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Integrated Seismic Refraction and MASW Surveys for Assessing Near-Surface Soil Engineering Properties and Hydrogeological Conditions in the Lekki Coastal Area, Southwestern Nigeria

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Abstract

Seismic refraction and Multichannel Analysis of Surface Waves (MASW) surveys were conducted along eight traverses in Lekki, southwestern Nigeria, to determine near-surface compressional wave velocity (Vp) and shear wave velocity (Vs) profiles and to evaluate soil engineering properties essential for structural foundation design and urban planning in this low-lying, flood-prone coastal environment. Data were processed using Seisimager software to generate layered Vp and Vs models. A consistent two-layer Vp structure was observed across all sites: the upper layer exhibited Vp values generally below 500 m/s, whereas the lower layer displayed significantly higher velocities, typically exceeding 1500 m/s. Refractor depths ranged from 1.8 to 4.2 m, aligning with a shallow groundwater table and thereby elevating near-surface saturation risk. The Vs model indicates that the upper 10 m is predominantly characterized by velocities below 200 m/s, corresponding to very loose to loose silty sands in the surficial layer. Vs increases to values greater than 200 m/s below approximately 10 m depth, marking the transition to a stiffer, more competent layer. Two-dimensional Vs sections further reveal lateral variations in subsurface stiffness, particularly pronounced within the top 10 m along certain traverses. Derived engineering parameters for the upper layer include bulk density ranging from 1275.95 to 1785.29 kg/m³, porosity from 0.33 to 0.57 (average ≈ 0.51), Poisson's ratio from 0.19 to 0.49 (average ≈ 0.40), shear modulus from 2.49×10^7 to 5.50×10^7 Pa, Young's modulus from 6.94×10^7 to 1.63×10^8 Pa, and bulk modulus from 5.09×10^7 to 2.09×10^9 Pa. These results confirm incompetent to slightly competent conditions in the uppermost subsurface. The high porosity of the predominantly loose silty sands also indicates strong saturation affinity, rendering the area highly vulnerable to flooding and differential settlement. The simultaneous acquisition of Vp and Vs using a single field setup proved efficient and cost-effective, delivering reliable geotechnical parameters for

foundation design while underscoring the necessity of ground improvement techniques in this unconsolidated coastal setting.

Keywords: Seismic refraction, MASW, shear wave velocity, Lekki, engineering properties, soil stiffness, coastal geotechnics, flooding susceptibility, foundation design

1.0 Introduction

Rapid urbanization in the coastal regions of Lagos, particularly along the Lekki axis in Lagos State, Nigeria, has intensified the demand for a detailed understanding of soil engineering properties. This knowledge is essential to ensure safe and efficient design and construction of building foundations and other infrastructure in such vulnerable settings. Soil engineering properties primarily govern the deformation and strength behavior of soil masses (Onunkwo et al., 2014). They encompass the mechanical characteristics of soil materials and their application to solving engineering problems, with particular emphasis on the interaction between structures and their supporting foundation soils. Beyond structural stability, these properties also play a central role in controlling soil erosion and supporting effective soil conservation strategies. The principal categories include physical and index properties, shear strength parameters, permeability, consolidation characteristics, modulus parameters (Young's modulus, shear modulus, bulk modulus), Poisson's ratio, and dynamic response . Conventional methods for determining in-situ geomechanical or geo-engineering properties typically involve intrusive geotechnical investigations, such as the Standard Penetration Test (SPT), Cone Penetration Test (CPT), and laboratory analysis of recovered samples. Several studies have applied these techniques to evaluate the geotechnical characteristics and shallow bearing capacities of soils in the Lekki axis and other coastal areas of Lagos (Warmate and Nwankwoala, 2019; Olele, 2016; Nwankwoala, 2019). While reliable, these approaches are invasive, costly, time-consuming, and limited to discrete point measurements.

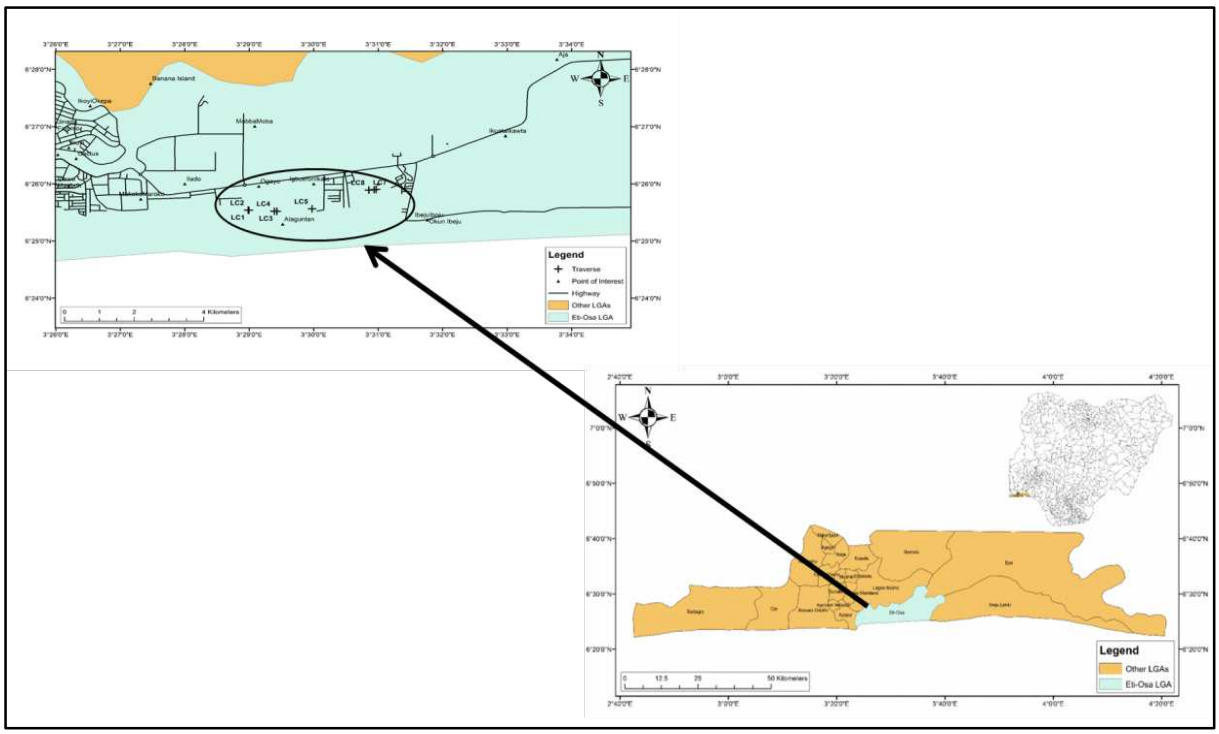
Geophysical methods provide a valuable non-invasive alternative for near-surface characterization and derivation of engineering properties across wider areas (Akinlalu et al., 2025). Techniques commonly employed for site characterization include seismic methods (refraction, reflection, Multichannel Analysis of Surface Waves [MASW], cross-hole seismic tomography), electrical resistivity methods (e.g., Vertical Electrical Sounding), electromagnetic methods, self-potential,

