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RESEARCH ARTICLE

APPLICATION OF SEISMIC REFRACTION METHOD FOR GEOTECHNICAL INVESTIGATION OF FUPRE CAMPUS AND ITS ENVIRONS' SUBSURFACE STRUCTURES

Olaseni V.B.[a*], Esi E.O.[b], Chukwusa F.O.[b], Umana Ondu[a] And Sibebo T.[a]

[a]*Department of Physics, Federal University of Petroleum Resources, Effurun, Nigeria*
[b]*Department of Physics, Dennis Osadebay University, Asaba, Nigeria.*
**Corresponding Author Email: olaseni.victor@fupre.edu.ng*

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ABSTRACT

The conventional approach to subsurface investigation (drilling and trenching) always result to shallow sub-structural information. This challenge now informed the application of seismic refraction method in 3 locations FUPRE-Campus, Okorikperhe, and Okoukouko for geophysical characterization. Twelve traverses were investigated using a 24-channel seismograph and the subsurface images in all locations revealed the presence of three subsurface layers. It is observed that there is a gradual increase of seismic velocities values with depth, first layer ranged from 113.02 to 235.45 m/s, the second ranged between 215.29 and 422.88 m/s while the third layer ranged 492.10–973.63 m/s, this showed that the subsurface experienced high pressure with depth. The first two layers is suspected to be composed of silty-sand formation due to the lower value of shear modulus that ranged 20.20 to 91.32 MPa while the third layer that has the highest seismic velocity value is classified as a dense sand environment due to its higher shear modulus value of 594.38 MPa. The values of other modulus (bulk and young modulus) also increased progressively from first to third layer across the study area and this further confirmed the stronger resistance to deformation with depth. However, the subsurface images generated also revealed a consistent very low value of poisson's ratio of 0.35 indicating a low measure of deformation in the study area, while the low-density value of 1800 kg/m^3 suggested a sedimentary rock composition. In conclusion, the third layer of the study area is the most suitable foundation zone for massive structural development.

KEYWORDS

Seismic refraction, subsurface investigation, geophysical characterization, FUPRE Campus, Okorikperhe, Okoukouko, subsurface layers, seismic velocity, shear modulus, Poisson's ratio, bulk modulus, Young's modulus, silty-sand formation, dense sand, foundation suitability, sedimentary rock.

1. INTRODUCTION

Subsurface characterization is a critical aspect of engineering and construction projects, as the integrity of foundations depends largely on the geotechnical properties of underlying materials. Conventional investigation techniques such as drilling and trenching, though widely used, are often time-consuming, costly, and limited in the detail they provide. As a result, geophysical methods-particularly seismic techniques-have gained increasing relevance for non-invasive, rapid, and reliable subsurface investigations. Among these methods, seismic refraction has proven especially useful in determining subsurface stratigraphy and geotechnical parameters. The method involves measuring the travel times of seismic waves generated by impulsive energy sources such as explosives, sledgehammers, or weight drops, which become critically refracted when propagating across media with varying seismic velocities (Kearey et al., 2002; Lowrie, 2007; Rosli, 2018). Through velocity analysis, the technique provides valuable insights into the composition, strength, and deformation resistance of subsurface materials, making it widely applicable in site investigations. Despite the growing use of seismic refraction, limited studies have focused on comprehensive geotechnical characterization in the Niger Delta region, particularly in FUPRE campus, Okorikperhe, and Okoukouko. These areas, which are undergoing increasing infrastructural development, require accurate knowledge of subsurface conditions to ensure structural stability and minimize construction risks. This challenge now informed the application of seismic refraction method in 3 locations FUPRE campus, Okorikperhe, and Okoukouko for geophysical characterization of the subsurface structures in all the three study areas and the following geotechnical parameters such as Poisson's ratio, density, shear modulus, bulk modulus, and Young's modulus were used to derive the most suitable layers for foundation of any massive structural development.

Several studies have demonstrated the effectiveness of seismic refraction in engineering applications. This also applied seismic refraction to study subsurface layers around FUPRE stadium, it was found out that the first two subsurface layers exhibited poor bearing capacities due to low shear strength and high compressibility, while the third layer proved more competent for foundation purposes of the structure that will be erected by the university management (Olaseni and Onifade 2024). It is assessed soil stability in Ibiono Ibom, Akwa Ibom State, and reported three stratified layers, with the deepest layer offering the best geotechnical quality (Aka et al., 2020). This studies also highlighted the usefulness of integrating

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seismic and electrical methods for delineating weathered profiles in engineering site characterization (Oladunjoye et al., 2017). While combined seismic refraction with cone penetration testing to confirm the depth to the most competent foundation-bearing strata (Adewoyin et al., 2021). Collectively, these studies underscore the reliability of seismic refraction for subsurface investigations across diverse geological settings in Nigeria. However, the present study applies the seismic refraction method across twelve traverses in these locations to derive key geotechnical parameters which includes Poisson's ratio, density, shear modulus, bulk modulus, and Young's modulus. The results aim to provide a detailed understanding of subsurface properties and identify the most competent layers for engineering foundations.

