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Stabilization of Soil Using Grinded Rice Husk Powder for Pavement Application

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Abstract: ***This study examined the effectiveness of ground rice husk powder (GRHP) as a sustainable stabilizing material for improving the engineering properties of lateritic soil intended for pavement subgrade applications. Laboratory investigations were conducted on natural soil and soil samples stabilized with varying GRHP contents of 0%, 2%, 4%, 6%, 8%, and 10%. The experimental programme included Atterberg limits, Standard Proctor compaction, soaked California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) tests. The results revealed a continuous reduction in liquid limit and plasticity index with increasing GRHP content, indicating reduced soil plasticity and improved stability. Compaction results showed a decrease in optimum moisture content and an increase in maximum dry density, with optimum performance achieved at 8% GRHP. Similarly, CBR and UCS values increased significantly with the addition of GRHP, attaining peak values of 19.6% and 166.7 kN/m², respectively, at 8% GRHP, before showing a slight decline at higher contents. These findings demonstrate that GRHP enhances the strength and load-bearing capacity of lateritic soil. The study concludes that ground rice husk powder is an effective, economical, and environmentally friendly soil stabilizer, with an optimum content of 8%, suitable for pavement subgrade improvement.***

Keywords: Pavement subgrade, lateritic soil, ground rice husk powder, soil stabilization, California Bearing Ratio, unconfined compressive strength.

I. INTRODUCTION

Pavement infrastructure is essential to national development as it facilitates transportation, trade, and economic growth. Based on structural performance, pavements are generally classified into rigid and flexible types, with each system designed to distribute traffic loads to the underlying soil in different ways. In many developing regions, particularly in parts of Asia and Africa, road pavements are commonly constructed directly on natural ground. Consequently, pavement performance and durability depend largely on the engineering properties of the surrounding and underlying soil, making soil strength assessment a critical component of pavement design, construction, and performance evaluation (Jaiswal & Lal, 2016).

Soil behavior is inherently complex due to variations in geological origin, depositional history, stress conditions, and mineral composition, which collectively influence particle size, shape, plasticity, and strength characteristics. Numerous studies have shown that civil engineering structures, especially pavements constructed on weak or poorly compacted soils, are susceptible to excessive deformation, settlement, and premature failure under traffic loading and environmental influences (Chen *et al*., 2022). Therefore, civil infrastructure that interacts directly with soil requires comprehensive geotechnical evaluation to ensure long-term performance and structural safety.

Geological and topographical conditions further influence construction practices and project outcomes. In regions dominated by weak or lateritic soils, inadequate subgrade strength often results in differential settlement and reduced pavement service life. Replacing unsuitable soils or relocating road alignments is frequently impractical and economically inefficient, highlighting the need for effective and affordable methods to improve in-situ soil properties (Latifi *et al*., 2016).

Soil stabilization has therefore become a crucial practice in pavement engineering for enhancing the mechanical properties of weak soils. Conventional stabilization techniques commonly involve the use of chemical additives such as Portland cement, lime, and fly ash, which improve soil strength through pozzolanic reactions and enhanced particle bonding. Although these methods have proven effective, their high cost and environmental concerns associated with material production have encouraged the search for sustainable alternatives.

In recent years, increasing attention has been directed toward the use of agricultural waste materials as soil stabilizers due to their availability, low cost, and environmental benefits. Rice husk, an abundant by-product of rice milling, poses significant disposal challenges when not properly managed.

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When processed into fine powder, rice husk exhibits pozzolanic characteristics that make it potentially suitable for improving soil engineering properties. The application of ground rice husk powder offers a cost-effective and environmentally friendly approach to soil stabilization while promoting sustainable waste management practices.

Therefore, this study investigates the effectiveness of ground rice husk powder as a stabilizing agent for lateritic soil by examining its influence on plasticity characteristics, compaction behavior, strength, and load-bearing capacity relevant to pavement subgrade applications. The findings are expected to support sustainable pavement engineering practices and provide technical guidance for the utilization of agricultural waste materials in soil stabilization.

II. LITERATURE REVIEW

The performance, durability, and safety of pavement infrastructure are strongly influenced by pavement structural design, traffic characteristics, and the engineering properties of the underlying subgrade soil. In developing regions such as Nigeria, challenges including premature pavement deterioration, traffic congestion, and road safety problems have frequently been associated with inadequate pavement design and weak subgrade support. Previous studies have emphasized that insufficient subgrade strength and excessive soil plasticity are major contributors to pavement distress and reduced service life (Jaiswal & Lal, 2016; Chen *et al.*, 2022).

