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Stabilization of Lateritic Soil with Portland Cement and Sand for Road Pavement

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Abstract

A solid foundation is always essential when it comes to the construction of roads and pavements. The foundation must be constructed of a long-lasting material that can sustain years of traffic while remaining dependable. The shortage of good-quality durable materials for pavement structure (base, subbase, and subgrade) on construction sites is a common issue in highway and pavement construction. As a result, the individual and combined influences of Portland cement and sand on the stabilization of lateritic soil from Agu-Awka in Anambra State, Nigeria for road pavement were evaluated. The soil sample had a California Bearing Ratio (CBR) value of 24%. This demonstrated that the laterite was insufficient for both subbase and base course materials for road pavement and so required stabilization. The soil was stabilized by adding different percentages of cement in the range of 3%, 6%, 9%, and 12% by weight, as well as various percentages of fine sand in the range of 15%, 30%, 45%, and 60% by weight. The soil was additionally stabilized using varying percentages of both cement and sand, for a total of 16 mix combinations. A soil-cement mixture with 6% cement gave the maximum CBR of 175%, while a CBR of 86% was obtained in a soil-sand mixture with 30% sand. For soil-cement-sand mixtures, mixtures containing 6% cement and 45% sand, as well as 9% cement and 45% sand, yielded a CBR value of 112%. Consequently, some soil-cement, soil-sand, and soil-cement-sand mixtures satisfied the criterion for road pavement subbase and base course materials.

Subject Areas

Civil Engineering

Keywords

Lateritic Soils, Sand, Portland Cement, Stabilization, Road Pavement

1. Introduction

A solid foundation is always essential when it comes to the construction of roads and pavements. The foundation must be constructed of a long-lasting material that can sustain years of traffic while remaining dependable. The shortage of good-quality durable materials for pavement structure (base, subbase, and subgrade) on construction sites is a common issue in highway and pavement construction [1] [2]. As a result, these materials must be delivered to construction locations, which adds to the project's cost. Hence, geotechnical methods that allow in-situ materials such as lateritic soils to be stabilized in order to meet the road authorities' minimal requirements for pavement materials are crucial. The stabilization of local soil on the construction site will help minimize construction costs, the depletion of natural resources from distant sources, and also the pollution of the environment caused by the use of fossil fuels when transporting these materials [3].

Soils in their natural form may not always satisfy the standards for base or sub-base course materials for highway construction due to their inadequate bearing capacity [1]. Lateritic soils, the most prevalent of all tropical soils in Nigeria, are the most commonly used earth resources for highway construction [4] [5]. Lateritic soils are defined as highly weathered natural materials with a high concentration of hydrated oxides of iron or aluminium as a result of residual accumulation or absolute enrichment caused by the solution, movement, and chemical precipitation of aluminium, iron, and manganese [6].

They are considerably affected by weathering due to the presence of meteorized materials enriched by minerals with poor solubility (e.g., iron and aluminium oxides), known as laterite gravel (LG). They typically do not meet the standards required by road agencies for high traffic road pavement and, in certain circumstances, medium to light traffic as well. This can be related to their particle-size characteristics, the type and strength of gravel particles, the degree of compaction, the volume of traffic, the climatic and hydrological regime of the construction site, and the geography of the area [7] [8].

Because of its swelling nature, lateritic soil is always difficult for engineering projects. When dry, it contracts and when wet, it expands [9]. Laterites range in color from yellowish to reddish-brown, depending on the amounts of iron and aluminium sesquioxides. Different methods are used to improve the geotechnical characteristics of laterites to meet the criteria for subbase and base course materials. Preloading, soil replacement, the use of recycled concrete aggregates, and the use of soil stabilizing chemicals are among these methods [10] [11] [12] [13] [14]. Soil stabilization is any procedure that improves and makes a soil material more stable, resulting in increased bearing capacity and plasticity, increased mechanical strength or stiffness, altered grain size distribution, and durability under severe moisture and stress conditions. Soil stabilization can be accomplished mechanically or chemically.

