

Evaluation of Geotechnical Parameters and Attributes of Amassoma Soil in Bayelsa State, South-south, Nigeria, Using Seismic Refraction Analysis as an Indicator for Its Engineering Strength Determination

ABSTRACT

In this paper, we have carried out analysis of seismic refraction data obtained from two locations around Amassoma and its environs in Bayelsa State, South-South, Central Niger Delta, Nigeria. The core objective of the study was to evaluate the elastic parameters and attributes of the soil and its geotechnical conditions in order to determine its soil strength to carry load. These geophysical parameters and attributes include the p-wave and s-wave velocities, V_p/V_s ratio, dynamic Poisson ratio σ , rigidity modulus μ , bulk incompressibility K , Young's modulus E , lamda-rho (lame's) attribute $\lambda\rho$, K/μ ratio, and E/μ ratio. The layer velocities were obtained as the inverse of the slope of the travel time versus geophone distance curves plotted with the available refraction data, while the layer thicknesses were obtained from the intercepts of the plots. The p-wave and s-wave velocities were used as inputs in various mathematical relations to obtain the elastic moduli and their ratios. The results obtained depict a two-layer model, with the mean p-wave velocities of the layers generally found to lie in the 218m/s - 392m/s range and mean s-wave velocities in the 128m/s - 231m/s range. The V_p/V_s ratio (the lithology discriminator) has values lying between 1.699 and 1.7 and the dynamic Poisson ratio has values between 0.235 and 0.240. The moduli have most of their values above $3.0 \times 10^7 \text{ N/m}^2$ and their ratios are clearly more than unity. Overall, these results show that the topsoil and underlying sediments in the study area which are composed mainly of clay and sandy clay can be described as well consolidated and competent geomaterials that can support foundation structures and loads placed on them. In the final analysis, all the results obtained were found to be in agreement with the values reported in the literature for the Niger Delta and across the globe. The seismic refraction method has therefore been shown in this study as an effective technique for assessing the geotechnical strength of the soil.

KEYWORDS: Geotechnical, parameters, attributes, seismic, refraction, engineering, strength

1.0 INTRODUCTION

In Nigeria, like in other parts of the world, road failures and engineering structure vulnerability may be attributed to inappropriate construction standards, non-compliance with design specifications, poor quality of materials, pressure on structure arising from frequency of use, lack of maintenance culture, and material depreciation. However, field observations and experiments show that vulnerability and failure are not only primarily due to the above factors but can equally arise from lack of adequate information on the geotechnical properties of the soil (Atat et al, 2012; Adiat et al, 2017). Studies clearly show that a low topsoil quality, presence of weak zones in shallow layers, and poor consolidation of geomaterials can contribute significantly to soil instability and subsequent failure of roads and engineering structures (Momoh et al., 2008; Oladapo et al, 2008; Atat et al, 2012). It is therefore essentially compelling that the engineering properties of the soil should first be tested and evaluated before construction commences.

Over the years, geophysical techniques have been largely employed in engineering site investigations to determine the quality of the soil that is intended to carry a load. Where the soil is not investigated or tested to ascertain that it has sufficient engineering strength and bearing capacity, any structure built on it could be vulnerable. Various geophysical techniques have been adopted for this purpose such as the electrical resistivity, electromagnetic and magnetic methods (Adiat et al. 2017), microtremor horizontal/vertical spectral ratio (H/V) and shear-wave test technique (Ferhat and Tazegul, 2011), etc. However, the seismic refraction method remains one of the most efficient and frequently applied surface geophysical techniques for determination of depth to bedrock and for analyzing the geotechnical strength of clastic sediments such as the sedimentary strata of the Niger Delta (Kearey et al, 2003; Papazachos et al, 2005; Emujakporue and Ekine, 2009; Atat et al, 2012). In such geotechnical studies, various elastic parameters have been used to diagnose the soil quality (the subgrade) and the lithologic structure of subsurface layers. These include V_p , V_p/V_s ratio, Poisson ratio σ , the lames constants such as rigidity (*shear modulus*) μ , bulk incompressibility (modulus) K , fluid incompressibility λ , and Young's modulus E .

Atat et al (2012) combined p- and s-wave velocities obtained from seismic refraction analysis to evaluate the elastic properties of the soil in some parts of the south-south region of Nigeria. The values of V_p , V_s , V_p/V_s , Poisson ratio, rigidity and incompressibility they obtained showed that the soil under study was porous, air-filled, anisotropic and had poor engineering strength. Bayo et al (2021) carried out a similar refraction survey in Yenagoa and its environs, South-south, Nigeria and found, based on the quantitative values of the elastic parameters obtained in the study area, that the topsoil was made up of competent geomaterials. In particular, the values of the Poisson ratio they

obtained lie within the 0.25 range and V_p/V_s was within the 1.7 range. These values characterize geomaterials that are classified as competent (Sheriff and Geldart, 1986). Castagna et al (1985), Omudu and Ebeniro (2005) and Nwankwo (2017a) carried out crossplotting of elastic rock properties and attributes for hydrocarbon exploration in rock formations and found that V_p/V_s , Poisson ratio σ , $\lambda\rho$, $\mu\rho$ and $\lambda\rho/\mu\rho$ ratio in addition to p-impedance Z_p , s-impedance Z_s and $P1$ (Poisson impedance) are robust attributes for identifying the lithology of the rock and for separating fluid-filled sand layers from encasing shales. Whereas lamdarho $\lambda\rho$ (the incompressibility modulus) quantitatively detects fluid types in layers, murho $\mu\rho$ (the rigidity modulus) is sensitive to the rock matrix. Interestingly, the crossplots of these attributes are characterized by very low values for gas-filled sand layers. Further studies show that layers with undercompacted shale/clay are weak zones, usually characterized by low velocity, low effective stress and high V_p/V_s ratio (Mukerji et al, 2002; Nwankwo 2017b). Boreholes drilled through such zones or layers are often susceptible to instability, kicks and washout, and may suffer from blowout in the extreme case. These observations in the literature are therefore clear pointers to the fact that elastic rock properties and attributes can be effectively used as indicators of the engineering strength of the soil. Generally, soils must have sufficient bearing capacity or low compliance (both of which are functions of rock attributes) to be able to withstand burdens.

