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APPLICATION OF SEISMIC REFRACTION TECHNIQUES IN GEOTECHNICAL EVALUATION FOR SUSTAINABLE FOUNDATION IN PARTS OF BAYELSA STATE, NIGERIA.

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Abstract

This study was carried out in Amassoama, Southern Ijaw Local Government Area of Bayelsa State and demonstrates the effectiveness of seismic refraction as a non-invasive, cost-efficient method for near-surface geotechnical characterization in the complex swampy terrain of Amassoama, Niger Delta. Utilizing an ABEM Terralog Mark 6 seismograph with 14 Hz geophones, we acquired four linear profiles measuring P- and S-wave travel times to depths of ~16 m. Velocity inversion of first-arrival data yielded detailed Vs (230–870 m/s) and Vp (420–1700 m/s) profiles, enabling derivation of key engineering parameters: elastic moduli, Poisson's ratio (0.26–0.35), and bearing capacity (Qa: 30–950 kPa). Results reveal a consistent velocity-depth relationship, with Vs increasing threefold from surface to bedrock, correlating with a 30-fold improvement in Qa. The method successfully identified weak surface soils (Qa < 50 kPa) requiring ground improvement, and competent strata at >10 m depth (Vs > 800 m/s, Qa > 280 kPa) suitable for pile foundations. These findings validate seismic refraction's capability to map soil-bedrock interfaces and quantify material competence in heterogeneous deltaic environments, providing critical data for foundation design while reducing reliance on extensive borehole investigations. The study establishes a framework for efficient geotechnical assessment in similar challenging terrains worldwide.

Keywords: Seismic Refraction, Geotechnical, Foundation, Sustainable, Non-invasive

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Introduction

Near-surface geotechnical parameters—such as soil stiffness, bedrock depth, and bearing capacity—are critical for safe and economical construction design (Bowles, 1997; Omonefe et al., 2019). In the Niger Delta, Nigeria, intricate sedimentary deposits, high water tables, and organic-rich swamp soils exacerbate geotechnical challenges (Nnurum et al., 2025), frequently resulting in foundation settlement (Nnurum et al., 2021:Udoh, et al., 2023), subsidence, and structural instability (Nwankwo & Aigbedion, 2018). Traditional borehole drilling and sampling methods, while accurate pointwise, are time-consuming, costly, and spatially limited—especially under dense vegetation or inundated conditions (Oyedele et al., 2016; Das et al., 2019, Nnurum et al., 2021).

Seismic refraction leverages the travel times of compressional (P) and shear (S) waves to infer subsurface layering and material properties. By analyzing first-arrival times across geophone arrays, velocity models can be constructed to estimate Vs, Vp, depth to bedrock, and elastic moduli, all without extensive drilling (Nnurum et al., 2024; Sawyer & Waters, 2004; Anbazhagan et al., 2016). Several studies in Nigeria and beyond demonstrate its efficacy: Opolo, Yenagoa (Omonefe et al., 2019); Tombia Town (Eteh et al., 2020); Zaria (Momoh et al., 2020); and Sinai, Egypt (Khalil & Hanafy, 2008). These works underscore seismic refraction's strengths—rapid deployment, broad spatial coverage, and detailed velocity profiling—while noting limitations in highly heterogeneous settings and at greater depths (>200 m) (Alsamarraie, 2020).

This study aims to evaluate the use of seismic refraction to delineate subsurface layers and bedrock depth, estimate key geotechnical parameters (e.g., elastic moduli, bearing capacities) and assess its suitability as an alternative to conventional methods in swampy, deltaic terrains.

Study Area

Amassoama lies within Southern Ijaw LGA of Bayelsa State, Nigeria (4°56′–4°58′ N; 6°05′–6°07′ E), in the central Niger Delta (Figure 1). The region experiences ~4,000 mm annual rainfall, with a short dry season (Nov–Mar) and extensive fresh- and mangrove-swamp forests Elevations reach up to 39 m, with shallow groundwater depths (<1–16 m) and poor drainage leading to frequent flooding (Eteh et al., 2019). Stratigraphically, the area comprises the Benin, Agbada, and Akata Formations—siliciclastic sands, interbedded shale, and marine clays, respectively (Short & Stauble, 1967). These conditions pose significant geotechnical risks, necessitating reliable near-surface characterization for safe construction.

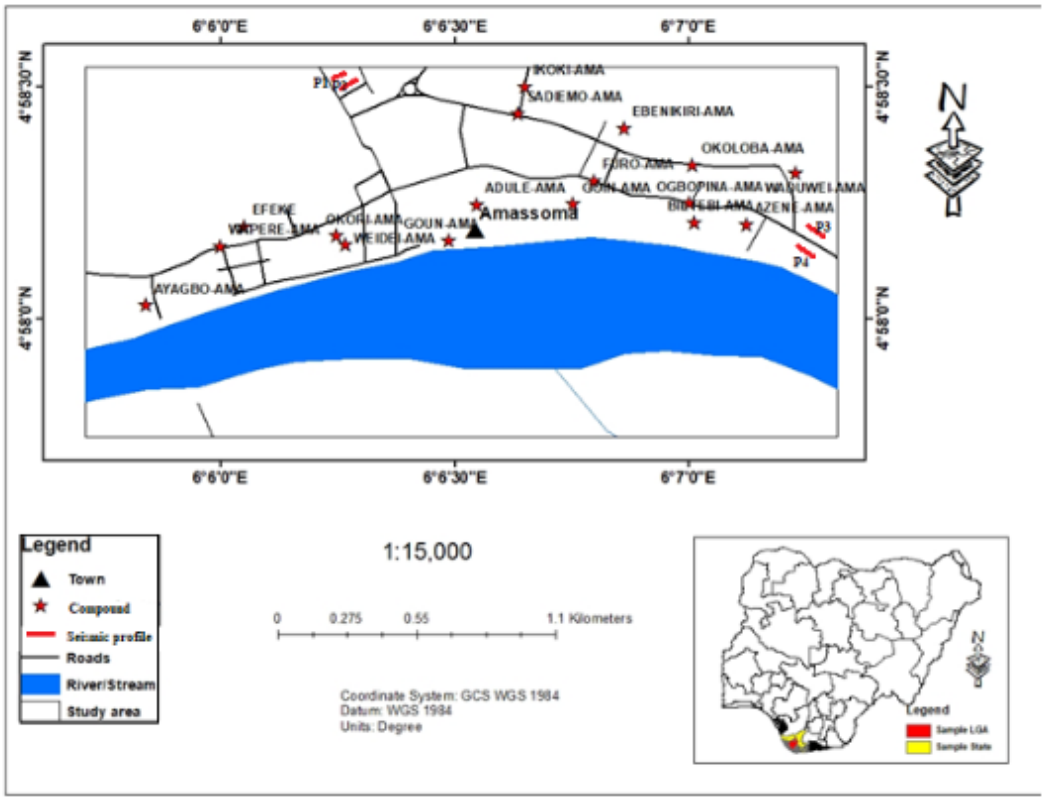


Figure 1: Map of Study Area.

