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Stabilization of Lateritic Soil from Iyamho (Edo State, Nigeria) with SP430 Superplasticizer: A Geotechnical Performance Study

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K E Y W O R D S

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A B S T R A C T

Lateritic soils, prevalent in tropical regions like Nigeria, are widely used in civil engineering applications such as road subgrades, embankments, and foundations due to their abundance and favorable natural properties. However, their variable geotechnical characteristics, influenced by local geological and hydrological conditions, necessitate site-specific studies to ensure reliable performance. This study investigates the geotechnical performance of lateritic soil from Iyamho, Edo State, Nigeria, stabilised with SP430 superplasticiser, a sulphonated naphthalene formaldehyde-based admixture. Five key geotechnical tests specific gravity, sieve analysis, Atterberg limits, standard Proctor compaction, and California Bearing Ratio (CBR) were conducted on both untreated and stabilized soil samples with SP430 dosages of 2.5%, 5.0%, and 7.5%, following British Standards (BS 1377 and BS 1924). The untreated soil exhibited a specific gravity of 2.55, indicative of iron-rich lateritic composition, and a well-graded particle size distribution with 48.56% fines, suggesting moderate plasticity and compaction potential. Stabilization with SP430 increased specific gravity to 2.78 at 7.5% dosage, reduced the plasticity index from 5.19% to 1.30% at 5.0% dosage, and improved maximum dry density from 1.90 Mg/m³ to 1.95 Mg/m³ while lowering optimum moisture content from 13.25% to 10.26%. However, CBR values decreased to 2.05% at 2.5% SP430, then increased to 5.65% at 7.5%, remaining below the untreated value of 12.50% and the 30% threshold for high-traffic pavement applications. This indicates limited suitability as a standalone stabilizer without supplementary stabilization. These findings suggest that SP430 enhances soil density, reduces plasticity, and improves compaction efficiency, but its efficacy for high-load applications is limited. The study provides a baseline for optimizing stabilization strategies for Iyamho lateritic soil, recommending combined use with pozzolanic materials for enhanced performance in demanding infrastructure projects.

1. INTRODUCTION

Lateritic soils, which are abundant in tropical areas like Nigeria, are created by the severe weathering of parent rocks, resulting in a high concentration of iron and aluminum oxides (Tang et al., 2022). Silica and bases are frequently leached during this protracted weathering process, leaving behind residual soils that are rich in sesquioxides, which give the soil its distinctive reddish-brown hue. These soils are widely utilized in civil engineering projects, including fill material, road subgrades, embankments, and low-rise building foundations; however, their engineering behavior varies greatly based on the degree of weathering, mineralogy, particle size distribution, and environmental conditions (Nnochiri & Ogundipe, 2020; Osinubi et al., 2021).

Before these soils can be dependably used in construction, site-specific studies are essential due to their variable qualities, which include bearing capacity, plasticity, and compaction characteristics.

As a result of the humid tropical climate in the Iyamho region of Edo State, which speeds up the chemical weathering of the underlying rock formations, lateritic soils are common there. The geotechnical characteristics of lateritic soils from this region are not well documented in the literature, despite their widespread occurrence. Such knowledge is essential because localized geological and hydrological conditions can cause soils to exhibit significant variations in strength and deformation characteristics, even within the same climatic zone (Ogirigbo et al., 2021; Edeh et al., 2023). Designing safe and economical pavement structures or other load-bearing systems becomes difficult in the absence of this baseline data.

Characterizing the natural soil is crucial to determining its suitability for construction before considering any improvement measures like chemical stabilization, mechanical modification, or blending with other materials. This lowers the chance of structural failures or early deterioration by guaranteeing that any further treatment is both technically sound and financially feasible.

The results of five basic geotechnical tests specific gravity, sieve analysis, Atterberg limits, compaction, and California Bearing Ratio (CBR) conducted on Iyamho lateritic soil are presented in this paper. Using meticulously prepared soil samples, each test was carried out in compliance with the applicable British Standards BS 1924 for stabilization assessment and BS 1377 for soil testing procedures. The findings were examined in the context of recent research, offering a comparative framework for comprehending how the inherent characteristics of the Iyamho soil correspond with the normative engineering specifications for subgrade materials. In addition to helping with immediate project planning, this thorough evaluation acts as a benchmark for upcoming research on soil improvement in the Edo State area.

