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DETERMINATION OF THE MECHANICAL PROPERTIES OF THE SOIL USING SEISMIC REFRACTION METHOD TECHNIQUE FOR ENGINEERING SITE CHARACTERIZATION IN FUPRE AND ITS ENVIRONS

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ABSTRACT: The study was carried out at the Federal University of Petroleum Resources to determine the mechanical properties of the soil to know the subsurface strength. Seismic refraction survey was conducted for data acquisition. Fifteen traverses were used for the data acquisition. The data was acquired using a 24-channel geophone (PASI-GEA 24) and was processed using the GEO-STRU software. A total of three geologic layers were identified along the fifteen traverse each having density of 1800kg/m³, and poisson's ratio of 0.35 for all the layers. Having a velocity range of approximately 220.5m/s – 371.7m/s for the first layer, the second layer has a velocity range of approximately 381.7m/s – 440.8m/s, and the last layer has a velocity range of approximately 902.1m/s – 1196.2m/s. The shear modulus for layer one and two range from 20mpa - 57mpa and 62mpa - 91mpa, respectively, which indicate that they are composed of silty sand. Layer three's shear modulus indicates that it is formed of dense sand with a shear modulus range of 338mpa – 594.38mpa. The first layer young's modulus ranges from around 54.53mpa – 154.98mpa for all the traverses which suggests loose sand, the second layer young's modulus also range from163.40mpa – 246.56mpa suggest sandy clay as the main material, and the third layer young's modulus ranges from about 912mpa – 1604.81mpa suggests dense sand.

INTRODUCTION

Due to the failure to conduct the required investigations before the construction of structures, developing countries have endured repeated collapse of engineering structures throughout the years. Recently, the statistics of building and engineering structure failures in these countries have risen exponentially (Alabi, 2020). The number of structural breakdowns in Nigeria in recent years is horrifying (Akintorinwa and Adeusi 2009). The geotechnical design necessary for projects requiring deep and shallow foundations, basements, slopes, tunnels, highways, embankments, mining tailings, seismic hazard assessments, site cleanup, and ground improvement must include site characterization as a crucial component (Lehane et al., 2018). It is crucial to assess the subsurface integrity before construction because when an engineering structure's foundation is built on a less capable earth layer, it poses a major threat to the structure and may even cause it to collapse (Ayodele et al, 2019).

Geophysical methods are often used in site investigation to determine the overburden thickness and to map subsurface conditions prior to excavation and construction. Geophysical data is an important parameter in contributing to the design and construction of Civil Engineering structures such as buildings, roads and dams. Electrical resistivity and seismic refraction methods are the most common geophysical techniques used for this purpose (Kurtenacker, 1934; Drake, 1962; Burton, 1976; Nunn, 1979; Keary and Brooks, 1984). However, in resistivity method, the depth of investigation and subsurface sections captured is limited to the array techniques employed during data acquisition that is resistivity sounding or resistivity imaging.

Seismic method is the geophysical method that gives the most detailed picture of subsurface geology because it gives us the opportunity to view the subsurface layers in two-dimensions (2D) or three-dimensions (3D) and to greater depths than that captured in resistivity method. Therefore, geologic sections computed from seismic method is a more reliable model of the subsurface since the earth is heterogeneous and 3D in geometry. That is why seismic method is often used to determine the characteristics of subsurface soils and rocks, (Ayolabi 2004) and structural setting of an area. The technique (seismic refraction) finds application in the determination of rock competence for engineering application, depth to bedrock, groundwater exploration, crustal structure and tectonics. To fully understand a region's near-surface geology, it is important to examine the soil (Adewoyin et al., 2021). The most common methods for characterizing soil are drilling, excavation, and geophysical studies. However, it may be difficult to extrapolate the same result in the expansion of a much wider space of the region studied because the results from these methods are site-specific and are only applicable to the tested spot, in light of the aforementioned, it is suggested that additional methods, especially geophysical studies, be employed in addition to geotechnical ones to accurately assess the condition of the subsurface (Adewoyin et al., 2021).

Olaseni and Onifade (2024) did shallow investigation using seismic refraction method using FUPRE stadium and its Environs as a case study, from his study of the subsurface lithology in study area, it was revealed that the first two layers have poor bearing capacity as a result of low shear strength values (i.e 33.61 MPa and 72.99 MPa for first and second layer respectively), however the third layer which 243.44Mpa has high compressibility to withstand any load attached to it.