2. Materials And Method

The seismic refraction survey in the study area was carried out using standard geophysical equipment and procedures. The materials employed included seismic cables, geophones, sledgehammers, a metallic plate, tape rules, and other accessories such as cutlasses and umbrellas for field operations. The energy source was generated by striking a metallic plate with a sledgehammer, producing seismic waves that propagated through the subsurface. These waves were subsequently detected by geophones placed along each traverse at intervals of 10 m. The geophones were connected to a 24-channel seismograph, which

recorded the seismic signals for further analysis. To ensure adequate coverage, twelve traverses were acquired across the study area in order to obtain a reliable detection of subsurface variations. For each traverse in the study area, first arrival seismic waves were picked from the recorded signals and used to calculate seismic velocities of the subsurface layers.

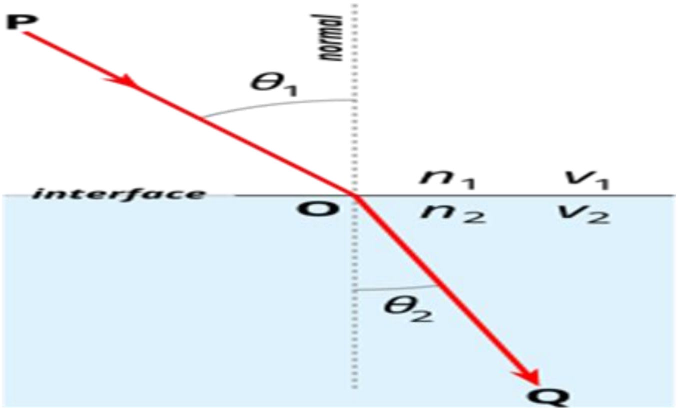
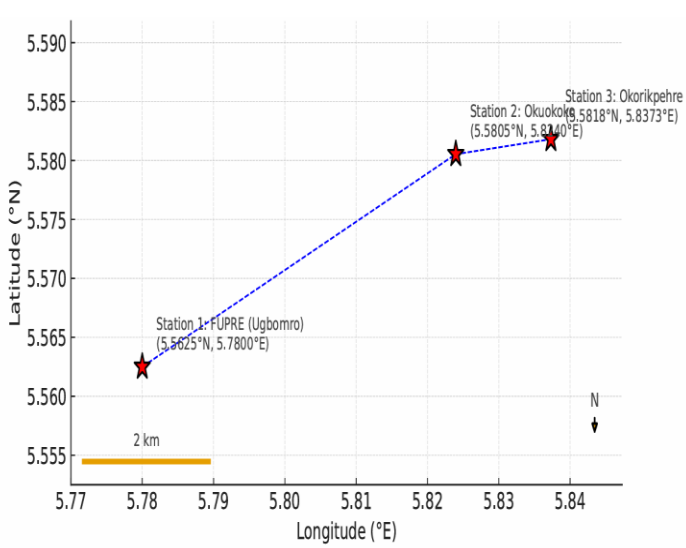


Figure 1: Images showing refracted ray with refraction angle Θ

2.1 STUDY AREA

The three locations (FUPRE campus, Okorikperhe, and Okoukouko) are located in Effurun, Delta state, SouthSouth part of Nigeria, the geology formation of Effurun city is the same as the Niger Delta which underlies as area of about 256,000km2 and was built over transgressive Paleocene protodelta (Short and Stauble., 1967). The geographical coordinates of all the three locations as shown in figure 2 are as follows; FUPRE campus has (5.5625oN, 5.7800oE), Okuokoko has (5.5805oN, 58240oE) and Okorikpehre has (5.5818oN, 5.8373oE).



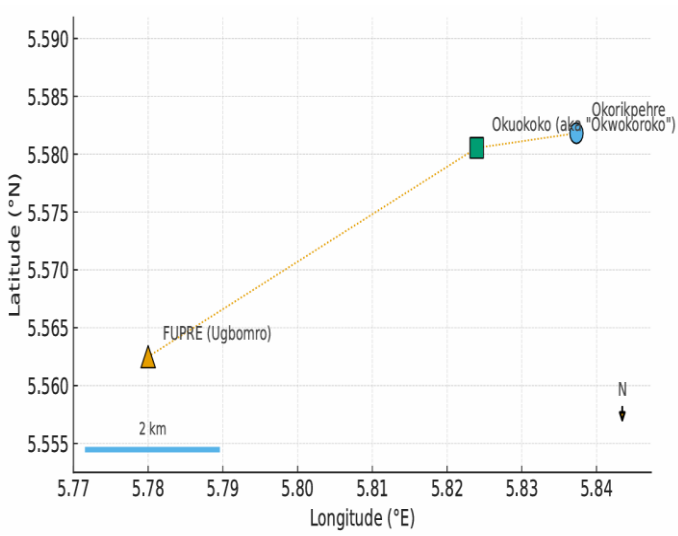


Figure 2: Geographical Field points of the three locations in the study area

2.2 THEORETICAL BACKGROUND

The theoretical background of this research is base on the Snell's law (as shown in figure 1 above that showed the relationship between the incident and refracted rays), the law states that for a given pair of media, the ratio of the sines of angle of incidence (θ1) and angle of refraction (θ2) is equal to the refractive index of the second medium with regard to the first (n21) which is equal to the ratio of the refractive indices (n2/n1) of the two media, or equivalently, to the ratio of the phase velocities (V1/V2) in the two media (see equation 1).

