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Research Article

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ABSTRACT

Rapid infrastructural and industrial expansion across Akwa Ibom State University and its surrounding communities in southeastern Nigeria demands rigorous near-surface characterization to guide safe foundation design within the physically challenging Niger Delta terrain. Expanding significantly beyond the spatial footprint of earlier localized shallow investigations, this study integrates seismic refraction profiling with empirically derived geotechnical parameters to evaluate subsurface load-bearing competency across elevations ranging from 9.0 to 19.0 m above sea level. Forward and reverse seismic refraction surveys were conducted using explosive sources and a 24-channel OYO McSEIS seismograph to measure compressional wave velocities (Vp), while shear wave velocities (Vs) were modeled through a regionally calibrated empirical Vp–Vs relationship. These velocity datasets were used to compute critical elastic and engineering indices, including porosity, void ratio, bulk density, Poisson's ratio, Young's, bulk, and shear moduli, Lamé's first parameter, material index, and seismic proxies for ultimate and allowable bearing capacities. Subsurface modeling delineates a predominantly two-layer, near-horizontal velocity structure. The upper weathering horizon comprises loose, unconsolidated lateritic soil (5.00–9.19 m thick) characterized by low Vp (377.05–805.50 m/s), Vs (170.82–366.39 m/s), an average density of ~1,634.3 kg/m³, and low allowable bearing capacity proxies (0.000020–0.000090 GPa), rendering it poorly suited for heavy structural loads without ground improvement. In contrast, the underlying consolidated stratum extends beyond the maximum investigation depth with markedly higher Vp (1,643.10–2,000.00 m/s), an average density of ~1,637.0 kg/m³, allowable bearing capacity proxies of 0.000300–0.000369 GPa, and ultimate bearing capacity proxies of 0.00120–0.00149 GPa, establishing it as the primary competent founding horizon. Spatial evaluation also reveals a notable geotechnical anomaly around Ikot Aba in the western sector, where elevated ultimate bearing capacities coincide across both the upper and lower strata. By synthesizing these multi-parameter results into a novel engineering competency zonation map, this work provides civil engineers and urban planners with an actionable spatial framework for optimizing foundation depths and mitigating structural risk across the developing university corridor.

Keywords: Seismic refraction, elastic properties, geotechnical properties, engineering foundation, and geological Formations.

1.INTRODUCTION

Fast demographic growth and infrastructural expansion have transformed Mkpat Enin Local Government Area and its surrounding communities in Akwa Ibom State, situated within the eastern coastal sedimentary terrain of Nigeria's Niger Delta. Driven largely by an upsurge in oil exploration activities and the establishment of tertiary institutions, this sustained

urbanization has placed unprecedented demand on land resources. As the footprint of residential, commercial, and institutional construction widens, building a reliable subsurface geological and geophysical database has become essential for informed land-use planning and safe foundation engineering.

Nowhere is this developmental surge more evident than at Akwa Ibom State University (AKSU), which has undergone rapid physical expansion within the study area (Figure 1). Existing subsoil engineering reports for the university rely on conventional static geotechnical methods that restrict subsurface probing to a depth of 5 m. While suitable for light, shallow structures, a 5 m investigation window leaves deeper sedimentary horizons uncharacterized—creating critical blind spots regarding load-bearing capacity, layer competence, and potential differential settlement for larger, multi-story structures. Moreover, because static tests are intrusive and point-specific, deploying them densely enough to capture lateral variations across expansive construction sites is often cost-prohibitive.

Near-surface seismic refraction provides a dynamic, non-invasive solution to these limitations. Widely applied across petroleum, mineral, and hydrogeological exploration, continuous technological advances in seismic recording equipment, energy sources, and interpretation techniques have firmly established the method as an effective tool for solving complex shallow geological and civil engineering problems (Haeni, 1986). Unlike intrusive tests that alter in-situ soil conditions at isolated points, seismic refraction analyzes the undisturbed subsurface continuously over broad areas at a comparatively lower cost. By resolving near-surface layering and elastic rock/soil properties in stratified terrains, it serves as an indispensable framework for guiding borehole placement and interpolating ground conditions between widely spaced geotechnical sample locations.

To overcome both the shallow depth ceiling and narrow spatial focus of previous site reports, this study introduces a deeper, wider-reaching geophysical characterization tailored to regional growth. By deploying explosive seismic sources, the investigation according to Alexopoulos et al. (2023) extends subsurface profiling beyond 20 m—more than quadrupling the vertical reach of existing campus records—while expanding coverage beyond the university perimeter into its rapidly urbanizing environs. Ultimately, this research establishes a foundational dataset of near-surface engineering properties to guide site development engineers in reliable foundation design and assist urban planners in managing sustainable infrastructure development across this evolving corridor of Southeast Nigeria.

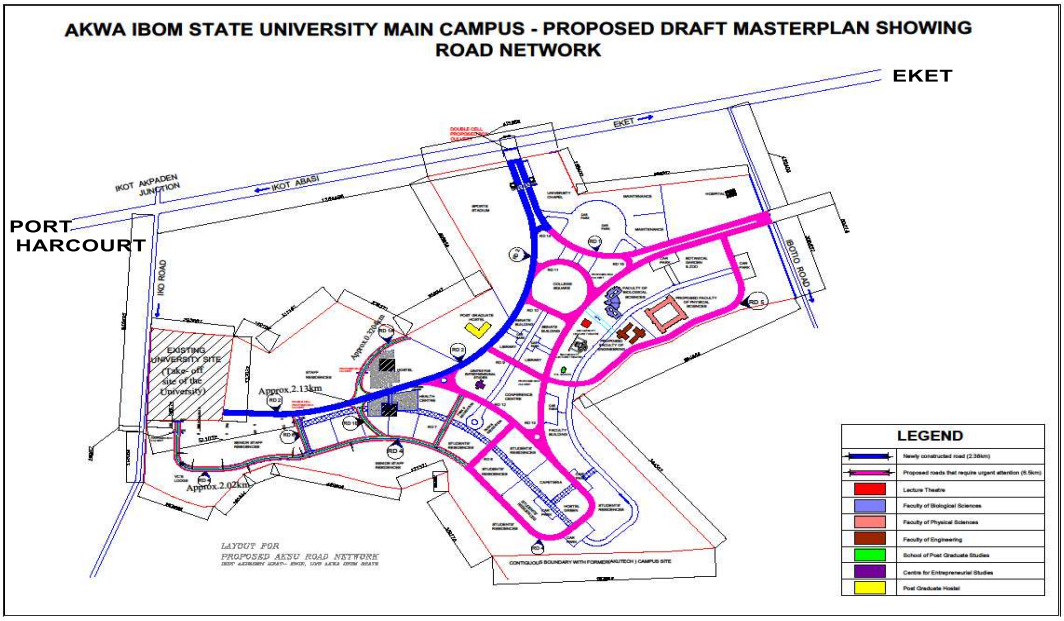


Fig.1. Akwa Ibom State university master Plan (courtesy: University Physical Planning Directorate).

Swift institutional growth and infrastructure expansion around Akwa Ibom State University have intensified the demand for safe, durable civil engineering structures across this part of Southeast Nigeria. Situated along the busy interstate expressway that links Eket to Port Harcourt (PH), the university corridor experiences continuous commercial and residential development that places substantial structural loads on shallow geologic formations. Designing reliable foundations in such unconsolidated coastal sedimentary environments requires an accurate understanding of subsurface stiffness, layer thickness, and elastic behavior. Traditional geotechnical investigations rely heavily on isolated boreholes and penetration tests, which provide valuable point data yet often miss lateral variations between test locations. Applying seismic refraction methods introduces a noninvasive, spatially continuous approach to characterizing near surface engineering properties, offering novel baseline geotechnical intelligence for structural engineers and urban planners working across the campus and its adjoining communities.

The investigation centers on Akwa Ibom State University and its surrounding settlements within Mkpat Enin Local Government Area (LGA) of Akwa Ibom State. Geographically, Mkpat Enin LGA spans latitudes 4°32′00″ N to 4°52′00″ N and longitudes 7°40′00″ E to 7°48′00″ E, while the university domain lies within latitudes 4°30′00″ N and 4°37′32″ N and longitudes 7°30′00″ E and 7°47′32″ E (Figure 2a). Occupying a central position within an integrated survey area of about 45 km^2 the campus serves as the geographic and developmental anchor for several neighboring communities. Alongside Akpaden, which functions as the immediate university town, the survey footprint encompasses Ikot Oyoro, Ikot Aba, Ikot Abia, Ibotio, and Ikot Ekong. Direct highway connectivity along the Eket to Port Harcourt corridor has accelerated population influx into these six interconnected settlements, steadily transforming agrarian land into an emerging educational and residential hub.

Topographically, the terrain across the 45 km^2 study area exhibits a gentle, low gradient relief with surface elevations varying from about 99 to 20 m (Figure 2b). This modest elevation

profile, combined with intense tropical rainfall and shallow groundwater conditions typical of regional coastal plain deposits, governs surface drainage, soil saturation, and differential settlement risks beneath heavy foundations (Obianwu et al., 2011). Loose to moderately compacted sandy and clayey strata near the ground surface frequently undergo seasonal strength fluctuations that can compromise shallow footings if left uncharacterized. By measuring compressional and shear wave velocities across these low relief formations, seismic refraction profiling resolves subsurface stratigraphy, competent bearing layer depth, and dynamic elastic moduli without disturbing the ground. Integrating these geophysical parameters with the specific spatial and topographic setting of Akpaden and its neighboring towns establishes an essential, forward looking foundation design framework for sustainable construction throughout the region

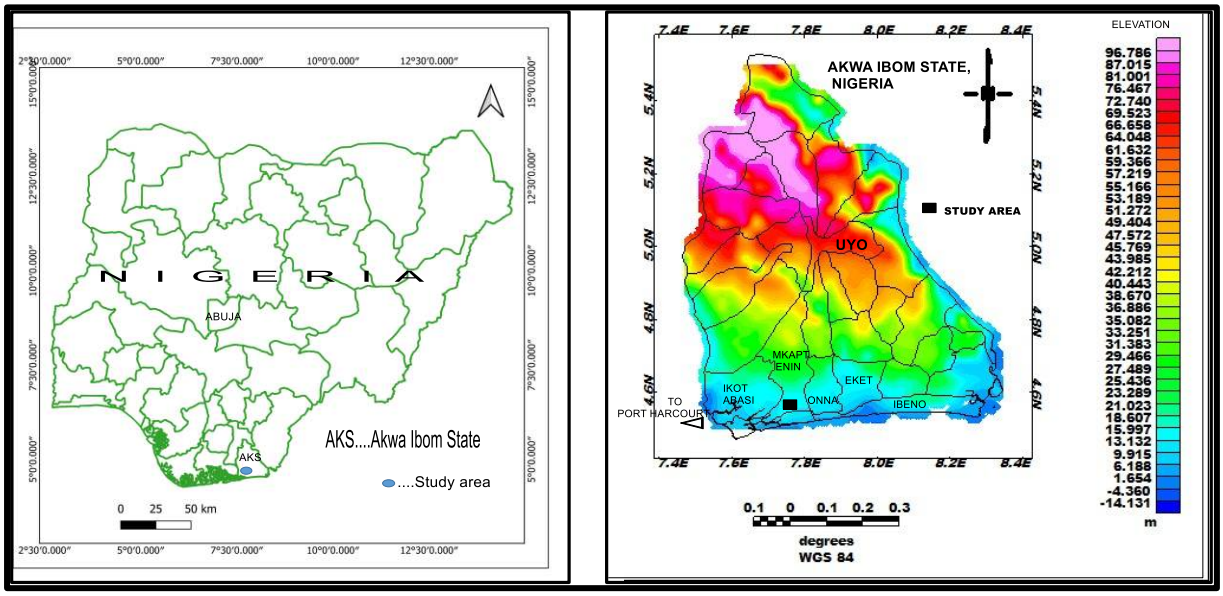


Figure 2: Location maps; (a: left) is Akwa Ibom State located in south of Nigeria, 2(b: right): map of Akwa Ibom State with topographic variations with study area shown as black box, (Credit: Bassey and Ekpo,2026).

2. Geology of Study Area

The infrastructural expansion across institutional corridors in southeastern Nigeria places escalating structural demands on shallow coastal plain sediments (Umoh et al., 2025). At Akwa Ibom State University in Mkpat Enin and its surrounding communities, the ongoing construction of multistory academic complexes, engineering laboratories, and residential facilities requires rigorous subsurface characterization prior to foundation design. Mkpat Enin occupies the low lying southern coastal zone of Akwa Ibom State (Fig. 2a), sitting at elevations between 9.9 and 18.6 m above sea level (Bassey and Ekpo, 2026). Because shallow coastal terrains frequently conceal abrupt lateral shifts in sediment compaction, water saturation, and clay content, relying exclusively on widely spaced borehole logs can leave localized weak zones undetected, exposing engineered structures to differential settlement and foundation distress.

Geographically, Akwa Ibom State lies within eastings of 7° 30' 00" and 8°30' 00"and northings of 4°30' 00" and 5° 30' 00" along the southeastern margin of the Tertiary Niger Delta sedimentary basin. As depicted in the regional tectonic framework (Fig. 2d), the basin architecture of the state is bounded to the northwest by the southern Benue Trough and flanked to the northeast by the crystalline basement of the Oban Massif alongside the Calabar Flank sedimentary belt. This regional tectonic configuration-controlled Cenozoic basin subsidence and clastic sediment dispersal, shaping the thick stratigraphic sequence that underlies Mkpat Enin and its environs.

Beneath the study area, the Tertiary Niger Delta succession comprises three distinct lithostratigraphic units deposited in prograding deltaic settings. At the base sits the marine, shale dominated Akata Formation, which functions as the primary petroleum source rock of the basin. Overlying this basal unit is the paralic Agbada Formation, a cyclical sequence of sands and shales that forms the principal hydrocarbon reservoir rock. Capping the sequence is the continental Benin Formation of Miocene to Recent age, which covers more than 60% of Akwa Ibom State (Fig. 2c) and extends southward toward the coast, where it is succeeded by younger alluvial and coastal deposits. Composed of poorly consolidated, fine to coarse sands with intercalations of clay and conglomerate, the Benin Formation forms the immediate geological substrate supporting civil engineering structures across the university campus and adjacent settlements.

The depositional heterogeneity of the Benin Formation produces marked spatial variations in soil stiffness, compressibility, and loading capacity, which are critical parameters governing safe foundation design (Castagna, 1985; George et al., 2024). At the same time, thickness variations within the formation impart a complex multiaquifer system to the subsurface and generate pronounced variability in seismic wave velocities and elastic properties (Jewel and Udosen, 2026). Where loose, unconsolidated sand horizons intertongue with soft, saturated clay lenses at shallow depths, localized reductions in shear strength and bearing resistance can occur over short lateral distances, posing substantial geotechnical challenges for shallow footings and raft foundations.