Several studies conducted in Anambra State have demonstrated the relationship between pavement condition, subgrade adequacy, and road functionality. Anene *et al.* (2023) analyzed traffic congestion at the Eke-Nibo Junction in Awka South Local Government Area and reported that poor pavement condition, geometric deficiencies, and inadequate structural capacity were major contributors to congestion. Similarly, Anene *et al*. (2023) assessed road traffic accidents along the Onitsha–Owerri Expressway and found that deficiencies in pavement structure and design significantly influenced accident occurrence. These findings are consistent with broader transportation engineering studies that link pavement structural inadequacy and weak subgrade support to operational inefficiencies and safety challenges (Garber & Hoel, 2015).

Beyond pavement surface performance, the geotechnical characteristics of subgrade soils play a critical role in pavement durability. A comparative geotechnical investigation by Anene *et al.* (2025) across Onitsha, Nnewi, Awka, and Ihembosi revealed significant variability in soil properties, with many lateritic soils exhibiting high plasticity, low bearing capacity, and unfavorable compaction characteristics. Similar observations have been reported for tropical and lateritic soils in other regions, where untreated soils often fail to meet standard subgrade requirements without improvement (Gidigasu, 2015; Oyediran& Ayeni, 2020). These studies highlight the necessity for soil stabilization to enhance load-bearing capacity and long-term pavement performance.

Traditional soil stabilization techniques, particularly soil–cement stabilization, have been widely adopted to address weak subgrade conditions. Ogunjiofor*et al*. (2025) reported that cement addition significantly improves soil strength and stability, making treated soils suitable for engineering applications. This agrees with findings by Basha *et al.* (2005) and Ingles and Metcalf (2012), who demonstrated that cementitious reactions improve soil fabric, reduce plasticity, and enhance strength. However, despite their effectiveness, conventional stabilization methods are often associated with high cost and environmental concerns related to cement production, prompting increasing interest in sustainable alternatives (Latifi *et al*., 2016).

Recent research trends have increasingly focused on the use of agricultural waste and natural materials to improve engineering performance while promoting sustainability. Studies on natural fibre-reinforced concrete have shown that agricultural waste fibres can enhance mechanical properties through improved bonding and crack-bridging mechanisms. Ogunjiofor*et al.* (2024) reported a significant increase in the tensile strength of concrete produced using coconut fibre, while Ogunjiofor*et al*. (2025) observed similar strength enhancement with the incorporation of oil palm fibre. Comparable improvements in soil behavior using agricultural waste-derived materials, such as rice husk ash, have also been reported, including reductions in plasticity and increases in strength and bearing capacity (Muntohar& Rahman, 2017; Rahman &Muntohar, 2020).

Although many of these studies focused on concrete or ash-based additives, the fundamental mechanisms of strength enhancement—such as improved particle contact, interfacial bonding, and increased resistance to deformation—are also relevant to soil stabilization. Similar interactions may occur when finely processed agricultural waste materials are incorporated into weak soils, leading to improvements in soil strength and load-bearing capacity. However, relatively few studies have specifically examined the use of rice husk in finely ground powder form for stabilizing lateritic soils intended for pavement subgrade applications.

A comprehensive assessment of ground rice husk powder as a sustainable stabilizing agent for improving the plasticity, compaction behavior, strength, and bearing capacity of lateritic soils is therefore lacking. By experimentally evaluating the efficacy of ground rice husk powder for pavement subgrade stabilization, this study aims to address this identified research gap.

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III. MATERIALS AND METHODS

A. Research Design

This study adopted an experimental research design to evaluate the effectiveness of ground rice husk powder (GRHP) as a stabilizing agent for improving the engineering properties of weak lateritic subgrade soils. The experimental approach was considered appropriate because it allows for controlled variation of stabilizer content and systematic assessment of its influence on key geotechnical parameters under laboratory conditions.

Natural soil samples were collected from selected locations, and soil–GRHP mixtures containing varying proportions of the stabilizer were prepared. Both untreated and treated soil samples were then subjected to laboratory testing under controlled conditions. In this study, the percentage of ground rice husk powder added to the soil constituted the independent variable, while the dependent variables included plasticity characteristics, compaction behavior, strength, and load-bearing capacity.

Standard geotechnical laboratory tests were employed to evaluate these parameters, enabling direct comparison between natural and stabilized soil samples. This approach ensured that the effects of ground rice husk powder on soil behavior were quantitatively assessed using reliable and reproducible experimental procedures. Consequently, the experimental design provided an objective basis for determining the optimum stabilizer content suitable for pavement subgrade applications.

