Assessment of Soil Suitability for Subgrade Road Construction Using Atterberg Limits and California Bearing Ratio Tests: A Case Study Of Road Failure along the Warri–Sapele Highway, Nigeria"

Oko-Ose Onolunose Hannah[1], Chokor Joseph Utienyi[2], Oko-Ose Josephine Ngozi[3]
[1,1]Department of Soil Science Faculty of Agriculture, University of Benin, Edo State Nigeria
[2]Department of Nursing Sciences, Faculty of Allied Health Sciences, Benson Idahosa University Edo State Nigeria.

Abstract

This study evaluates the suitability of soils along the Warri–Sapele Highway in Nigeria for subgrade road construction using Atterberg Limits and California Bearing Ratio (CBR) tests. Road failure and premature deterioration in this region have raised concerns about subgrade material quality. Soil samples were collected from multiple locations along the highway and subjected to standard geotechnical tests. Results revealed that a significant portion of the soils fall below recommended thresholds for subgrade performance, with high plasticity indices and low CBR values indicating weak bearing capacity and poor stability under load. The findings underscore the critical role of proper subgrade evaluation in preventing road failures and guiding infrastructure development in similar geotechnical settings.

Keywords

Subgrade soil, Atterberg limits, California Bearing Ratio (CBR), Road failure, Warri–Sapele Highway

Introduction

The performance and durability of flexible pavements are heavily influenced by the engineering properties of the subgrade soil upon which they are constructed [1]. A well-designed pavement structure must be supported by a subgrade that possesses sufficient strength, stability, and resistance to deformation under traffic loads and environmental conditions. However, in many parts of Nigeria, particularly the Niger Delta region, road failures have become a persistent issue, with visible signs of pavement distress such as rutting, potholes, and alligator cracking occurring shortly after construction or rehabilitation [2].

The Warri–Sapele Highway in Delta State, Nigeria, is a critical transportation route that supports economic and social activities in the region. Despite its importance, the highway has been plagued by frequent and severe pavement failures, leading to increased vehicle operating costs, travel delays, and safety hazards [3]. Preliminary observations suggest that the subgrade soils along this corridor may be a major contributing factor to these failures, due to poor engineering characteristics that are unsuitable for road construction.

This study aims to assess the suitability of soils along the Warri–Sapele Highway for use as subgrade material. The evaluation is based on two key geotechnical tests: the Atterberg Limits, which provide insight into the soil's plasticity and behavior under moisture variation, and the California Bearing Ratio (CBR), which measures the soil's strength and bearing capacity. By systematically analyzing these properties, the study seeks to identify the subgrade-related causes of pavement deterioration and propose data-driven recommendations for road design and maintenance in similar geotechnical environments.

Importance of Subgrade in Pavement Design

The subgrade layer forms the foundation of any pavement structure and plays a critical role in distributing traffic loads to the underlying soil. Its strength, stability, and deformation characteristics directly influence pavement performance, service life, and maintenance frequency [4]. Weak or improperly classified subgrade soils often lead to premature pavement failure, including rutting, cracking, and surface undulations.

A well-prepared subgrade must exhibit sufficient California Bearing Ratio (CBR) and low plasticity to resist traffic-induced stresses and environmental effects such as moisture changes [5]. In regions with high rainfall and clay-rich soils, such as southern Nigeria, the risk of moisture-induced subgrade deterioration is particularly high.

Use of Atterberg Limits in Soil Evaluation

The Atterberg Limits — Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) — are standard geotechnical indicators used to assess the behavior of fine-grained soils under varying moisture conditions. High PI values suggest expansive clays with a high potential for shrink-swell behavior, which can severely affect subgrade performance [6].

Studies by Ola (1983) and Adebayo et al. (2012) have shown that Nigerian clays often exhibit PI values above 20%, rendering them unsuitable for direct use as subgrade materials without modification. These soils are prone to water retention, softening, and volume changes, leading to structural instability of overlying pavement layers [7].

California Bearing Ratio (CBR) and Subgrade Strength

The CBR test is widely used to evaluate the load-bearing capacity of subgrade soils. A CBR value of **8% or higher** is typically required for subgrade use in flexible pavement systems [8]. Low CBR values indicate weak soils that cannot adequately support the imposed loads, especially under wet conditions [9].

In tropical environments, soaked CBR values are more relevant due to high seasonal moisture content. Numerous studies, including those by Ijimdiya and Eberemu (2014), have reported CBR values below 5% in expansive clay regions, resulting in rapid pavement failure unless the soils are stabilized [10].

Soil Conditions and Road Failure in Nigeria

Road failures in Nigeria are often attributed to poor geotechnical practices, especially inadequate soil investigations and improper subgrade preparation [11]. The Niger Delta region, which includes the Warri–Sapele corridor, is characterized by soft, organic-rich clays and high water tables, creating challenges for road construction [12].

Previous case studies in nearby areas (e.g., Port Harcourt, Benin City) have linked pavement failures to the use of naturally occurring lateritic and clayey soils with low bearing capacities and poor drainage characteristics. This underscores the need for site-specific soil evaluations before construction [13].

