Clayey Soil Stabilization Using Rice Husk Ash & Perlite

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Abstract

Clayey soils, characterized by their high plasticity and low strength, pose significant challenges in construction and geotechnical engineering. This study investigates the efficiency of rice husk ash (RHA) and perlite as sustainable stabilizers for improving the engineering properties of clayey soils. Rice husk ash, an agricultural by-product, and perlite, a volcanic glass, were utilized in varying proportions to treat the soil. A comprehensive suite of laboratory tests, including Atterberg limits, Light compaction, unconfined compressive strength (UCS), was conducted to evaluate the mechanical and physical properties of the stabilized soil. The results demonstrated that the addition of RHA and perlite significantly enhanced the soil's strength and reduced its plasticity. The optimal mix of 9% RHA and 8% perlite yielded the highest UCS values, indicating a substantial improvement in load-bearing capacity and stability. The formation of cementitious compounds, such as calcium silicate hydrate (C-S-H), during addition of RHA and Perlite contributed to the soil's enhanced strength and durability. The study concludes that the combined use of RHA and perlite is an effective, eco-friendly, and cost-efficient method for clayey soil stabilization, offering promising alternative to traditional stabilizers like lime and cement. This approach not only addresses the challenges of weak clayey soils but also promotes the sustainable utilization of industrial and agricultural waste materials.

Keywords: Clayey soil stabilization, Rice husk ash (RHA), Perlite, Unconfined compressive strength (UCS), Atterberg limits, Sustainable construction.

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1. Introduction

Clayey soils, ubiquitous in many regions, present significant challenges in geotechnical engineering due to their inherent plasticity, low permeability, and pronounced volume changes in response to moisture variations. These characteristics often manifest as lowshear strength, high compressibility, and susceptibility to swelling and shrinkage, compromising the stability and long-term performance of structures founded upon them. Effective soil stabilization is therefore paramount to mitigate these undesirable properties and ensure reliable infrastructure development. This report investigates the efficacy of perlite and rice husk ash (RHA) as stabilizing agents for clayey soils, examining their individual and combined influence on key geotechnical parameters. Perlite's unique structure contributes to enhanced soildrainage, a reduction in plasticity index, and improved workability. RHAis a rich source of silica and exhibits pozzolanic properties. These pozzolanic characteristics enable RHA to react with calcium hydroxide, a byproductof cement hydration, in the presence of moisture, leading to the formation of cementitious compounds. This reaction contributes to increased strength, reduced compressibility, and improved durability of the stabilized soil matrix.

This study systematically evaluates the influence of varying percentages of perlite and RHA on the geotechnical properties of a representative clayey soil. The investigation encompasses a comprehensive analysis of Atterberg limits and compaction characteristics. By meticulously examining these parameters, the research aims to identify the optimal proportions of perlite and RHAthat achieve the most significant improvements in the engineering characteristics of the clayey soil. Furthermore, the study explores potential synergistic effects arising from the combined use of perlite and RHA, recognizing that their individual stabilization mechanisms may be complementary.

The results of this research will provide valuable insights into the underlying mechanisms governing the stabilization process using these materials, offering a potentially cost-effective and environmentally sustainable alternative to conventional stabilization methods. This report aims to contribute to a deeper understanding of perlite and RHA stabilization and provide practical guidelines for their application in geotechnical engineering projects, ultimately promoting more resilient and sustainable construction practices.

1.1. Objectives of the Study

- To enhance soil's compressive and shear strength for better structural support.
- To minimize volume changes due to moisture variations, preventing cracks and instability.
- Lowering plasticity and permeability, reducing waterlogging and pore pressure.
- Utilization of eco-friendly waste materials (RHA and Perlite) reducing environmental impact and costs.
- To alter soil texture for easier excavation, handling, and faster construction.

1.2. Scope of the Study

- Improve soil stability.
- Reducing plasticity of highly plastic clay soil
- Assessing strength enhancement.
- Determination of the optimal RHA and Perlite proportions for stabilizing the soil.
- Evaluating the environmental and economic sustainability of using RHA and Perlite as stabilizing agent.

2. Materials And Methods

2.1. Materials Used

The various materials used in the experimental program are described below.