Ayodele et al. (2019) state that because of their non-intrusive approach to civil engineering sites, geophysical approaches have been shown to be extremely useful in the development of engineering projects. Seismic method is one of the main geophysical techniques for examining underlying layers and/or local anomalies. This technique is widely used in a variety of disciplines, including engineering, environmental science, groundwater research, hydrocarbon extraction, and the discovery of industrial minerals (Khalil and Hanafy, 2018). Seismic waves are produced by a controlled source and travel through the earth's crust during seismic surveys. After refraction or reflection at geological boundaries within the subsurface, certain waves will surface again (Kearey et al, 2022).

Seismic methods, especially the refraction seismic method, have been used to solve many problems related to civil engineering, and environmental geology works. Seismic methods are divided into two types: invasive and non-invasive. The invasive type requires borehole like (Cross-hole, Down hole, P-S suspension and logging). As for the second type which is the non-invasive, it is carried out on the surface like (Seismic Refraction and Reflection, Spectral Analysis of Surface Waves (SASW), Multi-channel Analysis of Surface Waves (MASW)) which enables us to calculate the velocities of the shear seismic waves (V_S), it in turn serves the engineering evaluation process for different sites. By utilizing processes that are quick and inexpensive, the seismic refraction surveying techniques provide pertinent information regarding soil behavior at very low strain levels for wide areas of soil that are evaluated in an undisturbed state (Foti et al, 2023).

METHODOLOGY

2.1 Location of The Study Area

The study area is located on the campus of Nigeria's Federal University of Petroleum Resources Effurun (FUPRE). The school's athletic complex is the designated study area. The research area is located within the blue rectangle on the map below (Figure 1.1).

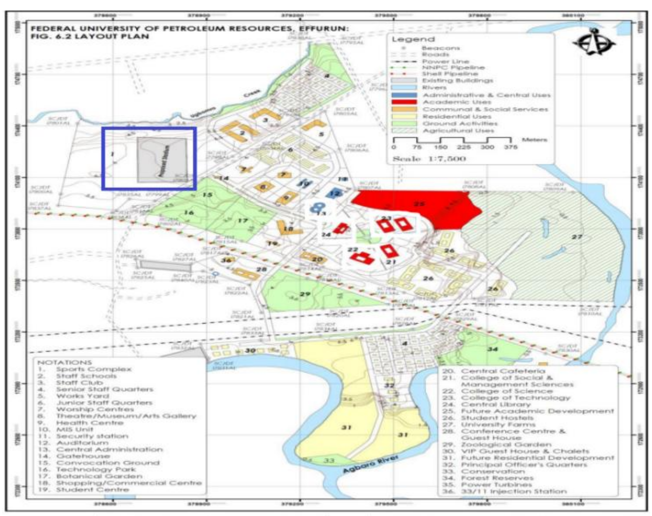

Figure 2. 1: Map of FUPRE campus showing the study areas in blue rectangle. (Source: Alaminiokuma 2020).

2.2 Geophysical Equipment

Measuring tape: This is used to get a straight profile and determine the offset between each geophone along the traverse.

Seismic cables: Also known as sensor cables, are cables designed to carry the signals generated by the geophones when they detect seismic waves, and transmit them to the seismograph for recording and analysis.

Geophones: These are instruments that detect seismic waves generated by explosions, and other sources of ground motion. They send detected vibrations through the seismic cable to the seismograph for recording.

GPS: This is used to get the coordinates (latitude and longitude) of the survey area. It's also used to get the elevation of the area in meters above sea level.

Ranging Pole: Ranging poles are survey instruments that are used for spotting and marking the position of survey stations. They can also be used to range straight lines.

Seismograph: This instrument is used to measure and record ground vibrations, including seismic waves generated by earthquakes and other sources of ground motion. It consists of a sensor (often a geophone) that detects ground motion and converts it into an electrical signal, and a recording device that records and displays the signal.

Hammer and Metal plate: A hammer and metal plate is used as a simple seismic energy source to generate seismic waves for the seismic surveys. The process involves striking a metal plate with a heavy hammer to create a sudden and localized disturbance, which generates a series of seismic waves that propagate through the surrounding subsurface.

2.2 Data Acquisition from the Study Area

In this research, a 24 channel PASI GEA-24 seismograph was used in the data acquisition and the data was acquired from 15 traverses. The geophone spacing of 4m was used during the acquisition and both forward and reverse shooting was done for each traverse at positions 0m, 50m and 100m respectively.