induced polarization, and Ground Penetrating Radar (GPR). Earlier investigations have successfully used geophysical approaches to assess soil engineering properties; in particular, Adepelumi and Olorunfemi (2000) combined vertical electrical soundings with penetrometer tests to characterize a reclaimed site in Lekki, Lagos.

Seismic methods are particularly effective because elastic wave velocities vary systematically with soil and rock type, density, and strength (Khalil and Hanafy, 2008). Seismic refraction surveys yield compressional wave velocity (Vp), while the Multichannel Analysis of Surface Waves (MASW) provides shear wave velocity (Vs). These velocities can then be used to estimate key elastic parameters, including Young's modulus (E), bulk modulus (K), Poisson's ratio (ν), and shear modulus (μ) (Lowrie, 2007). This study employs seismic refraction and MASW surveys to determine Vp and Vs profiles in the Lekki area. From these data, engineering parameters such as Young's modulus, bulk modulus, shear modulus, Poisson's ratio, and density are derived. The results are integrated with available borehole logs from the study area to provide a more comprehensive characterization of subsurface soil properties, supporting improved foundation design in this flood-prone coastal environment.

1.1 Geology and site description

Lekki Phase 1 covers about 445 km^2 which equals 25% of the total landmass of Lagos State (LGAs, 2010). It falls between longitudes 3°35' and 3° 55'N and latitudes 6° 25' and 6° 45'E in the creek zone of tropical Southwestern Nigeria (Figure 2). The area is relatively flat with an altitude of about 6.40 m. Lekki Phase 1 falls within the extensive Dahomey Basin in Southwestern Nigeria. It is underlain by sand, sandy clay and lignite, with vegetated freshwater deposits of mainly Recent-Quaternary alluvium above the Ilaro Formation (Malomo and Oloruniwo, 1983).



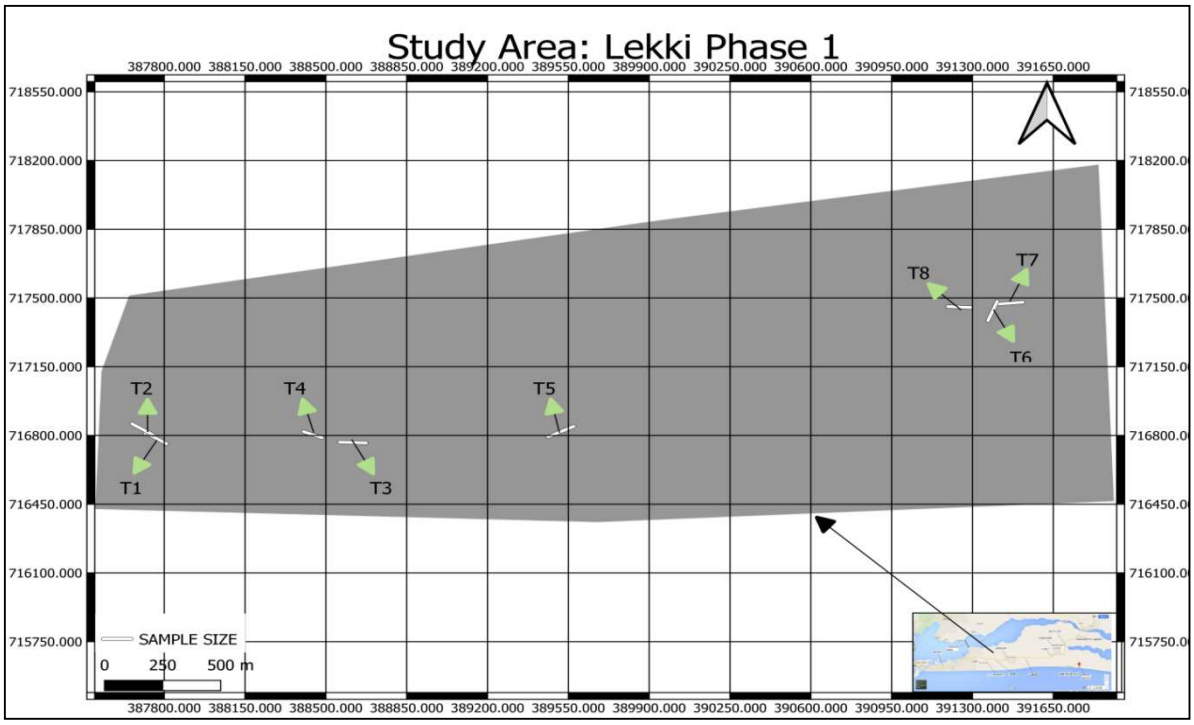


Figure 2. Map of Study Area

2.0 Methodology

2.1 Data Acquisition

A combination of seismic refraction and Multichannel Analysis of Surface Waves (MASW) measurements was used to acquire active seismic data along eight traverses in the study area. Data collection was performed using a Terraloc Mk6 seismograph alongside 24 vertical 4.5 Hz geophones. Geophone spacing was set at 2 m, and the seismic source consisted of a sledgehammer striking a metal plate. The same receiver array and shot configuration were employed for both seismic refraction and surface wave analyses, with acquisition parameters optimized to ensure high-quality signals suitable for both techniques. Shot points were positioned both inline (within the array) and at offset locations. A maximum offset of 20 m was achieved from each end of the array, providing sufficient coverage for reliable first-arrival picking in refraction analysis.