Literature Review

Seismic refraction exploits Snell's law and wave propagation principles to derive subsurface velocity structures (Alsamarraie, 2020). P-wave refraction determines depth to high-velocity layers (e.g., bedrock), while S-wave (via MASW) yields Vs profiles for stiffness estimation. Elastic and strength parameters—including Young's modulus (E), shear modulus (μ), constrained modulus (Ec), and reaction modulus (Rm)—can be correlated with measured velocities (Abd El-Rahman, 1989; Farauta et al., 2012). For instance, Qa (allowable bearing capacity) can be estimated from Vs via empirical relations (Abd El-Rahman, 1991).

Omonefe et al. (2019) mapped competent bedrock at approximately 12 meters depth, confirming suitability for shallow foundations. Eteh et al. (2020) used MASW-derived shear wave velocities (Vs) to compute key geotechnical parameters such as Standard Penetration Test N-values, ultimate bearing capacity (Qult), and allowable bearing capacity (Qa), recommending that heavier structures be founded on deeper, more stable layers. Similarly, in Zaria at the ABU Campus, Momoh et al. (2020) correlated seismic velocity sections with borehole data to validate subsurface models, revealing spatial variations in soil competency critical for campus infrastructure planning.

Globally, similar applications reinforce the value of seismic methods. Khalil and Hanafy (2008) identified a high-velocity bedrock (>5000 m/s) underlying soft sediments with velocities below 200 m/s. This sharp contrast highlighted zones unsuitable for heavy construction, providing essential data for regional infrastructure planning.

Seismic refraction is rapid, non-destructive, and cost-effective, offering high-resolution profiles to depths of a few hundred meters (Soupios et al., 2005; Alsamarraie, 2020). However, complex heterogeneity can complicate inversion, and refraction critically depends on clear velocity contrasts. Integration with borehole or CPT/SPT data enhances reliability (Sawyer & Waters, 2004).

Materials and Methods

Instrumentation: ABEM Terralog Mark 6 seismograph, 12 × 14 Hz vertical geophones, sledgehammer & metal plate seismic source, GPS, measuring tape.

Field Setup: Four profiles (Profile 1–4), each 60 m long, geophone spacing 5 m, shot spacing 5 m. MASW surveys employed 12 geophones at 2 m spacing.

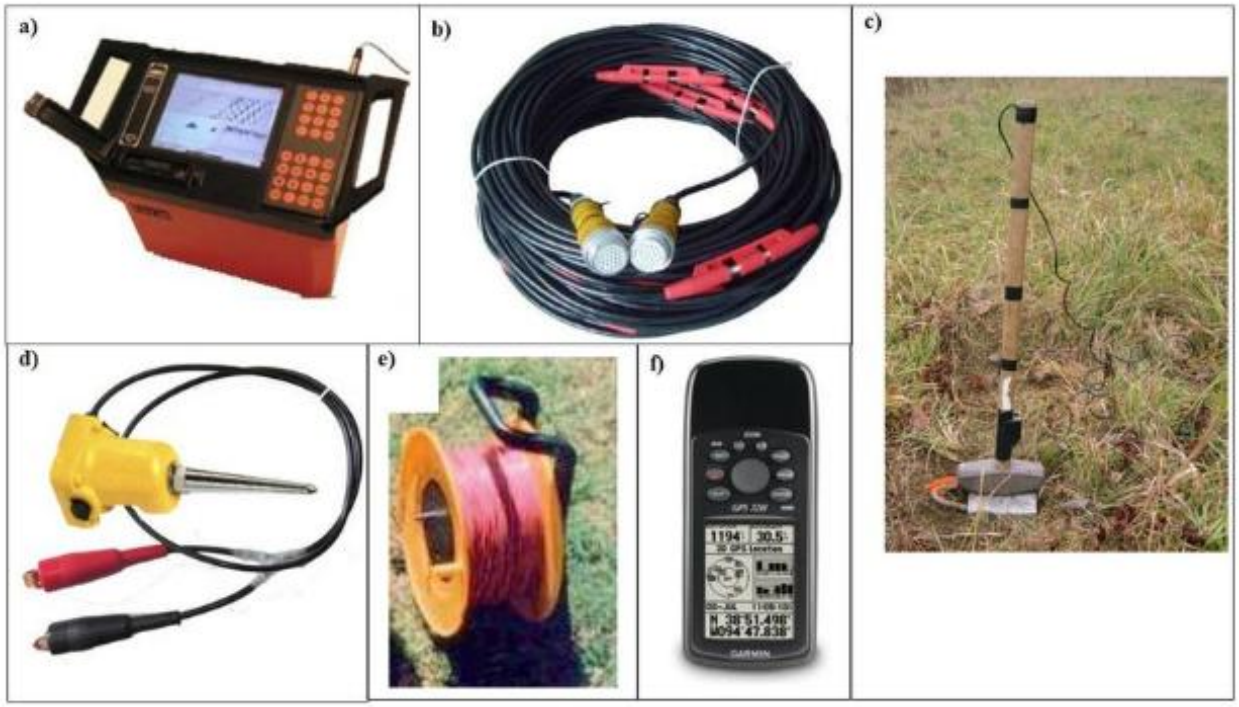


Figure 2: a) digital seismograph ABEM Terraloc MK8, b) seismic land cables, c) sledgehammer and metal plate, d) vertical geophone, e) reel wire, and f) GPS device

Data Acquisition: P- and S-wave travel times recorded; refraction first-arrival picks imported into SeisImager software.

Data Processing & Analysis:

1. First-arrival times inversion to obtain 1D velocity models per shot.
2. Construction of 2D velocity sections along each profile.
3. Derivation of elastic moduli (E, μ, Ec) and Poisson's ratio (ν) from Vs and Vp.
4. Estimation of Qult and Qa using empirical equations (Log Qa = 2.932 Log Vs – 4.553 for soft soil; 2.932 Log Vs – 4.729 for hard rock) (Abd El-Rahman, 1991).

