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Geophysical and geotechnical assessment of Obiaruku-Agbor road failure in Western Niger-Delta, Nigeria

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Abstract

Geophysical and geotechnical survey was conducted along the Obiaruku-Agbor Expressway in Delta State, Nigeria to determine the causes of its deterioration. The study used a 2D electrical resistivity approach using the ABEM SAS 1000 Terrameter and yielded subsurface resistivity values ranging from 5.12 Ωm to 4418 Ωm. The geo-electric resistivity result showed that the soil types range from clay to fine sand, with low-resistivity soil indicating inadequate building materials. The findings show that A-2 and A-7 soil types are the most common types. The soils from the stable sections have a higher specific gravity (2.59-2.89) and a smaller amount of clay (16.9 %) than the soils from the failed portions of A-7-6 which suggests substandard sub-grade materials. These soils correspond to A-2-6 on the AASHTO classification system. The bulk of soils from failed sections had significant values of linear shrinkage (> 8%) and a large proportion of fine particles (> 40%) resulting in loss of soil index strength. The majority of fines particles in lateritic soils, low California bearing ratio (08-63% un-soaked), intermediate/high OMC above guideline for most soil samples (07.4-20.1), maximum dry density (MDD) (< 2000 kg/m^3), and liquid limit (20.9-58.7) are the causes of the observed degree of instability. The main causes of road collapse were thin pavement, inadequate drainage, low-quality infill and incompetent clayey materials. Well-designed drainage system and soil stabilization are recommended. The study's findings will aid in repairing and rehabilitating the deteriorating sections of the road.

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1. Introduction

In Nigeria, choices about the design and building of roads are made without taking the geology and geotechnical behavior of the underlying soils into account. These have led to issues with roads and highways. The relationship between foundation soils and highway pavements is critical for any nation hoping to prosper. The resulting engineering soils in every situation are greatly influenced by the geological past of each locality [1, 2]. Despite continuous rehabilitation and reconstruction of the failing sections along the Obiaruku-Agbor road, pavement degradation emerges immediately after repairs. Every engineering structure is either built on rock or soil, and the soil's characteristics have an impact on the structure's functionality. The goal of engineering structures is to last over time, no matter where in the world they are constructed.

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Unfortunately, utilizing soils in civil engineering building projects requires a complete understanding of their geotechnical properties, which is currently lacking. A nation's ability to develop socioeconomically depends on its road system. Nigeria is one of the countries with the highest incidence of traffic accidents, frequently resulting in fatalities and property damage due to poor road conditions [3, 4]. Due to extensive and prolonged weathering of the source rock beneath them for sand variations, lateritic soils which are rich in iron and aluminum and are the most common surface deposits in the southern areas of Nigeria [5]. The only place where laterites and other subsoils can be used as the perfect soil material to solve any problem related to construction is in Nigeria. This includes building roads, embankments, earth dams, airfields, and foundation materials for supporting structures without considering the geotechnical performance of the soil in the field or whether it is classified as a problem or non-problem type. Issue sub-soils are laterites and subgrades that have characteristics that make building roads difficult. Even with light wheel loads, certain soil types when used as sub-base materials cause pavement to swell, sink, and move laterally when there is water present. When it comes to highway pavement and aircraft, these soil types are easily recognized. Their friable structure, high natural water contents, low natural densities, and liquid limits [4].

Therefore, soil materials (laterite, base, and subgrade) without these qualities are not problematic types. Lateritic soil is used to build roads in tropical places of the world, like Nigeria. It functions as the sub-grade for low-cost routes that usually experience little to moderate traffic as well as the base course, sub-base, and sub-grade for the majority of tropical roadways. They are also used as construction materials for brick molding and plastering. On Nigerian highways, failures are usually the result of insufficient geotechnical properties of the underlying soils that comprise the entire road surface. In their study, Ref. [6] examined the factors influencing pavement performance. These elements include a range of road failure types, including potholes, ruts, fractures, and road-cutting that causes the pavement to heave differently. Ref. [7] stated that over comparatively short distances, there may be a significant difference in the geotechnical characteristics of the soils. Ref. [8] looked into the geological basis for some of the failures in Nigeria's western Niger Delta. He concluded that as the soils beneath the failing components are not mechanically stable, extra stabilization is required. If there is a considerable concentration of clay element present, lateritic soil stability, strength, and integrity cannot be assured when water is present.Geotechnical properties of soil, such as specific gravity, grain size distribution, plasticity, compressibility, soil compaction, California bearing ratio, and so on, dictate how the soil responds to loads [9, 10]. These characteristics can be evaluated by the right laboratory. The failure of lateritic roads in Nigeria and other developing countries has brought attention to the necessity of conducting a comprehensive geotechnical examination of lateritic soil before using it for road building. In order to choose the appropriate soil materials for the pavement structure, this is required. The goal of this study is to identify the underlying causes of the Obiaruku-Agbor road's persistent failure soon after reconstruction and restoration. Consequently, it is necessary to remove and replace the unstable soil components that cause the continually failure.

2. Materials and methods

2.1. Location and study area geology

The Niger-Delta basin, which is the southwest corner of Nigeria, is home to the Obiaruku-Agbor study area. Figure 1 illustrates its location, which is confined to falls between latitudes 5.821°N and 6.27°N and longitudes 6.13°E and 6.21°E.