2.2 Data Processing

2.2.1 Seismic Refraction

The seismic refraction data analysis was carried out using the SeisImager software. The first arrivals were picked and the travel-time curve generated by a combination of shots at offset positions (depending on the clarity of the arrivals) and shot records obtained between Geophones 1&2, 6&7, 12&13, 18&19 and 23&24. Processes such as Travel Time Difference curve and reciprocal travel times were checked to ensure the quality of the travel-time curves picked. A reciprocity of less than 5% was ensured for all travel time curves from all the locations. Subsequently, the inversion was carried out using the time-term inversion technique (TT1) and Refraction Tomography Inversion (RTI). The TTI is a simple travel-time inversion with advantages of computational stability, computational fastness and robustness (Al-Heety, 2019). This technique utilizes both linear least squares and delay time analysis to invert the first arrivals for a velocity model. The travel time curves indicated a two-layer model, which was subsequently assigned on the travel time curves and the inversion run. The acceptable P-wave velocity model was based on a model with a matrix inversion error of less than 1.5%. The model obtained from the TTI was then utilized as the starting model for the RT inversion (Zhang and Toksöz, 1998). The RTI gives a gradational variation in the model as comparted to the discrete version of the TTI

model. It is expected that the geological variation in the study area should be gradational and as such, this inversion technique was adopted to produce the final model of the subsurface.

2.2.2 Surface Wave Analysis

One-dimensional (1D) and two-dimensional (2D) active surface wave analyses were performed on the obtained data using SeisImager software to derive shear wave velocity (Vs) profiles from the acquired MASW data. For the 1D analysis, the shot record exhibiting the clearest and most continuous dispersion curve was selected for each traverse. The software transformed the shot gather from the distance-time (x-t) domain into the frequency-phase velocity (f-v) domain through dispersion imaging. The dispersion curve was then manually picked by identifying the maximum amplitude ridge in the f-v spectrum, ensuring that picks remained within realistic wavelength bounds defined by the survey geometry (minimum and maximum wavelengths). The picked dispersion curves were subsequently inverted using an iterative least-squares inversion algorithm. This process began with an initial layered velocity model and iteratively adjusted layer thicknesses and velocities to minimize the misfit between the observed and theoretical dispersion curves, yielding a 1D Vs profile at each selected location. For the 2D analysis, the Common Midpoint Cross-Correlation (CMPCC) method was adopted, following the approach described by Hayashi and Suzuki (2004). This technique enhances phase-velocity resolution and enables the construction of high-resolution 2D Vs models by effectively increasing data density through midpoint binning. The software first computed CMPCC gathers from the input shot records. For each CMPCC gather, an f-v spectrum was generated, from which dispersion curves were extracted. These dispersion curves were individually inverted to produce 1D Vs profiles at regular midpoint intervals. The resulting 1D profiles were then laterally interpolated to construct a continuous 2D Vs section, providing detailed spatial variations in subsurface stiffness along each traverse. This combined 1D and 2D processing workflow allowed for both localized high-confidence velocity estimates and laterally continuous imaging of shear wave velocity structure, facilitating a robust interpretation of near-surface engineering properties across the study area.

2.3 Estimating elastic parameters

Determination of the elastic dynamic modulus such as Young Modulus (E), Rigidity Modulus (μ), Bulk Modulus (K), Poisson's ratio (σ) of the soil can be estimated if the longitudinal (Vp) and shear (Vs) wave velocities of the material are known. These parameters are important as they can inform structural design, flood risk assessment, urban planning and groundwater management, all of which are important concerns in the study area. Using established empirical relationships (equations 3.1 to 3.6), the density, porosity and elastic parameters – E, μ, k and σ were obtained.

Equation 3.1 offers a convenient means of obtaining the density of a material.

$$\rho = 0.31V_p^{0.25} \quad \text{……..} \quad 1.0 \qquad \text{(Gardner } \textit{et. al.,} \text{ 1974)}$$

The porosity is a measure of the void spaces in a material; this was achieved using equation 3.2

$$\emptyset = -0.175 \ln\left(V_p\right) + 1.56 \quad \text{…….2.0} \qquad \text{(Gardner } \textit{et. al.,} \text{ 1974)}$$

Equation 3.3 was used for calculation of Poisson's ratio (σ): and if the area shows high value, it reflects that the ratio of the voids in that area is saturated with water.

$$\sigma = \frac{1-2(\frac{V_S}{V_p})^2}{2-2(\frac{V_S}{V_p})^2} \quad \text{……..3.0} \qquad \text{(Kearey } \textit{et. al.,}\text{2002)}$$

Equation 3.4 was used for determination of rigidity modulus (Shear modulus (μ)) in the study area. It indicates how stiff a material is to shearing deformation.

$$\mu = \rho V_S^2 \quad \text{……..3.4} \qquad \text{(Kearey } \textit{et. al.,}\text{2002)}$$

Young's modulus (E) is the most important parameter for engineering purpose which is useful to know the bearing capacity of the material and also reflects the stiffness of earth materials.

$$E = 2\mu(1+\sigma) \qquad \text{……..3.5} \qquad \text{(Lowrie, 2007)}$$

The bulk (K) modulus is another elastic constant that reflects the resistance of the material to an overall gain or loss of volume in conditions of hydrostatic stress (P_h).

$$K = \frac{E}{3(1-2\sigma)} \text{.....3.6} \qquad \text{(Lowrie, 2007)}$$

3.0 Results and discussion

3.1 Seismic Refraction

The 2D Vp model of the subsurface for all the traverses is presented in figure 3.

