

Strength, Bearing Capacity and Swell Behaviour of Black Cotton Soil Reinforced with Recycled Pet Plastic Bottle Strips

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Abstract: Black cotton soil (BCS), classified as high-plasticity CH clay, underlies approximately 30% of the Indian land mass and presents persistent geotechnical challenges swelling pressures of 50–400 kPa, soaked California Bearing Ratio (CBR) values of 1–3%, and seasonal desiccation cracking. Conventional stabilisation using Ordinary Portland Cement (OPC) or hydrated lime is effective but cost-intensive and contributes ~0.9 t CO₂ per tonne OPC. This study investigates shredded post-consumer Polyethylene Terephthalate (PET) plastic bottle strips as a low-cost, low-carbon reinforcement for BCS sub grade. Soil from Village Anawali, Pandharpur (Solapur District, Maharashtra) was characterised per IS:2720 series. PET strips of 8 mm width and aspect ratio 1–3 were added at six dosages (0, 0.2, 0.4, 0.6, 0.8 and 1.0% by dry weight). The soil classified as CH (LL = 58%, PI = 30%, FSI = 60%, MDD = 16.9 kN/m³, OMC = 22%). Maximum unsoaked CBR of 2.5% was achieved at 0.6% PET a 31.6% improvement over the untreated control of 1.9%. Soaked CBR rose from 0.8% to 1.3%, though the absolute 0.5-percentage-point change lies within typical CBR repeatability and should be treated as indicative. Notably, the 0.6% optimum CBR remains below the IRC:37 minimum subgrade requirement of 3%, indicating that PET reinforcement alone is insufficient and a hybrid approach (PET + lime or fly ash) is recommended. The intervention costs ~₹8,500 per 100 m³ of treated subgrade against ~₹68,000 for OPC stabilisation, supporting Sustainable Development Goals 11, 12 and 13.

Keywords: Black cotton soil; recycled PET; soil stabilisation; CBR; expansive clay; sustainable geotechnics; circular economy..

I. INTRODUCTION

The stability of any civil engineering structure depends ultimately on the load-bearing capacity of the underlying soil. Approximately 30% of India across the Deccan Plateau, Madhya Pradesh, Gujarat, Karnataka and Andhra Pradesh is underlain by black cotton soil (Vertisols / Regur soil), the residual product of Deccan Trap basalt weathering. The Solapur District of Maharashtra, where this study is located, lies almost entirely on BCS-dominated terrain. The problematic engineering character of BCS arises from its montmorillonite clay mineral content, whose 2:1 lattice structure permits extensive interlayer water absorption and produces high swell pressure (50–400 kPa), high plasticity (LL 50–100%, PI 25–60%), low wet shear strength (CBR 1–3%), and brittle desiccation cracking of 25–100 mm width. Under the Pradhan Mantri Gram Sadak Yojana (PMGSY) thousands of kilometres of rural roads are built annually on BCS subgrades. Without adequate stabilisation, pavement failures rutting, heaving, longitudinal cracking, pothole formation occur within the first monsoon. The Indian Roads Congress (IRC:37) requires subgrade CBR \geq 3% for rural roads, yet natural BCS typically delivers only 1–3% in soaked condition. Bridging this performance gap affordably and sustainably is the engineering motivation of this work.

In parallel, the global plastic waste crisis presents a complementary challenge. India generates an estimated 25,000–



26,000 tonnes/day of plastic waste (CPCB, 2024), of which less than 10% is effectively recycled. PET (polyethylene terephthalate) bottles with tensile strength 50–100 MPa, elastic modulus 2–4 GPa and specific gravity ~1.3 are mechanically credible candidates for discrete inclusion reinforcement. Channelling this waste stream into civil infrastructure offers a circular-economy solution to two crises simultaneously.