Derivation of the elastic attributes requires V_p and V_s as key parameters. Both V_p and V_s can be derived from recorded compressional and shear waves that have travelled through the ground. As the waves propagate through the ground, part of their energy is reflected at geologic interfaces while some of it travels along boundaries as critically refracted waves (headwaves) before returning to the earth's surface where they are recorded by detectors (geophones). The compressional and shear waves are generated within the near-surface rock when vertical and horizontal external stresses are applied to it such that balanced internal stresses are set up within it. These stresses thus constitute a stress tensor composed of the symmetric part and the anti-symmetric part. The symmetric part corresponds to pure dilation and compression while the anti-symmetric part corresponds to pure rotation or shearing. For as long as the deformation of the rock is small and linearly elastic as is usually the case, the principal and shear stresses can be propagated due to the bulk and tangential strains imparted to the rock. Hence, compressional and shear waves can travel through the rock as body waves and are both useful for seismic acquisition of V_p and V_s .

Amassoma is a geologic environment which is composed of sediments of fluvial and alluvial origin. Such soil type may sometimes be seismically anisotropic which can significantly affect its level of consolidation and elastic strength. It is therefore necessary to investigate, through an appropriate geophysical means, if anisotropy and poor elastic strength exist in the Amassoma soil. However, up till today there is no known geophysical work that has been conducted in Amassoma to evaluate the elastic attributes of its alluvial topsoil and subgrade as a means of assessing its bearing capacity. In this study therefore, we have applied the seismic refraction technique to obtain V_p , while V_s was model-calculated from V_p . With V_p , V_s and density known, the elastic attributes were derived using the appropriate mathematical relationships. The attributes are simple combinations of the rock properties (V_p , V_s , bulk density ρ and porosity ϕ) and are very diagnostic of the strength of the subgrade that has to carry and sustain loads. Overall, we have been able to obtain detailed information on the competence and bearing capacity of the soil through this quantitative seismic refraction investigation. Our expectation is that this paper would contribute to the ongoing efforts towards forestalling road failures and engineering structure vulnerability in the Niger Delta region.

2.0 MATERIALS AND METHOD

2.1 The Study Area

This study was carried out around Amassoma and its environs, a rural and riverine community, in Southern Ijaw Local Government Area of Bayelsa State, South-South, Nigeria. Amassoma lies on longitudes $006^{\circ}06'32''$ and $006^{\circ}06'53''$ and latitudes $04^{\circ}58'23''$ and $04^{\circ}52'25''$ and is located within the central Niger Delta of Nigeria (Fig.1). The community hosts the first and foremost university of the state, the Niger Delta University (NDU), located in Wilberforce Island. It lies about 45km away from Yenagoa, the state capital. The presence of the university in the community has contributed in no small measure in uplifting the economic and social status of the community and its associated environments. Since the inception of the University in 2000, Amassoma has witnessed a steady influx of people from other parts of the country.

Amassoma is located within the Niger Delta sedimentary basin. The ground surface is relatively flat and the sloping is gentle seawards (Okiongbo and Mebine, 2015). The Niger Delta is a tertiary delta situated in equatorial West Africa in the Gulf of Guinea. The delta extends throughout the Niger Delta Province and borders the Atlantic Ocean at the Southern end of Nigeria between latitudes 3° and 6° and longitudes 5° and 8° (Orife and Avbovbo 1982). The underlying sediments of the study area form part of the stratigraphic sequence of the Niger Delta lithology. Reports on the Niger Delta

stratigraphy show that its subsurface lithology is comprised mainly of clay as the topsoil, an upper sandy formation called the Benin Formation, an intermediary unit of alternating sandstone and shale known as the Agbada Formation and a lower shaly formation called the Akata Formation. These three delta facies extend across the whole delta and are typically environments of depositions. The depositions constitute the sequences of subsurface clastic sediments which range in thickness from 9km to 12km (Ofodile, 1992). It is within the Benin Formation containing sediments made up of mainly clay as the topsoil, sandstone as well as some proportions of silt, laterite, and gravel, stacked in strata, that most of the engineering foundations, structures and roads are constructed.

