GSC Advanced Research and Reviews
eISSN: 2582-4597 CODEN (USA): GARRC2
Cross Ref DOI: 10.30574/gscarr
Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

Characterization of sub-surface structure, using seismic refraction and multi-channel analysis of surface waves methods in Ajere Ekori Yakurr LGA of cross river state

Atan Obeten Egor *

Department of Physics, Cross River University of Technology, Nigeria.

GSC Advanced Research and Reviews, 2023, 16(01), 188–200

Publication history: Received on 06 June 2023; revised on 16 July 2023; accepted on 19 July 2023

Article DOI: https://doi.org/10.30574/gscarr.2023.16.1.0311

Abstract

The study was to characterize the sub surface at Agere in Ekori, using seismic refraction method, multichannel analysis of surface waves technique and borehole intrusive technique. Data were collected using a 12channel seismograph and other accessories required for seismic refraction data collection. Software called seismicimager was used to examine the data. The primary wave velocity in the first layer varied from 690 m/s at 4.2 m to 96 m/s at 7.3 m. A Vp range of 315 m/s to 484 m/s at a depth of 2 m is present inside the layer and represents the organic soil constituents. A Vp range of 669 m/s to 1756 m/s represents loose sand (dry), loose made ground (rubble), landfill rubbish, disturbed soil, and clay landfill, all within a depth of 2.3 m to 12.1 m. In addition to the borehole intrusive method, multichannel analysis of surface wave (MASW) techniques was used to calculate the soil profile based on velocity. The source was a 7 kg sledge hammer, the detectors (receivers) were 24 units of 4.5 Hz geophones, and the recorder was a Terraloc Mark 8 ABEM. Seismicimager software was used for analysis. At Ajere 1 through 6, the MASW test configuration employed 5 m geophone spacing and a source offset distance of 5 m, while at Ajere 7, it used 1 m geophone spacing and a source offset distance of 2 m. Near the boreholes, all of the MASW test arrays were run. The trustworthy seismic data from Ajere 1 to 6 at depths of 0.7 m to 13.1 m and 4.7 m to 17 m. Based on SPT N values, the results showed that the shear wave velocities had been classified into three layers of soil: very soft, soft, and firm. The velocities below 164 m/s, between 164 and 190, and 190 m/s to 320 m/s were classified as these soil types. In the meantime, a drilling invasive technique based on SPT N value determines changes in the soil layer. Hard material shear wave velocity data was not provided. In conclusion, because of its non-destructive, non-invasive nature and relative speed of evaluation, the MASW technique has the potential to be adapted in soil study to complement intrusive technique.

Keywords: Seismic refraction; Multi channel analysis of surface waves; Velocity analysis; Hydrocarbon; Geophones

1. Introduction

The sub surface is the anchorage for many activities, its good health is of serious concern to humanity. When the sub surface begins to slide as in landslide, crack with deep fault lines or erodes uncontrollably at slightest rainfall, it becomes expeditiously necessary to understudy it in order to recommend remediation measures. The soil in AJERE community have exhibited some of the tendencies described above hence the reason for the study. The intent of this study is to use geophysics techniques to characterize the sub surface image. Specifically, the multi-channel analysis of surface waves (MASW)and the seismic refraction methods are deployed in the study.

By measuring the shear-wave velocity distribution, the seismic technique known as MASW may determine how the overburden and bedrock are arranged. It examines the dispersion of surface waves, typically Rayleigh waves in their fundamental mode. An array of geophones is utilized to measure the seismic waves, just like in other seismic techniques. Surface waves for MASW can be produced by an active source, such as a sledgehammer, or by ambient surface waves, such as those produced by heavy machinery and moving vehicles. Both 1D (depth) and 2D (depth and surface distance)

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*Corresponding author: Egor A. O

forms of the shear wave (Vs) profile are provided by the approach. The findings can be used to calculate soil and rock strength (stiffness), map subsurface geology (lateral and vertical variations), determine IBC Vs100 (Vs30) site classification, determine bedrock depth and topography, and assist in liquefaction potential analysis.

In situ field testing, as opposed to laboratory testing, allows for the examination of larger amounts of soil and so tends to be more representative of the soil mass. The advantage of in-situ field tests is that no samples need to be recovered. Sampling is a significant challenge for particularly soft clays, sands, and gravels since they easily alter the soil's structure and lead to disturbed samples. Field approaches are now accepted as a result of good correlations between field tests and laboratory tests [1].

InSite investigations involve a variety of in situ experiments, including penetration testing, dynamic probing, pressuremeter testing, field vane shear testing, plate loading testing, and geophysical testing. The main barriers preventing thorough subsurface investigation are financial and time restraints. Therefore, site inquiry may merely entail field testing for a small number of places or laboratory testing of samples gathered by site staff. This can cause the strength of the existing subsurface to be either underestimated or overestimated. Therefore, a comprehensive strategy must be used to increase the site investigation's level of assurance. Excellent resolution of spatial variability across a location can be achieved using geophysical approaches. The key benefits of such a technique are their relative quickness of assessment and nondestructive, non-invasive character. Details of stiffness with depth can be pretty easily determined if calibrated. The parameters to be studied determine which geophysics tests should be applied. But in the site research, establishing the soil stiffness profile is crucial (Mitchell and Jardine, 2002). The seismic method-based outcomes are empirically derived among geophysical approaches. maximal shear modulus, bulk modulus (B), Young's modulus (E), and Poisson's ratio are examples of geotechnical properties. The shear modulus profile from site investigation has been particularly effective for the seismic-based approaches [2],[3].

