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Improving Shear Strength and Microstructural Behavior of Black Cotton Soil Treated with Construction Demolished Waste

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Abstract

With its expansive character and low bearing capacity, black cotton soil presents considerable obstacles to construction projects. These challenges can be difficult to overcome. There is a tendency for it to rise and compress in response to variations in the amount of moisture present, and it also has weak strength properties, which makes construction activities more difficult. This study explores the possibility of stabilizing black cotton soil with recycled construction and demolition (C&D) waste in order to address these issues. Various C&D waste materials, like concrete, bricks, mortar, and other debris, are examined for their potential to enhance the shear strength of black cotton soil. The paper assesses the effectiveness of incorporating C&D waste blends ranging from 5% to 25% to mitigate soil swelling and shrinkage with improve shear strength. Previous to determining the soil's shear strength, index properties were assessed. Unconfined compression strength tests (UCS) are carried out on compacted specimens handled with C&D waste blends, with curing periods of 1 day, 7 days, and 28 days at room temperature. A comparison investigation showed that there was a comparable increase in UCS and a decrease in axial strain at failure as the amount of C&D waste in the soil rose. Micro-analyses displayed that the main factors prompting the interacting behavior of soil amended with C&D waste include changes in the gradation, cohesiveness, and the interplay between the particles, the mineralogical makeup, and the elemental, chemical, and microstructural components. The research aims to offer insights into sustainable methods for strengthening the performance of black cotton soil while reducing waste generation in construction activities.

Keywords: Unconfined compression strength, shear strength, Construction and Demolition (C&D) waste.

1. Introduction

Sometimes, during the building of engineering projects, it is necessary to modify the soil because it is weak. In the construction industry, black cotton soil (BCS) is a troublesome soil because of its expansive nature and shrink-swell behavior. This tendency causes cracking and differential settling in buildings and roads, which can be problematic. Stabilizing BCS is necessary to improve its engineering properties and suitability.[1] Construction on expansive soils, such as highways and railways, faces difficulties and suitable materials may not be readily available. Increases in strength and durability, as well as reductions in consistency limitations and shrinking-swelling behavior, are all essential components of the expansion of expansive soils. [2] Stabilization of soil using environmentally hazardous waste materials is becoming popular, economical, and environmentally friendly.[3] With their susceptibility to moisture-induced volume fluctuations, expansive soils provide issues in the field of geotechnical applications and civil engineering. [4] The physical and mechanical characteristics of Construction and Demolition Waste (CDW) materials for possible use in road construction, specifically as sub-base materials.[5] CDW accounts for a significant portion of waste generated in construction sectors, making its utilization for soil improvement important for sustainable building materials. Construction demolition waste (CDW) is a potential source of aluminosilicate for alkali-activated materials. [6] The investigation of the engineering characteristics of construction and demolition materials (CDMs) and their potential use as additives to enhance the properties of soils.[7] The demolition of buildings, especially older ones, generates a substantial number of construction and demolition waste (CDW). The proper handling and sorting of this waste are essential for effective recycling and resource conservation.[8] Recycling CD waste, especially concrete and brick waste, has gained attention as a sustainable solution. The mechanical behavior of recycled concrete aggregate (RCA), recycled brick aggregates (RBA), and their blends is being studied to assess their suitability in various geotechnical applications.[9] C&D waste, if not properly managed, can have negative effects on the environment, including air pollution. Therefore, there is a need for effective CWM practices in the Indian construction sector.[10] Discrete element numerical techniques (DEM) were used to examine the performance of the CDW-silty soil-cement mixture, and the percentage of CDW and silty soil to satisfy the needs of subgrade materials was examined.[11] The goals of improving soil are to decrease permeability, compaction tendency, and settlement thereby boosting stability, load resistance, durability, and capacity for bearings. employing fine-grained construction and demolition waste (CDW) to lessen the overuse of natural resources like sand and enhance the geotechnical behavior of soil.[12] It is common to refer to expansive soil as a concealed calamity. Expanded soil on building sites is linked to the degradation of structures due to changes in volume and shear strength along with elevated moisture levels.[13] To strengthen expansive soils and lessen plastic pollution in the environment, use waste plastic strips and brick waste powder.[3] Testing the soil and confirming the selected technique in the laboratory before implementing it in the field are essential for the successful stabilization of the soil. The process of strengthening weak soil's engineering qualities with stabilizing agents or admixtures is known as soil stabilization. It is necessary for construction projects to ensure stable foundations.[14] The study focuses on utilizing recycled Construction and Demolition (C&D) wastes to stabilize black cotton soil and enhance its shear strength. Various percentages of C&D waste blends are explored to reduce soil swelling and improve shear strength capacity through unconfined compression strength tests.[15] It highlights the improvement in swelling potential, shrinkage limits, compression, and durability of the handled test soils with the inclusion of dust from quarries. The Sorptivity behavior of the treated soils, which shows improvement in two phases with an inflection point.[16] The addition of sawdust ash and lime to BCS has shown promising results in improving its engineering characteristics, such as reducing liquid limit, differential free swell, and plasticity index, and increasing California bearing ratio (CBR) and specific gravity.[1] The expansive soil used was categorized as low-plasticity clay (CL) and required a comprehensive analysis to find the optimum percentage of WGP for construction projects.[2] Evaluates CDW for road construction, geocell reinforcement, and material properties. Compares CDW with natural aggregates for sub-base material suitability.[5] Focuses on alkali-activated CDW for large-scale soil enhancement. Addresses the mechanical effects of CDW on soil properties.[6] Focus on construction waste, reuse, and recycling in the industry. Emphasizes reducing pollution and protecting the environment. Discusses sustainable development and the impact of urbanization on waste. Addresses the importance of reusing materials to reduce environmental damage.[17] Investigated effects of construction and demolition materials on soil properties. Studied reduction in swelling potential and improvement in shear strength.[7] Focuses on recycled concrete and brick aggregates' geotechnical characteristics, assesses the aggregates' compaction properties, hydraulic conductivity, and shear strength, shows that compared to RCA, RBA has weaker protection against shear failure. Explores the specific gravity and resistance to shear failure of aggregates. [9] Focuses on using fine-grained CDW to improve weak soil properties. Emphasizes reducing sand use and environmental impact in construction. [12] Expansive soils require treatment for construction due to low strength. Waste plastic strips and brick powder enhance soil strength properties. Study focuses on reducing environmental pollution by utilizing waste materials.[3] A number of factors, such as modifications to the parental figure elements and shear strength parameters, the emergence of new minerals, enhancements to particle gradation, enhancements to inter-particle bonding, and modifications to the microstructure, influence the power and outstanding performance of soil-marble dust mixes.[18]

