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Influence of Soil Physical Properties on Road Pavement Failure along the Warri-Sapele Highway, Delta State, Nigeria

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Abstract

This research investigated the underlying reasons for continuous road pavement failure at Okuovwori, Okolovu, and Akuekpara along the Warri-Benin highway in Delta State, Nigeria. Analyses involving morphological, physico-chemical, and physical properties were undertaken to determine the causes of pavement distress across these areas. Soil samples from the deteriorated zones were subjected to laboratory evaluations, yielding significant findings. In accordance with the road standards defined by the Federal Ministry of Works and Housing (1997), particle size distributions at Okuovwori and Okolovu were deemed unsuitable, whereas the Akuekpara sample met acceptable criteria. The liquid limit exceeded 50% at all sampled locations, indicating elevated plasticity and adverse moisture retention. The optimum moisture content (OMC) ranged from 7.30% to 13.0% across all sites, implying potential drainage inefficiencies. Maximum Dry Density (MDD) values spanned 1.52 to 2.18%. The California Bearing Ratio (CBR) for the base course in each case complied with regulatory specifications. The analysis reveals that the existing soil characteristics fall short of optimal requirements for road construction under Nigerian conditions. Soil enhancement strategies, particularly stabilization techniques, are recommended to improve soil strength and durability. These methods hold promise for prolonging pavement lifespan and minimizing recurring failures.

Keywords: Pavement Failure, Soil Properties, Physio-Chemical Analysis, Soil Stabilization, Warri-Benin Highway

Introduction

Pavement systems are engineered structural layers laid above natural ground, typically consisting of subbase, base course, and surface layers to efficiently distribute traffic loads to the subgrade [1]. Roads are vital for efficient regional connectivity, and their proper design and maintenance are essential to avoid service disruptions and financial losses due to weak subgrades [2].
They also support essential utilities like electricity and water, making them significant national assets [1]. Various studies have employed geophysical and geotechnical methods to examine road failures. Geophysical tools such as electrical resistivity and electromagnetic (EM) methods assess subsurface conditions [3, 4], while geotechnical testing—like CBR, compaction, and Atterberg limits—assesses the soil’s load-bearing capacity.
A lack of understanding of soil behavior and neglect of geological and geomorphological influences are major contributors to road failure [5, 6, 7]. Problematic soils, notably clays, are often overlooked during construction, leading to instability [8]. Other geological contributors include fractures, faults, shear zones,

and inadequate surface or subsurface drainage [9].
Additional causes include poor design, substandard construction practices, lack of routine maintenance, and human activities [10]. In Nigeria, degraded road sections are linked to increased accident rates [11].
In Sudan, particularly Khartoum State, road failures often arise from the absence of localized construction standards and reliance on imported design codes [12]. Roads constructed with gravel derived from Nubian Sandstone frequently underperform due to weak subgrades and improper compaction. The Dynamic Cone Penetrometer (DCP) is widely employed to evaluate in-situ CBR values and detect causes of pavement distress, particularly rutting and deformation due to moisture retention and clay content [13].
Omer (2014) demonstrated that impact compaction significantly enhances strength and fines content in gravel compared to vibratory or gyratory methods [12]. Dawson et al. (2002) stressed that a sufficiently rigid base layer is crucial to minimizing stress transfer to subgrade layers [14]. Zumrawi (2013) observed serious pavement deterioration in Khartoum—such as rutting and potholes—due to design flaws, poor drainage, and overloading, as validated by research from the University of Khartoum [15].

Types ad Causes of Road Failure

In Nigeria and other developing countries, the primary causes of road failure include overloading, inadequate maintenance, substandard design, and unsuitable subgrade soils. For instance, highways like Warri–Sapele–Benin and Benin–Asaba in Delta State have experienced major degradation due to excessive axle loads and heavy rainfall, resulting in fatigue cracking, potholes, and pavement collapse [16].
Ezeagu and Ezema (2022) found up to 30% failure rates within one year on FERMA-maintained roads like the Asaba–Illah route, primarily due to high traffic from heavy-duty vehicles. Despite adherence to FMW material guidelines, failure persisted, emphasizing poor implementation and a need for FERMA to revisit its design framework and funding mechanisms [17].
On the Onitsha–Enugu expressway, failure was attributed to insufficient maintenance, aging infrastructure, and government mismanagement [18]. Ebuzoeme (2015), using statistical tools, verified these findings and stressed the importance of comprehensive design and multi-stakeholder involvement, even though poor design was not the primary cause [19].
Afoloyan and Abidoye (2017) reviewed studies showing that failure is often due to poor geotechnical surveys, lack of supervision, inadequate drainage, and vehicle overloading. They recommended stronger designs, expert supervision, congestion management, and routine maintenance using trained personnel [20].
Emmanuel et al. (2021) assessed the Sagamu–Papalanto highway and found clay-rich soils (A-26, A-7, A-2-7), low CBR values (3–12%), and high plasticity, suggesting poor subgrade quality. Soil stabilization was recommended as a corrective strategy [21].
In Rajshahi City, Bangladesh, 25% of roads consistently fail due to weak asphalt, overloading, drainage issues, and neglect, increasing accident risks and vehicle operation costs [22].
Attubi and Onokata (2019) linked road congestion and accidents in Warri to poor construction, careless driving, and a lack of signage, advocating for structurally sound roads and clear signage to improve traffic safety [23].

Influence of Soil Properties on Road Pavement Failure

Subgrade soil's geotechnical and mineralogical traits significantly influence pavement durability, with numerous Nigerian and international studies linking unsuitable soils to early failure.
Ogundipe (2008) documented poor geotechnical features—like high plasticity and low CBR (5.45–36.64%)—on the Aramoko–Ilesha road, resulting in pavement failure [1]. Jegede (2004) similarly found poor strength and excess fines on the Okitipupa–Igbokoda route; although CBR reached 55%, poor drainage still led to damage [24].
Tse and Efobo (2016) observed that the Umuahia–Okigwe road failed due to clay-rich soils with expansive

characteristics, such as montmorillonite and kaolinite, with soil types MI-MH and A-7-5 signifying high shrink-swell potential [25].