Mechanical stabilization entails the addition of one kind of soil to a parent soil or aggregate in order to increase its strength and stability by densifying the soil using mechanical energy [15]. To enhance the geotechnical qualities of natural soil, one alternative to mechanical stabilization is chemical stabilization, which involves the addition of additives such as lime, cement, fly ash, and bitumen to the soil [16]. Sand has been reported to improve the engineering qualities of natural soils. Due to a lack of sand and silt size particles, laterite gravels are gap graded; the addition of sand may enhance the grading curve and compaction properties of the laterites, hence reducing the flexibility of the fines and fines' characteristics [17]. Sand is used in Nigeria as a fine aggregate in the building sector, as test samples in geotechnical and soil science laboratories, as an experimental porous media in hydrogeology investigations, and for other purposes. The usage of sand for construction purposes has expanded rapidly as a result of the need for a more paved road of sand network and housing plans. Soil-cement is a basic yet highly compacted combination of soil, cement, and water.

When cement is blended with the other two ingredients, it increases the soil's characteristics, providing the finished material with the durability to handle traffic loading. This is all dependent on the kind of soil used, the amount of cement applied, the amount of moisture present, and the compaction of the mixture [18]. The use of a cement stabilized foundation to reinforce the base section directly beneath rigid or flexible pavements is very common in highway construction. Roads, parking lots, airports, residential streets, and other structures can all benefit from the soil-cement pavement. It's a low-cost pavement base that's recognized for its strength and longevity [19] [20]. The California Bearing Ratio (CBR) is a measurement of a road's or other paved area's subgrade strength, as well as the materials used in its construction [21]. It is simply the most popular in pavement design. The CBR test should be performed on soil with equilibrium determined moisture content. CBR values of 80%, 30%, and 10% are recommended for base course, sub-base, and sub-grade materials, respectively, according to the Nigerian General Specifications for road pavement design [22].

The impacts of sand and cement on soil stabilization to enhance the soil properties of Igumale shale were explored by [23]. It was reported that the use of sand in the alteration of shale suggests that sand may be used to stabilize laterite. In this study, cement was added to the laterite to cause chemical and physical changes in the natural soil, while sand was used to adjust the laterite's gradation and physical properties. The strength and durability of cement-treated lateritic soils were investigated by [24]. It was discovered that the maximum dry density of the treated soil improved as the cement concentration increased. This observation is in line with [25] and [26] findings. According to [27], when the proportion of sand in clay-sand mixtures stabilized with 4% cement was raised from 0% to 20%, the strength of the soil improved.

The different percentages of sand (15%, 30%, and 45%) and cement (3%, 6%, 9%, and 12%) were utilized by [25] to stabilize a Nigerian lateritic soil in two compaction energies. According to the authors, the addition of sand, cement, and greater compaction energy enabled the stabilized soil to meet the standards for usage as road material. The proportion of sand and cement that worked best for the mix design was 45 percent sand and 6 percent cement. Similarly, [28] reported that adding 2% to 3% lime or cement to laterite soil was sufficient to change its workability and mechanical strength for road paving applications. The utilization of cement at 2%, 3%, 6%, and 8% to stabilize granular lateritic soil was investigated by [29]. The authors discovered that the addition of cement increases the durability performance of the soil, with at least 6% cement required to make the mass losses in durability acceptable for use in the construction of road pavement layers.

According to [30], adding cement to laterite soil produces a material with better mechanical strength than the soil in its natural condition. The strength of Indian lateritic soils stabilized using pond ash and cement was studied by [31]. They claimed that pond ash and cement were effective lateritic soil stabilizers and that the stabilized soil could be used as a base or sub-base course material. Furthermore, prior studies by [32] [33] [34] and [35] confirmed that utilizing cement to stabilize diverse soil types, such as soft clay and lateritic soil, can increase their unconfined compressive strength (UCS). They reported that when the cement concentration and cure time increased, so did the UCS values. They attributed the soil's increased strength to a chemical interaction between cement clinker and water that created cementitious compounds of C-S-H (calcium-silicate-hydrate).

