the Study Area.

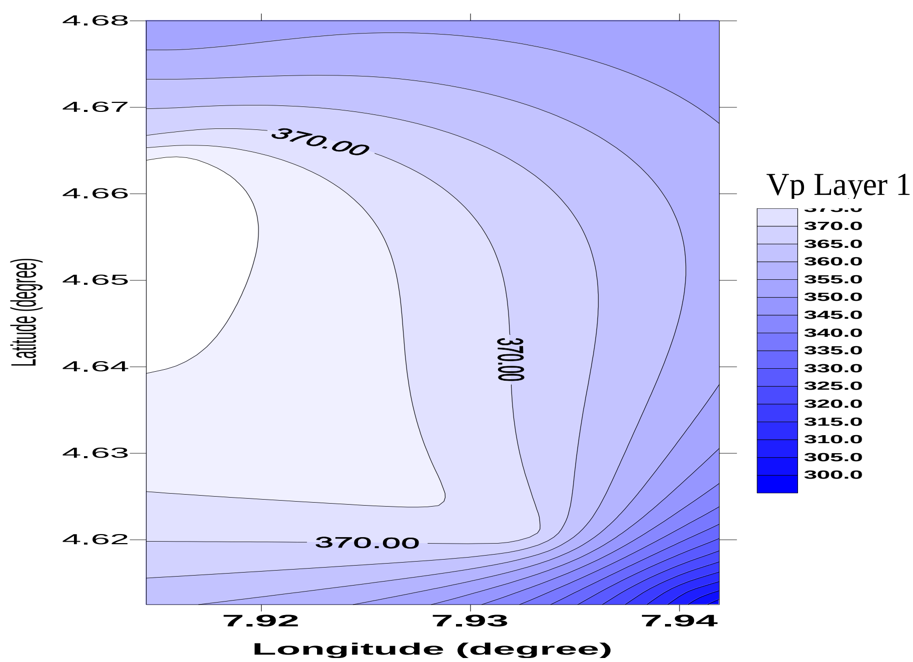

Figure 15: 2-D Contour Map of Layer One Vp in the Study Area.

