International Journal of Scientific Engineering and Science
Volume 8, Issue 7, pp. 66-71, 2024. ISSN (Online): 2456-7361

Assessing the Impact of Incorporating Waste Putty and Crushed Demolished Concrete on the Plasticity and Swelling Properties of Clay Soil

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Abstract**—** *The expansive nature of Clay Soils poses significant challenges for construction, as their tendency to swell and contract with moisture variations can lead to instability and structural damage. This research explores the use of Waste Putty and Crushed Demolished Concrete to improve the plasticity and swelling properties of Clay Soils, enhancing their suitability for construction applications. A comprehensive series of laboratory tests, including Atterberg limits, free swelling index, and standard Proctor compaction, was conducted on five Clay Soil samples mixed with varying amounts of Waste Putty (0%, 3%, 6%, 9%, 12%) and Crushed Demolished Concrete (0%, 5%, 10%, 15%, 20%). The findings reveal a marked reduction in the swelling capacity and plasticity of the modified soils, alongside an increase in dry density and overall stability. These results highlight the potential of using waste materials for Clay Soil stabilization. Specifically, the plasticity index was reduced from 20 to 16, and the free swelling index test showed a significant decrease in swelling potential, indicating improved behavior under moisture fluctuations. This offers a sustainable and effective approach to improving the performance and reliability of Clay Soils in construction. Furthermore, the standard Proctor compaction test demonstrated that the dry density of the treated soil increased as the moisture content decreased, confirming enhanced compaction characteristics. This study underscored the benefits of incorporating Waste Putty and Crushed Demolished Concrete to mitigate the adverse effects of Clay Soil expansion, thereby contributing to the durability and longevity of built structures.*

Keywords**—** *Clay Soil, Waste Putty, Crushed Demolished Concrete, Plasticity, Swelling.*

I. INTRODUCTION

Soil stabilization is a crucial component of civil engineering and construction since it significantly contributes to the stability, durability, and safety of created buildings. Geotechnical engineering encompasses the use of diverse methodologies and substances to enhance the mechanical characteristics of soil, resulting in an improved ability to carry loads and resist deformation [1]. The efficacy of soil stabilizing techniques significantly impacts the performance of buildings and infrastructures, as well as their capacity to endure external pressures, environmental conditions, and the passage of time.

The interaction between soil and buildings is a multifaceted process significantly influenced by variables such as soil type, moisture content, geological conditions, and the structural design of the building. Soil instability, including issues like settlement, subsidence, differential movement, and structural damage, can adversely affect buildings, potentially leading to costly repairs or even catastrophic failures. These problems arise when the soil beneath a structure cannot adequately support the load, resulting in uneven movement and stress on the building's foundation and overall structure [2]. Effective soil stabilization techniques, such as compaction, chemical stabilization, and the use of geosynthetics, are crucial in mitigating these issues. By improving the soil's load-bearing capacity and reducing its susceptibility to moisture changes and other environmental factors, engineers and construction professionals can ensure that buildings remain stable, durable, and safe throughout their intended lifespan. This understanding is essential for the successful execution and longevity of construction projects, as it helps in designing foundations that can withstand the dynamic interactions between soil and structures.

Clay Soils are a type of soil that undergo significant volume changes in response to changes in moisture content. These soils expand when they absorb water and contract when they dry out. Clay Soils are primarily composed of clay minerals and are characterized by their unique behavior, which can have significant implications for construction and infrastructure [2]. Wet Clay Soil will exert significant pressure against the structure built on it. Structures such as roads and small buildings built on Clay Soils are often subject to serious cracking and distress [3]. Thus, the infrastructure problems caused by the use of Clay Soil to construct buildings cost billions of dollars annually in repair costs [4]. The solution to the problem of foundations on Clay Soils cannot be obtained without an understanding of the basic properties of Clay Soils and the variables affecting swelling properties.

This introduction attempts to offer an overview of the relevance of soil stabilization in the context of its influence on structures. It will study the relevance of soil stabilization solutions in limiting the hazards associated with soil instability and boosting the structural integrity and performance of buildings. Additionally, it will cover the various techniques and materials utilized for soil stabilization and their consequences for building design, construction, and maintenance. By getting knowledge into the impacts of soil stabilization on buildings, engineers may make responsible choices regarding site selection, foundation design, and construction methods to enhance the stability, durability, and safety of built structures. Through proper soil stabilization

International Journal of Scientific Engineering and Science
Volume 8, Issue 7, pp. 66-71, 2024. ISSN (Online): 2456-7361

measures, the harmful impacts of soil-related concerns on buildings may be reduced, assuring the long-term resilience and functionality of the built environment.