From the previous works reviewed, it can be seen that few studies have been done on the combined effects of both cement and sand on the properties of laterite. Hence, this research aims to investigate both the individual and combined effects of Portland cement and sand on the geotechnical properties of lateritic soil, with a view to assessing the suitability of the stabilized laterite as a base and subbase course for road pavement.

2. Materials and Methods

2.1. Materials

Natural reddish-brown lateritic soil samples were taken at consistent depths from borrow pits in Anambra State, Nigeria, near Enugwu-Agidi along Amawbia to Igbariam Road and Nawfia. Sand and cement were used as stabilizing agents. The Portland Limestone cement (Grade 42.5 N) was purchased from a roadside shop in Awka, Nigeria. The lateritic soil sample was stabilized by adding cement by weight at rates of 3%, 6%, 9%, and 12% to the non-stabilized soil sample. The sand was also used to stabilize the soil sample at 15%, 30%, 45%, and 60% by weight. The laterite was additionally stabilized with varying percentages of both cement and sand. After stabilizing the soil with the individual and combined addition of cement and sand, a CBR test was carried out on the stabilized soil.

The soil samples were produced in compliance with [36] requirements. For the aim of categorization in accordance with [37], index property tests such as particle size distribution analysis and an Atterberg limit test were performed on soil samples according to the standards of [36]. A 6 kg dry soil sample was compacted using the British Standard Heavy (BSH) method. BS [38] specifies the processes for BSH compaction. In addition, the soil's optimal moisture content (OMC) was evaluated and utilized to calculate the soil's CBR value.

2.2. Methods

Major preliminary tests were carried out in order to fully comprehend the behaviour of the laterite samples adopted in this study. The Sieve analysis, moisture content test, and Atterberg Limits test were among the preliminary tests evaluated.

Moisture content is the ratio of the weight of water present in a given soil mass to the weight of dry soil. Some moisture occurs in many residual soils as water crystallisation inside the structure of the mineral present in the solid particles, which may or may not have an impact on the soil's engineering performance. However, part of this moisture can be removed by drying at temperatures higher than the standard drying temperature (105˚C).

For the moisture content to be determined, the metal containers were cleaned, dried, and weighed with a lid. The soil sample was gathered in its natural state and placed loosely in the weighed metal containers. These were dried in the oven until the combined mass of the dirt and container was consistent. The containers were taken out of the oven after drying and placed in desiccators to cool. The dry soils were weighed and recorded in the containers. Hence, the water content of the soil was calculated using Equation (1).

$$\text{Moisture content} = \frac{\text{Mass of Water}}{\text{Mass of Dry Soil}} \times 100 \tag{1}$$

As indicated in Equation (2), the California Bearing Ratio (CBR) is the ratio of forces per unit necessary to enter a soil mass with a circular plunger of 50 mm in diameter at a pace of 1.25 mm/min compared to that required to pierce a standard material. From Equations (3) and (4), it can be seen how the CBR ratio can be determined for penetrations of 2.5 and 5 mm. When the 5 mm ratio is greater than the 2.5 mm ratio, the 5 mm ratio is used. The California Bearing Ratio (CBR) test was used to assess the bearing capacity of a non-stabilized soil sample and determine whether it needed to be improved.

A 6 kg dry soil sample was used. A compaction test was used to determine the maximum dry density for the remoulded sample, and the soil was mixed using the Optimum Water Content (OMC) as determined by the compaction test. The soil sample was sieved with a 20 mm sieve to remove coarser material, which was left on the sieve and replaced with an equivalent weight of material. After carefully mixing the sample, it was separated into five pieces. Five layers of material were used to fill the mould. A 4.5 kg rammer was used to condense each layer with 25 blows.