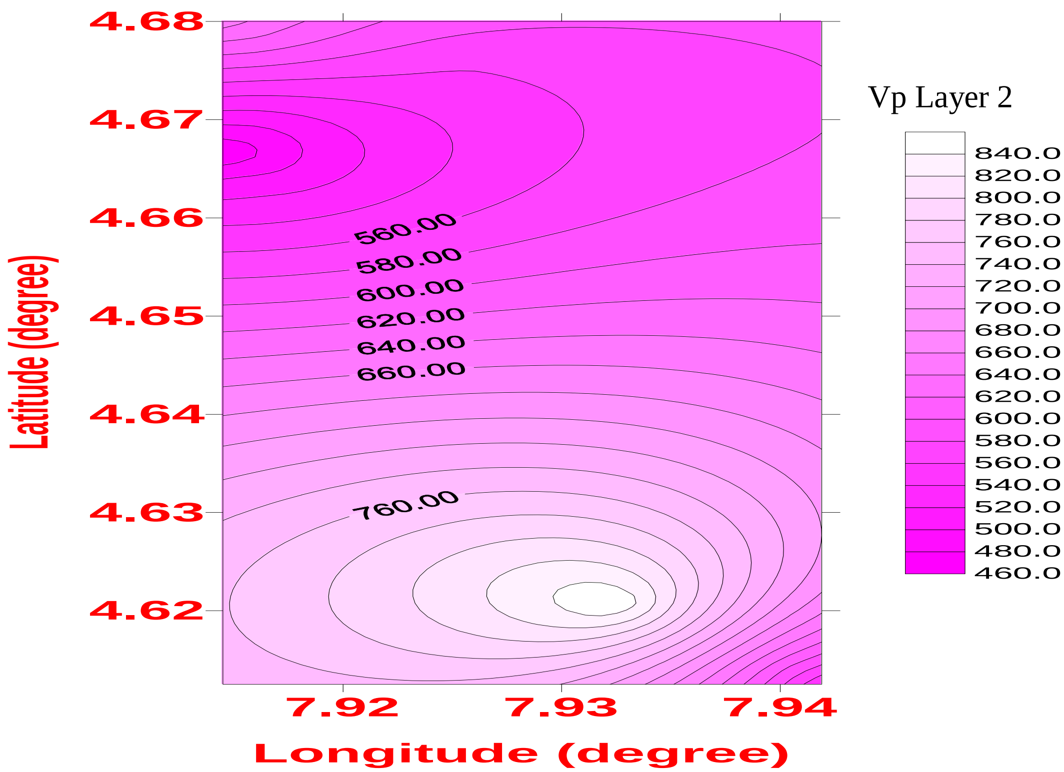

Figure 16: 2-D Contour Map of Layer Two Vp in the Study Area.

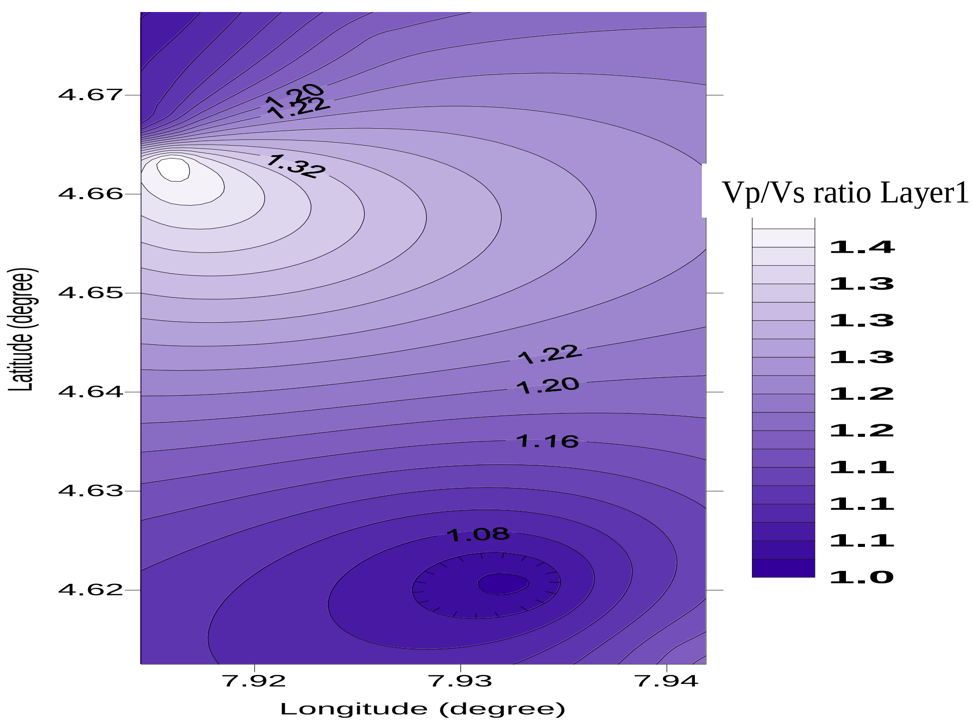

Figure 17: 2-D Contour Map of Layer One Vp/Vs Ratio in the Study Area.