Results

Table 1 presents the seismic refraction results for four survey profiles in Amassoama, Bayelsa State, Niger Delta. The data includes shear-wave velocity (Vs), compressional-wave velocity (Vp), and allowable bearing capacity (Qa) across varying depths (1–16 m) while figure 3 shows the travel-time across all four Profiles.

Table 1: Velocity Profiles: All profiles show Vs increasing from ~230–270 m/s at 1–3 m depth to ~790–900 m/s at 15–16 m. Vp rises from ~420–500 m/s to ~1476–1685 m/s.

Profile	Depth Range (m)	Vs Range (m/s)	Vp Range (m/s)	Qa Range (kPa)
1	1.0–16.1	232–865	434–1619	32–350
2	1.0–15.3	226–901	422–1685	30–360
3	1.0–14.8	226–789	423–1476	30–280
4	1.0–15.6	230–952	433–1700	32–380



Figure 3: Travel-time curves for All Profile.

Figures 4 (Velocity Stratigraphy Log) and 5 (Vs and Vp vs. Depth) provide valuable insights into the subsurface geotechnical characteristics of Profile 1 in Amassoama, within the Niger Delta. The interpretation of these figures helps to delineate the material properties, foundation suitability, and potential engineering challenges associated with the site.

The velocity stratigraphy log (Figure 4) reveals a three-layered subsurface profile, each with distinct seismic velocity signatures and corresponding geotechnical implications:

Layer 1 (0–3 m depth) is characterized by low shear wave velocities (Vs = 230–270 m/s) and compressional wave velocities (Vp = 430–500 m/s). This layer likely comprises very soft, water-saturated swamp alluvium, rich in organic clays and peats. The high compressibility and poor load-bearing capacity (Qa ≈ 30–50 kPa) render this layer unsuitable for supporting shallow foundations without substantial ground improvement measures such as surcharge fills or geotextiles.

Layer 2 (3–10 m depth) exhibits moderate shear and compressional wave velocities (Vs = 400–600 m/s, Vp = 800–1200 m/s), indicative of moderately dense silty sands belonging to the Benin Formation. Partial saturation is probable at this depth. This layer may support light structures with Qa values ranging from approximately 100 to 200 kPa, provided adequate compaction is achieved.

However, for heavier structures, deep foundation systems such as driven piles would be necessary to bypass the weaker upper materials.

Layer 3 (>10 m depth) is distinguished by high Vs (800–865 m/s) and Vp (1500–1619 m/s) values, corresponding to dense, weathered sandstone of the Agbada Formation or highly compacted sands. The geotechnical properties of this layer suggest it is highly competent, with an allowable bearing capacity of around 350 kPa. Consequently, this layer offers an excellent bearing stratum for raft or pile foundations with minimal settlement risk, making it suitable for supporting heavy infrastructure.

Figure 5, which plots Vs and Vp against depth, underscores key trends in material properties across the profile.

The **nonlinear increase in seismic velocities** with depth reflects progressive soil consolidation and decreasing water content. This pattern highlights the transition from loose, saturated near-surface materials to denser, more competent strata at greater depths. A ratio of ~2.0 in the shallow layers indicates saturated and unconsolidated sediments, corroborating the interpretation of swampy, organic-rich soils. A lower ratio (~1.8) in deeper layers suggests drier and stiffer materials, consistent with the transition to dense sands or weathered rock. Values around ~0.35 in the shallow layers reflect high compressibility, typical of clay-rich, water-saturated soils.In contrast, values decreasing to ~0.25–0.30 at depth indicate lower compressibility, aligning with sandy or rocky lithologies. The combined analysis of Figures 4 and 5 highlights critical considerations for foundation engineering at this site. The soft, compressible upper layer necessitates caution, particularly for shallow footings, which may experience excessive settlement unless ground improvement is employed. Intermediate sands offer limited bearing capacity but can support lighter structures when properly compacted. The dense, deeper layer represents the most favourable foundation horizon for major structures, warranting the use of deep foundation systems to exploit its superior load-bearing capacity and stability.

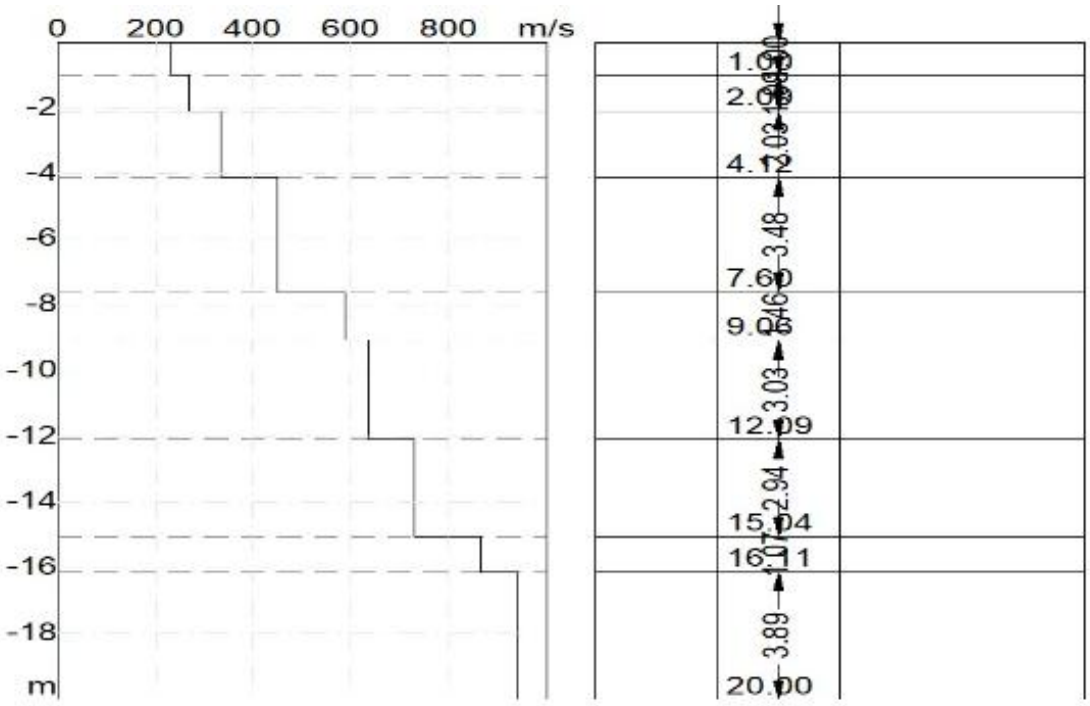


Figure 4: Velocity stratigraphy log of Profile 1.

