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Integration of seismic refraction, electrical resistivity and geotechnics in characterizing near surface soil: a case study of Niger Delta Region

Okezie Uchegbulam^{1*}, Elijah Ovie Izeze²

ABSTRACT

Water saturated near surface soil of Niger Delta's sedimentary terrain was characterized by using seismic refraction, electrical resistivity and geotechnical data due to topographic complexities that may cause geotechnical instabilities. Seismic refraction survey occupied two traverses, the two profiles revealed a 3-layered subsurface structure having different mechanical properties with compressional wave V_p and shear wave V_s velocities that increased with depth. Compressional wave increased from 270.87m/s in the first layer to 921.18m/s in the third layer, while shear wave increased from 130.12 m/s in the first layer to 442.52 m/s in the third layer. The electrical resistivity ρ result delineated five geo-electric layers with HKQ curve of resistivity $Q_1 > Q_2 < Q_3 > Q_4 > Q_5$ indicating loose dry fine sand with resistivity $\leq 3684.7\Omega m$ at the depth of about 0 – 7m beneath the surface and saturated medium coarse sand of resistivity $\leq 442.52\Omega m$ at the depth of 38m and beyond. Geotechnical parameters derived from seismic sections shows that Young's modulus increased from 82.29MPa in the first layer to 951.71MPa in the third layer. Likewise, shear modulus recorded an increment of 30.48MPa in the first layer to 352.48MPa in the third layer. Bulk modulus also increased from 101.59MPa in the first layer to 1174.95MPa in the third layer. Poisson's ratio and density are about 0.35 and 1800kg/m³ respectively in the three layers because near surface soil of the area is composed of lateritic soil with high percentage of sand. The area has porosity of 0.31 indicating sand materials. The increment of the wave velocities and elastic constants with depth is an indication of more consolidation of materials beneath the surface. The implication of the results is that foundation for superstructures should get to the second or third layer at depth ($\geq 10m$) beneath the surface where earth materials are stiffer for structural stability.

Keywords: Near Surface; Refraction; Resistivity; Seismic; Stiffness.

1. INTRODUCTION

Structural defects are often traced to faulty foundation in the Niger Delta region where the near surface soil is porous and water saturated. The nature of the soil equally impact road construction, underground storage tanks, and other engineering

works that involve soil. This is in addition to its changes overtime due to atmospheric fluctuations and local geological impacts that the study of the near surface soil of the area cannot be overemphasized. There are serious consequences if there are no pre-knowledge of the local soil properties and when such information are ignored before construction works are carried out due to the complexities of the subsurface and varied topography in some areas (Akinrinmade and Uko, 2014; Balogun et al., 2023). This study stresses the importance and necessity of accurate soil characterization to lessen the risks of tilting of gigantic structures, foundation cracking, road failures, and other structural defects prevalent in the region. It can also be utilized as a proxy to describe the behavior of undersurface media in engineering and mining sites qualitatively (Eze et al., 2026; Emmanuela et al., 2023). It points out the advantages of integrated seismic refraction and geotechnical investigation over traditional methods of soil tests for comprehensive soil characterization. Seismic refraction, which is the use of acoustic wave to probe the subsurface offers a non-invasive, effective and efficient geophysical method to investigate the subsurface without disturbing the natural positions of soil particles (Reynolds, 2011). From the analysis of these elastic waves as they travel through different layers of soil and rock types, their velocities and arrival times can be known. The arrival times and velocities of these waves have direct link to the distance of earth materials beneath surface, how rigid, dense, and elastic the subsurface materials are, which will eventually reveal how they will respond when stress is applied upon them (Aka et al., 2018). It offers a better option to drilling or excavation of soils from their natural position; which can be expensive, time consuming and sparse samples are often taken in vast areas. These will result in missing vital hidden features of the subsurface and lead to serious errors in interpretation (Ighere, 2024). Other workers utilized seismic method successfully to probe the near surface (Airen and Osifo, 2019; Aka and Agbasi, 2022; Allo et al., 2012). The work done by Ighere (2024) near the area revealed that the first two subsurface layers have low shear strength of 33.61 MPa and 72.99 MPa respectively, indicating poor bearing capacity, while the third layer had 244.4 MPa which is fairly compressible and suitable for construction. This points to the fact that geology is localized due to topographical complexities, hence the need to regularly carry out geophysical survey before construction work. However, seismic refraction is vulnerable to environmental noise and challenging site conditions, and its interpretations become ambiguous in complex geological formations (Adegbite et al., 2022), hence the need to complement it with electrical resistivity investigation.

Electrical resistivity method has been successfully used by several researchers to study environmental problems and groundwater studies. The effectiveness of electrical methods for the characterization of oil contaminated subsoil has been reported by several works (Vanhala *et al.*, 1992, Atekwana *et al.*, 2000, Osella *et al.*, 2002). Ayolabi (2005) used geoelectric method in the evaluation of Olushosun landfill site in Southwest Nigeria and its implication on groundwater. Atakpo and Ayolabi (2008) evaluated the aquifer vulnerability and the protective capacity in some oil producing communities of Western Niger Delta using geo-electric method. The longitudinal conductance calculations showed that some soils have high protective capacity, which will prevent contaminants from infiltrating into the fresh water aquifer, while some areas have low protective capacity and are prone to pollution.