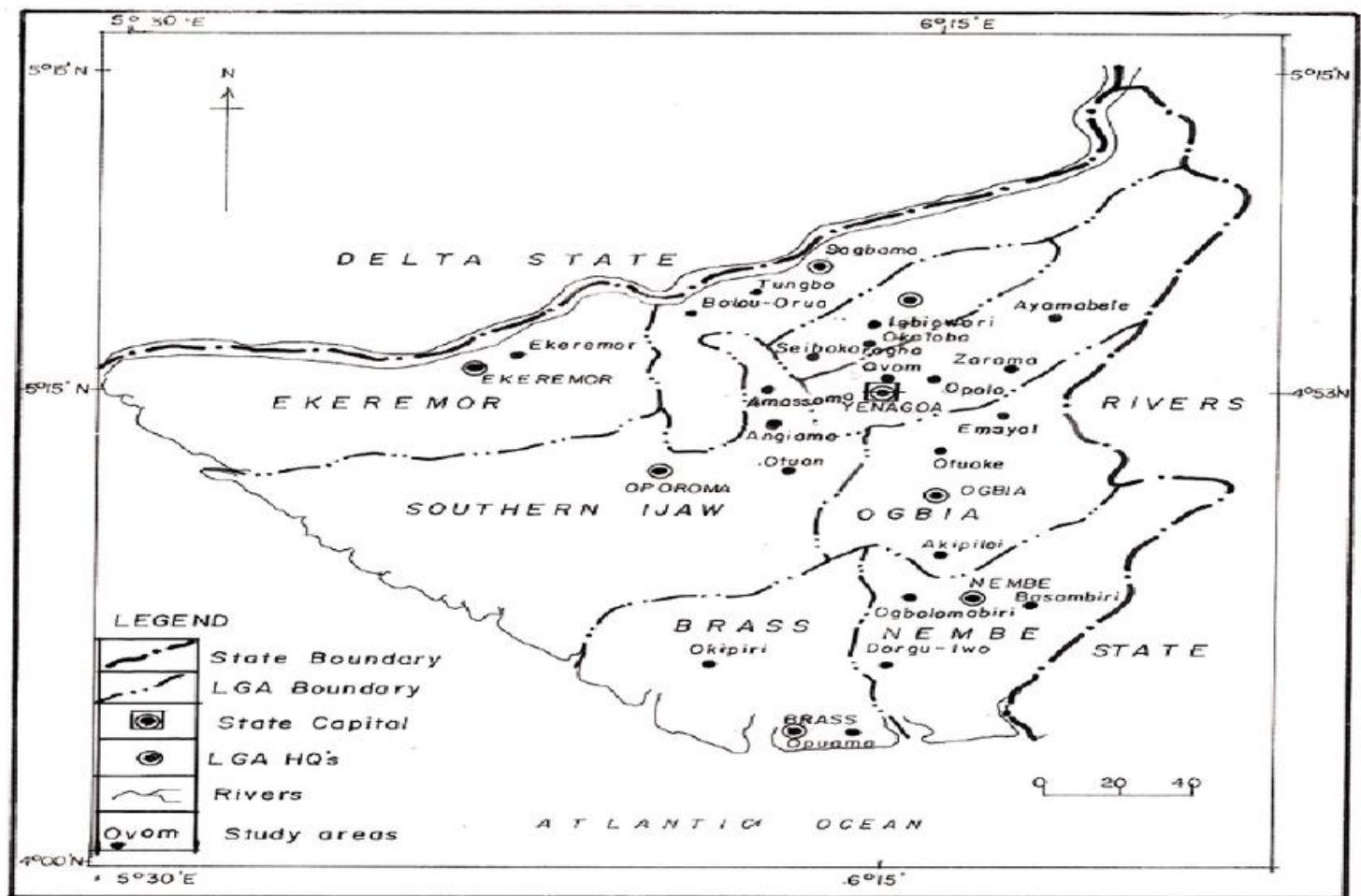


Fig1: Map of Bayelsa State showing Amassoma and its environs (the study area) (Source: Ebiegbere et al, 2013)

2.2 METHOD

A dynamic low strain seismic refraction survey was carried out in order to analyse a two-layer system, which comprises of the topsoil and underlying shallow layer (the overburden). The profile lines each consisted of 12 geophones positioned along a straight line and covered a distance of 85m

from the zero offset shot point. The first geophone was positioned at a distance of 30m from the shot point and a 5m spacing was maintained between the geophones. With the geophones cascaded to a 12-channel Terraloc ABEM Signal Seismograph, the first arrivals were detected and recorded as photographic traces in SEG-2 format. A 16kg sledgehammer and metal plates were used for generating the primary (p-) waves. To generate the waves, the metal plate was struck vertically with the sledge hammer. This strike orientation of the hammer and plate was necessary because the direction of particle vibrations associated with the passage of p-wave is the same as the direction of the wave itself, and thus allows the geophones to detect and pick the p-arrivals. A total of three profiles were shot in two locations – two profiles in the first location and one profile in the second location all within the same study area, with 3-4 stacks recorded for every p-wave shot made. Forward and reverse shots were carried out in each case in order to account for bed dipping.

The seismic refraction data was processed using the ReflexW Version 3.5.7 Software. First, the software was used to pick the first arrivals consisting of direct arrivals and refracted arrivals (Fig. 2 and Fig.3). In typical refraction surveys, the direct waves and critically refracted waves are usually the first arrivals and are picked by the seismometer ahead of other waves. The arrival times of the direct waves from the first layer/topsoil and the refracted waves from the deeper layers vary depending on paths traveled and the layer velocities. After picking the first breaks for all the seismic events, t-x curves (showing graphs of the arrival times against the geophone positions) were plotted. The velocities (V_p) of the homogeneous and isotropic layers were obtained as the inverse of the slope of segments of the curves, while the layer depths/thicknesses were obtained from the intercepts of the seismic plots. For the multi-layer case with n layers, the thickness Z_i of an ith layer can be determined using the travel time intercept for any ray critically refracted along the top surface of the (n+1)th layer. This is given by

$$t_n = \frac{x}{V_n} + \sum_{i=1}^{n-1} 2Z_i \sqrt{V_n^2 - V_i^2} \frac{1}{V_n V_i} \quad (1)$$

where x is the geophone distance and V_n , V_i are the appropriate input velocities.

With V_p obtained from the seismic refraction analysis, the V_s was model-calculated from V_p as given by Adewoyin et al (2017) using the linear regression equation

$$V_p = 1.7V_s \quad (2)$$

The values of V_p , V_s and bulk densities ρ of the layers are required for computation of the elastic attributes using appropriate relations. However, the bulk density data for layers are not always available from a seismic refraction survey but may be derived analytically from its relationship with V_p , given by

$$\rho = 0.31V_p^{0.25} \quad (3)$$

where, for Equation (3), the bulk density is measured in g/cm^3 when V_p is in m/s. Equation (3) is the familiar Gardener's relation. The elastic attributes of interest in this study are the Poisson ratio σ , V_p/V_s ratio, Young's modulus E , bulk modulus (incompressibility) K , fluid modulus (incompressibility) λ , and shear modulus (rigidity) μ . They characterize the soil and indicate its elastic strength. The Poisson ratio, which depends only V_p and V_s and is independent of density, may be expressed as

$$\sigma = \frac{[(V_p/V_s)^2 - 2]}{[2(V_p/V_s)^2 - 2]} \quad (4a)$$

$$\text{or } \sigma = 0.5 \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{\left(\frac{V_p}{V_s}\right)^2 - 1} \quad (4b)$$

Equation (4a or b) gives V_p/V_s ratio as

$$\frac{V_p}{V_s} = \left(\frac{2(1 - \sigma)}{1 - 2\sigma} \right)^{1/2} \quad (5)$$

The dimensionless dynamic Poisson ratio defines the soil's measure of resistance to longitudinal and lateral strain due to the application of a stretching force. Thus, the Poisson ratio and by extension V_p/V_s are both indicative of the soil's degree of consolidation. A value of Poisson ratio typically of about 0.25 represents a consolidated soil. This value gives a V_p/V_s ratio of 1.7. Generally values of V_p/V_s above 2.0 or Poisson ratio of values more than 0.25 are indicative of soils that are poorly consolidated and incompetent. On the other hand, values of V_p/V_s ratio below 2.0 or Poisson ratio of value 0.25 or less is characteristic of hard rocks and soils that are well consolidated and competent (Sheriff and Gedart, 1986). Studies reported in the literature interestingly show that Poisson ratio has its maximum value of 0.5 for liquids and drops significantly from a value of about 0.4 to 0.1 when water in unconsolidated sandstone pores or cracks is replaced with gas or air (Gardner and Harris, 1968; Domenico, 1976; Kearey et al, 2003). Therefore, sediments characterized by the Poisson ratio

of about 0.1 are unconsolidated and are made up of gas- or air-filled pores. Furthermore, V_p/V_s of values less than $\sqrt{2}$ requires a negative Poisson ratio and indicates a soil that is anisotropic, porous and air-filled (Love 1927; Atat et al. 2012). In geotechnical context, such sediments represent the vulnerable zones since the bulk of the soil becomes compressible or compliant due to the gas or air presence.