B. Design of the Study

This study was designed as a structured experimental investigation conducted in sequential phases to evaluate the effectiveness of ground rice husk powder (GRHP) as a stabilizing agent for weak lateritic subgrade soils. The first phase involved soil sampling and preliminary characterization to establish the baseline engineering properties of the natural soil. This was followed by the preparation of stabilized soil mixtures containing varying proportions of GRHP. The final phase consisted of laboratory testing and comparative evaluation of untreated and treated soil samples to assess the influence of GRHP on soil behavior.

During the sampling and characterization phase, soil samples were collected from selected locations in Otuocha and subjected to preliminary tests, including natural moisture content determination, particle size distribution, Atterberg limits, and compaction tests. These tests provided essential information on the initial plasticity, grading characteristics, and compaction behavior of the soil.

In the stabilization phase, ground rice husk powder was incorporated into the soil at proportions of 2%, 4%, 6%, 8%, and 10% by dry weight of the soil. Each soil–GRHP mixture was thoroughly homogenized to ensure uniform distribution of the stabilizer and cured under controlled laboratory conditions for a specified period. The stabilized samples were subsequently subjected to standard geotechnical tests, including California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and Atterberg limits tests. The results obtained were compared with those of the untreated soil to determine the effectiveness of GRHP and to identify the optimum stabilizer content for pavement subgrade applications.

C. Area of Study

Soil samples used in this study were obtained from Otuocha, a semi-urban town located in Anambra East Local Government Area of Anambra State, Nigeria. Otuocha lies within the Anambra Basin and is predominantly underlain by lateritic soils typical of tropical climatic conditions. The area has experienced frequent pavement failures, which have been largely attributed to poor subgrade soil properties, particularly during the rainy season when the soils exhibit increased plasticity and reduced strength.

The study area is suitable for this research not only because of its geotechnical characteristics but also due to the presence of rice milling activities in nearby settlements. These rice mills provide a readily available source of rice husk, making Otuocha an appropriate location for evaluating the potential of ground rice husk powder (GRHP) as a sustainable and locally sourced stabilizing material for pavement subgrade applications.

D. Sample Collection and Sampling Technique

A purposive sampling technique was adopted to select soil sampling points from locations in Otuocha with a documented history of pavement distress. This approach was considered appropriate because it allowed for the deliberate selection of soils with unfavorable engineering properties, which are most suitable for stabilization studies.

Soil samples were collected from depths ranging between 0 and 1.5 m below the ground surface using hand augers and spades. To prevent contamination and moisture loss, the collected samples were placed in labeled polyethylene bags and transported to the geotechnical laboratory for analysis. The ground rice husk powder (GRHP) used for stabilization was sourced from rice processing mills in nearby towns such as Omor and Nteje, where rice milling activities are prevalent.

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E. Instruments and Apparatus

Standard geotechnical laboratory equipment was used in this study to ensure accuracy, reliability, and repeatability of the experimental results. Compaction moulds fitted with manual or automatic rammers were employed for Proctor compaction tests, while sieve sets and mechanical shakers were used for particle size distribution analysis. Atterberg limit tests were conducted using Casagrande apparatus and standard grooving tools.

The load-bearing capacity and strength characteristics of the soil samples were evaluated using California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) testing machines, respectively. Additional equipment, including drying ovens, digital balances, desiccators, mixing bowls, graduated cylinders, mixing trays, and spatulas, was used for sample preparation, moisture control, and thorough mixing of soil with the stabilizing agent.

F. Method of Data Collection

Data collection for this study involved a combination of field sampling and laboratory testing procedures. In the field, disturbed soil samples were collected from selected locations using appropriate hand tools. The samples were immediately sealed in labeled polyethylene bags to prevent contamination and moisture loss and were subsequently transported to the geotechnical laboratory for analysis.

In the laboratory, the soil samples were air-dried, gently pulverized, and passed through a 4.75 mm sieve to obtain uniform test specimens. Ground rice husk powder was produced using a milling machine and oven-dried to remove residual moisture prior to use. Each soil sample was then mixed with ground rice husk powder at the specified proportions and subjected to a series of standard geotechnical laboratory tests.

The tests conducted included Atterberg limits tests to evaluate soil plasticity, Standard Proctor compaction tests to determine the maximum dry density (MDD) and optimum moisture content (OMC), California Bearing Ratio (CBR) tests to assess load-bearing capacity, and Unconfined Compressive Strength (UCS) tests to determine strength characteristics of the stabilized soils. All observations and measurements obtained during the testing process were carefully recorded for subsequent analysis.