According to [4], there are two ways to collect seismic wave data that can be useful for site investigation: borehole methods and surface methods. The surface approach is used to collect surface wave data and is thought to be more practical in the field than other methods because it is not restricted by any ground models [5]. In Japan, where it was first developed 50 years ago, the Multi-channel Surface Wave (MSW) approach was first known as the Micro Tremor Survey approach (MSM). The Kansas Geological Survey created multi-channel analysis of surface wave, or MASW, electronic equipment for the MSW in the late 1990s [6]. This method has been created and put to the test for uses in civil engineering, such as site characterization [7], compaction control, and assessing the quality of stone columns [8] In comparison to traditional surface wave analysis methods that are based on a single transmitter-receiver pair, the MSW approach has many advantages. Multiple-receiver measurement techniques shorten survey times and enable lateral resolution [6].,[9]; meanwhile, sub-surface characterization in the vertical and lateral axes offers a useful 2-D representation [10].

In order to identify, isolate, and remove noise from dispersed and reflected waves during the data analysis, Park et al. (1999) created MASW, which employs several receivers with only one shot. The phase angle-distance map can then have a best fit line drawn through it, limiting the impact of data variances and enabling more robust data processing. The complete MASW process typically involves three steps: obtaining multi-channel field records, extracting dispersion curves, and ultimately inverting these dispersion curves to produce 1-D or 2-D shear wave velocity and depth profiles. By sampling the spatial wave field with numerous receivers, the MASW approach has enhanced field production and better characterization of dispersion relationships [6]. In general, the Multi-channel of Surface Wave (MASW) approach has a number of advantages over other surface wave techniques since it uses multi-channel receivers to record all seismic wave energy, including both body and surface waves. Body waves and surface waves are two types of seismic waves that travel. Body waves typically aren't dispersive, which makes them different from other waves.

The velocity of surface waves does not considerably change as a function of propagation distance in a solid and homogenous material. However, surface waves become dispersive when the medium's qualities change with depth, causing the propagation velocity to change in relation to the wavelength or frequency. The passive approach (sources include traffic and tidal motion) can only go a few hundred meters, whereas the multichannel of surface wave (MASW) method has research depth shallower than 30 m. Redundancy in sampling caused by many receivers gives the signal processing method used to obtain the dispersion curve flexibility. Numerous benefits have already been mentioned, thus in order to educate stakeholders about this technique for site investigations on soft soil, an evaluation of it is being done. This study aims to investigate the soil profile based on MASW technique and calibrated with borehole data at Ajere in Ekori. The location of this study is shown in Figure-1,

In order to ascertain the subsurface nature, thickness, bedrock arrangement, and fracture zones in Kashshi, Abuja, [11] conducted a seismic refraction survey. Geophone, potential electrodes, and a 48 channel Geode TM are the tools employed. The layers are dipping and undulating with dip angles of -0.3 (down-dip) and 0.79 (up-dip), respectively, according to an analysis of the data. The obtained results indicate that the upper slow velocity layer is loose over burden materials, the second layer (1572+0.004 m/s) for water bearing fractured zones having a thickness range from 18.7m to 214m, and the third layer (3385+0.002 m/s) represents the crystalline fresh basement rock, respectively.

1.1. Geology and location of the study area

Ekori is large semi cosmopolitan community in Cross River State of Nigeria it is in the Southsouth of Nigeria located on Latitude 5^0 50’-5^0 55N and longitude 8^0 18’-8^0 36E. It is bounded in the North and West by the Cross-River plains. The access to this area is by a major road identified as the Calabar – Ikom highway which spanned from the Southeast to Northwest and branch off to Oferepke community.