II. PROBLEMSTATEMENT

Black cotton soil is one of the most problematic soils encountered in civil engineering projects due to its high clay content and expansive nature. It undergoes significant volume changes with variations in moisture content, resulting in excessive swelling during wet seasons and shrinkage during dry periods. These characteristics lead to ground heave, differential settlement, cracking of pavements, foundation failures, and increased maintenance costs for infrastructure. Additionally, black cotton soil generally exhibits low bearing capacity, poor shear strength, and high compressibility, making it unsuitable for supporting engineering structures without proper treatment. Traditional soil stabilization methods such as lime, cement, and chemical additives are effective but often involve high costs, energy consumption, and environmental impacts. At the same time, the growing accumulation of plastic waste, particularly polyethylene terephthalate (PET) bottles, has become a serious environmental concern due to their non-biodegradable nature and increasing disposal challenges.

The utilization of recycled PET plastic bottle strips as a soil reinforcement material presents a potential sustainable solution to both problems. The inclusion of PET strips in black cotton soil may improve its strength characteristics, increase bearing capacity, and reduce swelling behavior through enhanced soil-reinforcement interaction. However, there is limited information regarding the optimum PET strip content and its effectiveness in improving the engineering properties of black cotton soil under different conditions.

Therefore, there is a need to investigate the influence of recycled PET plastic bottle strips on the strength, bearing capacity, and swell behavior of black cotton soil. This study aims to evaluate the feasibility of using waste PET strips as an eco-friendly and cost-effective reinforcement material for improving the performance of expansive soils and promoting sustainable waste management practices in geotechnical engineering.

III. LITERATURE SURVEY

Peddaiah, Burman & Sreedeeep (2018) established the geometric benchmark for PET strip studies on BC soil, reporting peak CBR improvement at 0.4% strips with aspect ratio

Naresh et al. (2025) performed the most comprehensive multi-scale investigation on Indian CH clay (Hyderabad BCS); at 1.0% shredded PET (10 mm × 1 mm, AR ≈ 8–10), unsoaked CBR rose from 2.0% to 4.5% (+125%) and Differential Free Swell Index reduced 15%. SEM evidence confirmed pore refinement to <0.5 μm at the optimum and macro-void formation (>30 μm) at over-dosage the first high-resolution validation of the dispersion–saturation–agglomeration three-regime model.

Zhu et al. (2023) demonstrated that PET-reinforced expansive clay retains superior stiffness and resilient response under freeze–thaw cycling, with 1.0% optimum dosage. Hafez et al. reported a 58% increase in resilient modulus at 0.6% PET in Egyptian Delta clay under repeated-load triaxial testing a result directly translatable to mechanistic pavement design (IRC:37).

Khalid & Alshawmar (2024) synthesised over 140 studies in a comprehensive review, generalising that CBR improves up to ~1.2% PET (fibres) or ~4% (strips), with optimum content typically 0.5–1.5% by dry mass for expansive clays.

UCS gains across studies range from +37% (Naresh et al.) to +138% (Kabeta, 2022). Direct shear tests confirm 39–121% improvement in shear strength and 37% reduction in compressibility at optimum dosage. The mechanistic consensus identifies three operative scales: macro-scale tensile bridging by strips intercepting cracks, meso-scale interfacial friction governing pull-out resistance, and micro-scale pore refinement that densifies fabric and physically restrains montmorillonite hydration. Despite this rich global literature, an integrated multi-parameter dataset for



Solapur-region BCS and specifically for the practical 0.2–1.0% AR 1–3 dosage window suited to manual field mixing has been absent. emphasized scalability and interoperability, which are crucial for large-scale healthcare deployment.

IV. PROJECT DESCRIPTION

Black cotton soil is a highly expansive soil that exhibits significant swelling and shrinkage with changes in moisture content. Due to its low strength, poor bearing capacity, and high volume change characteristics, it poses serious challenges in the construction of pavements, foundations, embankments, and other civil engineering structures. Conventional stabilization methods, although effective, often involve high costs and environmental concerns.