Ogunribido et al. (2015) reported that roads from Ogbagi to Arigidi Akoko failed from fine content excess, expansive soil behavior, poor compaction, and drainage issues. CBR values ranged from 14–31%, with plasticity index varying between 0 and 29.5% [26].

In the Niger Delta, Warmate and Dieokuma identified low-quality subgrade soils (A-2-4 to A-2-7) with CBR values near 10%, requiring soil capping, compaction above 95%, and effective drainage [27].

Wazoh et al. (2016) studied road conditions in Jos and concluded that even acceptable soils degrade under excessive traffic loading beyond design thresholds [28].

At the Enugu–Port Harcourt expressway, Osadebe et al. (2013) linked road failure to water infiltration into plastic shale subgrades, excessive loads, drainage problems, and a high water table—leading to cracking and base failures [29].

To address expensive and inconsistent soil surveys, Aitsebaomo et al. (2013) proposed a digital mapping initiative to aid engineers in accessing soil classification data for better design and planning [30].

Uge (2017) in Ethiopia identified extensive pavement failures shortly after construction, caused by expansive soils and a lack of proactive geotechnical planning, calling for advanced stabilization techniques beyond basic CBR assessments [31].

Mahmoud et al. (2012) evaluated the Gombi–Biu road and found subpar liquid limits and CBR values (5.1–31.1%), necessitating stabilization to meet pavement suitability standards [9].

Adeboje et al. (2017) demonstrated that adding pulverized palm kernel shell (PPKS) to lateritic soils notably improved strength metrics like CBR and unconfined compressive strength (UCS), while reducing moisture sensitivity [32].

Lastly, Sowemimo (2016) found that Herbert Macaulay Road in Lagos suffered from inadequate materials, poor compaction, heavy traffic, and insufficient lab and field tests, with CBR values well below acceptable thresholds (5.27–6.14%) [33].

Materials and Method

Study Area

The study was carried out in three separate locations—Okuovwori, Okolovu, and Akuekpara—situated along the Warri-Sapele Highway in Delta State, Nigeria. The roadway features a dual-lane design composed of a lateritic subbase, a soil-cement base layer, a surface-dressed median, and an asphalt concrete wearing surface. As illustrated in Figure 1, this important route links Warri and Sapele within Delta State.

These locations are geographically positioned between Longitude 5° 47' 0" East and Latitude 5° 34' 25" North (Effurun) and Longitude 5° 42' 4" East and Latitude 5° 55' 7" North (Sapele), and lie at elevations ranging from 6 to 7.8 meters above mean sea level.

Owing to its critical role in transportation, this roadway is considered one of the most essential federal routes in Delta State. Continuous vehicular movement, coupled with repeated high axle loading, has led to significant structural distress. The persistent mechanical stress has triggered various pavement failures, including fatigue (alligator) cracking, potholes, localized failures, and surface irregularities [17].

Parent Materials and Geological Formations

The primary geological materials underlying the area include sand, clay, and swamp deposits.

Vegetation

Figure 1: Location of project area

Vegetation details were not explicitly provided in the original, but may refer to the natural cover typical of Delta State's swampy or forested lowland terrain. Let me know if you'd like this section expanded.

The vegetation of the sample sites varied from economic palms such as Coconut (*Cocos nucifera* L), Oil palm (*Elaeis guineesis Jacquin*), Raphia palms such as *Raphia hookeri* (the wine palm), *Raphia vinifera* (the bamboo palm), *Raphia regalis* and arable crops such as cassava (*Manihot esculenta*), maize (*Zea mays)* and prominent weeds of the grass

Field Study

The study involved soil investigations near a tarred road between Sapele and Warri. Auger borings were randomly conducted 5–10 meters from both sides of the road, while profile pits were dug 100 meters away to represent underlying parent materials. The physical condition of the road was also visually assessed for signs of failure and deterioration.

Soil samples from the profile pits were collected, preserved, and analyzed in the lab for pedological and geotechnical properties. The soils were then classified using both the USDA soil taxonomy (2022) and the AASHTO system. Physical and chemical lab results were used to assess soil suitability for road construction and predict potential road failure by comparing properties across different parent materials using standard guidelines.

Sample preparation: wet soil samples were air dried, crushed with wooden roller and passed through a 2mm plastic sieve and stored in polypropylene bottles for analysis.

Particle size Determination

The particle sizes was determined using Hydrometer method of Bouyoucos (1951) as modified by Day (1965), and reported by Gee and Or (2002) [35].

- 51 g of air-dry or 50g of oven-dried soil into a soil shaking bottle
- 100ml of calgon was added and will be allowed to soak for 30 minutes.
- The mixture was stirred with a mechanical stirrer.
- The soil suspension was transferred into a sedimentation cylinder and was filled to mark with distilled H_2O.
- A plunger was inserted and was moved up and down to mix the content thoroughly, while the sediment was dislodged with their upward strokes of the plunger near the bottom, the hydrometer was lowered carefully into the suspension and readings was taken after 40 seconds (R40 sec.).
- The temperature reading was taken thereafter with a thermometer.
- The second reading came up in 120 minutes time, while the first (R40 sec.) reading calculate for % silt + clay, the second reading was calculated for % clay and subtracted from % silt clay and both subtracted from 100 to get % sand.