II. Literature Review

The stabilization of expansive soils such as black cotton soils has become a significant area of research due to their problematic swelling and shrinkage behavior when interacting with water. Various studies have explored the use of wastes as stabilization agents to improve the geotechnical properties of these soils, thereby reducing their adverse effects on construction projects. One study focused on the stabilization of Clay Soils using marble powder and brick dust. The researchers replaced 30% of the soil with these stabilizers to create a mixture of 70% soil and 30% stabilizer. they conducted a series of tests including compaction tests, Atterberg limit tests, linear shrinkage tests, and swelling tests to evaluate changes in soil properties. The results show a significant improvement in soil behavior and significantly reduced swelling and shrinkage. This suggests that the use of marble powder and brick dust can effectively stabilize expansive Clay Soils and improve their suitability for construction purposes [5].

In a similar vein, another research project investigated the stabilization of black cotton soil using higher amounts of marble powder and brick dust. In this study, 40% of the soil was replaced with stabilization agents, resulting in a mixture of 60% soil and 40% stabilization agents. The same series of tests were carried out to assess the properties of the soil after stabilization. The findings showed a significant reduction in both swelling and shrinkage, further confirming the effectiveness of marble powder and brick dust as stabilizers for expansive soils. The potential of using this waste to improve the performance of black cotton soil in construction applications has been shown [6].

The challenge of building on weak soils with high compressibility and low bearing capacity has prompted researchers to explore the use of construction and demolition waste (CDW) as a method of soil improvement. One notable study examined the incorporation of fine CDW into poor soils to improve their geotechnical properties. Mixing recycled waste mortar powder with soil in varying percentages of CDW significantly improved soil consolidation settlement, reduced settlement time, and lowered the plasticity index. Among the tests conducted to assess the plasticity index, it was observed that as the percentage of CDW increased, the values for Liquid Limit, Plastic Limit, and Plasticity Index decreased. This indicates that incorporating higher amounts of CDW into the soil enhances its properties, making it less prone to deformation and improving its overall stability. As the percentage of CDW increases, the dry density of the dry density test increases and the water content decreases. The incorporation of CDW also increased the pre-consolidation pressure, consolidation rate, and permeability of soil & CDW mixtures. These findings highlight the benefits of using CDW for soil improvement, providing a sustainable solution for solid waste management while addressing the challenges associated with settling soft soils under shallow foundations. This approach not only reduces the environmental footprint and conserves natural resources but also supports the circular economy by reusing waste in construction [7].