Considering the findings of the research gaps the aim of this study is to determine how to enhance the soil for black cotton by varying the percentages of construction demolished waste material added to it. This is done through an experimental activity. Lack of focus on institutional barriers to construction waste reuse limited emphasis on comparing reuse and recycling strategies in construction.

2. MATERIALS AND METHOD USED.

2.1. Material Used

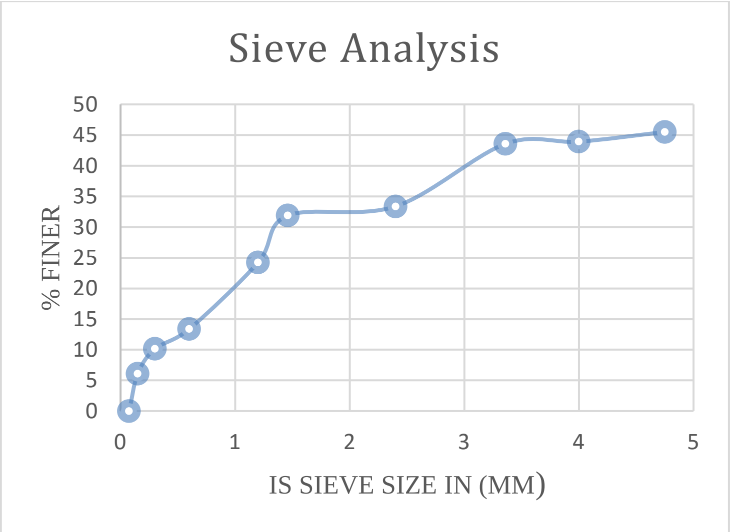
2.1.1. Black Cotton Soil:

Figure 1: Black Cotton Soil

Figure 1 displays that black cotton soil is taken from Indapur region for this investigation. Known as expansive soil, the black cotton soil presents a significant issue in the building industry. The swelling behavior of black cotton soil is mostly discovered by its mineralogical composition, which is enhanced by minerals such as illite and montmorillonite. It creates large cracks in dry conditions, up to 150 mm broad and 3.0 to 3.5 meters deep. On the other hand, it can grow by 20% to 30% in wet conditions, applying significant pressure. This upward force has the potential to raise foundations and cause walls above them to break. Interestingly, these fissures usually get broader at the top and narrow at the base. Because of these unique characteristics, building on black cotton soil necessitates specific methods. Soil with a size lower than 4.75 mm is employed in experimental research. The characteristics of the Black cotton soil are displayed in Table 1, and the mechanical sieve analysis method was used to find the grain size distribution showed in graph 1.