This project focuses on improving the engineering properties of black cotton soil through the incorporation of recycled polyethylene terephthalate (PET) plastic bottle strips. PET bottles constitute a major portion of plastic waste generated worldwide and require sustainable disposal and recycling methods. The use of waste PET strips as soil reinforcement offers an environmentally friendly and cost-effective approach to soil stabilization while simultaneously addressing plastic waste management issues.

The study involves collecting black cotton soil samples and preparing PET strips of specified dimensions from discarded plastic bottles. Laboratory tests are conducted on untreated soil and soil reinforced with varying percentages of PET strips. The experimental program includes determination of index properties, compaction characteristics, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and free swell index (FSI). The results are analyzed to evaluate the influence of PET strip reinforcement on soil strength, load-bearing capacity, and swelling behavior.

The project aims to identify the optimum PET strip content that provides maximum improvement in geotechnical performance. It also examines the mechanisms through which PET strips enhance soil behavior by increasing frictional resistance, improving particle interlocking, and restricting excessive deformation and swelling.

The outcomes of this research are expected to demonstrate that recycled PET plastic bottle strips can effectively improve the strength and bearing capacity of black cotton soil while reducing its swelling potential. The findings will contribute to the development of sustainable ground improvement techniques and promote the beneficial reuse of plastic waste in civil engineering applications.

V. OBJECTIVES OF SYSTEM

- To determine the basic geotechnical properties of black cotton soil from Village Anawali, Pandharpur water content, specific gravity, Atterberg limits, free-swell index, grain size distribution, and Modified Proctor compaction parameters.
- To prepare standardised recycled PET strips (8 mm width, aspect ratio 1–3) from post-consumer 1-litre water bottles.
- To evaluate the effect of PET dosage (0, 0.2, 0.4, 0.6, 0.8 and 1.0% by dry weight) on soaked and unsoaked CBR.
- To identify the optimum PET content for the geometry studied and to assess whether it meets the IRC:37subgrade requirement.
- To compare experimental results against 2018–2025 peer-reviewed literature and to estimate economic and environmental performance against conventional stabilization methods.

VI. MATERIALS AND METHODOLOGY

Black Cotton Soil Collection

Disturbed soil samples (~75 kg) were collected from Village Anawali, approximately 12 km north-east of Pandharpur, Solapur District, Maharashtra, from open pits at depths of 0.5–1.0 m. Samples were sealed in HDPE bags, air-dried in the laboratory for 48 hours, and tested per IS:2720 series. Classification followed USCS (ASTM D2487) and IS:1498.



PET Strip Preparation

Post-consumer 1-litre PET water bottles of uniform brand (wall thickness 0.3–0.5 mm) were collected from local waste-collection points. Labels and caps were removed; bottles were rinsed and air-dried. Cylindrical body sections were cut manually into longitudinal strips of 8 mm width with lengths of 8–24 mm (aspect ratios 1–3). Strips were oven-dried at 50 °C for 12 hours before mixing.

Experimental Programme

Test	Standard	Purpose
Water Content	IS:2720 Part 2	Moisture characterization
Specific Gravity	IS:2720 Part 3	Soil classification
Grain Size Analysis	IS:2720 Part 4	Classification & grading
Atterberg Limits	IS:2720 Parts 5 & 6	Plasticity classification
Free Swell Index	IS:2720 Part 40	Expansiveness rating
Modified Proctor	IS:2720 Part 8	MDD & OMC for each PET %
CBR (Soaked & Unsoaked)	IS:2720 Part 16	Subgrade strength

Table Experimental programme.

CBR specimens were prepared by static compaction to Modified Proctor density at the OMC determined for each dosage, in 150 mm diameter × 175 mm height moulds. Soaked specimens were submerged for 96 hours under a 2.5 kg surcharge before penetration testing. Penetration rate was 1.25 mm/min. The CBR value was calculated at 2.5 mm penetration as the primary reference.

