

STABILIZATION OF BLACK COTTON SOIL USING CONSTRUCTION AND DEMOLITION WASTE

¹ Md. Naseem Ahmed, ² Vishal.M, ³A. Anurag, ⁴ K. Abhiram

^{1,2} Assistant Professor, ^{3,4} Undergraduate Student,
^{1,2,3,4} Department of Civil Engineering,

1, 2 Assistant Professor, Nalla Malla Reddy Engineering College Ghatkesar, Hyderabad, Telangana 500088

3,4 Student, Nalla Malla Reddy Engineering College Ghatkesar, Hyderabad, Telangana 500088

Abstract: Expansive soils, such as Black Cotton Soil (BCS), present significant challenges in civil engineering due to their low bearing capacity and high swelling-shrinkage characteristics, which often lead to structural cracks and foundation failures. This research evaluates a sustainable and cost-effective stabilization method using processed fine powder derived from Construction and Demolition (C&D) waste. Laboratory tests were performed on BCS blended with varying percentages of C&D waste ranging from 5% to 25%. The geotechnical parameters evaluated include Atterberg limits, compaction characteristics via the Standard Proctor test, Unconfined Compressive Strength (UCS), and shear strength via Direct Shear testing. The experimental findings reveal that 20% C&D waste content serves as the optimum stabilizer dosage. At this percentage, the Maximum Dry Density (MDD) increased by 33%, the Liquid Limit dropped by 35%, the Shrinkage Limit increased by 41%, and the Angle of Internal Friction almost tripled. The research validates that integrating recycled concrete debris offers benefits of both environmental and technical advantage, creating a volume-stable subgrade material while minimizing landfill waste.

Index Terms – Black Cotton Soil (BCS), Construction and Demolition (C&D) waste, Shear Strength- (UCS, Direct Shear Test).

1. INTRODUCTION

Black Cotton Soils (BCS) are expansive soils heavily enriched with montmorillonite clay minerals. These minerals exhibit immense volume changes—dramatic swelling upon wetting and severe shrinkage upon drying—which trigger differential settlement, cracking, and eventual failure of overlying lightweight structures, pavements, and canals. Standard stabilization methods rely heavily on commercial binders such as traditional cement or lime, which are highly economical and leave a heavy carbon footprint. Simultaneously, rapid urbanization yields millions of tons of Construction and Demolition (C&D) waste annually, placing a severe burden on landfills and causing widespread land degradation. This study explores a recycled alternative by pulverizing segregated masonry waste into a fine powder stabilizer. This mechanism utilizes calcium-rich components within crushed concrete and mortar to provide mechanical reinforcement and chemical stabilization to weak soils. The primary objective is to evaluate the influence of varying percentages of C&D waste on the index and engineering properties of expansive black cotton soil.

NEED OF THE STUDY.

This study investigates the use of construction and demolition (C&D) waste to improve the geotechnical properties of black cotton soil. This stems from two major concerns: environmental challenges caused by increasing industrial waste generation and engineering challenges associated with poor soil properties.

The scope of the study includes:

- Evaluating the index properties of black cotton soil with and without varying percentages of C&D waste.
- Improving the engineering properties of black cotton soil using C&D waste additives.
- Studying the compaction characteristics of black cotton soil mixed with different proportions of C&D waste.
- Assessing the strength behaviour (shear parameters) of black cotton soil with and without C&D waste at various percentages.

2.0 Literature Review

Extensive global literature demonstrates the viability of utilizing industrial and construction byproducts to transform weak soils into stable subgrades.

Alam et al. (2024): Tested partial replacement of BCS with 5% to 20% C&D debris, showing structural enhancements in shear parameters and bearing profiles.

Swapnil Chavan et al. (2023): Investigated clay soil stabilization utilizing blends of copper slag and fly ash, concluding that structural stabilization notably raises bearing resistance and checks swelling.

Zhao et al. (2022): Documented that fine fractions of processed C&D waste possess mechanical and chemical attributes that encourage compressive strength development while lowering carbon impacts compared to virgin lime or cement.

Dhananjaya et al. (2019): Evaluated C&D waste addition (3%, 6%, and 9%) into BCS and reported an upward shift in the California Bearing Ratio (CBR), signaling an enhancement in road pavement subgrade performance.