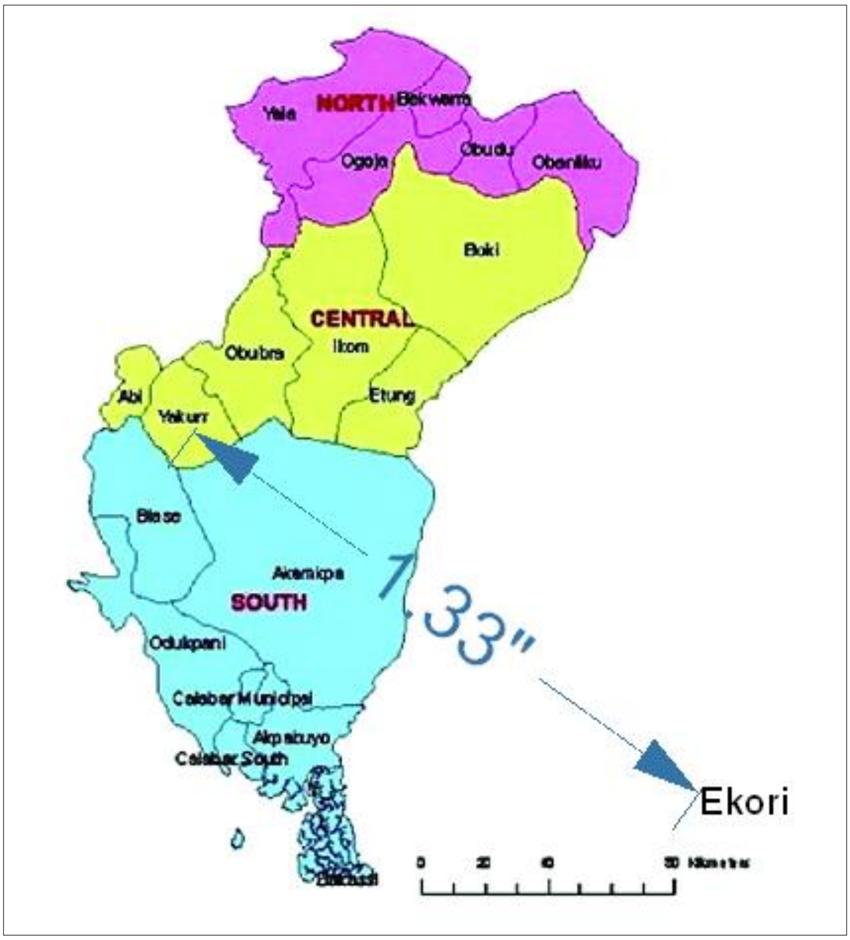


Figure 1 Southern Nigeria showing the Cross River State and the study area

1.2. Statement of problem

There have been observe cases of land slide at very small scale and other features of soil inconsistency in the study area. This had led to a lot of questions as per the strength of the soil. Resolving these questions will require the use of geophysical techniques which is nondestructive but capable of generating the desired result.

Aim of the study

The aim of this research is to determine the sub-surface structure of the soil, how it affects human and natural activities, its related vibration problem in the rural area Agere of Ekori, in Yakurr LGA. The specific objective is to apply seismic refraction method to measure elastic parameters like bulk modulus, shear modulus Poisson’s ratio, Primary and Secondary waves velocities that will enable the achievement of the aim earlier stated. Furthermore, Multichannel Analysis Surface Wave (MASW) and borehole intrusive techniques were deployed to confirm the results from each method

2. Material and methods

Similar tools were employed in the seismic refraction approach by the multi-channel of surface wave (MASW) method, but the geophones' frequency was different. The source that hit the metal plate was a 7 kg sledgehammer. The detector is a 24 units 4.5 Hz vertical geophone connected to a 24-channel cable, and the recorder is an ABEM Terraloc MK 8 seismograph. For the MASW test, the seismograph configuration required a longer record time, or around 2 seconds to measure seismic data. The sampling time is between 250 and 500 s, and there are between 4096 and 8192 samples. Approximately five times of hammering the ground will generate waves. The array length and the distance from the seismic source to the first geophone at Ajere 1, 2, 3, and 4 are, respectively, 115 and 5 meters and 23 and 2 meters. Closed MASW tests were performed at the borehole site. The following tools were used to collect data using the seismic refraction method: a 12 Channel signal enhancement seismograph, a base plate, a GPS, a safety boot, a glove, 2m potential cables, meter tape, a sledge hammer weighing 12 kg, a computer, seis-imager software, a battery charger, and a 10Hz geophone.

Table 1 Seismic compressional waves (p-s waves) velocities in earth materials

Earth materials	**V_p (ms^{-1})**	**V_s (ms^{-1})**
Unconsolidated materials		
Sand (dry) / Top soil	190 – 1000	0.2 – 1.0
Sand (water saturated)	1500 – 1900	1.5 – 2.5
Clay	1000 – 2500	1.0 – 2.5
Glacial till (water-saturated)	1500 – 2500	3.5 – 4.0
Sedimentary rocks		
Sandstones	1900 -6000	
Limestones	1900 – 6000	2.0 – 2.5
Dolomite	2500 – 6500	2.5 – 6.5
Salt	4500 – 5000	4.5 – 5.0
Anhydrite	4500 – 6500	4.5 – 6.5
Gypsum	1900 – 3500	2.0 – 3.5
Igneous/metamorphic rocks		
Granite	5500 – 6000	5.5 – 6.0
Gabbro	6500 – 7000	6.5 – 7.0
Ultramafic Rocks	7500 – 8500	5.5 – 6.5
Serpentinite	5599 – 6500	5.5 – 6.5
Pore fillings		
Air	300	0.3
Water	1400 – 1500	1.4 – 1.5
Ice	3400	3.4
Petroleum	1300 – 1400	1.3 – 1.4

Source : [12] and www.eoas.ubc.ca)

The earth layer materials in sub-soil makes up layer with different thickness. The seismic waves penetrate the sub-soil layer which have a low frequency, high amplitude and high wavelength.

The seismic wave's analog data was captured using field measurement equipment. The first arrival time information from each geophone was then automatically plotted in a graph of the relationship between the geophone number and the arrival time of P-waves and S-waves for each shooting point for forward and reverse arrival [11]. The first arrival time was then selected from this plots and time-distance. Seismicimager software was used to create the P-wave and S-wave plots displayed in figures 3, 4, and 5. The data analysis used the Wyrobek approach [13]. The following relationship was applied to the slopes to determine the average velocities V1 and V2 for the first layer and the refraction:

$$\text{Slope}= \frac{\textbf{\textit{Change in time}}}{\textbf{\textit{Change in distance}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