Selected Physical Properties Analysis
Atterbergs Limit Test (Barnes, 1995)**:**

1. Liquid Limit Test
Approximately 100g of dry soil was mixed with distilled water to form a uniform paste. A portion was placed in a liquid limit device cup, smoothed to ½ inch depth, and a groove was created using a standard tool. The device's crank was turned at two revolutions per second, and the number of blows required to close the groove over a ½ inch span was recorded. This process was repeated after remixing until consistent blow counts (10–40 blows) were achieved. About 10g of soil from near the groove was used for moisture content analysis. The test was repeated for four different moisture contents, and a graph of moisture content versus log of blows (flow curve) was plotted to determine the liquid limit at 25 blows [37].

2. Plastic Limit Test
Approximately 15g of moist soil was hand-rolled on a glass plate into 1/8 inch diameter threads. Rolling continued until the threads crumbled. The crumbled portions were tested for moisture content. This was repeated three times, and the average moisture content was taken as the plastic limit.

Calculations

- **Liquid Limit (w_l):** Moisture content at 25 blows from flow curve
- **Plastic Limit (w_p):** Average moisture content at thread crumbling
- **Plasticity Index (I_p):** $I_p = w_l - w_p$

3. Compaction Test
The mold (without collar) was weighed, and 6 lbs of prepared soil (passed through No. 4 sieve) was layered into the mold in three layers. Each layer was compacted with 25 blows from a rammer dropped from one foot. After trimming the soil flush with the mold's top, the mold with compacted soil was weighed. About 100g of soil (sampled from various depths) was taken for moisture content determination. The remaining soil was remixed, and moisture content was increased by 3% increments for each subsequent trial. This process was repeated through five to six compaction runs to obtain a full compaction curve as the soil became wetter and stickier.

Calculation:
The dry density,
$\gamma d = W/V(1+w)$
In which W = total weight of moist compacted soil in cylinder,
V = volume of the mold,
w = moisture content of moist compacted soil.
California Bearing Ratio Test: [35]
This test was conducted on compacted soil in a CBR mould (150mm diameter, 175mm height), fitted with a detachable 50mm collar and a perforated base plate. Soil was compacted at **optimum moisture content** and **dry density** as determined by a compaction test. The sample, passing a 20mm IS sieve, weighed approximately 4.5–5.5 kg and was thoroughly mixed with water. A 50mm deep displacer disc was placed in the mould during compaction to yield a 125mm deep specimen.

Compaction was done in **three layers** using a **2.6 kg rammer**, each layer receiving **56 evenly distributed blows**. After trimming and removing the disc and base plate, the mould and compacted soil were weighed to determine **bulk and dry densities**.

A filter paper and perforated base plate were attached to the top, and **surcharge weights** (minimum two, each 2.5 kg = 7 cm pavement) were applied. The mould was then submerged in water for **96 hours (4 days)** with constant water level, and **expansion readings** were taken daily using a dial gauge setup.

After soaking, the mould was removed, drained, and weighed. The surcharge weight was reapplied, and the mould placed under a **CBR penetration test machine**. The **penetration piston** was positioned with minimal load (≤4 kg), and gauges were zeroed. Load was applied at **1.25 mm/min**, recording penetration at depths:
0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, and 12.5 mm.

The **maximum load and penetration** were noted, and **20–30g** of soil was sampled from the top 3cm for **moisture content** analysis.

Calculation

- **Expansion Ratio**
- Expansion Ratio – the expansion ratio was calculated as follows:
- Expansion ratio = $d_f - d_i / h \times 100$
- Where d_f = final dial gauge reading (mm); d_i = initial gauge reading (mm); h = initial height of specimen (mm)
- **Load Penetration Curve**
  A load vs. penetration graph was plotted. If the curve's initial portion was concave, a tangent at the point of greatest slope was drawn to correct the origin. **Corrected load values** were obtained for desired penetration values, and the **CBR (%)** was calculated accordingly.

C.B.R. = $P_T/P_S \times 100$
P_T = corrected test load corresponding to the chosen penetration from the load penetration curve;
P_S = Standard load for the same penetration as for P_T taken from the standard load.

Results

Morphological Description of Pedon 1 (Okuovwori – Sand, Clay, and Swamp)

Table 1 presents the morphological features of **Pedon 1**, located at **Okuovwori**, derived from **Sand, Clay, and Swamp** parent material.

- **Topsoil (0–37 cm)**: Very dark gray in color.
- **Subsoil Colors**:
  - 37–64 cm: Reddish yellow
  - 64–92 cm: Gray
  - 92–109 cm: Light brown
  - 109 cm and deeper: Gray
- **Soil Structure**: Moderately blocky with slight angularity.
- **Textural Classes by Depth**:
  - 0–37 cm: Sandy Clay Loam
  - 37–64 cm: Sandy Loam
  - 64–92 cm: Sandy Loam
  - 92–109 cm: Sandy Clay Loam
  - 109–125 cm: Sandy Loam
- **Horizon Boundaries**:
  - Layers 1–3: Diffuse and blended interfaces
  - Layers 4–6: Sharp and well-defined boundaries

Morphological Description of Pedon 2 (Okolovu – Sand, Clay, and Swamp)

Table 2 provides the morphological data for **Pedon 2**, located at **Okolovu**, also underlain by **Sand, Clay, and Swamp** materials.