Shilpa Devi Gadde et al. (2019) & S.A. Kanalli et al. (2015): Investigated industrial byproducts like copper slag, noting how granular additives alter soil gradation, flatten moisture-density relations, and minimize swelling-shrinkage behaviors. The

stabilization of expansive soils using industrial and construction-derived waste materials has gained considerable attention due to increasing environmental concerns and the demand for sustainable geotechnical practices. Numerous researchers have investigated alternative stabilizers to improve the engineering behavior of weak and problematic soils.

Bambhaniya Mehul Ashokbhai et al. (2018) conducted an experimental study using lime and fly ash for expansive soil improvement and observed considerable enhancement in soil strength and reduction in plasticity indices through chemical stabilization mechanisms.

Jinka Chandrasekhar et al. (2015) reviewed the utilization of copper slag in geotechnical applications and reported that industrial by-products possess significant potential to improve density characteristics and reduce soil plasticity. Their study highlighted the environmental benefits of replacing conventional stabilizers with recycled materials.

Similarly, **S. A. Kanalli et al. (2015)** investigated the use of mine waste in Black Cotton Soil stabilization and concluded that waste-derived granular materials contribute to improved compaction behavior and reduction in volume instability.

Black Cotton Soil stabilization.

Therefore, the present study addresses this research gap by systematically evaluating the effect of varying proportions of processed C&D waste on the index properties, compaction characteristics, and strength performance of expansive Black Cotton Soil, with the objective of developing a sustainable and economically viable stabilization technique.

3. Materials and Methodology

3.1 Materials Used

Black Cotton Soil (BCS):

Black Cotton Soil was collected from NMREC college campus, Hyderabad, because of its high plasticity, swelling–shrinkage behavior, and low load-bearing capacity. The soil was collected at 1 meter below ground level which was air-dried, pulverized, and prepared for laboratory testing.

Construction and Demolition (C&D) Waste:

C&D waste was been collected from IDA-Jeedimetla C&D waste plant at Hyderabad, consisting mainly of masonry debris, segregated, crushed, and processed into fine powder. The material acts as a stabilizing agent through densification and calcium-based interaction.

3.2 Methodology

The experimental study was carried out in five stages:

1. Collection and preparation of Black Cotton Soil samples.
2. Determination of baseline properties of untreated soil.
3. Preparation of soil mixes with 5%, 10%, 15%, 20%, and 25% C&D waste.
4. Laboratory evaluation following Indian Standard procedures.
5. Analysis of results to identify the optimum stabilization percentage.

3.3 Laboratory Testing Program

1. Atterberg Limits: Conducted as per IS 2720 (Part 5) to determine consistency characteristics.
2. Specific Gravity: Determined according to IS 2720 (Part 3) using the density bottle method.
3. Standard Proctor Test: Performed as per IS 2720 (Part 7) to determine MDD and OMC.
4. Unconfined Compression Test (UCS): Conducted to evaluate compressive strength behaviour.
5. Direct Shear Test: Performed to determine cohesion (C) and angle of internal friction (ϕ).

IV. RESULTS AND DISCUSSION

4.1 Results of Descriptive Statics of Study Variables

4.1 Baseline Geotechnical Properties of Untreated Soil

The initial physical baseline of the pure Black Cotton Soil is highlighted in Table 4.1:

Table 4.1: Engineering Properties of Untreated Black Cotton Soil

Descriptions	Experimental Baseline Value
Specific Gravity	2.273
Liquid Limit (%)	79.6%
Plastic Limit (%)	27.8%
Optimum Moisture Content (OMC)	18.61%
Maximum Dry Density (MDD)	1.19 g/cc
Baseline Compaction:	1.34 g/cc
Cohesion (C)	22.37 (kN/m ²)
Angle of Internal Friction (ϕ)	11°