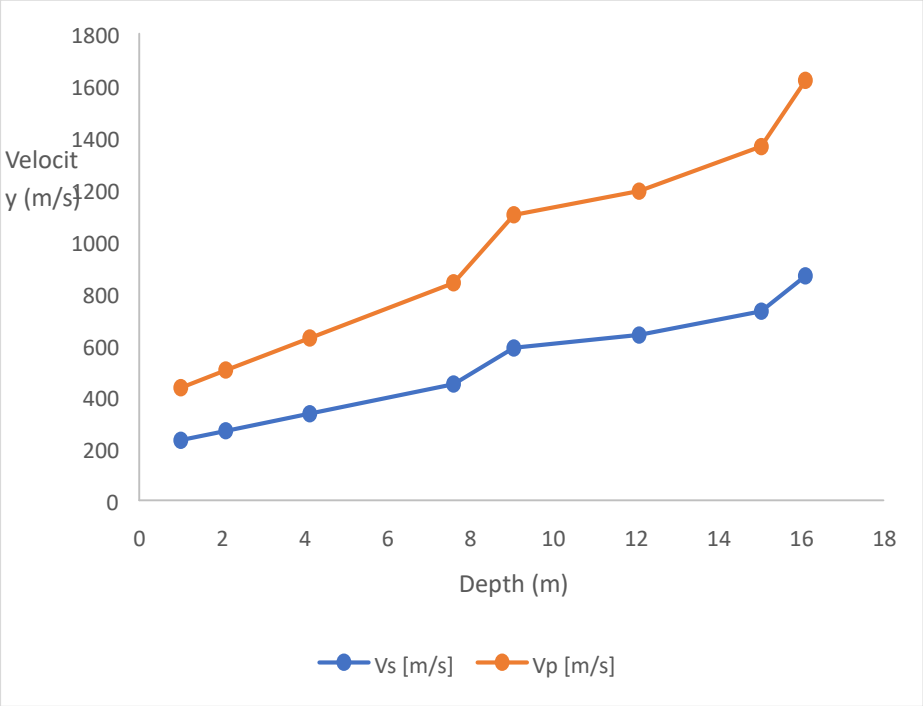


Figure 5: Inverted Vs and Vp vs. depth for Profile 1.

Figures 6 (Velocity Stratigraphic Log Section) and 7 (Seismic Velocities vs. Depth) illustrate the subsurface conditions encountered along Profile 2 in Amassoama, Niger Delta. These results complement those of Profile 1, while also revealing distinct site-specific variations that hold important implications for geotechnical evaluation and foundation design.The velocity stratigraphic log (Figure 6) delineates three principal subsurface layers, each with characteristic seismic velocity signatures and engineering properties:

Layer 1 (0–4 m Depth):

This uppermost layer is defined by low shear wave velocities (Vs = 226–350 m/s) and compressional wave velocities (Vp = 422–700 m/s). These values are consistent with very soft, organic-rich swamp deposits dominated by clays and peats with a high degree of water saturation. The geotechnical implications of this layer are significant: It possesses an extremely low allowable bearing capacity (Qa ≈ 30–60 kPa). The high compressibility and susceptibility to differential settlement render it unsuitable for supporting shallow foundations without substantial improvement measures.For lightweight structures, preloading or the incorporation of geosynthetic reinforcement would be required to mitigate settlement risks.

Layer 2 (4–12 m Depth):

Beneath the soft surface deposits lies a transitional zone characterized by moderately increasing seismic velocities (Vs = 350–700 m/s, Vp = 700–1300 m/s). This layer likely consists of interbedded silty sands and clays within the Benin Formation. It exhibits moderate stiffness, with an allowable bearing capacity of approximately 100–250 kPa. Suitability for supporting light to medium structures, such as low-rise buildings, provided proper compaction and quality control are implemented during construction.A potential susceptibility to localized liquefaction during seismic events due to the partial saturation of finer-grained layers, which warrants careful consideration during seismic hazard assessments.

Layer 3 (>12 m Depth):

The deepest layer identified in Profile 2 exhibits higher seismic velocities (Vs = 700–901 m/s, Vp = 1300–1685 m/s), suggesting dense, competent materials such as weathered sandstone of the Agbada Formation or compacted sandy gravels. This layer presents highly favourable geotechnical properties. A high allowable bearing capacity (Qa ≈ 250–360 kPa), making it an excellent target for foundation design. Suitability for terminating pile foundations at depths of 12 meters or greater.Minimal risks of long-term settlement, ensuring stability for heavy infrastructure and critical facilities.

Velocity-Depth Trends

The seismic velocity trends plotted in Figure 7 provide additional insight into the geotechnical nature of the subsurface profile. The **gradual increase in shear wave velocity** (Vs) with depth suggests a relatively uniform compaction trend compared to the more nonlinear velocity pattern observed in Profile 1. This uniformity implies a progressive improvement in material competence with depth. The **Vp/Vs ratio** varies from approximately 2.1 in the shallow swamp deposits to around 1.9 in the deeper competent layers. This trend reflects the decreasing saturation and increasing grain-to-grain contact stiffness at depth. **Poisson's ratio (v)** similarly evolves with depth. In **Layer 1**, values of around 0.33 indicate high compressibility typical of clay-dominated, water-saturated soils. By **Layer 3**, Poisson's ratio decreases to approximately 0.27, consistent with the lower compressibility of dense sands and rock-like materials.

Summary of Geotechnical Implications

The seismic data for Profile 2 reveal a subsurface profile that, while broadly similar to Profile 1, exhibits a more linear compaction gradient and slightly higher stiffness in the transitional and deep layers. The presence of a soft, highly compressible near-surface layer remains a critical engineering challenge, particularly for shallow foundation design. However, the competent deeper strata offer excellent potential for supporting heavier structures through the use of deep foundation systems.These findings underscore the importance of site-specific geophysical investigations in the Niger Delta, where complex depositional environments and variable saturation conditions can produce highly heterogeneous subsurface profiles with direct implications for infrastructure performance and long-term stability.