The shear modulus μ is mathematically related to V_s and density ρ by

$$V_s = \sqrt{\frac{\mu}{\rho}} \quad (6)$$

so that: $\mu = V_s^2 \rho$ (7)

The bulk modulus K can be obtained from V_p , μ and ρ using

$$V_p = \sqrt{\frac{k + \frac{4\mu}{3}}{\rho}} \quad (8)$$

Whereas the shear modulus μ indicates a measure of the rigidity or shear strength of the soil (the strength of its solid (matrix) component), the bulk incompressibility reveals its bulk or volumetric strength (a measure of its tendency to resist a deformation of its bulk volume). Equation (8) can be further transposed to reveal fluid presence within a layer. This is represented by the fluid term, λ , also known as the fluid incompressibility. It is sensitive to the contained pore fluids in rocks with the lowest values for gas. The presence of fluid saturant, especially gas, weakens the soil. The fluid incompressibility λ may be obtained from the relation

$$V_p = \sqrt{\frac{\lambda + \frac{2\mu}{3}}{\rho}} \quad (9)$$

Equation (9) allows us to derive the fluid modulus (lamdarho) $\lambda\rho$ which is very sensitive to the presence of fluid in a weak porous soil. This is given by

$$\lambda\rho = V_p^2 \rho^2 - c V_s^2 \rho^2 \quad (10)$$

where c is a constant (the discriminant) which has been assigned a characteristic value of 2.0 to account for the clastic sediments of the Niger Delta.

Like the Poisson ratio, there is a correspondence between the ratio K/μ and the velocity ratio V_p/V_s (Tatham ,1982). This correspondence facilitates determination of K , μ , K/μ ratio from known values of Poisson ratio and V_p/V_s . The bulk modulus K may be obtained from Poisson ratio σ and rigidity modulus μ using the Dorbin's (1988) correspondence equation, given by

$$K = \frac{2\mu(1+\sigma)}{3(1-2\sigma)} \quad (11)$$

$$\text{or } \frac{K}{\mu} = \frac{2(1+\sigma)}{(1-2\sigma)} - \frac{4}{3} \quad (12)$$

With V_p/V_s known, the K/μ ratio is given by:

$$K/\mu = \left(\frac{V_p}{V_s}\right)^2 - \left(\frac{4}{3}\right) \quad (13)$$

while the Young's modulus E is related to Poisson ratio and rigidity modulus by

$$E = 2\mu(1+\sigma) \quad (14)$$

$$\text{such that } E/\mu = 2(1+\sigma) \quad (15)$$

In terms of V_p/V_s , we have:

$$E/\mu = \frac{\left(\frac{3V_p}{V_s}\right)^2 - 4}{\left(\frac{V_p}{V_s}\right)^2 - 1} \quad (16)$$

The reciprocal of K gives the compressibility or level of compliance of the soil while the reciprocal of E determines its bearing capacity. Thus, the elastic parameters $1/K$ and $1/E$ in addition to K/μ and E/μ ratios are robust parameters that give an idea of the vulnerability of the soil. Generally, soils with high compliance or low bearing capacity have poor engineering strength and therefore vulnerable. They are characterized by a low plastic yield point beyond which they snap or fracture.

In our overall analysis, the rock properties (V_p , V_s) in addition to their attributes - σ , V_p/V_s , μ , K , E , $\lambda\rho$, K/μ , and E/μ - have been quantitatively assessed and interpreted to determine if the soil under study has sufficient engineering strength to withstand burdens.

3.0 RESULTS

Figures 2 and 3 are the typical seismograms generated from processing of the field data. Figure 2 shows the seismograms for the forward and reverse shots for the profiles in the first location while Figure 3 shows the forward and reverse seismograms obtained from the second location within the same study area. The first arrivals were picked from the seismograms using the ReflexW Version 3.5.7 Software.

Figures 4 and 5 are the t-x plots for the two profiles in the first location, while Fig.6 is the t-x plot for the profile shot in the second location within the study area.

Table 1 shows the quantitative values of the elastic properties and attributes we obtained from the various mathematical relations, giving us clear information on the engineering strength of the soil. Table 2 obtained from Sheriff and Geldart (1986) and Bayo et al (2021), enabled us to determine the competence of the geomaterial of the topsoil in the study area.

