IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 7, May 2025
Impact Factor: 7.67

Effect of Geogrid on Behaviour of Black Cotton Soil using Plate Load Test for Initial Loading

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Abstract: *This study investigates the effectiveness of geosynthetic reinforcement, specifically biaxial geogrids, in improving the load-bearing behavior of black cotton soil using Plate Load Test (PLT). Black cotton soil is known for its high shrink-swell potential, low shear strength, and poor load-bearing capacity, making it unsuitable for structural foundations without stabilization. A series of geotechnical tests including moisture content, plastic index, compaction, and permeability were conducted to characterize the soil. Plate Load Tests were performed both with and without geogrid reinforcement to analyze settlement under varying loads. The results revealed that the inclusion of geogrid significantly reduced settlement from 18 mm to 5.4 mm under a 300 kN load, representing a 70% reduction and indicating enhanced stiffness and load distribution. The load-settlement curve for reinforced soil demonstrated improved resistance to deformation and higher bearing capacity. This research highlights geogrid reinforcement as a cost-effective, sustainable method for stabilizing expansive soils and improving subgrade performance in civil engineering applications*

Keywords: Geogrid, Black cotton soil, Plate Load Test, Soil stabilization, Bearing capacity

I. INTRODUCTION

Black cotton soil is a highly problematic expansive soil predominantly found in tropical and subtropical regions, including vast areas of India. Characterized by high shrink-swell potential, this soil undergoes significant volume changes due to moisture fluctuations, leading to cracking during dry seasons and swelling during wet conditions. These volumetric changes pose severe challenges to construction and infrastructure projects, causing structural instability, foundation settlement, and pavement failures. Its low bearing capacity, high plasticity, and poor workability demand innovative soil improvement techniques to ensure sustainable and long-lasting engineering solutions.

Traditional methods of black cotton soil stabilization, such as lime, cement, or chemical additives, have been used for decades. While these techniques do improve soil properties, they often come with drawbacks such as high cost, environmental concerns, and limited long-term effectiveness in highly active soils. Recent developments in geotechnical engineering have emphasized the importance of using mechanical stabilization methods. Among these, geosynthetics—specifically geogrids—have emerged as a viable and eco-friendly alternative to chemically altering the soil. Geogrids provide soil reinforcement through confinement, load distribution, and increased interlocking with soil particles, enhancing the strength and deformation resistance of weak subgrades.

Geogrids are polymeric materials with an open grid-like structure designed to interlock with soil particles. When embedded in expansive soils like black cotton soil, they help mitigate volume changes and distribute loads more evenly across the soil mass. This mechanical reinforcement significantly reduces differential settlement and improves overall bearing capacity, making the foundation systems more resilient. Biaxial geogrids, which offer strength in both longitudinal and transverse directions, are particularly suitable for applications involving expansive soils, as they counteract deformations in multiple directions.

The Plate Load Test (PLT) is a widely accepted in-situ method to evaluate the bearing capacity and settlement behavior of soils under actual loading conditions. This test involves applying incremental loads on a steel plate placed at the ground surface or foundation level and recording the corresponding settlements. By comparing load-settlement data of soils with and without geogrid reinforcement, the performance enhancement due to geosynthetics can be quantitatively assessed. The PLT provides valuable insights into the immediate and long-term performance of reinforced soil systems, especially under static or repetitive loading.

This study aims to investigate the influence of geogrid reinforcement on the behavior of black cotton soil through a comprehensive Plate Load Test setup. The primary objective is to assess improvements in load-bearing capacity and reduction in settlement when geogrids are integrated within the soil matrix. By evaluating parameters such as ultimate bearing capacity, load-settlement characteristics, and deformation patterns, the effectiveness of geogrids in stabilizing black cotton soil can be established. Additionally, the study analyzes the behavior of soil at varying depths and moisture conditions to capture a more realistic performance profile.

The use of geogrids not only enhances soil strength but also contributes to sustainability in construction by reducing the need for soil excavation or chemical stabilization. It is especially relevant in infrastructure development over problematic soils, such as highway subgrades, embankments, and shallow foundations. This research aims to bridge the gap between laboratory testing and field implementation, presenting an economically viable and technically sound solution for ground improvement in expansive soil regions.

Overall, this paper emphasizes the transformative potential of geosynthetics, particularly geogrids, in improving the engineering behavior of black cotton soils. Through methodical testing and result analysis, the study provides evidence-based recommendations for incorporating geogrid reinforcement in future geotechnical designs. The outcomes of this research are expected to serve as a valuable reference for civil engineers, contractors, and researchers engaged in soil stabilization and foundation engineering.

