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Exploring the Properties of Black Cotton Soil by Blending Recycled Construction and Demolition (C and D) Waste

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Abstract
Black cotton (BC) soil is widely recognized for its problematic nature, primarily due to its high compressibility and significant volumetric changes in response to moisture variations. These properties cause low bearing capacity and structural instability, posing challenges for construction. This research explores the potential of construction and demolition (C&D) waste as a sustainable additive for improving the geotechnical properties of BC soil. C&D waste was incorporated into BC soil at varying proportions (10%, 20%, 30%, 40%, and 50%) to evaluate its effectiveness in enhancing soil strength, load-bearing capacity, and resistance to swelling. The study evaluated the impact of C&D waste on the geotechnical properties of BC soil. A detailed analysis was performed on plasticity index, OMC, MDD, and DFSI. The inclusion of recycled C&D waste enhances the mechanical performance of BC soil and reduces its plasticity and swelling. The results indicate that the inclusion of recycled C&D waste significantly improves and mechanical performance of BC soil while reducing its plasticity and swelling potential. This study underscores the viability of using recycled construction materials for eco-friendly soil stabilization, aligning with sustainable engineering practices and circular economy principles.
Keywords: *Expansive soil, Black cotton soil, Construction and demolition waste, Sustainable soil improvement, Geotechnical engineering.*

1. Introduction
Soil is perhaps one of the major factors that affect construction. The challenges presented by Black Cotton Soil (BCS), distinguished by its expansive characteristics and shrink-swell behavior, significantly complicate construction endeavors.[1] Moreover, it plays a considerable role in the generation of construction and demolition waste (CDW), thereby rendering its application for soil enhancement vital for sustainable construction methodologies.[2] The introduction further elucidates the environmental and economic advantages associated with the recycling of construction and demolition waste.[3] This strategy not only ameliorates soil characteristics but also mitigates environmental issues linked with traditional stabilizers, thereby fostering sustainable engineering methodologies.[4] The study's objective is to investigate the mechanical application of diverse construction waste materials to improve soil quality, offering an extensive analysis of their properties and potential uses.[5] The research is concentrated on the stabilization of black cotton soil (BCS), which is susceptible to deformation due to its volumetric changes and shrinkage tendencies, particularly in India, where it occupies a considerable geographical expanse.[6] Expansive soils have the propensity to form severe fissures and cause significant structural damage, raising global concerns due to the economic repercussions associated with such phenomena.[7] The introduction elaborates on the ubiquity of black cotton soil in the Deccan Trap region of India, accentuating its variable thickness and the underlying viscous black material.[8] Various waste materials, including quarry dust, sawdust ash, and lime, are underscored for their potential to augment the strength and durability of expansive soils.[9] The

study aspires to employ recycled construction and demolition (C&D) waste for soil stabilization, addressing the environmental challenges associated with conventional stabilizers.[10] It categorizes soil into organic and inorganic types, with black cotton soils being a highly clayey variant distinguished by montmorillonite clay.[11] It posits soil stabilization as a contemporary technique for utilizing waste materials, substituting finer soil particles with coarser stabilizing agents to enhance geotechnical properties.[12] The primary objective is to empirically assess the impacts of varying proportions of C&D waste on the characteristics of black cotton soil.[13] Furthermore, it advocates for incorporating e-waste to ameliorate soil stability, emphasizing that soil stabilization enhances engineering properties, rendering it more appropriate for construction applications.[14] In the construction of any edifice, the engineering properties of soils constitute a critical factor to be considered.[15] The introduction characterizes soil as a non-homogeneous, porous substance comprised of mineral particles, air, water, organic matter, and other constituents, which are influenced by moisture content and density.[19,20] This is accomplished through an experimental methodology.[16] The insufficient focus on institutional impediments to the reuse of construction waste has constrained the emphasis on juxtaposing reuse and recycling strategies in the construction sector.[17] Consequently, the present study aims to investigate the impact of shredded rubber tires on the strength and swelling behavior of locally available black cotton soils. It is proposed to analyze the causative factors behind road failures on black cotton soil. [20][21] The typical behavior of these soils under varying climatic conditions has rendered the construction and maintenance of roads financially burdensome and exceedingly challenging. [22][24]