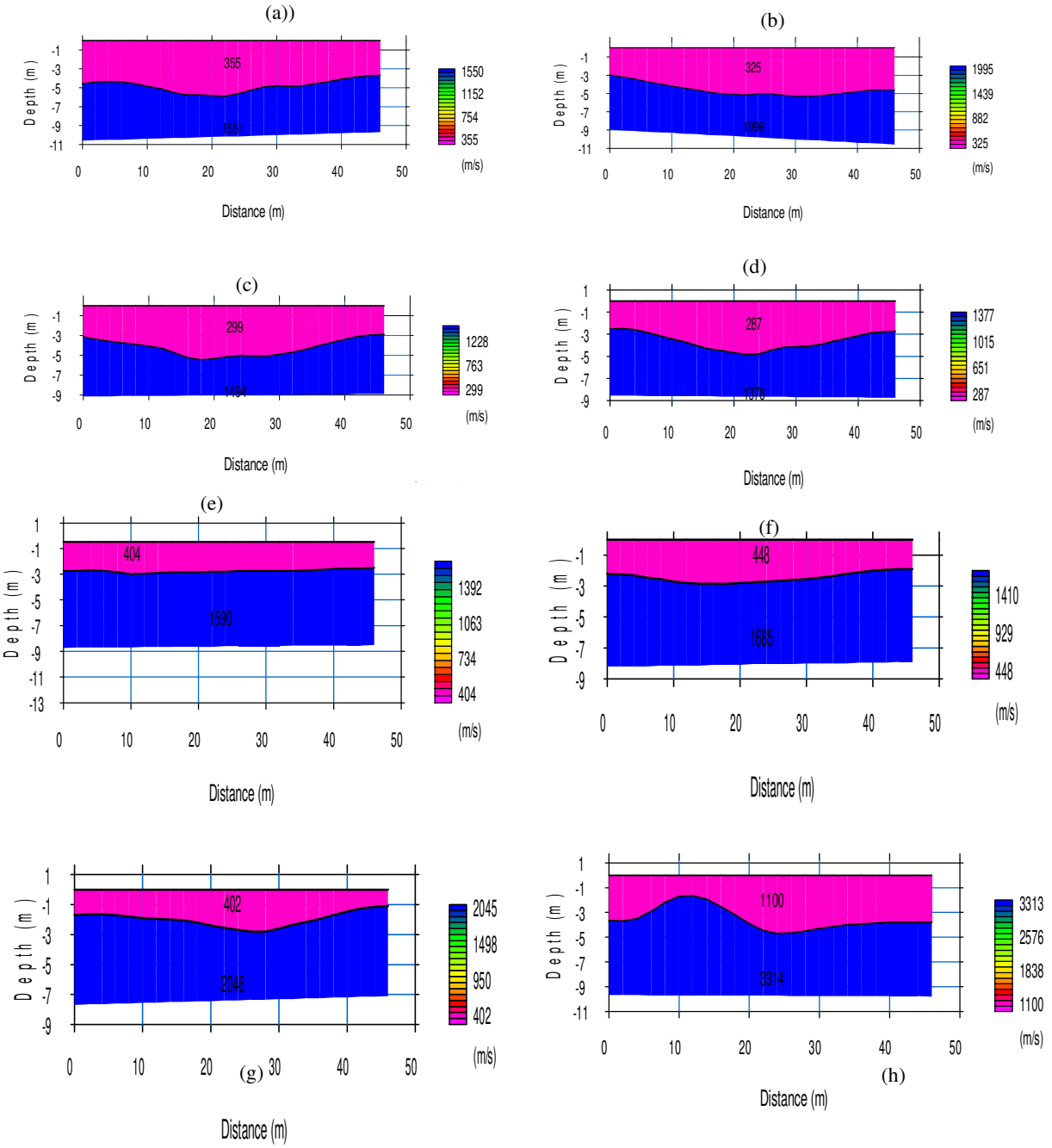


Figure 3: P-wave velocity for location for (a) location 1, traverse 1 (b) location 1, traverse 2 (c) location 2, traverse 1 (d) location 3, traverse 2 (e) location 3 Traverse 5 (f) location 4 Traverse 6

A summary of the results obtained from the Velocity models is presented in Table 1.

Table 1: Summary of Results from Seismic Refraction

Location	**Vp 1(m/s)**	**Vp 2 (m/s)**	**Ratio of Vp2:VP1**	**Depth to Refractor (m)**
Tr 1	355	1551	4.4	4.2
Tr 2	325	1996	6.1	3
Tr 3	299	1494	5.0	3
Tr 4	287	1378	4.8	2.5
Tr 5	404	1590	3.9	2.5
Tr 6	448	1685	3.8	2.3
Tr 7	402	2046	5.1	1.8
Tr 8	1100	3314	3.0	3.6

The Vp models derived show a consistent two-layer subsurface structure throughout the study area. The upper layer exhibits low compressional wave velocities, generally ranging from 287 to 1100 m/s, all locations have Vp less than 500 m/s, except in Travers 8. This layer maintains relatively uniform thickness and velocity along most profiles, although minor lateral variations appear in some sections. Below this lies a second layer with markedly higher velocities, typically above 1500 m/s and occasionally reaching values well in excess of 3000 m/s. This velocity contrast points to a clear lithological and hydrological transition. The Vp for the second layer ranges from 1378 – 3314 m/s, with an average of about 1800 m/s, suggesting that the area is saturated (Reynolds 2011; Foti et al. 2015;). The interface between the two layers - the refractor - occurs at depths between 1.8 and 4.2 m. The depth to the refractor depth provides a guide to the water table.

3.2 MASW

Figure 4 shows the seismogram and the corresponding dispersion image and 1D Vs model for traverse 2. For all the traverses, the extracted dispersion curve and corresponding Vs model obtained is presented in figures 5 and 6. The shear wave velocity (Vs) models obtained from Multichannel Analysis of Surface Waves (MASW) surveys along the eight traverses in Lekki exhibit a general pattern of low velocities in the near surface, gradually increasing with depth.

Across most profiles, Vs remains below 200 m/s from the surface down to approximately 8 to 12 m depth, with values typically ranging from 100 to 180 m/s in the uppermost layers. This low-velocity zone is particularly evident in the clustered profiles highlighted by the circled area, where multiple traverses (such as Tr2, Tr3, Tr5, and Tr6) show stepwise increases but stay predominantly under 180 m/s through the top 10 m. Below this depth, Vs transitions more sharply to values exceeding 200 m/s in several traverses (e.g., Tr1, Tr4, Tr7, and Tr8 reaching 220–280 m/s by 15–20 m), though the exact depth to this threshold varies slightly among the lines, with some showing a more gradual ramp-up. This Vs structure reflects the unconsolidated nature of the coastal sediments in the Lekki area, where the shallow low-velocity interval (Vs < 200 m/s) corresponds to loose to very loose silty sands with high porosity and low stiffness, typical of recent Quaternary alluvial deposits in the Dahomey Basin. The transition to higher Vs (>200 m/s) at greater than 10 m depth marks the onset of a slightly competent layer, suggests medium-dense sands or more compacted materials with reduced pore space and improved intergranular bonding.