Despite growing awareness of these lithological and hydrogeological complexities, geotechnical evaluations in Mkpat Enin have traditionally leaned on discrete borehole sampling or regional groundwater surveys rather than continuous near surface mechanical profiling. Bridging this gap demands a nondestructive geophysical methodology capable of resolving spatial subsurface variations across broad construction footprints. Seismic refraction profiling addresses this need by analyzing compressional and shear wave travel times through the shallow subsurface to map layer thicknesses, depth to competent bearing strata, soil rippability, and in situ dynamic elastic moduli, including Young's modulus, shear modulus, bulk modulus, and Poisson's ratio. By integrating near surface seismic refraction tomography with the local stratigraphic and tectonic setting of Akwa Ibom State University and its environs, this research establishes a quantitative, site-specific engineering framework that advances safer and more reliable foundation designing across the coastal plain of southeastern Nigeria.

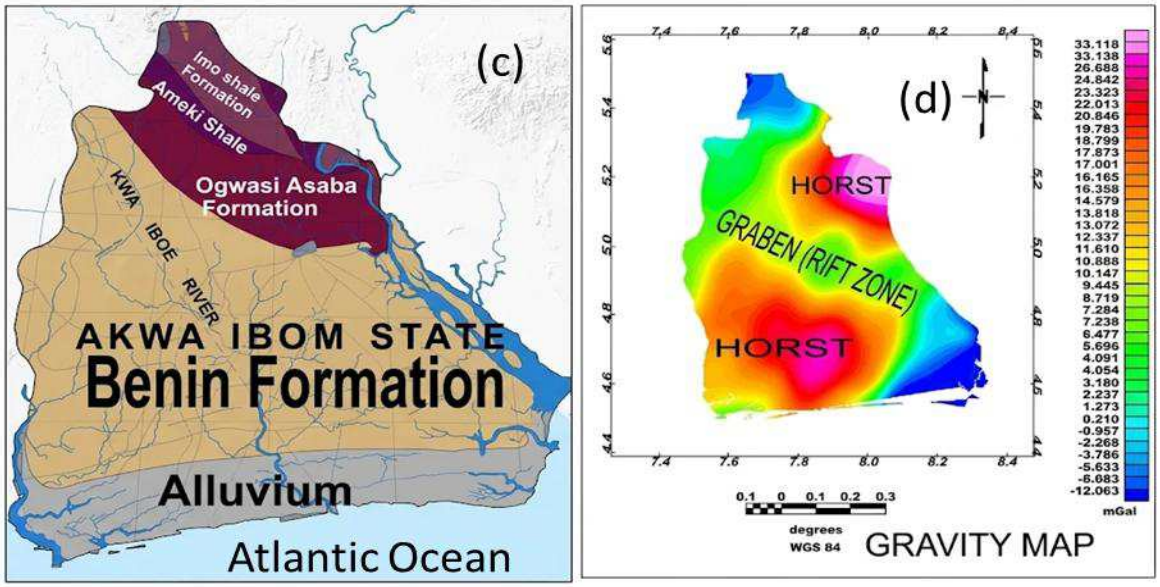


Figure 2c (left) geological map of Akwa Ibom State and 2d (right) a regional tectonic map of Akwa Ibom State (Adapted from Geological map of Nigeria, published by Nigerian Geological Survey Agency,2006)

3. **Methodology**

Seismic Refraction Theory and Engineering Utility

The infrastructural expansion around Akwa Ibom State University and its surrounding communities in Southeast Nigeria has placed unprecedented demand on the shallow subsurface. Every civil engineering structure, from large academic buildings to highway networks, relies on a foundation system capable of safely transferring structural loads into the underlying earth. When the bearing capacity of local soils or bedrock proves inadequate for the imposed load, the ground can yield through shear failure, lateral sliding, or excessive differential settlement. Evidence of such geotechnical distress is already visible across the study area, where recurring road failures, ground subsidence, and structural defects affect sections of the major expressway traversing the corridor, as shown in Figure 3. Addressing these engineering challenges requires moving beyond localized point testing toward comprehensive subsurface characterization prior to construction.

Seismic refraction offers an economical, noninvasive geophysical approach for mapping continuous variations in subsurface competence across large development footprints. The technique introduces controlled seismic energy at the ground surface, generating compressional (P) and shear (S) waves that propagate downward and refract along subsurface geological boundaries before returning to surface geophones linked to a seismograph (Dobrin, 1976; Keller et al., 1981). By analyzing the precise arrival times of these refracted waves, geophysicists compute the propagation velocities of both wave types through distinct soil and rock layers. Because seismic velocities respond directly to intrinsic physical properties such as bulk density, confining pressure, and grain cementation, they serve as sensitive indicators of in situ ground stiffness and structural integrity.

Integrating P and S wave velocities bridges the gap between geophysical measurements and quantitative geotechnical design (Grant and West, 1965; Ulugergedi and Uyanik, 2007). From these paired velocities and formation densities, a complete suite of dynamic elastic parameters can be derived, specifically Young's modulus, shear modulus, bulk modulus, Poisson's ratio,

compressibility, and compliance. Together, these constants describe how shallow geological materials resist compression, shear distortion, and volumetric strain under applied loads. These properties also govern the subgrade coefficient, which quantifies the contact stress per unit area relative to the settlement induced at the foundation interface. Evaluating the subgrade coefficient alongside rock and soil stiffness allows engineers to establish both ultimate and allowable bearing capacities with far greater spatial confidence than isolated borehole logs alone can provide.

Despite ongoing urbanization around Akwa Ibom State University, empirical data linking dynamic elastic moduli to foundation load thresholds within this coastal plain setting remains scarce. Relying on generalized soil assumptions in an environment prone to pavement failure and structural cracking exposes new infrastructure to costly remediation and safety risks. By combining seismic refraction profiling with geotechnical bearing capacity modeling, this study establishes a predictive subsurface framework for the university and its environs. The resulting elastic and load bearing profiles equip civil engineers, planners, and developers with actionable baseline parameters to optimize foundation depth, select appropriate structural designs, and prevent ground failure across Southeast Nigeria.

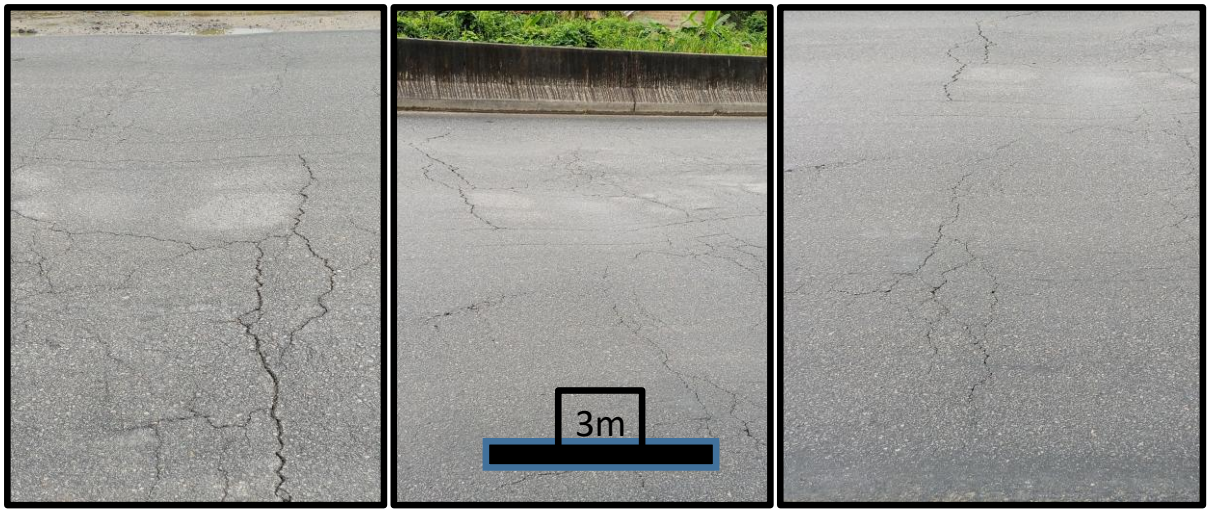


Fig. 3. Road failure due to settlement along Eket – Port Harcourt express way in study area.

Conventional geotechnical site assessments rely heavily on static testing techniques, which yield isolated, point specific data and severely limit spatial coverage. To overcome these constraints across Akwa Ibom State University and its environs in Southeast Nigeria, this study introduces a dynamic seismic refraction approach that characterizes broad tracts of terrain rapidly and economically. Moving beyond localized sampling to continuous subsurface profiling gives civil engineers a comprehensive view of ground behavior, enabling smarter foundation designs that protect structural integrity. This work directly advances United Nations Sustainable Development Goal 11 on Sustainable Cities and Communities by encouraging safe, resilient infrastructure growth. Through this geophysical evaluation, the research resolves shallow subsurface stratigraphy by identifying distinct soil and rock layers alongside their true depths and thicknesses, while quantifying elastic moduli and load bearing capacities to verify the competence of the underlying formations. Figure 4 illustrates the complete methodological workflow adopted for this investigation.

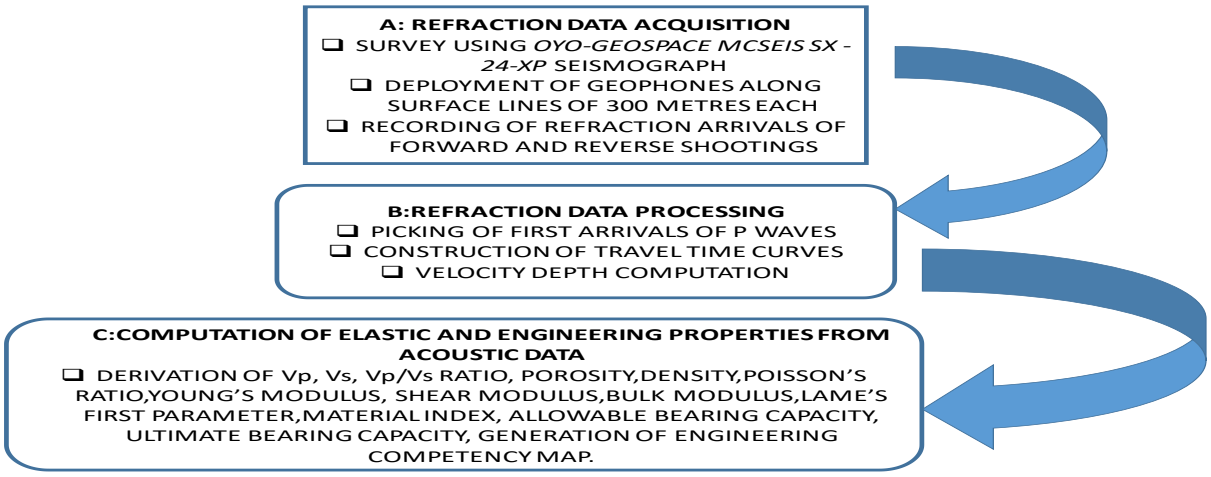


Figure 4. Workflow of methodology.

Evaluating subsurface suitability for foundation design at Akwa Ibom State University and its environs in Southeast Nigeria requires determining key geotechnical stiffness properties, specifically Young's modulus, shear modulus, and Poisson's ratio. Within the framework of elastic wave propagation theory, calculating these parameters relies on assuming continuous shallow strata, small strain levels, predominantly elastic deformation during wave transit, and an isotropic or near isotropic medium. These theoretical conditions align closely with the local geology of the study area, which consists of unconsolidated to semi consolidated sedimentary deposits exhibiting minimal structural deformation. The consistently positive Poisson's ratio values recorded across the site further validate the mechanical isotropy of these formations. Because conventional seismic refraction directly captures compressional wave velocities (Vp), the corresponding shear wave velocities (Vs) needed to compute the elastic moduli were derived using the empirically calibrated Castagna et al. (1985) relation:

$$Vs = aVp+b \quad (1)$$

Where a=0.4563 and b= -1.2 m/s for unconsolidated and lateritic soils within the Niger delta region. This well calibrated regional model was adopted to ensure reliable estimation of Vs in the absence of its direct measurement.

Table 1 presents key parameters and their associated equations. The parameters indicate their relevance to predict soil/rock stiffness, load bearing capacity and compressibility.

Table 1: Derived engineering and elastic parameters (Φ, e, λ, Qa, Qf, Mi, ρ) and (μ, E, K, σ).

SN	Parameter	Equation	Unit	Interpretation
1.	Porosity (Φ)	Φ=-0.175 ln (V_p) + 1.56	-	Fraction of void space in soil; higher values indicate more compressible soils with lower stiffness.
2.	Void ratio (e)	e =Φ/1-Φ	-	Ratio of void volume to solid volume; higher value reflects loose, more compressible soils.
3.	Density (ρ)	ρ =γ/g, where γ=γ_0 +0.002 V_p γ_0=16 kN/m^3	Kg/m^3	Bulk density of soil; higher density connotes stiffer, more competent material.
4.	Poisson's ratio (σ)	$\sigma = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{2\left(\frac{V_p}{V_s}\right)^2 - 1}$	-	Ratio of lateral strain to axial strain, higher values indicate soft unconsolidated rocks.
5.	Shear modulus (μ)	μ = ρ Vs	Pa	Resistance to shear deformation, low value for weak superficial deposits, high values for stronger and more competent materials.

6.	Young's modulus (E)	$E=2\mu(1+\sigma)$	Pa	Measure of soil stiffness, low E means soft soil, high E connotes dense load bearing soils.
7.	Bulk modulus (K)	$K=\frac{E}{3(1-2\sigma)}$	Pa	Resistance to volumetric compression, higher values for less compressible soils.
8.	Lame's first parameter (λ)	$\lambda=K-2\mu/3$	Pa	Describes materials response to multi-axial stress; relevant to layered soil, resistance to volume change; when λ is high soil is incomprehensible.
9.	Material index (Mi)	$Mi=1-4\sigma$	-	Indicates ductility and stiffness, higher values for stiffer soils.

10.	Ultimate bearing capacity (Q_f)	$Q_f = Ks/40$, $Ks = 4\gamma Vs$	Pa	Maximum stress the soil can support a structure without failure.
11.	Allowable bearing capacity (Q_a)	$Q_a=\frac{Q_f}{n}=4$	Pa	Safe bearing capacity, takes into consideration factor of safety; guides foundation design.

Porosity(Φ): This refers to the quantity of void space in a material, it directly affects compressibility and water storage potential. It's computed from Vp using the empirical formula in Equation 2 (Watkins et al.,1972):

$\Phi=-0.175 \ln(V_p) + 1.56$ ……..(2).

Higher porosity, means higher material compressibility and lower shear strength.