Geotechnical investigation which involves the application of geological and geophysical principles to investigate engineering behaviors and problems of soil as well as solving them is incorporated in this study to have detailed information of soil properties beneath the surface. Soil properties are basically divided into physical characteristics and geotechnical parameters. Physical properties comprises texture, structure, porosity, and moisture content. Geotechnical parameters such as Poisson's ratio, shear strength, permeability, compressibility, and bearing capacity are important for delineating soil stability and its response to stress. The evaluation of soil properties is essential to understanding how soil interacts with natural forces and human activities (Olaseni and Onifade, 2024). Proper knowledge of soil properties help engineers and environmental Scientists make informed decisions regarding land use and development (Nwankwo, 2018; Ewienure et al., 2025).

Niger delta is a sedimentary terrain environment, the area consists of fresh water swamp, coastal plain sands, mangrove swamps, and Sombreiro-Warri plains (Omo – Irabor and Oduyemi, 2006). Water table in the study area is close to the surface, approximately 4 to 5 m beneath the surface (Uchegbulam et al., 2022). These makes the near surface soil to be loose and wet almost throughout the year. The top soil also tends to be slippery when wet under a load where there is intercalation of clay hence; a detailed knowledge of the near surface soil, about 1-30m depth is necessary for effective construction and other engineering works. Most work done in the area either utilized seismic refraction, electrical resistivity or geotechnical investigation of soil, hence this study integrated the three methods for better soil characterization.

The Study Area

The study area is situated in Kwale area of Western Niger Delta, Southern Nigeria. Kwale has coordinates range of 5°41' 27. 83"N – 5°42' 39. 24"N and 6°24' 2.47"E – 6°26' 28.68"E. The terrain of the area is generally flat and undulating, with an average elevation of less

than 21 meters above sea level, characteristic of the coastal lowland environment. The area has gas fields, oil and gas producing companies like Agip and Total are operating in the city. The map of the study area is displayed in Figure 1.

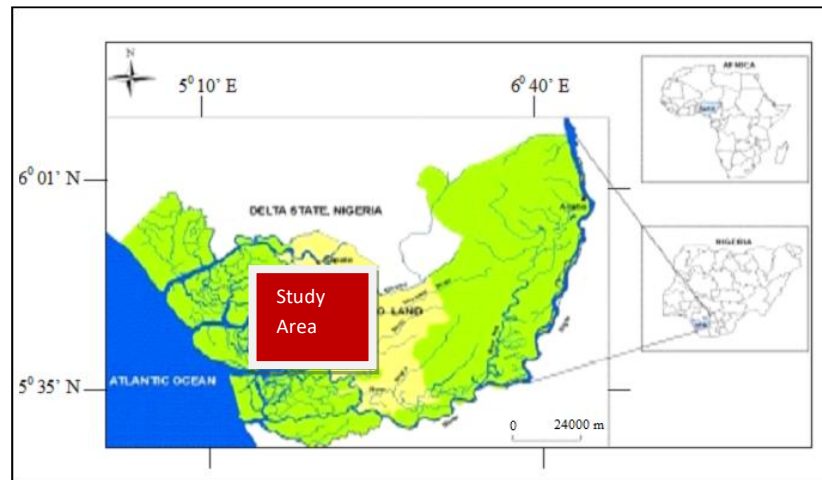


Figure 1. Map of Delta State showing the Study Area (After Odemerho, 2007).

Principles of Seismic Refraction Survey

Seismic refraction investigation utilizes the fact that body waves (Primary-P and Secondary-S waves) travel with different velocities in different rocks. It is based on the principle of elastic wave propagation and Snell's law of refraction. P-waves involve particle motion parallel to the direction of wave propagation, causing compression and dilation of the material. S-waves propagate with particle motion perpendicular to the direction of wave propagation. S-waves travel slower than P-waves and cannot propagate through liquids (as liquids have no shear modulus).

In Seismic refraction, P waves are the most important because they are the first to arrive as refraction is concerned with first arrivals. The velocity of these seismic waves depends on the elastic constants and density of the material through which they travel (Burger et al., 2020).

When a seismic energy strikes a boundary between different velocities at a critical angle, head wave is set up which travels along the interface at the higher of the two velocities. The energy from the head wave is propagated to the surface as a seismic refraction (Lowrie, 2007).