2. Literature Review

Soil stabilization with waste materials is crucial for enhancing engineering properties and mitigating environmental pollution [1][2]. Studies have shown that the incorporation of building demolition waste (BDW) increases the Maximum Dry Density (MDD) while decreasing the Optimum Moisture Content (OMC) [2]. A range of research highlights the influence of various stabilizers on soil characteristics [4][2], promoting a sustainable approach to soil engineering [3]. This literature review consolidates existing studies on building waste and its use in improving mineral soils, categorizing the wastes based on origin and type, and assessing their environmental impacts. It identifies optimal ratios for soil improvement and emphasizes the role of laboratory experiments and statistical analysis in evaluating the effectiveness of construction waste in soil enhancement. The review suggests that a C&D waste proportion of 10-50% typically yields the best results for strength improvement, depending on the soil type [5][24]. In India, the construction industry generates substantial CD waste that can be repurposed for enhancing soil stability and load-bearing capacity [5]. Black Cotton (BC) soil, which is prone to moisture-induced volume changes, often leads to structural issues in India due to its expansive properties [7]. This soil, common in many Indian regions, experiences cracking during dry seasons due to its clay content, with deep cracks forming that can damage foundations [9]. The study aims to explore using recycled C&D waste for stabilizing this type of soil, addressing both environmental issues and reducing landfill waste. The review also highlights the need to stabilize Black Cotton Soil, known for its high compressibility and significant shrinkage-swelling behavior. This soil causes consolidation settlements when saturated and can be problematic for construction due to its expansive nature [8]. The review stresses the importance of geotechnical assessments before construction on BC soil to mitigate risks associated with moisture fluctuations and structural damage [10]. Additionally, the review discusses the role of recycled C&D waste, such as concrete and brick aggregates, in improving soil behavior and stability. While C&D waste is mainly used as concrete aggregate, its potential for soil stabilization is becoming more recognized [11][12]. The study includes laboratory investigations of BC soils from depths of 1 to 1.5 meters to analyze their physical and engineering properties. The review emphasizes the importance of understanding the mineralogy and composition of BC soils, which are rich in montmorillonite clay and have a high base

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exchange capacity [16]. These soils cover significant portions of central and western India, presenting challenges for construction due to their swelling and shrinkage characteristics [18][19]. Finally, the review outlines the effectiveness of various stabilizers such as fly ash, cement, and manufactured sand, with fly ash being particularly noted for its cost-effectiveness and environmental advantages. These stabilizers improve BC soil's bonding properties and reduce swelling and shrinkage. Soil stabilization is essential for various construction sectors, including roads, runways, and dams, due to its economic and long-term service life benefits [23].

3. Significance of Present Study

After overall study the reviews finding following gaps and problem statements were drawn

- Limited focus on institutional barriers to construction waste reuse and comparison of reuse vs. recycling strategies.
- Insufficient research on hydraulic properties of fine-grained soils with CDMs.
- Lack of studies on CDMs impact on undrained shear strength.
- Few studies on CDW effect on geotechnical properties.
- Limited research on CDW for soil consolidation and its impact on settlement time and compression index.