$$\frac{sin\theta1}{sin\theta2} = n21 = \frac{n2}{n1} = \frac{v1}{v2} \qquad (1)$$

3. Presentation And Discussion Of Results

From the twelve traverses (four traverses per location) investigated in the study area using seismic refraction method, the acquired data were processed and filtered using SeisImager software to generate all the subsurface images in the study locations of FUPRE-campus, Okorikperhe, and Okoukouko. The results of all the shots initiated during the survey are presented in Figures 3 to 22. These figures consist of travel-time curves, subsurface refractor morphologies, and velocity maps derived from the recorded seismic data.

The travel-time curves provide the first-arrival picks of seismic waves, from which the seismic velocities of the subsurface layers were determined. The velocity maps, in turn, illustrate lateral and vertical variations in seismic velocity within each location, allowing for the identification of distinct subsurface layers. Three subsurface layers structure were observed in all locations ranging from low-velocity shallow layers to deeper and denser formations. Although from figures 8, 16 and 24 which showed the velocity maps of all three locations revealed the variations in velocity values and thickness of each subsurface layer. Figures 7, 15 and 23 showed the morphological models of the subsurface refractors in the three study areas and this revealed undulating layer boundaries, suggesting spatial heterogeneity in soil composition across the study areas. The shallow layers generally exhibited lower seismic velocities, indicative of loose, unconsolidated materials such as silty sand, whereas the deeper layers displayed higher velocities, consistent with dense sand or compacted sedimentary formations.

3.1 FUPRE-CAMPUS LOCATION

Figures 3, 4, and 5 displayed the seismic signals generated from three shot points at lateral distances of 4 m, 50 m, and 96 m, respectively. The travel-time curves derived from these shots are presented in Figure 6, where first-arrival times were plotted against geophone positions. The curves revealed three distinct refracted layers with corresponding seismic velocities. Figure 7 illustrated the subsurface morphology, highlighting the internal structure and stratification of the layers, while Figure 8 showed the velocity distribution map across the FUPRE-campus location.