The study region is an oil-producing town in addition to having numerous wells and related pipelines for the purpose of exporting crude oil through the gorgeous bonny terminal. Since then, the town's industrial and agricultural operations in Delta State which include fish, tree, and rubber plantations have led to a sharp increase in population. These activities provide an explanation for the sharp increase in population during the past ten years. The area experiences two distinct seasons in its equatorial climate: the overcast, rainy season lasts from April to September. October to March is the bitterly hot and partly overcast dry season.

The Warri Portharcourt highway, the Sapele-Benin expressway, the Amukpe-Asaba road, and the path leading to Anambra, the biggest market in sub-Saharan Africa, are just a few of the roadways that link the region. The oil-rich Niger Delta region of Nigeria is home to the research area. Over the late Cretaceous to Eocene, the region changed as the continental crust collapsed over the marine crust. It is well known that the enormous drainage basins of the Niger and Benue, Nigeria's two principal rivers, contributed significantly to the region's faulting and silt accumulation. Consequently, the region progressively sloped upward, focusing the supplied sediments into an arcuate depobelt. Five depobelts have been identified in the Niger Delta: According to Ref. [9], there are five depobelts in the Niger Delta: the Northern Delta, Great Ughelli, Central Swamp, Coastal Swamp, and Offshore depobelts.

Three vertical lithostratigraphic subdivisions may be seen in the sedimentary basin of the Western Niger Delta: the lower pro-delta lithofacies, middle delta front lithofacies, and upper delta top facies. The Benin, Agbada, and Akata Formations are the three primary Formations that make up these units, which are well-discussed by Refs. [2, 10] (Figure 2). About 2000 meters thick, the Benin Formation is composed of unconsolidated sand, gravel, and sporadic shale intercalation [2, 5]. It is the formation in the western Niger Delta that contains freshwater. The quaternary, recent sediment known as Somebreiro-Warri Deltaic plain sand overlies the Benin Formation in the western Niger Delta. It is approximately 120 m thick [11], and it forms the beach sand sediments that border the Atlantic Ocean and the Forcados estuary. The aquifer media is composed of clays, sand, swamps, and gravel (Figure 2). The Agbada Formation, which ages from Eocene to Oligocene, is an oil-bearing formation with a thickness of approximately 3000 m and is composed of intercalation of sand and shales. The Akata Formation is the basal units of the Niger Delta sedimentary basin and overlies the basement complex region.

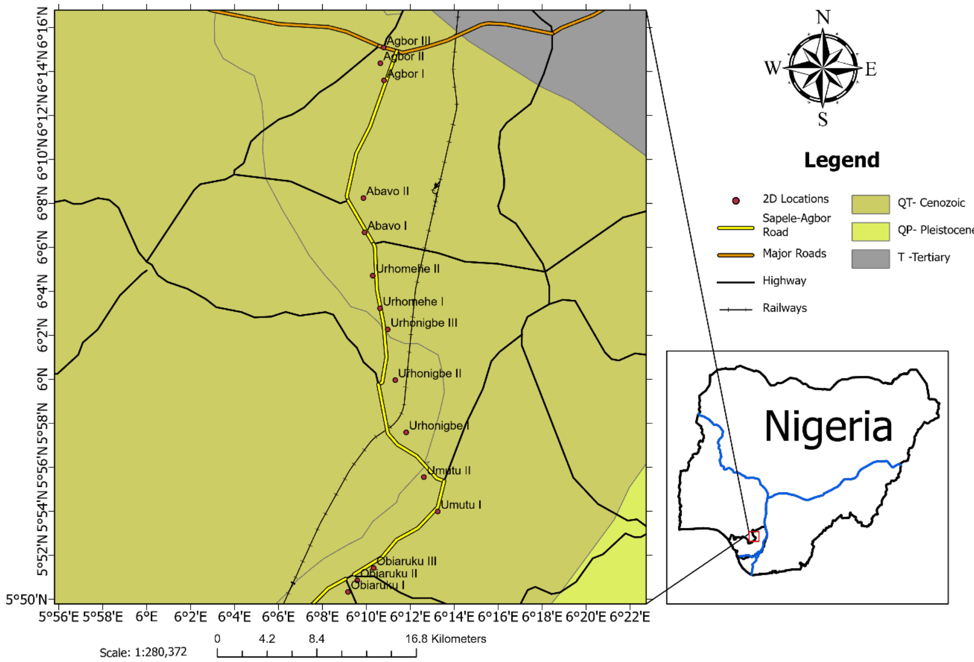

Figure 1: Map of Delta state showing Obiaruku-Agbor express road.

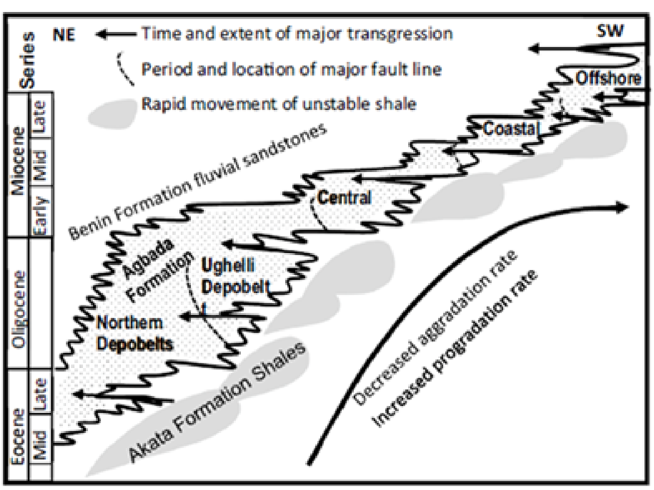

Figure 2: Niger-Delta stratigraphy [11].