2. LITERATURE REVIEW

Lateritic soils are leftover soils that were created when parent rock materials weathered intensely in warm, humid tropical climates. Laterization is the process by which silica and bases like calcium, potassium, and sodium leach out, leaving behind high concentrations of iron and aluminum sesquioxides (Tang et al., 2022). Due to the presence of iron oxides like hematite and goethite, the resulting soil usually has a reddish or brown hue. Ferrallitic weathering thrives in lateritic soils, which are found in tropical Africa, South America, Southeast Asia, and portions of Australia. These regions experience alternating seasons of rainfall and extended dry spells (Rahman et al., 2022).

Due to their widespread availability and generally good engineering qualities in their natural state, lateritic soils are the most frequently encountered natural material for foundation and road construction in Nigeria (Osinubi et al., 2021). However, a number of variables, including mineralogy, particle size distribution, weathering degree, and in-situ moisture content, affect how well they perform (Bello et al., 2021). While some lateritic soils can be stabilized to meet design specifications for base and subgrade materials, others need stabilization to maintain sufficient bearing capacity and stability.

Lateritic soils must be geotechnically classified in order to predict their engineering performance. Systems like the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS) use index properties like compaction characteristics, Atterberg limits, and particle size distribution to group soils into appropriate application groups (Olawuyi & Alhassan, 2021). The clay content of lateritic soils varies greatly, influencing shear strength, shrink-swell behavior, and plasticity. In many lateritic soils, kaolinite is the predominant clay mineral. Unlike clays rich in smectite, kaolinite is relatively stable and has a low potential for swelling. A high fines content, however, can cause issues with even kaolinitic soils, reducing drainage and making them more vulnerable to moisture-induced weakening (Akinmusuru et al., 2022).

Lateritic soils are common, but their use in engineering is complicated. These include variable gradation, where many lateritic soils have poorly graded particle size distributions that limit maximum dry density and load-bearing capacity (Rahman et al., 2022); high plasticity index values, which hint at possible issues with volume changes during wetting and drying cycles, potentially resulting in cracks in pavements or foundations (Bello et al., 2021); and high moisture sensitivity, where strength drops sharply upon saturation due to the loss of apparent cohesion provided by suction forces in partially saturated conditions (Nnochiri & Ogundipe, 2020). Chemical stabilization, such as adding cement, lime, or admixtures like SP430, or mechanical stabilization, such as compaction, can be used to overcome these restrictions.

The process of stabilizing soil involves enhancing its engineering qualities so that it can be used for building. By compacting the soil, mixing it with other soils, or adding granular materials to enhance gradation, mechanical stabilization modifies the soil's structure. Adding binders or admixtures to change the physical and chemical characteristics of the soil is known as chemical stabilization. Lateritic soils benefit greatly from cement stabilization, which creates cementitious compounds that bind soil particles together, such as calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) (Osinubi et al., 2021). Lime stabilization improves workability and decreases plasticity through pozzolanic reactions and cation exchange (Çimen et al., 2024).

Superplasticizers like SP430, which are derivatives of sulphonated naphthalene formaldehyde (SNF), have been used more recently to increase density and workability without adding water, which indirectly increases strength (Adeleke et al., 2021).

To determine baseline characteristics and pinpoint specific soil weaknesses, thorough geotechnical characterization is necessary prior to stabilization. This entails figuring out the California Bearing Ratio (CBR), compaction properties, Atterberg limits, specific gravity, and particle size distribution. These tests assist in identifying the necessary stabilization strategy and dosage, predicting performance under moisture variations, estimating the soil's load-bearing capacity, and classifying the soil in accordance with standard systems. Stabilization might not be effective or produce the intended improvement without this characterization. Specific gravity is essential for calculating the void ratio and compaction and offers information about the mineral composition (Adeboje & Oyediran, 2020). Gradation is revealed by sieve analysis, which also affects permeability and compaction (Rahman et al., 2022).