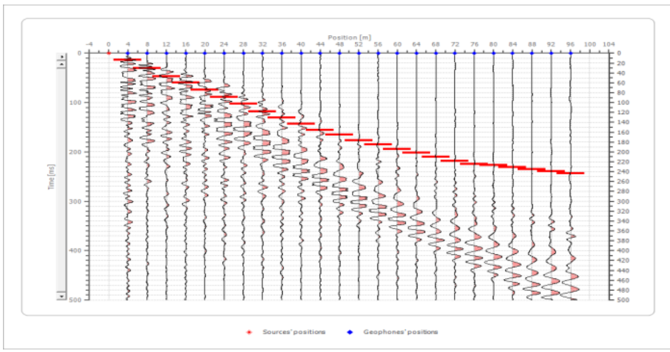


Figure 3: 1st Shot at Arrival in FUPRE-campus

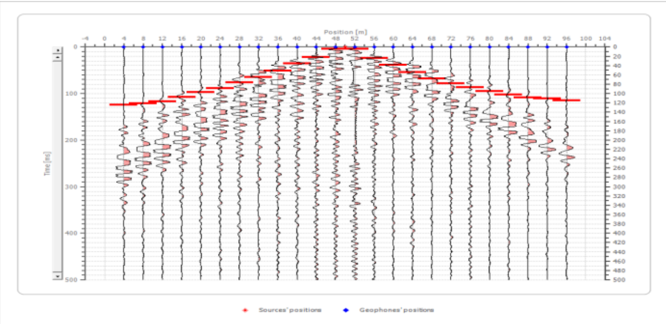


Figure 4: 2nd Shot at Arrival in FUPRE-campus

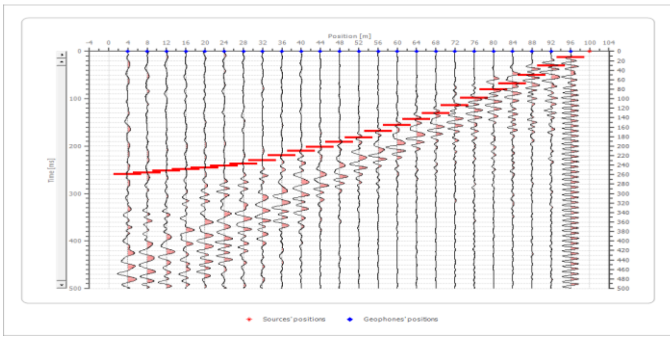


Figure 5: 3rd Shot at Arrival in FUPRE-campus

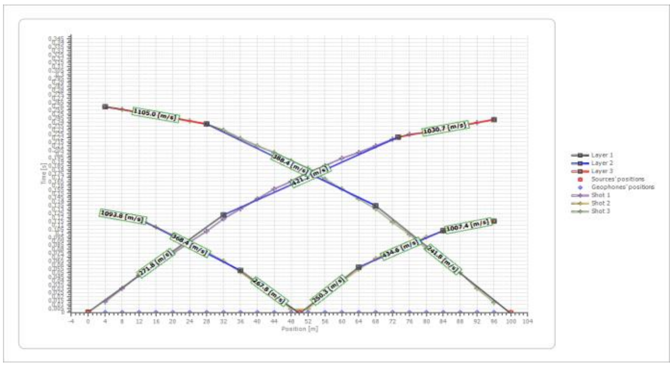


Figure 6 : Travel Time Curve in FUPRE-campus

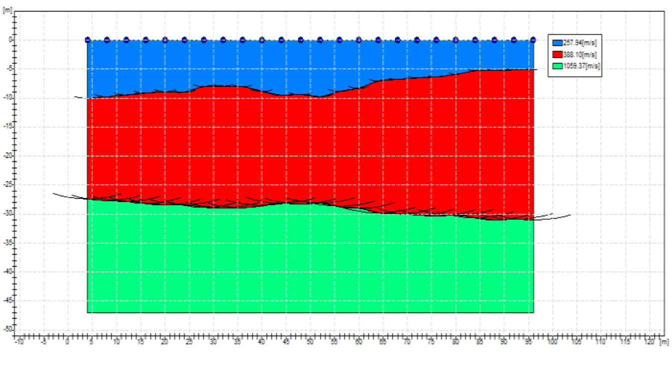


Figure 7: Morphology of the Subsurface Refractors in FUPRE-campus

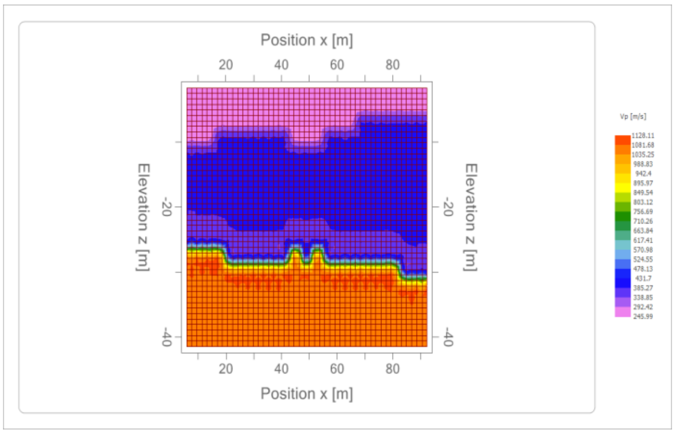


Figure 8: Velocity Map of the Subsurface in FUPRE-campus

3.1.1 DISSCUSSION ON FUPRE-CAMPUS LOCATION

FUPRE-Campus subsurface layers were explained using the following derived geotechnical parameters; Poisson's ratio, density, shear modulus (G_0), oedometric modulus (E_o), bulk modulus (K), and Young's modulus (E). The Poisson's ratio has a value of 0.35, suggesting the dominance of silt within the subsurface geology. Silt commonly occurs in mudrock as clumps which indicate the presence of fine-grained particles that are easily compacted yet prone to erosion. The density of all the three subsurface layers is 1800 kg/m^3 which are the characteristic of sedimentary rock formations. Seismic velocities revealed increasing competence with depth: the first layer ranged from 129.91–259.94 m/s, indicative of very loose, unconsolidated sand; the second layer ranged from 186.44–388.10 m/s, reflecting a clayey-sand mixture; while the third layer exhibited velocities of 508.90–1059.37 m/s, consistent with coarse sand deposits. However, shear modulus values for the first two layers ranged from 27.64–62.56 MPa, confirming their silty-sand composition. In contrast, the third layer exhibited a significantly higher shear modulus of 466.17 MPa, which indicate a dense sand formation with high load-bearing capacity and enhanced stability. Similarly, bulk modulus values increased from 92.13 MPa in the first layer and 208.55 MPa in the second layer to 1553.89 MPa in the third layer, highlighting the latter's superior resistance to deformation under stress. Young's modulus values further supported this trend: 74.62 MPa in the first layer and 168.93 MPa in the second suggested loose and sandy formations, while the third layer's value of 1258.65 MPa indicated a dense and competent subsurface environment. Overall, the results from FUPRE-campus demonstrated that while the first two layers are geotechnically weak and unsuitable for supporting heavy structures, the third layer provides the strongest and most stable foundation material.

3.2 OKORIKPERHE LOCATION

Figures 8 to 12 displayed the seismic signals generated from three shot points at lateral distances of 4 m, 50 m, and 96 m. The corresponding travel-time curves are presented in Figure 13, where arrival times were plotted against geophone positions. The results revealed three distinct refracted layers with varying seismic velocities. Figure 14 illustrated the subsurface morphology, showing the internal structure and stratification of the layers, while Figure 15 presented the velocity distribution map across the Okorikperhe location.