It is composed of highly pressurized open marine facies and spans the Eocene to Oligocene epochs [2, 11]. It is roughly 6000 meters thick and mostly composed of shales; it is recognized as the source rock for hydrocarbon generation in the Niger Delta region [12]. The geology of Niger-Delta has been thoroughly described by Refs. [2, 9, 13–18].

2.2. *Amplified Wenner survey*

The amplified wenner survey was carried out using four metallic electrodes which were symmetrically placed along unbent (straight) line. The potential electrodes were placed on the insides and current electrodes positioned outside and both current and potential electrodes with constant spacing. The electrodes were then moved along a profile and progressively advancing the entire spread. A minimum of one person handled each electrode and its associated cable, while an additional person managed the recording equipment, making a team of five. For the purpose of gathering data, the electrode spread (Amplified Wenner array configuration) covered a length of 140 m for each profile with electrode spacing of 5 m, 10 m, and 15 m. During the fieldwork, the ABEM Terrameter SAS 1000 was also utilized. Specifically, electrodes 0, 5, 10, and 15 were utilized for the first measurement inset up order of C_1, P_1, P_2, and C_2 accordingly. The electrodes (C_1, P_1, P_2, and C_2) were positioned symmetrically at equal intervals of $a = 7.5$ m. The electrodes to be checked (measured) for the second measurement are 5, 10, 15, 20, and C_1, P_1, P_2, and C_2 in the respective order, as depicted in Figure 3. The measurement process otherwise follows the usual pattern. These patterns were applied to the electrode positions 75, 90, 105, and 120 in a manner consistent with the preceding measurement. Nevertheless, the next phase for 2a, 3a, 4a, 5a, 6a, 7a, 8a, 9a, and 10a follows the same pattern and process as the first step after the measurement is taken at a = 7.5.

A high-resolution two-dimensional image of the earth's surface was created using the amplified Wenner geo-electrical arrangement. The obtained numbers are utilized to obtain a qualitative analysis of the profiles. The goal of the shallow depth of 7.5 m electrode spacing for near substructure resistivity differences is to investigate the change in the electrical characteristics of the profile subsurface under examination at the lateral depth. Its usefulness for vertical absolute changes in the subsurface resistivity beneath the array center was characterized by widening (increasing) the amplified Wenner array separation (spacing) to 12.5 m, 22.5 m, 17.5 m, 25.0 m, 32.5 m, 37.5 m, 45.0 m, 52.5 m, 60.0 m, 67.5 m, 75.0 m, 77.5 m, 85 m, 92.5 m, 82.5 m, 90.0 m,

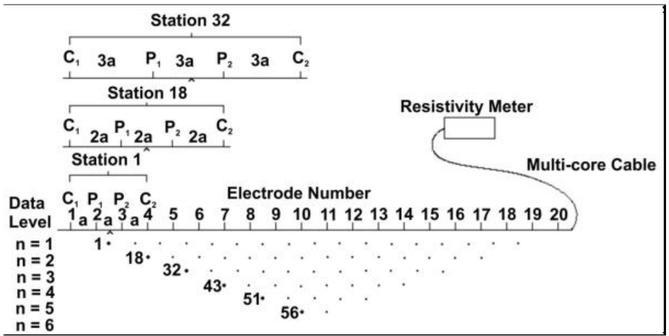

Figure 3: Electrodes sketch for two dimensional (2D) Electrical Resistivity [19].

and 97.5 m.The resistivity raw field data were analyzed utilizing RES2DINV computer software which independently gives the 2D approximate resistivity image of the earth subsurface characteristics for the data gathered (collected) from the subsurface (underlying) electrical survey.This process yields apparent resistivity values that rely on measurable voltages (V) in response to subsurface variability in vertical conductivity. According to Ref. [20], this array often offers excellent and accurate signal-to-noise ratios, high (excellent) horizontal layer image quality, and decent depth sensitivity when utilizing the software.

2.3. Geotechnical survey

Comprehensive geological field mapping is part of this research project, which aims to determine the local geology of the area and identify stable and failing areas of the route under study. The rock and soil exposures on the field were noted and documented. Nine trial pits yielded thirty-six bulk samples of the soils. At sampling depths of 0.2 m to 2.1 m, twenty-four samples from six failed sections and twelve obtained samples from three stable portions of the road acting as a control were collected. This allowed for the acquisition of real representative samples of the fillings,materials that are subgrade and subbase. Before being transported to the lab in sealed polythene bags to avoid contamination and moisture loss, each soil sample was meticulously labeled in sample bags. In the lab, the natural moisture content was ascertained right away. Prior to further investigation, soil samples were allowed to air dry for two weeks in order to partially remove natural water. Following drying, the samples' lumps were carefully ground under light pressure so as not to decrease the size of the individual particles. The materials were subjected to natural moisturecontent (amount), specific gravity, atterberg (consistency) limits, linear shrinkage, compaction, grain size distribution, and the ratio of California bearings tests in the laboratory. The British Standard Methods of Testing Soils for the use of civil engineering [21, 22] were followed in the execution of these laboratory investigations. Grain size analysis samples were immersed in a mild calgon solution to aid in the disintegration process during wet sifting.