Void ratio (e): expressed as

$e = \Phi/1-\Phi$ …….(3)

It compliments porosity (Φ) by expressing the volume of voids relative to that of solids. Higher ratios indicate increased susceptibility to consolidation and settlement under engineering loads.

Density (ρ): Computed from unit weight relationship viz: -

$\rho = \rho = \gamma/g$ ……..(4)

where $\gamma = \gamma_0 + 0.002\ Vp$ ……(5)

with $\gamma_0 = 16\ kN/m^3$ (mean weight of loose unconsolidated soil, Aka et al. (2018), and $g = 9.8\ m/s^2$.

Poisson's ratio (σ) provides a ratio of lateral to axial strain. It is computed viz:

$$\sigma=\frac{\left(\frac{V_p}{V_s}\right)^2-2}{2\left(\frac{V_p}{V_s}\right)^2-1} \quad \text{…….. (6)}$$

where Vp =compressional wave velocity, and Vs shear wave velocity. High σ is indicative of unconsolidated moisture rich materials. Lower σ indicates dense sands, sandy clays etc., connoting less deformable materials.

The shear modulus (μ), and young's modulus (E) express the resistance of heterogeneous materials to shear deformation and overall stiffness. The two moduli help in predicting settlement, deformation and load transfer behaviour of foundations.

For shear modulus we have:

$$\mu = \rho Vs^2 \quad (7)$$

and Young's modulus:

$$E = 2\mu (1+\sigma) \quad (8)$$

Where ρ=density, Vs=shear wave velocity, σ=poisons ratio.

The bulk modulus (K) provides information on volumetric compressibility under isotropic stress and was calculated as

$$K = E / \{3(1-2\sigma)\} \quad (9)$$

Lame's first parameter (λ) provides information on material's response to multi-axial stress conditions. It is particularly relevant for a layered soil configuration. It is computed thus:

$$\lambda = K-(2\mu/3) \quad (10)$$

where K = bulk modulus, μ=shear modulus.

The material index (M_i) is given as:

$$Mi = 1-4\sigma \quad (11).$$

where σ=poison's ratio, its inclusion is to facilitate comparative assessment of material ductility and stiffness across layers. It provides fast, inexpensive insight into expected engineering attributes like permeability, compressibility, and shear strength without running complex long –term test. The index is defined as the degree to which the material is deformed based on its modulus of elasticity. It refers to the composition of the material, the degree of solidification, is rupture and jointing, the presence or absence of liquid in the pores which affect elastic modulus (Shebl et al., 2019)

The ultimate bearing capacity (Q_f) is computed from

$$Q_f = Ks/40 \quad (12)$$

$$\text{Where } K_s = 4\gamma V_s \quad (13)$$

Vs =shear wave velocity, $\gamma = \gamma_0 + 0.002$ Vp,

With $\gamma_0 = 16$ KN/m^3 (average unit lose weight of unconsolidated soil). The allowable bearing capacity Q_a is computed from

$$Q_a = Q_f/n \quad (14)$$

Where n is safety factor of soil with a value of 4.

These parameters provide quantitative data and guidance for foundation design. They provide a link between elastic properties and engineering criteria. The computed parameters are used to generate maps to see their variations in geographic space, to assist in site selection for foundation design and land use planning.

Refraction survey design

To characterize the shallow subsurface for foundation design at Akwa Ibom State University and its environs in southeast Nigeria, a seismic refraction investigation was conducted to map the low velocity layer (LVL) and evaluate near surface engineering properties. Field data acquisition was carried out by Erisel Geophysical Enterprise of Port Harcourt, Nigeria, utilizing a symmetrical split spread geometry of 24 geophones (Figure 5) with parameters in Table 2. Twelve receivers were laid out on either side of the spread center at 12.5 m intervals, covering a total profile length of 300 m (Figure 5d). Seismic energy was generated using a 0.4 kg explosive charge detonated with a single cap and recorded on a refraction seismograph (Figure 5c). To detect and resolve any dipping subsurface strata, shots were executed in both forward and reverse directions at either end of the spread, supplemented by offset shots positioned 12.5 m beyond the first and last geophone stations. The base map of the survey area and its corresponding geographic coordinates are presented in Figures 5a and 5b, respectively.

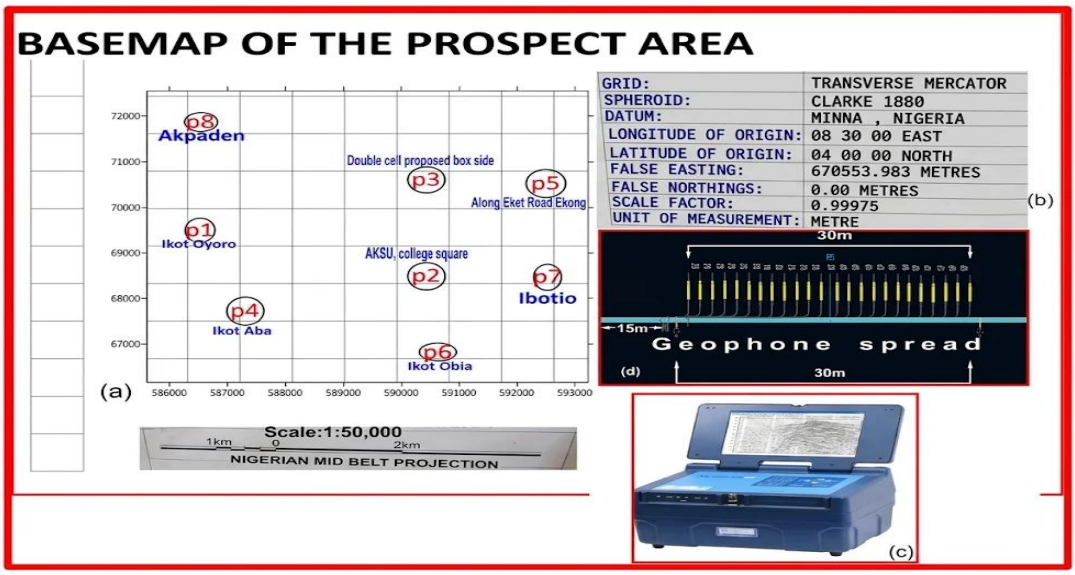


Figure 5a: base map of survey area and its geographic coordinates (5b), 5c shows refraction seismograph used, 5d is the geophone spread, and 5e shows sample of forward and reverse seismograms.

Under the tropical sky of Southeast Nigeria, a survey crew unloaded their gear from a field pickup van across the grounds of Akwa Ibom State University and its surrounding terrain. Their mission was to probe the hidden strength of the shallow earth before future building foundations could ever be laid. Canvas bags hit the soil alongside coils of firing line, connecting cables, and two sprawling main cables stretching one hundred and fifty meters each. Using a measuring tape to mark exact intervals, the team planted twenty-four geophones into the ground, each housing a ten hertz JFS 1 20DX sensor and a three hundred- and ninety-five-ohm damping resistor sealed tightly inside a protective marsh case. Strings of eighteen basic unit wires linked the array together, calibrated to SEG compliant polarity so that any downward jolt of a casing sent a clean positive voltage racing down the line.

A short distance away, a wide survey umbrella cast shade over the makeshift command post, shielding an OYO GEO SPACE McSEIS SX 24 XP portable digital recorder and a laptop computer from the glare. Steady power flowed from a twelve-volt car battery wired directly into the detonating pack. Near the very first geophone station, explosives rested packed inside boreholes dug one to two meters deep.

Once every safety check cleared, voices crackled across two portable communication radio sets and a sharp blast from a whistle warned the crew to stand back. The operator triggered the

detonating pack, unleashing a voltage discharge down the firing line to ignite the blasting caps. At that exact fraction of a second, the blasting unit sent a simultaneous field time signal straight into the seismograph, marking zero hour as shockwaves rippled through the subsurface and registered their arrival sequence across the sensors. With the shot confirmed successful, the recorder locked the seismic traces into its internal memory, spun out an immediate hard copy printout on site, and saved the digital files onto a flash drive ready for deeper interpretation on the laptop

Table 2: Geophone Parameters

Resistance	1850 Ω ± 5%
Damping	0.704 ± 10%
Natural frequency	10 Hz
Harmonic mean	<0.2%
Sensitivity	1.8 V/CM/S ±7.5%
Leakage	>2 Ω x10^6

As part of the acquisition exercise land surface elevation data (topographic data) survey was undertaken and elevation map produced over the study area see Figure 6.

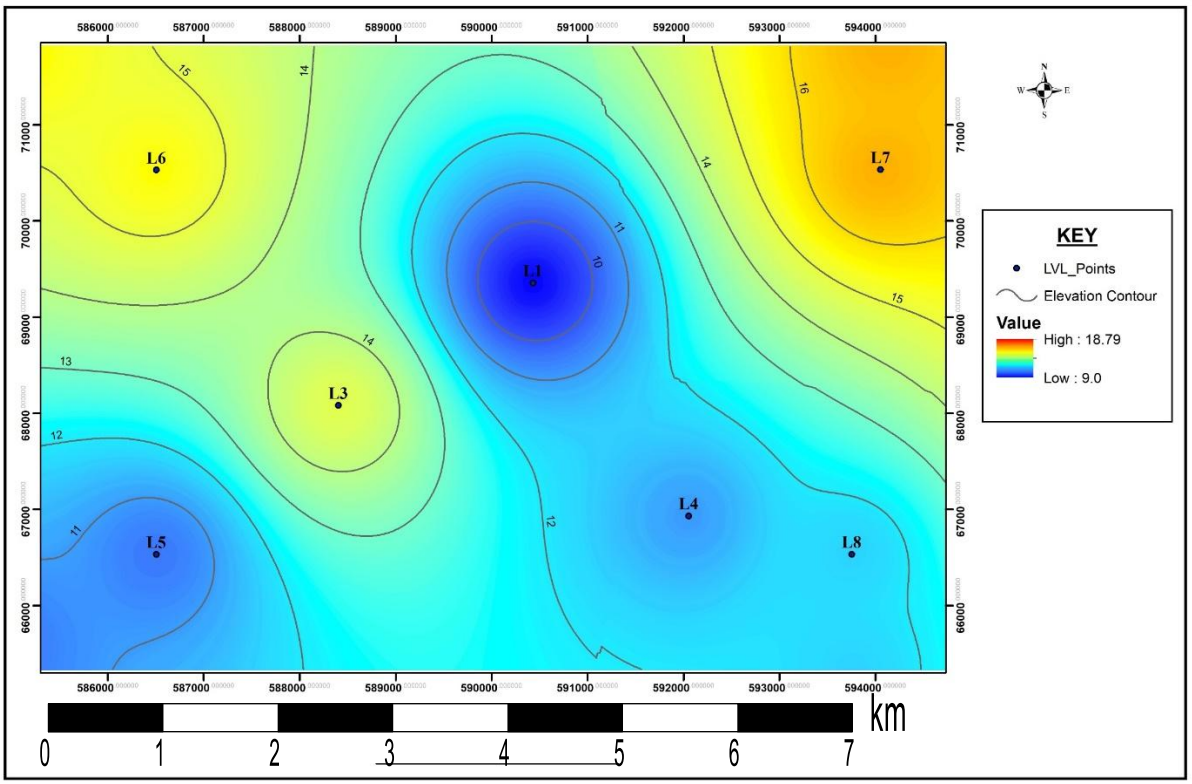


Figure 6. Elevation map of study site.

Eight LVLs were surveyed and all were recorded at points of intersections of source and receiver lines. At the points of intersection, the LVL cable was either laid along the receiver line or source line depending on the line direction that is free from obstruction or is more level.

Data Processing /Analysis

For the LVL survey shots were fired twice, one at each end of the (forward and reverse) and recorded accordingly. A time –offset graph was plotted with a seismic wave processing software (*upshere version 1.9*), after which a line of best fit was plotted for the various layers

respectively but automatically. The graphs generally show a two-layer subsurface configuration (Figure 7). The overall harmonic thickness of the weathering zone ranges from 5.50-9.19 m. While the weathering velocity ranges from 377.02-805.48 m/s. The velocity of the consolidated layer ranges from 1643.10 -2000 m/s. See Table 3.

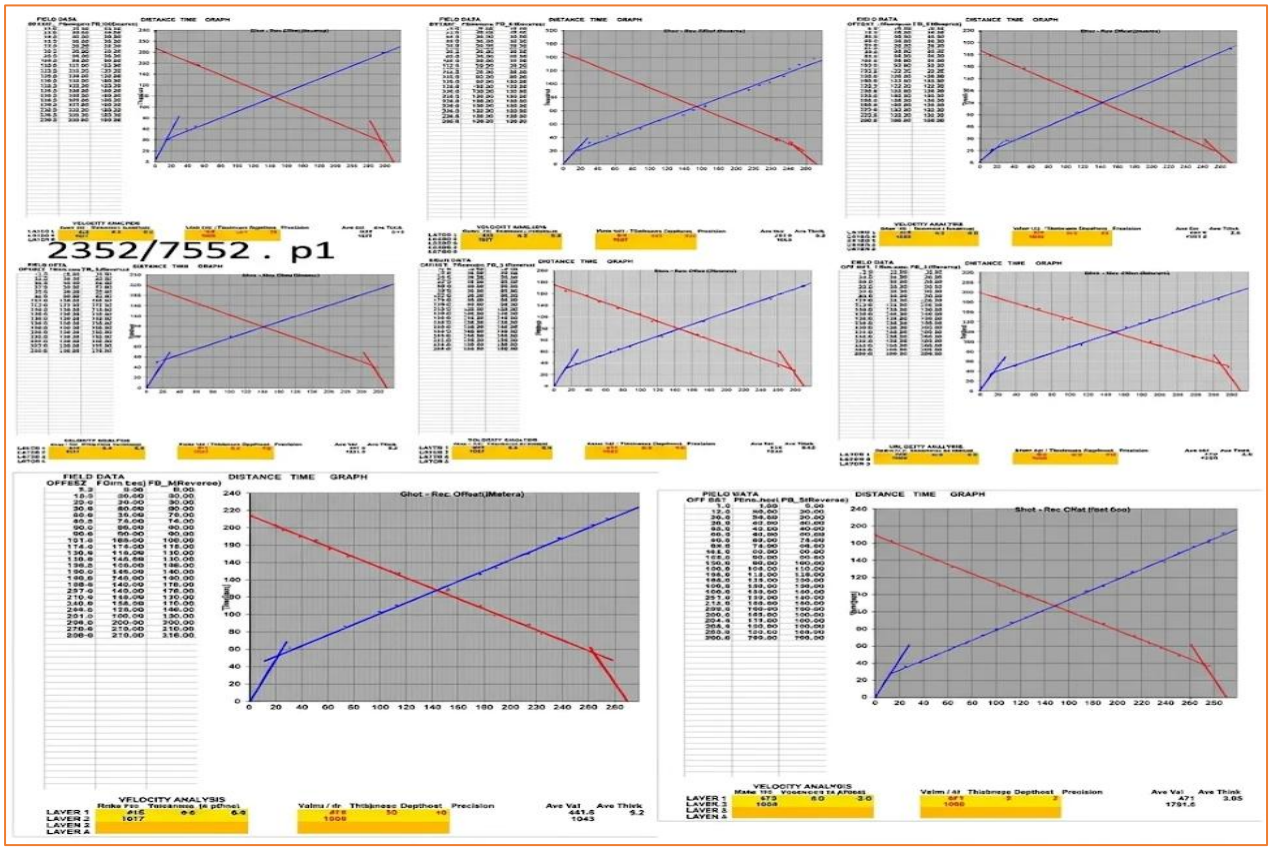


Figure 7: Time – distance graphs from seismic data acquired.