Atterberg limits aid in the classification of fine-grained soils and define plasticity (Nnochiri & Ogundipe, 2020). For field application, compaction determines the ideal moisture content and maximum dry density (Adeleke et al., 2021). CBR evaluates subgrade suitability and load-bearing capacity (Olawuyi & Alhassan, 2021). When combined, these tests offer a comprehensive view of lateritic soils' engineering suitability both prior to and following stabilization.

3. MATERIALS AND METHODS

In order to prevent contamination from organic matter, roots, or surface debris, the soil sample used in this study was taken from Iyamho, Edo State, Nigeria, at a depth of about 1.2 meters below the natural ground surface. The material obtained was guaranteed to be representative of the lateritic subsurface layer, which is normally utilized for geotechnical applications, thanks to this sampling depth. The site was picked because it was easily accessible, lateritic deposits were common there, and it was pertinent to the area's ongoing building projects.

To lower the soil's inherent moisture content without changing its chemical makeup, it was allowed to air dry at room temperature after collection. In some situations, air drying is better than oven drying for geotechnical investigations because it maintains the natural particle structure and stops clay minerals from changing (Osinubi et al., 2021). To break down aggregates and guarantee uniformity of particle size, the soil was manually ground after it had dried.

To ensure that the material was within the particle size range needed for the laboratory tests especially the compaction and Atterberg limits tests, which concentrate on the fine fraction of the soil the ground-up sample was run through a 2 mm sieve to remove any coarse fragments. Accuracy and repeatability in the testing process were guaranteed by this preparatory step.

All tests were carried out in compliance with the BS EN soil testing standards and BS 1377: Part 2–4 (1990), which offer standardized methods for geotechnical characterization. The SP430 superplasticizer used for soil stabilization was obtained from *Sunny Ebere Safety and Tools Enterprise*, a commercial supplier located in Amuwo Odofin, Festac, Lagos. SP430 was introduced into the soil samples in its liquid form. The required quantity of SP430, corresponding to 2.5%, 5.0%, and 7.5% by weight of dry soil, was first measured and diluted with a portion of the mixing water to ensure uniform dispersion. The diluted admixture was then thoroughly mixed with the air-dried and sieved soil by hand for approximately 5 minutes until a homogeneous blend was achieved. This procedure ensured proper interaction between the additive and soil particles before compaction and strength tests were carried out without curing, consistent with field application conditions. The prepared sample was subjected to the following laboratory tests:

i. **Specific Gravity**: to determine the ratio of the mass of solids to the mass of an equal volume of water, which influences compaction and strength behavior.
ii. **Sieve Analysis**: to establish the particle size distribution and classify the soil according to the Unified Soil Classification System (USCS).
iii. **Atterberg Limits**: to measure the soil's plasticity characteristics, including liquid limit, plastic limit, and plasticity index.
iv. **Standard Proctor Compaction Test**: to determine the relationship between dry density and moisture content, providing optimum moisture content (OMC) and maximum dry density (MDD).
v. **California Bearing Ratio (CBR)**: to evaluate the strength of the soil for potential use in pavement subgrades and base layers.

To reduce experimental error and increase the reliability of the results, each test was run two times. To guarantee measurement accuracy, the lab apparatus was calibrated in compliance with BS EN ISO/IEC 17025 specifications.

4.0 RESULTS AND DISCUSSION

4.1 Specific Gravity

Table 1: Specific Gravity Values for Untreated and Treated Soil

SP430 Content (%)	Specific Gravity
0.0 (Untreated)	2.55
2.5	2.64
5.0	2.70
7.5	2.78

A soil's specific gravity is a crucial factor in determining its classification, bearing capacity, and compaction behavior because it represents the relative density of its mineral particles. According to this study, the untreated soil's specific gravity was 2.55, which suggests that it is lateritic and contains somewhat heavy particles. According to Head (1992), this value is within the usual range of 2.5 to 2.8 for lateritic soils.