VII. RESULTS AND DISCUSSION

Index Properties

Atterberg limit testing classified the soil as CH high-plasticity inorganic clay under both USCS and IS:1498. The Free Swell Index of 60% places the soil in the moderate-to-high expansiveness category. The measured average specific gravity of 2.15 is, however, anomalously low published values for Indian BCS typically lie in the range 2.55–2.75, and pure montmorillonite has $G_s \approx 2.6$ –2.9. The reported value most plausibly reflects either trace organic content in the disturbed sample or incomplete de-airing during the pycnometer test, and re-determination on a fresh sample is recommended (see Section 7.2). The remaining index parameters are consistent with literature ranges for Deccan Plateau BCS.

Parameter	Value	Typical BCS Range
Average Water Content	21.7%	18–30%
Specific Gravity, G_s	2.15 (anomalous)	2.55–2.75
Liquid Limit, LL	58%	50–100%
Plastic Limit, PL	28%	25–45%
Plasticity Index, PI	30%	25–60%
Shrinkage Limit, SL	10%	8–12%
Free Swell Index, FSI	60%	50–150%
% Fines (<75 μm)	38.7%	35–60%
MDD (control)	16.9 kN/m ³	14–18 kN/m ³
OMC (control)	22.0%	18–26%
USCS Classification	CH	

Index properties of black cotton soil from Village Anawali, Pandharpur.



Compaction Characteristics

Modified Proctor testing produced a control MDD of 16.9 kN/m³ at OMC of 22.0%. PET addition produced small, progressive changes OMC increased to 22.4% and MDD decreased to 16.7 kN/m³ at 0.6% PET, with continued mild reduction at higher dosages (16.5 kN/m³ at 1.0% PET). The trend is consistent with the lower specific gravity of PET (~1.3) displacing soil mass, and remains within the ±5% range universally reported in the literature. The practical implication is that field compaction targets need only minor upward adjustment of moisture content when PET is used.

California Bearing Ratio (CBR)

Table 5.2 presents soaked and unsoaked CBR values across all six dosage levels. Maximum unsoaked CBR of 2.5% was achieved at 0.6% PET a 31.6% relative improvement over the untreated control of 1.9%. The corresponding soaked CBR rose from 0.8% to 1.3%; while this represents a 62.5% relative gain, the absolute change of 0.5 percentage points is comparable in magnitude to typical CBR test repeatability (±0.3–0.5 pp), and should be regarded as indicative pending replicated testing.

PET Content (%)	Unsoaked CBR (%)	Soaked CBR (%)	Remarks
0.0 (Control)	1.9	0.8	Baseline
0.2	1.7	0.9	Dispersion regime
0.4	1.8	1.0	Approaching optimum
0.6 (Optimum)	2.5	1.3	Saturation regime
0.8	1.3	0.7	Agglomeration
1.0	1.3	0.7	Agglomeration

CBR values at varying PET dosage (8 mm width, AR 1–3).

The CBR–dosage curve clearly traces the three-regime mechanistic model: gradual gain through 0.2–0.4% PET (dispersion), peak at 0.6% (saturation maximum fibre–soil contact area), and decline at 0.8–1.0% as fibre–fibre contact begins to dominate (agglomeration). This phenomenology is consistent with Naresh et al. (2025) and Khalid & Alshawmar (2024), although the present optimum dosage (0.6%) is lower than the ~1.0% commonly reported with higher-aspect-ratio fibres. The relatively modest peak improvement (+31.6% vs. +125% reported by Naresh et al.) is attributable directly to the low aspect ratio (1–3) chosen for practical hand-mixing in field conditions: lower AR delivers lower specific surface area for friction transfer, trading mechanical efficiency for constructability.