A metal plate and sledge hammer was used for the generation of the seismic wave, the hammer was released on the metal plate to create a disturbance that produces wave which is capable of penetrating the Earth, which travels through the Earth penetrating different layers and reflected back to the surface, the waves are detected by the geophones which are strategically placed on the Earth surface which is then transmitted to the laptop.

The data was recorded on a laptop which was connected to the seismograph using a seismic cable, the data was processed using the GEO-STRU software and seismic waves for each traverse were generated. First breaks were picked for each traverse using the software and time-distance graphs plotted for each traverse using the GEO-STRU software. The time distance graphs were analyzed to obtain information about the velocity of the waves as they propagate through the subsurface and also the intercept time of the waves. The thickness of the subsurface layers for each traverse was calculated using the G.R.M method, and with the knowledge of these the mechanical properties of the subsurface which includes: Seismic velocity, Density (ρ), Poisson's ratio (σ), Young's modulus, shear modulus and bulk modulus. The morphology of the subsurface reflectors was generated using the software for each traverse and also the velocity map for each traverse was also generated.

DISCUSSION OF RESULTS

Traverse 1 tables and graphs

Table 3.1 below is the offset values taken during acquisition of data while table 3.2 to table 3.4 are the time distance values. Figures 3.1 to 3.3 are the images of graph generated after each shot.

Table 3.1: Offset Geophones' geometry

	Position X [m]	Position Z [m]
1	4.0	0.0
2	8.0	0.0
3	12.0	0.0
4	16.0	0.0
5	20.0	0.0
6	24.0	0.0
7	28.0	0.0
8	32.0	0.0
9	36.0	0.0
10	40.0	0.0
11	44.0	0.0
12	48.0	0.0
13	52.0	0.0
14	56.0	0.0
15	60.0	0.0
16	64.0	0.0
17	68.0	0.0
18	72.0	0.0
19	76.0	0.0
20	80.0	0.0

21	84.0	0.0
22	88.0	0.0
23	92.0	0.0
24	96.0	0.0

Shots data

Shot 1

Location: Back of College of Science

Source position X 0 [m]

Source position Z 0 [m]

Co-ordinates: Latitude: 5° 34' 12.9" N, Longitude: 005° 50' 30.2" E, Elevation: 3 m