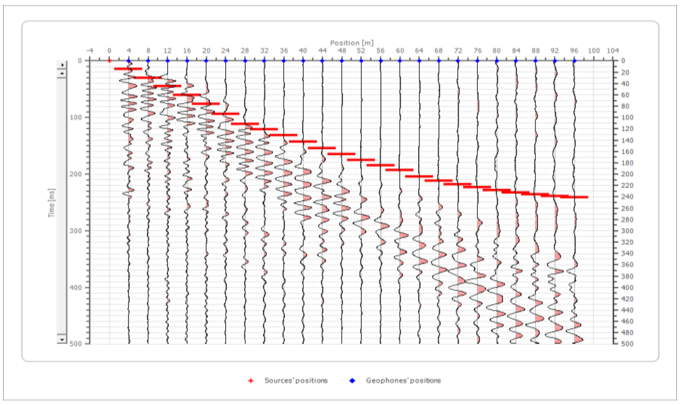


Figure 9: 1st Shot at Arrival in Okorikperhe

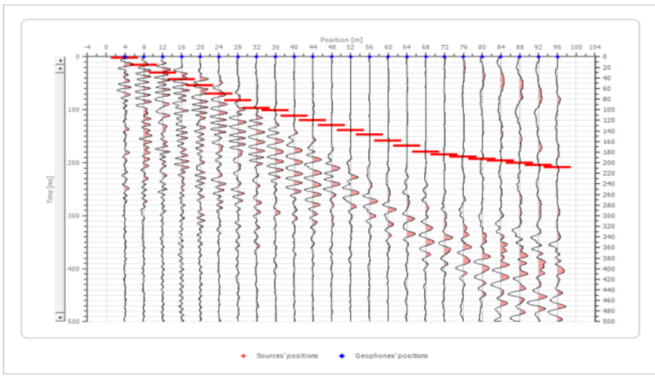


Figure 10: 2nd Shot at Arrival in Okorikperhe

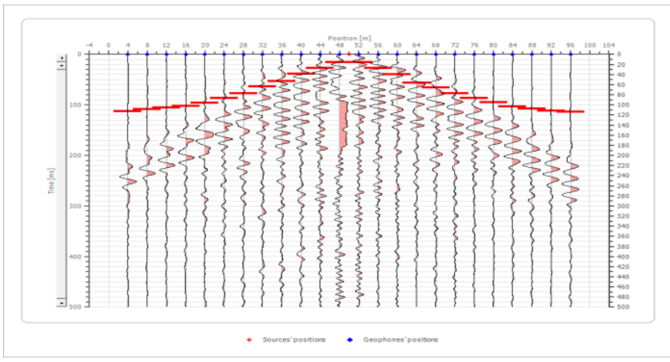


Figure 11: 3rd Shot at Arrival in Okorikperhe

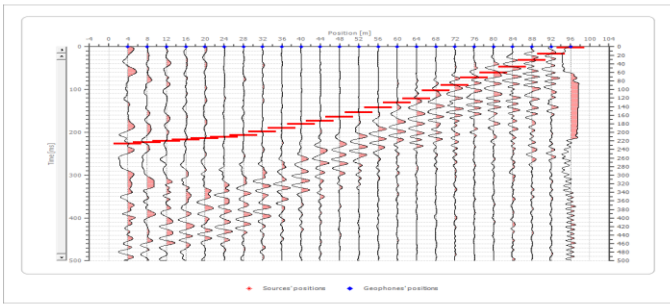


Figure 12: 4th Shot at Arrival in Okorikperhe

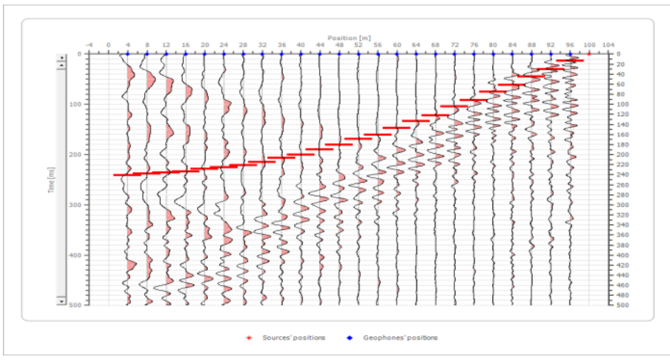


Figure 13: 5th Shot at Arrival in Okorikperhe

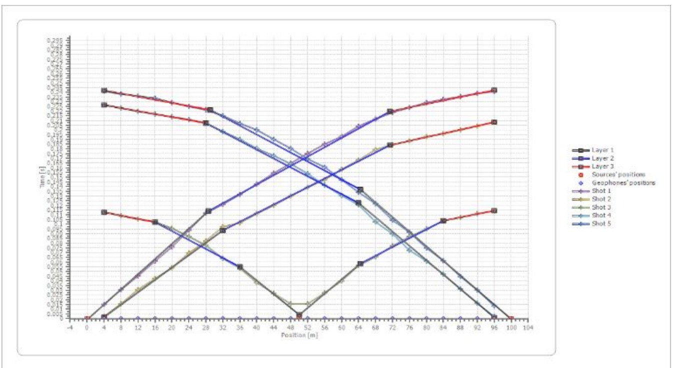


Figure 14: Travel Time Curve in Okorikperhe

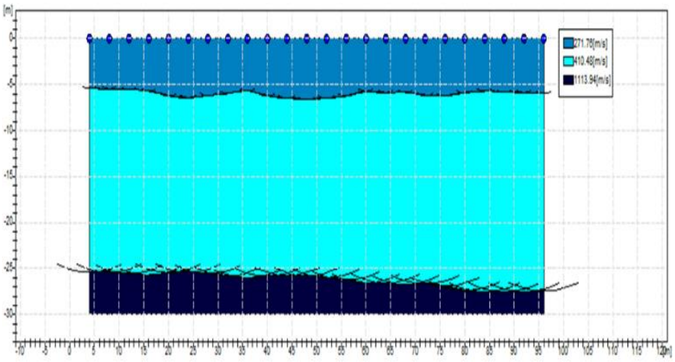


Figure 15: Morphology of the Subsurface Refractors in Okorikperhe

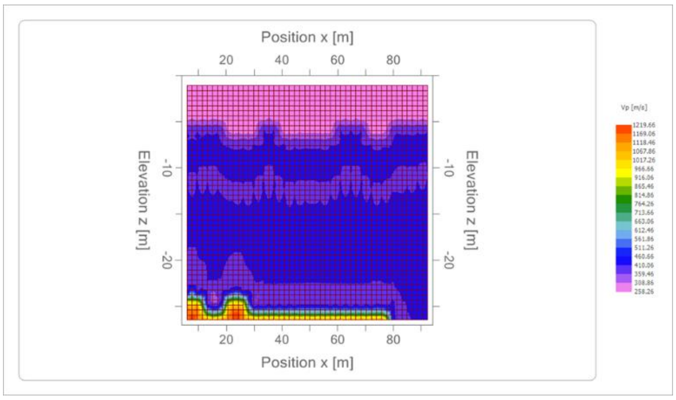


Figure 16: Velocity Map of the Subsurface in Okorikperhe

3.2.1 DISSCUSSION ON OKORIKPERHE LOCATION

The Poisson's ratio was uniform across all the three subsurface layers with a value of 0.35, indicating the dominance of silt in the subsurface geology. Silt commonly occurs in clumps within mudrock, suggesting that the subsurface particles are fine-grained, easily compacted, and prone to erosion. The density of all three layers in the subsurface is 1800 kg/m^3 which is consistent with sedimentary rock formations. Seismic velocities further confirmed the increasing strength of the formation with depth: the first layer ranged from 130.55–271.76 m/s, interpreted as loose, unconsolidated sand; the second layer ranged from 197.19–410.48 m/s, representing a clayey-sand mixture; while the third layer, with velocities between 535.12–1113.94 m/s is also consistent with coarse sand deposits. Shear modulus values of the