Geotechnical Improvement Techniques

To address subgrade inadequacy, soil stabilization techniques such as lime, cement, or bitumen treatment have been widely recommended. Lime stabilization is especially effective in clay-rich soils, reducing plasticity and increasing CBR values significantly [14]. The adoption of geotextiles and improved drainage design has also shown positive results in enhancing pavement life in water-logged areas.

Materials and Methods

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 [15].

Parent Materials and Geological Formations

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

Vegetation

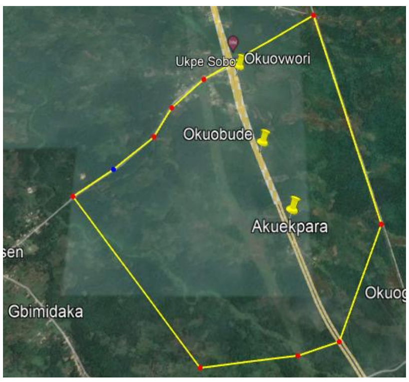

Figure 1: Location of project area

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 [16].

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) [17].

- 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 [18]**:**

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 [19].

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: [20]

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_2h	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)

ISSN PRINT 2319 1775 Online 2320 7876
 Journal UGC CARE Listed (Group-I) Volume 14, Iss 05 2025

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

ISSN PRINT 2319 1775 Online 2320 7876
 Journal UGC CARE Listed (Group-I) Volume 14, Iss 05 2025

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)

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)

Table 4: AASHTO Classification of Pedon 1 (Okuovwori – Sand, Clay and Swamp)

Pedon 1 (Okuovwori – Sand, Clay, and Swamp): According to Table 4, soils in Okuovwori consist mainly of silty or clayey gravel and sand, with some layers predominantly clayey. Subgrade quality ranges from poor to excellent. Group index values are between 0–1 cm, with group classifications from A-2-6 to A-6, and final classifications from A-2-6(0) to A-6(1).

Depth	Layer	Significant Constituent materials	General Ratings as Subgrade	Group Index	Group Classification	Final Classification
(cm)				(cm)		

ISSN PRINT 2319 1775 Online 2320 7876
Research Paper © 2012 IJFANS. All Rights Reserved, Journal UGC CARE Listed (Group-I) Volume 14, Iss 05 2025

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

Pedon 2 (Okolovu – Sand, Clay, and Swamp): As shown in Table 5, Okolovu soils vary from silty or clayey gravels and sands to more clay-dominant layers. Subgrade performance ranges

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)

from low to excellent. Group index values are between 0–3 cm. Classification ranges from A-3 to A-2-6, with final classifications from A-3(0) to A-2-6(0).

Table 6: AASHTO Classification of Pedon 3 (Akuekpara -Sand, Clay and Swamp)

Depth	Layer	Significant Constituent materials	General Ratings as Subgrade	Group Index	Group Classification	Final Classification
(cm)				(cm)		
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)

Pedon 3 (Akuekpara – Sand, Clay, and Swamp): Table 6 indicates that Akuekpara soils are predominantly silty across all layers. Subgrade quality is generally fair to poor. The group index is 0 cm, with both group and final classifications consistently 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 [21]. High PI indicates medium to high swelling potential, increasing the risk of road section failure due to high compressibility [22].

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[23].

Compaction

FMWH (1997) recommends Maximum Dry Density (MDD) values between 1.50–1.78 g/cm³ 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 [24]. Additionally, heavy-duty vehicle traffic may affect compaction rates, which were originally suited for low-volume traffic[25].

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

This study assessed the suitability of soils along the Warri–Sapele Highway for subgrade construction using Atterberg Limits and California Bearing Ratio (CBR) tests. The results revealed that:

- The majority of soil samples exhibited **high plasticity**, with Plasticity Index values exceeding recommended limits for stable subgrades.
- **Soaked CBR values ranged between 2.5% and 6.8%**, significantly below the acceptable minimum of 8% for subgrade layers in flexible pavement systems.
- Soil classification results, primarily A-7-5/A-7-6 (AASHTO) and CH/CL (USCS), confirmed that the soils are **poorly suited** for subgrade applications without modification.
- There was a **strong correlation between weak geotechnical properties and observed pavement distress**, particularly in segments showing surface deformation and pothole formation.

These findings suggest that subgrade failure is a major contributor to the structural deterioration of the Warri–Sapele Highway. The inadequacy of native soil materials in supporting vehicular loads, especially under wet conditions, underscores the need for more robust geotechnical evaluations in road design and rehabilitation projects.

Recommendations

Based on the study findings, the following recommendations are proposed:

1. **Soil Stabilization**: Weak subgrade soils should be stabilized using techniques such as lime or cement treatment to improve bearing capacity and reduce plasticity.
2. **Drainage Improvements**: Proper drainage systems should be incorporated to prevent moisture infiltration and reduce the risk of subgrade weakening due to water accumulation.
3. **Material Selection Guidelines**: Future road construction along similar geotechnical zones should follow strict soil suitability criteria, avoiding high-PI soils unless appropriately treated.
4. **Geotechnical Investigations**: Routine and detailed subgrade investigations should be mandated for all new road construction and rehabilitation projects in the Niger Delta region.
5. **Monitoring and Maintenance**: Implementation of a proactive road condition monitoring program will help identify early signs of pavement distress and allow timely intervention.

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).

.