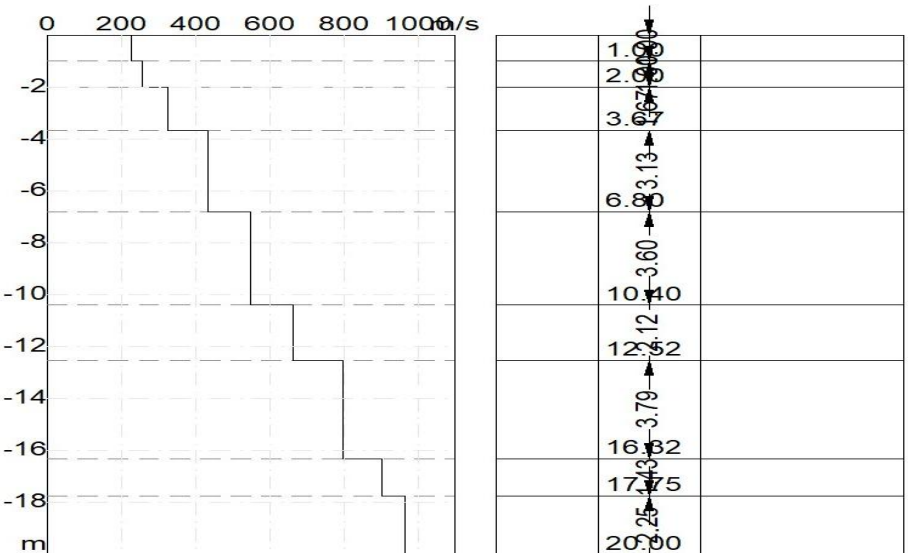


Figure 6: Velocity Stratigraphic Log Section of profile 2.

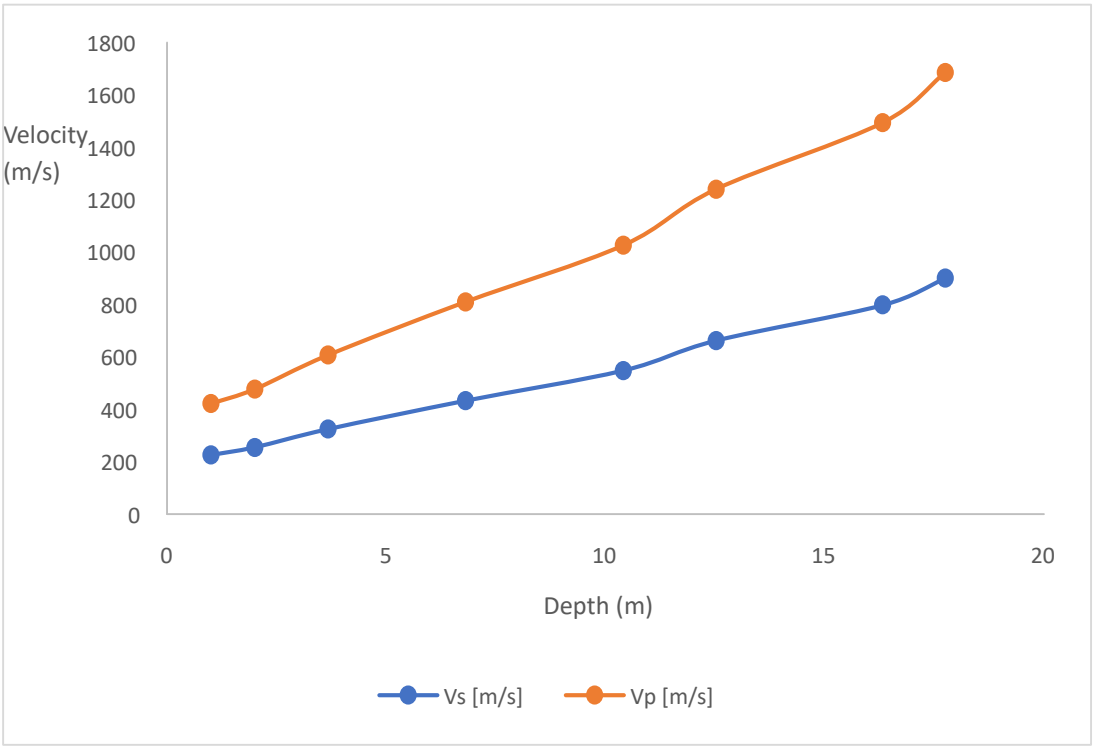


Figure 7: Seismic Velocities vs. Depth of profile 2.

Figures 8 (Velocity Stratigraphy Log Section) and 9 (Velocity vs. Depth Graph) present the seismic characterization of **Profile 3** in **Amassoama**, located in the Niger Delta. These figures offer valuable insights into the subsurface conditions of the site, complementing previous findings from Profiles 1 and 2, while also highlighting unique geotechnical features specific to this location.

The velocity stratigraphy log (Figure 8) identifies three distinct geotechnical units, each with characteristic seismic properties and engineering implications:

Layer 1 (0–4 m Depth):

The shallowest layer is marked by low seismic velocities (Vs = 226–300 m/s; Vp = 423–600 m/s), consistent with very soft, organic-rich swamp deposits composed primarily of peaty clays and silts. These materials exhibit high compressibility and extremely low bearing capacity (Qa ≈ 30–50 kPa). The geotechnical implications are significant. There is a high risk of differential settlement if this layer is used for direct foundation support. Extensive **ground improvement** techniques (such as **surcharge loading** or **vertical drains**) would be required prior to construction to mitigate settlement risks and improve subgrade stability.

Layer 2 (4–12 m Depth):

This transitional zone displays moderately increasing velocities (Vs = 300–650 m/s; Vp = 600–1200 m/s), indicative of interbedded sands and clays belonging to the **Benin Formation**. The geotechnical characteristics of this layer include**moderate stiffness**, with an allowable bearing capacity of approximately 100–220 kPa. Suitability for supporting **light structures**, provided that proper foundation design is employed.The presence of localized weak zones, as evidenced by velocity fluctuations within this depth range, suggests that careful **site-specific assessment** and **detailed foundation planning** are essential to avoid unexpected settlements.

Layer 3 (>12 m Depth):

The deepest layer is defined by relatively high velocities (Vs = 650–789 m/s; Vp = 1200–1476 m/s), suggesting the presence of **competent weathered sandstone** or **compact sandy gravels** likely associated with the **Agbada Formation**. The geotechnical significance of this layer includes **agood bearing capacity** (Qa ≈ 220–280 kPa), making it suitable for supporting heavier structures.Its characteristics make it an excellent target for **deep foundation systems**, such as **piles** or **caissons**.The minimal risk of long-term settlement further enhances its suitability for critical infrastructure.

The **velocity vs. depth plot** (Figure 9) reveals several key trends and features that further inform the geotechnical interpretation.

The velocity increase with depth is more gradual than observed in Profiles 1 and 2, suggesting a more **uniform sediment compaction** profile through the subsurface. This indicates consistent consolidation behaviour across the stratigraphy. A **notable low-velocity zone** is observed at depths of 6–8 m, where Vs drops to approximately 400 m/s. This feature may reflectthe presence of a **localized clay lens**, zones of **higher water content** and **variations in sediment composition**.

