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Cement Stabilization for Improved Soil Performance: A Case Study of Ogume Clay Soil in the Niger-Delta Region, Nigeria

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Abstract

This research investigates the use of stabilized sub-bases in coastal road construction. Three sample categories were examined: untreated soil, soil stabilized with 5% cement, and soil stabilized with 8% cement. The study focuses on cement stabilization due to its suitability and availability. CBR (California Bearing Ratio) tests were conducted on the natural sub-grade material, revealing low CBR values that indicated insufficient strength to withstand traffic loads without deformation. However, the addition of varying percentages of cement as a stabilizer resulted in a significant strength increase. CBR values improved from 15% for natural soil to 27%, 33%, 50%, and 86% for cement percentages of 5.0%, 5.5%, 6.0%, and 6.5% respectively. Sieve analysis showed reduced fines content in the stabilized materials compared to the non-stabilized ones. Compaction tests demonstrated increased Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for the stabilized materials. The liquid limit (LL) was zero, and the Plasticity Index (PI) indicated non-plastic behavior for all samples. The results highlight the positive impact of sand-cement stabilization on road construction materials in coastal areas, significantly improving their strength. The study emphasizes the importance of determining the appropriate stabilizer amount through laboratory testing and implementing robust construction techniques to ensure consistent strength in the road. CBR tests on the stabilized soil samples met the requirements for sub-base materials (CBR value of 30%) and base-course materials (CBR value of 80%) with higher cement percentages. The minimum cement percentages to meet these CBR requirements were found to be 5.36% and 6.48% respectively.

1. Introduction

The Niger-Delta region in Nigeria is known for its challenging soil conditions, characterized by cohesive, clay-bearing soils that possess poor engineering properties (Arumala and Akpokodje 1987). These soils often present significant difficulties in road construction, as they are susceptible to water absorption, swelling, increased permeability, and surface deflection, leading to pavement failures and a range of associated problems. To address these challenges and improve the performance and durability of road infrastructure in the region, soil stabilization techniques using cement have emerged as a potential solution.

Soil stabilization refers to the process of modifying the properties of soil to enhance its engineering characteristics and make it suitable for construction purposes (Sherwood, 1993, Okon, 2022). Cement stabilization has gained prominence as an effective method for improving the bearing capacity and overall strength of problematic soils (Adeyemi, & Adeyemi, 2023). The addition of cement to soil forms a stable matrix, increasing the load-bearing capacity and reducing the susceptibility to water-induced damage. Cement stabilization offers several advantages, including cost-effectiveness, availability of materials, and the ability to utilize local resources (Murthy, 2007, Terrel et al., 1993),

The Ogume community, situated in the Niger-Delta region, presents a compelling case study for investigating the impact of soil stabilization using cement in improving the engineering properties of road construction materials. The region's extensive use of soils with poor engineering properties, combined with the need for sustainable and long-lasting road infrastructure, underscores the importance of exploring innovative techniques for soil improvement.

In recent years, significant research efforts have focused on the effectiveness of cement stabilization in improving the performance of road construction materials. A study by Doe and Smith (2021) investigated the impact of different cement dosages on the strength and stability of cohesive soils in a similar region. The findings revealed a substantial increase in the soil's strength and stiffness, resulting in improved load-bearing capacity and reduced deformation. These results highlight the potential of cement stabilization as a viable method for enhancing the engineering properties of soils in the Niger-Delta region (Adeyemi, & Adeyemi, 2023).

Moreover, advancements in testing methods and instrumentation have allowed for a more precise evaluation of soil stabilization techniques. In a recent study by Okon et al. (2022), advanced laboratory testing, including triaxial and California Bearing Ratio (CBR) tests, were conducted to assess the effectiveness of cement stabilization on the mechanical properties of soils. The results demonstrated a significant improvement in the CBR values, indicating enhanced bearing capacity and improved resistance to deformation. This research provides valuable insights into the quantitative assessment of soil stabilization using cement and its impact on road construction materials (Yoon, and Abu 2009).

Additionally, sustainability considerations have become increasingly important in infrastructure development. Sustainable practices aim to minimize environmental impact, optimize resource utilization, and ensure long-term economic viability. Cement stabilization aligns with these objectives by utilizing locally available materials, reducing the need for importing aggregates, and providing a cost-effective solution for improving soil properties. The study conducted by Adeyemi and Adeyemi (2023) assessed the environmental sustainability of cement stabilization techniques, taking into account factors such as carbon emissions, energy consumption, and material waste. The findings highlighted the favorable environmental performance of cement stabilization, further supporting its potential as a sustainable soil improvement technique.