Clayey Soil

The collection of soil samples, was conducted in Nilambur in Malappuram District, at locations identified with building foundation failures, characterized by cracking and settlement. Standard tests including Specific gravity test, Dry Sieve Analysis and Hydrometer Analysis, Atterberg's Limits, Unconfined compressive strength, Light Compaction were performed to determine the Properties of the soil.

Figure 1: Clayey soil

Details are given in Table 1. Grain size distribution of the soils is shown in 2. According to the Unified Soil Classification System (USCS), the soil sample collected is classified as High Plasticity Clayey soil (CH).

Properties	Value
Natural Water Content,WC,%	25.33
Liquid Limit, LL %	74
Plastic Limit, PL, %	33.27
Plasticity Index, PI	40.73
Specificgravity	2.6
Gravel (>4.75mm)%	1.25
Sand (0.075 – 4.75mm) %	19.49
Silt (0.002 – 0.075mm)%	36.70
Clay (<0.002mm)	43.81
Dry Density, g/cc	1.6
Unconfined Compressive Strength, kN/m^2	61.78
Undrained Shear Strength,kN/m^2	30.40
Soil Classification (USCS)	CH

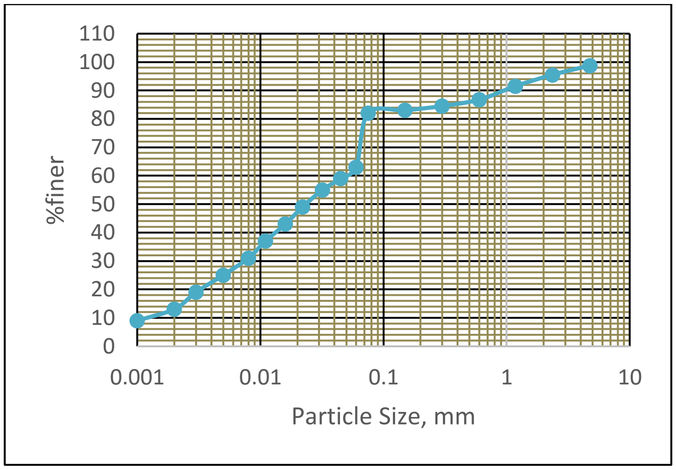

Figure 2: Particle Size Distribution Curve

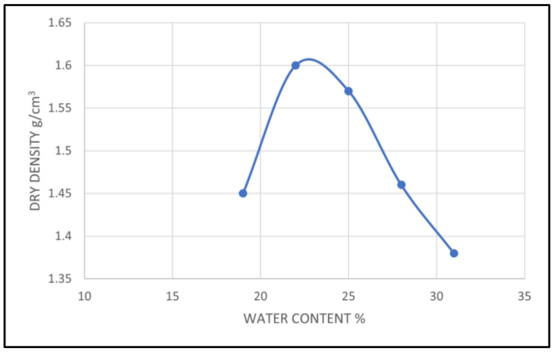

Figure 3: Dry Density v/s Water content of Soil sample

Table 1: Properties of Clayey soil

Rice Husk Ash

Rice husk ash (RHA)is a by product obtained from the combustion of rice husks, which are the outer protective layers of rice grains.RHA's high silica content and pozzolanic activity make it a valuable resource for enhancing soil properties and improving soil conditions.

Figure 4: Rice Husk Ash

Perlite

Perliteis a naturally occurring lightweight, porous, volcanic glass. Perlite acts as a structural amendment, modifying the physical properties of the soil to improve its stability, drainage, and workability. This makes it a valuable tool in various soil stabilization applications.

Figure 5: Perlite

2.2. Laboratory Investigations

The initial testing program was conducted on the clayey soil samples to determine its basic and engineering properties at their natural state. After initial study, Tests are conducted in two phases. The first phase was the case only Rice Husk Ash used as stabilization admixture and the second phase was the case both RHA and Perlite used as stabilization admixtures. Laboratory Tests including Atterberg's Limit, Unconfined Compressive Strength, Light Compaction are conducted on both phases.

Liquid limit: The liquid limit test was conducted on samples passing 0.425 mm (No. 40) sieve; clayey soil, soil mixed with (0, 3, 6 and 9%) rice husk and soil mixed with 9% RHA and Perlite (0%, 4%, 8%, 12%) using Casagrande's liquid limit apparatus as per the procedures laid down in ASTM D 4318-00.