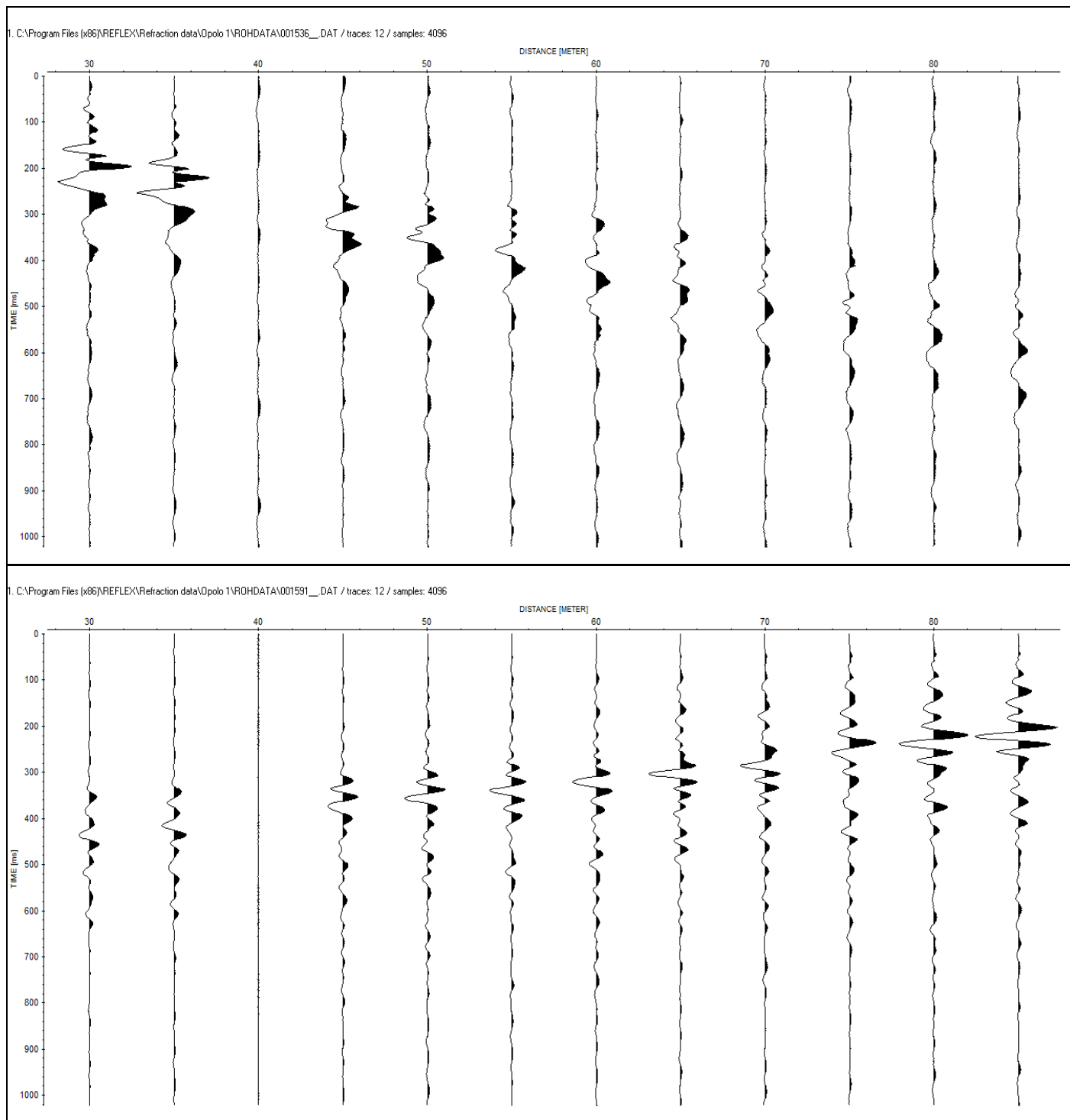


Fig2: The seismogram obtained for the forward and reverse shots representing Profile 001536 in the first location of the study area

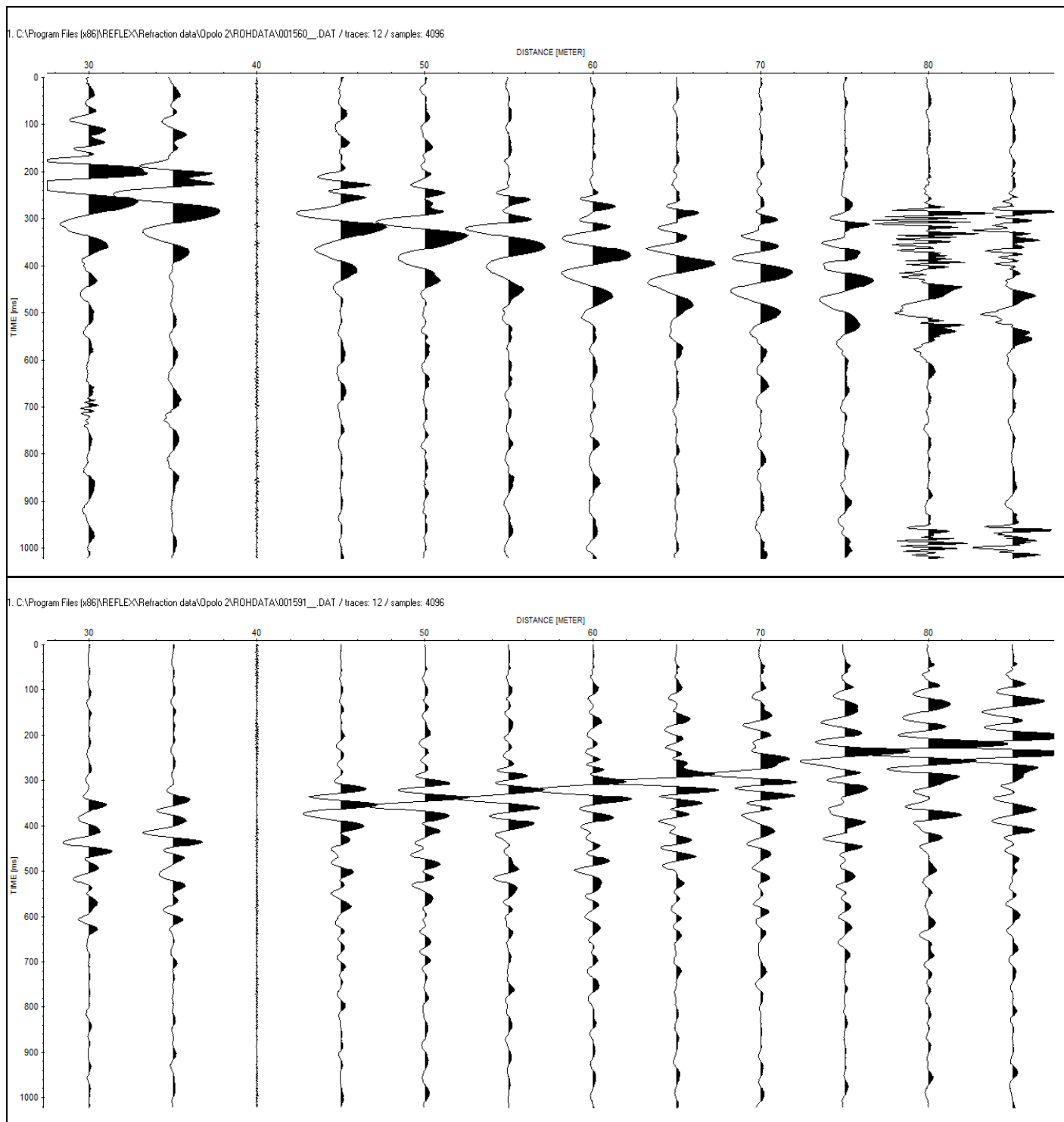


Fig3: The seismogram obtained for the forward and reverse shots for Profile 001569 in the second location within the study area.

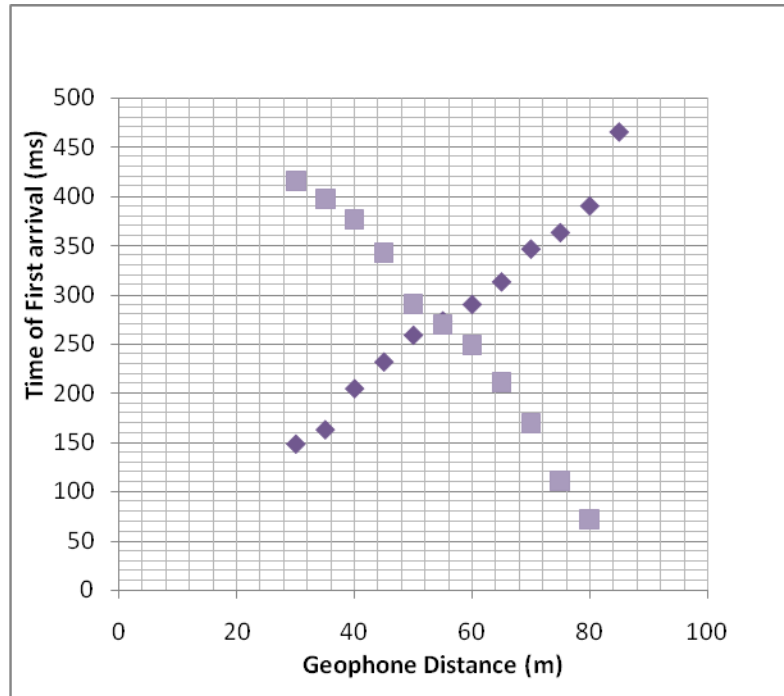


Fig4: Travel time- geophone distance (t-x) plot for the first profile in the first location of the study area