G. Method of Data Analysis

The experimental data obtained from the laboratory tests were analyzed using descriptive and inferential statistical techniques. Descriptive statistics, including mean values, percentages, and standard deviations, were employed to summarize the results of the various geotechnical tests. Graphical representations such as line graphs and bar charts were used to illustrate trends in soil behavior with increasing ground rice husk powder (GRHP) content.

Comparative analysis was carried out to identify the percentage of ground rice husk powder that yielded optimum performance in terms of strength, compaction characteristics, and load-bearing capacity. Where applicable, regression analysis was performed using Microsoft Excel or SPSS software to model the relationship between stabilizer content and key soil improvement parameters. This analytical approach facilitated the determination of the optimum dosage of ground rice husk powder suitable for pavement subgrade applications.

IV. RESULTS AND DISCUSSION

A. Introduction

The results of laboratory tests conducted on natural and stabilized soil samples treated with varying proportions of ground rice husk powder (GRHP) as a stabilizing agent are presented in this chapter. The tests performed include Atterberg limits, Standard Proctor compaction, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS). The findings are discussed in terms of improvements in the engineering properties of the soil and their suitability for pavement subgrade applications.

B. Atterberg Limits

The Atterberg limits tests were conducted to evaluate the plasticity characteristics of both untreated and ground rice husk powder (GRHP)-stabilized soil samples.

Table 1: Atterberg Limits of Soil Samples with Varying Ground Rice Husk Powder (GRHP) Content

GRHP Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0	48.3	24.5	23.8
2	45.2	25.8	19.4

4	42.6	26.7	15.9
6	39.8	27.6	12.2
8	37.5	28.2	9.3
10	36.1	28.7	7.4

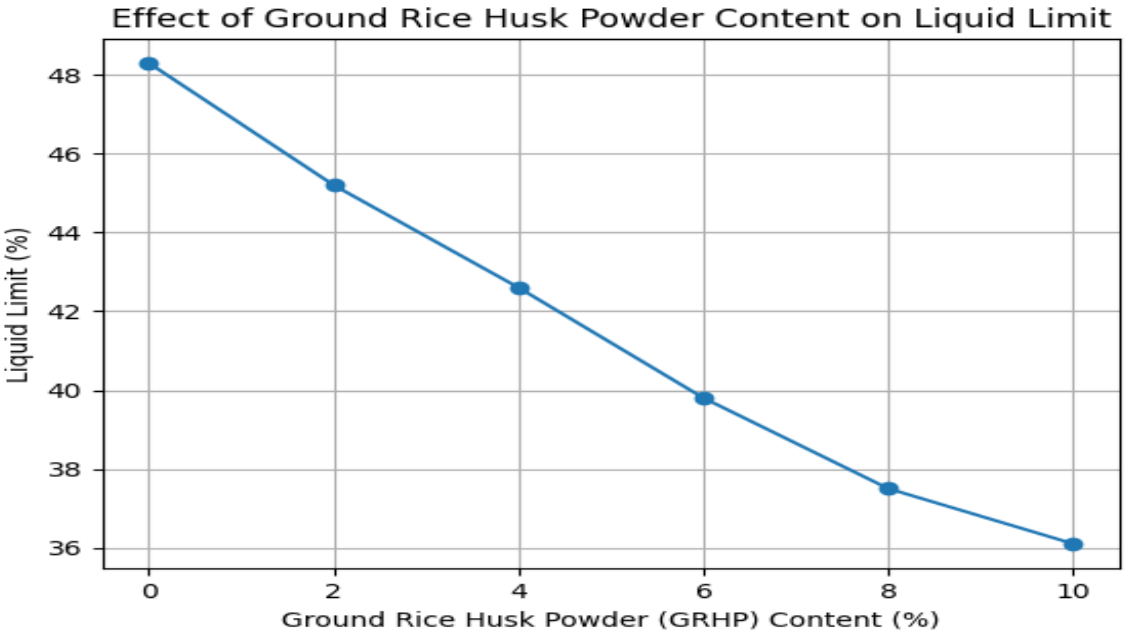
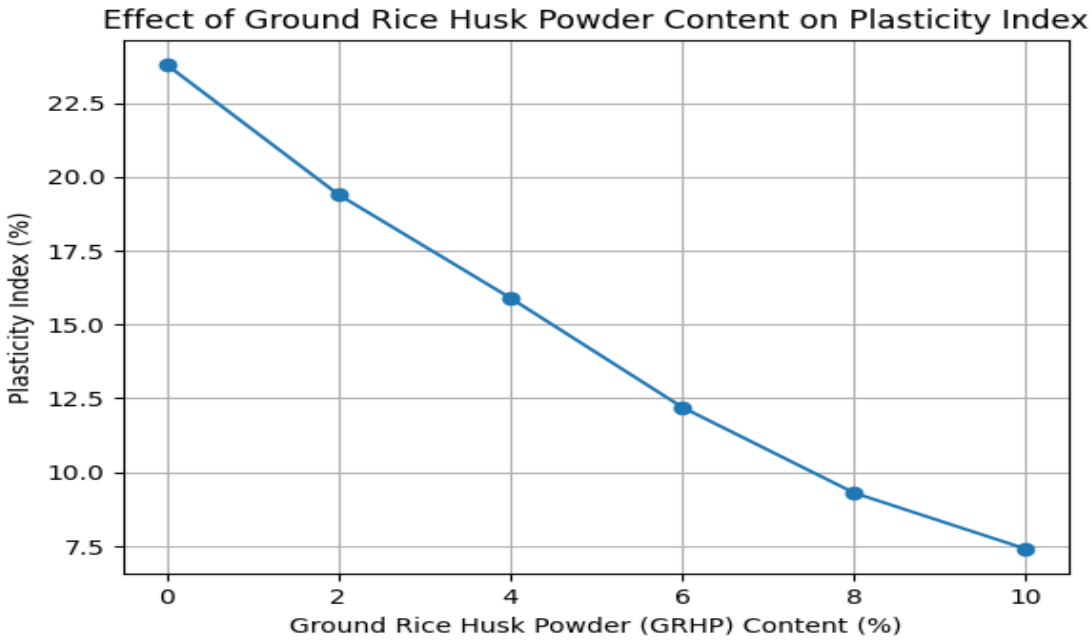