The velocity of P-wave, V_p is given by

$$V_p = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} \quad (1)$$

where,

k = bulk modulus

μ = shear modulus

ρ = density

Depth to a refractor (bedrock) is given by

$$Z = \frac{x_c}{2} \sqrt{\frac{v_2 - v_1}{v_2 + v_1}} \quad (2)$$

$$\text{or } Z = \frac{t_0 v_2 v_1}{2\sqrt{(v_2 - v_1)}} \quad (3)$$

where

Z = depth to a refraction

x_c = critical distance

t_0 = intercept time

v_1 = velocity of first layer

v_2 = velocity of second layer

Geology and Hydrogeology of the study Area

The Niger Delta region is a geologic area in West Africa also known as the Niger Delta basin. The province is in the Gulf of Guinea and extends throughout the Niger Delta. The Niger Delta province is an oil producing region in Southern Nigeria, West Africa.

Niger Delta has three stratigraphic units; from top to bottom-Benin, Agbada and Akata formations (Klett et al., 1997). Benin formation is the main aquifer unit, with coarse to medium grained sand. Agbada has mixture of sandstone and shale. The lithology of Akata formation is basically shale. Kwale is in Sombreiro – Warri deltaic plain, which is part of Benin formation. The aquifer is largely phreatic, these formations are overlain by various types of quaternary deposits made up of topsoil, red laterite, clay, fine sand, medium sand and coarse sand in form of pebbles. The thickness is variable but generally exceeds 6000ft (Egbai, 2012). The study area consists of fresh water swamp, coastal plain sands, mangrove swamps, and Sombreiro-Warri plains (Omo – Irabor and Oduyemi, 2006). The water table in the study area is close to the surface, approximately 4 to 5 m beneath the surface.

2. METHODOLOGY

The seismic refraction survey was designed to investigate the undersurface soil properties along two traverses, each covered a total length of 92 meters. The layout consist of 24 geophones arranged at 4-meter intervals to provide good lateral resolution. Vertical Electrical Sounding (VES) data using Schlumberger configuration for better vertical resolution and Electrical Resistivity Tomography (ERT) data were also acquired in the same site (Figure 2).

Data Acquisition

Seismic refraction data were acquired using a 24-channel PASI GEA seismograph connected to 24 geophones spaced at 4 meters apart, giving a total spread of 92 meters.

Shots were taken at three different source locations (near-end 4m, mid-point 46m, and far-end 92 m) along each traverse to obtain multiple ray paths through the subsurface layers. After every shot, the recorded waveforms were reviewed in the field to ensure signal quality, amplitude, and polarity consistency across the channels.

Data Processing

Acquired seismic data were exported from the seismograph to GEOSTRU software for processing and interpretation. The first step involved identifying and picking the first arrival times of seismic waves from each seismic trace. The travel times were then plotted against the corresponding source-to-receiver distances to produce time–distance graphs (T–X plots).

From the slopes of the linear segments on the T–X plots, the seismic velocities of the subsurface layers were determined. The intercept-time method was used to calculate the depths to refracting layers beneath each traverse. The velocities and depths obtained were used in interpreting the subsurface structures based on the geology revealed. The base map of the study area is displayed in Figure 2 below.

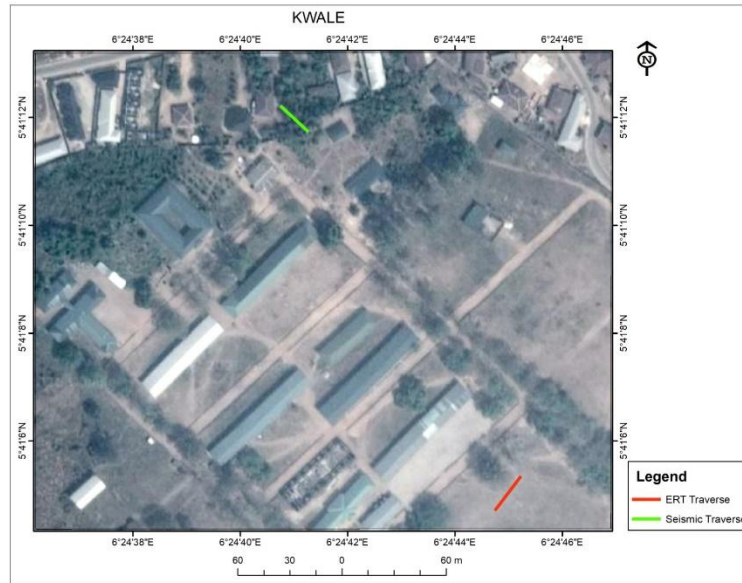


Figure 2. Base map of the study area showing Seismic refraction and ERT/VES traverses.

3. RESULTS AND DISCUSSION

The results are presented as Tables and Figures. Generalized Reciprocal Method (GRM) was employed in analyzing seismic sections. Tables 1 and 2 are shot 1 travel time and shot 3 travel time of traverse 1 respectively. While Table 3 is the interpretation with GRM. Figures 3 and 4 are velocity map and morphology of subsurface reflectors and respectively. Table 4 is the seismic velocities and geotechnical data for traverse 1.

Table 1. Traverse 1 shot 1 travel times.