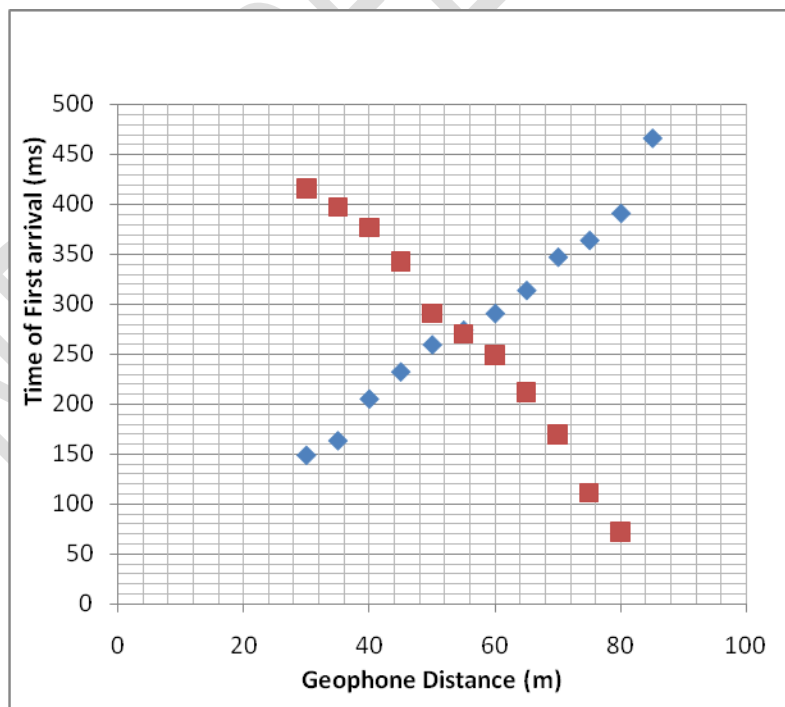


Fig5: Travel time-geophone distance (t-x) plot for the second profile in the first location of the study area

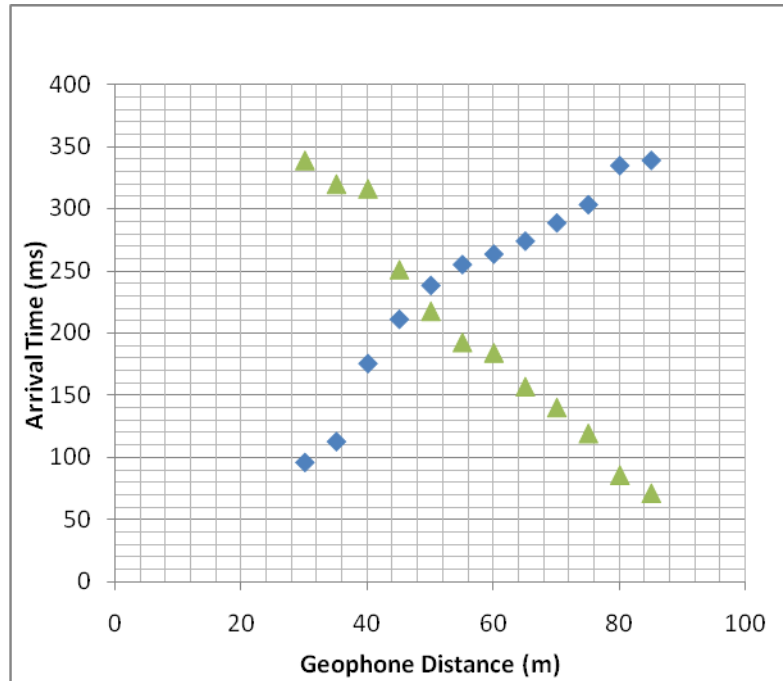


Fig6: Travel time-geophone distance (t-x) plot for the profile in the second location of the study area

Table1: Values of elastic parameters and attributes

	Mean Thick- ness (m)	Mean Vp (m/s)	Mean Vs (m/s)	Vp/Vs Ratio	Poisson Ratio σ	Rigidity μ ($\times 10^7$ Pa)	Bulk Modulus K ($\times 10^7$ Pa)	Young's Modulus E ($\times 10^7$ Pa)	K/ μ	E/ μ	Lame's Attribute $\lambda\rho$ ($\times 10^{10}$ Pa $\times \text{kg/m}^3$)
Profile A001536 Location1											
Layer 1	10.3	218	128.0	1.70	0.240	1.95	3.04	4.84	1.5 6	2.482	2.09
Layer 2	11.8	226	132.9	1.70	0.240	2.12	3.31	5.26	1.5 6	2.481	2.28
Profile B001560 Location 1											
Layer 1	3.0	229	134.7	1.70	0.240	2.20	3.43	5.46	1.5 60	2.482	2.35
Layer 2	10.6	392	230.6	1.699	0.235	7.34	11.40	18.13	1.5 53	2.470	9.01
Profile A001569 Location 2											
Layer 1	6.0	266	156.5	1.699	0.235	3.06	4.75	7.56	1.5 53	2.471	3.42
Layer 2	17.1	374	220.0	1.70	0.240	6.6	10.30	16.37	1.5 60	2.480	8.01

Table 2: Description of Soil Strength/Competence in Terms of Poisson Ratio (Sheriff and Geldart, 1986)

Soil Description Parameter	Competent to slightly competent	Fairly to moderately competent	Competent materials	Very high competent materials
Poisson Ratio σ	0.4-0.49	0.35 – 0.27	0.25 – 0.16	0.12 – 0.03