Figure 1 Effect of Ground Rice Husk Powder (GRHP) Content on Liquid Limit



C. Compaction Test (Standard Proctor)

The Standard Proctor compaction test was conducted to determine the optimum moisture content (OMC) and maximum dry density (MDD) of both untreated and ground rice husk powder (GRHP)–stabilized soil samples.

Table 2: Compaction Test Results

GRHP Content (%)	OMC (%)	MDD (g/cm3)
0	17.5	1.83
2	16.9	1.86
4	16.2	1.88
6	15.7	1.91
8	15.3	1.93
10	15.1	1,91

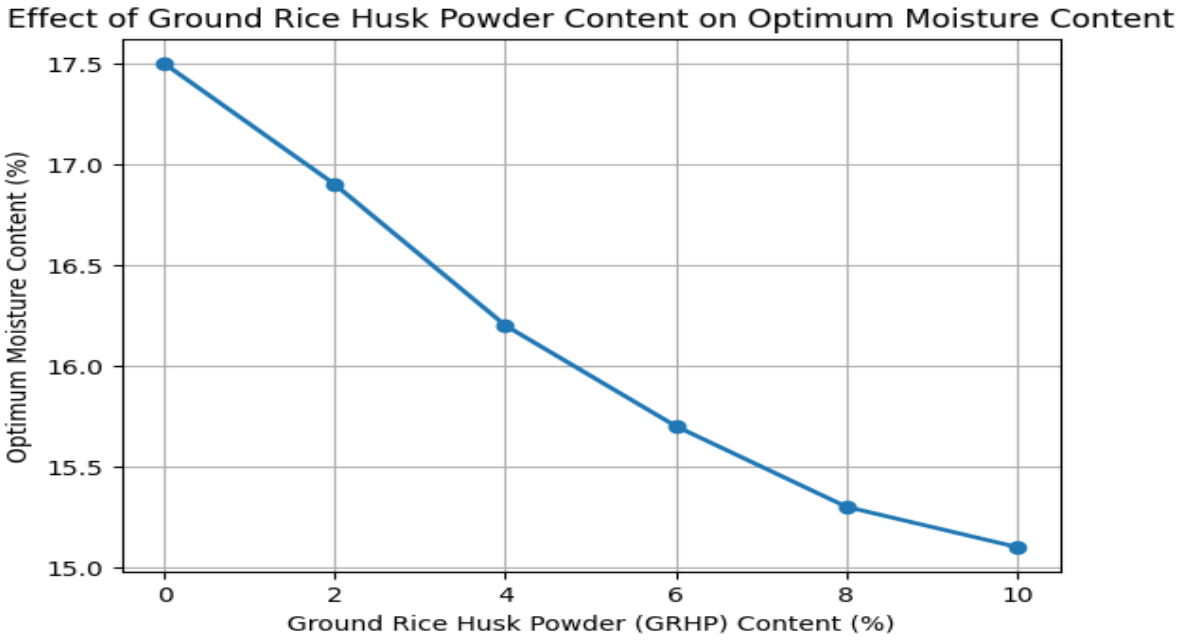


Figure 3: Effect of Ground Rice Husk Powder (GRHP) Content on Optimum Moisture Content (OMC)

