# Assessment of Environmental Impacts on Bearing Capacity (CBR) of Sisal Fiber-Reinforced Black Cotton Soil

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*Abstract* — Expansive black cotton soils pose severe challenges to infrastructure due to their low bearing capacity and high swell–shrink behaviour. This study investigates the efficacy of randomly distributed sisal fiber reinforcement as a sustainable stabilization technique. Sisal fiber was mixed with black cotton soil at 0%, 0.25%, 0.5%, 0.75%, 1.0%, and 1.25% by dry weight. The optimum fiber content of 1.0% increased soaked CBR by 551.5% (1.71% → 11.14%) and unsoaked CBR by 220.9% (2.54% → 8.15%). At this dosage, plasticity index reduced by 48.8%, free swell index by 44.6%, and swelling pressure by 44.8%. Compaction characteristics exhibited a modest 5.3% decrease in maximum dry density and 9.9% increase in optimum moisture content. Durability tests under 28-day exposure to water, acid (pH 4), leachate, and freeze–thaw cycles revealed excellent freeze–thaw resistance (only 10.2% CBR loss), good performance under water and leachate (24.9–31.5% loss), and moderate resistance in acidic conditions (40.1% loss). Most degradation occurred within the first 14 days. The results confirm that 1.0% sisal fiber reinforcement transforms weak black cotton soil into a competent, durable subgrade material suitable for pavements across diverse Indian climatic zones while offering significant environmental and economic advantages over conventional stabilizers.

**Keywords:** Black Cotton Soil, Sisal Fiber, Soil Stabilization, California Bearing Ratio (CBR), Environmental Durability, Expansive Soil, Sustainable Geotechnical Engineering

## I. INTRODUCTION

India's rapid infrastructure growth is increasingly constrained by the scarcity of good construction sites, forcing development on problematic expansive soils such as black cotton soil, which covers approximately 20% of the country's land area (0.8 million km²). These montmorillonite-rich soils exhibit high plasticity, low shear strength, and extreme volume changes with moisture fluctuations, leading to frequent pavement distress and foundation failures.

Traditional stabilization using lime and cement is effective but environmentally burdensome and costly. Natural fiber reinforcement has emerged as a sustainable, low-carbon alternative. Among natural fibers, sisal (Agave sisalana) possesses high tensile strength (347–378 MPa), good alkali resistance, and abundant availability as an agricultural by-product.

This research evaluates the influence of sisal fiber content on index properties, compaction characteristics, CBR, swelling behaviour, and especially long-term durability under aggressive environmental conditions rarely addressed in previous studies.

## II. MATERIALS AND METHODS

*A. Soil Black cotton soil was collected from Bhopal, Madhya Pradesh. Basic properties: liquid limit 49.83%, plastic limit 23.8%, plasticity index 26.03%, free swell index 58.5%, and classification CH (high plasticity clay) as per IS 1498.*

*B. Sisal Fiber Commercially available sisal fiber (length 20–30 mm, diameter ~0.2 mm, tensile strength 347–378 MPa, water absorption ~110%) was used without surface treatment.*

### *C. Testing Program*

- Atterberg limits (IS 2720 Part 5)
- Standard Proctor compaction (IS 2720 Part 7)
- CBR (both unsoaked and 4-day soaked) (IS 2720 Part 16)
- Free swell index and swelling pressure
- Durability: 28-day continuous exposure to distilled water, acidic solution (pH 4), municipal solid waste leachate, and 12 freeze–thaw cycles
- Residual tensile strength of retrieved fibers

## III. RESULTS AND DISCUSSION

### *A. Effect on Index Properties (Table 6.1 data reproduced as Table 1 in paper)*

| Sisal Fiber Content (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) |
|---|---|---|---|
| 0 | 49.83 | 23.8 | 26.03 |
| 0.25 | 48.5 | 24.68 | 23.82 |
| 0.5 | 46 | 25.45 | 20.55 |
| 0.75 | 43.2 | 26.35 | 16.85 |
| 1 | 40.9 | 27.58 | 13.32 |
| 1.25 | 39.1 | 29.15 | 9.95 |

Table 1. Variation of Atterberg limits with sisal fiber content

The reduction in PI is attributed to replacement of clay particles by non-plastic fiber and absorption of water by hydrophilic fiber, improving workability.