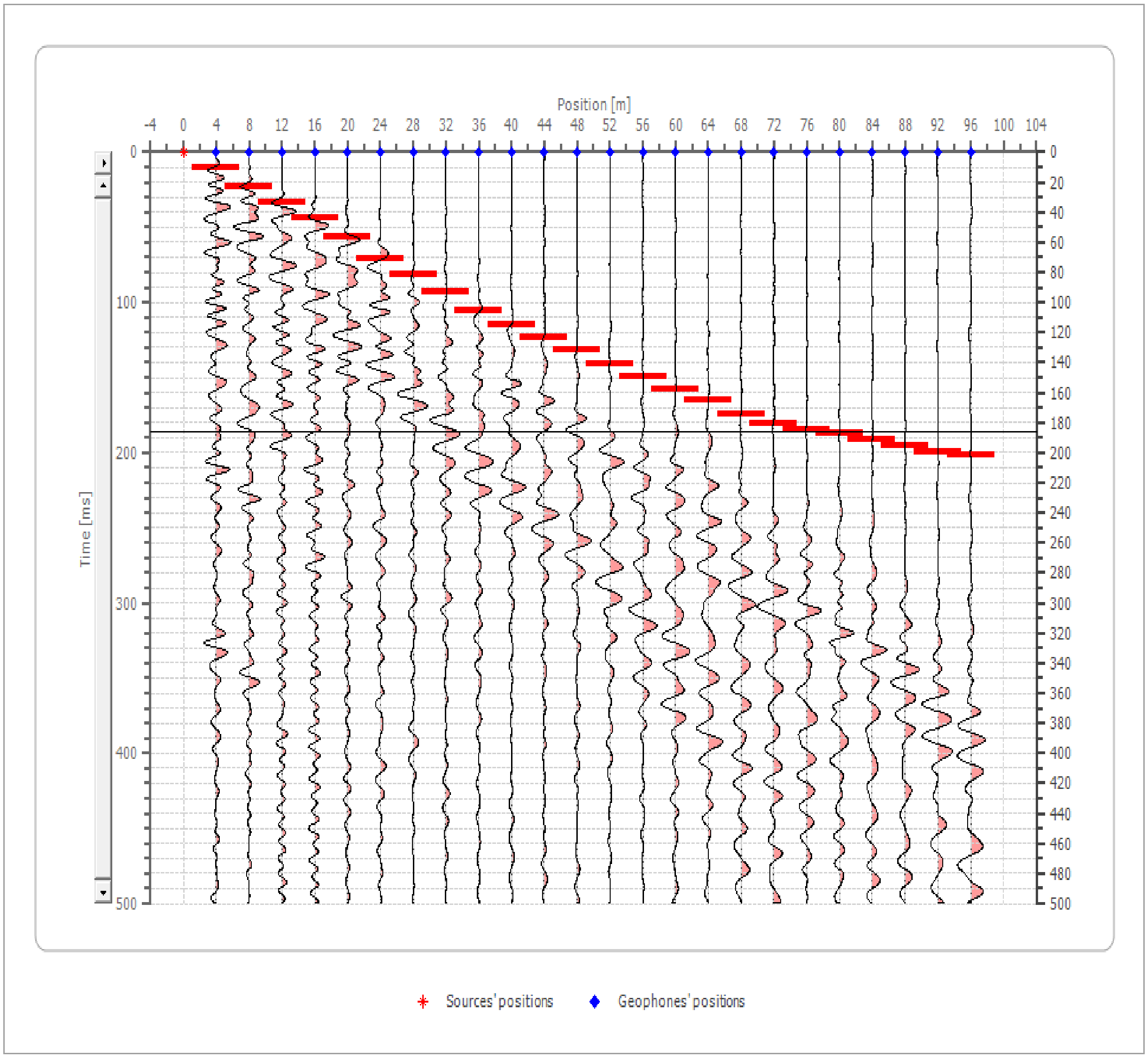

Figure 3. 1: Traverse 1 shot 1

Table 3. 2: Traverse 1- Shot1 travel times

Geophone position [m]	Arrival Time [ms]
4.0	10.1551
8.0	23.2116
12.0	33.3667
16.0	43.5217
20.0	56.5783
24.0	71.0855
28.0	81.2406
32.0	92.8464
36.0	105.9029
40.0	114.6073
44.0	123.3116
48.0	132.0159
52.0	140.7203
56.0	149.4246
60.0	158.1290
64.0	165.3826
68.0	174.0870
72.0	180.7651
76.0	184.9447
80.0	187.0345
84.0	191.2140
88.0	195.3935
92.0	199.5731
96.0	201.6628

Shot 2
Location: Back of College of Science
Source position X 50 [m]
Source position Z 0 [m]
Co-ordinates: Latitude: 5° 34' 12.0" N, Longitude: 005° 50' 31.6" E, Elevation: 3 m