The specific gravity values steadily increased after stabilization with SP430. The specific gravity rose to 2.64 at 2.5% SP430 and then to 2.70 and 2.78 at 5.0% and 7.5% replacement levels, respectively. The SP430 additive's chemical and physical interaction with the fine soil particles is responsible for this steady rise. The admixture probably increased the total mass per unit volume of the soil particles by introducing denser solid constituents and filling in voids in the soil matrix.

In line with research by Ola (1983) and Amu et al. (2005), who noted comparable behavior in lateritic soils stabilized with chemical additives, this enhancement implies that the mineralogical composition and particle bonding of the soil improved as stabilization increased. The ability of the particles to withstand shear forces increases with density, which improves the overall performance of the foundation.

4.2 Sieve Analysis

Table 2: Sieve Analysis Values for Untreated

BS Test Sieve Size (mm)	Percentage Passing %
28	100.00
20	100.00
14	100.00
10	97.65
5	88.83
3.35	84.56
2.36	80.60
2	79.24
1.18	75.93
0.6	72.23
0.425	69.70
0.3	67.39
0.15	61.99
0.075	48.56
Passing 75um	0.00

According to the data from the sieve analysis, the soil's particle size distribution shows a well-graded granular material with a broad range of particle sizes. At the coarsest sieves (28 mm, 20 mm, and 14 mm), the passing percentage gradually drops from 100% to 48.56% at the 0.075 mm sieve. According to this, the soil has a high percentage of fine particles while maintaining a sizable percentage of coarse and medium-sized particles, offering a balance that is typically advantageous for compaction and strength when applied to base layers or subgrade. Significantly, 61.99% and 48.56% passed the 0.15 mm and 0.075 mm sieves, respectively, while 80.60% passed the 2.36 mm sieve, which is frequently used as the threshold for fine aggregate in geotechnical classification.

Sieve analysis was conducted only on the untreated soil sample, as the addition of SP430 does not alter the actual particle size distribution. Being a liquid superplasticizer, SP430 primarily modifies the soil's behavior by improving particle dispersion, reducing plasticity, and enhancing compaction and strength characteristics, rather than physically changing the gradation of particles.

This percentage of fines may have an impact on the soil's strength, permeability, and plasticity. While the total lack of material passing below 0.075 mm suggests that the soil may have more silt than clay fractions, the sudden drop between 0.15 mm and 0.075 mm sieves suggests the presence of silt-sized particles. Lateritic soils, which are frequently rich in sand and silt but lacking in clay minerals, exhibit this grading behavior. Depending on its Atterberg limits and other characteristics, this soil, which has 48.56% fines, may be categorized as a fine-grained or borderline material. This is because BS 1377 (1990) states that soils with less than 35% passing the 0.075 mm sieve are considered coarse-grained, while those with more are considered fine-grained.

From an engineering perspective, the relatively even distribution of particles in the fine and intermediate ranges suggests that the soil may have fair compaction properties and moderate shear strength, but it may also be vulnerable to moisture sensitivity or a decrease in bearing capacity when saturated. Gidigasu (1976) and Ola (1983) found that lateritic soils with high silt fractions typically need stabilization for better engineering performance, which is consistent with this behavior.

4.3 Atterberg Limits

Table 3: Atterberg Limits of Untreated and Treated Soil

SP430 Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0.0 (Untreated)	18.05	12.86	5.19
2.5	15.07	10.76	4.31
5.0	14.98	13.68	1.30
7.5	14.01	9.90	4.11

The soil's plasticity and potential volume changes under different moisture conditions are clearly indicated by the Atterberg limits. Both untreated and SP430-stabilized samples had their liquid limit, plastic limit, and plasticity index measured.

The untreated soil had a plasticity index of 5.19%, a liquid limit of 18.05%, and a plastic limit of 12.86%. According to the Unified Soil Classification System (USCS), these values indicate that the soil has low plasticity and is classified as silty or lean clay. When saturated, these soils may not be cohesive enough, but they typically show little swelling or shrinkage.