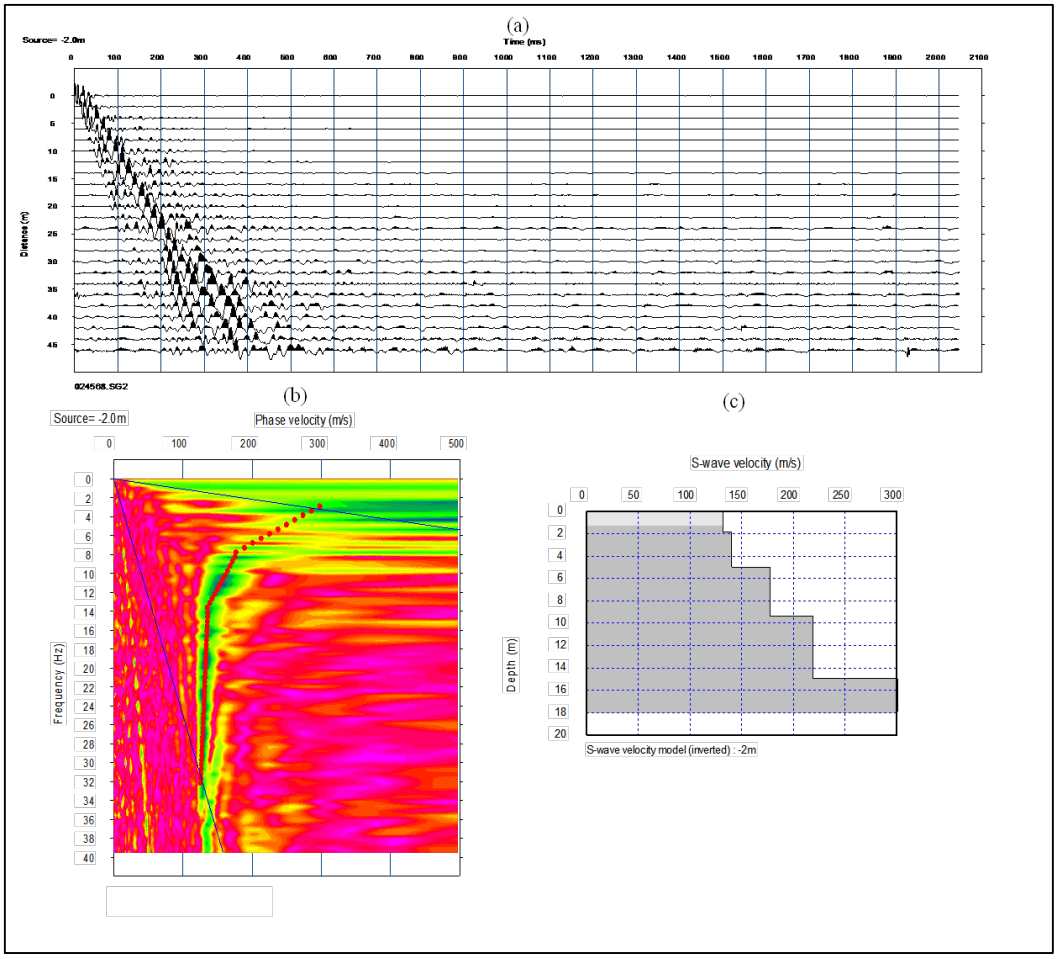


Figure 4. Result from 1D MASW Data Analysis for Traverse 2 (a) Shot gather (b) Dispersion Image showing the picked dispersion curve and (c) 1D Vs Model