III. Methodology & Materials

A. *Methodology*

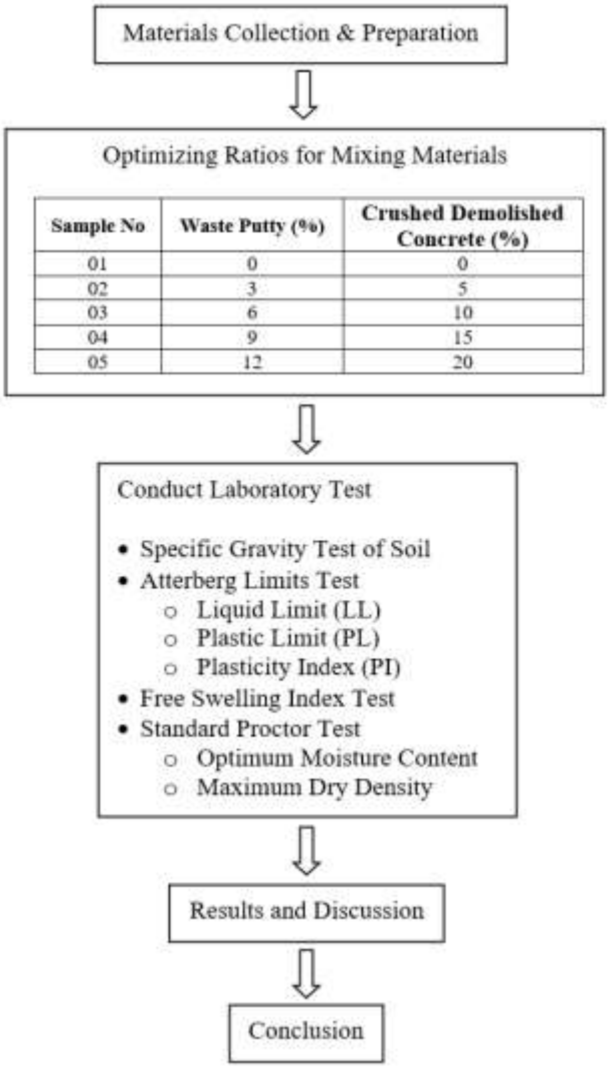

Fig. 1. Methodology

TABLE 1. Testing Standards

Testing Methods	Standard Code
Specific Gravity Test of Soil	IS 2720 (Part 3-1) - 1980
Free Swelling Index Test	IS 2720 (Part 40) - 1977
Atterberg Limits Test	IS 2720 (Part 5) - 1985
Standard Proctor Test	IS 2720 (Part 7) - 1974

The method of conducting the test is shown step by step in Fig. 1 above. While mixing the materials, without changing the amount of clay soil, the percentages were calculated according to the weight of the clay used, and that amount was used for the 5 samples the percentage of Waste Putty and the percentage of Crushed Demolished Concrete were increased. TABLE 1 shows the standard codes of tests carried out as above.

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B. Materials

1) Clay Soil

Clay Soil, characterized by its fine composition and high plasticity, has a unique ability to absorb and retain water, leading to significant expansion when wet and shrinkage when dry. This cyclical swelling and shrinking can cause severe problems in construction, including differential settlement, subsidence, and structural damage such as cracks and distortions in buildings and pavements.

While searching for an area with Clay Soil, it was found in the Veyangoda area to be chosen as a suitable place. Inspecting the buildings and gathering opinions from local residents, the Clay Soil from this area was selected for the research, and soil samples were collected using a random sampling method. Accordingly, samples were randomly taken from three places at a depth of 0.5 meters below the surface for testing, amounting to approximately 25 kg of soil samples based on the number of tests conducted. These soil samples were then transported to the testing location, well-covered, and prepared to prevent contamination. Large-sized particles were removed from the soil samples to obtain uniformly sized samples through a Sieve Analysis test, using a 2 mm sieve. Additionally, all samples were dried to remove moisture content.

2) Waste Putty

Waste Putty is a residual material from construction and renovation projects, often comprising excess or leftover putty used in tasks such as sealing and finishing. This material is typically fine and cohesive, making it suitable for enhancing soil properties when used as an additive. Waste Putty can improve the mechanical characteristics of Clay Soil by reducing its plasticity and flexibility.

Fig. 2. Waste Putty

Waste Putty was utilized as the primary material in this experiment, collected during the final stages (Finishing) of building construction from the Design & Construction of 1000 housing units at Stadiumgama. The collection was conducted with the permission of the project manager, ensuring that precautions were taken to prevent mixing with other discarded materials. Approximately 2 kg of Waste Putty samples were taken from the site according to the number of tests conducted. These samples were then transported to the testing location, where they were carefully covered and prepared to prevent any contamination. Additionally, all samples were dried to eliminate moisture. A figure of the Waste Putty used to conduct this test is shown below in Fig. 2.

3) Crushed Demolished Concrete

Crushed Demolished Concrete is produced by processing concrete from demolished structures into smaller, usable fragments. In this experiment, Crushed Demolished Concrete was used as another primary material, and this material was obtained from the same place as the discarded Waste Putty used for the samples. Collection of the Crushed Demolished Concrete was conducted with the permission of the project manager, with precautions taken to prevent mixing with other discarded materials. Approximately 4 kg of Crushed Demolished Concrete samples were taken from the site based on the number of tests conducted. These samples were transported to the testing site, following the same careful procedures to prevent contamination. All samples were dried to eliminate moisture content. Large-sized particles were removed from both the Crushed Demolished Concrete and soil samples to obtain uniformly sized samples, selected through a Sieve Analysis test. The sieve was conducted using a 0.425mm sieve to achieve uniformity in the Crushed Demolished Concrete samples. A figure of the Crushed Demolished Concrete used to conduct this test is shown below in Fig. 3.