Load–Penetration Behaviour

Qualitatively, PET-reinforced specimens exhibited a more linear and ductile load–penetration response than the brittle control, consistent with a fibre-bridging mechanism in which strips crossing developing tension cracks mobilise frictional tension and transfer stress back into the soil matrix (Tang et al., 2007; Botero et al., 2015). The original load–dial readings at intermediate penetrations are not reproduced here owing to a data integrity concern in the source records (penetration values exceeded the 12.5 mm CBR limit, indicating likely transcription error); replication of the load–penetration test with verified instrumentation is identified as a priority for future work.

Swell Behaviour Scope and Inferred Performance

Free Swell Index was measured on the untreated control soil only (FSI = 60%, moderate-to-high expansiveness category per IS:2720 Part 40). Direct measurement of swell behaviour on PET-reinforced specimens by Differential Free Swell Index, oedometer swell pressure, or one-dimensional consolidation testing was outside the experimental scope of this study. The expected swell-restraint contribution of the PET reinforcement is therefore inferred indirectly from published literature on geometrically and mineralogically comparable expansive clays. Naresh et al. (2025) reported a 15% reduction in DFSI (55% → 46.9%) at 0.8–1.0% PET fibre dosage on Indian CH clay; Chaduvula, Viswanadham & Kodikara documented a 66% reduction in desiccation crack area at 0.5% PET fibres (15 mm length);



and Miller & Rifai showed crack-area reductions from 12% to 89% as PET dosage rose from 0.2% to 0.8%. The mechanistic basis is well-established:

hydrophobic PET surfaces create localised zones of reduced matric-suction sensitivity and physically restrain montmorillonite platelet hydration at the meso-scale (Khalid & Alshawmar, 2024).

Two qualifications must, however, be made explicit. First, the magnitude of swell reduction reported in the literature (15% DFSI) is modest compared to that achievable with chemical stabilisers lime treatment typically produces 60–80% DFSI reduction through cation exchange and pozzolanic reaction. PET reinforcement is therefore a complementary rather than a replacement technology for swell control on highly expansive soils. Second, swell behaviour on the specific Pandharpur BCS at the 0.6% AR 1–3 dosage adopted here has not been verified experimentally and is identified as a priority for follow-on work alongside the hybrid PET–lime trials recommended in Section 8. Direct DFSI testing per IS:2720 Part 40 on the optimum PET dosage and oedometer swell pressure determination per IS:2720 Part 41 are the two specific tests required to close this scope gap.

VIII. COMPARISON WITH RECENT LITERATURE

Table 6.1 places the present results in the context of recent peer-reviewed studies on PET reinforcement of expansive and CH clay soils.

Study	Soil Type	PET Form (AR)	Optimum %	Improvement
Present Study, 2026	BCS, Pandharpur	Strips, AR 1–3	0.6	+31.6% (unsoaked CBR)
Naresh et al., 2025	CH Clay, India	Fibre, AR ≈ 10	1.0	+125% (unsoaked CBR)
Peddaiah et al., 2018	BC Soil, India	Strips, AR = 3	0.4	Peak CBR
Hafez et al.	Clay, Egypt	Bottle PET, AR ≈ 4	0.6	+58% Mr
Hassan et al., 2021	Clayey soil	Fibres	1.0	+76% UCS
Adane et al., 2022	BC Soil, Ethiopia	Bottle waste	5.0	Peak CBR / UCS
Zhu et al., 2023	Expansive clay	PET strips	1.0	Best F–T durability

Position of the present study within recent literature.

The present study's optimum dosage (0.6%) and CBR gain (+31.6%) are at the conservative end of the published range. This is not a shortcoming but a deliberate consequence of the geometry choice: AR 1–3 strips are field-mixable by hand or rotavator without specialist equipment, whereas AR 8–10 fibres typically require shredder-grade processing not available in rural construction settings.