4.2 Effect of C&D Waste on Plasticity and Consistency Limits

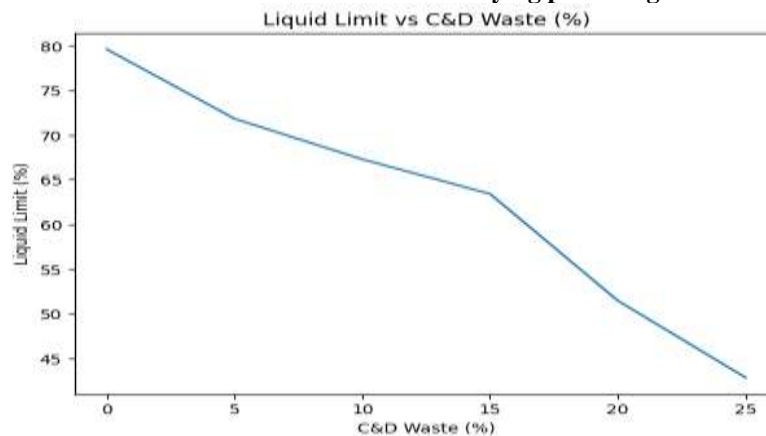
Gradual additions of granular, calcium-bearing C&D powder significantly reduced the plastic characteristics of the soil matrix, as detailed in Table 4.2.

Table 4.2: Atterberg Limits of Soil-C&D Waste Mixtures

Combination Mix	Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)
Pure BCS	79.60	27.80	11.31
BCS + 5% C&D Waste	71.83	23.58	12.76
BCS + 10% C&D Waste	67.29	22.73	14.21
BCS + 15% C&D Waste	63.42	21.96	14.97
BCS + 20% C&D Waste	51.47	20.54	15.95
BCS + 25% C&D Waste	42.87	19.04	16.72

The liquid limit dropped consistently from 79.6% to 51.47% at the 20% optimum mark, while the shrinkage limit expanded by more than 41% (moving from 11.31% up to 15.95%). This structural expansion of the shrinkage limit is critical; it demonstrates that the soil mix transitions into a more volume-stable zone that is less prone to cyclic swelling and shrinking.

GRAPH.4.2 Variation of Liquid Limit for BCS with varying percentages of C&D Waste



4.3 Compaction Properties (Standard Proctor Analysis)

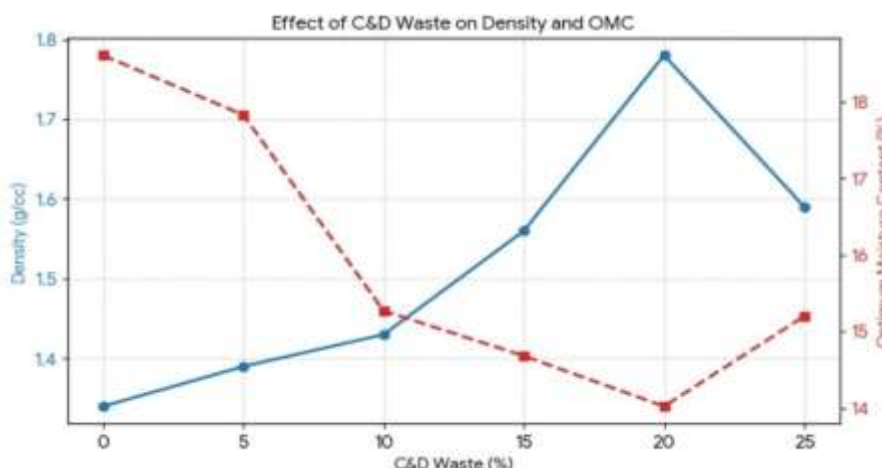
As finer soil grains were substituted by coarser, higher density reclaimed construction wastes, the compaction parameters shifted favorably, as shown in Table 4.3

Table 4.3: Compaction Parameters Variation

Parameters	Pure BCS	BCS + 5%	BCS+ 10%	BCS+ 15%	BCS+ 20%	BCS+ 25%
OMC (%)	18.61	17.83	15.27	14.68	14.02	15.20
MDD (g/cc)	1.34	1.39	1.43	1.56	1.78	1.59

The Maximum Dry Density peaked at 1.78 g/cc under a 20% replacement ratio, indicating an approximate 33% increase in dry density over raw soil. This occurs because the granular waste effectively fills the microscopic voids within the expansive clay structure. Beyond 25%, the density falls back to 1.59 g/cc due to particle interference. Concurrently, the OMC drops from 18.61% to 14.02% at the optimum 20% dosage, reducing the water required for fieldwork compaction.