The mold's collar was removed, and the mold's top was levelled using a spatula. The mould was then immersed in water for 24 hours after the collar was replaced. The mould was placed on the CBR machine after soaking for 24 hours. The machine's dial gauges were set to zero, and the sample was loaded. After 30 seconds, the plunger had penetrated 7 mm, and the dial reading was taken. The bottom of the mould was loaded after it was turned. In addition, until 7 mm of penetration was achieved, the dial reading was taken every 30 seconds.

CBR was estimated at penetration depths of 2.5 mm and 5.0 mm. Both the top and bottom were calculated. The material's CBR was calculated by averaging one top (CBR value) at 2.5 mm and one bottom (CBR value) at 5.0 mm. Force (load) vs. penetration was plotted on a graph.

$$\text{CBR} = \frac{\text{Load}\left(\text{force}\right)}{\text{Standard load}} \times 100 \tag{2}$$

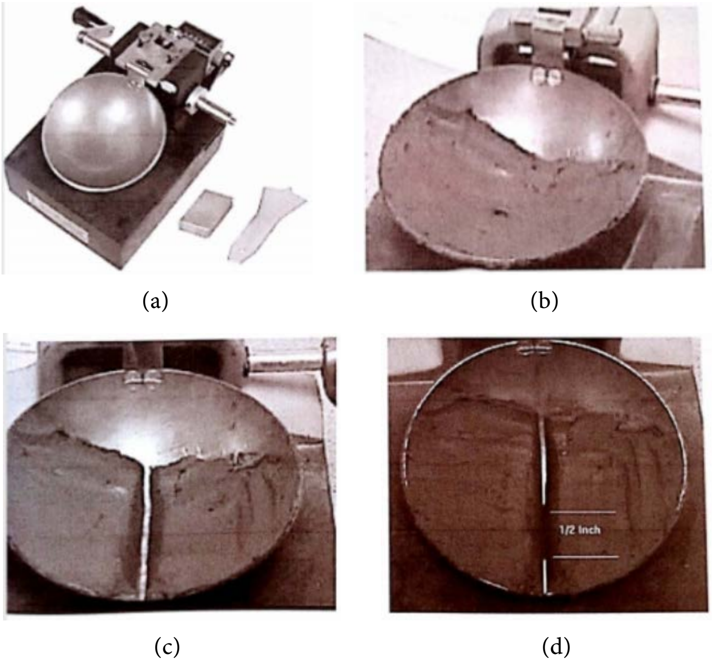
$$\text{CBR at 2.5 mm} = \frac{\text{Dial gauge reading} \times \text{proving factor} \times 100}{13.24} \tag{3}$$

$$\text{CBR at 5.0 mm} = \frac{\text{Dial gauge reading} \times \text{proving factor} \times 100}{19.96} \tag{4}$$

3. Results and Discussion

3.1. The Basic Properties of the Lateritic Soil

The properties of the investigated soil in its natural state are shown in **Table 1**, whereas **Figure 1** depicts the particle size distribution. The particle size distribution revealed that the soil sample contains 64.92% sand content and 35.07% fines content. With a plasticity index of 34.80%, the liquid limit was found to be 43.50%.



(a) (b)

(c) (d)

Figure 1. Soil sample. (a) Liquid limit apparatus; (b) Soil sample initially placed in the casagrande cup before grooving to partition the soil; (c) A portion of soil sample in the liquid limit device cup; (d) Soil sample showing closure after certain number of blows.

Table 1. Properties of the natural lateritic soil.