Such heterogeneities could affect local foundation performance and require targeted mitigation during construction. The **Vp/Vs ratio** of approximately **2.0** in the upper layers corresponds to **saturated and unconsolidated materials**, such as swamp deposits.A gradual decrease to approximately **1.85** in the deeper layers reflects an increase in sediment density and grain contact stiffness, indicating more stable, better-compacted materials.A Poisson's ratio of approximately **0.34** in Layer 1 aligns with the **high compressibility** typical of clay-rich, water-saturated soils. A lower ratio of approximately **0.28** in Layer 3 reflects **lower compressibility**, consistent with dense sands and weathered rock.

The seismic characterization of **Profile 3** underscores the complexity and heterogeneity of the subsurface conditions in the **Amassoama** area. While the soft, organic-rich upper layer presents substantial challenges for shallow foundations, the presence of competent deeper strata offers viable options for **deep foundation systems**. The observed velocity fluctuations in the intermediate zone highlight the need for **site-specific geotechnical investigation** and **careful foundation design** to ensure long-term stability and performance. These results, when combined with those from Profiles 1 and 2, contribute to a more comprehensive understanding of the regional subsurface behaviour and its engineering significance.

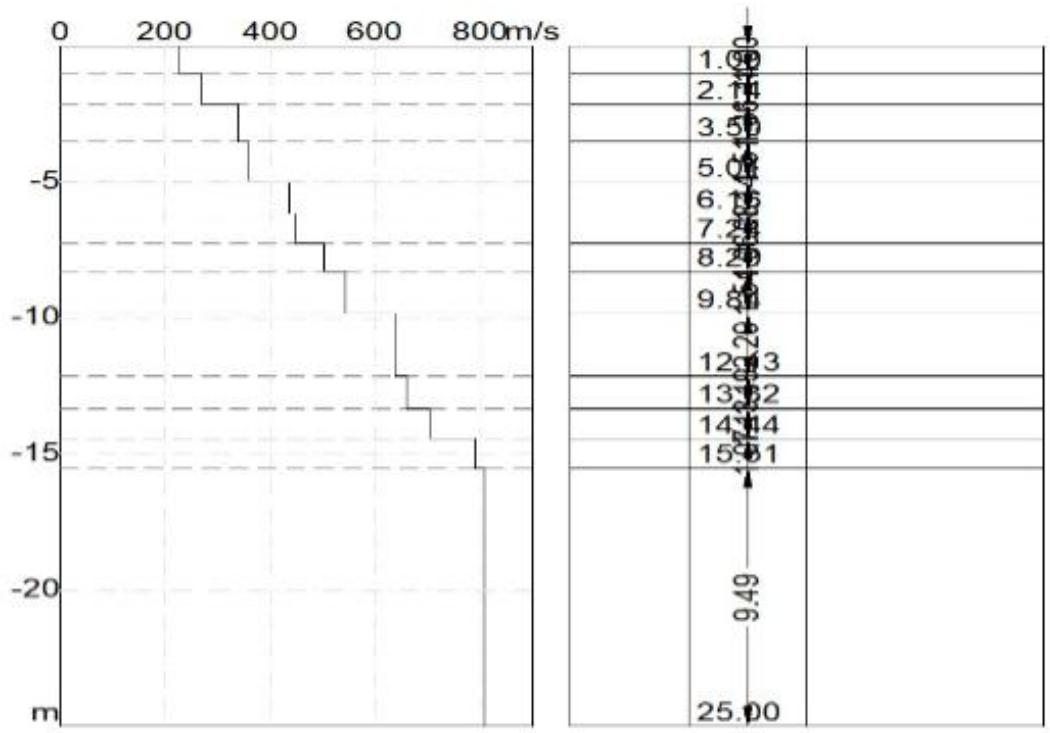


Figure 8: Velocity Stratigraphy Log Section of profile 3.

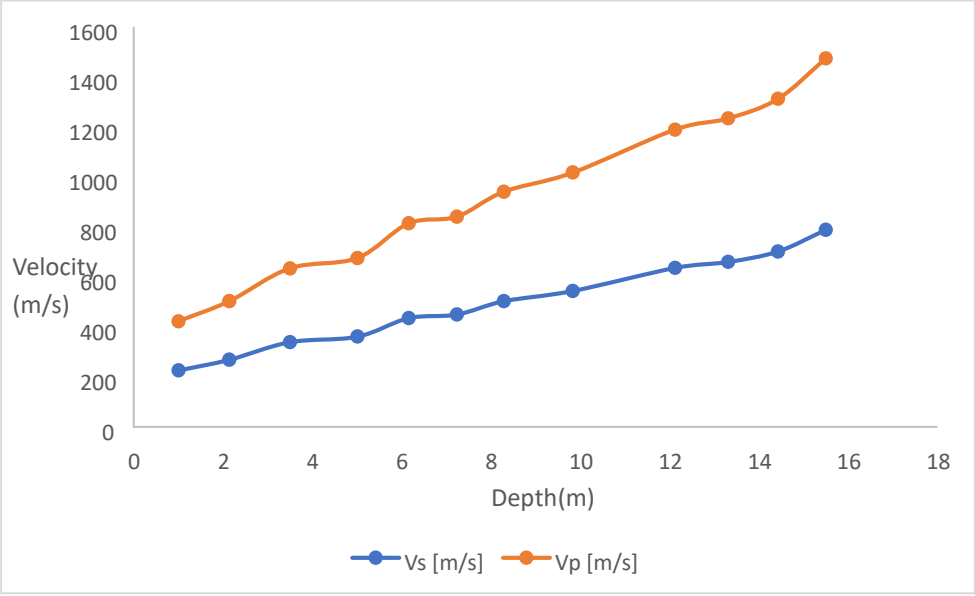


Figure 9: Velocity graph Profile 3.

Figures 10 (Velocity Stratigraphic Log Section) and 11 (Velocity vs. Depth Graph) illustrate the subsurface conditions encountered along **Profile 4** in **Amassoama**, Niger Delta. Among all the surveyed profiles, this profile presents the most **geotechnically favourable conditions**, characterized by a well-compacted and high-strength subsurface profile. These findings provide critical insights for foundation design and construction planning in the region. The velocity stratigraphy log (Figure 10) delineates three well-defined engineering geological units, each with distinct seismic properties and significant implications for load-bearing performance:

Layer 1 (0–3.5 m Depth):

The shallowest layer exhibits low to moderate seismic velocities (Vs = 230–400 m/s; Vp = 433–750 m/s), corresponding to **soft, organic-rich swamp deposits**. From a geotechnical perspective, this layer provides the **lowest bearing capacity** (Qa ≈ 32–80 kPa). It is characterized by **high compressibility**, with an estimated Poisson's ratio (ν) of approximately **0.35**, indicating a clay-rich, saturated behaviour.For structural applications, it is recommended that this layer be **excavated and replaced** or otherwise stabilized if shallow foundations are considered.