4. Materials and Methods

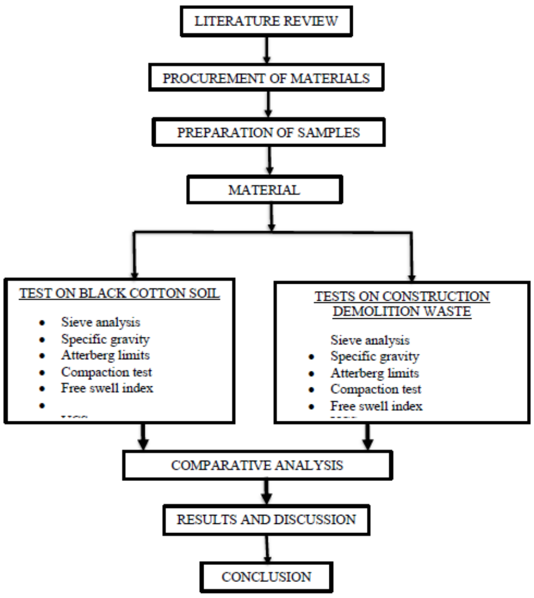

Figure 1 Flow Chart of Methodology

Figure 1 presented details about the methodology carried out in this research, after obtaining all of the materials. Preliminary tests on soil sample were carried out. This paper examines the stabilization of black cotton soil using recycled aggregates, bricks, clay tiles from acquired C&D wastes. It investigates the changes in the properties of black cotton soil resulting from the addition of recycled C&D wastes.

4.1 Construction and Demolition (C&D) Waste

As shown in Image 1, the Construction and Demolition (C&D) waste was collected from a dumping site located in Indapur, Pune. The collected sample underwent a segregation process to separate components such as concrete waste, mortar, brick masonry, clay tiles, and others. A total of 50 kg of the segregated material was then crushed using a rammer. Figure 2 shows Construction and Demolition (C&D) Wastes.

Figure 2 Construction and Demolition (C&D) Wastes

The mixed crushed sample, with particle sizes below 4.75 mm, was blended with soil in varying proportions of 10%, 20%, 30%, 40%, and 50%. This was done to evaluate the resulting changes and identify the optimal percentage of C&D waste for soil stabilization. The same set of tests was performed on the stabilized soil in accordance with IS 2720 standards. Based on the test results, the optimum C&D waste content for effective soil stabilization will be determined.

4.2 Black Cotton Soil

As illustrated in Image 2, black cotton soil commonly referred to as expansive soil poses significant challenges for construction projects. Predominantly found in central and southern regions of India, this

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soil is rich in clay and varies in texture from clayey to loamy. It is typically observed in shades ranging from light to dark grey. A key characteristic of black cotton soil is its dramatic response to moisture changes: in dry conditions, it shrinks and hardens, offering high load-bearing capacity similar to stone; however, when wet, it swells and becomes soft, resulting in a substantial reduction in strength and stability. The distinctive swelling behavior of black cotton soil is largely attributed to its mineralogical composition, which includes a high content of minerals such as montmorillonite and illite. In dry conditions, the soil tends to form wide and deep cracks some reaching up to 150 mm in width and extending 3.0 to 3.5 meters in depth. In contrast, during wet conditions, the soil can expand by 20% to 30%, generating considerable upward pressure. This expansion has the potential to lift building foundations and create visible cracks in overlying walls. Typically, these cracks are narrower at their base and become wider toward the top. Owing to these problematic characteristics, specialized construction methods are essential when building on black cotton soil. Table 1 shows Mass of Soil Sample Taken for Analysis is 2000 gm. Various materials such as lime, cement kiln dust, waste rubber, rice husk ash, and incinerated sludge are frequently employed for soil stabilization. In contrast, the use of Construction and Demolition (C&D) waste particularly recycled concrete aggregates is a more recent approach in this field. In the present study, the C&D waste used was sourced from a dumping site located in Indapur, Pune. The typical composition of these materials is depicted in the accompanying chart (Figure 3).

Figure 3 Black Cotton Soil

5. Experimental Work

5.1 Grain Size Distribution of BC Soil by Sieve Analysis

Table 1 Mass of Soil Sample Taken for Analysis is 2000 gm

IS Sieve Designation	Particle Size (mm)	Mass Retained in each Sieve	Percentage on each Sieve	Cummulative % age Retained on each Sieve	% Finer
4.75 mm	4.75	60.5	3.025	3.025	96.975
4.00 mm	4.00	70	3.5	6.525	93.475
3.36 mm	3.36	104	5.2	11.725	88.275
2.40 mm	2.40	125	6.25	17.975	82.025
1.46 mm	1.46	410.5	20.525	38.5	61.5
1.20 mm	1.20	284.5	14.225	52.725	47.275
600 µ	0.60	380	19	71.725	28.275
300µ	0.30	370.5	18.525	90.25	9.75
150µ	0.15	125.5	6.275	96.525	3.475
75µ	0.075	59	2.95	99.475	0.525
Pan	Pan	10.5	0.525	100	0