Plastic limit: The plastic limit test was conducted on samples passing 0.425 mm (No. 40) sieve; clayey soil, soil mixed with (0, 3, 6 and 9%) rice husk and soil mixed with 9% RHA and Perlite (0%, 4%, 8%, 12%), as per the specifications laid down in ASTM D 4318-00. Plasticity index were calculated from obtained results.

Compaction: The standard proctor compaction tests were performed in accordance with ATSM D 698.Standard proctor Test Apparatus is used. The tests are conducted on samples retained between 20mm and 4.75mm sieves. The tests determine the relationship between holding water content and Dry unit weight of soil samples (compaction curve) using a standard compaction effort.

Unconfined compression test: This test was conducted on samples passing 0.425 mm (No. 40) sieve in accordance with ASTM D 2166-00. The sample sizes were of 38 mm diameter and 76 mm length. At the optimum moisture content (OMC) and maximum dry unit weight, the tests were performed.

3. Results And Discussion

This study investigates the impact of varying proportions of perlite and rice husk ash on the stabilization ofdifferentsoil properties. The results and discussions on this study are given below.

3.1 Effect on Atterberg's limits

3.1.1 Effect on Liquid Limit

The first phase tests evaluated the influence of RHA (0%, 3%, 6%, and 9%) on the liquid limit (LL) of clayey soil. The results showed LL values of 74, 75.9, 73.5, and 72.6, respectively. The initial increase at 3% RHA (75.9) suggests a slight rise in water retention, possibly due to the porous nature of RHA temporarily holding more moisture. However, as RHA content increased to 6% and 9%, the LL decreased marginally (73.5 and 72.6). This indicates that higher RHA percentages may contribute to slight stabilization, likely through pozzolanic reactions that reduce the soil's affinity for water.

The second Phase test examined clayey soil stabilized with aoptimum 9% RHA and varying perlite content (0%, 4%, 8%, and 12%). The LL values decreased markedly from 72.6 (0% perlite) to 44 (12% perlite), demonstrating a strong correlation between perlite addition and reduced water sensitivity. Unlike RHA, perlite—being a non-plastic, granular material—effectively disrupts the clay's cohesive structure, reducing its ability to retain water. The substantial LL reduction highlights perlite's dominance in controlling the soil's liquid limit, even in the presence of RHA. The combined use of 9% RHA with 8–12% perlite appears highly effective in transforming expansive clay into a more workable and stable material.

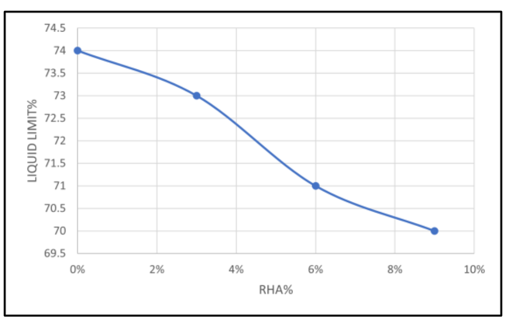

Figure 6: LL of Soil + RHA Sample

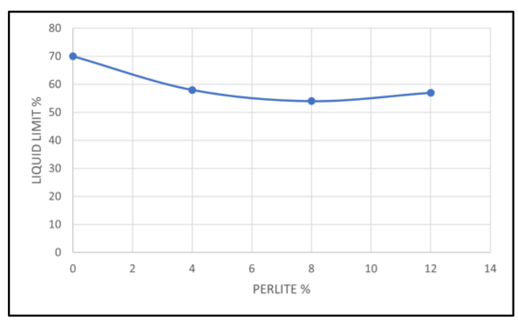

Figure 7: LL of Soil + RHA +Perlite Sample

3.1.2 Effect on Plastic Limit

The plastic limit test was conducted on clayey soil mixed with 0%, 3%, 6%, and 9% RHA, yielding plastic limit values of 33.27%, 37.7%, 41%, and 45.7%, respectively. The results indicate a consistent increase in the plastic limit with higher RHA content. This trend suggests that RHA enhances the water-holding capacity of the soil, likely due to its fine particles and porous structure, which absorb more water and increase soil plasticity. The rise in plastic limit signifies improved workability. However, excessive RHA content could lead to excessive shrinkage and cracking upon drying, requiring further investigation.