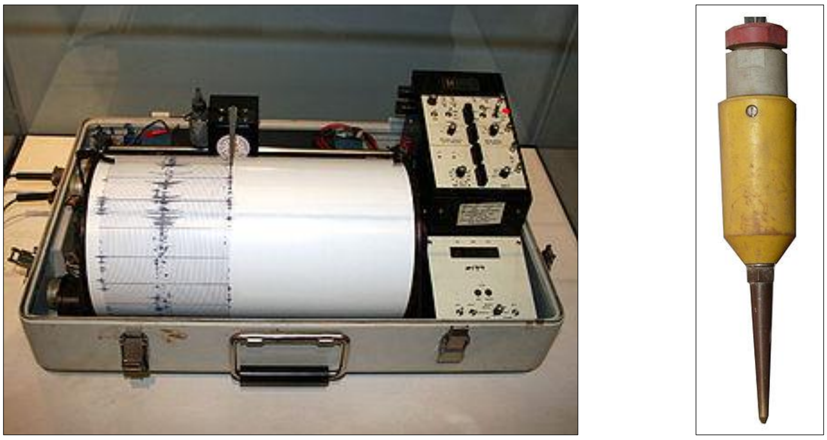
$$\text{V}=\frac{\mathbf{1}}{\textbf{\textit{Slope}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The intercept time was also determined from the graph and the depth to the refractor was calculated by diving the intercept time by two which is also called delay time (D), this delay time (D) values were multiplied by an appropriate factor to obtain time depth according to the relation shown by equation:

$$\text{Z} = \frac{\text{V}_1\text{V}_2}{\text{V}_2^2 \quad \text{V}_1^2} \qquad (3)$$

Were Z is the refractor depth, Ti is the intercept time, V_1 and V_2 are the velocities of the 1st and refractor layer respectively. This procedure was carried out for all shot point to obtain the already mentioned quantities.

2.1. Seismic refraction equipment used



Seismograph Geophone

Figure 2 Seismic refraction equipment

2.2. Method of analysis of seismic refraction data

Understanding the fundamentals of seismic wave generation, transmission, absorption and attenuation in earth material as well as their reflection, refraction, and diffraction characteristics at discontinuities is crucial because one of the fundamental techniques used in this work is the seismic refraction method. Since seismic waves alter the material in which they travel like an elastic band does when it is stretched, seismic waves are also known as elastic waves.

There are observable changes in a material's size and shape when stress is applied to its surface. The internal forces within the body act in opposition to the external stress due to deformation and its ability to regain its initial size and shape define the material's elasticity. The elastic properties and density of the earth directly influence the speed of seismic waves passing through it. 2009 [13]. Several elastic parameters include;

2.2.1. Poisson Ratio

[14] defined "Poisson Ratio as the ratio of lateral contraction to linear extension in a strained element, for extension in the $x - direction$. Mathematically it is defined as:

$$\sigma = \frac{x}{2(x+u)} \ldots\ldots\ldots\ldots (4)$$

In seismic methods, waves are generated into the earth and all information afterwards retrieved, such as the wave velocity, is as a result of the waves' propagation through elastic material. Therefore, it is important to derive the wave equation in the context of the elastic properties of the subsurface materials.

$$Vp/_{Vs} = \frac{\sqrt{x+2\mu}}{\mu} = \frac{\sqrt{\tau}}{\mu} + 2 \quad \text{..............} (5)$$

Expressing the ratio Vp/Vs in term of the Poisson's ratio, σ, we have:

$$\frac{vp}{vs} = \frac{\sqrt{\sigma E}}{(1+\sigma)(1-2\sigma)} x \; 2 \frac{(1+\sigma)}{£}) + 2 = \frac{\sqrt{2\sigma}}{1-2\sigma} + 2$$

$$\frac{vp}{vs} = \left(\frac{1-\sigma}{\frac{1}{2}-\sigma} \right) \text{..........} (6)$$

The Poisson ratio cannot be greater than ½ in an ideal soil Vp is the velocity of the compressional wave or it can be called p-wave velocity, while Vs is the shear wave velocity. The p-wave velocity, Vp is always greater than the shear wave velocity Vs.

$$\mathrm{V_P} \sqrt{X + \frac{2u}{p}} \text{....................} (7)$$

$$\mathrm{V_s} = \sqrt{\frac{u}{p}} \quad \text{.................} (8)$$

The p-waves equation is also written as follows:

$$\mathrm{V_p} = \mathrm{k} + 4\ 3\mu \text{ .... } (9)$$

$$\mathrm{V_s} = \mu \quad \text{.......... } (10)$$

Where
K = bulk modulus
µ = shear modulus
P = density of material (sub-soil layers)
The seismic waves speed (V_p and V_s) changed from layer to another dependent to density and porous.

2.2.2. Bulk modules

The bulk modules k is given by:

$$\mathrm{K} = -\frac{p}{\theta} = \mathrm{x} + \frac{2}{3}\mu \text{...........} (11)$$

speed at which seismic waves travel. The lithological characteristics of rocks define the magnitude of the velocities v in the first place, but the velocities also reflect the conditions in which the rocks originated, evolved, and were deposited. The elastic parameters and rock densities that determine rock velocities are impacted by the lithological characteristics of the rocks. The velocity of seismic wave propagation is only little impacted by density changes. Young's modulus of elasticity and Poisson's ratio are two elastic parameters that have a significantly greater impact.