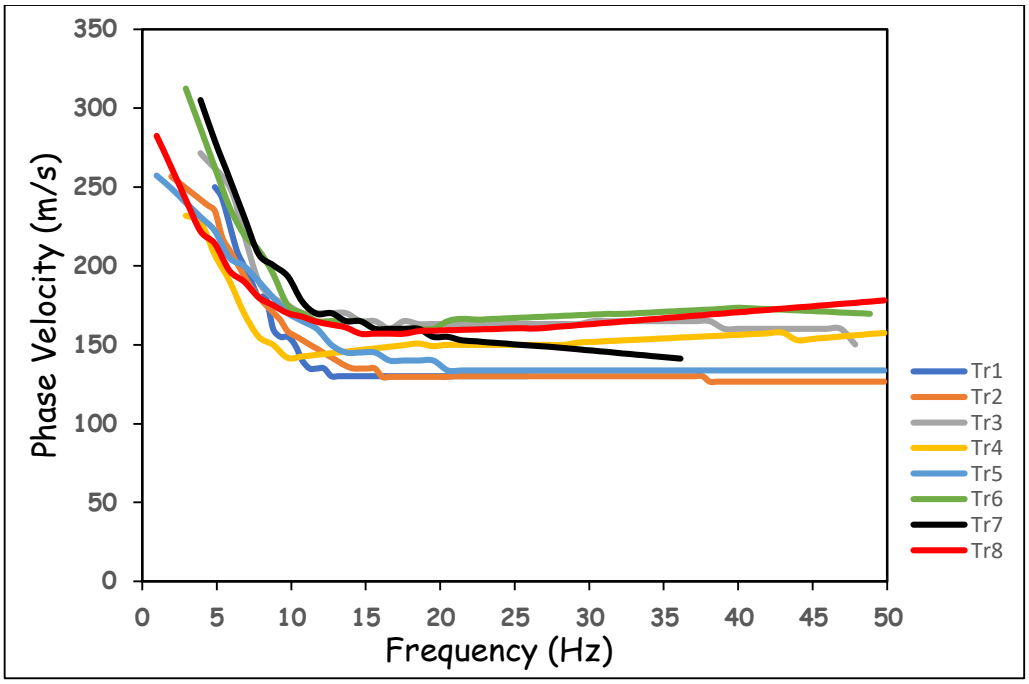


Figure 5: Dispersion curves obtained from all the traverses

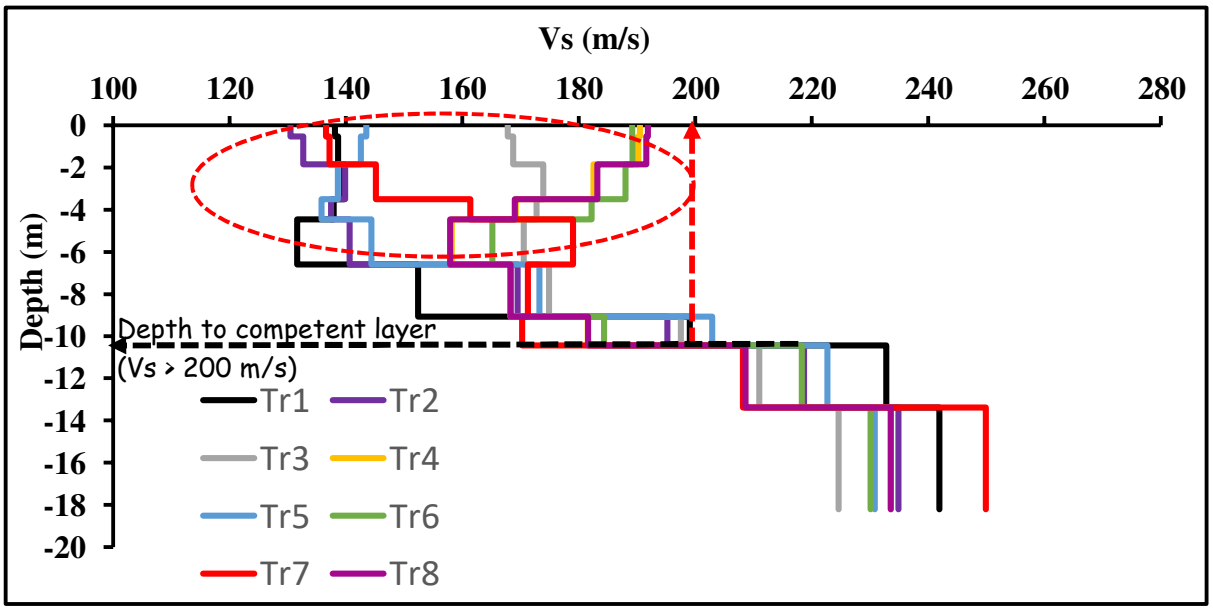


Figure 6: 1D Vs models for all the traverses

The 2D Vs section of all the lines reveals that the shear wave velocity of the materials for this study was less than 272m/s, down to a depth of about 20m, an indication that the composition of the materials for this site are not stiff and reflecting the variations in the composition of the subsurface materials. Examples of the Vs models obtained for locations 1, 2 and 5 are shown in figures 12 – 13. Location 1 model depicts a 3 layer model for both traverse 1 and 2. Both traverses are characterized by a general increase of Vs with depth, an increase in Vs greater than 200 m/s at depths below 10 m.