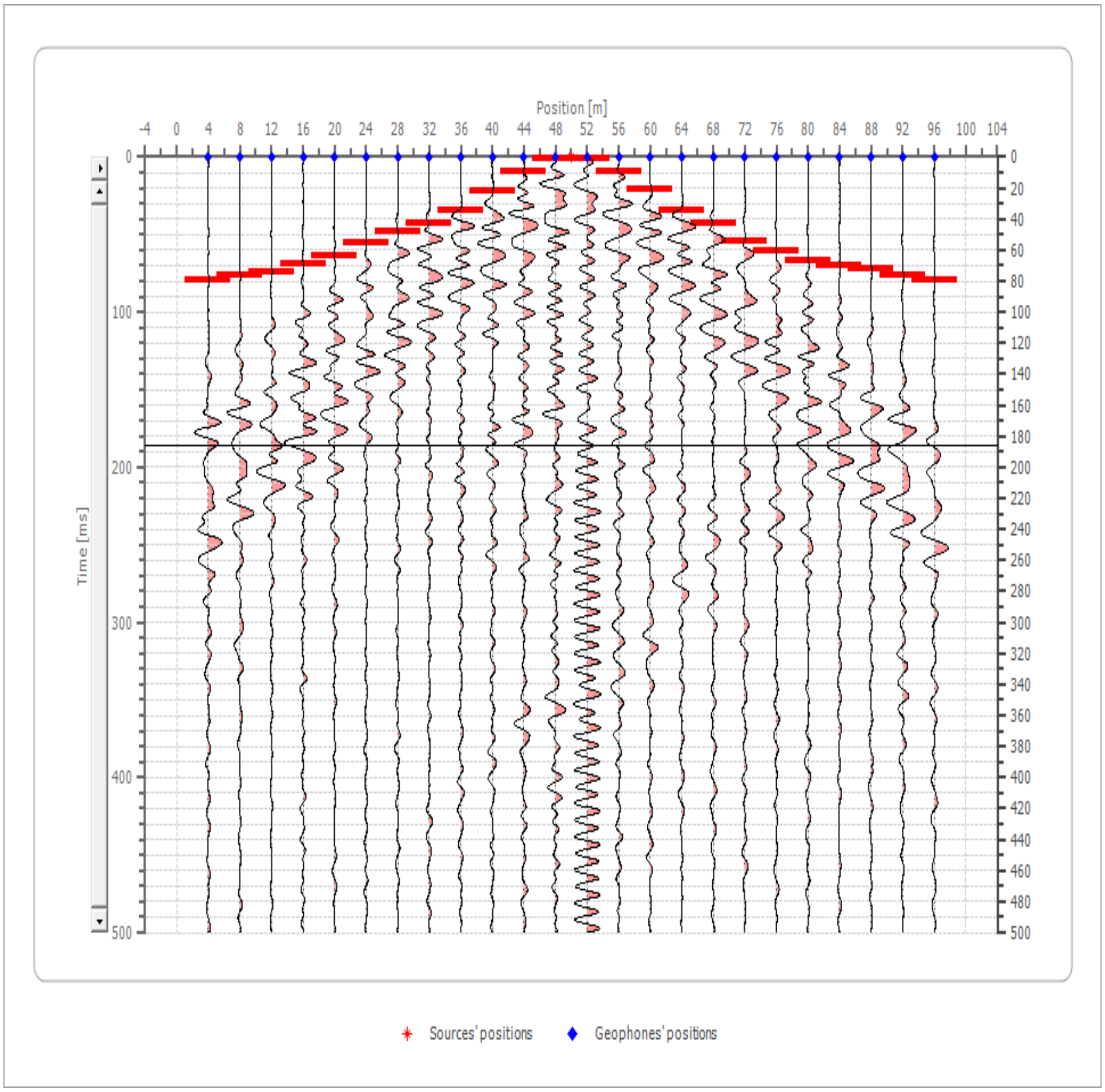

Figure 3. 2: Traverse 1 shot 2

Table 3. 3: Traverse 1- Shot2 travel times

Geophone position [m]	Time [ms]
4.0	79.7596
8.0	76.6249
12.0	73.8386
16.0	68.9624
20.0	63.7380
24.0	55.3789
28.0	48.0647
32.0	42.8403
36.0	34.4812
40.0	21.9426
44.0	9.4040
48.0	1.0449
52.0	1.0449

56.0	9.7523
60.0	20.8977
64.0	34.4812
68.0	42.8403
72.0	54.3340
76.0	60.6033
80.0	66.8727
84.0	70.0073
88.0	72.0971
92.0	76.2766
96.0	79.4113

Shot 3
Location: Back of College of Science
Source position X 100 [m]
Source position Z 0 [m]
Co-ordinates: Latitude: 5° 34' 11.0" N, Longitude: 005° 50' 32.9" E, Elevation: 3 m