GRAPH.4.3 Variation of MDD and OMC For BCS with varying percentages of C&D Waste



4.4 Strength Enhancement Analysis

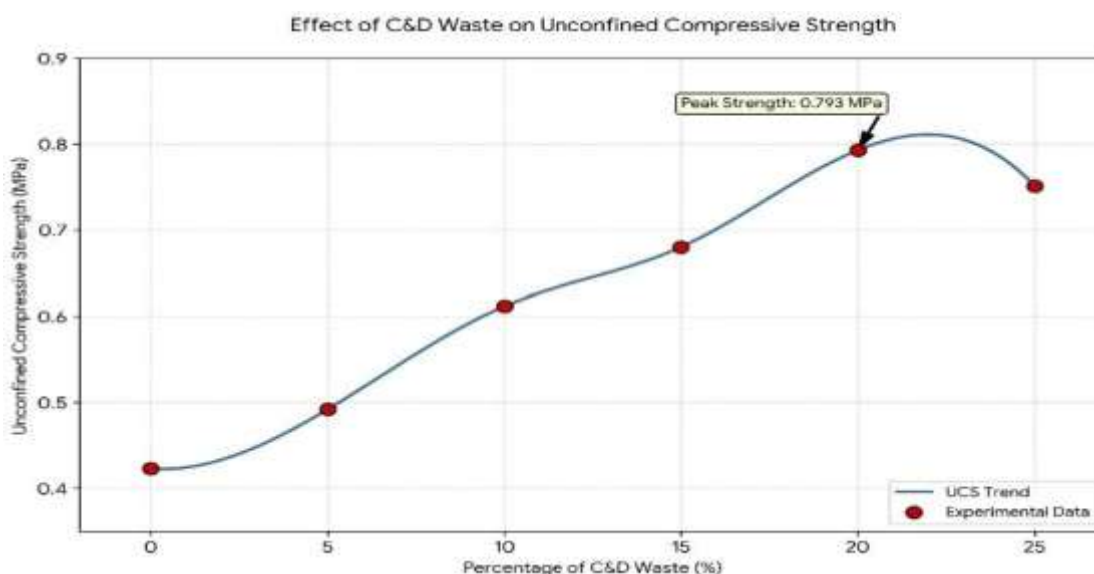
Unconfined Compressive Strength (UCS) The results from UCS testing demonstrate a progressive increase in soil stiffness and compressive resistance, as outlined in Table 4.4

Table 4.4: Unconfined Compressive Strength Data

Soil Combination Mix	Axial Strain at Failure	Failure Compressive Stress (MPa)
Pure BCS	0.0060	0.423
BCS + 5% C&D Waste	0.0053	0.492
BCS + 10% C&D Waste	0.0046	0.612
BCS + 15% C&D Waste	0.0037	0.680
BCS + 20% C&D Waste	0.0026	0.793
BCS + 25% C&D Waste	0.0021	0.751

The failure stress peaked at 0.793 MPa under 20% dosage—marking an 88% structural strength gain over the base soil . When the dosage was further increased to 25%, the compressive stress dropped slightly to 0.751 MPa, confirming 20% as the optimal blending ceiling. The axial strain dropped significantly from 0.0060 to 0.0026, indicating that the modified subgrade becomes stiffer and more brittle due to the interlocking granular matrix.