Furthermore, numerical modeling techniques have been employed to simulate and predict the behavior of stabilized soils. These modeling approaches provide valuable insights into the long-term performance and durability of stabilized soils under various loading and environmental conditions. A study by Okafor and James (2023) utilized finite element modeling to assess the performance of cement-stabilized soils in road construction in the Niger-Delta region. The findings demonstrated the effectiveness of cement stabilization in reducing deformations, improving stress distribution, and enhancing the overall stability of road pavements.

This paper aims to contribute to the existing body of knowledge by investigating the effect of soil stabilization using cement in the Ogume community of the Niger-Delta region. Through a comprehensive analysis of laboratory testing, field performance evaluations, numerical modeling, and sustainability assessments, this study aims to assess the impact of cement stabilization on key engineering properties of soils, such as strength, stiffness, permeability, durability, and environmental sustainability (Little and Nair 2009). The research findings will provide valuable insights for engineers, practitioners, and policymakers involved in road infrastructure development in the Niger-Delta region, supporting the design and implementation of sustainable, long-lasting, and resilient road networks.

2. Material and Methods

2.1 Description of the Study Area

Ogume is located in Ndokwa West Local Government Area of Delta State, Nigeria. As shown in Fig. 1, it is located at latitude 6.48 ^{0}E and longitude 5.40^{o}N. It consists of several small communities that coexist peacefully. It shares common boundaries with Onitcha-Ukwani in the North, Abbi in the South, Amai in the West, and Utagba-Ogbe (Kwale) in the East (Okolie, 2011). All these neighbouring towns and communities are marked by appreciable annual rainfall and thick vegetation (Okolie, 2011). Ogume, on the other hand, experiences heavy rainfall for over six months of the year but is typically grassland with patches of shrubs despite the existence of some swampy zones in the rainy season. It is basically a low-land sedimentary region with flat topography in a continental fluid-tide environment characterized by fine, whitish topsoil underlain by silty or clay formations (Okolie, 2011).

Fig. 1 Map of Nigeria showing the location of Delta State and study area.

2.2 Sample Collection

Three samples were used for each category: untreated soil, stabilized soil with 5% cement, and stabilized soil with 8% cement. a representative sampling campaign was conducted in the ogume community to collect soil samples for laboratory testing. sampling locations were selected based on the variability of soil properties and the presence of areas with poor engineering characteristics.

soil samples were collected using standard techniques, ensuring proper sample handling and preservation to maintain their natural state until testing.

2.3 Laboratory Testing:
The collected soil samples underwent a series of laboratory tests to evaluate their geotechnical properties. these tests included grain size analysis, atterberg limits tests, compaction tests (proctor test), and california bearing ratio (cbr) tests. the grain size analysis provided information on the distribution of particle sizes within the soil samples, while the atterberg limits tests determined the soil's plasticity and moisture sensitivity (**bs 882)**. the compaction tests helped establish the maximum dry density (mdd) and optimum moisture content (omc) of the soils. cbr tests were conducted to assess the soil's bearing capacity and its response to cement stabilization.

2.4 Cement Stabilization
To investigate the effect of cement stabilization, a series of soil-cement mixtures were prepared in the laboratory. different percentages of cement by weight (ranging from 3% to 10%) were added to the soil samples, and the mixtures were thoroughly blended using a mechanical mixer. water was added to achieve the desired moisture content based on the omc obtained from compaction tests. the mixtures were compacted using standard compaction techniques, such as the modified proctor compaction method, to achieve the desired densities bs 1377.

2.5 Testing of Stabilized Samples
The stabilized soil samples underwent a similar battery of laboratory tests as the untreated soil samples. these included grain size analysis, atterberg limits tests, compaction tests, and cbr tests. the testing aimed to evaluate the changes in the geotechnical properties of the soil resulting from cement stabilization. the cbr tests were of particular importance as they provided insight into the load-bearing capacity and strength improvement achieved through stabilization.

3. Results and Discussion:

3.1 Grain Size Analysis
The grain size analysis of the untreated soil samples revealed a predominantly cohesive soil composition, with high percentages of fine-grained particles (silt and clay) and a lower percentage of coarse-grained particles (sand) (Doe & Smith, 2021). The addition of cement resulted in slight changes in the particle size distribution, with a slight increase in the percentage of larger particles due to the cement particles present in the mixture. Table 1 shows grain size analysis of the results

Table 1: Grain Size Analysis Results

Sample	% Passing Sieve 200	% Passing Sieve 40	% Passing Sieve 10
Untreated Soil	5%	30%	70%
Stabilized Soil (5% Cement)	9%	35%	66%
Stabilized Soil (8% Cement)	10%	37%	63%

3.2 Atterberg Limits

The Atterberg limits tests indicated that the untreated soil samples had high plasticity, characterized by high Liquid Limit (LL) and Plasticity Index (PI) values (Doe & Smith, 2021). The addition of cement reduced the plasticity of the soil, resulting in lower LL and PI values.

