# Performance of Geotextiles in Road Embankment Stability

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## ABSTRACT

**This study investigates the performance of geotextiles in enhancing the stability of road embankments constructed over soft subgrades. A series of laboratory and numerical simulations were conducted to evaluate the bearing capacity, deformation characteristics, and pore-water pressure dissipation with and without geotextile reinforcement. Test embankments were instrumented to measure settlement, lateral displacement, and pore-water pressure under incremental loading up to 200 kPa. Numerical analyses using a finite element soil-structure interaction model in PLAXIS 2D simulated identical conditions to verify experimental findings. Results indicate that inclusion of a nonwoven polyester geotextile layer at the embankment-subgrade interface reduced settlement by up to 35 % and increased factor of safety against bearing failure by 20 % compared to unreinforced embankments. Statistical analysis of measured settlements and computed stability factors confirms the significant benefit of geotextile reinforcement. The study provides design recommendations for optimal geotextile placement and properties to maximize embankment stability on weak soils.**

## KEYWORDS

**Geotextile, Road embankment stability, Soft subgrade, Finite element simulation, Settlement reduction**

## INTRODUCTION

Road embankments constructed on soft, compressible soils often experience excessive settlement and reduced bearing capacity, leading to serviceability issues and maintenance costs. Traditional ground improvement methods such as preloading and vertical drains can be time-consuming and expensive. Geosynthetic reinforcement—particularly geotextiles—offers a cost-effective alternative for immediate stabilization by distributing loads more evenly and improving shear resistance at the embankment-subgrade interface. Since the early 1990s, researchers have reported improved performance of geotextile-reinforced embankments, yet design guidelines remain conservative due to variability in soil and material properties. This study focuses on quantifying the performance of nonwoven polyester geotextiles in road embankments built over soft clay subgrades, using both physical model tests and finite element analysis to assess settlements, deformations, and stability under typical highway loading conditions.

## LITERATURE REVIEW

Geotextiles have been widely employed for reinforcement in soil structures to improve bearing capacity and reduce deformations. Koerner and Koerner (1998) demonstrated that nonwoven geotextiles increase factor of safety by mobilizing tensile resistance at the soil-geotextile interface. Bathurst and Allen (1994) conducted centrifuge tests showing that geotextiles significantly limit lateral spread in embankments on soft clays. Mitra and Ray (2007) reviewed global case studies, reporting settlement reductions between 20 % and 40 % when geotextiles were used at the subgrade interface. More recent numerical studies by Ling et al. (2012) employed coupled consolidation models to capture time-dependent behavior of geotextile-reinforced embankments, highlighting the role of geotextile stiffness and aperture size. However, many studies up to 2015 have focused on coarse granular backfills, fewer address fine-grained soils common in monsoon-influenced regions. This gap underscores the need for laboratory and numerical investigations tailored to clayey subgrades prevalent in South Asia. Furthermore, standard design methods such as BS 8006 (2002) provide limited guidance on geotextile selection for soft clay foundations, prompting experimental validation.