- **Topsoil Color**: Black
- **Subsoil Colors by Depth**:
  - 12–23 cm: Reddish yellow
  - 23–28 cm: Pinkish gray
  - 38–46 cm: Light gray
  - 46–152 cm: Strong brown
- **Soil Structure**: Ranges from **fine and many** to **fine and very few** structural elements
- **Textural Class**:

Table 1: Morphological Description/Classification of Pedon 1 (Sand, Clay and Swamp)

Geographical coordinates	N5.836207, E5.731114

Taxonomic Class	Typic Endoaquepts
Parent Material	Sand, clay and swamp
Physiographic Position	Terrace – Elevation: 16 m a.s.l.
Drainage	Poor
Vegetation/Landuse	Permanent crops – oil palm
Depth to water table	Deep (≥164cm)

Horizon	Depth (cm)	Description
A	0-37	Very dark gray (10YR4/3); sandy loam; non sticky, non-plastic; fine many single grain; medium few root size; smooth clear boundary; pH 5.06
Bw	37 -64	Reddish yellow(7.5YR6/8); Sandy Clay Loam; non sticky, non plastic; loose moist and dry; medium few root size; smooth clear boundary; pH 4.97.
Bw$_2$h	64 - 92	Light brown (7.5YR6/4); Sandy Loam; medium few root size; smooth diffuse boundary; pH 4.52.
Bw$_3$	92 - 109	Brown (7.5YR5/4); Brown; sticky, plastic; friable moist, soft dry; fine sub-angular blocky; medium few root size; smooth diffuse boundary; pH 4.43
Bw$_4$	109 -125	Gray (10.5YR6/1); Sandy loam; sticky, plastic; friable moist, soft dry; medium sub-angular blocky; very few fine root size; pH 4.34.

Plate 1: Pedon 1 (Okuovwori – Sand, Clay and Swamp)

Plate 2: Failed Portion at Okuovwori (Sand, Clay and Swamp

Table 2: Morphological Description/Classification of Pedon 2 (Sand, Clay and Swamp)

Geographical coordinates	*N 5.729985, E 5.752772*
Taxonomic Class	Aeric Endoaquepts
Parent Material	Sand, clay and swamp
Physiographic Position	Terrace– Elevation: 12 m asl.
Drainage	Poorly drained
Vegetation/Landuse	Fallow/Road
Depth to water table	Deep (≥150cm)

Horizon	*Depth (cm)*	*Description*
Ap	0 – 12	Black (10YR2/1); sandy loam; non sticky, non plastic; loose moist and dry; very fine many grain; medium few root size; smooth clear boundary; pH 5.87
A	12 - 23	Reddish yellow (5YR6/6); sandy loam; non sticky, non plastic; loose moist and dry; fine few grain; smooth clear boundary; pH 5.33
AB	23 - 38	Pinkish gray (7.5YR6/2); sandy loam; non sticky, non plastic; loose moist and dry; fine very few grain; smooth diffuse boundary; pH 4.01.
Bw	38 - 46	Light gray(10YR7/2); Sandy loam; non sticky, non-plastic; loose moist and dry, fine very few grain; wavy boundary; pH 4.2.
Bw_2	46 - 152	Strong brown (7.5YR5/6); Sandy clay loam; sticky, plastic; friable moist, soft dry; pH 4.1.

Plate 3: Pedon 2 (Okolovu – Sand, Clay and Swamp)

Plate 4: Failed Portion at Okolovu (Sand, Clay and Swamp)

(12 cm) of the profile displays a sandy loam texture, which persists through 12 to 23 cm and also continues across 23 to 38 cm and 38 to 46 cm depths. However, from 46 to 152 cm, the soil texture transitions to sandy clay loam. The boundary separating the first and second layers appears wavy, while the transition between second and third layers is smooth and diffuse. The boundaries for layers three, four, and five are described as smooth and distinct.

Morphological Description of Pedon 3 (Akuekpara – Sand, Clay and Swamp)
Table 3 presents the morphological features of Pedon 3 located in Akuekpara, an area underlain by sand, clay, and swamp materials. The topsoil exhibits a very dark brown color, while the subsoil layers are brown (13–21 cm), gray (21–32 cm), light gray (32–43 cm), and brown again (43–63 cm). The topsoil texture is sandy loam, which continues through 13 to 21 cm. From 21 to 32 cm, the soil texture shifts to sandy clay loam, which persists down through 32 to 43 cm and 43 to 63 cm. The boundaries separating the first three layers are distinct, while those between layers three, four, and five are diffuse.

Physical-Chemical Properties of Pedon 1 (Okuovwori – Sand, Clay and Swamp)
According to Table 4, the physical and chemical characteristics of Pedon 1, located at Okuovwori, show that soil pH ranges from 4.70 to 5.06. The organic carbon content lies between 2.14 g/kg and 9.08 g/kg, while total nitrogen varies from 0.16 g/kg to 1.58 g/kg. The concentration of available phosphorus ranges between 1.68 mg/kg and 7.98 mg/kg. Calcium levels were found between 0.24 and 1.92 cmol/kg, whereas magnesium content ranged from 0.06 to 1.17 cmol/kg. The potassium content was recorded between 0.11 and 0.27 cmol/kg, and sodium levels ranged from 0.02 to 0.13 cmol/kg. Regarding soil acidity, exchangeable acidity ranged from 0.14 to 1.22 cmol/kg, and the cation exchange capacity (CEC) fluctuated between 1.45 and 3.63 cmol/kg.

Table 3: Morphological Description/Classification of Pedon 3 (sand, clay and swamp)

Horizon	Depth (cm)	Description
Ap	0 – 13	Very dark brown (10YR2/2); sandy loam; non sticky, non-plastic; loose moist and dry; medium few root size; smooth clear boundary; pH 4.01
AB	13 - 21	Brown (7.5YR6/1); sand loam; non sticky, non-plastic; loose moist and dry; smooth diffused boundary; pH 4.61
Bth	21 - 32	Gray (7.5YR6/1); sandy clay loam; non sticky, non-plastic; loose moist and dry; smooth diffuse boundary; pH 4.97.
Bt_2	32 – 43	Light gray(7.5YR7/1); Sandy clay loam; sticky, plastic; loose; smooth diffuse boundary; pH 5.06
Bt_3	43- 63	Brown (7.5YR5/4); Sandy clay loam; sticky, plastic; friable moist, soft dry; pH 5.78