Property	Value
Fines content	35.07%
Sand content	64.92%
Liquid Limit (L_L)	43.50%
Plastic Limit (P_L)	34.80%
Plasticity Index (P_I)	8.16%
Specific gravity (G_s)	2.61
Maximum dry unit weight	18.2 kN/m^3
Optimum moisture content	13.85%
AASHTO Classification	A-2-7
USCS Classification	Silty Clay (SC)

According to the Unified Soil Classification System (USCS), the soil is classed as silty clay (SC) with moderate plasticity, medium to low dry strength, and medium to no toughness and as A-2-7 by the American Association of State Highway and Transportation Officials (AASHTO). According to the standards of the Federal Ministry of Works for highway construction in Nigeria [39], the fundamental qualities of natural soil do not meet the requirements for base and subbase materials for road pavement, and hence would require stabilization.

The compaction behaviour of the natural soil for BSH compaction energy is shown in **Table 2** and **Figure 2**. From **Figure 2**, it can be seen that the maximum dry density of 2020 kg/m^3 was obtained at 8.3% optimum moisture content. The measured CBR is 24% at the optimum moisture content.

3.2. Individual Effects of Cement and Sand on the Lateritic Soil

The compaction behaviour of the natural soil, when stabilized with cement and sand, is shown in **Figure 3** and **Figure 4** respectively. The relationship between the dry density and the moisture content of the soil-cement and soil-sand mixtures at different percentages is shown in the figures. It can be observed from **Figure 3** that as the percentage addition of the cement increased, the optimum moisture content of the lateritic soil gradually decreased until a maximum dry density was attained. This indicates that less water is required to achieve the correct density in the field. The increase in the maximum dry density of the laterite with cement content is in agreement with [5]. An optimum maximum dry density of 2125 kg/m^3 was obtained at an optimum moisture content of 5.8% when the lateritic soil was stabilized with 3% cement. It was also observed that the obtained optimum maximum dry density of 2125 kg/m^3 at 3% cement was higher than the maximum dry density of 2020 kg/m^3 at 8.3% optimum moisture content that was obtained for the lateritic soil (control).

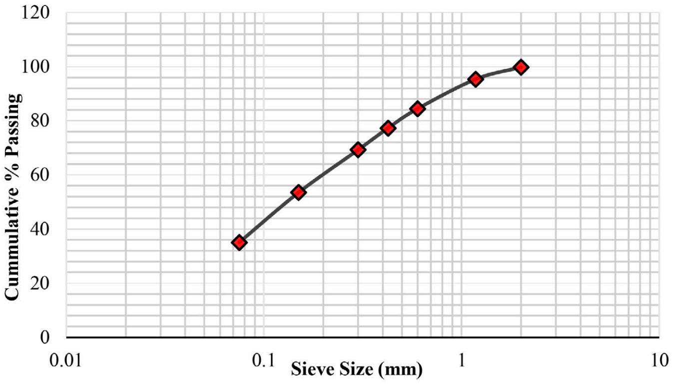


Figure 2. Particle size distribution curve of the natural lateritic soil.

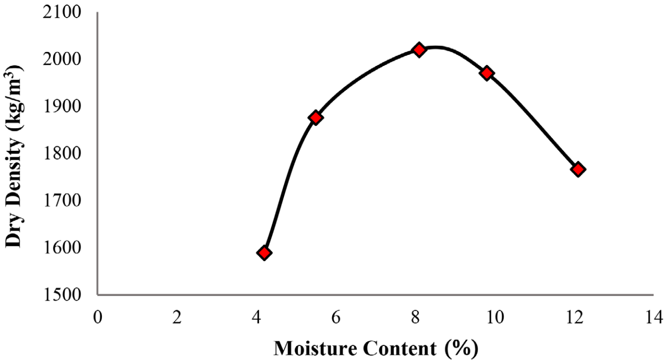


Figure 3. Compaction curve of the unstabilized soil.