Graph 4.4. Effect of C&D waste on Unconfined Compressive Strength



4.5 Shear Strength Parameters

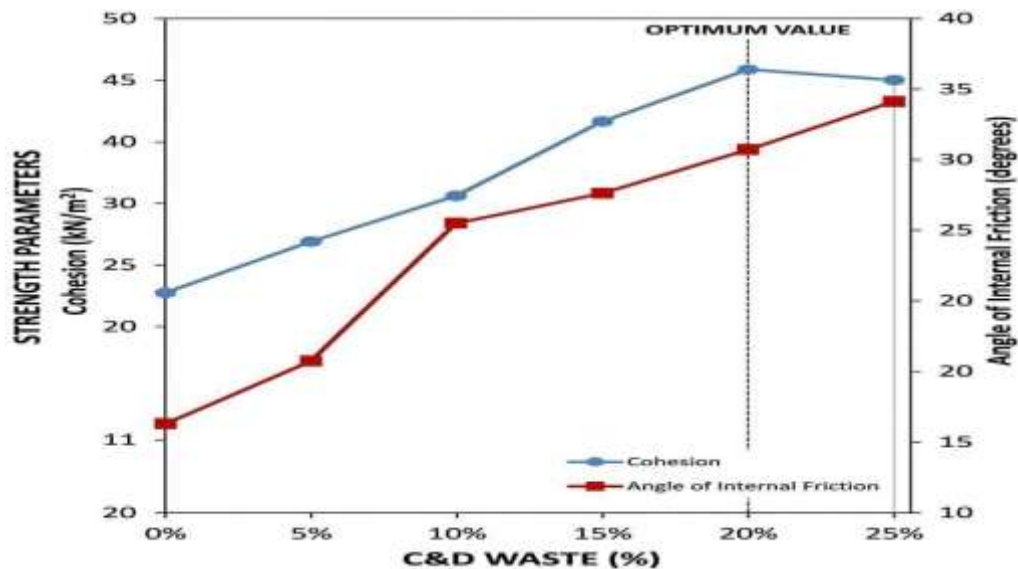
Data collected via direct split-box shear testing show clear technical improvements in both internal cohesion and frictional angles, as shown in Table 4.5

Table 4.5: Shear Parameters Response

Parameter	Pure BCS	BCS + 5%	BCS + 10%	BCS + 15%	BCS + 20%	BCS + 25%
Cohesion (kN per square meter)	22.37	26.43	30.21	36.84	41.26	40.28
Angle of Internal Friction (Degrees)	11	15	28	30	32	34

Cohesion parameters increased by 84%, reaching a maximum of 41.26 (kN per meter square) at the 20% optimum threshold. Simultaneously, the internal friction angle nearly tripled, jumping from (11 degree) to (32 degrees). This shifting profile from a weak, highly plastic clay into a soil with high frictional resistance confirms successful subgrade stabilization

4.5 Shear strength parameters vs soil with different proportions C&D waste



5. Conclusion

This study investigated the feasibility of utilizing Construction and Demolition (C&D) waste powder as a sustainable stabilizing agent for Black Cotton Soil (BCS) and evaluated its influence on the engineering behaviour of expansive soil. Based on the experimental investigation, the following conclusions are drawn:

1. The incorporation of C&D waste significantly improved the geotechnical characteristics of Black Cotton Soil by reducing its expansive behaviour and enhancing its load-bearing performance.
2. Among all mix proportions examined, 20% C&D waste replacement was identified as the optimum dosage, providing the most balanced improvement in strength, compaction, and consistency properties.
3. The addition of C&D waste resulted in a substantial reduction in Liquid Limit and Plasticity characteristics, indicating improved dimensional stability and reduced susceptibility to moisture-induced swelling and shrinkage.
4. Compaction studies demonstrated an increase in Maximum Dry Density (MDD) accompanied by a reduction in Optimum Moisture Content (OMC), confirming enhanced packing efficiency and improved field compaction behaviour.
5. Mechanical performance indicators including Unconfined Compressive Strength (UCS), cohesion, and angle of internal friction showed considerable enhancement, validating the effectiveness of C&D waste in improving the structural resistance of expansive soils.
6. The stabilization mechanism is attributed to the combined effect of particle rearrangement, void filling, and calcium-induced cementitious bonding, which transformed the weak clay matrix into a denser and more stable soil structure.
7. From a sustainability perspective, the proposed method promotes resource recovery, waste valorisation, reduction of landfill dependency, and lower environmental impact compared with conventional stabilization materials.

Overall, the research demonstrates that processed Construction and Demolition waste can serve as a technically efficient, economically feasible, and environmentally sustainable alternative for expansive soil stabilization, particularly for subgrade improvement and low-cost infrastructure applications.

Future Recommendation

Further studies may include long-term durability assessment, cyclic wetting–drying analysis, microstructural characterization (SEM/XRD), and field-scale validation to establish broader implementation potential.

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