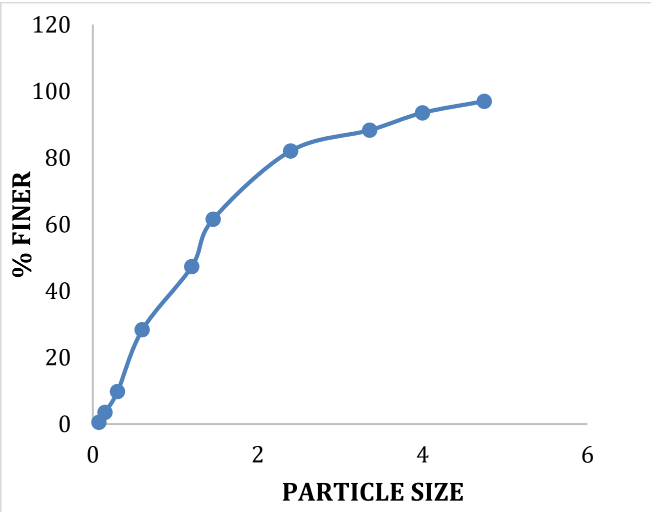

Figure 4 BC Soil by Sieve Analysis

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A semi-logarithmic graph, known as the grading curve, was plotted with particle size on the logarithmic scale and the percentage finer on the arithmetic scale. From this curve, the particle sizes corresponding to 10%, 30%, and 60% finer were identified and denoted as D10, D30, and D60, respectively. The effective particle size, D10, was found to be 0.26 mm, while D30 and D60 were determined as 0.62 mm and 1.2 mm, respectively. Using these values, the coefficient of curvature (Cc) was calculated as 1.23, and the uniformity coefficient (Cu) was found to be 4.61. Based on these parameters, the soil sample is classified as well-graded gravel. Figure 4 shows BC Soil by Sieve Analysis.

5.2 Grain Size Distribution of CD Waste by Sieve Analysis

Table 2 **Mass of CD Sample Taken for Analysis Is 2000 GM**

IS Sieve Designation	Particle Size (mm)	Mass Retained in each Sieve	Percentage on each Sieve	Cumulative % age Retained on each Sieve	% Finer
4.75 mm	4.75	1060.5	53.025	53.025	46.975
4.00 mm	4.00	60.5	3.025	56.05	43.95
3.36 mm	3.36	3	0.15	56.2	43.8
2.40 mm	2.40	200	10	66.2	33.8
1.46 mm	1.46	35	1.75	67.95	32.05
1.20 mm	1.20	150	7.5	75.45	24.55
600 µ	0.60	180	9	84.45	15.55
300µ	0.30	39	1.95	86.4	13.6
150µ	0.15	120.5	6.025	92.425	7.575
75µ	0.075	28.5	1.425	93.85	6.15
Pan	Pan	123	6.15	100	0

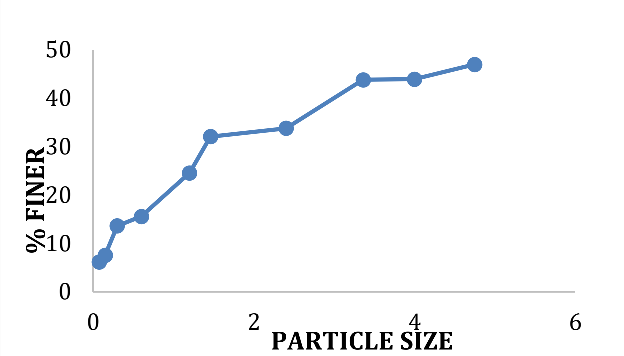

Figure 5 **CDW by Sieve Analysis**

A grading curve was plotted by representing particle size on the logarithmic scale and the percentage finer on the arithmetic scale using semi-logarithmic graph paper. This curve helps visualize the CD Waste particle size distribution. Table 2 shows Mass of CD Sample Taken for Analysis Is 2000 GM. From the graph, the particle sizes corresponding to 10%, 30%, and 60% finer were determined and are referred to as D10, D30, and D60, respectively.