The rate at which seismic waves spread throughout the pone filling, the porosity (the proportion of pore volume in the rock's volume), and the seismic wave velocity in the solid portion (matric) all affect how quickly seismic waves move through a rock. According to [15], seismic velocities in high porosity rocks are typically lower than those in low porosity rocks and water-bearing rocks. While the nature of the filling (air, water, or oil) determines the velocity in the pore filling, which is typically lower than the velocity in the rock matrix, the velocity of seismic waves propagation in the rock matrix depends on its mineralogical composition. It's crucial to consider the pressure that the rocks are or have been under. A decrease in porosity is brought on by an increase in pressure, which also results in an increase in the young's modulus E and velocity. The seismic wave velocities at the earth's surface are significantly lower than those in the same rocks found at depth because there is essentially no pressure there and the rocks are subject to intense weathering. Young's modulus, which determines velocity, is also increased by cementing and metamorphosis. We can argue that seismic wave velocity is often higher in older rocks than in younger ones. Low-velocity layer (LVL) is a term used to describe the uppermost portion of a geological section, which is often formed by unconsolidated or worn rocks. Elastic constants were calculated using the following universal relation:

$$\text{Bulk modulus } K = \frac{E}{3\,(1-2\sigma)} \text{............}(12)$$

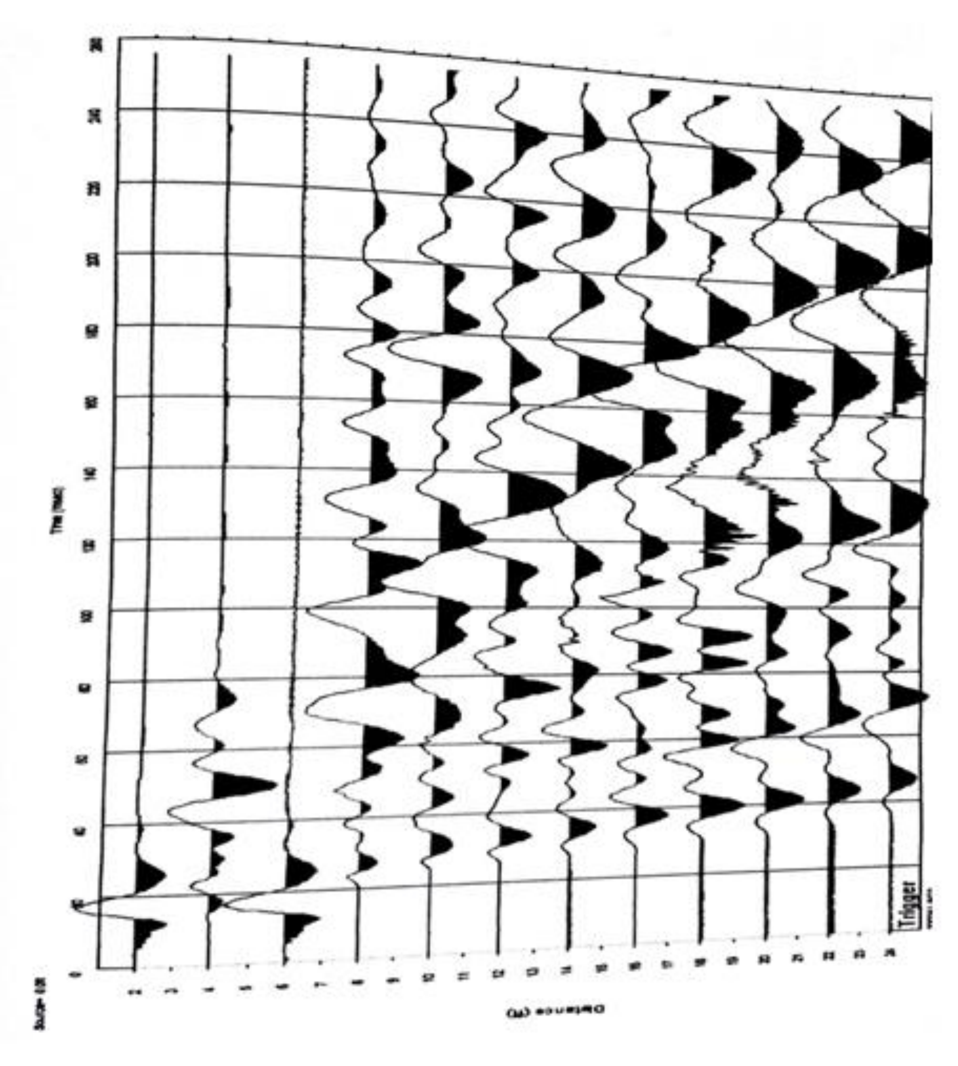
$$\text{Young modulus } E = 2\mu\,(1+\sigma) \text{ ....}(13)$$

$$\text{Shear modulus } \mu = \rho^{v2}\, s \text{ ....}(14)$$

$$\text{Poisson's Ratio } \sigma = \frac{0.5\,(Vp2-2v2s)}{V2p-V2s} \text{............}(15)$$