Geophone position [m]	Time [ms]
0.0	2.8604
4.0	15.7322
8.0	25.7436
12.0	35.7550
16.0	45.7664
20.0	55.7778
24.0	65.7892
28.0	77.2308
32.0	85.8120
36.0	95.8234
40.0	104.4046
44.0	114.4160
48.0	122.9972
52.0	130.1482
56.0	138.7294
60.0	147.3106
64.0	155.8917
68.0	161.6125
72.0	165.9031
76.0	170.1937
80.0	173.0541

84.0	177.3447
88.0	180.2051
92.0	184.4957

Table 2. Traverse 1 shot 3 travel times

Geophone position [m]	Time [ms]
0.0	213.0997
4.0	207.3789
8.0	201.6581
12.0	195.9373
16.0	191.6467
20.0	187.3561
24.0	183.0655
28.0	177.3447
32.0	171.6239
36.0	165.9031
40.0	155.8917
44.0	145.8804
48.0	137.2992
52.0	125.8576
56.0	115.8462
60.0	105.8348
64.0	95.8234
68.0	82.9516
72.0	70.0798
76.0	58.6382
80.0	45.7664
84.0	34.3248
88.0	21.4530
92.0	5.7208

Table 3. Interpretation with the method G.R.M. (Transverse 1)

	Layer n. 1	Layer n. 2	Layer n. 3
G= 0.0 [m]	3.3	26.5	--
G= 4.0 [m]	2.8	26.2	--
G= 8.0 [m]	2.3	26.0	--
G= 12.0 [m]	2.4	25.4	--
G= 16.0 [m]	2.5	25.2	--
G= 20.0 [m]	2.6	24.9	--
G= 24.0 [m]	2.7	24.7	--
G= 28.0 [m]	3.9	23.8	--
G= 32.0 [m]	4.5	23.1	--
G= 36.0 [m]	5.3	22.3	--
G= 40.0 [m]	5.0	22.2	--

G= 44.0 [m]	5.0	21.9	--
G= 48.0 [m]	5.0	21.6	--
G= 52.0 [m]	4.2	21.8	--
G= 56.0 [m]	3.9	21.6	--
G= 60.0 [m]	3.6	21.5	--
G= 64.0 [m]	3.3	21.3	--
G= 68.0 [m]	1.9	21.8	--
G= 72.0 [m]	0.1	22.5	--
G= 76.0 [m]	0.0	22.3	--
G= 80.0 [m]	0.0	21.8	--
G= 84.0 [m]	0.0	21.7	--
G= 88.0 [m]	0.0	21.2	--
G= 92.0 [m]	0.0	21.0	--
Velocity [m/sec]	295.1	431.5	951.3
Description			

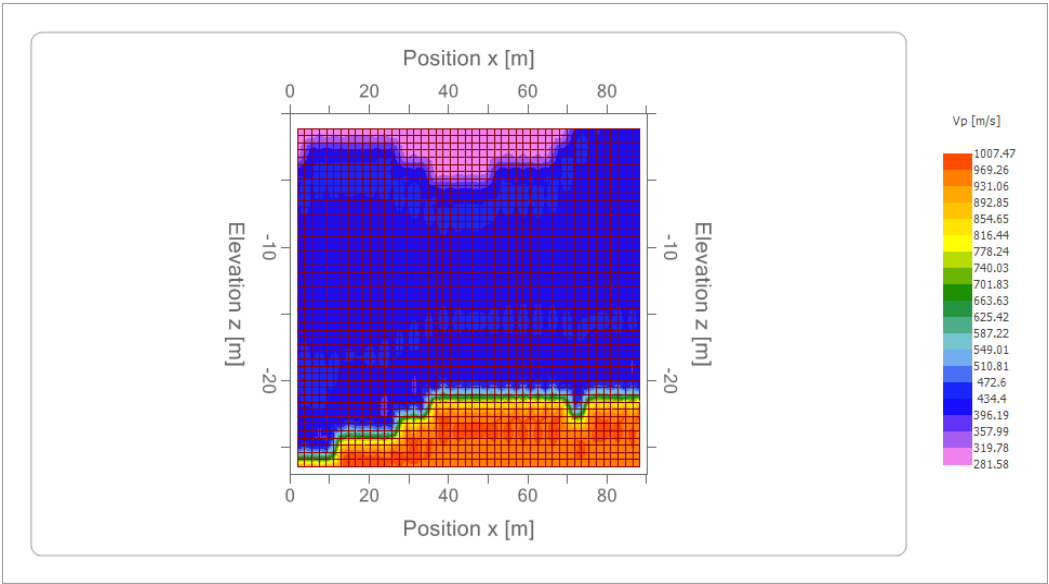


Figure 3. Velocity map of the subsurface (Traverse 1)