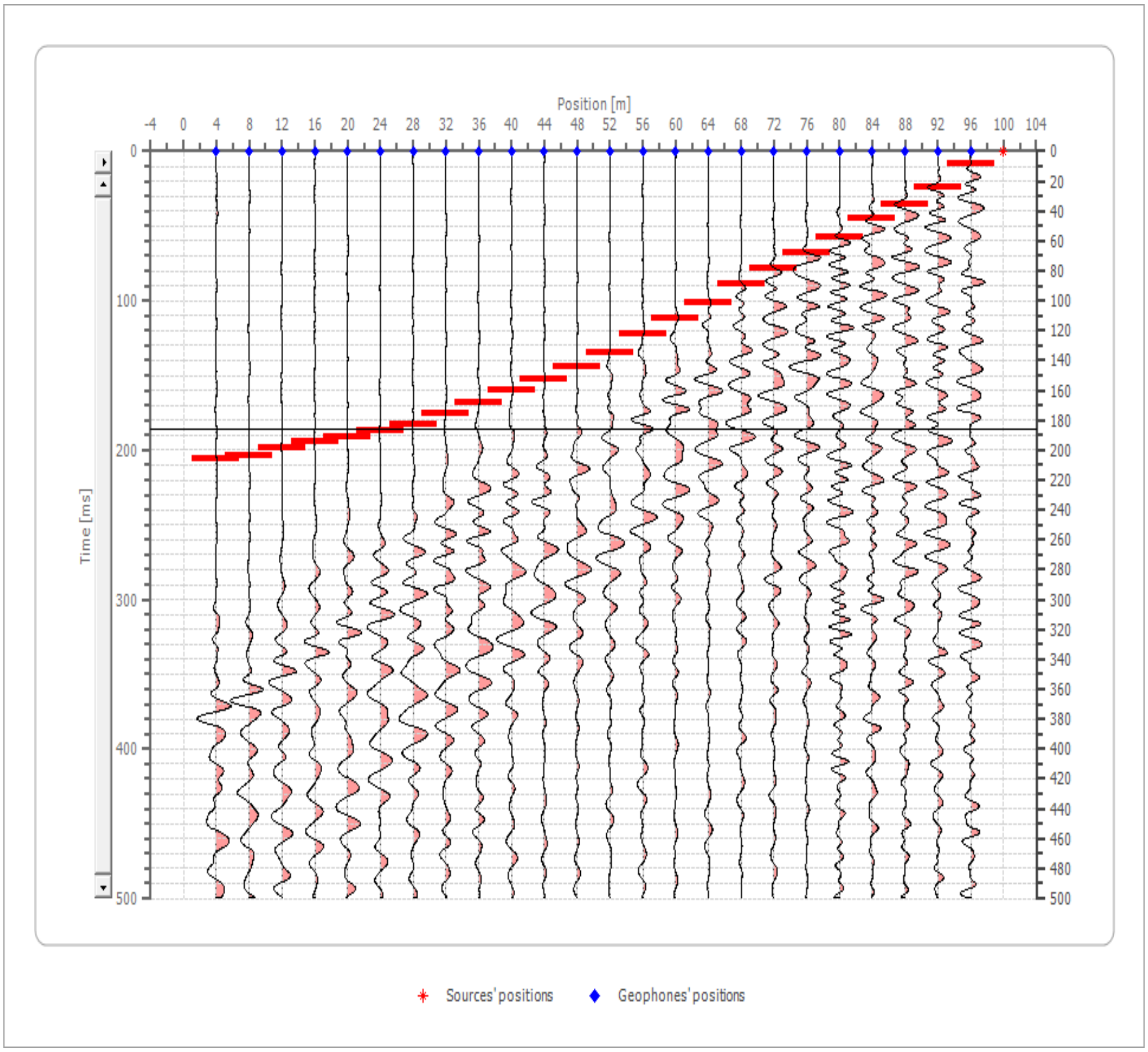

Figure 3. 3: Traverse 1 shot 3

Table 3. 4: Traverse 1- Shot3 travel times

Geophone position [m]	Time [ms]
4.0	205.8424
8.0	203.7526
12.0	198.5282
16.0	194.3487
20.0	191.2140
24.0	187.0345
28.0	182.8549
32.0	175.5407
36.0	168.2265
40.0	159.8674
44.0	152.5532
48.0	144.1942
52.0	134.7902
56.0	122.2516
60.0	111.8027
64.0	101.3539
68.0	88.8152
72.0	78.3664
76.0	67.9175
80.0	57.4687
84.0	44.9301
88.0	35.5261
92.0	24.0324
96.0	8.7043