Layer 2 (3.5–11 m Depth):

Below the organic-rich surface, seismic velocities increase substantially (Vs = 400–800 m/s; Vp = 750–1400 m/s), indicating the presence of **well-graded sandy sediments** belonging to the **Benin Formation**. This layer offers more favourable geotechnical properties such as a **good intermediate bearing capacity** of approximately **150–300 kPa**, Suitability for **shallow foundations**, provided proper design and construction techniques are employed.With **Vs values exceeding 400 m/s**, this layer presents a **minimal liquefaction risk**, even under seismic loading conditions.

Layer 3 (>11 m Depth):

The deepest layer identified in the profile exhibits very high seismic velocities (Vs = 800–952 m/s; Vp = 1400–1700 m/s), indicative of **very dense sandstone** or **gravelly sand** typically associated with the **Agbada Formation**. This layer is the most competent of the profile. It offers an **excellent bearing capacity** of approximately **300–380 kPa**, making it ideal for supporting **heavy structural loads**.The dense nature of this stratum ensures **negligible settlement concerns**, providing a highly stable foundation base for critical infrastructure. The **velocity vs. depth relationship** (Figure 11) reveals several distinctive trends that further reinforce the favourable geotechnical characteristics of Profile 4. A particularly steep gradient is observed between **5–11 m depth**, indicating a **rapid densification of sediments** within this interval. This reflects a strong transition from less competent to highly competent materials. The profile terminates at velocities of **Vs = 952 m/s** and **Vp = 1700 m/s** at approximately **15.6 m depth**. These values represent the **most competent strata** encountered in the entire Amassoama survey, signalling excellent support potential.
The **Vp/Vs ratio** progressively decreases from approximately **2.05** at the surface to **1.78** at depth. This trend reflects a **decreasing influence of water content** and an increase in grain-to-grain contact stiffness as depth increases. The estimated **Poisson's ratio** similarly decreases from approximately **0.35** near the surface to about **0.26** at depth, marking a transition from **clayey, compressible behaviour** in the shallow sediments to **granular, dense behaviour** in the deeper strata.

The results from **Profile 4** indicate the most **favourable geotechnical conditions** across all profiles surveyed in **Amassoama**. The dense, well-compacted deeper layers, particularly those exceeding 11 m in depth, provide an ideal foundation base for **heavy structural loads** with minimal settlement risks. Meanwhile, the intermediate sandy layers offer viable options for **shallow foundations**, assuming appropriate ground improvement is undertaken to address the compressible nature of the overlying organic-rich deposits.

The seismic characterization of Profile 4 shows a reliable basis for **safe and cost-effective foundation design** in this portion of the Niger Delta, contributing valuable knowledge toward sustainable infrastructure development in the region.

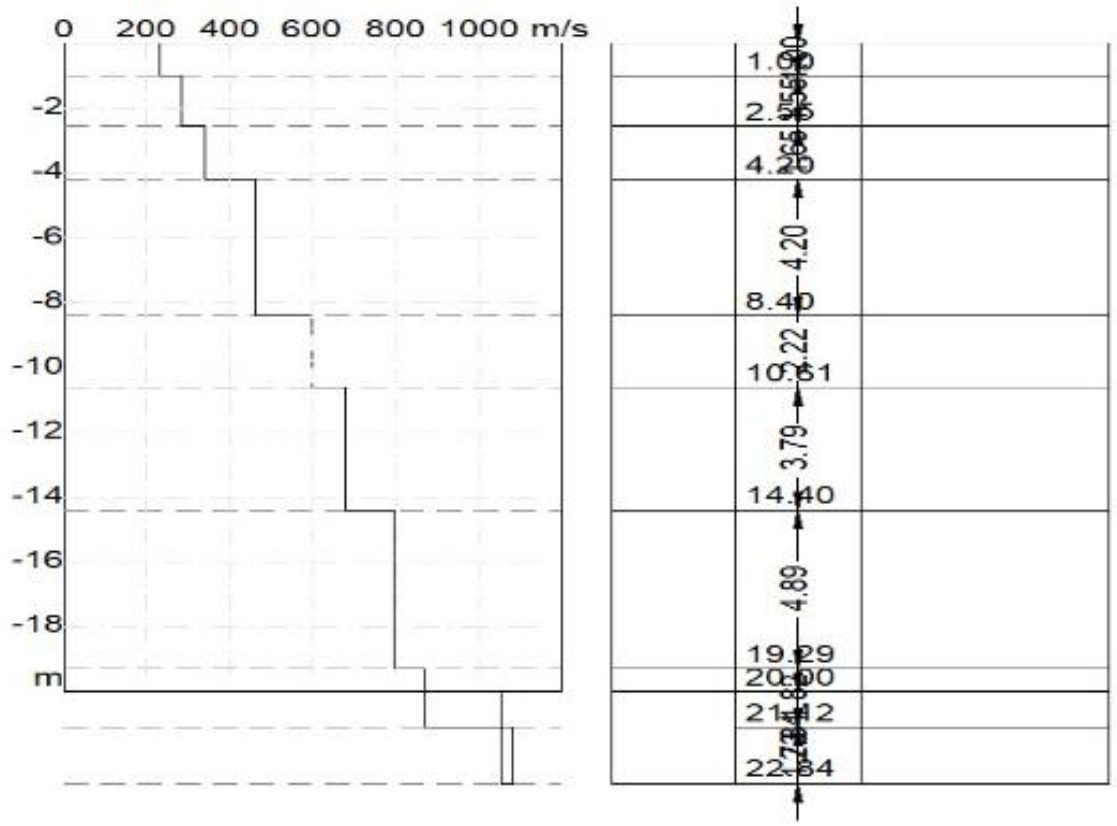


Figure 10: Velocity Stratigraphic Log Section of profile 4.