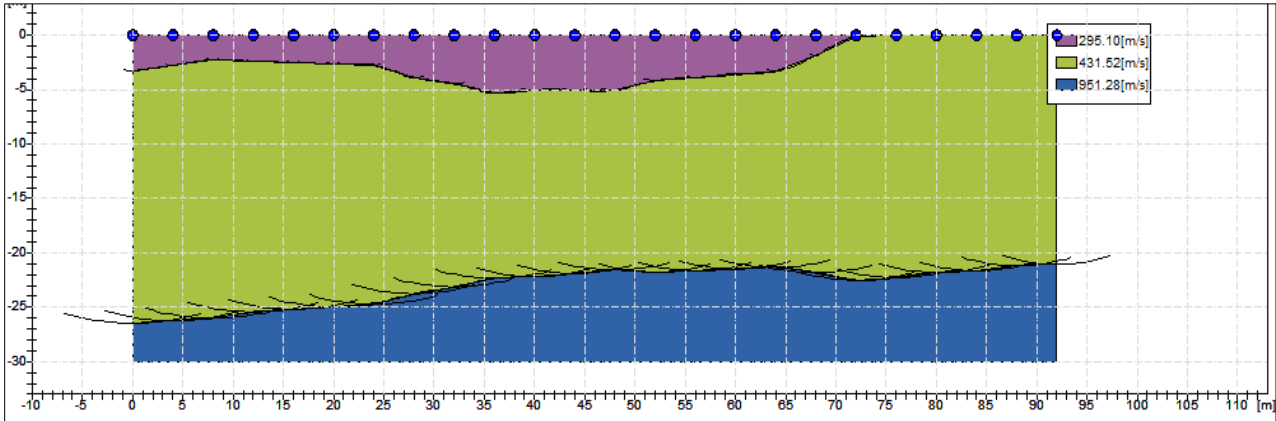


Figure 4. Morphology of the subsurface reflectors (Traverse 1)

Table 4. Geotechnical parameters of Traverse 1

	Layer n. 1	Layer n. 2	Layer n. 3
Poisson's ratio	0.35	0.35	0.35
Density [kg/m ³]	1800.00	1800.00	1800.00
Vp [m/s]	295.10	431.52	951.28
Vs [m/s]	141.76	207.29	456.98
G0 [MPa]	36.17	77.35	375.89
Ed [Mpa]	156.75	335.17	1628.86
M0 [MPa]	120.58	257.82	1252.97
Ey [Mpa]	97.67	208.84	1014.91

G0: Shear modulus;

Ed: Oedometric modulus;

M0: Bulk modulus;

Ey: Young's modulus;

Traverse (Profile) 2 Results

Transverse 2 shot 1 travel time and shot 3 are shown in Tables 5 and 6. Table 7 is the interpretation with GRM. Figures 5 and 6 shows the velocity map and morphology of subsurface reflectors respectively. Table 8 is the seismic velocities and geotechnical data of traverse 2.

Table 5. Traverse 2 Shot 1 travel times

Geophone position [m]	Time [ms]
0.0	4.2906
4.0	15.7322
8.0	30.0342
12.0	41.4758
16.0	51.4872
20.0	61.4986
24.0	72.9402
28.0	80.0912
32.0	88.6724
36.0	97.2536
40.0	105.8348
44.0	114.4160
48.0	122.9972
52.0	131.5784
56.0	140.1596
60.0	150.1710
64.0	155.8917
68.0	160.1823
72.0	165.9031
76.0	171.6239
80.0	175.9145
84.0	180.2051
88.0	183.0655
92.0	187.3561

Table 6. Traverse 2 Shot 3 travel times

Geophone position [m]	Time [ms]
0.0	211.6695
4.0	207.3789
8.0	203.0883
12.0	197.3675
16.0	193.0769
20.0	187.3561
24.0	181.6353
28.0	177.3447
32.0	171.6239
36.0	165.9031
40.0	155.8917
44.0	145.8804
48.0	135.8690
52.0	127.2878
56.0	117.2764
60.0	107.2650
64.0	97.2536
68.0	84.3818
72.0	70.0798
76.0	58.6382
80.0	47.1966
84.0	35.7550
88.0	20.0000
92.0	5.7208

Table 7. Interpretation with the method G.R.M. (traverse 2)

	Layer n. 1	Layer n. 2	Layer n. 3
G= 0.0 [m]	4.6	25.6	--
G= 4.0 [m]	4.2	25.9	--
G= 8.0 [m]	3.8	26.1	--
G= 12.0 [m]	3.3	25.9	--
G= 16.0 [m]	3.4	25.7	--
G= 20.0 [m]	3.6	25.1	--
G= 24.0 [m]	3.9	24.4	--
G= 28.0 [m]	4.4	23.7	--
G= 32.0 [m]	4.9	23.0	--
G= 36.0 [m]	5.4	22.2	--
G= 40.0 [m]	5.1	22.1	--
G= 44.0 [m]	4.9	22.0	--
G= 48.0 [m]	4.7	21.9	--
G= 52.0 [m]	4.7	21.5	--
G= 56.0 [m]	4.4	21.4	--
G= 60.0 [m]	4.4	21.1	--
G= 64.0 [m]	3.7	21.4	--