Sr.no	Properties	Value
1	Specific Gravity	1.45
2	Grain-size Analysis Gravel Sand Silt Clay	 15.8% 28.7% 33.0% 22.5%
3	Liquid Limit	83.5%
4	Plastic Limit	64%
5	Plasticity Index	19.5%
6	Optimum Moisture Content	34.8%
7	Maximum Dry Density	1.62
8	Swelling Potential	98%

Table 1 Properties of Black cotton soil.



Graph 1 Grain Size Distribution of BC soil

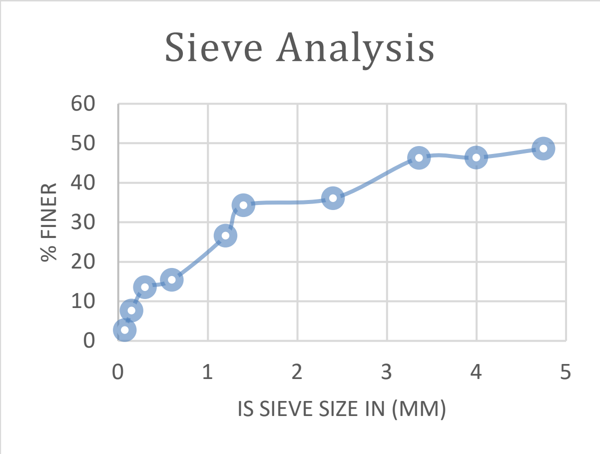
2.1.2. Construction and Demolition (C&D) waste:

Figure 2: Construction and Demolition (C&D) Waste

Figure2 shown the Construction and Demolition (C&D) waste materials were sourced from a disposal site situated at S.B. Patil Campus, Indapur, Pune. Upon collection, the samples underwent segregation to separate various components such as concrete waste, mortar, bricks, masonry, clay tiles, and others. A 50kg sample was then subjected to crushing using a rammer. The crushed sample, measuring below 4.75 mm in size, was mixed with soil in varying proportions of 5%, 10%, 15%, 20%, and 25%, respectively. This process aimed to observe the effects of different proportions of crushed sample added to the soil and determine the optimal amount for soil enhancement. Subsequently, the stabilized soil underwent testing following the guidelines outlined in IS 2720. The optimal proportion of C&D waste input for soil stabilization process will be ascertained depended on the outcomes of these studies. The characteristics of the C&D waste are displayed in Table 2.

Sr.no	Properties	Value
1	Specific Gravity	2.32
2	Grain-size Analysis Gravel Sand Silt Clay	 44.5% 38.7% 11.0% 03.8%
3	Liquid Limit	23.5%
4	Plastic Limit	11%
5	Plasticity Index	12.5%
6	Optimum Moisture Content	21.73%
7	Maximum Dry Density	1.8
8	Swelling Potential	19%

Table 2 Properties of Black Cotton Soil.



Graph 2. Grain Size Distribution CD waste

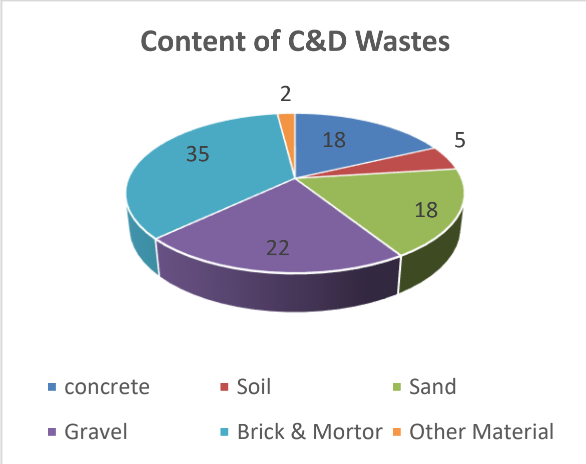


Figure 3. Content of C&D Wastes

2.2. Laboratory Method

2.2.1. Sample Preparation

For all experimental purposes, the particles going through a 425-mm and 4.75mm IS sieve have been employed to discover the Consistency limits, compaction and UCS test respectively. The characteristics of the parent materials and the combinations of those materials respectively. There aren't many noteworthy studies on the use of C&D wastes up to 25% to stabilize the soils. To prepare the mixes, the appropriate quantities of C&D wastes and oven-dried soil are first thoroughly mixed while dry. The visualization of the dry mixes' uniform color and texture ensures their consistency. Next, by manually adding the required amount of distilled water, wet mixing is carried out. Additionally, the samples are utilized in experiments.