### *B. Compaction Characteristics*

| Sisal Fiber Content (%) | Maximum Dry Density (kN/m³) | Optimum Moisture Content (%) |
|---|---|---|
| 0 | 18.66 | 16.97 |
| 0.25 | 18.45 | 17.34 |
| 0.5 | 18.22 | 17.75 |
| 0.75 | 17.96 | 18.18 |
| 1 | 17.68 | 18.65 |
| 1.25 | 17.38 | 19.15 |

Table 2: Maximum Dry Density and Optimum Moisture Content of Soil with Sisal Fiber

At 1.0% fiber: MDD decreased by 5.3% (18.66 → 17.68 kN/m³) and OMC increased by 9.9% (16.97% → 18.65%). These changes are acceptable and lower than those reported for coir or jute.

### C. California Bearing Ratio

| Sisal Fiber Content (%) | Un-Soaked CBR at 2.5mm (%) | Soaked CBR at 2.5mm (%) | Improvement over Control (%) |
|---|---|---|---|
| 0 | 2.54 | 1.71 | - |
| 0.25 | 3.59 | 4.65 | 172 |
| 0.5 | 4.65 | 6.4 | 274.3 |
| 0.75 | 6.09 | 8.86 | 418.1 |
| 1 | 8.15 | 11.14 | 551.5 |
| 1.25 | 7.36 | 10.18 | 495.3 |

Table 3: Un-Soaked CBR and Soaked CBR of Soil with Sisal Fiber

Maximum improvement occurs at 1.0% fiber. Beyond this, fiber–fiber interaction reduces effectiveness. The soaked CBR of 11.14% comfortably exceeds the minimum 7–10% typically required for subgrade in high-traffic roads (IRC:37-2018).

### D. Swelling Behaviour

| Sisal Fiber Content (%) | Free Swell Index (%) | Swelling Pressure (kPa) | Reduction in Swelling (%) |
|---|---|---|---|
| 0 | 58.5 | 165 | - |
| 0.25 | 51.8 | 145 | 11.5 |
| 0.5 | 45.2 | 126 | 22.7 |
| 0.75 | 38.6 | 108 | 34 |
| 1 | 32.4 | 91 | 44.6 |
| 1.25 | 28.1 | 78 | 52 |

Table 4: Swelling Characteristics with Sisal Fiber Reinforcement

At 1.0% fiber, free swell index reduced from 58.5% to 32.4% (−44.6%) and swelling pressure from 165 kPa to 91 kPa (−44.8%). Fiber restrains lateral expansion and bridges micro-cracks.

### E. Environmental Durability (1.0% fiber)

| Parameter | Without Fiber | With 1% Sisal Fiber | Change (%) |
|---|---|---|---|
| Index Properties | | | |
| Liquid Limit (%) | 49.83 | 40.9 | -17.9 |
| Plastic Limit (%) | 23.8 | 27.58 | 15.9 |
| Plasticity Index (%) | 26.03 | 13.32 | -48.8 |
| Compaction Characteristics | | | |
| Maximum Dry Density (kN/m³) | 18.66 | 17.68 | -5.3 |
| Optimum Moisture Content (%) | 16.97 | 18.65 | 9.9 |
| Strength Properties | | | |
| Un-Soaked CBR (%) | 2.54 | 8.15 | 220.9 |
| Soaked CBR (%) | 1.71 | 11.14 | 551.5 |
| Swelling Characteristics | | | |
| Free Swell Index (%) | 58.5 | 32.4 | -44.6 |
| Swelling Pressure (kPa) | 165 | 91 | -44.8 |

Table 6.9: Performance Summary at Optimal 1% Sisal Fiber Content

## IV. Conclusions

This comprehensive experimental program demonstrates that sisal fiber reinforcement provides exceptional enhancement of black cotton soil properties:

1) Optimum sisal fiber content is 1.0% by dry weight of soil.
2) Soaked CBR increased by 551.5% (1.71% → 11.14%), far superior to most natural fibers reported in literature.
3) Plasticity index, free swell, and swelling pressure reduced by 48.8%, 44.6%, and 44.8% respectively.
4) The stabilized soil exhibits excellent durability under freeze–thaw, good durability under continuous wetting and leachate, and moderate resistance in acidic environments.
5) Sisal fiber reinforcement is a technically viable, environmentally sustainable, and cost-effective alternative to chemical stabilizers for black cotton soil improvement across diverse Indian climatic conditions.

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