G= 68.0 [m]	2.2	22.3	--
G= 72.0 [m]	0.8	23.2	--
G= 76.0 [m]	0.0	23.5	--
G= 80.0 [m]	0.0	23.2	--
G= 84.0 [m]	0.0	23.0	--
G= 88.0 [m]	0.0	22.4	--
G= 92.0 [m]	0.0	22.3	--
Velocity [m/sec]	270.9	452.3	921.2
Description			

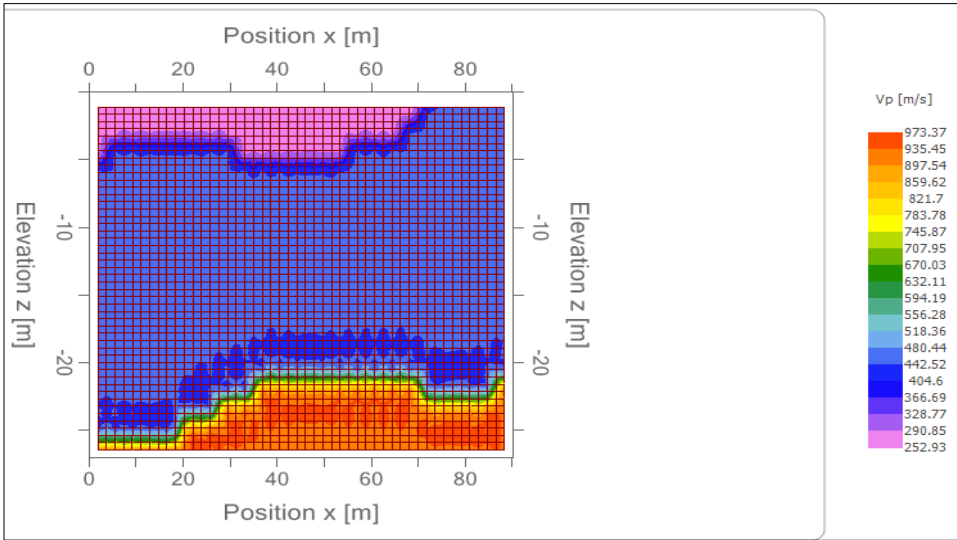


Figure 5. Velocity map of the subsurface (Traverse 2)

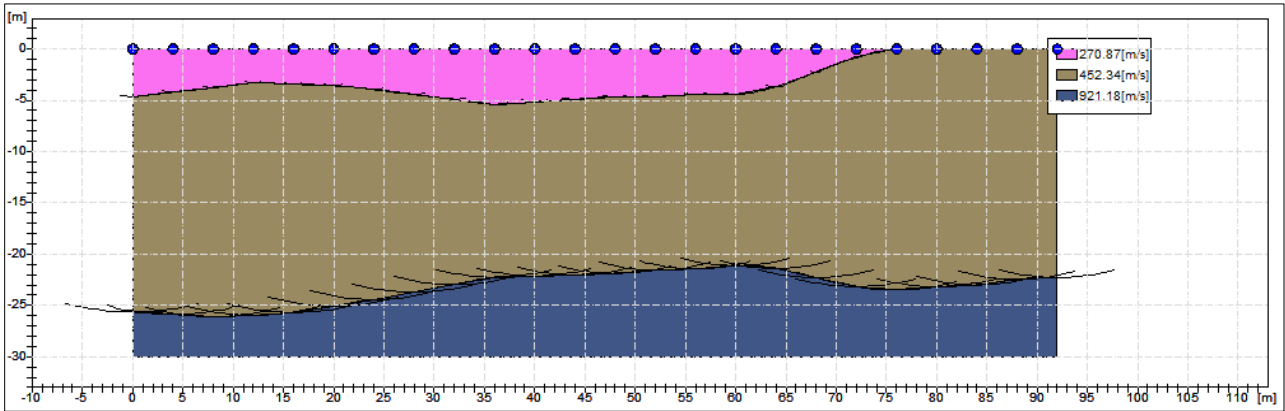


Figure 6. Morphology of the subsurface reflectors (Traverse 2)

Table 8. Geotechnical parameters of Traverse 2

	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]	270.87	452.34	921.18
Vs [m/s]	130.12	217.30	442.52
G0 [MPa]	30.48	84.99	352.48
Ed [Mpa]	132.07	368.30	1527.43

M0 [MPa]	101.59	283.31	1174.95
Ey [Mpa]	82.29	229.48	951.71

G0: Shear modulus;

Ed: Oedometric modulus;

M0: Bulk modulus;

Ey: Young's modulus;

Table 4 is the summary of elastic constants of layers for traverse 1. The summary of the elastic constants of the layers for traverse 2 are shown in Table 8. Summary of the results of P-wave and S-wave velocities of layers of the two profiles are shown in Table 9.