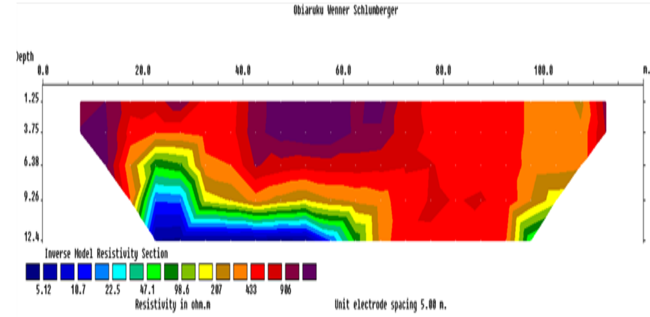

Figure 4: 2D Geoelectric earth model at Obiaruku.

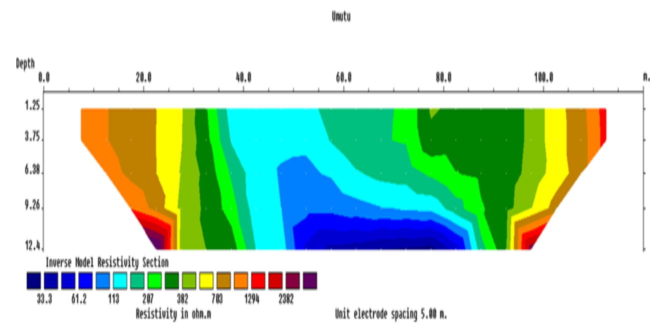

Figure 5: 2D inversion arrangement caption at Umutu.

3. Results and discussion

3.1. Wenner-Schlumberger (amplified Wenner) array

The results of the geoelectric (enhanced Wenner) survey covering various lateral locations of the faulted sections along the Sapele-Agbor road are shown in Figures 4-10. The data was collected to automatically create an electrical resistivity image of the Earth's subsurface from two-dimensional (2-D) resistivity models.

The inverse representation of the resistance areas along the Obiaruku trend is shown in Figure 4. The resistivity measures 320 Ωm to 1379 Ωm at a depth of 7.5 m to 116 m and extends to 12.4 m below the surface. The entire profile section has been explained. This suggests the presence of a fine-coarse sand formation, except for an extent of 20.0 m to 60.0 m, and a limited clay formation with a thickness of about 4 m and comparatively small resistivity values (trends) ranging between 5, 12 Ωm and 207 Ωm vary. This was found under a stable section of road, but the results indicate that the road is likely to fail before reaching its design age.

The resistivity sections along Umutu's profile are visible in Figure 5's inverse model. At a depth of 12.4 meters below the Umutu surface, it displays a resistivity range of 33.3 Ωm to 382 Ωm. The existence (occurrence) of clay, loamy sand, and sandy loam structures in the zone for the faulted Umutu Strait subsections is the conclusion. Both intermediate and stable zones with resistivity values up to one along the sketched profile vertical depth of approximately 13 m from 207 Ωm to 3470 Ωm from the outer surface are found within this zone, which varies in width from 7.0 m to 35 m and in length from 75 m to 117 m

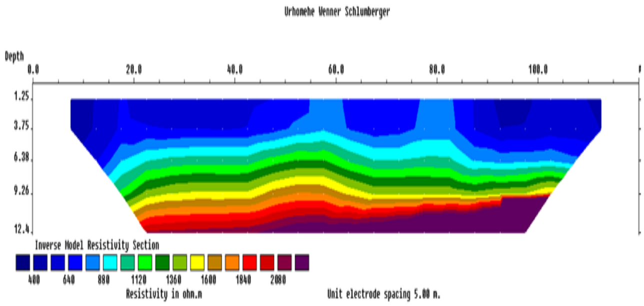

Figure 6: 2D inversion at Urhomehe.

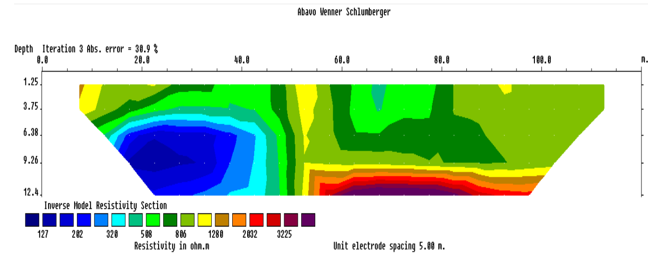

Figure 8: Abavo2D inversion Result.

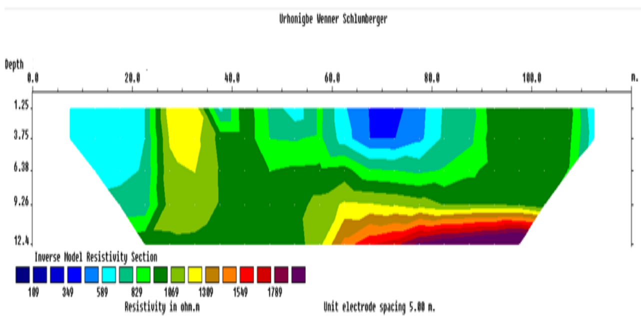

Figure 7: Result of 2D model photo at Urhonigbe.