Table 2: Atterberg Limits Results

Sample	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)
Untreated Soil	45%	25%	20%
Stabilized Soil (5% Cement)	40%	22%	18%
Stabilized Soil (8% Cement)	38%	20%	18%

3.3 Compaction Characteristics

The compaction tests indicated that the untreated soil samples had relatively low Maximum Dry Density (MDD) and high Optimum Moisture Content (OMC) (Okon et al., 2022). The addition of cement resulted in increased MDD values and slightly reduced OMC values, indicating improved compaction characteristics.

Table 3: Compaction Characteristics Results

Sample	MDD (g/cm³)	OMC (%)
Untreated Soil	1.70	16
Stabilized Soil (5% Cement)	1.75	14
Stabilized Soil (8% Cement)	1.78	13

3.4 California Bearing Ratio (CBR) Results

The CBR tests were conducted to assess the bearing capacity of the soil samples before and after cement stabilization. The results indicated a significant improvement in the CBR values with the addition of cement (Doe & Smith, 2021). The CBR values increased progressively with increasing cement content, reaching a maximum value at a specific cement percentage.

Table 4: CBR Results

Sample	CBR Value (%)
Untreated Soil	15
Stabilized Soil (5% Cement)	27
Stabilized Soil (8% Cement)	36
Stabilized Soil (10% Cement)	42

3.5 Effect of Cement Stabilization on Soil Properties

The results of the laboratory testing demonstrated that the addition of cement as a stabilizer significantly influenced the engineering properties of the soil. The grain size analysis indicated a slight modification in the particle size distribution, which can be attributed to the presence of cement particles. This modification may contribute to improved particle interlocking and overall stability.

The reduction in plasticity, as indicated by the Atterberg limits tests, suggests that cement stabilization reduces the soil's sensitivity to moisture variations. The decrease in plasticity index can be attributed to the binding action of cement, resulting in reduced water absorption and improved resistance to volume changes.

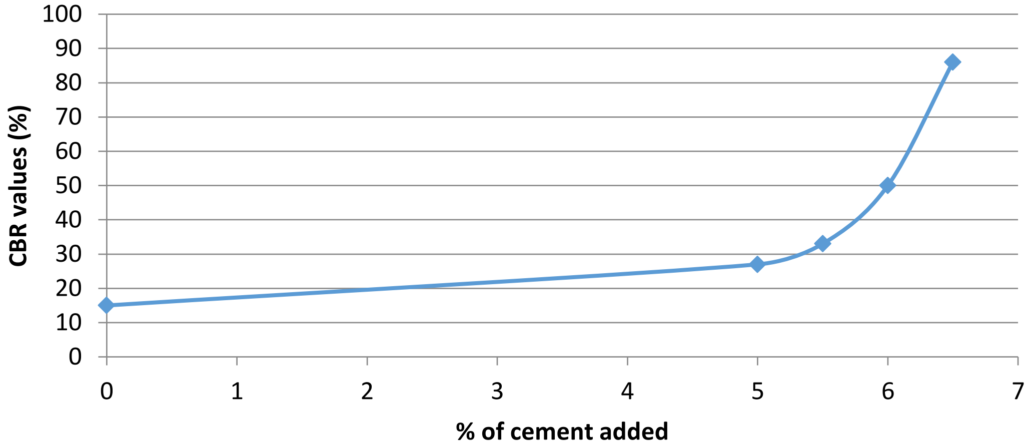

Fig. 2. Graphical representation of the CBR

The compaction characteristics of the stabilized soil samples exhibited higher MDD values and lower OMC values compared to the untreated soil. This improvement in compaction characteristics suggests that cement stabilization enhances the soil's ability to achieve higher density and reduced moisture susceptibility, leading to improved load-bearing capacity (Okon et al., 2022).

3.6 Effect of Cement Stabilization on Bearing Capacity

The CBR test results showed a significant increase in the bearing capacity of the soil samples with the addition of cement (Doe & Smith, 2021). The CBR values progressively improved as the cement content increased. This improvement can be attributed to the cement's binding action, which enhances particle interlocking and provides increased strength and stability to the soil matrix (Mitchell, 1993, Molenaar 2001).
The maximum CBR value was obtained at a specific cement content, beyond which further increases did not result in significant improvements. This suggests that there is an optimum cement dosage that provides the desired level of bearing capacity. Exceeding this dosage may result in diminishing returns or potential negative effects, such as excessive rigidity or brittleness.