Table 9. Summary of results showing velocities of layers in Traverses1 and 2

Traverse 1:		
Layer	V_p(m/s)	V_s(m/s)
1	295.10	141.76
2	431.52	207.29
3	951.28	456.98
Traverse 2		
Layer	V_p(m/s)	V_s(m/s)
1	270.87	130.12
2	452.34	217.30
3	921.18	442.52

Interpretation of seismic sections

Generalized Reciprocal Method (GRM) was employed in analyzing the two seismic profiles to delineate the nature of subsurface soil. The two profiles revealed a three-layered subsurface structure with compressional seismic wave velocities V_p and elastic constants that increases with depth (Tables 4 and 8). The increment of the compressional wave velocities and elastic constants of earth materials with depth is an indication of more consolidation of materials beneath the surface. These can be explained as compressional wave travels faster in compact materials than in loose soils. Shear wave V_s equally maintain increased velocity with depth but cannot be used for interpretation of the true nature of the materials beneath the surface because of its slow arrival time. Moreover, it terminates when it encounters liquid and gaseous media. It equally suggests progressive improvement in soil stiffness and bearing capacity. The velocities of the body waves in the two profiles confirms the progressive compactness of materials within the depth of investigation (Table 9).

Interpretation of elastic constants derived from seismic section

Poisson's ratio and density of earth materials maintains constants values of 0.35 and 1800 kg/m³ respectively in the three layers. These can be attributed to the predominantly soil structure in the area which are basically fine-grained to coarse sands at near surface. Poisson's ratio ranges from 0.05 to 0.02 for most non-indurated elastic sedimentary rocks, depending on porosity and weathering. It further confirms the litho-stratigraphy data of the area (Figure 8) and the permeability results obtained from the laboratory test of soils of near the area which is 6.00×10^{-5} m/sec and porosity of 0.31 (Uchegbulam et al., 2022; Uchegbulam and Ugbe, 2021). The knowledge of Poisson's ratio prior to construction of structures that rest on ground is vital, because it gives strain-rate of materials when stress is applied. Young's modulus and shear modulus increases with depth, this is as result of more compaction as depth increases since the materials becomes stiffer with increase in depth. Top soils tends to be loose and dry as a result of exposure to weather changes near the surface, while materials buried more deep in the subsurface are more compact and saturated with water. The implication is that for foundation of gigantic structures to be firm and stable, they must get to the depth where there is compaction of sand materials, especially in the study area where the soil is water saturated. Oedometric modulus increases with depth, this is understandably because its value tends to increase with stress. The overburden adds stress to materials beneath the surface, so the value generally will increase with depth. Bulk modulus of elasticity, which gives the indication of squeezability of material when stress is applied also increases with depth due to the nature of earth materials beneath the surface since materials tends to be stiffer as depth increases. Oghonyon *et al.*, (2015) in their work on geotechnical attributes of Niger Delta soils, Warri environs reported that grain size distribution are mainly sand. Earth materials at depth (20–50m) tend to be brittle when stress is applied since temperature near the surface is low.

Electrical Resistivity Interpretation

The results of Vertical Electrical Sound data is shown in Table 10.

Table 10. VES Results of VES point 1

AB/2	MN/2	R	K	AR
1	0.25	590.4	6.28	3707.712
2	0.25	92.2	25.12	2316.064
3	0.25	32.16	56.54	1818.326
4	0.25	20.81	100.54	2092.237
6	0.25	9.21	226.2	2083.302
6	0.5	16.04	113.1	1814.124
9	0.5	6.742	254.47	1715.637
12	0.5	3.625	452.4	1639.95
15	0.5	2.264	706.86	1600.331
15	1	4.265	353.45	1507.464
20	1	2.041	628.32	1282.401
25	1	1.259	981.75	1236.023
32	1	0.8063	1608.5	1296.934
40	1	0.5757	2513.28	1446.895
40	2.5	0.7504	1005.31	754.3846
50	2.5	0.4965	1570.8	779.9022
65	2.5	0.2619	2654.65	695.2528
80	2.5	0.2569	4021.24	1033.057
100	2.5	0.1716	3141.6	539.0986

The geoelectric curve of the result is shown in Figure 7.