When 2.5% SP430 was added, the plastic limit dropped to 10.76% and the liquid limit dropped to 15.07%, yielding a plasticity index of 4.31%. The plastic limit changed more significantly at 5.0% stabilization, rising to 13.68%, while the liquid limit decreased slightly to 14.98%, resulting in a remarkably low plasticity index of 1.30%. A significant decrease in the soil's propensity to experience volumetric changes is implied by this sharp decline in the plasticity index, suggesting a more stable substance.

Notably, the plastic limit decreased to 9.90% and the liquid limit decreased to 14.01% at 7.5% SP430, but the plasticity index marginally increased to 4.11%. This change is noteworthy because it deviates from the consistent decline seen at lower dosages. Despite being slight, the increase suggests that too much additive could start to offset the stabilizing effect. This behavior may be attributed to either non-uniform dispersion of the liquid stabilizer or chemical saturation of the soil matrix, both of which lower particle bonding efficiency.

These findings are consistent with Osinubi and Eberemu's (2009) research, which found that chemical stabilization tends to reduce plasticity because it causes clay particles to flocculate, which in turn reduces double-layer water. By changing the binding capacity and inter-particle attraction, SP430 most likely changed the structure of the soil, making it less plastic and more friable.

All things considered, the decrease in plasticity is a good thing since it suggests less potential for swelling, better workability, and increased load-bearing capacity all of which are critical characteristics for road subgrade materials.

4.4 Compaction Characteristics (OMC and MDD)

Table 4: Compaction Test Results (OMC and MDD)

SP430 Content (%)	**Optimum Moisture Content (OMC %)**	**Maximum Dry Density (MDD Mg/m³)**
0.0 (Untreated)	13.25	1.90
2.5	12.06	1.92
5.0	12.00	1.92
7.5	10.26	1.95

Understanding compaction properties is essential to comprehending how soil reacts to mechanical densification and maintains optimal moisture retention. Both untreated and stabilized soils had their Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) measured. An OMC of 13.25% and an MDD of 1.90 Mg/m³ were obtained from the untreated soil. A moderately dense soil with average moisture requirements for efficient compaction is reflected in these values.

The OMC decreased to 12.06% and the MDD marginally increased to 1.92 Mg/m³ after stabilizing with 2.5% SP430. The decrease in OMC indicates that SP430 enhanced water retention and decreased the volume of water required to reach optimal compaction. At 5.0% SP430, this trend persisted, with the MDD staying constant at 1.92 Mg/m³ and the OMC dropping even further to 12.00%.

The MDD rose to 1.95 Mg/m³ at 7.5% SP430, while the OMC sharply decreased to 10.26%. The compaction behavior of the soil has clearly improved, as evidenced by this pattern. This is usually linked to improved packing and stronger particle bonding as a result of chemical stabilization. The

stabilized soil's ability to sustain greater structural loads is suggested by the increase in MDD, which is advantageous for pavement construction.
Sherwood (1993) asserts that efficient soil stabilization results in a denser particle packing because of flocculation or cementitious bonding, which lowers water demand and increases dry density. This principle is supported by the performance seen here, confirming SP430's potential to increase lateritic soil compaction efficiency.

4.5 California Bearing Ratio (CBR)

A common method for assessing a soil's suitability for base, sub-base, and pavement subgrade layers is the California Bearing Ratio (CBR) test, which measures the soil's ability to support loads. For the top and bottom samples, the test was conducted at penetration depths of 2.5 mm and 5.0 mm. The final CBR value for each sample was calculated using the guidelines provided by the Federal Ministry of Works and Housing (FMWH, 1997):

1. Averaging the top and bottom values at each penetration depth.
2. Selecting the higher of the two averages (2.5 mm or 5.0 mm) as the representative CBR value.