When the clayey soil was mixed with a constant 9% RHA and varying percentages of perlite (0%, 4%, 8%, 12%), the plastic limitvalues obtained were 45.7%, 42%, 46.5%, and 51.9%, respectively. Initially, the addition of 4% perlite reduced the plastic limit compared to 9% RHA alone, possibly due to perlite's lightweight and non-absorptive nature temporarily disrupting soil cohesion. However, at higher perlite contents (8% and 12%), the plastic limit increased significantly, suggesting that perlite, when sufficiently mixed, may contribute to better water retention and plasticity. The highest plastic limit (51.9%) at 12% perlite indicates a synergistic effect between RHA and perlite, enhancing the soil's ability to retain moisture and maintain plasticity. Both RHA and perlite influence the plastic limit of clayey soil, with RHA steadily increasing plasticity and perlite showing a variable effect depending on its proportion. The combined use of 9% RHA with higher perlite content (12%) resulted in the highest plastic limit, suggesting improved soil modification.

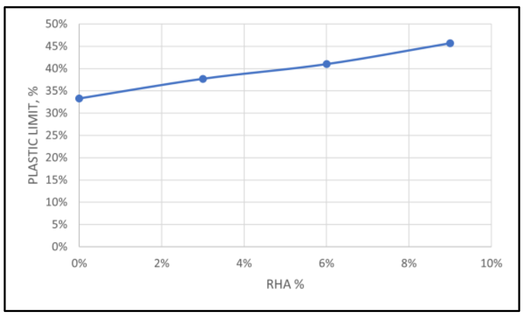

Figure 8: PL of Soil + RHA Sample

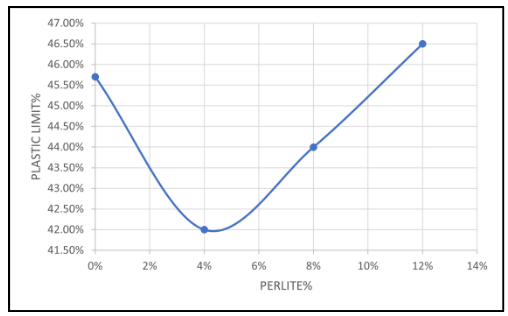

Figure 9: PL of Soil + RHA +Perlite Sample

3.1.3 Effect on Plasticity Index

The plasticity index (PI) of the clayey soil decreased significantly with the addition of RHA. The untreated soil had a PI of 40.73%, indicating high plasticity. However, as RHA content increased (0% to 9%), the PI reduced progressively to 35.30%, 30%, and 24.30%, respectively. This reduction can be attributed to the pozzolanic nature of RHA, which reacts with clay minerals, reducing their water-holding capacity and thus decreasing plasticity. The non-plastic, porous structure of RHA also dilutes the clay fraction, leading to a less cohesive and more granular soil matrix.

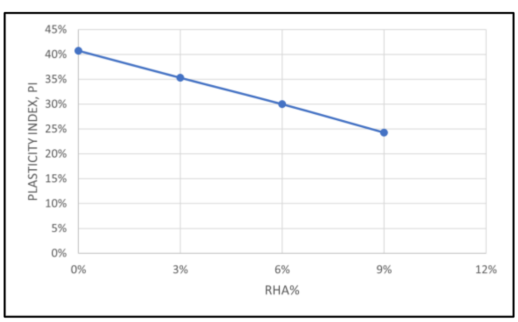

Figure 10: PI of Soil + RHA Sample

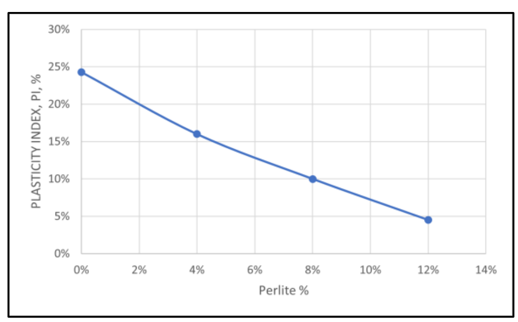

Figure 11: PI of Soil + RHA +Perlite Sample

When the soil was first stabilized with a constant 9% RHA (resulting in a PI of 24.3%) and further mixed with varying percentages of perlite (4%, 8% and 12%), the PI exhibited a more drastic reduction—16%, 10%, and 4.5%, respectively. Perlite, being a lightweight, porous material, further reduces the soil's plasticity by decreasing its ability to retain water. The combined effect of RHA (which modifies clay structure) and perlite (which introduces non-plastic fines and improves drainage) leads to a substantial decline in PI. At 12% perlite, the PI dropped to 4.5%, indicating near non-plastic behaviour, which is desirable for subgrade stabilization and reducing shrinkage-swelling potential. The combined use of these additives transforms highly plastic clay into a more workable and stable material.