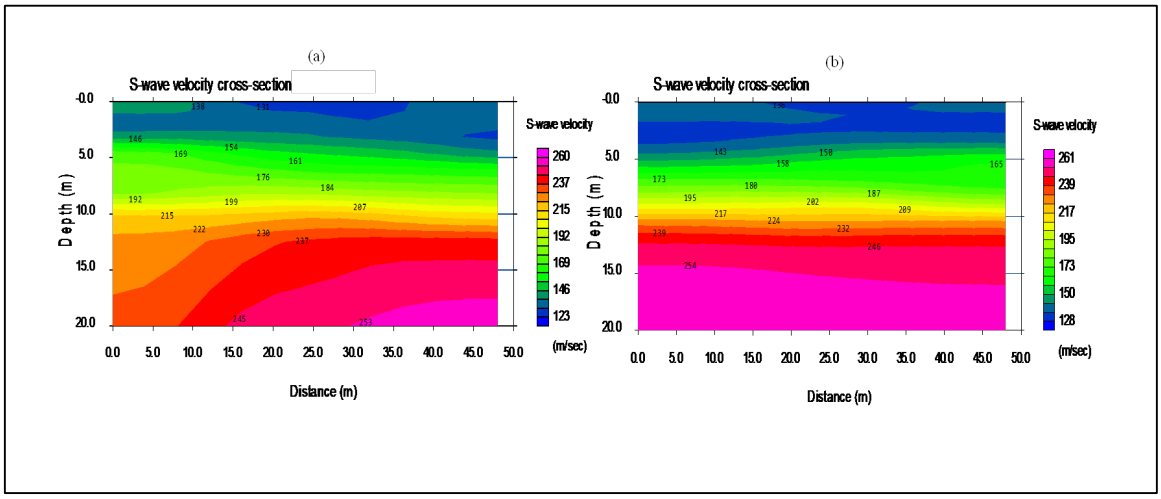


Figure 11. 2D Vs model for location 1 (a) Traverse 1 and (b) Traverse 2

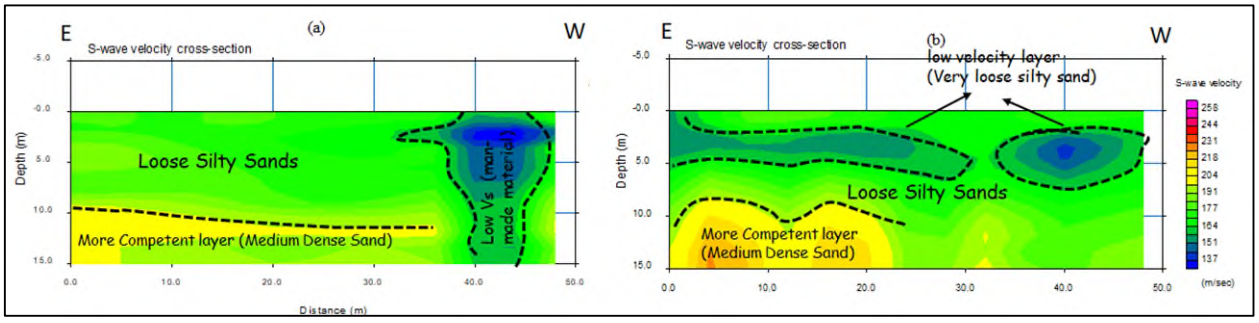


Figure 12. 2D Vs model for location 2 (a) Traverse 3 and (b) Traverse 4

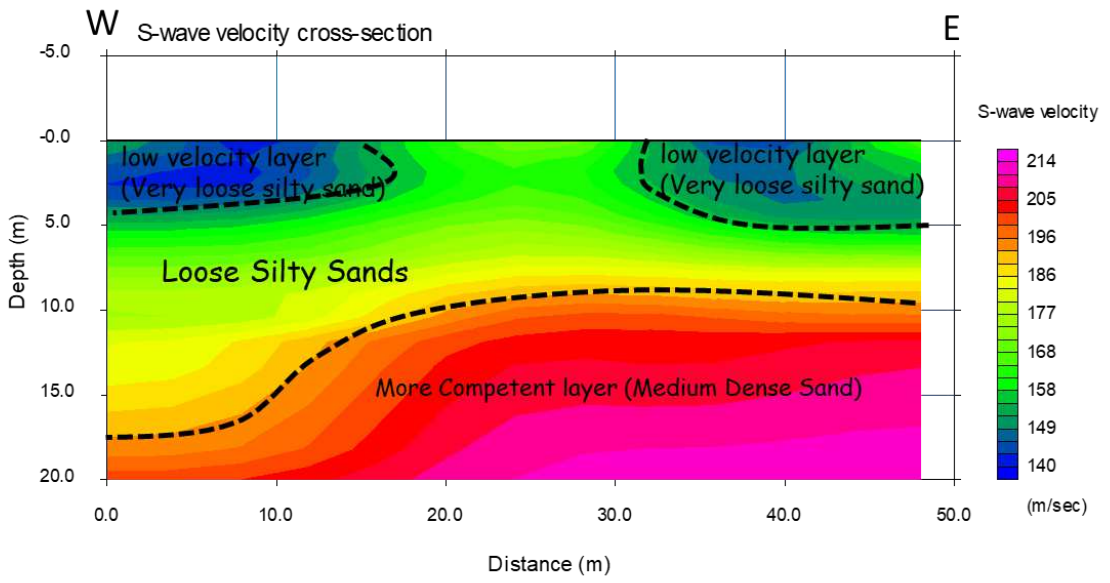


Figure 13: 2D Vs model for location 5 Traverse 8

The 2D Vs cross-sections for Location 2 (east - west oriented traverse) show a gradational velocity profile with pronounced lateral heterogeneity. The uppermost layer exhibits very low Vs (≈137 - 160 m/s) in localized pockets or lenses (dark blue zones labeled as very loose silty sand), particularly noticeable in within the top 5m. These very loose zones overlie a thicker intermediate layer of loose silty sands (Vs ≈160–220 m/s, green to yellow tones) extending to approximately 8–12 m depth. Below this, Vs increases to >220–244 m/s in the more competent medium-dense sand layer (orange-yellow to red hues), with the transition boundary (dashed black line) occurring at ~10–12 m depth and showing a gentle eastward deepening.

For traverse 8, the Vs model shows a gradational velocity structure, with a shallow low-velocity zone (Vs ≈100 - 160 m/s) in discontinuous lenses labeled as very loose silty sand, overlying a thicker intermediate layer of loose silty sands (Vs ≈160 - 200 m/s) extending to ~8–12 m depth. Below this, Vs transitions to >200 m/s in the more competent medium-dense sand layer.

The Standard Penetration Test result for a location around the study area (Opene - Odili, 2020) is presented in table 3. In addition, the result of borehole log obtained from around the area as reported by Olele, 2016 is shown in table 4.

Table 3: SPT at Lekki Peninsular Scheme, Eleghusi, Lagos (Opene-Odili, 2020)

Depth (m)	**Lithology**	**NSPT**
0 – 11	Loose Greyish Brown Silty Sands	0 – 8
12 – 21	Medium Dense Greyish Brown Fine to Coarse Sands	12 – 27
22 – 30	Dense to Very Dense Fine to Coarse Grey Sand	30 - 42

Table 4: Thickness of Layers (m) – lagoonal sands, where og is Organic Matter Present, Ss is Silty Sand and Cl is Clayey Sand (Olele, 2016)

Borehole Number	THICKNESS OF LAYERS - LAGOONAL SANDS						
	Fill	Very Loose	Very Loose to Loose	Loose	Medium Dense	Dense	Water Table Below GL (m)
TP1-1B	0-4.5	4.5-9.0ss,og		9.0-11.5ss 15.0-19.0	11.5-15.0ss 19.0-20.0		2.3
TP1-2B	0-1.0		6.5-9.5 11.0-12.5	1.0-3.0 9.5-11.0 15.0-18.0ss	3.0-6.5 12.5-15.0ss 18.0-20.0ss		1.0-1.3
TP1-4B	0-1.5	7.5-9.5		1.5-7.5ss,og 9.5-11.0	11.0-18.5ss,og	18.5-20.0	1.0-1.3
TP1–2	0-1.0			1.0-3.0ss,og 6.0-9.0og 9.0-11.25	3.0-6.0		1.1-1.6
TP1–5	0-0.5			6.0-10.5 ss,og	0.5-6.0og 10.5-12.0ss,og 12.0-15.5		0.5

The combined 1D and 2D Vs models across the eight traverses in Lekki reveal a consistent layered near-surface velocity structure that correlates well with borehole SPT results. In the upper 10 m,

both 1D profiles and 2D sections show Vs predominantly below 200 m/s (typically 100–180 m/s in the top 1–6 m), corresponding to the loose greyish brown silty sands (NSPT 0–8) observed from 0–11 m in boreholes. The 2D models further highlight discontinuous low-velocity pockets or lenses of very loose silty sand (Vs 100–160 m/s, 1 - 4 m thick), particularly evident in the clustered upper portions of multiple traverses (e.g., Tr1-Tr8), indicating localized zones of poorer compaction or higher saturation.

Below ~10 m, Vs increases to 200 - 280 m/s, marking the transition to a more competent medium-dense sand layer that aligns with the SPT rise to NSPT 12 - 27 at 12 - 21 m. The boundary exhibits gentle lateral variations across traverses, with some profiles showing eastward or westward deepening, reflecting depositional heterogeneity typical of coastal alluvial/littoral environments.

The low-velocity upper zone (high porosity, low stiffness) and localized very-low-Vs pockets confirm incompetent near-surface conditions, poor shallow bearing capacity, and elevated risks of differential settlement, flooding, and potential liquefaction in this unconsolidated coastal setting. These findings support the recommendation for deep foundations targeting the medium-dense sand or ground improvement measures to ensure long-term infrastructure stability.

The soil's dynamic properties such as density, porosity, Poisson's ratio, rigidity modulus, Young's Modulus and Bulk modulus were estimated (Table 5). These parameters show a dependency on Vs and Vp, and were obtained from the 2-D Vs model and Vp for each traverse.