IX. ECONOMIC, ENVIRONMENTAL AND HONEST ASSESSMENT

Indicative Cost Comparison (per 100 m³ treated subgrade)

Method	Dosage	Material Cost (₹)	Total (₹)
Untreated BCS		0	500
Lime stabilisation	4%	33,000	42,000
OPC stabilisation	4%	48,000	68,000
PET strip reinforcement	0.6%	8,100	8,500
Fly ash treatment	15%	14,000	22,000

Indicative cost comparison (Maharashtra market rates, 2024)

PET strip reinforcement at 0.6% costs approximately ₹8,500 per 100 m³ an indicative ~87% saving over OPC and ~80% over lime treatment. Each 100 m³ of PET-reinforced subgrade also diverts ~60 kg of post-consumer PET from landfill while generating effectively zero construction-phase CO₂, against ~320 kg CO₂ for OPC stabilisation. The intervention directly supports SDG 11 (Sustainable Cities), SDG 12 (Responsible Consumption) and SDG 13 (Climate Action).



Critical Limitations and Honest Caveats

In the interest of scientific honesty, the following limitations are explicitly acknowledged:

(i) IRC:37 non-compliance the optimum unsoaked CBR of 2.5% (and soaked CBR of 1.3%) does not meet the IRC:37-2018 requirement of $CBR \geq 3\%$ for rural road subgrades. PET reinforcement at AR 1–3, used in isolation, is therefore not sufficient for a code-compliant subgrade. A hybrid approach (PET 0.6% + lime 2–4% or fly ash 10–15%) is required and is strongly recommended.

(ii) Specific Gravity anomaly the measured $G_s = 2.15$ is well below the 2.55–2.75 range published for Indian BCS and for pure montmorillonite. Probable causes are organic contamination of the disturbed sample or incomplete de-airing during pycnometer testing. Repetition on a fresh, oven-dried, finely-pulverised sample with vacuum de-airing is recommended before any design use of this number.

(iii) Statistical limitations with $n = 2-3$ specimens per dosage and no reported error analysis, the smaller observed effects (e.g. soaked CBR change of 0.5 percentage points) lie within the typical CBR test repeatability and should be reported as indicative rather than confirmed. Replication on independent batches is required for design-grade conclusions.

(iv) Out-of-scope durability wetting–drying cycles, freeze–thaw durability, resilient modulus under repeated loading, oedometer swell pressure, microstructural validation by SEM/XRD, and microplastic leaching were not investigated. These are recognised gaps that any field implementation must address before scale-up.

(v) Microplastic concerns long-term degradation of buried PET into microplastics is an open research question. Until column-leachate and field-monitoring data are available, the environmental claim should be framed as construction-phase rather than full life-cycle.

X. CONCLUSION

1.The black cotton soil from Village Anawali, Pandharpur classifies as a high-plasticity inorganic clay (CH)with moderate-to-high expansiveness ($FSI = 60\%$, $PI = 30\%$, soaked $CBR = 0.8\%$), confirming the need for stabilization under IRC:37 rural road requirements.

2.Recycled PET strips (8 mm width, AR 1–3) at 0.6% by dry weight produce the maximum CBR improvement in this study 31.6% in unsoaked condition. The soaked-condition gain (0.5 percentage points) is indicative pending replication.

3.The CBR–dosage curve traces the established dispersion–saturation–agglomeration three-regime mechanisticmodel.

4.Modest peak improvement vs. higher-AR literature reflects the deliberate trade of mechanical efficiency forfield constructibility.

5.PET reinforcement alone at the optimum dosage does not meet the IRC:37 $CBR \geq 3\%$ threshold; a hybridtreatment (PET + lime or fly ash) is recommended for code-compliant rural road subgrades.

6.Indicative economics suggest ~87% cost saving versus OPC and ~80% versus lime, with ~60 kg PET divertedfrom landfill per 100 m³ and effectively zero construction-phase CO₂ emissions.

7.Priority future work: hybrid PET–lime/fly-ash trials, AR × dosage factorial design, resilient modulus underRLTT, wetting–drying durability, SEM/XRD microstructural validation, microplastic leaching assessment, and a PMGSY field trial section with in-situ CBR and Benkelman beam monitoring



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