2.2.2. Laboratory Work

Standard processes are used in determining the source materials' and their mixes' geotechnical qualities. Every experimental task is carried out at room temperature. Throughout the test period, the ambient temperature ranged from 22 to 31 °C. Both IS 2720 (Part 5) (1985) and IS 2720 (Part 6) (1972) apply to the parent elements and their mixtures. The samples are analyzed using IS 2720 (Part 40) (1977) and IS 2720 (Part 3) 1980 to determine their particular gravity and free swell index, respectively. A density test is used to obtain the values of all the samples' maximum dry density (MDD) and optimal Moisture content (OMC).[18] According to IS 2720 (Part 10) (1973), unconfined compressive strength (UCS) tests are conducted on all combinations at various curing times 1day 7days & 28 days, with a constant strain rate of 1.2 mm/min. Static compaction is used to prepare the 100 mm tall and 50 mm diameter cylindrical specimens at their respective OMC and MDD.

2.3 Micro Analysis

In an effort to gain a better understanding of the mechanism that is responsible for the behavioral changes that occur in the soil that has been amended with C&D wastes, thorough X-ray diffraction (XRD) micro-analyses have been performed on samples that were collected from the cracked part of the UCS specimen that was examined. The mineralogical alterations in the samples are ascertained by means of the X-ray diffraction (XRD) spectrometer examination. The samples are gradually ground into a fine powder before being forced into the glass sample holder's hollow. The samples are flattened with a tiny glass slide after being gently squeezed into the holder's hollow. After removing any