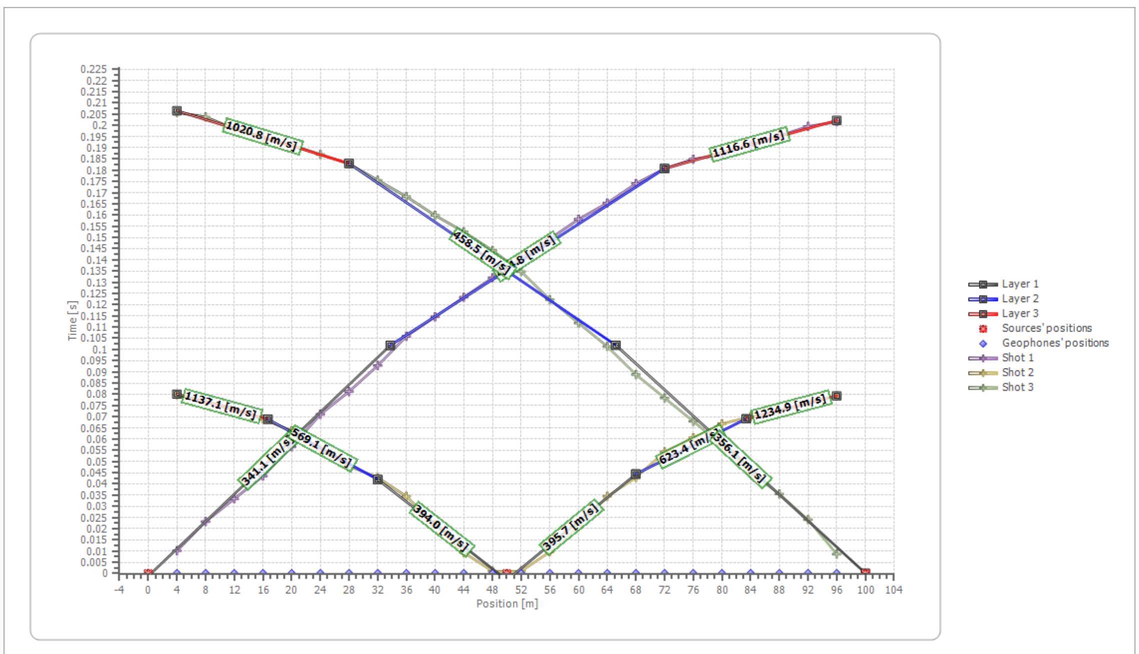

Figure 3. 4: Traverse1 travel time curve for the 3 shots showing the 3 subsurface layers

Table 3. 5: Other geotechnical parameters

	Layer n. 1	Layer n. 2	Layer n. 3
Poisson's ratio	0.35	0.35	0.35
Density [kg/m³]	1800.00	1800.00	1800.00
Vp [m/s]	371.73	468.87	1068.82
Vs [m/s]	178.58	225.24	513.44
G0 [MPa]	57.40	91.32	474.53
Ed [Mpa]	248.74	395.71	2056.28
M0 [MPa]	191.33	304.39	1581.75
Ey [Mpa]	154.98	246.56	1281.22

G0: Shear modulus;
Ed: Oedometric modulus;
M0: Bulk modulus;
Ey: Young's modulus;

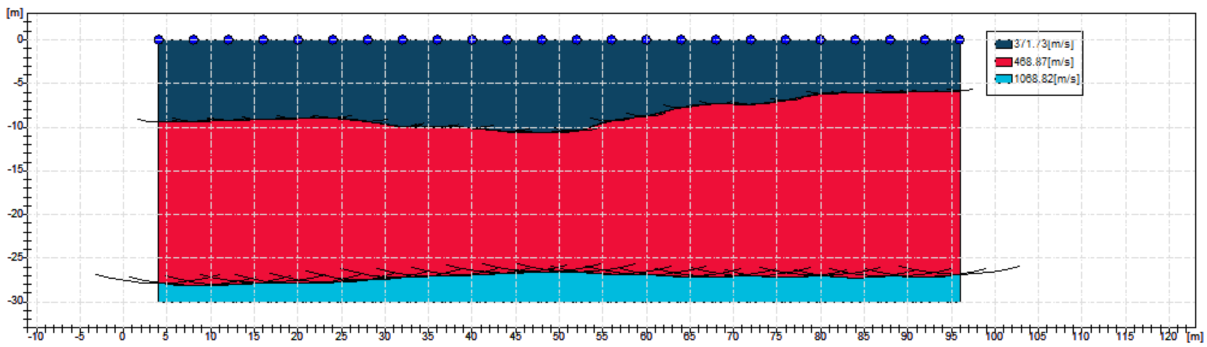

Figure 3. 5: Morphology of the subsurface reflectors (Traverse 1)