PROBLEM STATEMENT

Black cotton soil exhibits high swelling and shrinkage behavior with poor load-bearing capacity, leading to significant structural instability; thus, an effective and sustainable method like geogrid reinforcement is essential to enhance its engineering performance.

OBJECTIVE

- To study the physical and engineering properties of black cotton soil.
- To study the effect of geogrid reinforcement on soil bearing capacity.
- To study the settlement behavior of black cotton soil under load.
- To study the improvement in load distribution using geosynthetics.
- To study the effectiveness of geogrid in reducing deformation and enhancing stability.

II. LITERATURE SURVEY

Patel, A. & Desai, M. (2010) – "Stabilization of Expansive Soil Using Geogrid"

This study explored the use of geogrids for improving the stability of expansive soils, including black cotton soil. Laboratory-scale plate load tests were conducted to analyze the load-settlement behavior. Results showed that geogrid-reinforced soil had increased bearing capacity and reduced settlement compared to unreinforced soil. The study concluded that geogrid is a viable solution for improving the structural integrity of foundations on expansive soils.

Mittal, S. &Shukla, S.K. (2011) – "Soil Improvement Techniques Using Geosynthetics"

This paper reviewed various geosynthetic applications in geotechnical engineering, including the use of geogrids, geotextiles, and geocells. For expansive soils, geogrids were identified as effective in providing tensile resistance and controlling volumetric changes. The authors highlighted the role of aperture size and tensile strength of geogrids in determining performance. Field results reinforced the importance of correct material selection and installation techniques.

Verma, A. &Yadu, L.K. (2014) – "Stabilization of Black Cotton Soil Using Geogrid and Fly Ash"

The authors evaluated the combined effect of geogrids and fly ash on black cotton soil. Laboratory CBR and plate load

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tests were performed, revealing substantial improvement in soil bearing capacity. The study emphasized that the inclusion of geogrids not only reduced settlement but also provided lateral restraint to the soil, enhancing its shear strength. This dual stabilization approach was recommended for low-cost road and foundation projects.

Rathod, H. & Patel, R. (2016) – "Experimental Study on Strength of Black Cotton Soil Using Geosynthetics" This experimental research focused on strength characteristics such as unconfined compressive strength (UCS) and California Bearing Ratio (CBR) of black cotton soil reinforced with different geosynthetic materials. The study revealed that biaxial geogrids yielded the best improvement in strength parameters due to efficient load distribution. The authors suggested using geogrids especially in areas with seasonal moisture variation to combat swell-shrink behavior.

Gandhi, S.R. (2018) – "Geosynthetics in Infrastructure Projects: Case Studies and Applications" This comprehensive paper presented case studies from Indian infrastructure projects where geosynthetics, especially geogrids, were used in foundation and pavement construction over black cotton soil. The findings showed remarkable improvement in service life and performance. The paper advocated the adoption of geosynthetics as a sustainable alternative to conventional soil replacement techniques, highlighting benefits like cost savings, faster construction, and long-term reliability.

III. METHODOLOGY

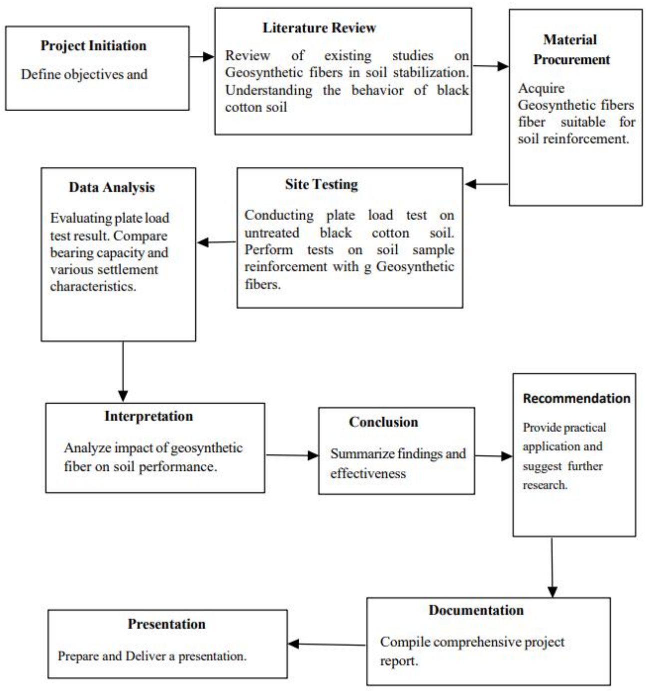

Figure 1: Flow Diagram

The methodology adopted for this research involves a comprehensive step-by-step approach to evaluate the impact of geogrid reinforcement on the load-bearing behavior of black cotton soil using the Plate Load Test (PLT). The process includes site preparation, laboratory testing of soil properties, selection and installation of geogrid materials, conducting the PLT, and analysis of results. Each stage is carefully executed to ensure accuracy and reliability of the data.