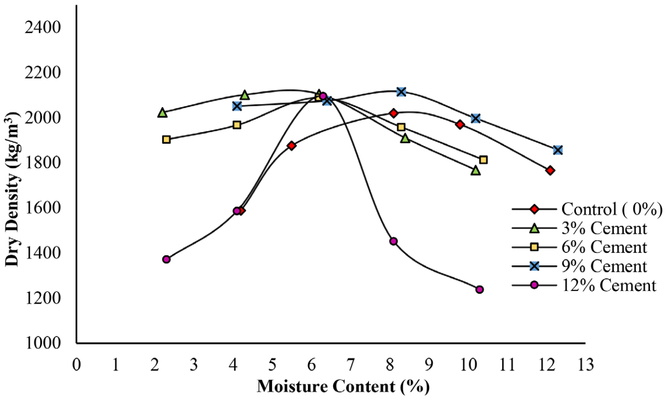


Figure 4. Compaction curves of soil-cement mixtures.

Table 2. Properties of the natural lateritic soil.

Dry Density (kg/m³)	Moisture content (%)
1589	35.07%
1876	64.92%
2020	43.50%
1970	34.80%
1766	8.16%

A very similar trend can also be observed in **Figure 4** when the lateritic soil was stabilized with sand. As the percentage addition of the sand increased, the optimum moisture content of the lateritic soil gradually decreased until a maximum dry density was attained. This indicates that there will be less demand for water to achieve the desired density in the field. An optimum maximum dry density of 2125 kg/m^3 was obtained at an optimum moisture content of 6.2% when the lateritic soil was stabilized with 15% sand.

It was also observed that the obtained optimum maximum dry density of 2125 kg/m^3 at 15% sand was higher than the maximum dry density of 2020 kg/m^3 at 8.3% optimum moisture content that was obtained for the lateritic soil (control). The increase in maximum dry density with the individual percentage addition of cement and sand could be attributed to voids in the natural lateritic soil being filled with the missing sand-size particles, which resulted in a denser compact mass and cement, which has a higher specific gravity of 3.15.

From **Figure 5**, it can be observed that the CBR of the stabilized soil increased with the individual percentage addition of cement and sand when compared with the unstabilized soil. For the soil-cement mixtures, the maximum CBR value of 175% was obtained when the lateritic soil was stabilized with a 6% addition of cement. While for the soil-sand mixtures, the mix with a 30% addition of sand gave the maximum CBR value of 86%. It can also be observed that the increase in CBR value of the stabilized soil-cement mixtures is more significant than that of soil-sand mixtures. The CBR values of both the soil-cement and soil-sand mixtures are directly proportional to the individual percentage addition of cement and sand, respectively, up to certain content. It should be noted that at the highest individual percentage addition of cement and sand (12% cement and 60% sand), significantly decreased CBR values of 68% and 30%, respectively, were obtained. However, these significantly decreased CBR values didn't decrease below the CBR value of 24% that was obtained in the control.

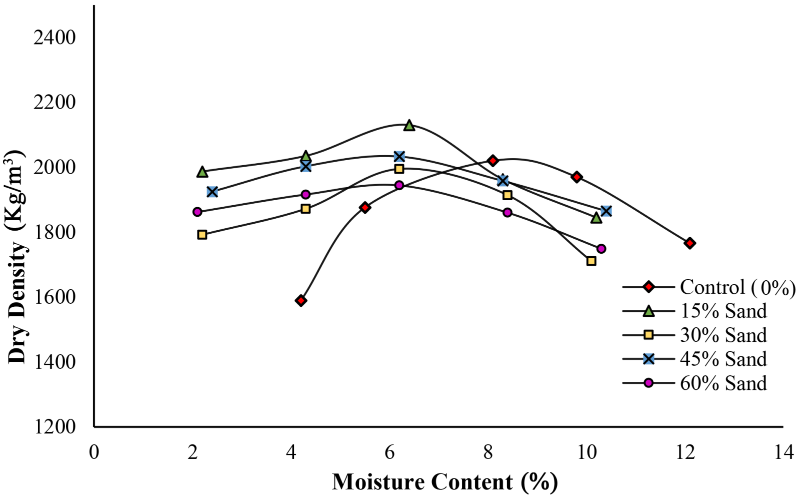


Figure 5. Compaction curves of soil-sand mixtures.