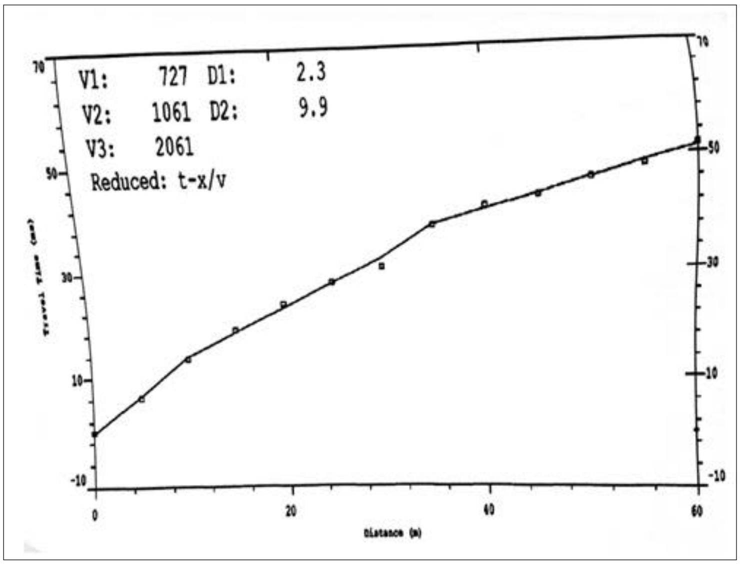
$$\text{Lame's constant } ƛ = \frac{\in\sigma}{(1-\sigma)(1-2\sigma)} \text{..........}(16)$$

V_p and V_s are P- and S-waves velocities respectively, ρ is the density of the soil.



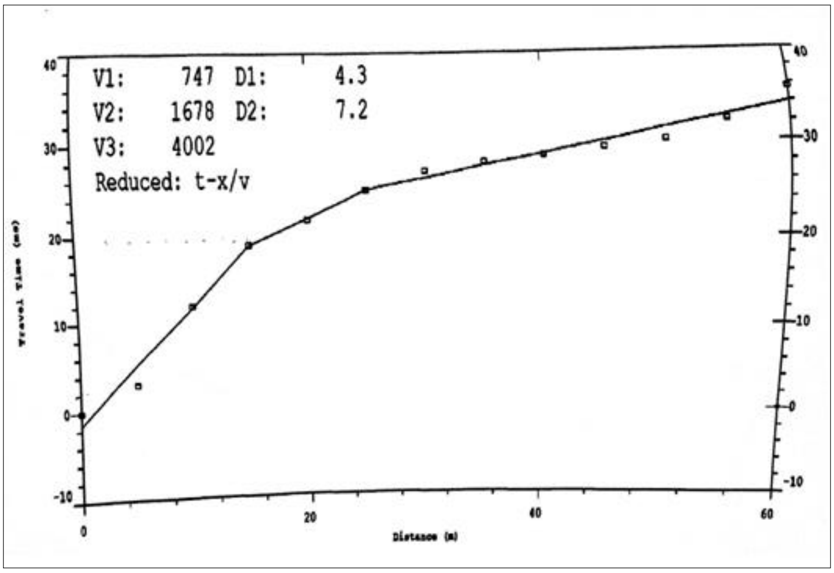
Source: Author'sfiledwork,(2022).

Figure 3 A sample of Seismic wiggle showing forward arrival time of P-wave for a 12-channel seismic equipment obtained from Ajere in Ekori



Source: Author's filedwork, (2022)

Figure 4 A sample of TX Plot from Ajere 1



Source: Author's filedwork, (2022)

Figure 5 A sample of TX Plot from Ajere 4

3. Result and discussion

A profile listing Ajeres 1 through 7 was created. Three separate layers were scanned, and the data reveals a clear difference in primary wave velocity (Vp) with depth. Primary wave velocity varied in the first layer from 690 m/s at a depth of 4..2 m to 960 m/s at 7.3 m. A Vp range of 315 m/s to 484 m/s at a depth of 2 m is present inside the layer and represents the organic soil constituents. Further, for road construction, a Vp range of 669 m/s to 1756 m/s represents loose/sand (dry), loose madeground (rubble)/landfill refuse/disturbed soil, and clay landfill, all within a depth of 2.3 m to 12.1 m. This layer must be torn since it lacks the necessary bearing capacity [16], referenced by Labtransportumy.wordpress.com).

The location profiles identified a top layer that was up to 7.2 meters deep. From the first layer to the second layer, there is a general rise in velocity (Vp), which can be explained by the consolidation of the earth materials as one descends deeper. The fundamental wave's velocity varies as well. Calculations of elastic characteristics, including the bulk modulus, Poisson ratio, young modulus, and Lame constant, are shown in Table 8. These calculations were performed using the 2,670kgm-3 average rock density [17];[18]. A overview of all the findings is provided in Table 7. The findings demonstrate that the first layer's shear modulus varies across all sites, with an average of 4.2 x 10N/m2 and a minimum of 2.6x108N/m2 at Crin Ajere 1 and a high of 6.25x108N/m2 at Ajere 5. The second layer's shear modulus ranges from 4.29x108N/m2 at Ajere 2 to 14.8x108N/m2 at Ajere 5, with a mean value of 7.23 x 108N/m2 in between. The third laver has an average of 31.15 x 108N/m2, a minimum of 11.20 x 108N/m2 at Ajere 7, a maximum of 43.2 x 108N/m2 at Ajere 5, and a range of values in between. AJERE 6 has the lowest bulk modulus of the first layer (3.90x108N/m2) and the highest bulk modulus of the first layer (17.60x108N/m2), with a mean of 17.28 x 108N/m2. The second layer's bulk modulus ranges from 0.06 x 108 N/m2 at Ajere 2 to 150 x 108 N/m2 at Ajere 5, with an average value of 41.81 x 108 N/m2. The third layer has a mean value of 214.66X108N/m2, a low of 62.4X108N/m2 at Ajere 3 and a maximum of 747.0X108N/m2 at Ajere 6.