4.0 DISCUSSION OF RESULTS

The results obtained from the data as depicted in Table 1 show a two-layer system/model. The limitation in depth of penetration must have resulted from the low energy source used or profile distance deployed but satisfactorily serves the purpose of this geotechnical study. The results show the velocity of the layers increasing with depth mainly due to compaction effect and variation in the compositions of the subsurface lithology (Kearey et al, 2003). In the first location, the p- wave velocity of the first layer varies from 202 – 234 m/s with a mean velocity of 218m/s for the first profile and from 224-236m/s with a mean of 229m/s for the second profile. The s-wave velocity varies from 118-138m/s with an average of 128m/s and from 132-139 with an average of 135m/s. The layer has a mean thickness of 10m and 3m for the first and second profile respectively. In the second layer, the p-wave velocity varies from 194-289m/s with a mean of 226m/s with respect to the first profile and from 299-512 m/s with a mean of 392m/s in respect of the second profile. The s- wave velocity varies from 114 -170m/s with an average of 133m/s and from 176 - 301m/s with an average of 231m/s. The second layer has a mean thickness of 11.8m and 10.6m for the first and second profile respectively. In the second location, the mean p-wave velocity lies within 266m/s for the first layer and 374m/s for the second layer, while the mean s-wave velocity has a value of 157m/s for the first layer and 220m/s for the second layer. The first and second layers have mean thicknesses of 6.03m and 17.08m respectively. The values of the p-wave velocities are linearly higher than the s-wave velocities across the two locations, arising from the correlation between p-wave velocity and s-wave velocity (Castagna et al, 1985). The p-wave and s-wave velocities have been found to be in semblance across the locations within the study area, with slight differences in the values most likely due to lateral variations in lithology composition. The values of p-wave and s-wave velocities obtained in this study are also consistent with the values of velocities obtained by Atat et al (2012), Nwankwo et al. (2013) and Bayo et al .(2021) from refraction analyses carried out in their previous works in the eastern and central Niger Delta.

In respect of V_p/V_s and Poisson ratios, we obtained a mean value between 1.699 and 1.7 for layers 1 and 2 across the two locations. By extension, this gives Poisson ratio values of about 0.235 to 0.24. The topsoil and the underlying second layer can be described as made up of hard and competent geomaterial that can sustain loads placed on them. This is a consistent result. Observations from many laboratory and experimental studies show that soils, rocks and geomaterials with V_p/V_s and Poisson ratios within the range of 1.7 and 0.24 and below are well consolidated and competent (Gardner and Harris, 1968; Domenico, 1976; Sheriff and Geldart, 1986). Atat et al (2012) carried out

p-wave and s-wave seismic refraction study in some parts of Akwa Ibom state, eastern Niger Delta in order to determine the elastic parameters in the area. They found, based on their results, that most parts of the study area were characterized by porous and weak air-filled topsoil with V_p/V_s having a value less than $\sqrt{2}$, and a negative Poisson ratio, showing anisotropy of the soil. However, traversing away from the area with the weak porous topsoil, some locations were found to be characterised by V_p/V_s ratio of about 1.7 and Poisson ratio of 0.235. These locations were reported by the authors as having a consolidated and competent topsoil that can support loads. This also supports the fact that the engineering strength or vulnerability of the soil varies laterally from one location to another. Similarly, the seismic refraction survey carried out by Bayo et al. (2021) around Yenagoa in Bayelsa State, central Niger Delta, reveals the topsoil to be made up of well consolidated and competent geomaterials. They found that Poisson ratio around Yenagoa lies between 0.232 and 0.239, 0.234 and 0.235 and between 0.235 and 0.242 across the sites surveyed. Our results are therefore in agreement with the values reported in the literature for the Niger Delta and across the globe.

In terms of the elastic constants and attributes, in the first location we found the mean rigidity of the topsoil to lie between 1.95×10^7 and $2.20 \times 10^7 \text{ N/m}^2$ and that of the second layer to lie between 2.12×10^7 and $7.34 \times 10^7 \text{ N/m}^2$. In the second location, the rigidity μ has a mean value of $3.06 \times 10^7 \text{ N/m}^2$ in the first layer and $6.6 \times 10^7 \text{ N/m}^2$ in the second layer. In the first location, the bulk modulus K has a mean value of between 3.04×10^7 and $3.43 \times 10^7 \text{ N/m}^2$ in the first layer, and between 3.31×10^7 and $11.40 \times 10^7 \text{ N/m}^2$ in the second layer. In the second location, K has a mean value of 4.75×10^7 and $10.30 \times 10^7 \text{ N/m}^2$. Furthermore, in the first location, the value of the Young's modulus E lies between 4.84×10^7 and $5.46 \times 10^7 \text{ N/m}^2$ in the first layer and between 5.26×10^7 and $18.13 \times 10^7 \text{ N/m}^2$ in the second layer for the two profiles surveyed. In the second location, E has a mean value of $7.56 \times 10^7 \text{ N/m}^2$ in the first layer and $16.37 \times 10^7 \text{ N/m}^2$ in the second layer. The modulus/incompressibility ratio K/μ is clearly higher than unity in the first and second layers across the locations, with values ranging from 1.55 to 1.56. The E/μ ratio in the first and second layers across the locations follows the same trend, with values ranging from 2.47 to 2.48. The high and positive values of the elastic moduli and the fact that their ratios K/μ and E/μ are more than unity clearly show that the topsoil and underlying sediments in the study area are not porous, air-filled, and weak but can be classified as rigid, non-compliant, and having high bearing capacity that can sustain burdens. Values of unity or less for the ratios indicate the presence of air in the soil, which weakens the soil considerably. Again, the values of the moduli and their ratios reported in this study

are consistent and comparable to the values obtained from the seismic refraction analyses carried out by Bayo et al (2021) around the same study area.

Finally, the lamdarho (Lame's attribute) $\lambda\rho$ is sensitive to the presence of fluid especially gas in weak porous media. Values of $\lambda\rho$ obtained across the two locations in the first and second layers lie between 2.09×10^{10} and 9.01×10^{10} Pa x kg/m³. These values are reasonably high and show that the topsoil is not air-filled or compliant and has sufficient bearing capacity.

5.0 CONCLUSION

In this paper, we have carried out analysis of seismic refraction data obtained from two locations within the same study area located around Amassoma and its environs in Bayelsa State, South-South, Central Niger Delta, Nigeria. From our analysis, we have presented values of the seismic p-wave and s-wave velocities, V_p/V_s (velocity ratio), dynamic Poisson ratio, elastic moduli and attributes as well as the ratios of the various moduli. The air-sensitive lamda-rho attribute has also been presented. The values obtained clearly indicate that the topsoil and underlying sediments in this part of the Niger Delta (composed mainly of clay and sandy clay) are competent, has high bearing capacity and sufficient engineering strength to support foundation structures or loads that may be placed on them. Furthermore, provided required engineering standards are not compromised, roads constructed on this section of the soil will not be vulnerable. From our results, we have further supported the fact that elastic parameters and attributes can be obtained from seismic refraction method as a way of assessing the geotechnical conditions of the soil for engineering construction purposes.