Table 3 **Properties of Black Cotton Soil and CD Waste**

Sr. No	Properties	BC Soil Value	CD Waste Value
1	Specific Gravity	2.04	2.62
2	Sieve-size Analysis Cu-Cc	4.61 1.23	28.12 1.12
3	Liquid Limit	60%	-
4	Plastic Limit	48%	-
5	Plasticity Index	12%	-
6	Optimum Moisture Content	31.81%	33.33%
7	Maximum Dry Density	1.55 gm/cc	1.38 gm/cc
8	Swelling Potential	100%	7.69%

The effective size (D10) was found to be 0.32 mm, while D30 and D60 were recorded as 1.8 mm and 9 mm, respectively. Using these values, the coefficient of curvature (Cc) was calculated to be 1.12, and the uniformity coefficient (Cu) was found to be 28.12. Based on these parameters, the soil sample is

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categorized as well-graded sand. Figure 5 shows CDW by Sieve Analysis. Table 3 shows Properties of Black Cotton Soil and CD Waste.

5.3 Constituents of C&D Wastes

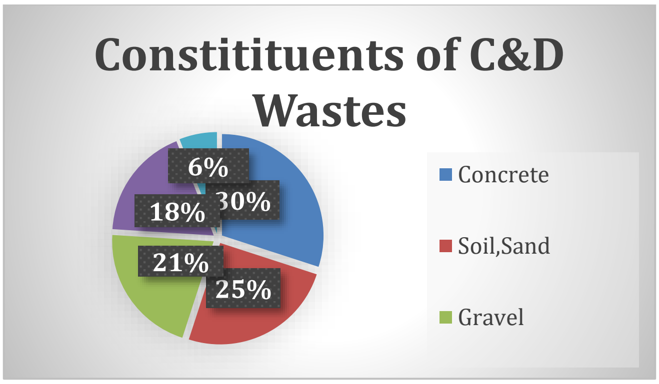

Figure 6 Constituents of C&D Wastes

Table 4 Properties for Black Cotton Soil with CD Waste

Engineering Property	Black cotton soil	10% of C&D Waste	20% of C&D Waste	30% of C&D Waste	40% of C&D Waste	50% of C&D Waste
Liquid limit (%)	60	55	52	50	43	32
Plastic limit (%)	48	46.11	34.08	30.45	28.87	24.63
Plasticity index (%)	12	8.89	17.92	19.55	14.13	7.37
Shrinkage Limit	26.77	22.03	20.04	16.72	15.95	6.08
Maximum dry density	1.55	1.52	1.56	1.67	1.78	1.83
Optimum moisture content (%)	31.81	28.12	27.5	25.58	23	20
Free swell index (%)	100 (Very High)	66.67(Very High)	20(High)	17.39(Very Low)	14.28(Very Low)	10.71(Low)

6. Experimental Work

The crushed material was added to the black cotton soil sample in proportions of 10%, 20%, 30%, 40%, and 50%. Subsequently, the following tests were shown in table 4 to observe and understand the behavior of black cotton soil (expansive soil) Figure 6 shows Constituents of C&D Wastes. Figure 7 shows Consistency Limits In % BC Soil with CD Waste.