3.2 Effect on Compaction Characteristics

The light compaction test results indicate that increasing the percentage of RHA in clayey soil reduces the maximum dry density (MDD) while increasing the optimum moisture content (OMC). The MDD decreased from 1.6 g/cc (0% RHA) to 1.35 g/cc (9% RHA), showing a 15.6% reduction. Simultaneously, the OMC increased from 10% (0% RHA) to 16% (9% RHA), a 60% rise. This trend occurs because RHA is a lightweight, porous material that lowers soil density while requiring more water for proper compaction due to its high surface area and water absorption capacity.

When 9% RHA was kept constant and perlite was added in varying proportions (0% to 12%), the MDD further decreased from 1.35 g/cc (0% perlite) to 1.18 g/cc (12% perlite), a 12.6% reduction. Meanwhile, the OMC significantly increased from 16% (0% perlite) to 33% (12% perlite), more than doubling. This drastic change suggests that perlite, being highly porous and lightweight, further reduces soil density while demanding much higher water content for effective compaction.

Both RHA and perlite reduce the dry density of clayey soil while increasing water demand. While RHA alone moderately affects compaction properties, combining it with perlite exacerbates these effects, particularly in OMC. These results suggest that while these additives can improve certain soil properties excessive use may compromise compaction efficiency and stability.