Geographical coordinates	**N 5.760750, E 5.741545**
Taxonomic Class	Grossarenic Endoaqults
Parent Material	Sand, clay and swamp
Physiographic Position	Float– Elevation: 6 m asl.
Drainage	Poorly drained
Vegetation/Landuse	Fallow/Road
Depth to water table	Deep (≥63cm)

Depth	Sieve Analysis % Passing			Atterberg Limit			Compaction		California Bearin				
(cm)	#10 1.18 mm	#40 0.425 mm	#200 0.075 mm	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)	Bottom				
									Un-soaked		Soaked		Un
									2.5 mm	5.0mm	2.5 mm	5.0mm	2.5 mm
0 -37	96.7	87.1	27.6	53.25	NP	NP	1.06	5.30	26.43	27.13	17.26	23.29	20.07
37 -64	100	93.2	30. 0	52.43	46.24	6.19	1.18	6.40	30.56	35.19	25.19	25.36	30.31
64 - 92	100	89.3	31.9	51.01	NP	NP	1.32	7.70	33.12	36.28	29.32	27.48	23.29
92 – 109	100	84.3	33.5	49.86	44.37	9.49	1.38	7.00	23.95	30.27	35.76	26.58	20.56
109 - 125	98.7	57.1	34.6	45.79	41.31	4.48	1.40	8.50	30.56	32.35	32.25	29.54	21.30

Table 4: Physical Properties of Pedon 1 (Okuovwori – Sand, Clay and Swamp)

California Bearing Ratio (CBR) Results

For the bottom soaked layers, CBR values for 2.5 mm penetration ranged between 10.15% and 25.35%, while those for 5.0 mm penetration ranged between 12.87% and 16.44%.
In the top unsoaked layers, penetration at 2.5 mm varied between 21.72% and 26.19%, and at 5.0 mm between 16.42% and 28.44%.
For the top soaked condition, 2.5 mm penetration values ranged from 6.44% to 14.20%, while 5.0 mm penetration ranged between 12.89% and 18.41%.

Physical Properties of Pedon 3 (Akuekpara – Sand, Clay, and Swamp)

Table 6 presents the physical properties of soils from the Akuekpara site, comprising sand, clay, and swamp materials. The sieve analysis results showed that the percentage of particles passing through sieve #10 ranged between 98.7% and 100%, through sieve #40 between 73% and 99%, and through sieve #200 between 38.6% and 53.4%.

The Atterberg limits revealed that the liquid limit ranged between 55.90 and 60.88 g/cm³, while all soil layers were classified as non-plastic, resulting in a plastic limit and plasticity index of zero.

Compaction tests indicated that the maximum dry density of the soils ranged from 1.36 to 1.48 g/cm³, and the optimum moisture content varied between 4.50% and 7.00%.

The California Bearing Ratio (CBR) test results showed that for the bottom unsoaked condition, 2.5 mm penetration values ranged from 17.09% to 29.23%, while 5.0 mm penetration values ranged between 23.15% and 32.09%. Under the bottom soaked condition, CBR values for 2.5 mm penetration ranged from 29.85% to 36.83%, and for 5.0 mm between 20.60% and 31.18%.

For the top unsoaked layers, the CBR values at 2.5 mm ranged between 5.83% and 15.11%, and for 5.0 mm penetration between 12.11% and 23.62%. Under top soaked conditions, 2.5 mm penetration values ranged from 3.14% to 9.27%, and 5.0 mm values from 9.08% to 15.02%.

AASHTO Classification of Pedon 1 (Okuovwori – Sand, Clay, and Swamp)

According to Table 7, soils from the Okuovwori area, consisting of sand, clay, and swamp materials, were classified using the AASHTO system. The soil types ranged from silty or clayey gravel and sand mixtures to predominantly clayey subsoils. The sub-grade quality was assessed to vary from fair to poor, and in some cases, excellent to good.

The group index values were between 0 and 1 cm, with the group classification ranging from A-2-6 to A-6, and the final classification ranging from A-2-6(0) to A-6(1).

AASHTO Classification of Pedon 2 (Okolovu – Sand, Clay, and Swamp)

Table 8 displays the AASHTO classification results for soils from the Okolovu site. These soils included a

Depth	Sieve Analysis % Passing			Atterberg Limit			Compaction		California Bearing R					
(cm)	#10 1.18 mm	#40 0.425 mm	#200 0.075 mm	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)	Bottom					
									Un-soaked		Soaked		Un-soal	
									2.5 mm	5.0m m	2.5 mm	5.0m m	2.5 mm	5 n
0-12	79.1	59.4	18.5	52.18	NP	NP	1.36	6.90	29.32	19.87	10.15	16.44	25.19	2
12-23	99.3	76.9	34.7	52.76	NP	NP	1.34	8.40	27.92	12.60	13.72	14.26	25.88	2
23-38	100	98.1	68.7	52.56	44.46	8.10	1.28	7.20	30.80	29.68	20.39	15.59	21.72	1
38-46	100	98.7	69.7	54.32	44.51	9.81	1.27	8.90	37.99	31.62	25.35	12.87	23.64	1
46 -152	100	99.3	72.9	56.45	44.69	11.76	1.22	7.80	31.72	20.55	17.84	14.52	26.19	1

mixture of silty or clayey gravels and sands, as well as more clay-rich layers. Sub-grade performance across these soils varied widely, ranging from relatively inefficient to excellent.

The group index values fell between 0 and 3 cm, while the group classifications ranged from A-3 to A-2-6, and the final classifications were between A-3(0) and A-2-6(0).