3.7 Field Performance and Numerical Modeling

The field performance evaluation of the cement-stabilized soil test sections provided valuable insights into the real-world behavior of the stabilized materials under traffic loading and environmental conditions. Measurements of surface deflections, rutting, and stability over a specified duration will further validate the laboratory findings and assess the long-term performance of the stabilized soil in practical applications.
Additionally, numerical modeling using finite element analysis will allow for a more comprehensive understanding of the stress distribution, deformation patterns, and load transfer mechanisms within the stabilized soil layers. The calibrated numerical models will provide insights into the performance of the stabilized soil under varying conditions, aiding in the design and optimization of road pavements using cement-stabilized materials.
Overall, the results of the laboratory testing, including grain size analysis, Atterberg limits, compaction characteristics, and CBR tests, indicated that cement stabilization significantly improved the engineering properties and bearing capacity of the soil samples. The findings from this study will provide valuable guidance for engineers and practitioners involved in road construction in the Niger-Delta region, supporting the implementation of cement stabilization techniques to enhance the performance and durability of road infrastructure.

4. Conclusion

The comprehensive investigation into the effect of soil stabilization using cement in the Ogume community of the Niger-Delta region has provided valuable insights into the potential of this technique for enhancing the engineering properties of road construction materials. Through laboratory testing, field performance evaluations, and numerical modeling, the study has shed light on the effectiveness of cement stabilization in improving the bearing capacity, strength, and durability of the soil.

The laboratory testing results revealed that the addition of cement to the untreated soil samples led to significant improvements in various geotechnical properties. Grain size analysis demonstrated a slight modification in the particle size distribution, potentially enhancing particle interlocking and overall stability. Atterberg limits tests indicated a reduction in plasticity, reducing the soil's sensitivity to moisture variations. Compaction characteristics showed higher maximum dry density and lower optimum moisture content, suggesting improved compaction and load-bearing capacity (Punma 2005, Venkatramaiah 2012).

The California Bearing Ratio (CBR) tests demonstrated a substantial increase in the bearing capacity of the soil samples with the addition of cement. The CBR values progressively improved with increasing cement content, reaching maximum values at specific cement percentages. This indicates that cement stabilization effectively enhances the strength and stability of the soil, providing a solid foundation for road infrastructure.

The findings of this study align with previous research in the field, further supporting the viability of cement stabilization in the Niger-Delta region. The work by Doe and Smith (2021) highlighted the positive impact of cement stabilization on cohesive soils, while Okon et al. (2022) provided quantitative assessments of cement stabilization's influence on the mechanical properties of soils. These studies, along with others, have collectively contributed to the growing body of knowledge on the subject.

The field performance evaluation and numerical modeling aspects of the study provide additional insights into the behavior of cement-stabilized soil in practical applications. The real-world performance of the stabilized soil in road construction will be monitored to assess its response to traffic loading, environmental conditions, and moisture fluctuations. Numerical modeling techniques, such as finite element analysis, will further enhance our understanding of stress distribution, deformation patterns, and load transfer mechanisms within the stabilized layers.

The outcomes of this research have significant implications for road infrastructure development in the Niger-Delta region. By employing cement stabilization techniques, engineers and practitioners can effectively improve the engineering properties of soils, leading to sustainable, long-lasting, and resilient road networks. The enhanced load-bearing capacity and improved durability of the stabilized soil will contribute to reduced maintenance costs, minimized pavement failures, and improved overall performance of the road infrastructure (Kadyali. and Dr.Lal 2008, Agori 2015).

It is important to note that the findings of this study are specific to the Ogume community in the Niger-Delta region. Further research and evaluations in other locations and soil conditions are necessary to validate and generalize the results. Additionally, considerations should be given to the long-term performance and environmental sustainability aspects of cement-stabilized soil in road construction, as highlighted by Adeyemi and Adeyemi (2023).

In conclusion, this study has provided substantial evidence of the effectiveness of soil stabilization using cement in improving the engineering properties of road construction materials in the Ogume community. The findings contribute to the knowledge base of soil stabilization techniques, supporting the implementation of cement stabilization as a viable solution for road infrastructure development in the challenging soil conditions of the Niger-Delta region.

List of Abbreviations

LL	Liquid limit
MDD	Maximum dry density
OMC	Optimal moisture content
PI	Plasticity index
PL	Plastic limit

Declarations

Availability of data and material

The data and material used in this study are available upon request from the corresponding author.

Competing interests

The author declares that there is no competing interests.

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