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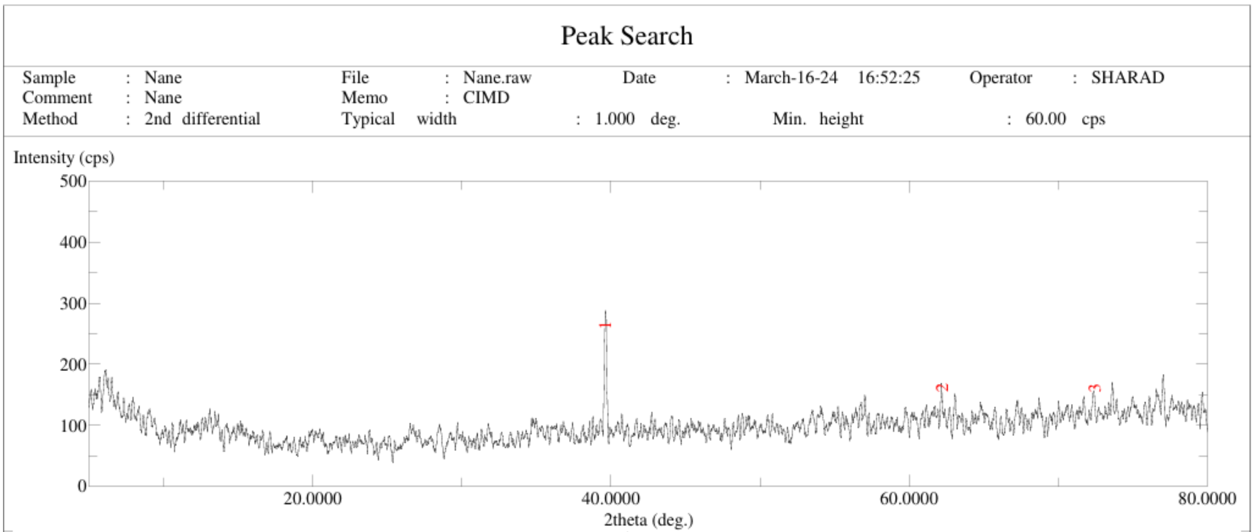
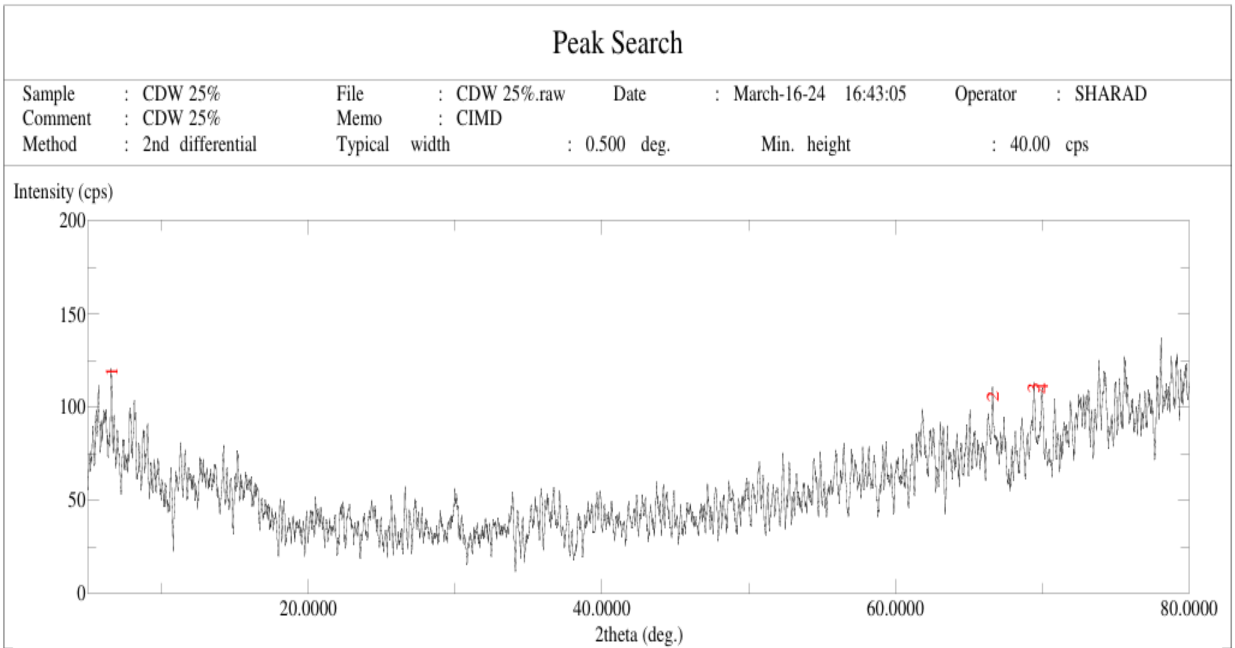
remaining powder from the area surrounding the sample holder's cavity, the holder is carefully placed into the apparatus. For Bragg's angle (2θ) ranging from 5° to 90°, the sample is scanned at a speed of 1°/min using a graphite monochromator and Cu-Ka radiation. The diffractometer captures precisely angles at which various intensity diffracted beams are recorded.



Peak no.	2theta	Flex Width	d-value	Intensity	I/Io
1	39.600	0.588	2.2740	258	100
2	62.200	0.565	1.4913	156	61
3	72.420	0.541	1.3039	155	61

Figure 4. XRD analysis of BC soil



Peak no.	2theta	Flex Width	d-value	Intensity	I/Io
1	6.600	0.306	13.3813	117	100
2	66.660	0.259	1.4019	103	89
3	69.420	0.329	1.3527	108	93
4	69.980	0.282	1.3433	108	93

Figure 5. XRD analysis of BC soil +25% CD waste

To investigate the production and alteration in mineral peaks, the mineralogical analyses of the source materials (soil and CD waste) are paired with the XRD analyses of the soil-CD waste mixtures. It has been noted that the CD waste is primarily composed of dolomite, calcite, and quartz, whereas the soil is primarily composed of montmorillonite, aluminium, and quartz. The results of the XRD analysis conducted on BCS + 25%CD Waste show in figure 4 and 5. These results imply that a compacted soil matrix developed, which produced the ideal rise in strength and fall in the percentage of swelling.