first two layers ranged between 30.68–69.99 MPa, consistent with silty-sand material. In contrast, the third layer exhibited a shear modulus of 515.44 MPa, reflecting a dense sand formation with high load-bearing capacity and greater stability. Bulk modulus values followed the same trend: 102.26 MPa in the first layer and 233.30 MPa in the second layer, increasing sharply to 1718.12 MPa in the third layer. This indicates that while the upper layers are weak and easily deformable, the third layer is strong and highly resistant to volume change under stress. However, Young's modulus values were 82.83 MPa for the first layer and 188.98 MPa for the second, suggesting loose and sandy formations, respectively. The third layer's Young's modulus of 1391.68 MPa highlighted its competence as a dense sand environment. The Okorikperhe location exhibits a geotechnical profile similar to FUPRE-campus, with weak and unconsolidated upper layers overlying a dense, mechanically strong third layer that offers excellent foundation properties.

3.3 OKUOKUOKO LOCATION

Figures 16 to 20 displayed the seismic signals generated from three shot points at lateral distances of 4 m, 50 m, and 96 m. The corresponding travel-time curves are presented in Figure 21, where arrival times were plotted against geophone positions. The results revealed three distinct refracted subsurface layers with varying seismic velocities. Figure 22 illustrates the subsurface morphology, showing the internal structure and stratification of the layers, while Figure 23 presents the velocity distribution map across the Okuokuoko location.