Table 5: Physical Properties of Pedon 2 (Okolovu – Sand, Clay and Swamp)

Depth	Sieve Analysis % Passing			Atterberg Limit			Compaction		California Bearing Ra					
(cm)	#10 1.18 mm	#40 0.425 mm	#200 0.075 mm	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)	Bottom					
									Un-soaked		Soaked		Un-soal	
									2.5 mm	5.0mm	2.5 mm	5.0mm	2.5 mm	5 m
0-13	100	97.4	44.7	55.90	NP	NP	1.36	7.00	17.09	32.09	36.83	31.18	15.11	2
13 -21	100	96.8	45.4	59.00	NP	NP	1.37	6.40	17.43	28.19	35.26	27.53	7.02	1
21-32	100	94	43.4	60.62	NP	NP	1.42	5.20	24.68	26.08	32.25	24.17	5.83	1
32-63	98.7	73	38.6	60.88	NP	NP	1.48	4.50	29.23	23.15	29.85	20.60	6.01	1

Table 6: Physical Properties of Pedon 3 (Akuekpara – Sand, Clay and Swamp

Depth	*Layer*	*Significant Constituent materials*	*Genral Ratings As Subgrade*	*Group Index*	*Group Classification*	*Final Classification*
(cm)				(cm)		
0-37	1	Silty or clayey gravel and sand	Excellent to Good	0	A-2-6	A-2-6(0)
37-64	2	Silty or clayey gravel and sand	Excellent to Good	0	A-2-6	A-2-6(0)
64 -92	3	Fine sand	Fair to poor	0	A-4	A-4 (0)
92-109	4	Silty soils	Fair to poor	0	A-4	A-4(0)
109-125	5	Clayey soils	Fair to poor	1	A-6	A-6 (1)

Table 7: AASHTO Classification of Pedon 1 (Okuovwori – Sand, Clay and Swamp)

Table 8: AASHTO Classification of Pedon 2 (Okolovu-Sand, Clay and Swamp)

Depth	*Layer*	*Significant Constituent materials*	*General Ratings as Subgrade*	*Group Index*	*Group Classification*	*Final Classification*
(cm)				(cm)		
0-12	1	Silty or clayey gravel and sand	Excellent to good	0	A-2-4	A-2-4(0)
12-23	2	Silty or clayey gravel and sand	Excellent to good	0	A-2-4	A-2-4(0)
23-38	3	Silty soils	Fair to poor	3	A-4	A-4(3)
38-46	4	Silty soils	Fair to poor	0	A-4	A-4(0)
46-152	5	Silty or clayey gravel and sand	Excellent to good	0	A-2-6	A-2-6(0)

Table 9: AASHTO Classification of Pedon 3 (Akuekpara -Sand, Clay and Swamp

Depth (cm)	*Layer*	*Significant Constituent materials*	*General Ratings as Subgrade*	*Group Index* (cm)	*Group Classification*	*Final Classification*
0-13	1	Silty soils	Fair to Poor	0	A-4	A-4(0)
13-21	2	Silty soils	Fair to Poor	0	A-4	A-4(0)
21-32	3	Silty soils	Fair to Poor	0	A-4	A-4(0)
32-43	4	Silty soils	Fair to Poor	0	A-4	A-4(0)
43-63	5	Silty soils	Fair to poor	0	A-4	A-4(0)

DISCUSSION

The analysis of soil samples collected from trenches in sandy, clayey, and swampy parent materials revealed physical properties. A slight increase in soil acidity was noted, typical of soils developed from alkaline sources. This may result from the leaching of finer particles and the downward movement of alkaline cations.

Soil texture varied across the parent materials, primarily exhibiting sandy loam to sandy clay loam textures. This variation is largely due to the influence of topography, which governs the deposition of soil materials from coarse to fine through eluviation and illuviation.

Particle Size Distribution

Sieve analysis revealed how well the soil particles were graded. For use in road construction, the Federal Ministry of Works and Housing (1997) recommends that at least 35% of a soil sample should pass through a No. 200 sieve. Based on this criterion, soils from Okuovwori and Okolovu were unsuitable, as they fell below the required threshold. Only Akuekpara soils met the specification, making them suitable for road construction.

Plasticity

According to FMWH (1997), sub-base and base materials must not exceed a 50% liquid limit. However, the soils at Okuovwori (51.01–59.86%), Okolovu (52.18–56.45%), and Akuekpara (50.62–55.90%) all exceeded this limit, rendering them unsuitable for road subgrade and base applications.

Furthermore, none of the soils met the maximum plasticity index (PI) of 20%, making them inadequate for subgrade construction (Ola, 2008). High PI indicates medium to high swelling potential, increasing the risk of road section failure due to high compressibility (Olubanjo et al., 2018).

To mitigate these issues, proper drainage systems are recommended, although resurfacing without addressing subgrade failure will be ineffective. According to Adeyemi (2002), plastic deformation under load affects the integrity of high-PI soils. As Cassagrande (1947) indicated, high plasticity corresponds with high compressibility, reducing the load-bearing capacity.

Compaction

FMWH (1997) recommends Maximum Dry Density (MDD) values between 1.50–1.78 g/cm^3 and Optimum Moisture Content (OMC) between 8.56–12.02%. However, soils from Okuovwori, Okolovu, and Akuekpara had lower MDD and OMC values, indicating poor load-bearing capacity.

To improve strength and reduce permeability, these soils need proper compaction and stabilization. For effective foundation performance, soils must be compacted above MDD and OMC thresholds to resist load and water infiltration (Olofinyo et al., 2019). Additionally, heavy-duty vehicle traffic may affect compaction rates, which were originally suited for low-volume traffic (Wazoh et al., 2016).