REFERENCES

- Adewoyin OO, Joshua HO, Akinwumi II, Omejel M, Joel ES (2017). Evaluation of geotechnical parameters using geophysical data. *J. Eng. Technol. Sci.* 49(1):95-113
- Adiat KAN, Akinlalu AA, Adegoroye A.A (2017). Evaluation of road failure vulnerability section through integrated geophysical and geotechnical studies. *NRIAG Journal of Astronomy and Geophysics*, 6:1, 244-255
- Allen JRL (1965). Late quaternary Niger Delta and adjacent areas: sedimentary environments and lithofacies: *Bulletin AAPG*, 48: 547-600

Atat JG, Akpabio GT, George NJ, Umoreu EB (2012). Geophysical assessment of elastic constants of topsoil using seismic refraction compressional and shear wave velocities in the Eastern Niger Delta, Nigeria. *International Journal of Modern Applied Physics* 1(2): 7-12

Bayo AR, Okiongbo KS, Sorronadi-Ononiwu GC (2021). Determination of elastic moduli and bearing capacity of sediments using geophysical and cone penetration test techniques in Yenagoa, Southern Nigeria. *NRIAG Journal of Astronomy and Geophysics* 10:1-17

Castagna JP, Batzle MI, Eastwood RI (1985). Relationship between compressional and shear wave velocities in clastic silicate rocks. *Geophysics* 50:571-581

Castagna JP, Batzle ML, Eastwood RL (1985). Relationship between compressional wave and shear wave velocities in clastic silicate rocks. *Geophysics*, 50: 571 – 581

Domenico SN (1976). Effect of brine–gas mixture on velocity in an unconsolidated sand reservoir. *Geophysics* 41:882 – 894

Dorbin MB (1988). *Introduction to geophysical prospecting*. International Ed. McGraw Books & Company

Ebiegberi O, Goddy JU, Hycienth ON (2013). Geoelectric delineation of aquifers in Yenagoa and Ogbia areas of Bayelsa State, Nigeria. Available from www.researchgate.net/figure/map-of-bayelsa-state-showing-study-location. Accessed on 5th October, 2021

Emujakorue GO, Ekine AS (2009). Determination of rock elastic constants from compressional and shear wave velocities for western Niger Delta, Nigeria. *Journal of Applied Sciences & Environmental Management* 13(3):55-64

Ferhat O, Tazegul O (2011). Geophysical analysis of the soils for civil (geotechnical) engineering and urban planning purposes: some case histories from Turkey. *International Journal of the Physical Sciences* Vol. 6(5):1169-1195

Gardner GHF, Harris MH (1968). Velocity and attenuation of elastic waves in Sands: Soc. Prof. Well log Analysis's 9th Annl. Logging Symp. M1 – M19

Kearey P, Michael B, Ian H (2003). *An introduction to geophysical exploration*: Blackwell Publishing, p21-27

Klimis NS, Papazachos CB, Efremidis, ChF (1999). Determination of the behavior of a sedimentary rock mass: comparison of measured static and dynamic properties, Proc. of the 9th Int. Congress on Rock Mechanics, Paris, France

- Love AEH (1927). A treatise on the mathematical theory of elasticity. Cambridge University Press, P104
- Luna R, Jadi, H (2000). Determination of dynamic soil properties using geophysical methods. Proceedings of the First International Conference on the Application of Geophysical and NDT Methodologies to transportation facilities and infrastructure. Geophysics 2000, Federal Highway Administration, Saint Louis
- Momoh LO, Akintorinwa O, Olorunfemi MO (2008). Geophysical investigation of highway failure –a case study from the basement complex terrain of southwestern Nigeria. J. Appl. Sci. Res. 4(6), 637–648
- Mukerji T, Dutta N, Prasad M, Dvorkin, J (2002). Seismic detection and estimation of overpressure (the rock physics basis): Stanford Rock Physics Laboratory, Stanford California USA and Western Geco, Houston Texas USA CSEG Recorder, 34 – 57.
- Nwankwo CN, Emujakporue GO, Nwosu LI (2013). Seismic refraction investigation for groundwater potential in parts of Rivers State. Nigeria Pacific Journal of Science and Technology. 14(2):505-511
- Nwankwo RC (2016). Application of 3D poststack amplitude inversion for hydrocarbon reservoir characterization: a case study of a field in the onshore central Niger Delta: Journal of Research in Physical Science 12(1):13-37
- Nwankwo RC (2017a): Hydrocarbon fluids identification using rock properties crossplots. Journal of Nigerian Association of Mathematical Physics 41: 205 –210
- Nwankwo RC (2017b): Generating velocity information for pore pressure prediction in the Niger Delta using poststack inverted seismic amplitude data: Scientia Africana 16(2): 152-171
- Okiongbo KS, Mebine P (2015). Estimation of aquifer hydraulic parameters from geoelectric method: a case study of Yenagoa and environs, Southern Nigeria. Arabian J. Geosci. 8(8):6085-6093
- Oladipe MI, Olorunfemi MO, Ojo JS (2008). Geophysical investigation of road failure in the basement complex terrain areas of southwestern Nigeria. Res. J. Appl. 3(2): 103-112
- Omudu LM (2007). Extraction of rock properties from seismic amplitude data and application to AVO analysis in the onshore Niger Delta: PhD dissertation, Department of Physics, University of Port Harcourt, Nigeria
- Omudu, LM, Ebeniro JO (2005). Crossplot of rock properties for fluid discrimination, using well data in offshore Niger Delta: Nigerian Journal of Physics 17: 16-20

Orife JM, Avbovbo A A (1982). Stratigraphic and unconformity traps in the Niger Delta: AAPG Bulletin, 66(2): 251 – 262

Papazachos CB, Vargemezis G, Fikos I (2005). Application of seismic methods for geotechnical site characterization. International Workshop in “Geoenvironment and Geotechnics”, Milos Island, Greece

Sheriff RE, Geldart LP (1986). Exploration seismology. Cambridge University Press, p316

Tatham RH (1982). Vp/Vs and lithology. Geophysics 47(3):336 - 344

Whiteman A (1982). Nigeria: Its petroleum geology, resources, and potential: London, Graham, and Trotman, P394.