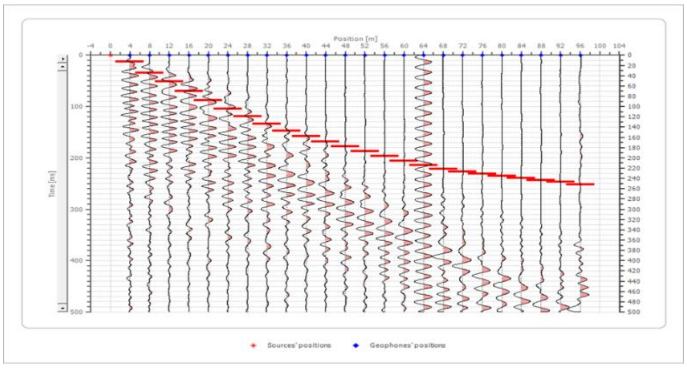


Figure 17: 1st Shot at Arrival in Okuokuoko

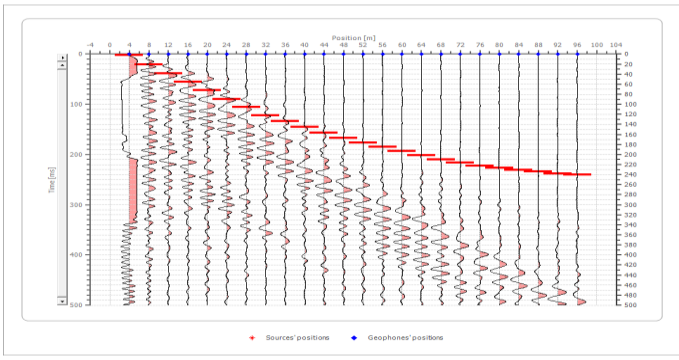


Figure 18: 2nd Shot at Arrival in Okuokuoko

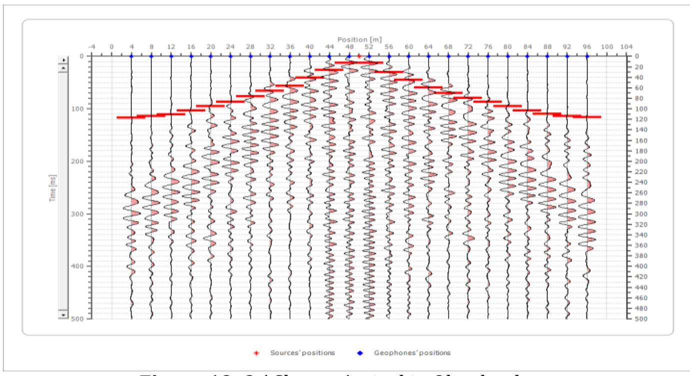


Figure 19: 3rd Shot at Arrival in Okuokuoko

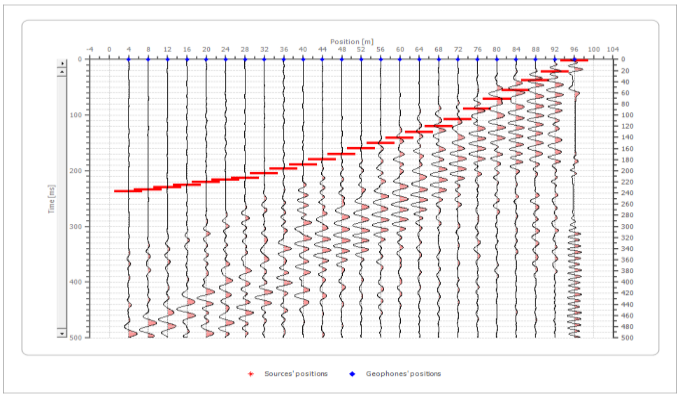


Figure 20: 4th Shot at Arrival in Okuokuoko

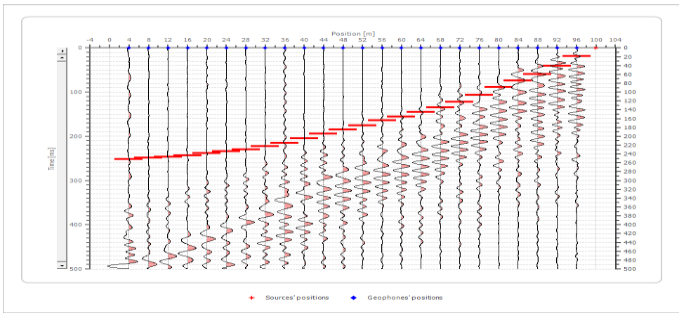


Figure 21: 5th Shot at Arrival in Okuokuoko

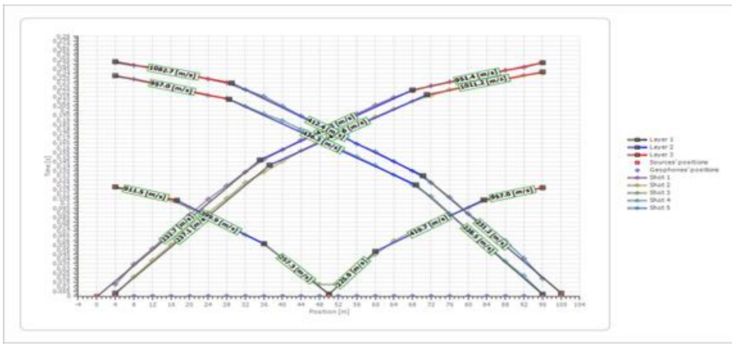


Figure 22: Travel Time Curve in Okuokuoko

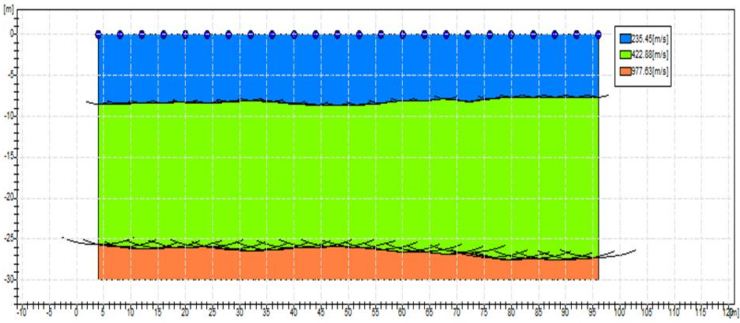


Figure 23: Morphology of the Subsurface Refractors in Okuokuoko

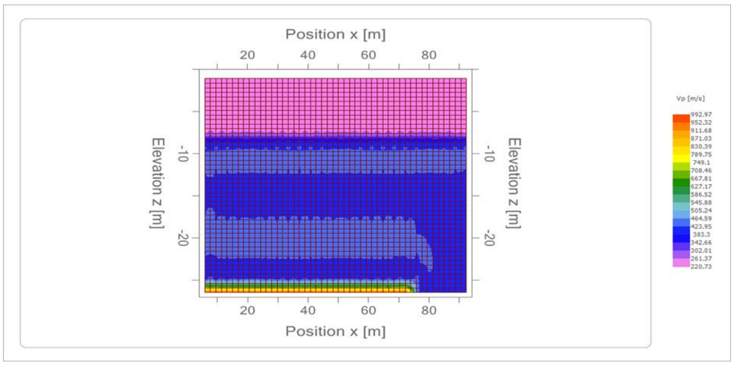


Figure 24: Velocity Map of the Subsurface in Okuokuoko

3.3.1 DISSCUSSION ON OKUOKUOKO LOCATION

As revealed in other two investigated locations (FUPRE-campus and Okorikperhe), poison's ratio has the same value of 0.35. This is interpreted that the subsurface materials in Okorikperhe are fine-grained, easily compacted, and prone to erosion by surface runoff. The density value of 1800 kg/m^3 across the three layers is consistent with sedimentary formations of relatively low density. Also, as it was displayed in other two study areas, the seismic velocities have progressive lithological changes with depth: the first layer ranged from 113.11–235.45 m/s interpreted as very loose, unconsolidated sand; the second layer ranged from 203.15–422.88 m/s, representing a clayey-sand mixture; while the third layer, with velocities between 469.64 and 977.63 m/s is an indicative of coarse sand deposits with higher competence. Shear modulus values of the first and second layers ranged between 23.03 and 74.28 MPa is consistent with silty-sand formations. The third layer exhibited a much higher shear modulus of 397.01 MPa which reflect a dense sand formation with enhanced load-bearing capacity and greater stability. Bulk modulus values followed a similar trend: 76.76 MPa in the first layer and 247.61 MPa in the second layer, increasing sharply to 1323.35 MPa in the third layer. This is concluded that the third layer is significantly more resistant to volumetric deformation under stress compared to the upper layers. Young's modulus values are recorded as 62.18 MPa for the first layer and 200.57 MPa for the second, reflecting loose and sandy formations, respectively. The third layer exhibited a Young's modulus of 1071.92 MPa, suggesting a dense and mechanically strong environment. Overall analysis showed that Okuokuoko location exhibits a weak, unconsolidated surface layer underlain by progressively stronger formations, culminating in a dense sand layer at depth. This third layer provides the best geotechnical competence for structural foundations in the study area.

4. Conclusion