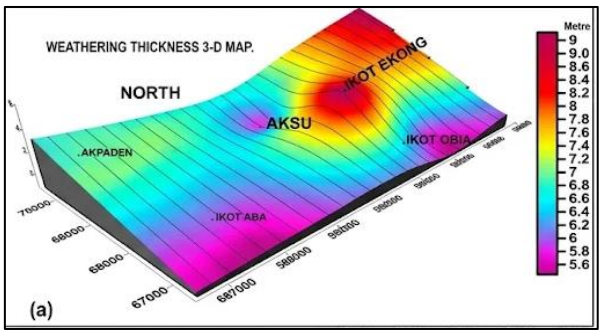


Figure 8: Weathering thickness (layer1) map

Table 3 shows elevation, low velocity layer, and consolidated layer data in the study area.

Table 3: Elevation, weathering thickness, weathering velocity, and consolidated layer velocity data.

LINE NO	EASTINGS	NORTHINGS	SURFACE ELEVATION (m)	WEATHERING THICKNESS (m)	WEATHERING VELOCITY (m/s)	CONSOLIDATED LAYER VELOCITY (m/s)
1.	590432.8	69356.1	9.0	6.05	377.0	1656.0
2.	588405.4	68082.0	14.8	6.3	805.5	2000.0
3.	592055.5	66932.2	11.0	5.5	799.5	1943.5
4.	591233.7	68356.6	18.8	8.2	407.5	1820.5

5.	586505.9	66532.1	10.5	5.6	456.0	1915.0
6.	586506.1	70531.1	15.5	7.7	419.0	1756.0
7.	59055.4	70532.8	16.7	9.2	441.5	1643.0
8.	593754.9	66533.4	11.7	6.0	471.0	1751.5

4. RESULTS

From examination of computed data, the study area is vertically divided into two layers; an upper weathering layer and a lower consolidated layer based on P and S wave velocities. The Table 4a and 4b below present geophysical and geotechnical parameters computed from the above formulae; these parameters include primary (Vp) and secondary (Vs) velocities, Vp/Vs ratio, porosity (Φ), void ratio (e), density (ρ), poisson's ratio (σ), shear modulus (μ), Young's modulus (E),bulk modulus (K), Lame's first parameter (λ), material index (Mi), ultimate bearing capacity (Qf), allowable bearing capacity (Qa).

Table 4a: Geophysical and geotechnical parameters and their corresponding layers.

Velocity		Porosity Φ (%)		Void ratio (e)		Density ρ (kg/m^3)		Poisson's ratio (σ)		Shear modulus μ (GPa)	Shear Modulus μ (GPa)	Vp/Vs	D (σ
s)	Vs (m/s)												
/	Layer 1/Layer 2	Layer 1	Layer 2	Layer 1	Layer 2	Layer 1	Layer 2	Layer1	Layer2	Layer 1	Layer 2	Layer 1	
656.0	170.8/754.4	52.19	26.29	1.091	0.357	1633.4	1636.0	0.371	0.369	0.0477	0.0931	2.207	0.
000	366.4/911.4	38.90	22.98	0.637	0.298	1634.3	1636.7	0.370	0.369	0.0219	0.0136	2.198	0.
643.5	363.6/748.7	39.03	26.42	0.640	0.359	1634.3	1636.0	0.370	0.369	0.0216	0.0917	2.198	0.
820.5	184.7/829.5	50.82	24.63	1.034	0.327	1633.5	1636.4	0.371	0.369	0.0557	0.0113	2.206	0.
915.0	206.7/872.6	48.86	23.74	0.955	0.311	1633.6	1636.6	0.371	0.369	0.0698	0.0125	2.206	0.
756.0	190.0/800.0	50.34	25.26	1.014	0.338	1633.5	1636.2	0.371	0.369	0.0589	0.0105	2.205	0.
643.0	200.2/748.5	49.42	26.43	0.977	0.359	1633.6	1636.0	0.371	0.369	0.0655	0.0917	2.206	0.
751.5	213.7/798.0	48.29	25.31	0.934	0.339	1633.6	1636.2	0.370	0.369	0.0746	0.0104	2.204	0.

4b: more geotechnical parameters

Lines	Layer	Young modulus E (Gpa)	Bulk Modulus K(Gpa)	Lame's first constant λ (Gpa)	Material index Mi	Ultimate bearing capacity Qf (Gpa)	Allowable bearing capacity Qa (Gpa)
1	1	2.553	3.295	3.261	-0.483	0.0003	0.00007
	2	2.549	3.245	2.624	-0.476	0.0012	0.00030
2	1	3.724	4.758	4.612	-0.478	0.0006	0.00002
	2	3.722	4.734	3.828	-0.476	0.0015	0.00037
3	1	2.512	3.211	3.067	-0.478	0.0006	0.00002

	2	2.511	3.196	2.585	-0.476	0.0012	0.00030
4	1	3.087	3.979	3.942	-0.483	0.0003	0.00007
	2	3.083	3.922	3.171	-0.476	0.0013	0.00033
5	1	3.416	4.432	4.357	-0.483	0.0003	0.00008
	2	3.412	4.340	3.509	-0.476	0.0014	0.00035
6	1	2.871	3.696	3.657	-0.482	0.0003	0.00008
	2	2.867	3.649	2.951	-0.476	0.0013	0.00032
7	1	2.512	3.236	3.191	-0.482	0.0003	0.00008
	2	2.510	3.194	2.583	-0.476	0.0012	0.00030
8	1	2.856	3.672	3.622	-0.482	0.0003	0.00009
	2	2.853	3.630	2.936	-0.476	0.0013	0.00032

Figures 9 to 20 show spatial variations of the tabulated parameters over the study area for layers 1 and 2, respectively.

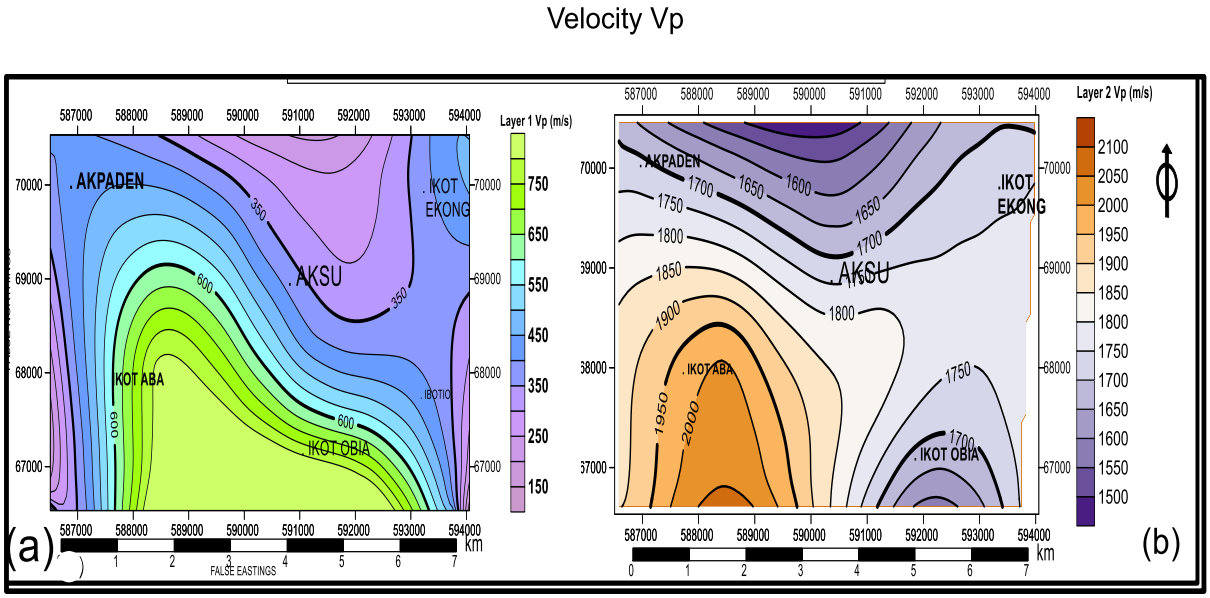


Figure 9 a shows compressional wave variation for layers 1 and 9b shows compressional wave variation for layer 2

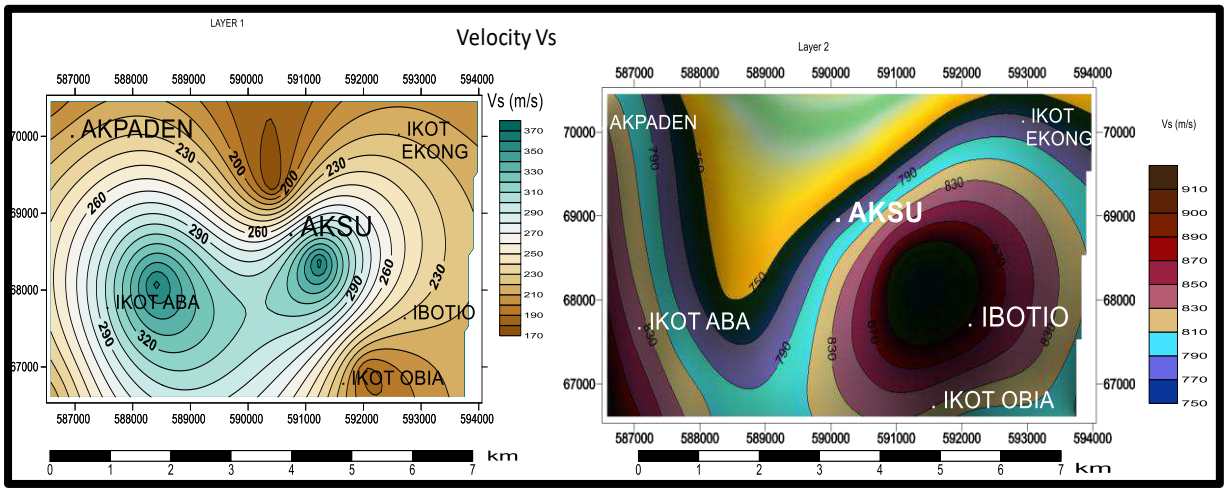


Figure10: shows shear wave velocity variation maps for layers 1(left) and layer 2 (right)

Figure 11

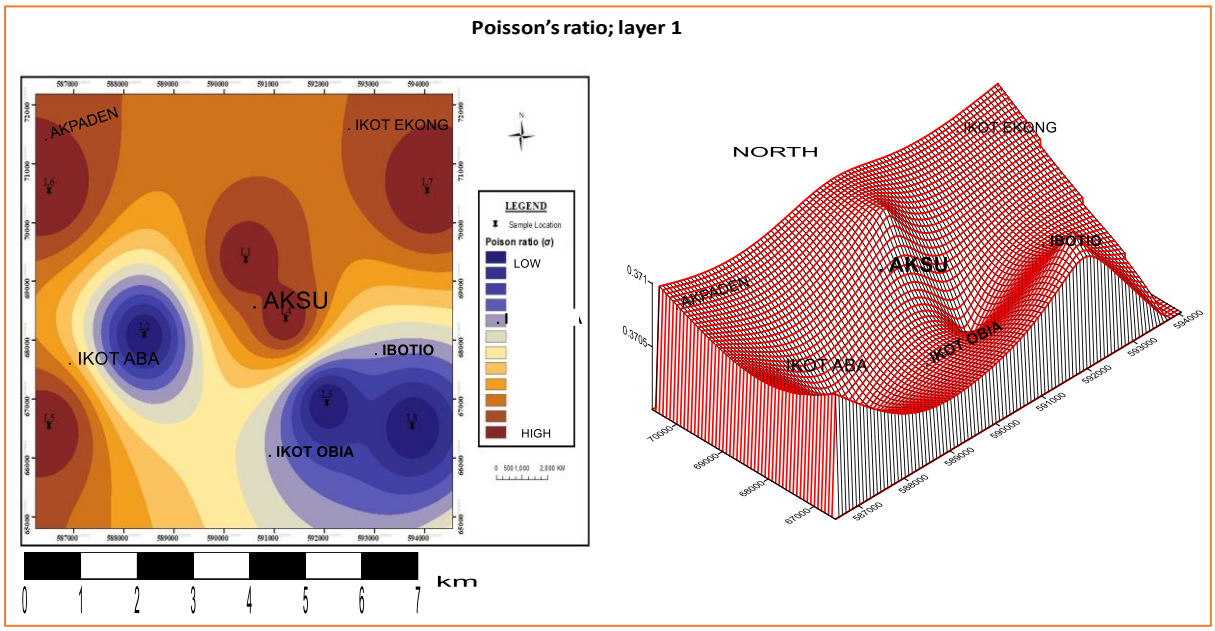


Figure 11 shows a 2D Poisson's ratio map for layer 1 (left) and 3D (right)

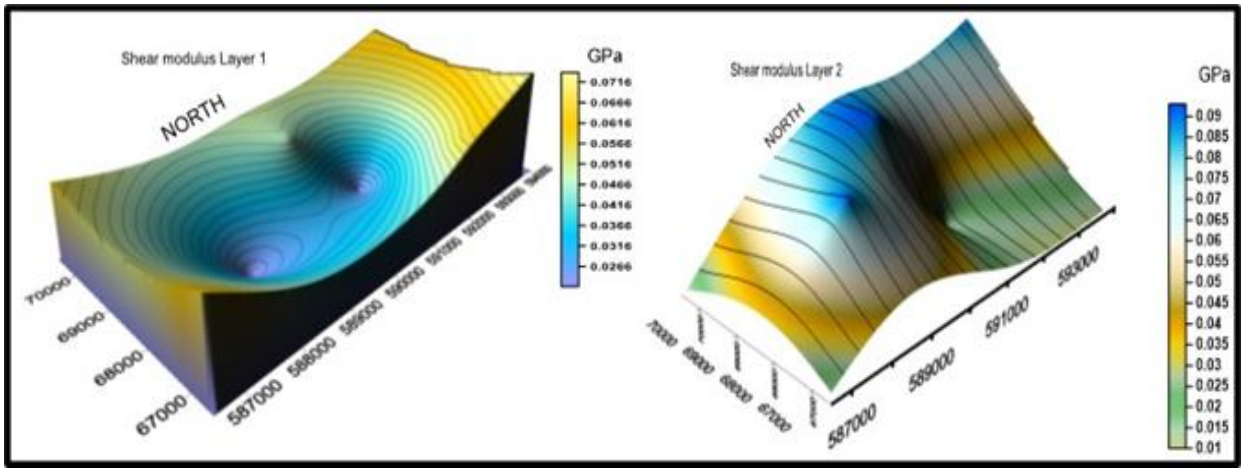


Figure12: shows shear modulus variation maps for layers 1 and 2, respectively.