The Young modulus E in the list layer has an average value of 10.38 x 108N/m2, a lowest value of 6.79x108N/m2 at Ajere 1 and a maximum value of 84.60x108N/m2 at Ajere 4. The Young modulus in the second layer is lowest at Ajere 2 with a value of 10.4x108N/m2, highest at Ajere 5 with a value of 43.70x108N/m2, and averages out at 31.07x108N/m2. Young modulus values range from 33.0x108N/m2 in the third layer to 120x108N/m2 in the fifth layer, with a mean value of 74.77x108N/m2 for the entire structure. The second layer's Poisson ratio has a low of 0.12 at Ajere 3 and a maximum of 0.46 at Ajere 7 with a mean value of 0.35, whereas the first layer's Poisson ratio has a minimum value of 0.03 at Ajere 6 and a maximum value of 0.36 at Ajere 7. The third layer has a mean value of 0.43, a minimum value of 0.33 at Ajere 4 and a highest value of 0.47 at Ajere 7.

For surface soils and shallow sediments, the porosity and poisson ratio were determined from compressional P- and horizontal S-wave velocities using in situ seismic refraction measurements. the difference in lithology across layers caused by variations in grain size, shape, type, and stiffness (ranging from 29% to 66%). Wide differences in (from 0.01 to 0.43) were induced by the clay content, air and water saturations, anisotropy, and the high degree of both lateral and vertical heterogeneity. For surface soils and shallow sediments, P- and horizontal S-wave velocities were used to measure the Poisson's ratio (σ) and porosity (Φ).

The results of the analysis indicate that there were variations in the porosity (between 29% and 66%), size, shape, kind, and stiffness of the grains. Wide differences in (0.01-0.43) were induced by the clay content, air and water saturations, anisotropy, and high degree of heterogeneity both lengthwise and perpendicularly. [19] increases with depth, with rising water saturation, and with decreasing porosity for the top layer of the soils and sediments studied, Porosity and the value of are empirically associated (Cc=0.90).

The fact that the soils, sediments, or younger rocks are more compressible close to the surface but less compressible and more plastic with depth (higher bulk modulus, lower compressibility, and greater Poisson's ratio) may be the cause of the value of increasing with depth. Poisson ratio value of 0.05 depicts very hard rigid rocks, while σ of 0.45 connotes soft, poorly consolidated materials. Liquids have no resistance to shear and hence for them $\mu = 0$ and $\sigma = 0.5$.

Seismicimager software was used to evaluate the shear wave velocity profiles at the test sites of Ajere 1 through 6 and 7. This produced a 1-dimensional velocity profile. At Ajere 1, MASW testing revealed information down to a depth of 27 m, whereas Ajere 7 test site revealed information down to a depth of 13 m. The length of the MASW array utilized in the investigation determines the depth of penetration. Three boreholes are present in Ajere test site. The soil layers were separated into extremely soft, soft, firm, and hard clay layers based on data from boreholes. The summary of the borehole and MASW data at Ajere 1 to 6 Spreadline 1 and 2 were summarized in Tables 4 and 5. Table 6 displays the outcome at the AJERE 7 test location. Due to the limitations of the MASW test, the shear wave velocity data at deeper layers was not accessible. As a result, the subsurface can be classified as very soft soil if the SPT N value is less than 2, and if the shear wave velocity is less than 164 m/s. The shear wave velocity of the soft soil layer, indicated by the SPT N between 2 and 4, is between 171 m/s and 190 m/s. The shear wave velocity of the firm soil layer at SPT N between 4 and 8 ranges from 195 m/s to 320 m/s.

Table 2 Results of seismic velocities and depth from Ajere in Ekori

Study location	**Coordinates Latitude**	**Coordinates Longitude**	**Vp (m/s)**	**Vp2 (m/s)**	**Vp3 (m/s)**	**Vx1 (m/s)**	**Vx2 (m/s)**	**Vx3 (m/s)**	**Vp1 (m/1)**	**Vp2 (m/2)**	**Vp3 (m/3)**	**Dp1 (m)**	**Dp2 (m)**	**Ds1 (m)**	**Ds2 (m)**
Ajere 1	5.80716	8.0846	690	1158	1931	475	527	675	1.45	2.20	3.33	4.2	10.9	2.9	5.3
Ajere 2	5.82236	8.08622	584	815	1806	313	480	705	1.87	1.70	2.74	4.9	10.7	2.5	9.5
Ajere 3	5.88002	8.12083	602	669	2457	363	601	833	1.79	1.57	2.17	6.9	8.2	7.1	6.6
Ajere 4	5.8418	8.5663	602	669	2457	363	401	456	1.66	1.67	1.81	2	12.1	4.4	5.2
Ajere 4	5.93388	8.23822	669	1471	5368	347	747	1247	1.93	1.97	1.97	7.3	8.7	4.8	8.6
Ajere 5	5.95102	8.26269	822	2524	2572	484	745	1272	1.70	3.39	2.35	25	2.3	5.1	9.2
Ajere 6	5.98881	8.27063	634	1241	2983	454	615	799	1.40	2.02	6.72	4.6	8.6	4.2	5.9
Ajere 7	5.99794	8.31577	960	1756	1134	444	460	649	2.16	3.82	3.96	5.5	5.2	2.5	7.7