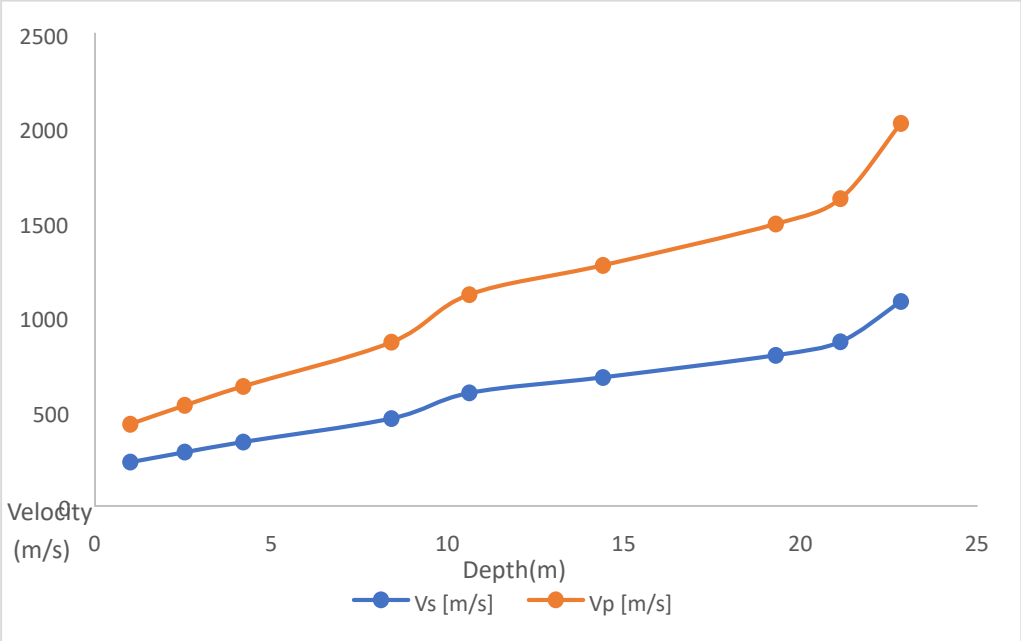


Figure 11: Velocity wave graphs of Profile 4.

Discussion of Results

The results of this seismic refraction study in Amassoama, Niger Delta provide compelling evidence for the technique's effectiveness in near-surface geotechnical characterization, as highlighted by the title. The velocity profiles (Table 1) demonstrate a consistent increase in both shear-wave (Vs) and

compressional-wave (Vp) velocities with depth across all four survey lines, confirming the expected transition from soft surface soils to competent subsurface materials. Figure 3's travel-time curves exhibit clear first arrivals and refractions, validating data quality and enabling reliable velocity inversions. The stratigraphic logs (Figures 4.1-7.1) and velocity-depth plots (Figures 4.2-7.2) reveal three distinct geotechnical units: (1) very soft swamp deposits (Vs 226-270 m/s, Qa 30-50 kPa) in the upper 3-4 m, (2) moderately stiff sandy layers (Vs 400-700 m/s, Qa 100-250 kPa) at intermediate depths, and (3) competent sandstone/gravelly strata (Vs 789-952 m/s, Qa 280-380 kPa) below 10-12 m depth. These findings align with previous Niger Delta studies (Eteh et al., 2020; Omonefe et al., 2019) while providing new site-specific data for Amassoama.

Key observations from the figures show important spatial variations. Profile 4 (Figures 10-11) shows superior geotechnical conditions with Vs reaching 952 m/s at 15.6 m depth - the highest recorded in the study - suggesting it as the most favorable construction zone. In contrast, Profile 3 (Figures 8-9) exhibits more gradual velocity increases and localized weak zones, requiring more careful engineering solutions. The Vp/Vs ratios (1.78-2.05) and Poisson's ratio estimates (0.26-0.35) derived from these plots provide valuable insights into material behavior, with surface layers showing high compressibility ($\nu \approx 0.35$) typical of deltaic clays, transitioning to more rigid response ($\nu \approx 0.26$) at depth.

The study successfully addresses its objectives by demonstrating seismic refraction's ability to delineate soil-bedrock interfaces (Figure 4's sharp velocity jump at 10 m), estimate geotechnical parameters (Table 1's Qa values), and assess method suitability for swampy terrains. The consistent velocity trends across profiles validate the technique's reliability, while observed variations (e.g., Profile 2's 8 m low-velocity zone in Figure 7) emphasize the Niger Delta's heterogeneity. These results support seismic refraction as a cost-effective alternative to conventional methods in line with the paper's title, particularly when combined with selective borehole verification as recommended by previous researchers (Soupios et al., 2005; Sawyer & Waters, 2004). The empirical relationships between Vs and bearing capacity (Table 1) provide practical design guidelines that can improve construction safety while reducing investigation costs in similar deltaic environments worldwide.

Summary

This study demonstrates the successful application of seismic refraction for near-surface geotechnical characterization in Amassoama, Niger Delta. Analysis of four seismic profiles reveals three distinct subsurface layers: (1) soft swamp deposits (Vs 226-270 m/s) in the upper 3-4m with low bearing capacity (Qa 30-50 kPa), (2) moderately stiff sandy layers (Vs 400-700 m/s) at intermediate depths, and (3) competent strata (Vs 789-952 m/s) below 10-12m depth (Table 1). The velocity-depth profiles (Figures 5-11) show consistent increases in Vs and Vp with depth, confirming the transition from compressible surface soils to rigid subsurface materials. Notable spatial variations emerged, with Profile 4 exhibiting the most favorable conditions (Vs up to 952 m/s) and Profile 3 showing localized weak zones requiring special engineering attention. The Vp/Vs ratios (1.78-2.05) and Poisson's ratios (0.26-0.35) provide valuable insights into material behavior. The study validates seismic refraction as a cost-effective method for deltaic environments, particularly when combined with selective borehole verification. The empirical relationships between Vs and bearing capacity offer practical design guidelines, demonstrating how this approach can optimize foundation solutions while reducing investigation costs in challenging swampy terrains.

Conclusion

This study confirms seismic refraction as a practical, efficient technique for near-surface geotechnical characterization in the Niger Delta. Velocity models accurately mapped soil–bedrock interfaces, and derived parameters (E, μ, Qa) informed foundation suitability. In Amassoama’s swampy setting, seismic refraction provided critical insights lacking from limited borehole data. Integrating this approach into site investigations can enhance safety, reduce costs, and expedite project timelines.

Recommendations

1. **Deep Foundations:** Employ pile or raft foundations to bear on competent layers (> 10 m depth).
2. **Ground Improvement:** Stabilize soft near-surface soils via compaction, grouting, or geosynthetics.
3. **Integrated Testing:** Validate seismic results with selective boreholes or CPT/SPT for design calibration.

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