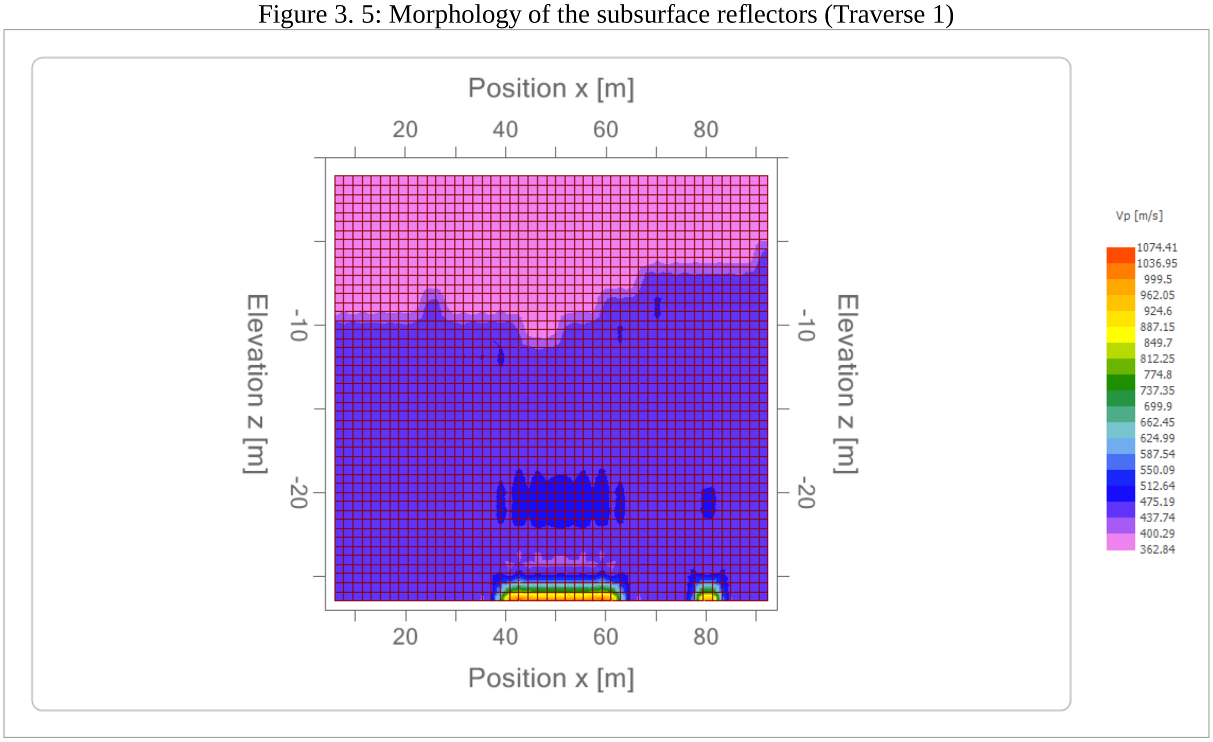

Figure 3. 6: Velocity map of the subsurface (Traverse 1)

DISCUSSION

The seismic refraction method has been used to characterized the subsurface in FUPRE, Okuokoko environment. Using a 3 shot point's survey configuration along the traverses, three layers were delineated across the fifteen (15) traverses of the study areas with a velocity range of approximately 220.5 m/s – 371.7 m/s for the first layer, the second layer has a velocity range of approximately 381.7 m/s – 440.8 m/s, and the last layer has a velocity range of approximately 902.1 m/s – 1196.2 m/s. The lithology of the layers is inferred from the velocity of the three levels to be loose and unconsolidated sand for the top layer, a mixture of clay and sand for the second layer, and wet coarse sand for the third layer. The presence of silt in the geologic layers is also indicated by the poisson's ratio of the three layers, which is around 0.35 for the 15 traverses. The first layer young's modulus ranges from around 54.53 mpa – 154.98 mpa for all the traverses also suggests loose sand, the second layer young's modulus also range from about 163.40mpa – 246.56 mpa suggest sandy clay as the main material, and the third layer young's modulus ranges from about 912.00 mpa – 1604.81 mpa suggests dense sand. The shear moduli of layers one and two indicate that they are composed of silty sand, with shear moduli range of around 20 mpa – 57 mpa and 62 mpa – 91 mpa, respectively. Layer three's shear modulus indicates that it is formed of dense sand with a shear modulus range of 338.00 mpa – 594.38 mpa.

CONCLUSION

Based on the acquired data from the seismic profiles, it appears that the subsurface geology is quite strong, as indicated by the high values of the Young's modulus (Ey), Shear modulus (G0), and Bulk modulus (M0) for all three layers from the traverses.

Young's modulus is a measure of a material's stiffness, and the high values for each layer indicate that the subsurface geology is very resistant to deformation. Similarly, the Shear modulus is a measure of a material's resistance to shear deformation, and the Bulk modulus is a measure of a material's resistance to volume change under pressure. The high values for these parameters indicate that the subsurface geology is strong and resistant to deformation under stress.

Additionally, the Poisson's ratio for all three layers is 0.35, which indicates that the subsurface geology is relatively incompressible and resistant to volume changes.

The density of the subsurface geology is 1800 kg/m³ for all three layers, which is a relatively low density, indicating that the subsurface geology is composed of sedimentary rocks rather than denser igneous or metamorphic rocks.

The seismic wave velocities for each layer are also high, with Vp and Vs values increasing with depth. This suggests that the subsurface geology becomes increasingly compact and homogeneous with depth, potentially indicating the presence of solid rock at greater depths.

Overall, based on the seismic profile data acquired, it appears that the subsurface geology is strong, dense, and resistant to deformation under stress, likely composed of sedimentary rocks, and potentially contains solid rock at greater depths. For construction purposes layer three is best to erect any structure.

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