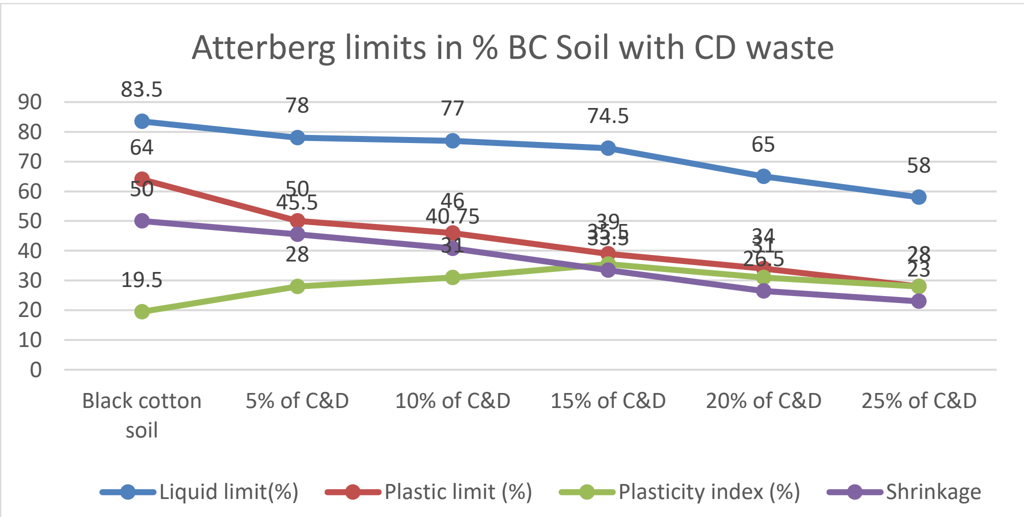
3. Experimental Results And Discussion

3.1 Index properties of Soil with C&D Waste

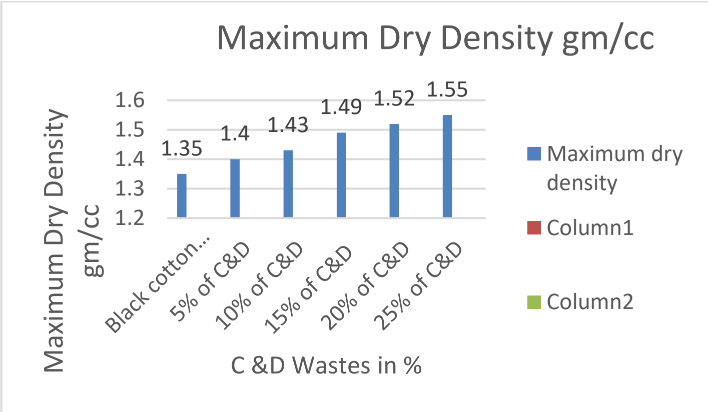
In the black cotton soil sample, the crushed construction and demolition waste material was added in the following proportions: 5%, 10%, 15%, 20%, and 25% total. Following that, the findings of the following explorations were shown in table 2 in order to take note of and comprehend the actions of black cotton soil, also known as expansive soil material.

Table 2: Properties for black cotton soil with CD waste

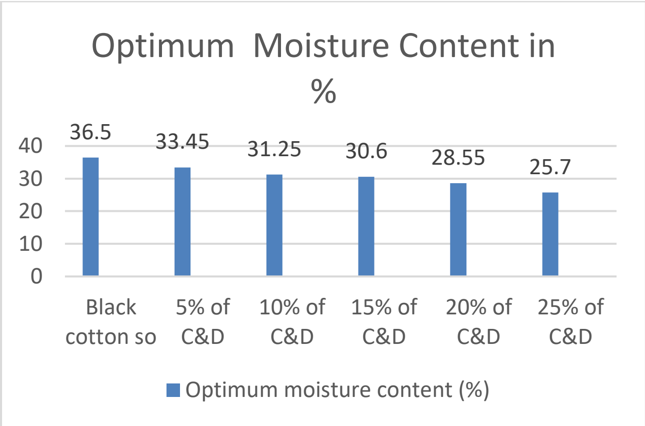
Engineering Property	Black cotton soil	5% of C&D Waste	10% of C&D waste	15% of C&D waste	20% of C&D waste	25% of C&D waste
Liquid limit (%)	83.5	78	77	74.5	65	58
Plastic limit (%)	64	50	46	39	34	30
Plasticity index (%)	19.5	28	31	35.5	31	28
Shrinkage Limit	50	45.5	40.75	33.5	26.5	23
Maximum dry density	1.35	1.40	1.43	1.49	1.52	1.55
Optimum moisture content (%)	36.5	33.45	31.25	30.60	28.55	25.70
Free swell index (%)	99 (Very High)	72(Very High)	60(Very High)	54(Very High)	52(Very High)	50(High)