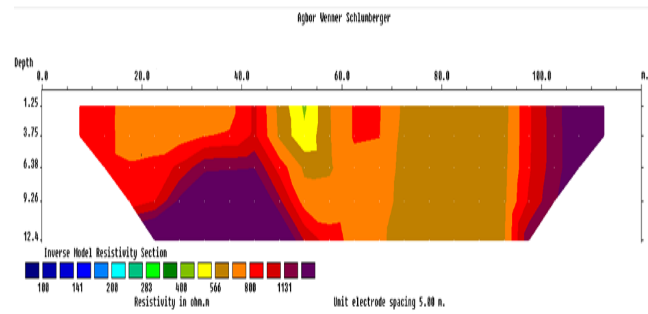

Figure 9: Pictorial Result of 2D inversion at Agbor profile 1.

across the profile. This formation is categorized as a sand settlement; Figure 5's resistivity section illustrates this formation with color bands in the shades of green, red, and purple.

The sections of the Urhomehe profile with inverse model resistivity are explained in Figure 6. From the surface to a depth of 6.77 meters, which is interpreted as sand formation, it transmits a uniform resistivity value changing from 400 Ωm to 880 Ωm across all sections of the road. Resistivity values rise to 2280 Ωm at a vertical depth of approximately 13 m in the profile, indicating the presence of fine, medium, and coarse sand settlements in the region. As a result, inadequate drainage and heavy traffic on thin building materials could cause the road to collapse.

The resistivity sections along the Urhonigbe profile are revealed by the inverse model, as seen in Figure 7. A significant portion of the cross profile can be described by the resistivity value within the range of 709 Ωm to 1309 Ωm, spanning from 7.5 m to 62 m wide distribution and reaching a width of 12.4 m from the Urhonigbe surface. On the stable sections of the road, this shows sand features (formation). A resistivity region spanning from the examined surface to a depth of 3.75 meters lies within this unit, with values between 229 and 589 Ωm. This suggests the formation of sand as well as sandy clay. Because sandy clay formation is present, excessive pressure from heavy-duty vehicles passing over the road can cause ruts, depressions, and other road failures. Rather than being present in the building process, the sandy clay materials were supplied. This section failed because the materials used to construct the road were not transported consistently. Some of the materials contained clay, which increased in volume and prevented the fluid from passing through, causing the asphalt to crack and form holes in the road (road failure). As the depth increased with a range of 590 Ωm to 2029 Ωm, a busy profile spread from 78.5 m to 114 m to 12.5 m depth was found with increasing resistivity metrics values. This explains the fine, medium, and coarse sand formation's delineation by the submaterials' extremely high resistivity.

Figure 8 is an inversion image model showing resistivity ribbon sections along the Abavo shape profile. At 7.5 m to 45 m along its profile, which runs from the surface down to 8 m depth, the resistivity index is characterized by values varying between 320 Ωm and 2032 Ωm and is a form of sand. Below these visible lateral distances are clay settlements with low resistivity coefficients of 127 Ωm to 202 Ωm and a thickness of about 12 m from 8 m depth. Therefore, this clay formation has the tendency to degrade the road and reduce its quality, preventing it from reaching its structural age (road failure). The resistivity changes from 508 Ωm to 1280 Ωm with sand formation along the span between 45 and 115 meters, starting at 10.26 meters below the surface.

Below this is a deposit of light, medium to large coarse sand observed at a specific depth of 3 m (9.26 m - 12.4 m) along the line with high resistivity ranges from 1656 Ωm to 4418 Ωm, and it is a formation of sand deposits. These clayey materials located on the subgrade or substructure can cause serious road failure as they do not support a stable road.

Figure 9 is a representation of the model depicting the studied resistivity sections along Agbor Stable Profile 1. A colossal (large) extent of the interval is identified with a resistivity difference between 341.5 Ωm and 1600 Ωm from 7.45 m to 105

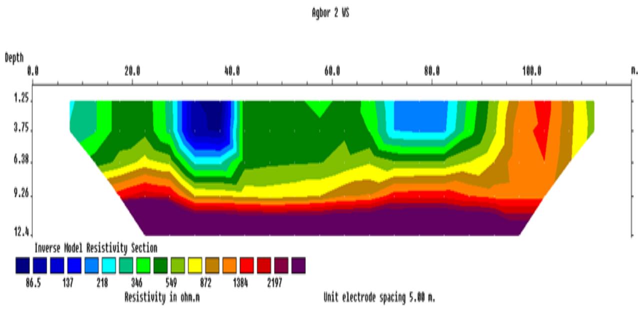

Figure 10: 2D inversion outcomes at Agbor profile 2.

m extent and to 7.38 m depth near the surface. This leads to a sand structure (formation). Within this declared formation is a domain (zone) of higher resistivity, extending from 683 Ωm to 965.5 Ωm in an apparent spread of 55 m to 100 m through the profile to a dimensional depth of 12.4 m from the Agbor interface changes. This also suggests the sand composition (subformation). In this stable zone there is a medium and coarse sand categorization (composition) with a moderate resistivity value of 1131 Ωm to 1600 Ωm at a transverse distance of 18 m to 50 m from the measured depth of 6.22 to 12.4 m and also at a depth from 92.5 m to 112.5 m included. The lateral length implies the presence of fine to coarse sand with a thickness of 12.39 m on the band surface with varying resistivity metrics from 800 Ωm to 1600 Ωm.