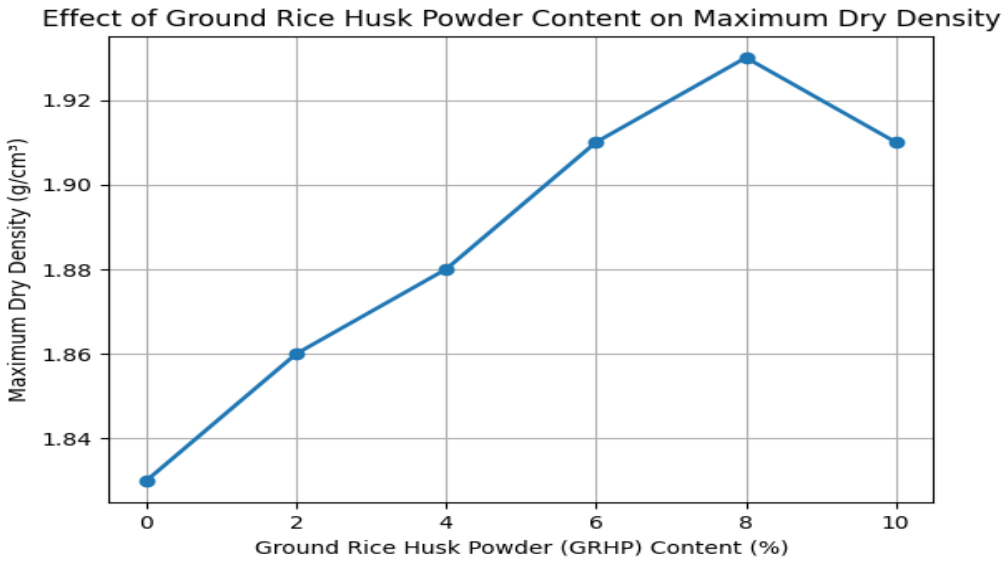


Figure 4: Effect of Ground Rice Husk Powder (GRHP) Content on Maximum Dry Density (MDD)

D. California Bearing Ratio (CBR)

Soaked California Bearing Ratio (CBR) tests were conducted to evaluate the load-bearing capacity of untreated and ground rice husk powder (GRHP)–stabilized soil samples under simulated field moisture conditions.

Table 3: CBR Test Results

GRHP Content (%)	CBR (%)
0	5.8
2	8.4
4	11.7
6	15.2
8	19.6
10	18.5

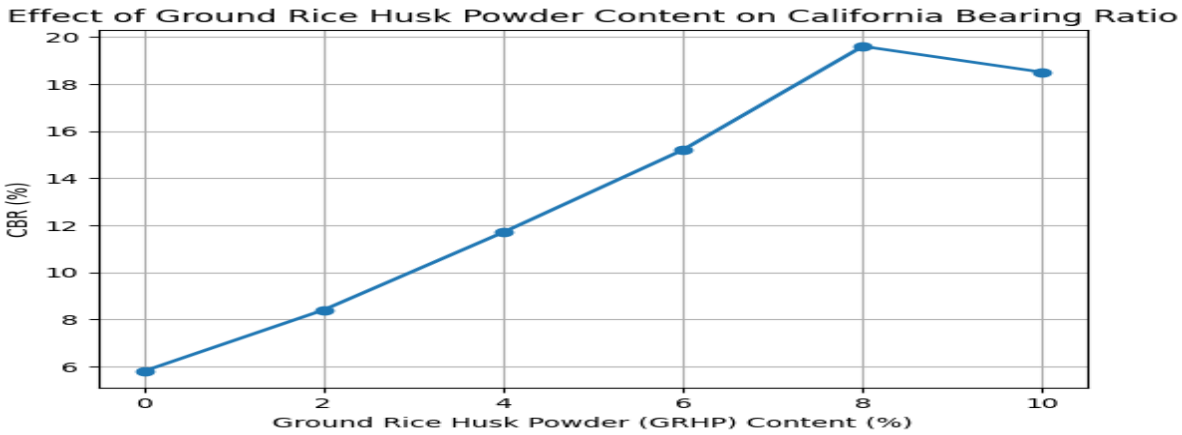


Figure 5: Effect of Ground Rice Husk Powder (GRHP) Content on California Bearing Ratio (CBR)