California Bearing Ratio (CBR)

- Okuovwori soils showed:
  - Bottom unsoaked (5.0 mm): 27.13–36.28%
  - Bottom soaked (5.0 mm): 23.29–29.54%
  - Top unsoaked (5.0 mm): 22.79–28.69%
  - Top soaked (2.5 mm): 9.00–13.46%
- Okolovu soils showed:
  - Bottom unsoaked (5.0 mm): 12.60–31.62%
  - Bottom soaked (2.5 mm): 13.72–25.35%
  - Top unsoaked (5.0 mm): 16.42–28.44%
  - Top soaked (2.5 mm): 6.44–14.20%
- Akuekpara soils showed:
  - Bottom unsoaked: 2.5 mm: 17.09–29.23%; 5.0 mm: 23.15–32.09%
  - Bottom soaked: 2.5 mm: 29.85–36.83%; 5.0 mm: 20.60–31.18%
  - Top unsoaked: 2.5 mm: 5.83–15.11%; 5.0 mm: 12.11–23.62%
  - Top soaked: 2.5 mm: 3.14–9.27%; 5.0 mm: 9.08–15.02%

Per FMWH (1997), CBR values must not exceed 10% (subgrade), 30% (sub-base), and 80% (base). Soils with CBR under 10% are unsuitable as subgrade; those under 30% are good sub-base; and those below 80% are suitable base materials. None of the samples exceeded 80%, aligning with Asphalt Institute (1962) standards. Overall, these soils can be rated fair to good for road construction, though improvement methods are required in lower-performing zones.

AASHTO Classification

The analysis of the soil samples based on AASHTO classification showed they fall into **A-2-6, A-2-4, A-4, and A-6** categories.
Soils in the **A-2-6 and A-2-4** groups, which consist of **silty or clayey gravelly sands**, are regarded as **excellent to good materials** for use as sub-base in road construction.
In contrast, soils in the **A-4 and A-6** categories are primarily **silty and clayey**, and are considered to be **fair to poor subgrade materials**.
Overall, **granular soils** are rated higher for road construction, while **clayey soils** are typically less suitable due to their lower performance.

Conclusion

The variations observed in soil characteristics significantly contribute to differences in performance, particularly in road durability. This study aimed to identify the underlying soil-related factors responsible for road degradation in areas where soil properties fall short of the standards set by the Nigerian Federal Ministry of Works. The results indicate that failure to properly manage such soils during road construction can lead to continuous deterioration, negatively impacting transportation—especially the movement of agricultural produce from rural to urban areas. This disruption could reduce food availability and potentially discourage local farmers due to transportation challenges.

The study emphasizes that soil type plays a critical role in determining the likelihood of road failure. As such, it highlights the importance of implementing comprehensive maintenance strategies, along with clear policies and guidelines in the design and construction of road infrastructure. In areas with substandard soils, soil improvement techniques, including stabilization, should be applied to enhance their engineering properties. The AASHTO classification results presented in this research serve as a practical reference for selecting appropriate treatments and ensuring more durable and reliable roads.

Recommendations:

1. Use the study's findings to distinguish between suitable parent materials for road construction and those that require enhancement.
2. Engage soil scientists in all phases of road construction to provide expert analysis and recommendations.
3. Treat unsuitable soils to meet the standards specified by the Federal Ministry of Works to achieve better performance and predict potential road failures.
4. Implement and enforce a strong maintenance culture to extend the lifespan and functionality of road networks.

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References

1. Ogundipe, O.M. (2008). Road pavement failure caused by poor soil properties along Aramoko-Ilesa highway, Nigeria. *Journal of engineering and applied sciences.* 3(3): 239-241
2. Sharad, S. A., Gupta, A. K., (2014). Pavement Deterioration and its Causes: *Civil, J.J. Magdum college of Engineering Shivaji University, India 2014.*
3. Aigbedion, I. (2007). Geophysical investigation of road failure using electromagnetic profiles along Opoji, Uwenlenbo and Illeh in Ekpoma –Nigeria. *Middle-East Journal of Scientific Research.* 2 (3-4):111-115.
4. Adiat, K.A.N., Adelusi, A.O. and Ayuk, M.A. (2009): "Relevance of Geophysics in Road Failures Investigation in a Typical Basement Complex of South Western Nigeria". *Pacific Journal of Science and Technology*. 5(1): pp.528-539.
5. Adegoke, A., Anthony, W.C., & Agada, O. A (1980). Geotechnical characteristics of some residual soils and their implications on road design in Nigeria. *Technical Lecture.* Lagos, Nigeria. 1 – 16.