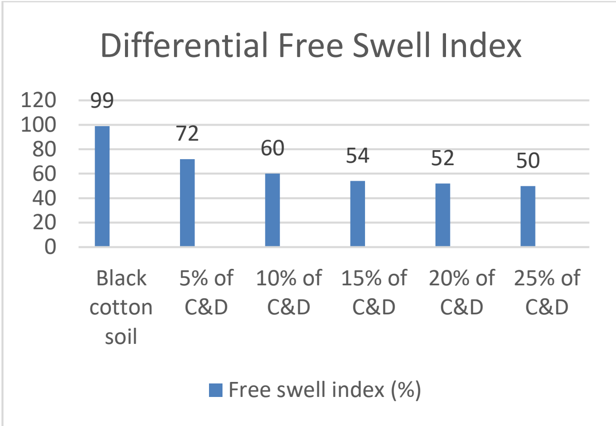
Graph 4. Consistency limits in % BC Soil with CD waste



Graph 5. Maximum Dry Density with CD waste



Graph 6. *Optimum Moisture content with CD waste*



Graph 7. Differential Free Swell Index

3.2 Unconfined Compression Test Results

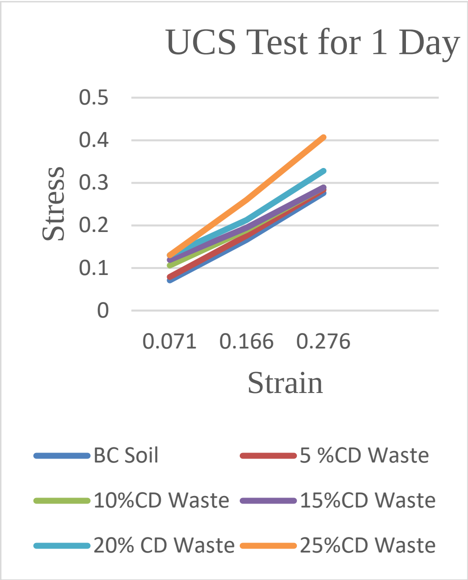
Under ASTM D2166-16, the Unconfined Compressive Strength (UCS) test was performed on pure BC soil and various combinations of C&D waste, to figure out how the admixtures affect the soil's strength characteristics. After one days, seven days, and twenty-eight days, the BC soil's observed UCS values are as showed in table no.4 respectively. Additionally, prior research has shown that, in BC soil, the UCS value rises as C&D waste reaches its ideal level. The pozzolanic/cementitious reaction between BC soil and C&D waste is what causes the rise in UCS value and changes the characteristics of BC soil.[19]

Figure 4. UCS Mould and Soil Sample

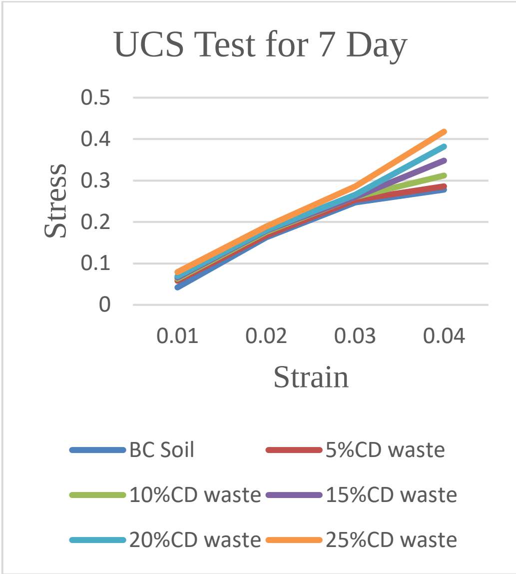
Figure 5. UCS Soil Testing and soil failure structure