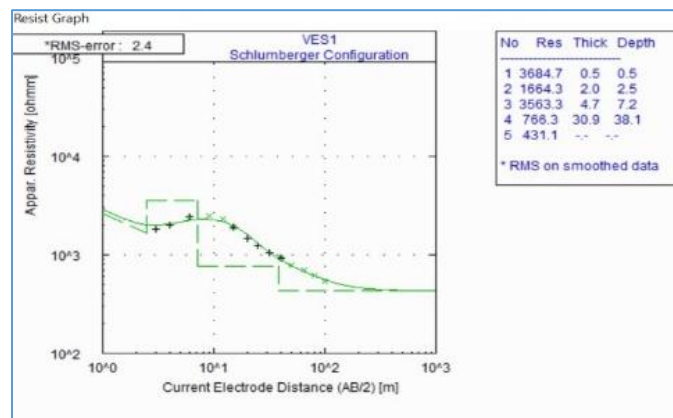


Figure 7. Geoelectric (HKQ) curve

The geoelectric curve type of (HKQ) which has five layers (Table 11). The top soil has a thickness of about 0.5m with resistivity of 3584.7 Ωm . The top soil is closest to the surface and contains some dry peats and weathering is high due to constant exposure to heat and pressure. At the depth of 0.5-2m with thickness of about 2m is dry fine sand materials with resistivity of 1664.4 Ωm , it is followed by dry medium fine sand of resistivity 3563.3 Ωm and thickness of 4.7m. Partially saturated medium grain sand of resistivity 766.3 Ωm and thickness 30.9m at the depth of 38.1m is where groundwater can be exploited in the area. Beyond 38.1m is saturated medium coarse sand. Foundation for superstructure should get to at least 7.2m in order to be firm. Table 11 shows the summary of layers resistivity, thickness and lithology.

Table 11. Resistivity and lithology of Layers

VES No	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	CURVE TYPE	LITHOLOGY
1	1	3684.7	0.5	0.5	HKQ $Q_1 > Q_2 < Q_3 > Q_4 > Q_5$	Topsoil
	2	1664.4	2.0	2.5		Fine Sand (dry)
	3	3563.3	4.7	7.2		Medium Fine Sand (dry)
	4	766.3	30.9	38.1		Medium Grain Sand (Partially Saturated)
	5	431.1	---	---		Medium Coarse Sand (Saturated)

Table 12 displays the summary of the seismic velocities, electrical resistivity and lithology of layers. The litho-stratigraphy of borehole of the area used as an aid in the interpretation is shown in Figure 8.

Table 12. Summary of Parameters of Seismic refraction and Electrical resistivity of the survey.

PARAMETERS	DEPTH (m)		
	0 – 7 (Loose fine sand-dry)	7 – 38 (Medium fine sand-dry)	38 – (Medium coarse sand- saturated)
V_p	270.87	452.34	921.18
V_s	130.12	217.20	442.52
$\rho(\Omega m)$	$1664.4 \geq \rho \leq 3684.7$	$\rho \geq 766.3$	$\rho \leq 431.1$
G0 [MPa]	30.48	84.99	352.48
Ed [Mpa]	132.07	368.30	1527.43
M0 [MPa]	101.59	283.31	1174.95
Ey [Mpa]	82.29	229.48	951.71
Density (kg / m^3)	1800	1800	1800
Poisson's Ratio	0.35	0.35	0.35
Porosity	0.31	0.31	0.31

V_p : Primary (Compressional wave)

V_s : Secondary (Shear wave)

$\rho(\Omega m)$: Electrical resistivity

G0: Shear modulus;

Ed: Oedometric modulus;

M0: Bulk modulus;

Ey: Young's modulus.

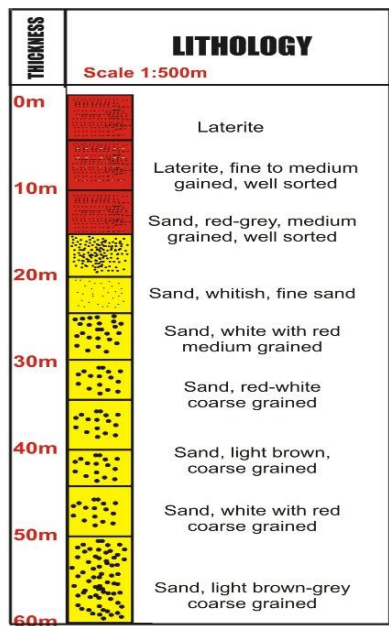


Figure 8. Litho-Stratigraphy of Kwale

4. CONCLUSION

The seismic refraction results shows that compressional wave velocity increases with depth due to the increase in the stiffness of earth materials as depth increases. Three layers with different seismic velocities and mechanical properties were identified. Elastic constants like Poisson’s ratio and density maintained constant value in the three layers, while Young’s and bulk moduli increased with depth. Oedometric modulus also increased with depth. The results of seismic velocities, elastic constants values, electrical resistivity and geotechnical parameters at near surface in the area are in agreement with the lithological stratigraphy of soils of the study area. It is recommended that foundation for gigantic structures get to second or third layers ($\geq 10\text{m}$) beneath the surface where there are stiffer earth materials for stability. It is also recommended that periodic investigation of the near surface soil using integrated geophysical and laboratory methods should be conducted before construction work because of local geologic fluctuations, weathering of near surface soil and topographical variations.

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Author Contributions

Okezie Uchegbulam: Geophysical data acquisition, processing, interpretation and original draft.
Elijah Ovie Izeze: Data analysis, editing, review and validation.

Informed consent

Not Applicable.

Conflicts of interests

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical approval & declaration

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

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Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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