Fig. 3. Crushed Demolished Concrete

IV. RESULTS AND DISCUSSION

A. Specific Gravity Test of Soil

(a) (b) (c) (d)

Fig. 4. Specific Gravity Test of Soil

$$G_s = \frac{(W_3 - W_1)}{(W_2 - W_1) - (W_4 - W_3)} \quad (1)$$

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Volume 8, Issue 7, pp. 66-71, 2024. ISSN (Online): 2456-7361

As Fig. 4 shown above there are 4 steps a, b, c, and d. According to **Error! Reference source not found.**) shown above, w_1, w_2, w_3, and w_4 replace the values obtained in those steps respectively. where (a)/W_1 - measuring the weight of the empty and clean volumetric flask, (b)/W_2 - Fill the flask with distilled water up to the mark and weigh it; (c)/W_3 - Weigh dry soil into a volumetric flask, (d)/W_4 - Fill the soil with distilled water up to the mark of the flask and measure the weight of the volumetric flask. The Specific Gravity test result of 2.23 for the soil sample indicates a density lower than the typical range for Clay Soils, which generally falls between 2.65 to 2.80. This lower value suggests the presence of finer particles, organic matter, void spaces, or lighter mineral compositions, resulting in a lower overall density. Understanding the Specific Gravity is essential as it provides insights into the soil's composition and density, which are crucial for further analysis of its engineering properties. This information aids in soil classification, determining compaction requirements, and assessing suitability for construction applications. It also helps predict potential settlement or stability issues in structures. Although the Specific Gravity value of 2.23 is below the typical range, it significantly contributes to a comprehensive understanding of the soil's characteristics and behavior.

B. Free Swelling Index Test

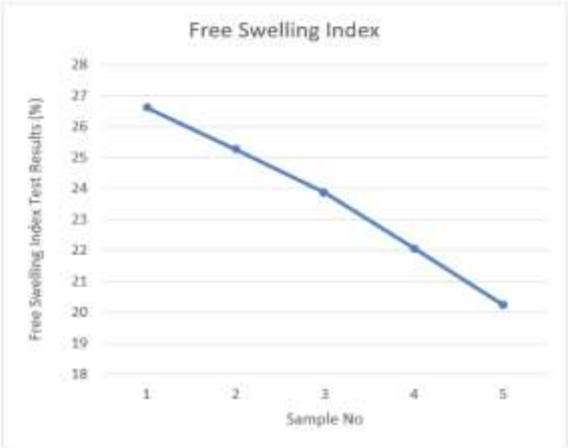

Fig. 5. Free Swelling Index Test Results

The Free Swelling Index (FSI) test results for the five samples show a consistent decrease in the swelling potential of Clay Soil with the increased incorporation of Waste Putty and crushed demolished concrete. As shown in Fig. 5 above this trend, evident in the declining FSI values, indicates a reduction in the soil's tendency to swell upon water absorption. The addition of waste materials appears to mitigate the soil's expansive behavior by filling void spaces and limiting soil particle movement.

In construction foundations, this reduction in swelling potential is highly beneficial. Excessive swelling of soil beneath foundations can cause uneven settlement, leading to structural damage and compromising stability. By minimizing swelling potential, the modified soil mixtures provide a more stable foundation, reducing the risk of differential settlement and associated structural issues. This improved control over soil expansion enhances the overall performance and longevity of construction foundations, ensuring durability and integrity over time.

Furthermore, the decreased swelling potential simplifies construction operations by reducing the need for extensive measures to mitigate soil movement, thus streamlining the foundation preparation process and contributing to cost-effectiveness. Overall, the FSI test results underscore the effectiveness of incorporating waste materials in reducing swelling potential and enhancing the performance of Clay Soil in construction foundations, ultimately contributing to safer, more resilient, and sustainable built environments.

C. Atterberg Limit Test

TABLE 2. Atterberg Limits Test Results

Sample	Ratio	LL (%)	PL (%)	PI (%)
01	0% WP + 0% CDC	37	16.68	20.32
02	3% WP + 5% CDC	34	14.79	19.21
03	6% WP + 10% CDC	31	12.02	18.98
04	9% WP + 15% CDC	28	10.58	17.42
05	12% WP + 20% CDC	25	8.76	16.24