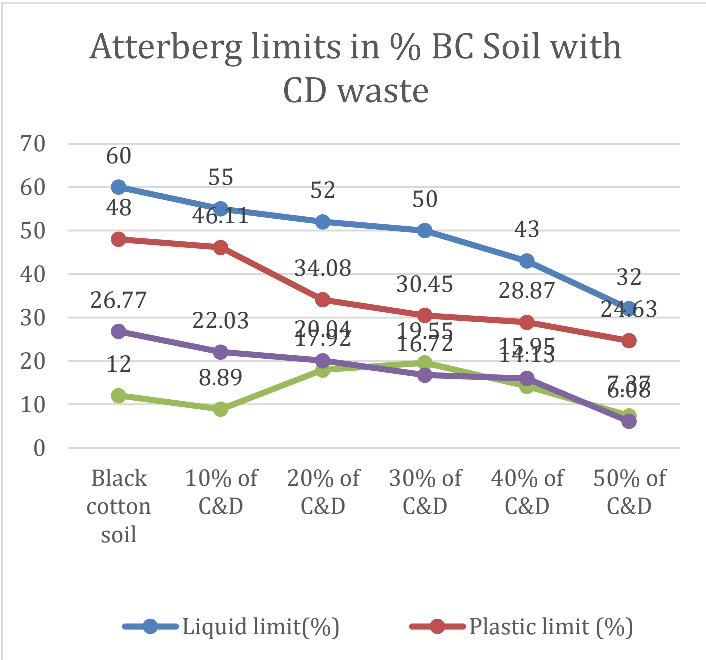

Figure 7 Consistency Limits In % BC Soil with CD Waste

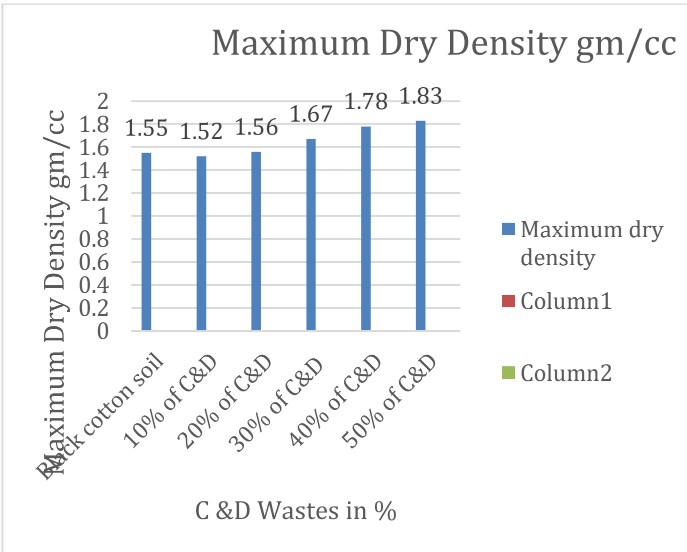

Figure 8 Maximum Dry Density with CD waste

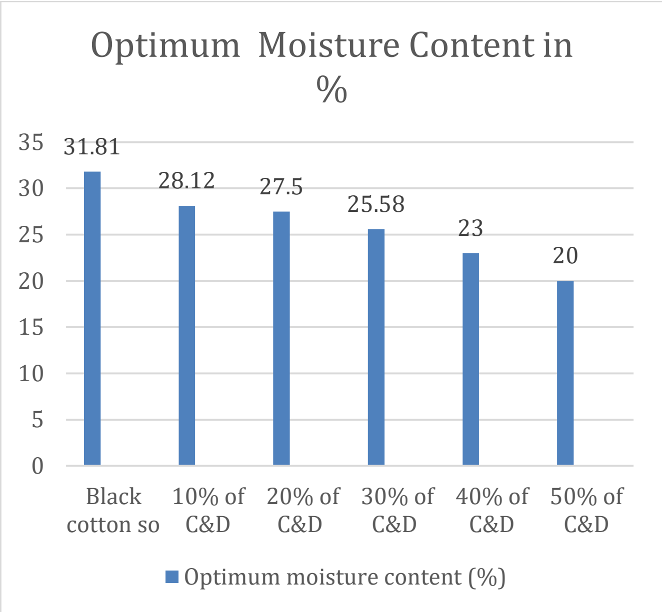

Figure 9 Optimum Moisture Content with CD Waste

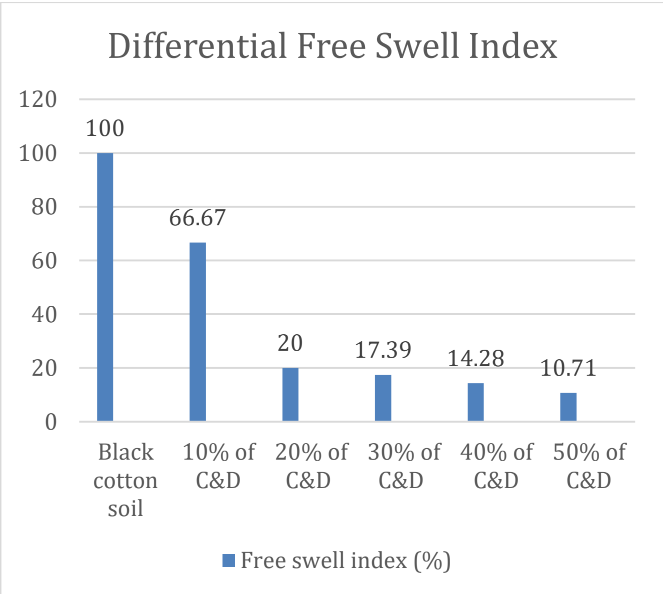

Figure 10 Differential Free Swell Index

7. Result and Discussion

This study focused on enhancing the engineering properties of black cotton soil through the addition of recycled Construction and Demolition (C&D) waste. Various proportions of C&D waste ranging from 10% to 50% were blended with the soil, resulting in significant changes to its key characteristics. Figure 8 shows Maximum Dry Density with CD waste. The Liquid Limit showed a consistent decrease from 55% to 32%, indicating a reduced water requirement for the soil to exhibit plastic behavior. Similarly, the Plastic Limit dropped from 46.11% to 24.63%, reflecting an increased resistance to deformation as the percentage of geopolymer content rose. The Plasticity Index initially increased, reaching a peak of 19.55% at 30% C&D waste content, before gradually stabilizing between 14.13% and 7.37% with higher additions. In addition, the Shrinkage Limit showed a steady reduction from 22.03% to 6.08%, suggesting enhanced dimensional stability and a lower tendency for volume changes. Overall, these results highlight the effectiveness of using geopolymer-enriched C&D waste to improve the performance and sustainability of construction materials. Figure 9 shows Optimum Moisture Content with CD Waste. The Maximum Dry Density (MDD) of black cotton soil showed a consistent rise with the incremental addition of Construction and Demolition (C&D) waste. As the C&D waste content increased from 10% to 50%, the MDD improved from 1.52 g/cc to 1.83 g/cc, indicating a positive impact on soil compaction and density. Alongside this, the Optimum