Table 4. Unconfined Compression Test Results

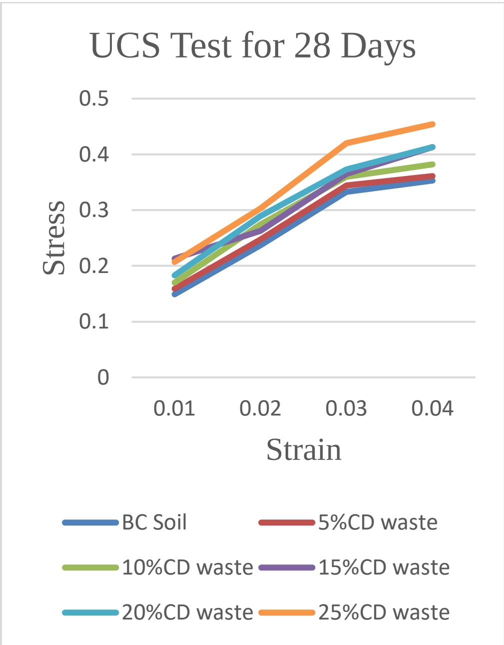
Sr.No.	Soil Combination	1 Day Unconfined Compression Stress	7 Days Unconfined Compression Stress	28days Unconfined Compression Stress
1	BC Soil	0.276 N/mm^2	0.278 N/mm^2	0.353 N/mm^2
2	BC Soil+5%CDW	0.284 N/mm^2	0.286 N/mm^2	0.361 N/mm^2
3	BC Soil+10%CDW	0.289 N/mm^2	0.312 N/mm^2	0.382 N/mm^2
4	BC Soil+15%CDW	0.289 N/mm^2	0.348 N/mm^2	0.413N/mm^2
5	BC Soil+20%CDW	0.328 N/mm^2	0.382 N/mm^2	0.413N/mm^2
6	BC Soil+25%CDW	0.407 N/mm^2	0.418 N/mm^2	0.454 N/mm^2



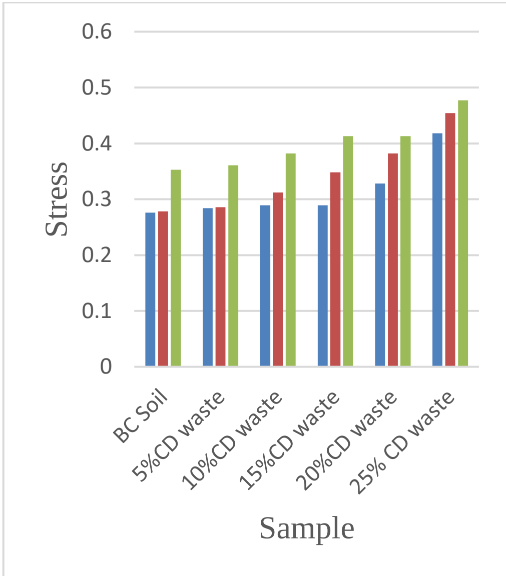
Graph 8. UCS Test result for 1 Day



Graph 9. UCS Test result for 7 Day



Graph 10. UCS Test result for 28 Day



Graph 11. Comparative Result Analysis of UCS Test

Conclusion

For the purpose of this paper project, we intend to bring about an improvement in the engineering features of Black cotton soil by incorporating recycled construction and demolition (C&D) garbage. The following are the study's findings:

After examining the addition of construction demolition trash in different percentages (5%, 10%, 15%, 20%, and 25%), significant changes were found in the material's primary characteristics. There was a discernible drop in the Liquid Limit%, from 83.5% to 58%, suggesting that less water was needed for plastic behaviour. Concurrently, the Plastic Limit% dropped from 64% to 28%, indicating that a larger geo-polymer content increases resistance to deformation. A general increase in the Plasticity Index% was connected with this decline in the Plastic Limit%.

In addition, the Shrinkage Limit progressively dropped from 50% to 23%, suggesting improved stability and reduced possibility of volume change as CD waste content increased. These results highlight the possibility of using improved construction waste to improve the sustainable nature and engineering qualities of building materials.

C&D wastes were added to the soil at different percentages, yet the soil's Maximum Dry Density (MDD) rose every time. The density of the soil was positively impacted by the MDD, which increased gradually from 1.35 g/cc to 1.55 g/cc between 5% and 25% of the C&D waste content. Moreover, the Optimum Moisture Content (OMC) values decreased with the inclusion of C&D wastes, ranging from 36.5% to 25.70% as waste content increased from 5% to 25%.

With the addition of 5%, 10%, 15%, 20%, and 25% of C&D wastes, respectively, the Differential Free Swell Index (FSI) dropped from 99% to 50%.

The combined input of C&D waste causes the UCS of BC soil to increase. Soil shear strength improves during a period of 1 day, 7 days, and 28 days, with the highest value. All of these results point to a significant improvement in Black cotton soil's engineering qualities. One practical way to address the issues of Black cotton soil in construction is to use C&D wastes as a soil stabilizer.

Furthermore, this approach presents an opportunity to mitigate the environmental consequences stemming from the substantial generation of C&D wastes, including water and land pollution, as well as the depletion of landfill capacities. By integrating C&D wastes into soil stabilization practices, not only can the engineering characteristics of the soil be enhanced, but also overall project costs can be reduced. Moreover, this strategy contributes to environmental sustainability by mitigating adverse impacts on the environment, thereby advocating for a more sustainable approach to construction practices.

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