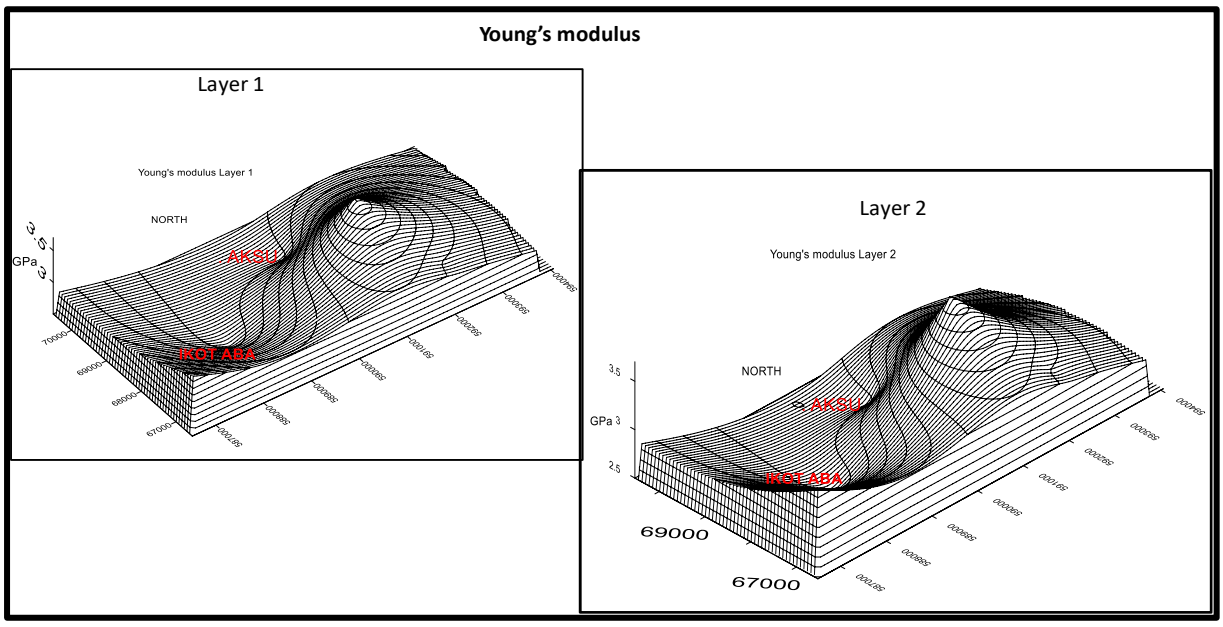


Figure13: shows Young Modulus variation maps in 3D for layers1 and 2, respectively.

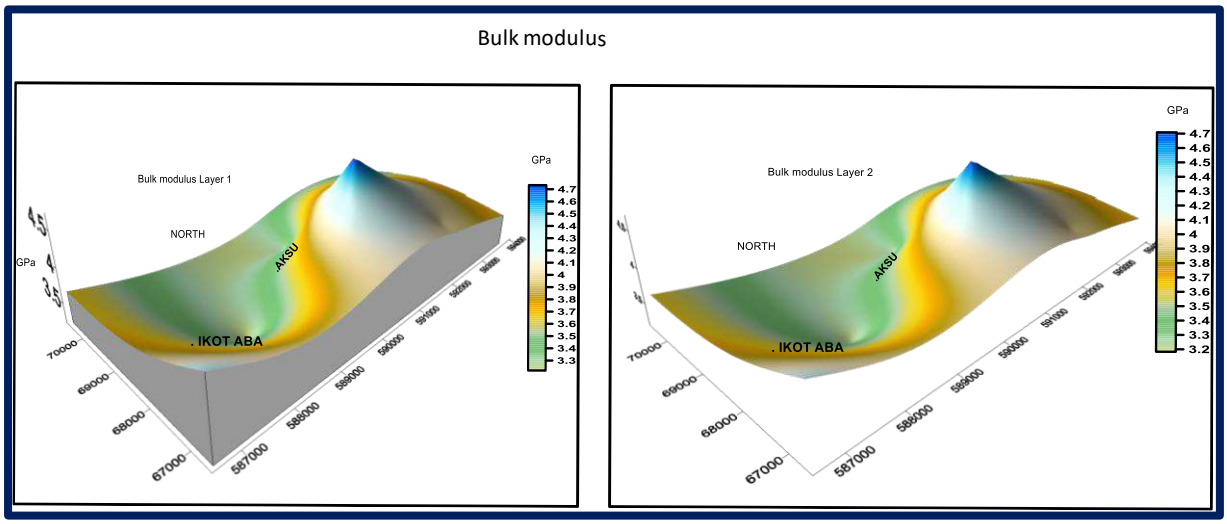


Figure14: Bulk Modulus variation maps in 3D for layers 1and 2, respectively.

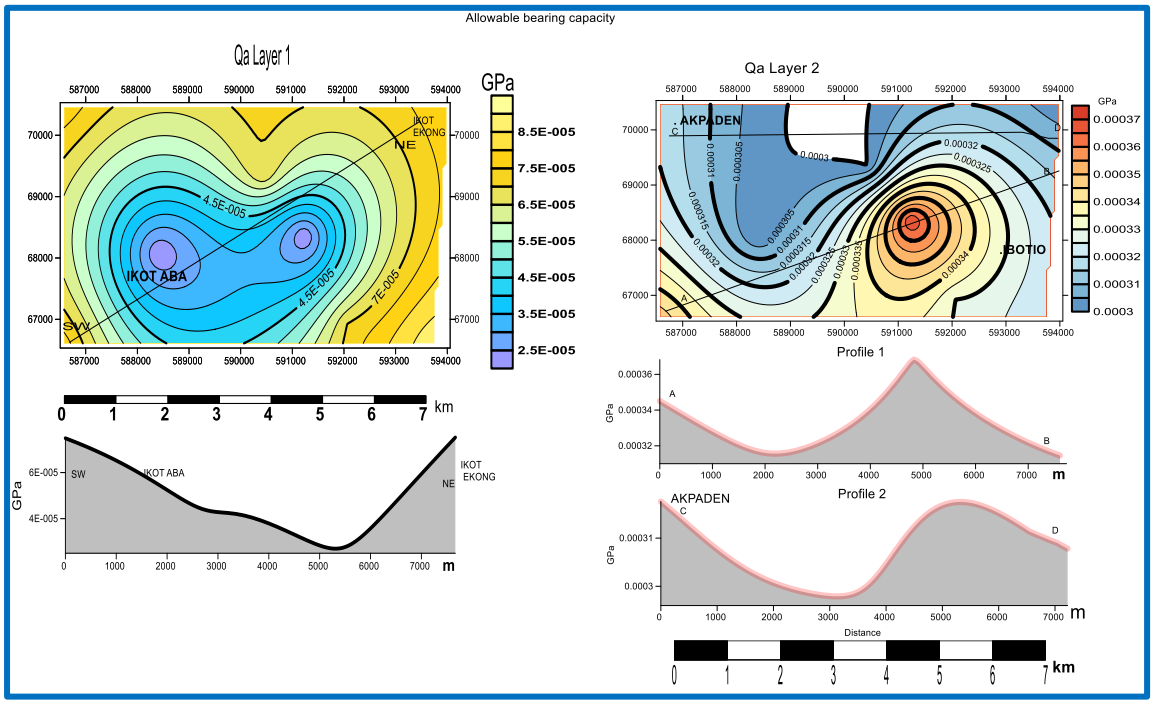


Figure15: shows allowable bearing capacity maps and some cross-sections for layers1 and 2, respectively.

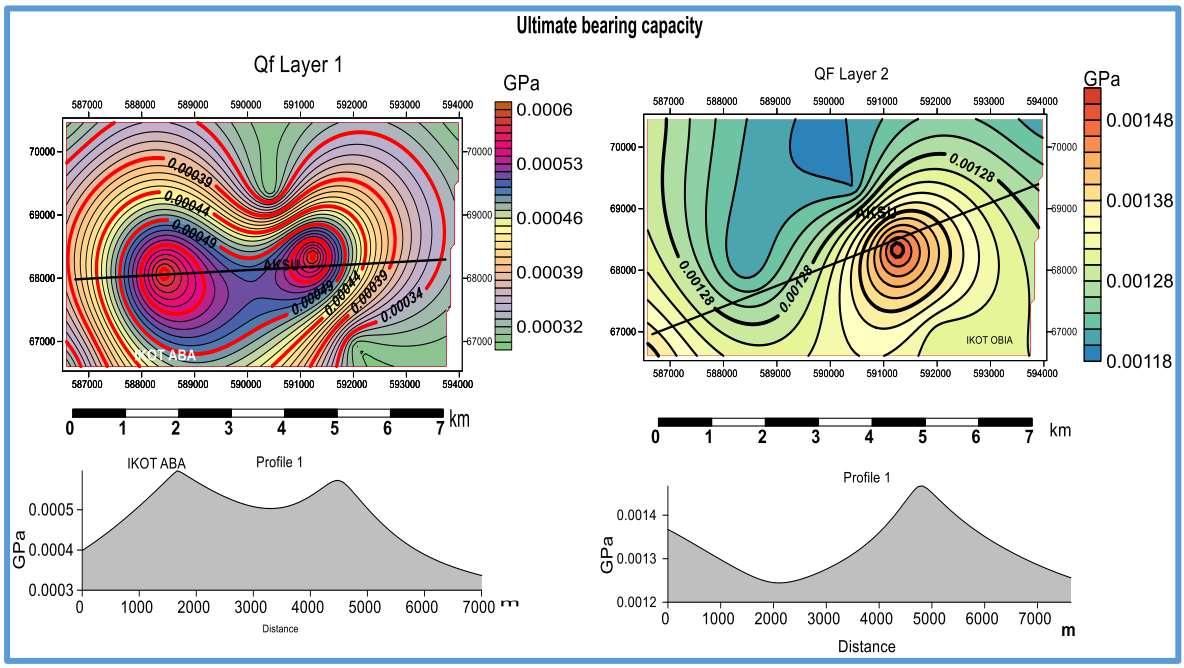


Figure16: shows ultimate bearing capacity maps and some cross-sections for layers1 and 2, respectively.

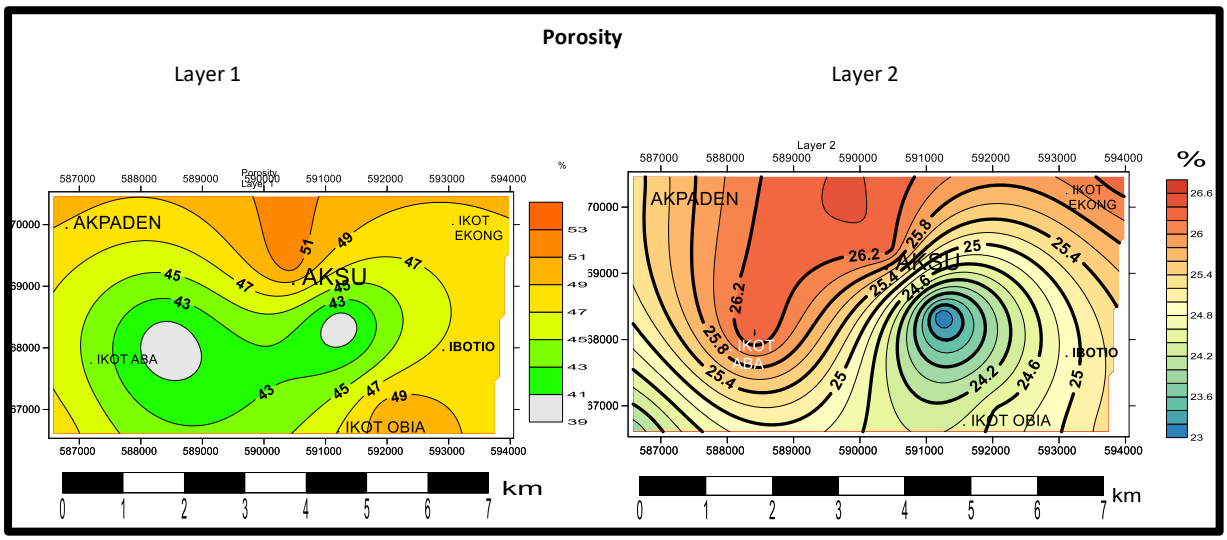


Figure17: shows porosity maps for layers1 and 2, respectively.

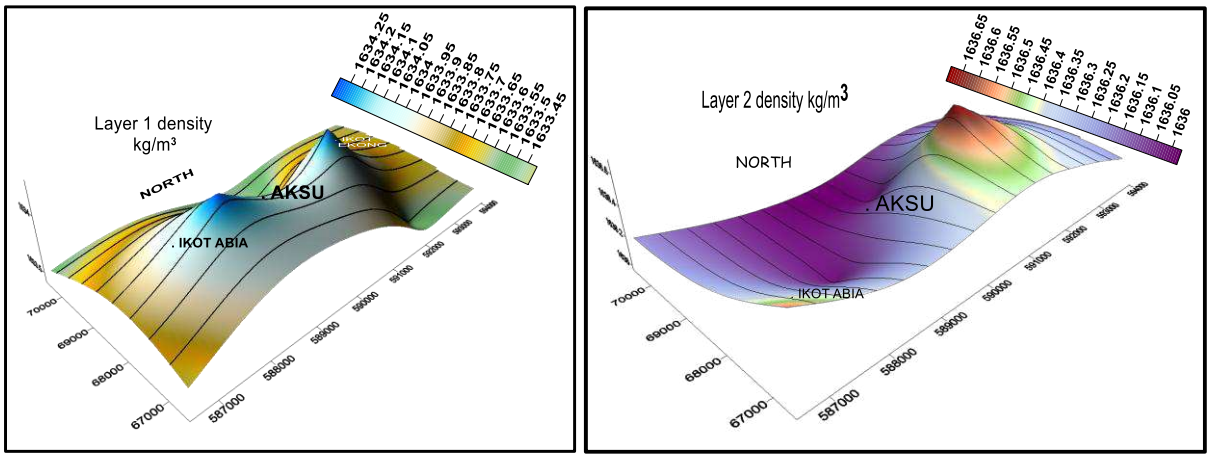


Figure18: shows bulk density maps in 3D for layers1 and 2, respectively.