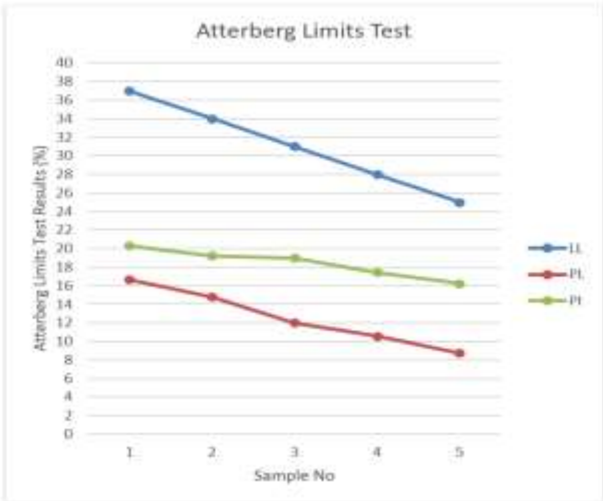

Fig. 6. Atterberg Limits Test Results

The results of Atterberg Limits tests are shown in the above TABLE 2 according to it, the inclusion of Waste Putty and crushed concrete shows significant changes in the characteristics of Clay Soils. The Fig. 6 shown above shows a reduction in the Liquid Limit from approximately 37 to 25, Plastic Limit from about 17 to 8, and Plasticity Index from around 20 to 16 suggesting a notable decrease in plasticity of the soil. This indicates that the modified soil mixtures are less prone to deformation and have a narrower moisture content range within which they remain plastic. For construction foundations, these changes offer significant benefits. The reduced plasticity enhances soil stability and reduces susceptibility to moisture-induced volume changes, thereby minimizing risks such as differential settlement, cracks, and compromised load-bearing capacity. The modified soil provides a more stable and reliable base for construction projects, ensuring long-term stability and durability of structures.

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Additionally, the decreased plasticity simplifies construction operations, making the soil easier to handle and compact, thus improving the efficiency of foundation preparation and overall construction processes. Overall, the Atterberg Limits Test results highlight the potential of incorporating waste materials to improve the performance and reliability of Clay Soil in construction foundations, contributing to safer, more durable, and sustainable built environments.

D. Standard Proctor Test

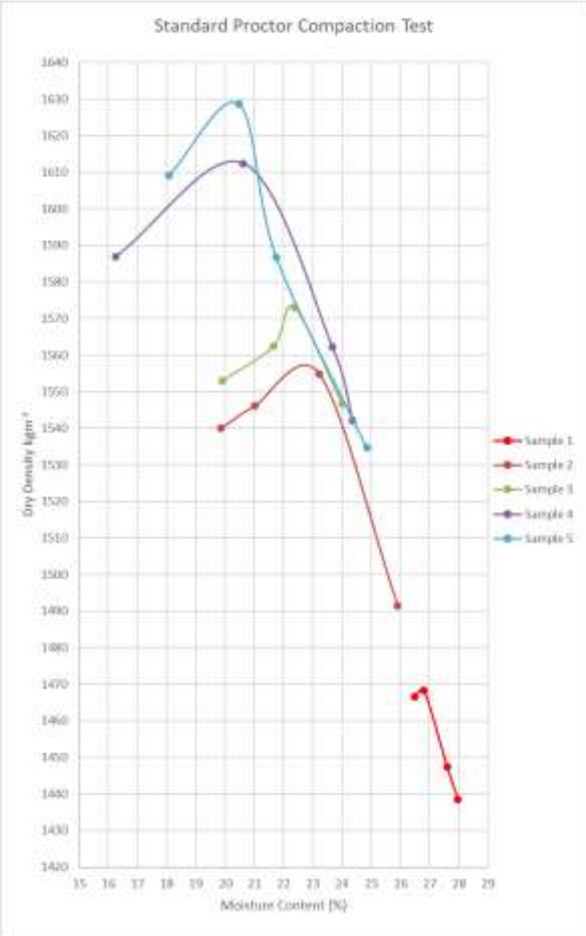

Fig. 7. Standard Proctor Test Results

TABLE 3. Maximum Moisture Content & Maximum Dry Density Results

Sample	Ratio	Maximum Moisture Content (%)	Maximum Dry Density (kgm^{-3})
01	0% WP + 0% CDC	26.77	1469.248
02	3% WP + 5% CDC	22.74	1557.353
03	6% WP + 10% CDC	22.25	1573.495
04	9% WP + 15% CDC	20.38	1612.970
05	12% WP + 20% CDC	20.24	1629.245

The standard Proctor composite test results for the five samples are shown above in Fig. 7. It reveals significant trends in soil moisture content and compaction characteristics with important implications for construction foundations. The results obtained by performing the test are as per the TABLE 3 shown above the samples show a consistent decrease in maximum moisture content (MMC) and an increase in maximum dry density (MDD) from samples 1 to 5. This is illustrated in Fig. 8 shown above. The decrease in MMC indicates that less moisture is required to achieve optimal compaction, improving the soil's resistance to moisture-induced volume changes like swelling and shrinkage. This reduction in moisture dependency minimizes the risk of soil movement and settlement, ensuring better structural integrity over time. Conversely, the increase in MDD signifies greater soil density and compaction, which enhances load-bearing capacity and reduces settlement risks. Denser and more compacted soil provides a stable foundation, crucial for supporting structures without significant settlement or shifting.