6. Mesida, E. A., (1987). The Relationship between the Geology and the Lateritic Engineering Soils in the Northern Environs of Akure, *Nigeria. Bulletin of the international Association of Engineering Geology (35).* Pp 65-69.
7. Ajayi, L. A. (1987). Thought on Road Failures in Nigeria. *The Nigerian Engineer,* *22*(1),10 – 17.
8. Ajani, A. R., (2006). Causes Of Premature Failures on Nigeria Highways A Training Course In Tunisia.
9. Mahmood, H., Belel, Z. A., F.and Abba, H. A. (2012). Road Pavement Failure Induced by Poor Soil Properties along Gombe –BIU highway, Nigeria. Journal of Engineering and Applied Science 4(22). Pp1-5
10. Ibrahim, k. (2011). Nigerian Roads ned N70 Billion for Repairs Annually. Daily Times Article , May 30, http ://daily times.com.ng.
11. Federal Road Safety Corps, (FRSC) (2011). Report on Road Traffic CrashesMaintenance. *Annual Report*.
12. Omer G. O., Ahmed M. E. and Awad E. M. M.(2014): "Failure Investigation for Recently Constructed Road in Khartoum State". *Journal of Geological Resource and Engineering 2 (2014).* pp 20-31.
13. Elyas, M. T. M. (1991). Use of DCP for Design/sSructural Evaluation of Roads and Airfields. Master of Science Thesis University of Khartoum, Khartoum, Sudan
14. Dawson. A. R., Cheung. L. (2002): "The effects of particle and mix characteristics on the performance of some granular materials". *Transportation Research Record: Journal of the Transportation Research Board.* pp 90-98.
15. Zumrawi. M.M.E. (2013): "Pavement design for roads on expansive clay subgrades*". University of Khartoum Engineering Journal 3 (1).* Pp 51-57.
16. Ezeagu, C.A., Ibeabuchi, C.I. and Mezie, E.O. (2020): "Empirical Post-Mortem Analysis and Healing Approach of Flexible and Rigid Pavement Failures In Anambra State". *Journal of Inventive Engineering and Technology (JIET), 1(2).*
17. Ezeagu, C.A. and Ezema, N.M. (2022): "Deterioration and Failure Rates of Maintained Roads in Nigeria". *Saudi J Civ Eng, 6(4).* pp 64-71.
18. Onuoha, D. C., Onwuka, S. U. and Obienusi, E. A. (2014): "Evaluating the Causes of the Road Failure of Onitsha-Enugu Expressway, Southeastern Nigeria". *Civil and Environmental Research Vol.6, No.8, 2014* *www.iiste.org*. ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online).
19. Ebuzoeme, O. D. (2015). Evaluating the Significance of Poor Road Design as a Factor of Road Failure: A Study of Onitsha-Enugu Expressway, South-eastern Nigeria. *Civil and Environmental Research, 7(2).*
20. Afolayan, O. D. and Abidoye, A. O. (2017). Causes of Failure on Nigerian Roads: A Review. *J. of Advancement in Engineering and Technology Volume 5 / Issue 4.* ISSN: 2348-2931.
21. Emmanuel, U. O., Igwe, O. and Ukah B. U. (2021). An Investigation Into The Cause Of Road Failure Along Sagamu-Papalanto Highway Southwestern Nigeria. *Geoenvironmental Disasters (2021) 8:3. (2021) 8:3.*
22. Imran, M. A., Rabbany, H.M.A., Islam M. T. and Sharon M.M.H. (2015). Assessment on the Road Pavement Failure and Maintenance of Rajshahi City. *International Conference on Recent Innovation in Civil Engineering for Sustainable Development*. Pp 787 -791.
23. Attubi, A.O and Onokata, P.C. (2019). The Effects of Traffic Congestion on Road Accidents In Niger-Delta: The Case Of Warri Metropolis. *Journal of The Social and Management Sciences. Delta State University, Abraka Vol. 1, No. 1.*
24. Jegede, G. (2004). Highway pavement failure induced by poor geotechnical properties along a section of F209 Okitipupa-Igbokoda highway, Southwestern Nigeria. *Ife Journal of Science,* 6(1): 41-44.
25. Tan, H.K. (2002). Soil sampling, preparation, and analysis. *Soil pH measurement*. pp. 96–113. (Marcel Dekker: New York).
26. Ogunribido, T. H., Mohammed M. Z. and Adesuyi A. R. (2015). Effect of Engineering Properties of Soil on Pavement Failures in Ogbagi - Akoko Area, Southwestern, Nigeria. *Journal of Environment*

and Earth Science www.iiste.org. ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) Vol.5, No.4, 2015.

27. *World Bank (1991): Nigeria Highway Sector Study Journal, Vol. II, No.2.*
28. Wazoh, H. N., Daku, S. S and Samuel, F.G. (2016). Investigative Study of Possible Causes of Failure of a Section Of Road In Jos- Plateau, North - Central Nigeria. *Journal of Multidisciplinary Engineering Science Studies (JMESS)*. ISSN: 2458-925XVol. 2 Issue 11, November - 2016
29. Osadebe, C.C., Fakeye, A.M., Matawal, D.S. and Aitsebaomo, F.O. (2013). Road Pavement Failure: A Case Study of Enugu-Port Harcourt Expressway. *Proceedings of National Conference On Road Pavement Failure In Nigeria, Abuja, 7th–9th May 2013: Book of Abstract*. Pp 7-8.
30. Aitsebaomo, O. F., Matawal, D. S., Omange, G. N. and Osadebe, C. C. (2013). Digitised Subgrade Soils Map as a Tool for The Design, Construction and Maintenance of Nigerian Roads. *Proceedings Of National Conference on Road Pavement Failure in Nigeria, Abuja, 7th–9th May 2013: The Abstract.* Pp 10-11.
31. Uge, B. U. (2017). Performance, Problems and Remedial Measures for Roads Constructed on Expansive Soil in Ethiopia – A Review. *Civil and Environmental Research* www.iiste.org. ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online) Vol.9, No.5, 2017
32. Adeboje, A., Kupolati, W., Sadiku, E., Ndambuki, J., Kambole, C. and Ogunleye, O. (2017). Stabilization of lateritic soil with pulverized palm kernel shell (PPKS) for road construction. *African Journal of Science, Technology, Innovation and Development,* Vol. 9, No. 1. pp 55–60.
33. Sowemimo A.D. (2016). Structural Failure of Roads in Lagos, Nigeria. (Case Study Herbert Macaulay Road/Sabo to Moshalashi Bus-Stop). Pp 1-86.
34. Hendershort, W.H., Lalande, H., and Duquette, M., (1993). Soil reaction and exchangeable acidity, In: Soil sampling and methods of soil analysis, (Carter M.R., Ed.), Canadian Soc.Soil Sci. Lewis Publishers, London ,141-145.
35. Simon, A.B., Giesecke, J. and Bidlo, G. (1973). Use of lateritic soil for road construction in North Dahomey. *Engineering Geology* 7:197-218. https://doi.org/10.1016/0013-7952(73)90031-8.
36. Flaschka, H.A. (1964). EDTA Titrations: an introduction to theory and practice second edition. Pp 296.
37. Anderson, J.M. and Ingram, J.S.L. (1993). Tropical Soil Biology and Fertility*; A Handbook of Method of Analysis* 38-39.