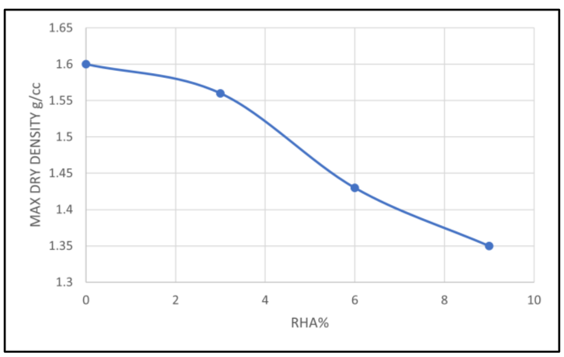

Figure 12: MDD of soil mixed with different RHA%

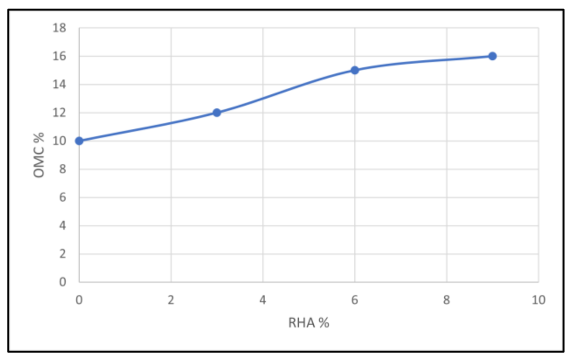

Figure 13: OMC of soil mixed with different RHA%

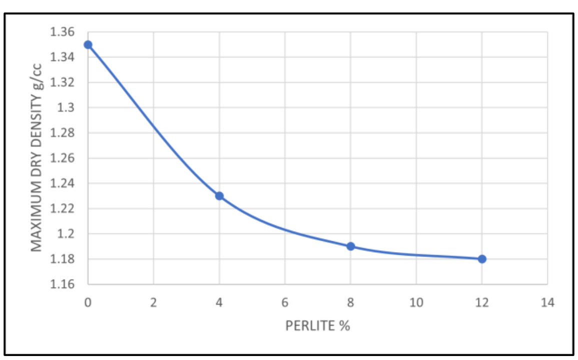

Figure 14: MDD of soil mixed with different Perlite%

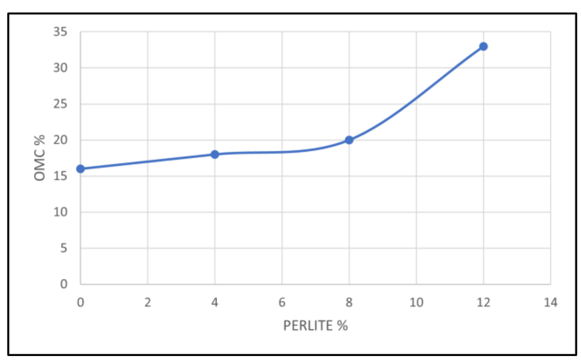

Figure 15: OMC of soil mixed with different Perlite%

3.3 Effect on Unconfined Compressive Strength

In the initial Phase the unconfined compressive strength (UCS) of clayey soil mixed with varying percentages of rice husk ash (RHA) (0%, 3%, 6%, 9%, 12%) showed significant variations. Initially, the addition of 3% RHA reduced the UCS (52.95 kN/m^2) compared to untreated soil (61.78 kN/m^2) possibly due to insufficient pozzolanic reaction or poor bonding at low RHA content. However, at 6% RHA, the UCS increased (83.35 kN/m^2), indicating improved soil stabilization. The highest strength was observed at 9% RHA (130.42 kPa), suggesting optimal pozzolanic activity and enhanced soil structure. Beyond this, at 12% RHA, the UCS slightly decreased (128.46 kPa), possibly due to excess RHA causing dilution effects or reduced cohesion.

In second phase soil was mixed with 9% RHA with varying percentages of perlite (0%, 4%, 6%, 8%, 10%), the UCS values recorded at 0% Perlite was(130.42kN/m^2). The initial decrease in UCS with 4% Perlite (110.81 kN/m^2) and 6% perlite (95.12 kN/m^2) may be attributed to the lightweight and porous nature of perlite, which could weaken the soil matrix at lower concentrations. However, at 8% perlite, the UCS peaked at 164.75kN/m^2, indicating that an optimal perlite content enhances strength, likely due to improved pore structure and better load distribution. At 10% perlite, the strength dropped again (128.46 kN/m^2), suggesting that excessive perlite may reduce soil cohesion. The study demonstrates that 9% RHA provides the best stabilization for clayey soil, significantly improving UCS. Further addition of 8% perlite to RHA-stabilized soil yields the highest strength, indicating synergistic effects between RHA and perlite. However, exceeding optimal percentages of either additive reduces effectiveness.

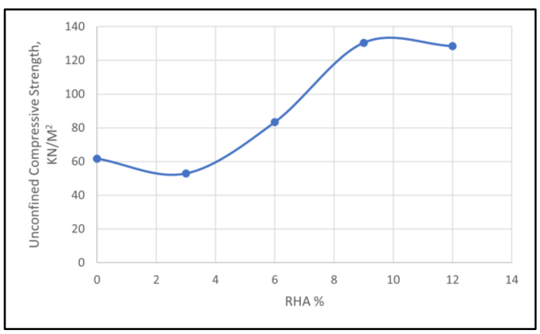

Figure 16: Effect of RHA onUCS of Soil

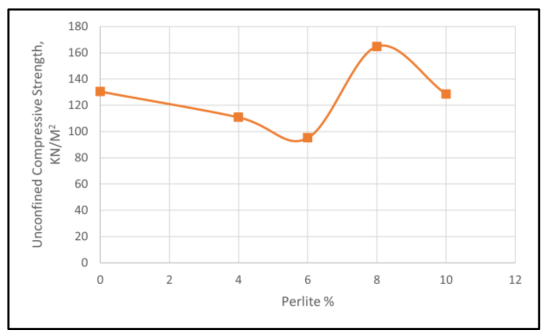

Figure 17: Effect of both RHA and Perlite on UCS of Soil

4. Conclusion

This study confirms that additives such as RHA and Perlite significantly improve properties of Clayey Soil. Key findings include:

1) Addition of RHA and Perlite reduces Liquid Limit of Clayey soil by about 23%, andPlasticity Index isreduced about36%
2) Treatment with RHA and Perlite showed a general reduction in the MDD with increase in the RHA and Perlite content and OMC increased with increase in RHA and Perlite content.
3) The addition of 9% Rice Husk Ash (RHA) and 8% Perlite significantly improved the unconfined compressive strength (UCS) of the clayey soil, increasing it from 61.78 kN/m² (untreated) to 164.75 kN/m². This indicates that RHA and Perlite are effective stabilizers for enhancing the strength characteristics of clayey soil.

4) Stabilizing clayey soil withRHA and Perlite is a sustainable solution. This method offers an eco-friendly alternative to traditional stabilizers, promoting resource efficiency and lower carbon footprint in geotechnical applications.

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