Figure 10 explains profile 2 of Agbor model units pointing out resistivity section values in order of 346 Ωm to 2197 Ωm from the profile 2 surfaces up to 8.36 m depth from 7.49 m to 114.9 m transverse stretch obtainable in the profile. This suggests sand establishment on the stable zones. Supported within this formation are two clearly outlined (marked) failed sections of the road with identifiable low resistivity numerical values and lateral pictured distances varying from 86.5 Ωm – 137 Ωm, 218 Ωm – 282 Ωm; 30.0 m – 40.0 m, 70.0 m – 85.0, to a depth of 5.48 m and 3.75 m respectively when measured from the surface. It was noted that there was clay intermingled in some areas. Beneath this lies a zone of high resistivity extending from 549 Ωm to 3010 Ωm at a depth of 6.18 m to 12.4 m. The sand formation is distributed over the profile from 7.5 m to 115.0 m. Low compressibility and sufficient strength from a solid foundation are key components of satisfactory pavement performance. In order to transfer loads evenly and effectively, pavement constructions rely on the physical and technical characteristics of the base and subgrade layers beneath them.

3.2. Index characteristics

Table 1 presents the results of the index tests that were run on the soil samples, which are important variables to consider when calculating soil engineering.

3.3. Natural moisture content

Natural moisture content in the examined soil samples from the highway's failing parts varied from 12.3 to 22.5% (Table 1), while it varied between 7.98 and 18.3% in the samples from the stable sections. These findings show that the soils from the failed areas have a high natural moisture content since they are higher than the FMWH, 2000 average range of 5–15% for engineered building. This implies a high water-absorbing capability of the soil composition. However, the performance of lateritic soil may be affected by the temperature, topography, and hydrology of the area where the road is to be developed [3, 4]. Different factors contribute to the natural moisture content fluctuations found in the soils within the studied regions. Natural moisture content is used as a proxy for soil shear strength since the shear strength of the material decreases with an increase in moisture content.

3.4. Specific gravity

The specific gravities of the soils ranged from 1.68 to 2.89, as Table 1 illustrates. Subgrade material is categorized by the American Association of State Highways and Transport Officials (AASHTO) as good to fair (category A-2-6). It is clear that soils from stable areas contain less clay (21.8%) and have higher specific gravities (Gs = 2.59 – 2.89). Based on this specific gravity, the examined soils can be classified as inorganic clayey soils (Ramamurthy and Sitharam, 2005). Specific gravity is calculated by dividing the weight of that particular soil by the weight of an equivalent volume of water. It indicates a dry, saturated state of the surface. The quantity of voids and quartz-like particles in the soil also plays a role. The majority of clay minerals have specific gravities that fall between 1.6 and 2.9, according to [3]. A rise in specific gravity causes a corresponding increase in soil laterization. This implies that soils from stable sections have a higher laterization than soils from sections that failed. The results show that the soils in the stable sections are mainly composed of quartz material, while the soils in the failing sections are montmorillonitic.

3.5. Particle size distribution

A summary of the results from the investigation of the grain size distribution is given in Table 1. In Figure 11, a sample grading curve is displayed. The proportion of soil in the stable sections is 16.9% to 21.8%, but the percentage in the failing areas that pass No. 200 (0.075 mm) ranges from 34.7% to 51.4%. The soils can shrink repeatedly as well-graded soils based to the grading curves. It is possible to see the high amount of particles (>50%) in the portions of failing soils (F1, F4, F5, and F6). This shows that in the humid tropical environment of southwest Nigeria, the earth's soil surfaces tend to repeatedly shrink and increase over the alternative seasons, both rainy and dry, generating significant hardship on the road.

The failures observed in the study region are believed to be caused by forces generated by the expanding soils. Furthermore, the high clay concentration of the soils from the collapsed sections suggests that they have a substantial tendency to swell, making them unsuitable for use as sub-grade material. Ref. [3] reported that the tested soils of the stable portions S1 have percentages passing 0.075 mm of 36% with an average of 36.3%, but the sections of the stable soils labeled S2 and S3 have percentages passing 0.075 mm of less than 35% with an average of

Table 1: Soil grains index properties of the studied area.

Road status	Pit count	Depth (m)	Natural moisture content (NMC)	Specific density (GS) variation	Grain distribution		AASHTO Grouping
					Clay sizes (%)	Fines (%)	
Failed	F1	0.2-2.1	13.8-18.2	2.32-2.56	34.7	52.1	A-7-6
Failed	F2	0.2-2.1	14.3-19.2	1.89-2.72	51.4	49.2	A-7-6
Failed	F3	0.2-2.1	12.3-17.6	1.68-2.42	41.3	49.9	A-7-6
Failed	F4	0.2-2.1	12.9-22.5	2.04-2.56	37.8	51.5	A-7-6
Failed	F5	0.2-2.1	15.2-20.9	1.69-2.33	45.8	50.3	A-7-6
Failed	F6	0.2-2.1	13.7-21.5	1.72-2.54	39.4	51.9	A-7-6
Stable	S1	0.2-2.1	11.3-18.3	2.68-2.79	21.8	36.3	A-2-6
Stable	S2	0.2-2.1	9.68-13.4	2.59-2.81	17.2	33.6	A-2-6
Stable	S3	0.2-2.1	7.98-12.8	2.81-2.89	16.9	29.7	A-2-6

Table 2: Atterberg limits of the investigated soils.