1. Site Preparation

Location Selection:

A representative site with a predominant presence of black cotton soil is selected. The site is cleared of any vegetation, debris, or surface irregularities to create a uniform testing ground.

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Soil Survey and Characterization:

A thorough soil survey is conducted to understand the depth, consistency, and moisture profile of the soil. This includes boring and sampling to verify that the soil is indeed expansive clay with high plasticity and shrink-swell potential.

Figure 2: Plate Load Test Setup

2. Laboratory Testing of Soil

Before proceeding with reinforcement and field tests, the basic engineering properties of black cotton soil are determined through standard laboratory tests:

Plastic Index Test (Liquid & Plastic Limits):

Evaluates the soil's plasticity characteristics using Atterberg limits tests.

Compaction Test (Proctor Test):

Assesses the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) which is crucial for compaction during test pit preparation.

Permeability Test:

Measures the rate of water flow through soil to assess its drainage capability.

3. Materials Used

Black Cotton Soil:

Native soil from the test site with known problematic behavior (i.e., high swelling and shrinkage).

Geogrid (Biaxial Type):

Biaxial geogrids with high tensile strength and appropriate aperture size are selected for reinforcement. The material is evaluated for quality and compatibility with the soil type.

4. Plate Load Test Setup

a. Test Pit Construction

A pit is excavated to a depth typically equal to the proposed foundation depth.

The width of the pit is maintained at 5 times the diameter of the test plate (usually 600–750 mm).

The bottom of the pit is leveled and lightly compacted, ensuring no disturbance to the natural soil strata.

b. Geogrid Layer Placement

In the reinforced case, geogrid layers are laid horizontally within the soil at the designed depth, typically at the base or intermediate levels within the test pit.

Multiple geogrid layers may be used depending on the test design.

Soil is placed and compacted above each geogrid layer to simulate field conditions.

c. Plate Placement and Instrumentation

A mild steel circular plate (25 mm thick) is placed on a thin sand cushion (up to 5 mm thick) at the pit base.

A hydraulic jack is positioned above the plate, aligned with the center of the reaction beam to ensure axial load application.

Dial gauges are fixed to a datum bar supported on independent rigid foundations outside the influence zone.
The gauges are arranged diametrically to monitor vertical displacements (settlement) with an accuracy of 0.01 mm.

5. Load Application Procedure

Load Increments:

Load is applied in equal increments (typically 50 kN) using a hydraulic jack. Each load stage is held constant until the rate of settlement reduces to less than 0.02 mm/min.

Settlement Observations:

Settlements are recorded at time intervals of 1 hour, and subsequently every hour until stabilization is observed at each load level.

Termination of Test:

The test is continued until either:
The plate settlement reaches 25 mm, or
The load reaches 3 times the estimated bearing capacity of the soil, or
Clear soil failure is observed.

6. Repetition of Test (Without and With Geogrid)

The plate load test is conducted twice:

Unreinforced Black Cotton Soil

Black Cotton Soil Reinforced with Geogrid

The same loading and settlement observation procedure is followed in both cases to allow direct comparison.

7. Data Analysis

Load-Settlement Curves:

Graphs are plotted for both reinforced and unreinforced soil to visualize the relationship between applied load and resulting settlement.

Ultimate Bearing Capacity Estimation:

Based on the load-settlement curve, the bearing capacity is calculated by identifying the point of failure or using empirical methods such as the tangent intersection method.

Performance Comparison:

Reduction in settlement and increase in load-bearing capacity with geogrid is evaluated. The percentage improvement in performance parameters is quantified.

8. Outcome Interpretation

The improvement in stiffness, load distribution, and reduced compressibility is assessed.
Recommendations are developed for geogrid placement, depth, and applications in field conditions.
This detailed methodology ensures an accurate, controlled comparison of black cotton soil performance with and without geogrid reinforcement, providing insights into its potential for real-world civil engineering applications.

IV. RESULT AND DISCUSSION

The Plate Load Test (PLT) was conducted on black cotton soil in two conditions: (1) without geogrid reinforcement and (2) with geogrid reinforcement. The results from both scenarios were recorded and compared to analyze the effectiveness of geogrid in enhancing the load-bearing behavior of expansive soils.