The application of seismic refraction techniques yielded significant insights into the subsurface geological structure of the investigated areas. The uniform Poisson's ratio of 0.35 in the third subsurface layer across all locations indicated a low measure of deformation in the study area and this means that the particular area may not experience plastic deformation while the consistent low density value of 1800 kg/m^3 across the study area confirmed that the formations are largely sedimentary in nature. However, it is observed that there is a gradual increase of seismic velocities values with depth, first layer ranged from 113.02 to 235.45 m/s, the second ranged between 215.29 and 422.88 m/s while the third layer ranged 492.10–973.63 m/s, this showed that the subsurface experienced high pressure with depth. The mechanical parameters of the first two layers is suspected to be composed of silty-sand formation due to the lower value of shear modulus that ranged between 20.20 and 91.32 MPa while the third layer that has the highest seismic velocity value is classified as a dense sand environment due to its higher shear modulus value of 594.38 MPa. The bulk modulus values were recorded from 67.32 to 1981.25 and this demonstrated the progression increase from a composition of a loose material formation at the near surface to mechanically competent dense sands that found at the third layer.

Finally, these derived geotechnical parameters (Poisson's ratio, shear modulus, bulk modulus, and Young's modulus) has confirmed that the first layer showed relatively weak geotechnical properties, while the third layer consistently demonstrated the highest values, indicating competent foundation-bearing material suitable for engineering structures. However, it can be concluded that the upper layers are loose, weak and unconsolidated to a moderately compacted sandy second layer while the third layer has the characteristic of a dense consolidated, high stiffness and load-bearing capacity. Collectively, these findings highlight the engineering significance of the third layer as the most stable foundation horizon, while also underscoring the geotechnical limitations of the surface strata.

Recommendation

Further work is encouraged using complementary geophysical techniques such as Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) in order to validate and enhance the accuracy of the seismic refraction findings. The results of this study should be directly applied in engineering projects, particularly in the design and construction of foundations, where due consideration must be given to the loose and unconsolidated nature of the first layer to avoid problems of settlement and instability. Continuous monitoring of subsurface conditions is also necessary, especially in areas exposed to environmental changes, groundwater fluctuations, or heavy construction activities that could compromise ground stability. Finally, the outcomes of this research should be made available to local authorities, policymakers, and urban planners so that land use, infrastructure development, and environmental management decisions are informed by reliable geotechnical evidence.

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