Moisture Content (OMC) demonstrated a decreasing trend, varying from 28.12% at 10% C&D waste to 20% at 50% addition. This suggests that as the percentage of C&D waste increased, the soil required less moisture to achieve maximum compaction. Additionally, the Differential Free Swell Index (FSI) demonstrated a significant decrease with rising amounts of C&D waste. Initially recorded at 100% for untreated soil, the FSI dropped to 66.67%, 20%, 17.39%, 14.28%, and 10.71% with C&D waste additions of 10%, 20%, 30%, 40%, and 50%, respectively. This trend indicates a substantial reduction in the soil's swelling potential, highlighting the stabilizing influence of the recycled material. Figure 10 shows Differential Free Swell Index.

Conclusion

The main aim of this research was to enhance the engineering properties of black cotton soil by reducing its swelling behavior and increasing its load-bearing strength. While previous investigations have assessed the effectiveness of stabilizing agents like lime, rice husk ash, and cement kiln dust, many of these materials have led to challenges such as excessive soil expansion and pavement damage. More recently, attention has turned to the use of Construction and Demolition (C&D) waste as an alternative soil stabilizer. The outcomes of this study are consistent with earlier findings, supporting the use of C&D waste as a practical solution for stabilizing expansive soils. In conclusion, the addition of C&D waste significantly enhances the geotechnical behavior of black cotton soil. Beyond improving soil performance, this approach offers an environmentally responsible solution for managing construction waste. By integrating C&D materials into soil stabilization practices, the construction industry can reduce waste-related environmental hazards, lower project costs, and promote sustainable building practices.

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