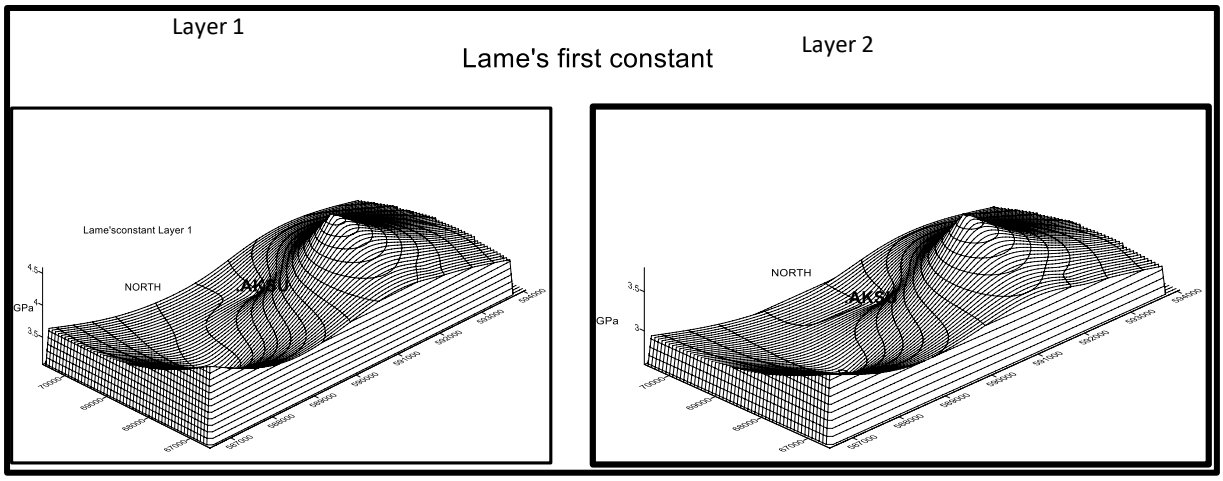


Figure19: shows Lame's first constant maps in 3D for layers1 and 2, respectively.

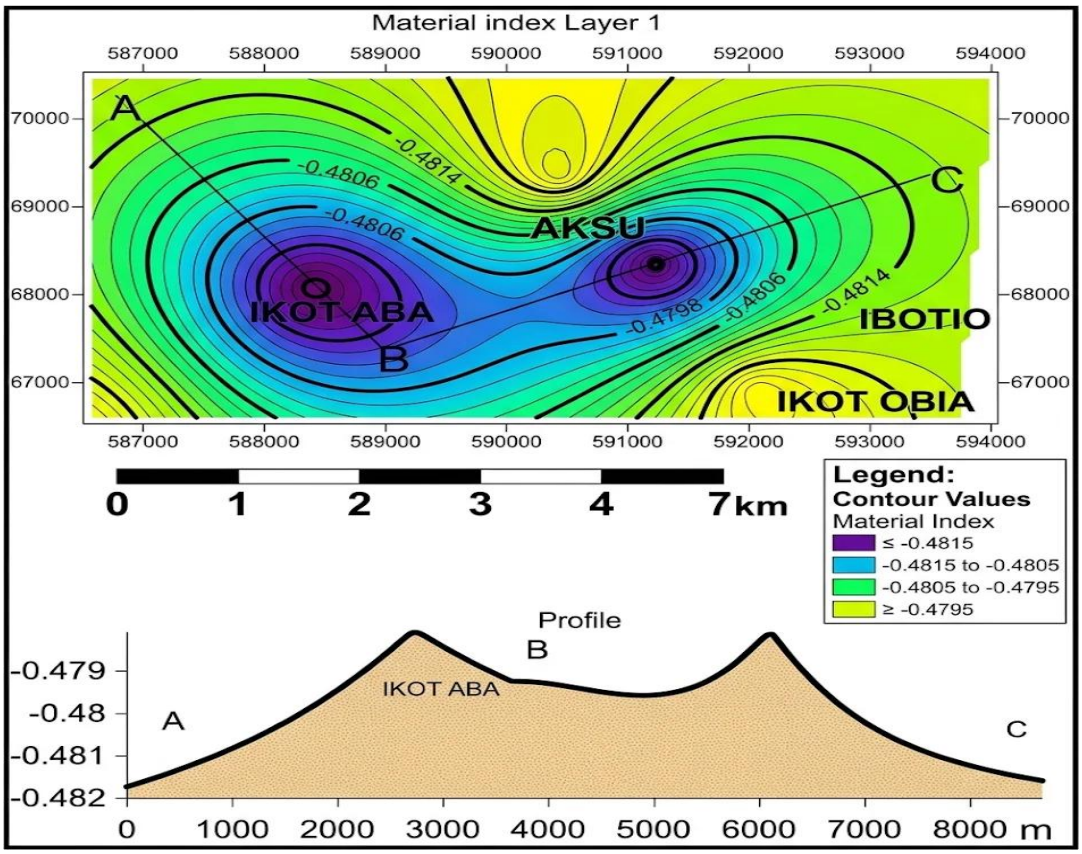


Figure20: shows Material index map with a cross-section for layer 1.

Spatial distribution maps in Figures 9 through 20, alongside the quantitative datasets in Tables 4a and 4b, uncover a distinct two-layer geomechanical architecture governing near surface foundation design across Akwa Ibom State University and its environs in Southeast Nigeria. Nearest the ground surface, the weathered overburden spans thicknesses from 5.50 to 9.19 m and exhibits comparatively low seismic velocities, with compressional P wave speeds occupying 377.05 to 805.99 m/s and shear S wave speeds measuring 170.82 to 366.39 m/s. Within this upper horizon, Poisson's ratio fluctuates narrowly between 0.37000 and 0.37099, reflecting loosely packed material behavior. Its elastic stiffness remains modest, defined by a shear modulus spanning 0.0477 to 0.0219 GPa, a Young's modulus between 2.51 and 3.72 GPa, and a bulk modulus reaching 3.19 to 4.73 GPa. Consequently, this shallow zone offers limited structural support, yielding an allowable bearing capacity of 0.000020 to 0.000089 GPa and an ultimate bearing capacity between 0.00030 and 0.00059 GPa, which highlights the vulnerability of shallow footings placed directly within the weathered mantle (Da col et al., 2022).

Beneath a depth of 9.19 m, the subsurface transitions sharply into a competent consolidated stratum whose full vertical extent continues beyond the probing limit of the seismic survey. Here, acoustic waves propagate markedly faster, with P wave velocities climbing to between 1,643.10 and 2,000.00 m/s and S wave velocities advancing to 754.43 through 911.39 m/s. Unlike the variable overburden above, this deeper horizon maintains a uniform Poisson's ratio of 0.3689, accompanied by a Young's modulus of 2.51 to 3.72 GPa, a bulk modulus of 2.51 to 3.72 GPa, and a shear modulus spanning 0.917 to 0.0136 GPa. This pronounced contrast in seismic rigidity translates directly into superior ground stability, elevating allowable bearing capacities to 0.000300 through 0.0004 GPa and ultimate bearing capacities to 0.00120 through 0.0015 GPa. Together, these findings establish a novel site-specific geophysical benchmark for civil engineers in Southeast Nigeria, demonstrating that seating heavy structural foundations within the deeper consolidated layer effectively bypasses weak surficial soils and secures long term structural resilience.

Characterization of computed parameters for rock competencies

To evaluate subsurface suitability for foundation design at Akwa Ibom State University and its environs in Southeast Nigeria, this study classifies local rock and soil strata into competent and incompetent layers using the geotechnical benchmarks of the Benin Formation compiled in Table 5 by Aka et al. (2018). Those reference parameters draw upon foundational rock physics and seismic principles originally formulated by Gassmann (1973), Tatham (1982), and Sheriff and Geldart (1986). Because Aka et al. (2018) investigated sections of the formation situated away from the current project site, integrating their diagnostic criteria with shallow seismic refraction measurements across the university campus and surrounding communities establishes novel, site specific engineering baselines where localized subsurface data were previously unavailable.

Table 5: Geotechnical properties of the Benin Formation from Aka et al. (2018), Gassman (1973), Tatham (1982) and Sherif and Geldart (1986).

Parameter	Weak/incompetent	Competent/compacted

Poisson's ratio σ	-11.10 to 0.04	-0.01 to 0.12
Young's modulus E	-30.17 to 3.24 GPa	2.92 to 9.70 GPa
Shear modulus μ	0.17 to 4.23 GPa	1.30 to 6.25 GPa
Allowable bearing capacity Qa	0.84 to 2.11 GPa	1.15 to 2.57 GPa
Ultimate bearing capacity Qf	3.37 to 8.44 GPa	4.61 to 10.31 Gpa
Material index Mi	-0.5 to 0.00	0.00 to >0.5

5. Discussion

Topographic relief across the study area spans 9.0 m to 18.79 m above sea level (Figure 6), displaying alternating ridges and depressions that align along a central northwest to southeast axis. This geomorphic fabric mirrors the regional drainage orientation of the Kwa Ibo River basin and aligns spatially with the northwest to southeast subsurface basement graben identified from residual gravity data by Bassey and Ekpo (2024, 2026). While shallow seismic refraction profiles capture near surface elastic contrasts rather than deep basement tectonics directly, this inherited structural trend actively regulates local weathering and drainage dynamics. Derived from the time offset curves in Figure 7, the isopach map of the weathered layer (Figure 8) reveals thickness variations between 5.50 m and 9.19 m that closely follow surface elevation. Elevated terrain in the northeast around Line 7 (8.09 m to 9.19 m) and in the northwest around Line 6 (6.61 m to 7.72 m) supports substantially thicker regolith profiles because deeper vadose zones promote prolonged downward chemical leaching. Conversely, central and southern lowlands exhibit thinner weathering mantles of 5.50 m to 6.61 m due to active surface runoff stripping and closer proximity to the saturated zone.

Evaluating the layer 1 isovelocity distribution (Figure 9a) alongside overburden thickness exposes two distinct near surface geotechnical regimes. Across the central and southern sectors, elevated primary wave velocities of 634.10 m/s to 805.48 m/s coincide directly with the thinner weathered zones of Figure 8, reflecting tighter grain packing and minimal structural degradation within the shallow soil column. By contrast, reduced acoustic stiffness arises through two contrasting geological mechanisms. Along the lowland southwestern and southeastern margins, specifically west of Ikot Abia and across Ibotio, low velocities reflect loose, unconsolidated alluvial and fluvial sediments accumulating within drainage depressions. In the elevated northeastern corridor between Ikot Ekong and Akwa Ibom State University (AKSU), however, low velocities overlap with the thickest weathered profile centered on Line 7, demonstrating intense chemical weathering that has leached cementing fines and increased secondary void ratios.

Beneath the weathered mantle, compressional wave velocities in the consolidated subweathering stratum (Figure 9b) rise markedly in response to greater overburden confinement, bulk density, and matrix compaction. Correlating these measured intervals with the standard rock velocity benchmarks adapted from Blyth and de Freitas (1979) in Table 6 confirms a lithological transition from loose surficial soils into compact, saturated sandy clays and consolidated Coastal Plain sands. Stratal competence reaches its peak in the southwest over Ikot Aba at 1850 m/s to over 2000 m/s, transitions through an intermediate zone of 1750 m/s to 1850 m/s south of Akpaden, AKSU, and Ikot Ekong, and drops to its lowest range of 1500 m/s to 1700 m/s in the southeast over Ikot Obia.

Integrating these elevation, thickness, and velocity patterns provides a direct framework for foundation engineering across AKSU and its surrounding communities. The central and

southwestern sectors, particularly around Ikot Aba, present the most favorable ground conditions for conventional shallow pad or strip footings, as thin overburden combines with stiff upper soils and high subweathering bearing competence. Conversely, infrastructural expansion along the northeastern corridor between AKSU and Ikot Ekong encounters a thick, mechanically weak weathered profile prone to differential settlement under heavy multistory loads, warranting deeper excavation, rigid raft foundations, or deep piles seated within the underlying intermediate velocity stratum. Finally, construction across the southeastern Ikot Obia sector requires conservative allowable bearing pressures and engineered subsurface drainage to compensate for lower consolidated stratal stiffness.

Table 6: standard P wave velocities (Zblyth and Freitas, 1979).

Lithology	P wave velocity (m/s)
Sandstone	1400-4300
Limestone	1700-4200
Clay	1100-4200
Loose sand	1800
Coarse (wet) sand	1550-1670
Sand with gravel (wet)	690-1150
Sand with gravel (dry)	490-690
Sandy clay	360-430

In the absence of direct shear wave measurements, adopting a well calibrated regional empirical model tailored to the unconsolidated lateritic soils of the Niger Delta provides a reliable mechanical baseline for evaluating subsurface stiffness across Akwa Ibom State University (AKSU) and its environs. The derived shear wave velocity (Vs) distribution reveals a pronounced two-layer geotechnical stratification (Figure 10). Within the surficial layer, Vs spans from 170.82 to 370.0 m/s, dividing the study area into distinct mechanical zones. The lowest velocities (170.82 to 236.01 m/s) cluster across the northern and peripheral corridor encompassing Akpaden, Ikot Ekong, and Ikot Obia, signaling loose, poorly cemented, and moisture laden overburden. This seismic signature aligns closely with geoelectric borehole logs from AKSU reported by George and Bassey (2026), which document a shallow stratigraphic sequence of topsoil (<10 m) overlying sandy clay (5 to 20 m), gravelly sand (20 to 60 m), and fine sand (60 to 70 m), punctuated by shallow sandy aquifers within 10 m of the surface. Conversely, intermediate to elevated Layer 1 velocities across the central AKSU campus and southward toward Ikot Aba reflect greater grain interlocking and mechanical compaction. Beneath this veneer, Layer 2 exhibits a sharp velocity jump to between 760.0 and >910.0 m/s, with peak values exceeding 850 m/s around Ibotio and its surroundings. Mechanically, this basal horizon represents a highly consolidated substratum capable of supporting substantial structural loads without excessive shear deformation.

Evaluating velocity ratios alongside elastic moduli clarifies how pore fluid and grain fabric interact under stress. Across the entire survey area, V_p -V_s ratios remain tightly constrained between 2.194 and 2.207 (Table 4a), demonstrating remarkable regional uniformity in fluid saturation. As established for unconsolidated to moderately consolidated sediments of the Benin Formation (Thomas and Udosen, 2026), pore water substantially elevates compressional wave velocity (V_p) because water is nearly incompressible, whereas Vs remains suppressed because fluids cannot transmit shear stress through weakly bonded, porous grain frameworks. Poisson's ratio further corroborates this poroelastic behavior (Figures 9e and 11). Typical of

cohesive soils and clays (0.30 to 0.45), values across the site indicate high lateral elasticity, meaning the sediments tend to deform laterally when subjected to vertical compression. Notably, Poisson's ratio transitions from a uniform 0.3690 in the stiffer second layer to a narrow range of 0.3700 to 0.3710 in the first layer (Table 4). While localities such as Ikot Aba and Ikot Obia exhibit slightly lower surficial values (0.3700 to 0.3705), the northern sector covering Akpaden, AKSU, and Ikot Ekong reaches 0.3705 to 0.3710. The minimal variance across these zones suggests that near surface lateral strain is governed predominantly by pervasive pore water saturation within the Benin Formation rather than abrupt lithological shifts.