Pit Count (Number)	Liquid limit range (%)	Plasticity index range (%)	Linear shrinkage
F1	36.3-45.3	12.6-19.8	13.2-16.4
F2	41.0-44.3	14.9-23.7	10.8-14.3
F3	42.3-57.2	16.9-20.9	09.8-17.2
F4	45.0-58.7	09.9-17.8	11.8-18.6
F5	38.2-53.6	15.2-28.2	07.1-15.7
F6	43.8-50.6	13.9-27.6	10.2-19.2
S1	23.5-34.5	10.3-14.9	06.9-11.7
S2	20.9-38.7	08.2-13.0	07.3-10.6
S3	25.3-35.9	08.3-11.5	08.1-12.4

32% value. The sub-grade highway material for these soils is often categorized as acceptable to good. For the failing's soils sections, AASHTO categorization group A-7-6 denotes inadequate material with fines ranging from 49 to 52% (Table 1). The frequency of penalties can be used to explain the degree (extent) of instability that has been detected.

3.6. Atterberg limits

An overview of the results of the linear shrinkage test, the plasticity index, and the water (liquid) limit is given in Table 2. In contrast to stable soil sections, which had values ranging from 21 to 39%, 8 to 15%, and 7 to 12%, respectively, the failing portions soils had liquid limits, plasticity indices, and linear shrinkages ranging from 36 to 59%, 10 to 28%, and 7 to 19%, respectively. According to Refs. [4, 22], liquid limit values between 35% and 50% indicate intermediate plasticity, strong plasticity if they are between 50% and 70%, and very high plasticity if they are 70% to 90%. Since all soils are categorized as somewhat plastic, they all show noticeable deformation under load. The results showed that the soils from the unsuccessful sections are not acceptable as base material or subgrade for pavement structure foundations due to their low geotechnical properties. The plasticity index frequently has a significant impact on the activity of the subgrade soils. Linear shrinkage in the failing soil section ranged from 7.0% to 19.0%. The soil in southwest Nigeria's humid tropical climate is prone to swelling and shrinking during the region's seasons, making it unsuitable for use as a foundation or highway due to its value exceeding the maximum 8% recommended by Ref. [23]. When creating the foundation of the pavement structure, the engineers must take this into account. The linear shrinkage soil values in the stable sections varied considerably above the necessary value for some subsurface material.Compared to the soil combinations identified in the stable areas, the fine soil mixtures of the failed portions comprised clay with higher plasticity index and linear shrinkage values. Because of reduced linear shrinkage, there is typically less tendency for soil to shrink after drying, according to Refs. [3, 24]. As a result, this study shows that stabilization remains a viable alternative for modifying the soils to satisfy the necessary requirements.

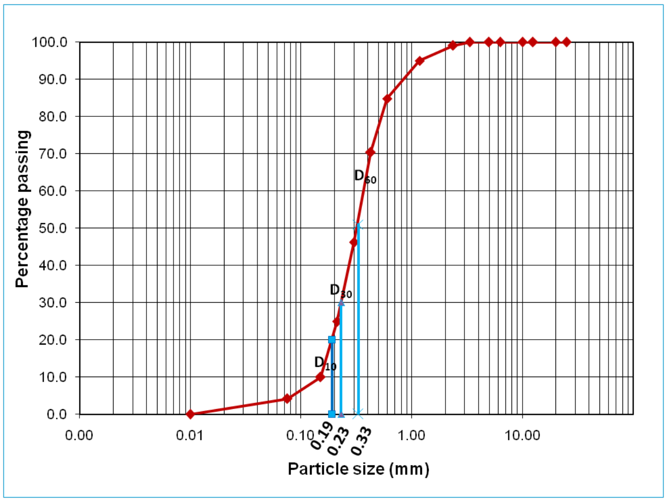

Figure 11: Particle (grain) texture distribution curve for soil sample acquired from failed section (F5).

3.7. Compaction features

In order to avoid damaging collapse under the weight of traffic or an embankment, soils for roadways must be crushed

Table 3: Strength behaviors of the investigated soils.

Pit Count	OMC range (%)	MDD (Kg/m^3)	CBR
F1 Obiaruku	10.6-19.9	1862-2118	16-34
F2 Umutu	14.4-20.1	1609-2018	08-36
F3 Urhomehe	11.7-12.5	1978-1963	16-42
F4 Urhonigbe	09.8-14.1	1829-2105	20-43
F5 Abavo	11.1-19.5	1842-2113	19-27
F6 Agbor	12.5-21.4	1703-2022	18-25
S1 Umutu	07.4-11.2	2152-2215	29-61
S2 Urhonigbe	08.8-10.4	2014-2187	40-63
S3 Agbor	08.1-14.0	2019-2316	45-53