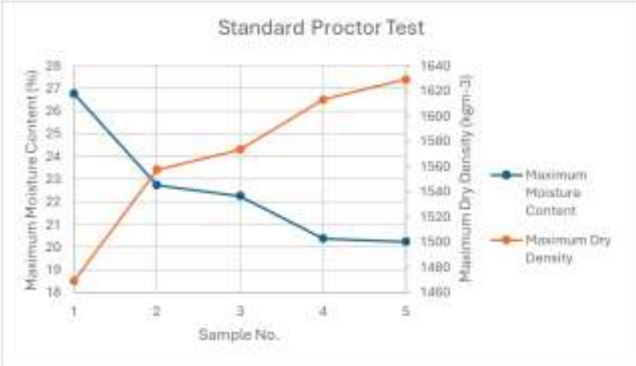

Fig. 8. Maximum Moisture Content & Maximum Dry Density Results

These improved compaction characteristics facilitate more efficient construction operations, allowing for quicker and more effective compaction during site preparation. This efficiency saves time and labor while ensuring proper foundation compaction, minimizing the likelihood of future settlement issues.

Overall, the Standard Proctor compaction test results underscore the importance of controlling moisture content and achieving optimal compaction to ensure stable and long-lasting construction foundations. Understanding and optimizing these factors enable construction professionals to make informed decisions about soil selection and compaction methods, ultimately contributing to the durability and safety of built structures.

V. RECOMMENDATIONS

Based on the findings of this research, several recommendations can be made to improve the robustness and applicability of this study on the effect of incorporating Waste Putty and crushed concrete on the plasticity and swelling properties of Clay Soils.

- Conduct Consolidation Tests: Future research should include consolidation tests to understand the settlement characteristics of the soil, which are essential for foundation design. This can be achieved by securing the necessary equipment or collaborating with institutions that have the requisite facilities.
- Increase the Ratio of Mixing Materials: To fully understand the effects of Waste Putty and Crushed Demolished Concrete on soil properties, future studies should experiment with a broader range of mixing ratios.

Testing these varying proportions will help identify the most effective combinations for improving soil stability and reducing swelling and plasticity.

- Diversify Soil Sample Locations: To enhance the generalizability of the results, future research should collect and test soil samples from multiple locations with varying soil properties. This will provide a more comprehensive understanding of how different soils respond to the incorporation of waste materials.
- Perform Long-Term Durability Studies: Including long-term studies to assess the durability and stability of the modified soil over time is crucial. Monitoring the treated soil under various environmental conditions will help evaluate its performance and sustainability.

VI. CONCLUSION

This research examined the effects of incorporating Waste Putty and crushed concrete on the plasticity and swelling properties of Clay Soils. Results from Atterberg Limits tests indicated that these materials reduced the liquid limit, plastic limit, and Plasticity Index, leading to decreased plasticity and flexibility of the Clay Soil. This reduction enhances soil stability and reduces deformation due to moisture variations, which is beneficial for construction. The Free Swelling Index test showed a decrease in swelling capacity, indicating a lower potential for volumetric changes and a more stable soil structure. Standard Proctor compaction tests revealed improved shrinkage characteristics and higher dry density, suggesting that the soil compacts better with less moisture, providing a thicker and more stable soil base. The findings emphasize the importance of selecting soils with optimal characteristics for construction. Low PI soil mixtures are preferred for their resistance to moisture-induced volume changes, providing a stable foundation. High dry density soil mixes demonstrate strong load-bearing capacity and resistance to moisture-related issues, ensuring structural integrity and durability.

Moreover, reusing waste materials from construction activities promotes environmental sustainability. Overall, this research supports the development of effective soil stabilization techniques, enhancing construction project success and sustainability.

ACKNOWLEDGMENT

I extend my deepest gratitude to my research advisor, Ms. Devaki Bandaranayake, for her expert guidance and support. Special thanks to Dr. J.A. Darshika Wanigarathna for lab access and invaluable advice. I am grateful to the University of Sri Jayewardenepura for its resources, and to my peers, colleagues, and family for their encouragement and support.

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