From **Figure 6**, it can be seen that it is only the soil-sand mixture with a 30% addition of sand that meets the CBR requirement for base course material, which is 80%. However, the soil-sand mixtures that gave low values of CBR that are below 80% suggest that the stabilized soil is only suitable as a subbase material for flexible pavement. Also, it can be observed from **Table 3** that all the soil-cement mixtures, except for the 12% addition of cement, met the CBR requirement for base course material. However, the soil-cement mixture that gave a low value of CBR suggests that the stabilized soil is only suitable as a subbase material for flexible pavement.

3.3. Combined Effects of Cement and Sand on the Lateritic Soil

The compaction behaviour of the natural lateritic soil, when stabilized with both cement and sand, is shown in **Table 4**. A total of 16 soil-cement-sand mixtures at different percentages were tested. It can be seen from **Table 4** that an optimum maximum dry density of 2100 kg/m^3 was obtained at an optimum moisture content of 7.9% when the lateritic soil was stabilized with the combination of 3% cement and 15% sand. The obtained optimum maximum dry density is higher when compared to the maximum dry density of 2020 kg/m^3 at 8.3% optimum moisture content that was obtained for the unstabilized lateritic soil.

This finding is in correlation with the findings from **Figure 3** and **Figure 4**, where it was observed that the individual addition of 3% cement and 15% sand gave the optimum maximum dry densities, which were higher when compared to the maximum dry density of the control. From **Table 4**, it can be observed that there was a significant increase in the CBR of the stabilized soil mixtures at all the different percentages of cement and sand when compared with the control. For the soil-cement-sand mixtures, a maximum CBR value of 112% was obtained when the lateritic soil was stabilized with the combination of 6% cement and 45% sand, and also when it was stabilized with 9% cement and 45% sand.

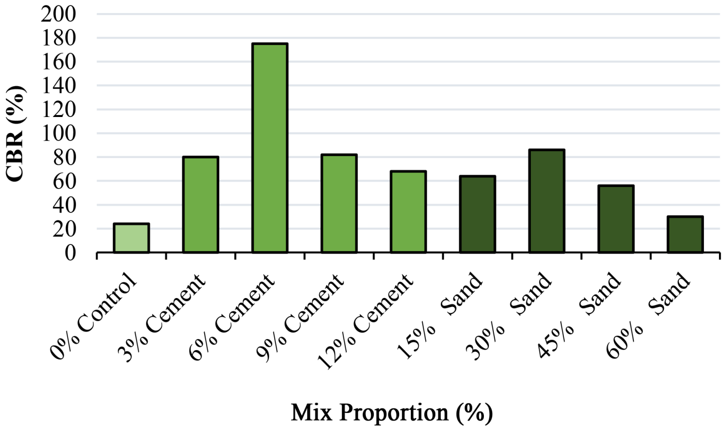


Figure 6. Variation of the individual effects of different percentages of cement and sand on the CBR of the soil.

Table 3. Experimental results.

Mix No.	Mix Proportion	Optimum Moisture Content (%)	Maximum Dry Density (kg/m³)	CBR Value (%)
1	Control (0%)	8.3	2020	24
2	Cement (3%)	5.8	2125	80
3	Cement (6%)	6.2	2090	175
4	Cement (9%)	8.0	2115	82
5	Cement (12%)	6.2	2100	68
6	Sand (15%)	6.2	2125	64
7	Sand (30%)	6.3	2000	86
8	Sand (45%)	5.9	2034	56
9	Sand (60%)	6.0	1950	30

Table 4. Experimental results.