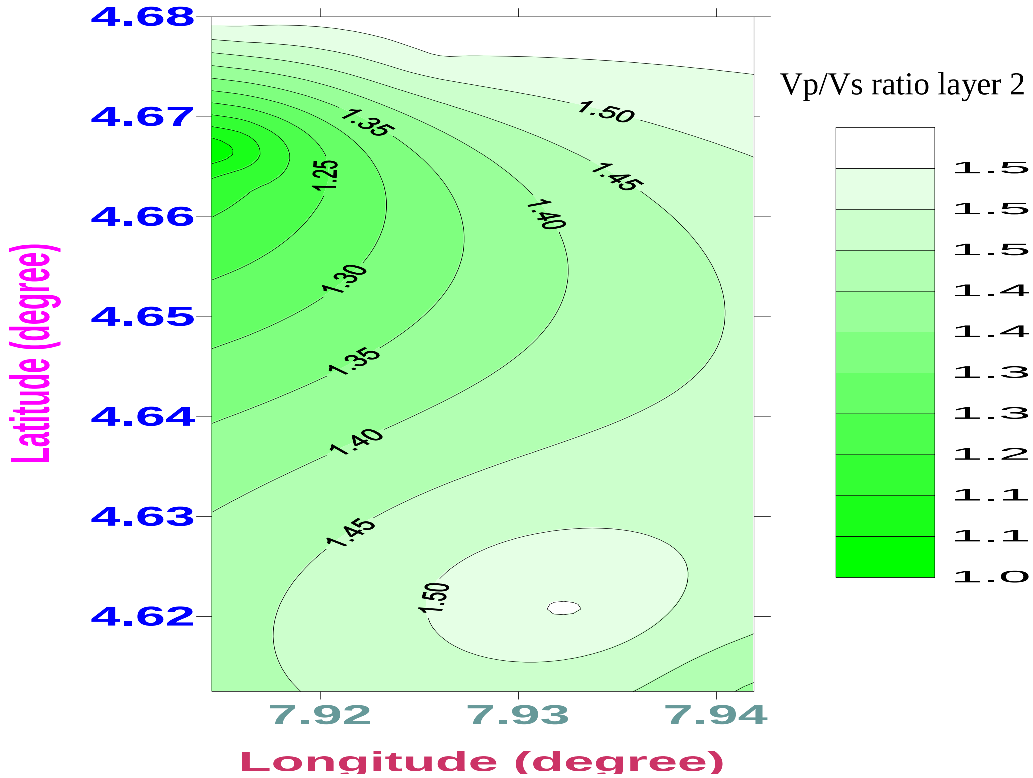

Figure 18: 2-D Contour Map of Layer Two Vp/Vs Ratio in the Study Area.

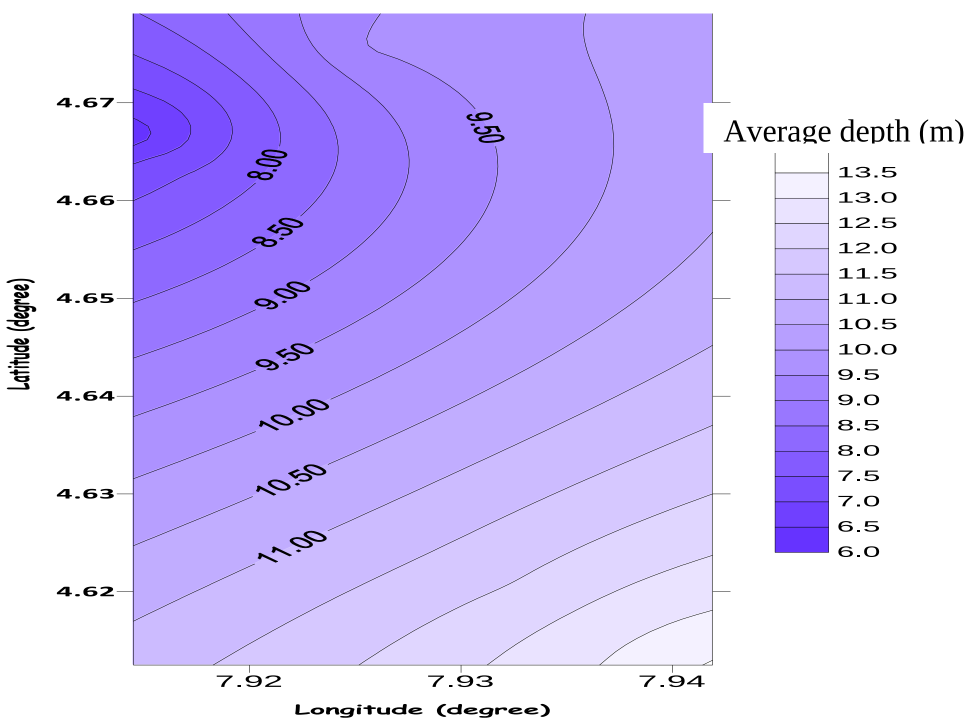

Figure 19: 2-D Contour Map of Average Depth in the Study Area.

CONCLUSION AND RECOMMENDATIONS

Geophysical testing has increasingly been useful and economical since its results can represent the true geological conditions of a geological province. In this study, P and S wave velocities were determined for the top soil of the weathered zone by carrying out seismic refraction survey. Altogether, two layers were penetrated at the maximum geophone separation. These layers are the loamy top soil and the sandy formation.