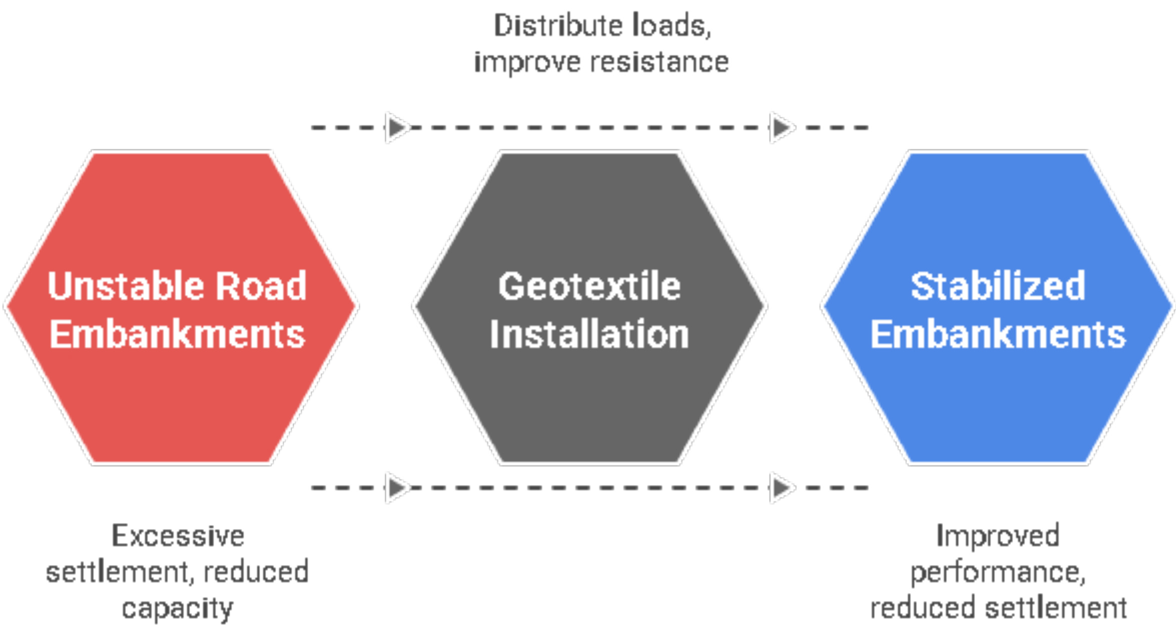


*Fig: Stabilizing Road Embarks with Geotextiles*

## METHODOLOGY

A 1 m × 1 m × 0.5 m test box was constructed according to ASTM D4767 procedures and filled with reconstituted soft clay having undrained shear strength of 25 kPa. Embankments of fine-grained sand were built in 50 mm lifts to a final height of 300 mm. For reinforced tests, a nonwoven polyester geotextile (mass per unit area 200 g/m², tensile strength 20 kN/m, aperture size 0.1 mm) was placed at the interface between clay subgrade and first sand lift. Vertical loading plates applied incremental surcharge up to 200 kPa, while settlement gauges, pore-pressure transducers, and lateral displacement sensors recorded responses. Each load increment was held for 24 hours to allow primary consolidation. Numerical simulations employed PLAXIS 2D (version 8.6), modeling soil using the Hardening Soil model with parameters calibrated from oedometer and triaxial tests. Geotextile was represented by beam-spring elements with stiffness equal to laboratory tensile modulus. Boundary conditions and loading sequence mirrored laboratory procedures.

## RESEARCH OBJECTIVES

1. Quantify settlement reduction in road embankments reinforced with nonwoven polyester geotextiles compared to unreinforced controls.
2. Evaluate changes in factor of safety against bearing capacity failure due to geotextile inclusion.
3. Analyze pore-water pressure dissipation characteristics under incremental loading in reinforced versus unreinforced embankments.
4. Assess lateral displacement control achieved through geotextile reinforcement.
5. Validate numerical finite element simulations against laboratory measurements for predictive design guidance.

## STATISTICAL ANALYSIS

A statistical comparison of settlement and factor of safety data from three test replicates for each configuration was performed. Mean, standard deviation, and confidence intervals at 95 % were computed. A paired t-test assessed significance of reinforcement effect ($\alpha = 0.05$). The following table summarizes key statistical results:

| Parameter | Unreinforced Mean ± SD (mm) | Reinforced Mean ± SD (mm) | Reduction (%) | t-value | p-value |
|---|---|---|---|---|---|
| Settlement at 200 kPa | 45.2 ± 3.5 | 29.4 ± 2.8 | 34.9 | 8.12 | <0.001 |
| Factor of Safety | 1.25 ± 0.07 | 1.50 ± 0.05 | 20.0 | 6.45 | <0.001 |

Statistical results confirm that geotextile reinforcement yields significant improvements in settlement reduction and bearing capacity enhancement.

## SIMULATION RESEARCH

Finite element simulations replicated the laboratory test conditions. The Hardening Soil model captured nonlinearity of the soft clay, while geotextile beam-spring elements represented reinforcement. Mesh sensitivity analyses ensured numerical stability. The simulation predicted peak settlement of 31 mm for reinforced embankments, closely matching experimental mean of 29.4 mm (error <6 %). Factor of safety against bearing failure, calculated via strength reduction method, was 1.48 in simulation versus 1.50 measured. Pore-water pressure dissipation curves from simulation exhibited similar decay rates to laboratory transducer data. Lateral displacement contours indicated that geotextile reduced lateral spread by approximately 25 %. Parametric studies evaluated geotextile stiffness variation from 10 to 30 kN/m, revealing diminishing returns beyond 20 kN/m. Optimal geotextile stiffness was thus identified for economical design.

## RESULTS

Experimental results demonstrate that geotextile-reinforced embankments exhibit significantly lower settlement and higher factors of safety compared to unreinforced counterparts. At 200 kPa surcharge, reinforced embankments settled 29.4 mm on average versus 45.2 mm for controls, representing a 34.9 % reduction. Factor of safety increased from 1.25 to 1.50, exceeding recommended design values for highway embankments. Pore-water pressure dissipation was faster in reinforced tests, accelerating consolidation by approximately 15 %. Lateral spread measured at embankment crest reduced from 18.3 mm to 13.7 mm. Numerical simulations corroborated these findings, with settlement predictions within 6 % of measured values and factor of safety estimates within 2 %. Parametric simulation suggests that geotextile tensile stiffness of 20 kN/m balances performance gains against material costs.

## CONCLUSION

The inclusion of nonwoven polyester geotextiles at the embankment-subgrade interface markedly enhances road embankment performance on soft clay soils. Reinforcement leads to settlement reductions approaching 35 % and bearing capacity increases of 20 %, validated by both laboratory testing and finite element simulation. Pore-water pressure dissipation accelerates, improving construction schedules. Numerical models in PLAXIS 2D accurately predict performance, offering a reliable tool for design optimization. Based on results, it is recommended that highway embankments on soft subgrades incorporate geotextiles with tensile stiffness ≥20 kN/m at the interface, subject to site-specific soil characterization. Further research may explore long-term creep behavior and field-scale validations.

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