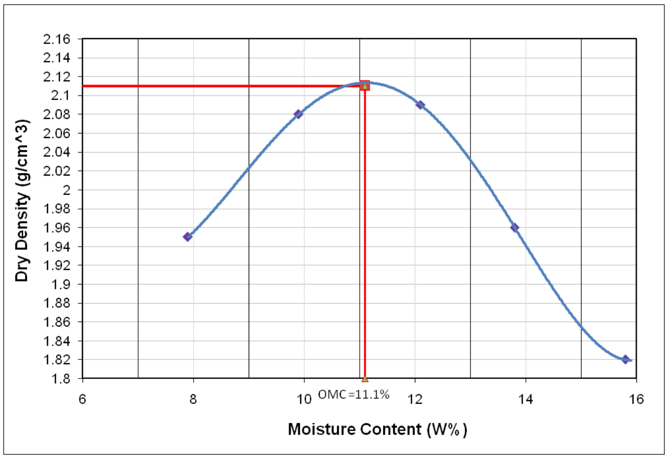

Figure 12: Compaction characteristic soil sample curve produced from Abavo failed section (F5).

(compacted) to a high-density during construction. Compaction also mitigates the adverse effects of water. Table 3 reports the optimal moisture content (OMC) and maximum (peak) dry density (MDD) of lateritic soils at the West African compaction level, and Figure 12 shows a typical compaction curve. While the soils from the stable parts had MDD ranging from 2014 to 2316 kg/m^3 at 7.4 to 14.0% (OMC), the soils from the failing roadway portions had MDD ranging from 1703 to 2118 kg/m^3 at OMC of 09.8 to 21.4% (Table 3). These numbers show how the soils cope with compaction progressively. Conversely, the best soil for a foundation is one with a high MDD and a low OMC [4, 7]. Compaction's primary objective is to increase the intended load bearing capacity of pavement projects. Road pavement and civil engineer-designed buildings are breaking down more frequently as a result of the underlying soils becoming saturated with water over time. The results show that the foundations of those constructions must always be compacted above the MDD (> 2000 Kg/m^3) and OMC ($\leq$ 8) in order to produce maximum strength, prevent water infiltration, and evenly distribute wheel loads throughout the pavement structures.

3.8. The CBR or California Bearing Ratio

When infill, subgrading, subbasing, and base course materials are utilized in the design of highways and airfields (landing fields), the soil strength is determined using a test known as the California Bearing Ratio. The un-soaked CBR values of the soils in the failed areas ranged from 8% to 43%, as shown in Figure 13 and Table 3. The CBR states that sub-grade soils in failed areas may change in volume if they are subjected to excessive rainfall. The un-soaked CBR values of samples from stable sections were found to be higher (29% to 63%) than those from failed sections. For highway sub-base and sub-grade soils, FMWH (2000) recommends an 80% lowest un-soaking CBR level, which is absent from all of the tested samples. Actions to enhance the soil are required since the CBR values in the research area are inadequate.

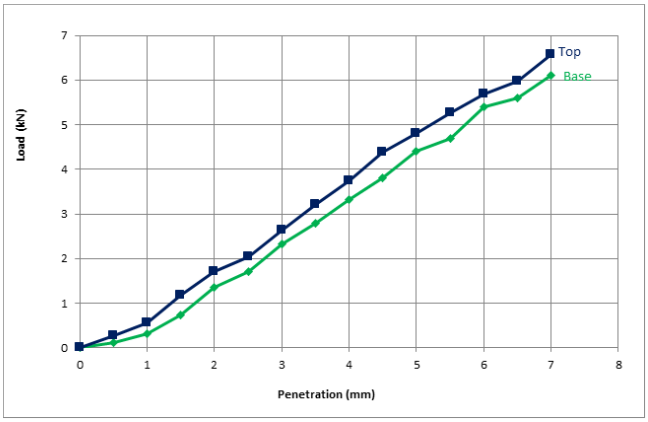

Figure 13: CBR sketch of Abavo failed section (F5).

4. Conclusion

The majority of the soils in the western Niger Delta of Nigeria, both above and below the surface, are clayey soils with low resistivity values of less than 63Ωm, according to the findings of geophysical and geotechnical investigations conducted along the Obiaruku-Agbor express route. The low specific gravity, high liquid limits, and low CBR in certain profiles, which indicated material incompetence, clearly demonstrate this truth. Through engineering property testing, lateritic and sub-grade soils which are typically encountered during the filling of Nigeria's Niger Delta were investigated. The samples are frequently well graded and exhibit low, moderate (medium), and high plasticity, which may be a sign of significant compressibility. The naturally occurring moisture content of the studied soil samples from the unsuccessful locations suggests that the soil composition has a considerable capacity for water adsorption. In order to prevent the development of pore water pressures beneath pavement structures, which could result in a significant loss of strength, it is imperative that the area have adequate drainage systems. Soils from stable sections have a higher specific gravity, indicating a higher degree of laterization, or stability, than soils from stumbled (failed) parts.

The study's conclusions will be useful in rebuilding the route's failed sections and could influence pavement design for new road construction. The AASHTO classification system places the failed soils portions in group A-7-6, indicating substandard materials for the roadway sub-grade. The percentage of soil strength lost after soaking the compacted samples shows how much the sub-grade and sub-base soils have been weakened by water interaction. The degree (level) of inconsistency and instability seen can be attributed to the low MDD and CBR values strength features in addition to the dominance of clayey particles in lateritic soils. Stabilization, however, will increase the robustness of stable structures.

Data availability

We do not have any research data outside the submitted manuscript file.

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