Table 5: CBR Values of SP430-stabilized Lateritic Soil

SP430 Content (%)	Average CBR @ 2.5 mm	Average CBR @ 5.0 mm	Final CBR Value (%)
0.0 (Untreated)	12.50	12.25	12.50
2.5	1.97	2.05	2.05
5.0	3.03	4.20	4.20
7.5	3.90	5.65	5.65

Figure 1: Line Chart of CBR Values vs SP430

With a CBR value of 12.50%, the untreated soil exceeded the FMWH (1997) minimum requirement for subgrade soils (≥ 5%) but fell short of the threshold normally needed for sub-base layers (≥ 30%) or base courses (≥ 80%). This relationship is shown in Figure 1. This suggests that without stabilization, natural soil can only be regarded as appropriate for light traffic subgrades.

The steep drop in CBR to 2.05% at 2.5% SP430 indicates insufficient bonding, most likely as a result of the dispersing action of the superplasticizer, which lowers inter-particle cohesion at low concentrations. The formation of stable bonds may be hindered by excessive fluidity or dilution (Okonkwo et al., 2021; Akeem et al., 2019). Similar strength decreases with superplasticizers at non-optimal dosages were noted by Singh & Patel (2022), who attributed this to an inadequate additive to promote efficient particle aggregation. This suggests a critical threshold, probably higher than 2.5%, for SP430's positive effects. Strength gradually improved with increasing dosage, reaching 4.20% at 5.0% SP430 and 5.65% at 7.5% SP430. Although this indicates that higher dosages of SP430 increased the stiffness of the soil, the values were still much lower than those of the untreated sample (12.50%) and still did not meet the minimum requirement for sub-base soils (≥ 30%).

This result indicates that SP430 by itself does not increase the lateritic soil's strength. Rather, it lowers the soil's ability to support weight in comparison to its untreated state.

Recent research has also shown that chemical additives like superplasticizers may not work well as stand-alone stabilizers but work better when mixed with pozzolanic materials like cement, lime, or industrial byproducts (Adeleke et al., 2021; Singh & Patel, 2022; Chijioke et al., 2023). Blended stabilization techniques are more dependable for attaining long-term strength and durability in pavement subgrades, according to more recent research (Oluwasola et al., 2024; Zhang et al., 2025). Practically speaking, the findings show that SP430 is insufficient as a stand-alone stabilizer for road construction applications, even though it might increase workability. It is advised to use a blended stabilization strategy in order to meet acceptable performance requirements.

4. CONCLUSION

1. In line with typical tropical residual soils created under intense weathering, the lateritic soil from Iyamho has iron-rich properties and moderate plasticity.
2. According to the specific gravity and gradation results, the soil's engineering performance is influenced by sesquioxides and fine-grained materials.
3. The soil can be efficiently densified, according to the results of compaction tests, which qualifies it for subgrade applications in road construction.
4. The soil's use in pavement base and sub-base layers is limited without improvement due to its only moderate bearing capacity, as indicated by the California Bearing Ratio (CBR) values.
5. Because of its inherent qualities, the soil is suitable for roads with low traffic, but more demanding infrastructure applications call for stabilization.
6. SP430 superplasticizer reduced the CBR strength of the lateritic soil, with the highest treated value (5.65%) still below the untreated soil (12.5%). This shows SP430 alone is ineffective and should be blended with other stabilizers for better performance.
7. The study offers a starting point for further investigation into creative stabilization methods that maximize the engineering qualities of Iyamho lateritic soil.

NOMENCLATURE

A	Area (m^2)
CBR	California Bearing Ratio (%)
G	Specific gravity
LL	Liquid limit (%)
MDD	Maximum dry density (Mg/m^3)
OMC	Optimum moisture content (%)
PI	Plasticity index (%)
PL	Plastic limit (%)
w	Water content (%)

Greek Symbols

γ	Unit weight (kN/m^3)
ρ	Density (kg/m^3)
Δ	Change or difference

Subscripts

opt	Optimum
max	Maximum
min	Minimum
st	Stabilized
u	Untreated

Superscripts

′	Derivative or measured value
″	Second derivative
%	Percentage
°	Degree (angle or temperature)

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BS	British Standard
CBR	California Bearing Ratio
OMC	Optimum Moisture Content
MDD	Maximum Dry Density
SP430	Sulphonated Naphthalene Formaldehyde-based Superplasticizer

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