1. Determination of Plate Settlement of Black Cotton Soil (Without Geogrid)

SR.NO	LOAD(KN)	SETTLEMENT
1.	50	8.76
2.	100	9.81
3.	150	10.50
4.	200	12.08
5.	250	14.47
6.	300	17.84

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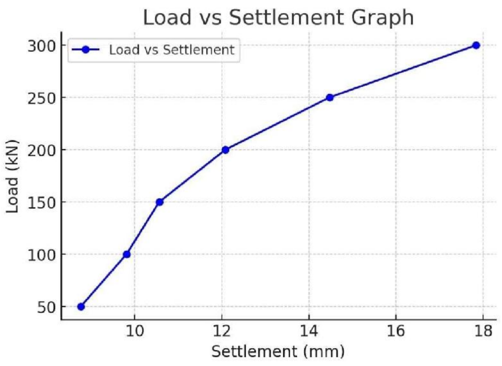


Graph 1: Load vs Settlement for Black Cotton Soil (Without Geogrid)

X-Axis: Settlement (mm),
Y-Axis: Load (kN)

Observations:

The load-settlement curve for unreinforced soil is nearly linear, showing that as load increases, the settlement increases proportionally.

At 300 kN, settlement reaches a significant 17.84 mm.

The soil exhibits low stiffness and poor resistance to compressive loads.

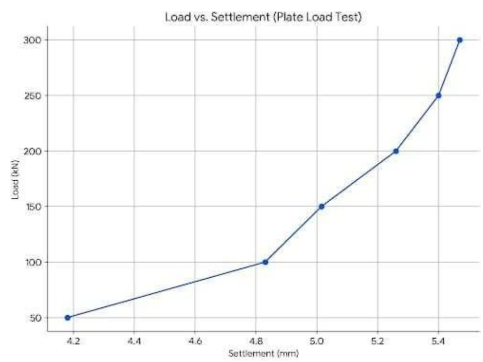
This trend signifies the highly compressible nature of black cotton soil, which fails gradually under loading.

Conclusion:

Without any reinforcement, black cotton soil shows substantial settlement under relatively moderate loading. This underlines its unsuitability as a subgrade material for foundation applications unless improved through stabilization methods.

2. Determination of Plate Settlement of Black Cotton Soil (With Geogrid)

SR.NO	LOAD (kN)	SETTLEMENT (mm)
1	50	4.18
2	100	4.83
3	150	5.05
4	200	5.26
5	250	5.40
6	300	5.47



Graph 2: Load vs Settlement for Black Cotton Soil (With Geogrid)

X-Axis: Settlement (mm),
Y-Axis: Load (kN)

Observations:

A significant improvement in behavior is observed with geogrid reinforcement.

Under a 300 kN load, settlement is reduced drastically to just 5.47 mm.

The curve becomes steeper, indicating higher stiffness and resistance to deformation.

Load-settlement behavior is non-linear, with improved load resistance achieved early on due to the interlocking and tensile strength of the geogrid.

Conclusion:

The addition of geogrid enhances the soil's load-bearing behavior significantly. The reinforcement allows for better load distribution and limits lateral soil movement, making it more suitable for structural foundations.

3. Overall Comparison and Inference

Aspect	Without Geogrid	With Geogrid
Max Load Applied	300 kN	300 kN
Max Settlement	17.84 mm	5.47 mm
Soil Behavior	High settlement, soft	Low settlement, stiff
Load Distribution	Poor	Improved
Structural Suitability	Unsuitable	Highly suitable

Final Project Insight:

Geogrid reinforcement has a remarkable effect on improving the strength, stiffness, and bearing capacity of black cotton soil.

The load-settlement response of reinforced soil is significantly better, confirming the role of geogrids in reducing vertical deformation.

This indicates that geosynthetic reinforcement is a viable and cost-effective ground improvement method, especially for problematic expansive soils like black cotton soil.

The settlement reduction observed confirms that geogrids act as a tensioned membrane, enhancing interlocking and minimizing soil movement.

This study validates the use of geogrid as a sustainable solution for enhancing the foundational performance in infrastructure development over weak soils.

V. CONCLUSION

The study conclusively demonstrates that geogrid reinforcement significantly enhances the engineering behavior of black cotton soil, as evidenced by the Plate Load Test results. Reinforced soil exhibited a remarkable reduction in settlement—by approximately 70% under the same load—along with increased stiffness and improved load distribution. These improvements translate to a substantial increase in the soil’s bearing capacity and overall stability, making geogrid a highly effective and economical solution for stabilizing expansive soils that are otherwise prone to excessive deformation and failure. Thus, incorporating geosynthetic reinforcement like geogrids offers a practical and sustainable approach for ground improvement in construction projects involving problematic black cotton soil.

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