Mix No.	**Mix Proportion (% by weight)**	**Optimum Moisture Content (%)**	**Maximum Dry Density (kg/m³)**	**CBR Value (%)**
1	Control (0%)	8.3	2020	24
2	3% Cement + 15% Sand	7.9	2100	74
3	6% Cement + 15% Sand	8.0	2025	75
4	9% Cement + 15% Sand	7.8	2065	83
5	12% Cement + 15% Sand	10.0	2030	92
6	3% Cement + 30% Sand	6.2	2030	64
7	6% Cement + 30% Sand	6.1	2015	88
8	9% Cement + 30% Sand	9.8	2000	76
9	12% Cement + 30% Sand	6.0	2010	85
10	3% Cement + 45% Sand	6.0	1960	82
11	6% Cement + 45% Sand	8.0	2010	112
12	9% Cement + 45% Sand	7.8	1950	112
13	12% Cement + 45% Sand	8.2	2050	92
14	3% Cement + 60% Sand	7.9	2030	73
15	6% Cement + 60% Sand	10.0	1990	79
16	9% Cement + 60% Sand	10.0	2000	87
17	12% Cement + 60% Sand	10.2	2000	100

The CBR values of the soil-cement-sand mixtures are directly proportional to the combined different percentage additions of cement and sand, respectively, up to certain content. It can also be seen that 11 soil-cement-sand mixtures met the CBR requirement for base course material, which is 80%. However, the soil-cement-sand mixtures that gave low values of CBR, which is below 80% but higher than the CBR of the control, suggest that the stabilized soil mixtures are only suitable as a subbase material for flexible pavement.

4. Conclusions

From the study carried out on the stabilization of lateritic soil with Portland cement and sand for road pavement, the following conclusions were reached:

- In compaction characteristics, there is considerable improvement in the maximum dry density of lateritic soils as the optimum moisture content gradually decreases when stabilized with any percentage addition of either sand or cement or both, but up to certain percentage content. Hence, this indicates that less water is required to achieve the correct density in the field for soil-cement, soil-sand, and soil-cement-sand mixtures.
- Cement is a very efficient and promising stabilizer for this lateritic soil based on the percentages of cement adopted. Almost all of the soil-cement mixtures have CBR values up to 80% and as such are suitable for use as a high quality base course material. However, a soil-cement mixture with 6% cement is the most suitable for use as a high quality base course material for road pavement because a CBR value of 175% was obtained when the lateritic soil was stabilized with 6% addition of cement.
- Sand is also an effective stabilizer for this lateritic soil based on the percentages of sand adopted. Although only one soil-sand mixture had a CBR value of up to 80%. The mix with a 30% addition of sand gave a maximum CBR value of 86% and, as such, is suitable for use as a high-quality base course material for road pavement. However, the rest of the soil-sand mixtures had a CBR value lower than 80%, but significantly higher than that of the unstabilized lateritic soil and, as such, are most suitable as a subbase material for road pavement.
- The varied percentage combination of cement and sand used in this investigation are very influential stabilizers for this lateritic soil because most of the soil-cement-sand mixtures have CBR values up to 80% and as such are suitable for use as a high-quality base course material. However, soil-cement-sand mixtures with 6% cement and 45% sand and also 9% cement and 45% gave a maximum CBR value of 112%, therefore, making them the most suitable base course material for road pavement.
- The shear strength of the soil-cement, soil-sand, and soil-cement-sand mixtures is directly proportional to the individual and combined percentage addition of cement and sand, but only up to certain percentage content.
- The increase in CBR values of the stabilized soil-cement mixtures is more significant than that of soil-sand and soil-cement-sand mixtures because a maximum CBR value of 175% was obtained in the 6% cement mix. Hence, it can be concluded that Portland cement is a more influential stabilizer than

sand or a combination of sand and cement for stabilizing lateritic soils for road pavement, based on the mixed proportions adopted in this research.

Conflicts of Interest

The authors declare no conflicts of interest.

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