Table 3 Results of elastic constants from Ajere in Ekori

Study location	**Cordinates Latitude**	**Cordinates Longitude**	**Density (kg/m3)**			**µ1 x 108 (N/M2)**	**µ2 x 108 (N/M2)**	**µ3 x 108 (N/M2)**	**E1 x 108 (N/M2)**	**E2 x 108 (N/M2)**	**E3 x 108 (N/M2)**	**K1 x 108 (N/M2)**	**K2 x 108 (N/M2)**	**K3 x 108 (N/M2))**
Ajere 1	5.82236	8.08622	2670	2670	2670	2.62	6.15	13.30	6.79	15.2	37.80	5.62	9.53	81.90
Ajere 2	5.88002	8.12083	2670	2670	2670	3.52	4.29	5.95	8.54	10.5		4.99	0.06	12.0
Ajere 3	5.84180	8.5663	2670	2670	2670	3.62	9.64	18.50	9.20	22.4	50.60	6.74	6.74	11.00
Ajere 4	5.93388	8.23822	2670	2670	2670	3.21	34.7	41.50	84.60	39.5	110.0	7.66	17.12	106.0
Ajere 5	5.95102	8.26269	2670	2670	2670	6.25	14.8	43.20	15.40	43.0	120.0	9.70	150.00	181.0
Ajere 6	5.98881	8.27063	2670	2670	2670	5.50	10.1	17.00	10.70	27.0	50.7	3.39	27.70	747.0
Ajere 7	5.99794	8.31577	2670	2670	2670	5.26	5.65	11.20	14.40	16.5	33.0	17.60	74.80	162.0

Table 4 Ajere 1 borehole 1 and spreadline 1

Dept(m)	Soil description	SPT N Value	Shear wave velocity(m/s)
0.0 —15.0	Very soft	0 —2	73 —150
15.0 —24.0	Soft	2 —4	171 —190
24.0 —30.0	Firm	4 —8	195 —320
30.0 —above	Hard	>30	Not avaliable

Table 5 Ajere 2 borehole 2 and spreadline 2

Dept(m)	Soil description	SPT N Value	Shear wave velocity(m/s)
0.0 —15.0	Very soft	0 —2	71 —160
15.0 —24.0	Soft	2 —4	170 — 190
24.0 —30.0	Firm	4 —8	190 —312
30.0 —above	Hard	>30	Not avaliable

Table 6 Ajere 7 test site borehole 3 and spreadline 3

Dept(m)	Soil description	SPT N Value	Shearwave velocity(m/s)
0.0 —15.0	Very soft	0 —2	33 —16
15.0 —24.0	Soft	2 —4	Not avaliable
24.0 —30.0	Firm	4 —8	Not avaliable
30.0 —above	Hard	>30	Not avaliable

The empirical conversion of Vs = 105.70N0.327, which is applicable for all types of soils, was used to estimate shear wave velocity using the SPT N value from borehole data [19] The shear wave velocities computed using an empirical formula and those observed using the MASW technique agree well. The shear wave velocities' empirical conversion, however, revealed a slight variation from the MASW-measured velocity. This is because, while the borehole SPT N value is particularly at a set depth, the MASW data measured a greater area and averaged the velocity over the area. At Ajere, the geophones were spaced 5 cm apart, and the length of an array was 115 m. The average shear-wave velocity in the surrounding soil was profiled against depth using the MASW results. Additionally, it is assumed that the soil is stratified with vertical heterogeneity and lateral homogeneity in MASW's theory of inversion techniques.

4. Conclusion

Based on SPT N values, the shear wave velocities were split into three soil layers, with very soft soil being categorized as a layer below 164 m/s, soft soil between 164 and 190 m/s, and firm soil between 190 m/s and 320 m/s. The shear wave velocity measured by the MASW method is the average of the velocity at a given depth along the array's lateral length. Due to the horizontal soil heterogeneity, it is therefore expected that the velocity from empirical conversion using the SPT N value slightly varied from the MASW test. Therefore, it is important to comprehend the limitations of the soil profile correlation between the MASW test and the borehole SPT N value. In conclusion, the borehole intrusive technique, which is non-destructive, non-invasive, and has a respectable rate of assessment, complements the MASW technique and may be appropriate for soil characterization investigations. The aforementioned findings show that a minimum amount of force is required at each location tested before a unit area of the soil in the research area can be stressed. All of the sites under investigation exhibit low values for E, K, and, suggesting that the soil in the research area is easily compressible and that a significantly less tangential force is needed to stress the soil than it is to compress it.

The low readings indicate that the local soils are easily compressible. At some areas, such as Ajere 1, and 3, the Poisson ratio values dropped in the second stratum. In the second stratum of Ajere 5, the reduction was from 0.45 to 0.39 in the third. This drop implies that, compared to the other two layers (layers one and three), the second layer in these regions was more consolidated. All other places show an increase in the Poisson ratio from the first layer to the third layer, with the exception of these locations where the value of in the second layers decreased.

Comparatively, the results from the three techniques used in this study are similar, complimentary and confirmatory pointing to the fact that the sub surface of AJERE is weak to a certain depth of 24m and will require remediation before engineering infrastructures can be hosted on it.

Compliance with ethical standard

Acknowledgement

Special thanks go to Tertiary Education Trust Fund for Sponsoring this Institutional Based Research. Also acknowledge is Bayelsa oil Company for providing the platform for data acquisition.

Disclosure of conflict of interest

No conflict of interest exists for this manuscript.

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