Table 5: Soil dynamic parameters as obtained from the MASW and seismic refraction results

Location	**Layer**	**Vp (m/s)**	**Vs (m/s)**	**Density (ρ) (kg/m^3)**	**Porosity (Ø)**	**Poisson Ratio**	**Shear modulus (Pa)**	**Young modulus (Pa)**	**Bulk modulus (Pa)**
Tr 1	1	355	137.66	1345.61	0.53	0.41	2.55E+07	7.20E+07	1.36E+08
	2	1551	213.26	1945.43	0.27	0.49	8.85E+07	2.64E+08	4.56E+09
Tr 2	1	325	137.66	1316.23	0.55	0.39	2.49E+07	6.94E+07	1.06E+08
	2	1996	228.78	2072.06	0.23	0.49	1.08E+08	3.24E+08	8.11E+09
Tr 3	1	299	170.39	1289.08	0.56	0.26	3.74E+07	9.43E+07	6.53E+07
	2	1494	226.53	1927.30	0.28	0.49	9.89E+07	2.94E+08	4.17E+09
Tr 4	1	287	178.42	1275.95	0.57	0.19	4.06E+07	9.63E+07	5.09E+07
	2	1378	242.41	1888.75	0.30	0.48	1.11E+08	3.29E+08	3.44E+09
Tr 5	1	404	140.03	1389.82	0.51	0.43	2.73E+07	7.80E+07	1.91E+08
	2	1590	250.30	1957.54	0.27	0.49	1.23E+08	3.65E+08	4.79E+09

Tr 6	1	448	183.20	1426.20	0.49	0.40	4.79E+07	1.34E+08	2.22E+08
	2	1685	246.41	1986.15	0.26	0.49	1.21E+08	3.59E+08	5.48E+09
Tr 7	1	402	145.08	1388.09	0.51	0.43	2.92E+07	8.33E+07	1.85E+08
	2	2046	273.95	2084.91	0.23	0.49	1.56E+08	4.67E+08	8.52E+09
Tr 8	1	677	175.47	1785.29	0.33	0.49	5.50E+07	1.63E+08	2.09E+09
	2	1791	222.62	2352.07	0.14	0.50	1.17E+08	3.49E+08	2.57E+10

Density values ranged from 1.28 to 2.35 g/cm³, consistent with wet sand according to density-depth literature curves as shown in Table 6. Porosity varied from 0.14 to 0.57, showing an inverse relationship with both density and seismic velocity: lower porosity in the second layer corresponded to higher density and velocity, aligning with established behavior of porous geomaterials (Mavko et al., 2009). Poisson's ratio ranged from 0.19–0.49 (average ≈0.40) in the upper layer and 0.48–0.50 (average ≈0.49) in the lower layer. These values match reported ranges for humus-rich, silty, and clayey materials (Davis & Schultheiss, 1980; Stuempel et al., 1984; Meissner et al., 1985; Salem, 1993), with the increase with depth reflecting greater compressibility and plasticity in younger near-surface sediments. Based on Sheriff and Geldart (1986), the geomaterials are classified as incompetent to slightly competent, corroborating the SPT data (NSPT 0 - 8 from 0 - 11 m) and the low-velocity upper layer (Vs < 200 m/s) identified in the Vp and Vs models.

Shear modulus ranged from 2.49×10^7 to 5.50×10^7 Pa (average $\approx 4.0 \times 10^7$ Pa) in the upper layer and 8.85×10^7 to 1.56×10^8 Pa (average $\approx 1.2 \times 10^8$ Pa) in the lower layer. Young's modulus varied from 6.94×10^7 to 1.63×10^8 Pa (average $\approx 9.5 \times 10^7$ Pa) and 2.64×10^8 to 4.67×10^8 Pa, while bulk modulus ranged from 5.09×10^7 to 2.09×10^9 Pa and 3.44×10^9 to 2.57×10^{10} Pa, respectively. The significantly higher moduli in the second layer confirm improved stiffness and competence below ~10 m.

Table 6: Literature values (Bruckl et al. 2005) used for density-depth curves

Rock type	Density (g/cm^3)	Rock type	Density (g/cm^3)
Dry sand	2.33-2.80	Sandstone	2.30-2.55
Wet sand	1.50-2.00	Dolomite/Carbonate	1.75-2.88
Gravel	1.95-2.20	Gypsum	2.31-2.33
Clay	1.25-2.32	Anhydrite	2.15-2.44

Claystone	2.65-2.75		

Conclusion

The integrated application of seismic refraction and Multichannel Analysis of Surface Waves (MASW) surveys in the Lekki coastal area has provided a comprehensive characterization of near-surface soil engineering properties and hydrogeological conditions, essential for informed foundation design and urban development in this rapidly expanding, flood-prone region. By leveraging a single field setup to simultaneously acquire compressional (Vp) and shear (Vs) wave velocity data, this study demonstrates an efficient, non-invasive approach that yields reliable geotechnical parameters while minimizing costs and environmental disruption compared to traditional intrusive methods.

The results reveal a consistent two-layer subsurface structure across the eight traverses: an upper layer of loose to very loose silty sands with low Vp (<500 m/s) and Vs (<200 m/s) extending to approximately 10 m depth, overlying a stiffer, more competent medium-dense sand layer with higher velocities (Vp >1500 m/s, Vs >200 m/s). The shallow refractor depths (1.8–4.2 m) align with a near-surface groundwater table, exacerbating saturation risks in this low-lying coastal environment. Derived elastic parameters further underscore the incompetence of the upper layer, with average values including bulk density of ~1500 kg/m³, porosity of ~0.51, Poisson's ratio of ~0.40, shear modulus of ~4.0×10^7 Pa, Young's modulus of ~9.5×10^7 Pa, and bulk modulus ranging from 5.09×10^7 to 2.09×10^9 Pa. These properties indicate high porosity, low stiffness, and elevated susceptibility to flooding, differential settlement, and potential liquefaction, consistent with borehole SPT data (NSPT 0–8 in the top 11 m) and the geological context of Quaternary alluvial deposits in the Dahomey Basin.

Lateral variations in Vs, particularly within the upper 10 m, highlight depositional heterogeneity and localized zones of very low stiffness, emphasizing the need for site-specific assessments. The correlation between geophysical models and borehole logs validates the efficacy of this combined seismic methodology in mapping subsurface variability over broader areas, offering a scalable tool for geotechnical site characterization in similar coastal settings.

Ultimately, these findings affirm the vulnerability of Lekki's near-surface soils to geohazards, necessitating ground improvement techniques such as soil stabilization, deep foundations, or drainage enhancements to ensure structural integrity and resilience against flooding. This study

not only contributes to safer urban planning in the study area but also underscores the value of integrated geophysical surveys in addressing engineering challenges in unconsolidated coastal environments worldwide.

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