The measured V_p and V_s were found to increase with depth and in all cases, the V_p was greater than V_s. Due to the coastal nature of the study area, the top layer was found to be a composition of marshy, sandy and argillaceous geomaterials. The V_p values in layer 1 were in some places lower than the velocity of P-wave in air (330m/s) while in some places, they were slightly higher than the P-wave velocity in air. Below the first layer, the second layer was found to have increase in velocity of P-wave. In the first and second layers in S-wave, what is applicable in P-wave is also applicable. A reasonable thickness of the top layer is porous, swampy, air-filled and weak according to the determined velocities. The $\frac{V_p}{V_s}$ ratios were generally less than $\sqrt{2}$ in layer one and were slightly greater than $\sqrt{2}$ in some locations in layer two. Due to possibility of lithologic changes, the use of the top and weathered soil for construction (road and building) should be discouraged. Rather, geophysical and geological information should be the guideline for engineering construction in the study area.

REFERENCES

1. Baker, G.S., D.W. Steeples, and C. Schmeissner. 1999. "*In-situ*, High-frequency P Wave Velocity Measurements within 1 m of the Earth's Surface". *Geophysics*. 64:323-325.

2. Bachrach, R. and A. Nur. 1998. "High-Resolution Shallow Seismic Experiments in Sand, Part I: Water Table, Fluid Flow, and Saturation". *Geophysics*. 63:1225-1233.

3. Dorbin, M.B. 1976. *Introduction to Geophysical Prospecting. 3rd ed*. McGraw-Hill Book Company: New York, NY. 1012-1018.

4. Ekwueme, B.N. and C.A. Onyeagoda. 1985. "Metamorphic Isograds of Uwet Area South East Nigeria". *Journal of African Earth Science*. 3:5-12.

5. Emujakporue, G.O. and A.S. Ekine. 2009. "Determination of Rock Elastic Constants from Compressional and Shear Waves Velocities for Western Niger Delta, Nigeria". *Journal of Applied Science and Environmental Management*. 13:1-5.

6. George, N.J., A.E. Akpan, A.M. George, and I.B. Obot. 2010. "Determination of Elastic Properties of the Overburden Materials in parts of Akamkpa, Southern Nigeria using Seismic Refraction Studies". *Archives of Physics Research*. 1(2):58-71.

7. Kearey, P. and M. Brooks. 1999. *An Introduction to Geophysical Exploration. 2nd Edition*. Blackwell Scientific Publications: London, UK. 22 – 23; 96 – 115.

8. Mota, R., F. Monteiro, and S. Dos. 2006. "2D Sections of Porosity and Water Saturation Percent from combined Resistivity and Seismic Surveys for Hydrogeologic Studies". *International Journal of Physical Science*. 2:3-11.

9. Okwueze, E.E. 1988. "Mapping Bedrock Surface and Lithology with Seismic Refraction". *Journal of Mapping and Geology*. 27(2):3-12.

10. Okwueze, E.E. 1991. "Shear Wave Observation in Seismic Refraction Prospecting". *Journal of Mapping and Geology*. 24(1 and 2): 61 – 65.

11. Pickett, G.R. 1963. "Acoustic Character Logs and their Application in Formation Evaluation". *J. Petr. Tech.* 659-667.

12. Schephers, R. 1975. "A Seismic Reflection Method for Solving Engineering Problems". *Journal of Geophysics*. 41(4):367 – 384.

13. Tathan, R.H. 1982. "Vp/Vs and Lithology". *Geophysics*. 47(3): 336 – 344.

14. Uyanik, O. 2010. "Compressional and Shear-wave Velocity Measurements in Unconsolidated Top-soil and Comparison of the Results". *International Journal of the Physical Sciences*. 5(7):1034-1039

SUGGESTED CITATION

Essien, U.E. and A.O. Akankpo. 2013. "Compressional and Shear-Wave Velocity Measurements in Unconsolidated Top-Soil in Eket, South-eastern Nigeria". *Pacific Journal of Science and Technology*. 14(1):476-491.

Pacific Journal of Science and Technology