E. Unconfined Compressive Strength (UCS)

Table 4: UCS Test Results

GRHP Content (%)	UCS (kN/nn2)
0	58.3
2	82,6
4	105.1
6	138,4
8	166,7
10	160.3

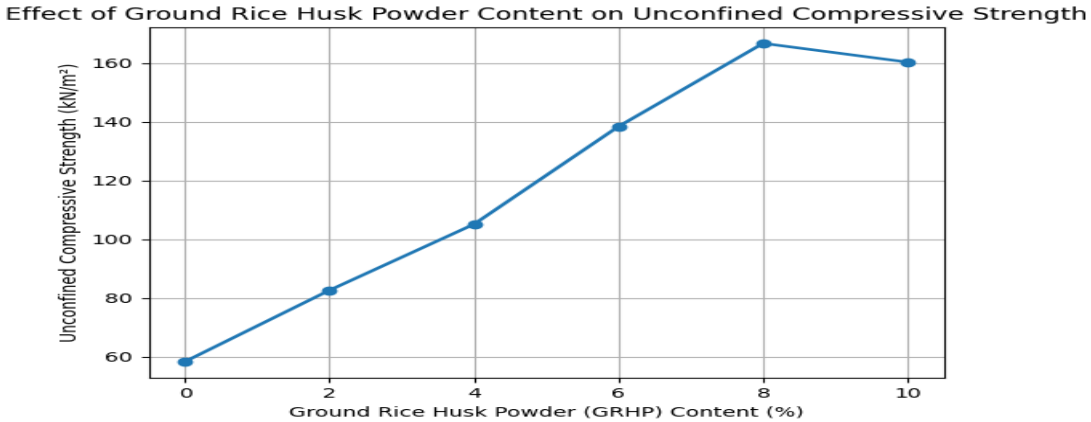


Figure 6 Effect of Ground Rice Husk Powder (GRHP) Content on Unconfined Compressive Strength (UCS)

Figures 1 and 2 show the effect of ground rice husk powder (GRHP) content on the liquid limit and plasticity index of the soil. A progressive reduction in both parameters was observed with increasing GRHP content, indicating a decrease in clay activity and an improvement in soil stability. The reduction in plasticity index further suggests a lower swelling potential, which is desirable for pavement subgrade materials.

Figures 3 and 4 illustrate the influence of GRHP content on the compaction characteristics of the soil. The optimum moisture content (OMC) decreased steadily with increasing GRHP content, reflecting a reduced water requirement for effective compaction. Conversely, the maximum dry density (MDD) increased progressively up to 8% GRHP, after which a slight reduction was observed at 10% GRHP. The peak MDD value of 1.93 g/cm³ at 8% GRHP indicates improved particle packing and densification, contributing to enhanced soil strength and durability.

Figures 5 and 6 present the variation of California Bearing Ratio (CBR) and unconfined compressive strength (UCS) with GRHP content. Both CBR and UCS increased consistently with GRHP addition, reaching maximum values at 8% GRHP before showing a slight decline at 10%. This behavior confirms that GRHP significantly enhances the load-bearing capacity and strength of the soil. The convergence of optimum values for MDD, CBR, and UCS at 8% GRHP clearly identifies this proportion as the optimum stabilizer content for improving the engineering performance of the lateritic soil for pavement subgrade applications.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

This study evaluated the effectiveness of ground rice husk powder (GRHP) as a stabilizing agent for improving the engineering properties of lateritic soil intended for pavement subgrade applications. Laboratory investigations conducted included Atterberg limits, Standard Proctor compaction, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) tests.

The results showed a progressive reduction in soil plasticity with increasing GRHP content, indicating improved soil stability. Compaction characteristics revealed a decrease in optimum moisture content and a corresponding increase in maximum dry density, with optimum performance achieved at 8% GRHP. Similarly, both CBR and UCS values increased significantly with GRHP addition, attaining peak values at 8% GRHP before exhibiting a slight reduction at higher stabilizer contents. These findings confirm that ground rice husk powder is an effective and sustainable stabilizing material, with 8% GRHP identified as the optimum content for enhancing the performance of lateritic soil as a pavement subgrade.