Integrating these elastic parameters yields practical criteria for foundation design across the expanding university corridor. Although the shallow Layer 1 soils at AKSU and Ikot Aba possess sufficient compaction for lightweight, shallow footings, their elevated Poisson's ratio and high moisture sensitivity imply vulnerability to differential settlement and lateral spreading if subjected to heavy concentrated loads or seasonal water table fluctuations. In contrast, the northern zone around Akpaden and Ikot Ekong combines low shear rigidity with high elastic compliance, requiring ground improvement, dewatering, or deeper foundation embedment even for moderate structures. For major institutional or commercial infrastructure, anchoring deep foundations such as driven piles or drilled shafts directly into the dense Layer 2 horizon, particularly within the high velocity (>850 m/s) zone around Ibotio, offers the most reliable safeguard against bearing capacity failure.

A comparative evaluation of the elastic moduli across the subsurface of Akwa Ibom State University (AKSU) and its environs reveals a critical geomechanical distinction between shear rigidity and volumetric stiffness. While shear modulus (μ) demonstrates pronounced vertical stratification and lateral heterogeneity (Figure 12), both Young's modulus (E, Figure 13) and bulk modulus (K, Figure 14) maintain remarkably uniform distributions across the weathered and consolidated strata, fluctuating within a narrow band of 2.51 to 3.72 GPa. This divergence reflects the physical sensitivity of seismic waves to subsurface pore conditions and grain framework integrity (Chi et al., 2026). Compressional stiffness parameters (E and K) are heavily governed by pore fluid incompressibility and bulk matrix packing, which mask subtle structural transitions between the upper and lower horizons. Conversely, shear modulus responds exclusively to intergranular friction and skeletal cementation, capturing the progressive stiffening driven by overburden compaction with depth.

Spatially, the subsurface fabric exhibits distinct directional controls that govern local ground competence. Within the upper weathered horizon, shear resistance increases southward, culminating in localized stiffness anomalies over Ikot Aba and Ikot Obia (0.0557 to 0.746 GPa). Beneath this zone, the consolidated stratum displays an eastward and central reduction in rigidity, contrasting sharply with the highly competent western and southwestern sectors where shear modulus exceeds 0.917 GPa around Ikot Aba. These westward and southward stiffening trends align with localized zones of peak axial and volumetric elasticity (3.62 to 3.72 GPa) situated southeast of AKSU and southwest over Ikot Aba, pointing toward advanced diagenetic cementation and denser grain packing in these corridors.

Translating these elastic parameters into geotechnical performance underscores the necessity of depth selective foundation engineering across the study area (Ijaz et al., 2025). The seismic derived allowable bearing capacity (Figure 15) rises substantially from the unconsolidated top layer (0.00002 to 0.00009 GPa) to the underlying consolidated stratum (0.00030 to 0.00035 GPa), a vertical enhancement echoed in the ultimate bearing capacity profiles (Figure 16),

where Layer 2 sustains 0.00120 to 0.00149 GPa against the predominantly lower upper layer baseline (0.00030 to 0.00590 GPa). Although prominent bearing capacity highs converge around Ikot Aba and the AKSU axis, the low shear rigidity and modest allowable load threshold of the upper horizon render shallow footings vulnerable to differential settlement under heavy structural loads. Consequently, major civil infrastructure in the northern, central, and eastern sectors should bypass the weathered overburden through deep foundation systems anchored within the consolidated second layer, whereas the mechanically robust southwestern corridor around Ikot Aba offers superior subgrade stability for demanding engineering designs.

Subsurface porosity (ϕ) exhibits a pronounced vertical decline from the upper horizon to the underlying substratum, decreasing from a range of 38.9% to 52.18% in Layer 1 down to 22.98% to 29.42% in Layer 2 (Figure 17). This downward attenuation reflects progressive overburden pressure, natural grain rearrangement, and enhanced cementation with depth. Spatially, localized zones of minimal porosity emerge around Ikot Aba and Ikot Obia within the upper layer, whereas the deeper horizon preserves its densest packing primarily beneath Ikot Aba. From a geotechnical standpoint, these low porosity anomalies delineate well compacted matrices capable of mobilizing high shear strength and bearing capacity, thereby supporting structural foundations with minimal ground remediation.

Because void ratio (e) quantifies the volumetric proportion of pore space relative to solid mineral grains, it scales monotonically with porosity as a direct mathematical function of the solid fraction. Consequently, the spatial contour distributions of void ratio across both subsurface layers mirror their respective porosity maps identically, making separate void ratio plots unnecessary for spatial interpretation (Ivonin et al., 2020). Within the compacted corridors of Ikot Aba and Ikot Obia, reduced intergranular void space restricts the capacity for volumetric compression when subjected to static foundation loads.

Conversely, elevated void ratios across looser segments of the near surface profile govern the mechanical vulnerability of local transport corridors. Field observations along the East West (Eket to Port Harcourt) highway reveal pronounced pavement subsidence and structural distress (Figure 11). Rather than arising from dense, tightly packed substrates, such settlement is mechanically driven by excessive intergranular void spaces and sharp lateral transitions between loose and compacted zones (Dan-Jumbo, & Metzger, 2019). Under repetitive dynamic traffic loads and seasonal pore pressure fluctuations characteristic of southeastern Nigeria, high void soils experience progressive grain collapse and differential consolidation, underscoring the need for targeted subbase stabilization before constructing heavy infrastructure



Figure 11: A section of the East–West (Eket–Port Harcourt) Highway showing pavement settlement, with a motorcyclist manoeuvring to avoid the affected portion of the road.

Spatial variations in bulk density across the Benin Formation reflect local geomorphology and hydrological conditioning rather than lithological strength alone. Within the surveyed grid, bulk densities span 1,633.45 to 1,637.00 kg/m³, with denser accumulations clustering southeast of Akwa Ibom State University (AKSU) and beneath Ikot Abia in the upper horizon before shifting toward Ikot Obia in the southeast at greater depth. Conversely, lower densities dominate the northern and eastern margins of the surficial layer and extend westward in the underlying stratum. Directly beneath AKSU and its immediate surroundings, values tighten within a narrow, relatively low bracket of 1,633.40 to 1,633.66 kg/m³. This localized reduction aligns with the campus sitting inside a topographic depression roughly 9.0 m above sea level that is dissected by multiple perennial streams. Continuous fluvial drainage and shallow groundwater flux promote leaching and sediment reworking, leaving the upper soil column loosely packed and vulnerable to hydrochemical softening.

Evaluating Lamé's first constant (λ) clarifies how these formations resist volumetric strain under structural confinement. Within the first horizon, λ fluctuates between 3.06 and 4.61 GPa, exceeding 4.0 GPa in the southeastern sector of AKSU and the extreme southwest while dropping below 4.0 GPa toward the northeast and west of the university. In the second horizon, values span 2.58 to 3.82 GPa, preserving the same spatial polarity with peak incompressibility anchored in the southeast and southwest. Zones exceeding 4.0 GPa therefore offer markedly superior resistance to pore collapse compared to the more compliant northeastern and western flanks. Crucially, the vertical transition from a stiffer surficial cap into a slightly more compressible second layer governs multiaxial stress distribution: as foundation loads propagate downward, volumetric strain response widens with depth, requiring careful control of confining pressures to prevent delayed consolidation.

Integrating the Material Index (M_i) with bulk density reveals an important geophysical decoupling between sediment mass and skeletal rigidity (Hammed et al., 2025)). In the upper stratum, M_i varies from negative 0.4830 to negative 0.4780, whereas the deeper layer homogenizes at a uniform value of negative 0.4760, signaling a vertical transition from laterally heterogeneous surficial deposits to a mechanically consistent substrate at depth. Because higher, less negative M_i values denote greater elastic stiffness, firmer ground characterizes AKSU, Akpaden, and the area southwest of Ikot Aba, while weaker matrices underlie Ikot Obio and Ikot Abia between negative 0.4805 and negative 0.4780. Notably, Ikot Abia exhibits elevated bulk density alongside lower elastic stiffness, whereas the AKSU corridor displays comparatively lower bulk density paired with higher dynamic rigidity. Within the coastal plain sands of the Benin Formation, higher mass density at Ikot Abia likely stems from fine clayey infill and pore water retention that add weight without strengthening intergranular contacts, whereas the sandy framework around AKSU preserves superior skeletal stiffness under dynamic seismic strain despite fluvial reworking.

Relying on any single elastic or gravimetric parameter would mischaracterize foundation suitability across this terrain. Around AKSU, although the mineral skeleton demonstrates favorable dynamic stiffness, the combination of low topographic relief, dense stream networks, and reduced bulk density creates a pronounced risk of seasonal saturation, effective stress reduction, and localized scour. Heavy civil structures on the university campus therefore require targeted ground improvement, perimeter subsurface drainage, and deep or reinforced

mat foundations anchored into the laterally uniform second horizon where M_i stabilizes at negative 0.4760. Meanwhile, developments extending toward Ikot Obia, Ikot Abia, and the northeastern flank must account for inherently weaker elastic matrices and higher volumetric compressibility through conservative bearing capacity thresholds and preloading strategies.

Engineering Competence Zonation Map of Consolidated Layer

Integrating the spatial distributions of allowable bearing pressure, ultimate bearing capacity, and bulk density within the consolidated stratum reveals a distinct geotechnical dichotomy across the Akwa Ibom State University environs, as illustrated in Figure 21. Rather than exhibiting uniform subsurface strength, the site separates into high competence corridors along the eastern and southwestern sectors and comparatively weak zones across the central and northeastern flanks. This lateral contrast reflects underlying variations in sediment compaction, grain packing, and natural cementation typical of shallow coastal plain deposits in southeastern Nigeria. Where seismic velocities and bulk densities peak in the east and southwest, the consolidated layer offers greater shear resistance and elastic stiffness, translating directly into elevated ultimate and allowable bearing thresholds capable of sustaining heavy structural loads without shear failure.

From a foundation design perspective, this spatial heterogeneity carries critical implications for campus infrastructure planning and structural longevity. The high competence eastern and southwestern sectors provide favorable ground conditions for conventional shallow foundations, such as reinforced pad or strip footings, to support multistory academic complexes and heavy civil infrastructure with minimal risk of excessive settlement. Conversely, the reduced density and lower bearing capacities observed across the central and northeastern zones point toward looser granular packing, localized clay intercalations, or higher pore fluid saturation that diminish soil stiffness. Constructing heavy structures directly upon these weaker formations without prior intervention would expose foundations to progressive consolidation and damaging differential settlement. Development within the central and northeastern sectors therefore requires targeted geotechnical remediation, including dynamic compaction, chemical stabilization, or the adoption of raft and deep pile foundations that bypass the weak horizon to anchor into more competent strata below.

Synthesizing seismic derived density and bearing parameters into a unified competence zonation framework elevates site investigation from isolated point assessments to proactive spatial risk management. Across rapidly expanding institutional landscapes in the Niger Delta basin, applying uniform foundation designs over variable subsurface terrain leads either to uneconomical overdesign in strong sectors or structural distress in weak ones. Figure 21 thus functions as a practical engineering blueprint, allowing planners to match structural load intensities with natural ground capacity and concentrate ground improvement investments strictly where subsurface conditions demand reinforcement.

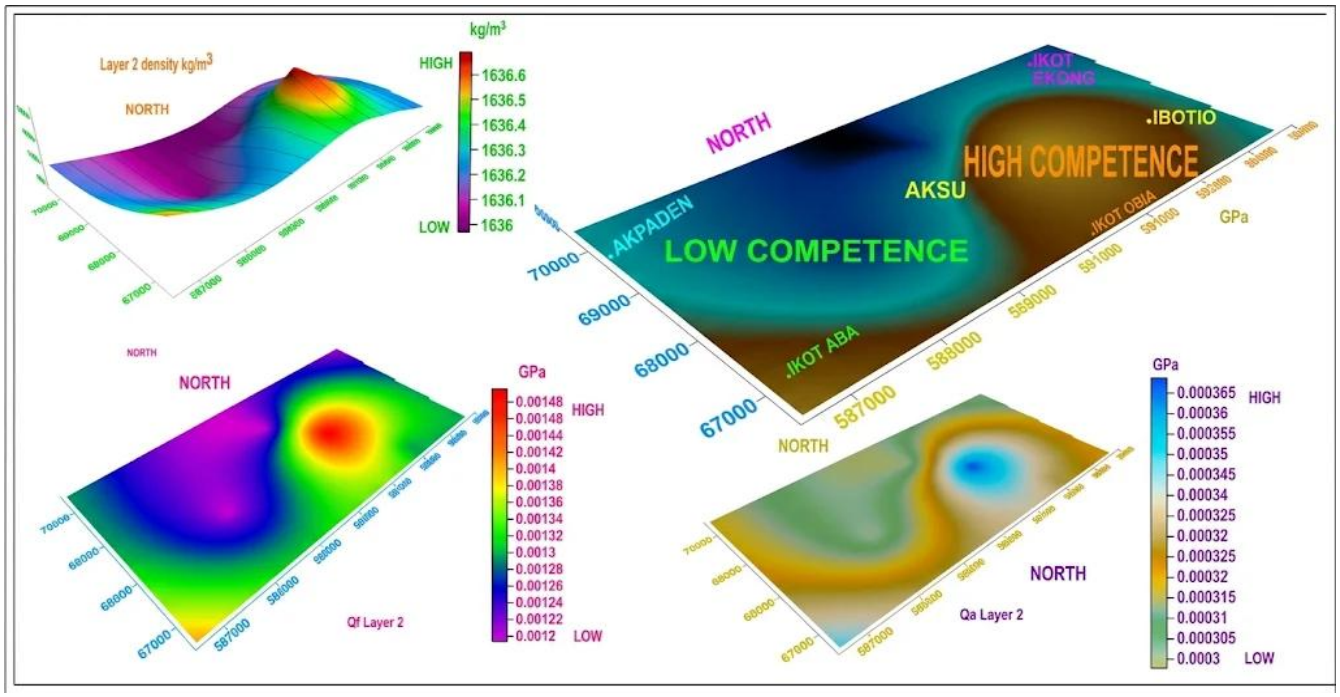


Figure 21: Engineering competence zonation map of consolidated layer (upper right) in study area derived from allowable bearing capacity map (lower right), ultimate bearing capacity (lower left) and density map (upper left).