B. Recommendations

Based on the findings of this study, the following recommendations are made:

Ground rice husk powder (GRHP) should be considered as a low-cost, sustainable, and environmentally friendly stabilizing agent for improving weak lateritic subgrade soils.

The use of GRHP is recommended for pavement construction projects, particularly in regions where rice husk waste is readily available.

Field-scale investigations are recommended to validate the long-term performance and durability of GRHP-stabilized soils under actual traffic loading and environmental conditions.

Further research should examine the combined application of GRHP with conventional stabilizers such as lime or cement, as well as conduct economic and life-cycle cost analyses to assess the feasibility of large-scale implementation.

Compliance with Ethical Standards

Disclosure of Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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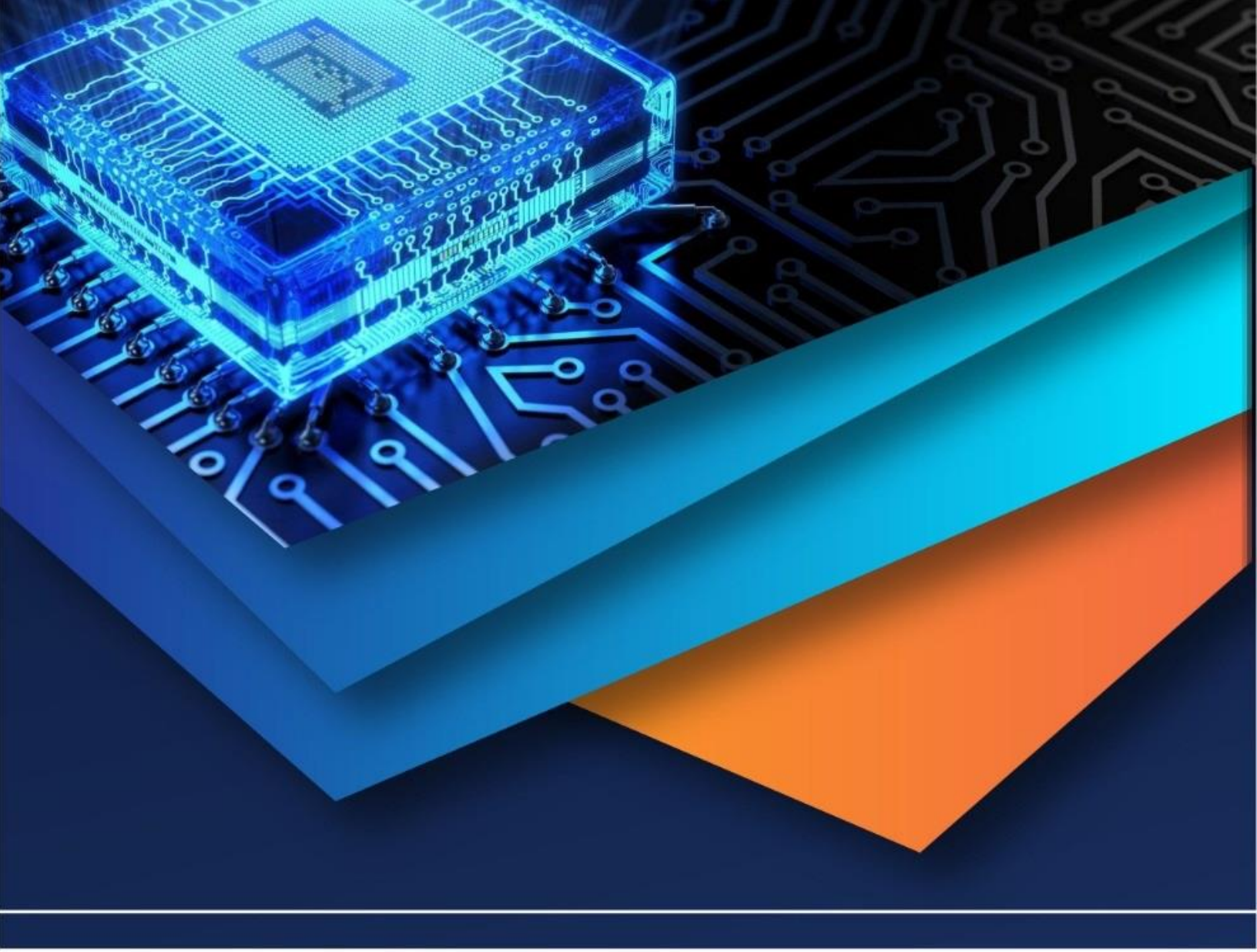
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