6. Limitation

This investigation is subject to specific environmental and methodological constraints that warrant consideration during geotechnical design. First, field acquisition occurred within a single climatic window in the humid tropical terrain of Akwa Ibom, where intense seasonal rainfall drives substantial fluctuations in water table elevation and vadose zone saturation. Because compressional wave velocities increase sharply with pore fluid saturation independently of soil frame rigidity, single season measurements may obscure true lithological boundaries or overestimate subsurface stiffness during wetter months. Second, shear wave velocities were derived empirically from compressional data rather than measured directly using dedicated shear sources. Relying on theoretical velocity ratios introduces analytical uncertainty into computed elastic moduli, particularly within heterogeneous Coastal Plain Sands where clay lenses and partial saturation decouple compressional and shear wave behavior. Finally, seismic refraction characterizes elastic small strain stiffness rather than the plastic large strain deformation governing structural settlement, while conventional refraction ray paths cannot resolve velocity inversions where soft compressible clays lie beneath indurated lateritic crusts**.**

7. **Summary**

Geodynamic Inheritance and Subsurface Elastic Anisotropy

A striking revelation of this investigation is that near surface geotechnical behavior at Akwa Ibom State University and its surrounding corridor is not merely a product of random tropical weathering, but is structurally governed by deep crustal architecture. Although reciprocal seismic travel time gradients and computed zero-degree layer dips confirm that the sedimentary strata remain essentially horizontal and undisturbed by fault overturning or folding, both surface topography and subsurface elastic properties exhibit pronounced directional alignment. The northwest to southeast topographic grain mirrors deep seated basement controls previously identified in regional gravity surveys of the Niger Delta, while the orthogonal northeast to southwest and northwest to southeast trends embedded within the weathered mantle reflect the

intersecting tectonic signatures of the Benue Trough and the Oban Massif. Even within flat lying coastal plain sediments, subtle upward propagation of basement fractures and joint sets channels groundwater percolation, creating preferential pathways for chemical leaching and differential weathering.

This tectonic imprint becomes even more revealing when contrasting wave propagation modes within the lower consolidated stratum. While compressional wave velocity in the deeper layer lacks a coherent directional preference, shear wave velocity and all derived elastic and bearing parameters align distinctly toward the northeast. In saturated or semiconsolidated deltaic formations, pore fluids tend to equalize bulk compressional wave speeds across varying grain orientations, effectively masking subtle textural fabrics. Shear waves, which do not propagate through fluids, remain acutely sensitive to skeletal grain alignment, cementation anisotropy, and the regional northeast structural grain of the Benue Trough. Similarly, the divergence of Poisson's ratio toward the northwest and its shift toward the east southeast in the southeastern sector highlight localized transitions in clay mineralogy and fluid saturation that govern lateral compressibility.

Stratigraphic Competence and Foundation Zonation

From a geotechnical standpoint, the sharp acoustic and mechanical contrast between the upper weathered mantle and the underlying consolidated horizon establishes a clear vertical competence gradient controlled by normal stratigraphic burial and diagenesis. The northward thickening of the upper layer, culminating in a pronounced depocenter in the northeast, delineates a zone of elevated void ratios, low shear rigidity, and negligible bearing resistance. In this northeastern sector, shallow spread footings or heavily loaded surface foundations would face acute risks of excessive consolidation settlement and localized shear failure. Conversely, the underlying consolidated stratum possesses the dense packing, reduced porosity, and elevated elastic moduli required to mobilize high ultimate and allowable bearing capacities.

Translating these geophysical contrasts into spatial engineering competence zones provides a practical decision framework for civil engineers and urban planners managing rapid institutional and industrial expansion in this part of the Niger Delta. Because the stratigraphic boundary between the two horizons is planar and subhorizontal, foundation engineers can reliably target the consolidated second layer as a uniform bearing stratum. Where the incompetent weathered overburden thickens toward the northeast, structural designs for multistory academic facilities and heavy industrial plants should bypass the upper horizon altogether in favor of deep foundation systems, such as driven piles or bored piers, socketed directly into the stiffer consolidated substrate.

Methodological Boundaries and Pathways for Integrated Site Characterization

Interpreting these subsurface models responsibly requires weighing the inherent assumptions of seismic refraction surveying against the complexities of deltaic geology. Because shear wave velocities and ultimate bearing capacities were derived through empirical transformations rather than direct mechanical testing, the resulting parameter maps carry epistemic uncertainties tied to how closely regional geological conditions match the underlying empirical calibration datasets. Furthermore, approximating a gradational tropical weathering profile as a discrete two-layer velocity model can obscure intermediate transition zones, perched water tables, or localized clay lenses that fall below the vertical resolution of refraction ray paths, while spatial interpolation between sparse borehole logs introduces smoothing across potential lateral facies changes.

Rather than diminishing the utility of the survey, these boundaries define a clear roadmap for advancing geotechnical practice in the region. Future site investigations should pair seismic refraction grids with multichannel analysis of surface waves to measure shear wave velocity profiles directly, alongside targeted Cone Penetration Testing and Standard Penetration Testing to establish locally calibrated empirical correlations. Incorporating formal uncertainty propagation into spatial interpolation workflows will further transform deterministic zonation maps into probabilistic risk models, enabling engineers to execute site specific, performance-based foundation designs across the evolving Niger Delta landscape.

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8. **Conclusion**

Integrating dynamic seismic refraction with derived geotechnical parameters effectively resolves spatial variations in shallow ground competence across Akwa Ibom State University and its environs. Subsurface characterization reveals a two-layer horizontal stratigraphy governed by the regional tectonic framework of the southeastern Niger Delta and the structurally controlled Kwa Iboe River, which drives distinct northeast to southwest and northwest to southeast trends in elastic behavior. The upper weathered horizon, extending from 5.50 to 9.19 m with maximum thickness in the northeast and northwest, consists of loose, compressible lateritic soils exhibiting low acoustic velocities, reduced elastic moduli, and poor bearing capacity. Conversely, the underlying consolidated stratum of the Benin Formation, occurring below 9.19 m with peak densities in the southeast, comprises stiff gravelly sands and intercalated clays capable of supporting heavy structural loads once the weak overburden is bypassed. Notably, the convergence of ultimate bearing capacities between both horizons at Ikot Aba identifies an economically advantageous zone where reduced excavation depths can significantly lower foundation costs. By probing beyond 9.19 m through dynamic profiling, this investigation overcomes the 5 m depth limitation of earlier static surveys on campus. Although localized direct testing remains essential to verify empirically derived parameters prior to final design, these findings establish a critical geotechnical baseline for resilient academic, public, and energy infrastructure aligned with United Nations Sustainable Development Goal 11.

Declarations

Ethics Approval and Consent to Participate:

Not applicable. This study did not involve human participants, human data, or animals.

Consent for Publication:

Not applicable. This manuscript does not contain any individual person's data in any form, including images or videos.

Availability of Data and Materials:

The datasets generated and/or analyzed during this study (e.g., geophysical measurements, borehole logs, hydrochemical data, remote sensing layers) are available from the corresponding author upon reasonable request.

Competing Interests:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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REFERENCES

Aka M.U., Okeke F.N., Ibuot J.C., Obiora D.N., Geotechnical investigation of near-surface structures using seismic refraction techniques in parts of Akwa Ibom State, Southern Nigeria. Model Earth Syst Environ. 2018;4(2):451–9. https://doi.org/10.1007/s40808-018-0440-2.

Alexopoulos, J. D., Dilalos, S., Voulgaris, N., Gkosios, V., Giannopoulos, I.-K., Kapetanidis, V., & Kaviris, G. (2023). The Contribution of Near-Surface Geophysics for the Site Characterization of Seismological Stations. *Applied Sciences*, *13*(8), 4932. https://doi.org/10.3390/app13084932

Blyth, F.G.H. and de Freitas, M.H. 1979. A geology for engineers. Edward Arnold Ltd London

Castagna J.P., Batzle M.L., Eastwood R.L., Relationships between compressional-wave and shear-wave velocities in clastic silicate rocks. Geophysics. 1985;50(4):571–81. https://doi.org/10.1190/1.1441933.

Chi, H., Wang, H., Jia, Y., Zou, D., Feng, W., Wen, Z., & Wang, W. (2026). Variance Analysis of Initial Elasticity Modulus and Bulk Modulus Parameters of Duncan–Chang E-B Model. *Symmetry*, *18*(5), 758. https://doi.org/10.3390/sym18050758.

Da Col, F., Accaino, F., Böhm, G., & Meneghini, F. (2022). Analysis of the Seismic Properties for Engineering Purposes of the Shallow Subsurface: Two Case Studies from Italy and Croatia. *Applied Sciences*, *12*(9), 4535. https://doi.org/10.3390/app12094535.

Dan-Jumbo, N. G., & Metzger, M. (2019). Relative Effect of Location Alternatives on Urban Hydrology. The Case of Greater Port-Harcourt Watershed, Niger Delta. *Hydrology*, *6*(3), 82. https://doi.org/10.3390/hydrology6030082

Dobrin, M.B. 1976: Introduction to geophysical prospecting. McGraw – Hill Books Co. London.

Ekanem, K.R., George N.J., Ekanem, A.M., Udosen, N.I., Thomas J.E., Mechanistic understanding of electrical prospecting for aquifer systems adjacent to main river channels and their tributaries in Akwa Ibom, Southern Nigeria: hydrogeological implications. J Coastal Conserv. 2025;29(5):1–27. https://doi.org/10.1007/s11852-025-01133-x.

Ekanem, A.M., Akpan, A.E., George, N.J. & Thomas, J.E (2021). Appraisal of protectivity and corrosivity of surficial hydrogeological units via geo-sounding measurements. *Environ Monit Assess* **193**, 718. https://doi.org/10.1007/s10661-021-09518-9.

Ekpo, A. E., Bassey, N. E., George, N. J., & Udo, I. G. (2024). Depth to basement estimation from aerogravity data over the Southeastern part of Niger Delta region of Nigeria. *Researchers Journal of Science and Technology*, *4*(5), 44–66. https://doi.org/10.83080/rejost.vol4no5.135

Essien U.E. 2021. Assessment of elastic parameters on near surface earth with seismic refraction in Uyo, Southern Nigeria. PhD thesis, Michael Opara University of Agriculture, Umudike, Nigeria.

Essien, U.E., Akankpo A.O., George N.J., Umoren, E.B., Determination of Poisson's ratio of surface soils and shallow sediments of Uyo and environs from seismic compressional and shear wave velocities. IOSR J Appl Geol Geophys. 2023;11(1):23–9. https://doi.org/10.9790/0990-1101012329.

Gassman, F. 1973. Siesmische Prospektion. BirkhaeuserVerlag. Stauttgart.p.417

George, N.J. & Bassey, N.E., 2026. Geoelectric and hydro-geochemical assessments of waterlogging and drainage for soil and agronomic groundwater evaluation at Akwa Ibom State University: Field and laboratory data mining approaches. Geosystems and Geoenvironment, 5(1), 100464. https://doi.org/10.1016/j.geogeo.2025.100464.

George N.J., Ekanem A.M., Thomas J.E., Udosen, N.I., Ossai, N.M., and Atat J.G., Electro-sequence valorization of specific enablers of aquifer vulnerability and contamination: A case of index-based model approach for ascertaining the threats to quality groundwater in sedimentary beds. Hydro Res. 2024; 7:71–85. https://doi.org/10.1016/j.hydres.2023.11.006.

Grant, F.S., West, G.F., 1965 Interpretation theory in applied geophysics, vol 2(44). McGraw Hill Textbook, New York, pp 8–12

Haeni, F.P. 1986: Application of seismic refraction method in ground water modelling in New England. Geophysics vol.51 No 2, pp. 236-249.

Hameed, F., Khan, M. R., Tian, J., Bilal, M. A., Wang, C., Wang, Y., Mughal, M. S., & Niaz, A. (2025). Geological Significance of Bulk Density and Magnetic Susceptibility of the Rocks from Northwest Himalayas, Pakistan. *Minerals*, *15*(8), 781. https://doi.org/10.3390/min15080781

Ijaz, N., Ijaz, Z., Zhou, N., Rehman, Z. u., Ijaz, H., Ijaz, A., & Hamza, M. (2025). Optimizing Subsurface Geotechnical Data Integration for Sustainable Building Infrastructure. *Buildings*, *15*(1), 140. https://doi.org/10.3390/buildings15010140

Imai, T. and Tonachi, K.1982. Correlation of N-Value with S-wave velocity and shear modulus. Proceedings of 2nd European Symposium on penetration testing. Amsterdam, pp.57-72.

Ivonin, D., Kalnin, T., Grachev, E., & Shein, E. (2020). Quantitative Analysis of Pore Space Structure in Dry and Wet Soil by Integral Geometry Methods. *Geosciences*, *10*(9), 365. https://doi.org/10.3390/geosciences10090365

Keller GR, Sinne YA, Sbar ML 1981 Seismic refraction in West and Central Arizona. J Geophys Res N Y 86(36):5023.

Obianwu, V., George, N. & Udofia, K (2011). Estimation of aquifer hydraulic conductivity and effective porosity distributions using laboratory measurements on core samples in the Niger Delta, Southern Nigeria, International Review of Physics, 5(1), 19 24.

Shebl, S., Gemail, K.S., Attwa, M., Soliman, S.A., Azab, A., Farag, M.H.,2019 Utilizing shallow seismic refraction in defining the geotechnical properties of the foundation materials: A case study at New Minia City, Nile Valley, Egypt. Egyptian J Petroleum. 28(2):145–54. https://doi.org/10.1016/j.ejpe.2018.12.006.

Sheriff, R.E. and Geldart, L. P.1986. Exploration Seismology. Cambridge University Press.

Thatam, R.J. 1982. Vp/Vs and lithology. Geophysics 47 (3), pp.336-344.

Thomas, J.E. & Udosen, N.I. (2026). High-resolution seismic refraction tomography for integrated geotechnical characterization of near-surface layers in engineering foundation assessments. Discover Geoscience, 4, 93., pp.1-28.https://doi.org/10.1007/s44288-026-00464-y.

Ulugergerli, E.U., Uyanik, O. 2007 Statistical correlation between seismic wave velocities and SPT blow counts and the relative density of soils. J Test Eval 35(2):1–5

Umoh, J.A., George, N.J., Ekanem, A.M. & Emah, J.B. (2025). Characterization of hydro-sand beds and their hydraulic flow units by integrating surface measurements and ground truth data in parts of the shorefront of Akwa Ibom State, Southern Nigeria. *Int J Energ Water Res* **9**, 13–29. https://doi.org/10.1007/s42108-022-00215-y

Weber KJ, Daukoru EM (1985) Petroleum.

Watkins, J.S., Walters, L.A., Godson, R.H., Dependence of in-situ compressional wave velocity on porosity. Geophysics. 1972; 37:29–35. https://doi.org/10.1190/1.1440249.