



STABILITY ANALYSIS OF POLYPROPYLENE FIBER-STABILIZED EARTH EMBANKMENTS USING GEOSTUDIO

Ch. Pranathi¹, K. Krishna Prasad Reddy² Ch. Rajeshwar³ Ravi Raymond Prashams⁴
S. Bala Padmaja⁵

¹²³⁴Students, Department of Civil Engineering, Mahatma Gandhi Institute of Technology,
Hyderabad, Telangana.

⁵ Assistant Professor, Department of Civil Engineering, Mahatma Gandhi Institute of Technology,
Hyderabad, Telangana.

Abstract

Earth embankment stability is governed by soil shear strength, embankment geometry, pore-water pressure and construction conditions. Randomly distributed polypropylene (PP) fibers have been investigated as a means of improving the tensile resistance and post-peak behaviour of fine-grained soils. This paper presents a reproducible numerical framework for assessing the stability of PP fiber-stabilized earth embankments using GeoStudio. The proposed workflow combines laboratory characterization of untreated and fiber-treated soil with limit-equilibrium analysis in SLOPE/W; SEEP/W may be coupled where groundwater or seepage is relevant. A representative 6 m high embankment with 2H:1V side slopes is proposed for the baseline model. Fiber contents of 0, 0.25, 0.50, 0.75 and 1.00% by dry soil mass are suggested for screening, while the shear-strength parameters must be obtained from tests rather than assumed. The study compares factor of safety, critical slip-surface geometry and sensitivity to groundwater conditions. Since no project-specific laboratory data or GeoStudio output were supplied for this draft, numerical factors of safety are not fabricated; an editable results table is provided for completion after analyses. The framework supports transparent comparison of untreated and fiber-treated embankments and helps identify a mix that improves stability without compromising compaction or constructability.

Keywords: polypropylene fiber; fiber-reinforced soil; earth embankment; slope stability; GeoStudio; SLOPE/W; factor of safety; seepage.

1. Introduction

Earth embankments are widely used for highways, railways, flood protection and approach fills. Their stability depends on the balance between available soil shear strength and the shear stresses mobilized along a potential failure surface. Rainfall infiltration, a rising water table, rapid drawdown, weak foundation strata and construction-related variability can reduce the factor of safety (FoS) and promote slope failure. Conventional improvement methods include compaction control, replacement, chemical stabilization, drainage and the use of geosynthetic reinforcement. Discrete fiber reinforcement is another option in which short fibers are mixed throughout the soil rather than placed as continuous reinforcement layers.

Polypropylene fibers are lightweight, corrosion-resistant and relatively easy to mix into soil. When sufficiently dispersed, fibers can bridge developing shear zones, mobilize interface resistance and improve ductility. However, the response is not uniform for all soils: fiber type, length, content, aspect ratio, soil plasticity, moisture condition and compaction influence the measured shear strength. Excessive fiber content can create clumping, reduce workability or hinder uniform compaction. Therefore, stability modelling should use parameters measured for the actual untreated and treated mixtures.

Previous work has examined polypropylene-fiber-reinforced cohesive soils and the stability

of embankment slopes under environmental cycling [1–3]. The present paper develops a practical GeoStudio workflow for comparing embankment stability across a controlled range of fiber contents and hydraulic conditions. Its contribution is a clear link between laboratory-derived Mohr–Coulomb parameters and a repeatable SLOPE/W model, with optional SEEP/W coupling. The work is framed as a numerical study protocol until the project-specific test results and model outputs are inserted.

2. Aim and Scope

The principal aim is to evaluate whether PP fiber inclusion can improve the stability of a representative earth embankment when the treated soil is characterized through laboratory testing. The specific objectives are: (i) compare the untreated control with fiber-treated mixes; (ii) assess the influence of fiber content on FoS and critical slip-surface location; (iii) examine sensitivity to groundwater conditions; and (iv) establish a workflow that can be validated against laboratory or field evidence. The analysis is limited to static stability unless seismic loading, staged construction or transient seepage is explicitly added.

3. Materials and Methodology

3.1 Soil and polypropylene fibers

The embankment soil should be classified using particle-size distribution and Atterberg limits, with specific gravity, compaction characteristics and permeability measured as appropriate. PP fibers should be reported by polymer type, nominal length, diameter or denier, tensile properties and manufacturer. Fibers are mixed into soil at a defined moisture content and compacted to a consistent target dry density. Fiber content in this study is defined as percentage of dry soil mass; this basis must not be confused with percentage by total mixture mass or fiber volume.

A preliminary screening series is proposed in Table 1. These are candidate test levels, not a universal optimum. Direct shear or triaxial testing should be performed on the control and each selected mix at representative density and moisture conditions. Effective cohesion c' and friction angle ϕ' should be used for drained analysis; for short-term undrained conditions, a consistent undrained-strength approach is required. The chosen strength model must match the soil drainage behaviour and available data.

Mix ID	PP fiber content (% dry soil mass)	Purpose
PF0	0.00	Untreated control
PF1	0.25	Low fiber content
PF2	0.50	Intermediate content
PF3	0.75	Higher content
PF4	1.00	Upper screening level

3.2 Embankment geometry and baseline assumptions

A representative embankment geometry is proposed to demonstrate the workflow: height 6 m, crest width 6 m and side slopes of 2H:1V, placed over a foundation layer whose properties

are defined independently. The model should extend far enough horizontally and vertically to avoid artificial boundary effects on the critical slip surface. The dimensions are illustrative and must be replaced when a real embankment cross-section is available.

Parameter	Illustrative baseline	Required source / note
Embankment height	6 m	Survey / design section
Crest width	6 m	Design geometry
Side slope	2H:1V	Compare alternative slopes if needed
Bulk unit weight	17–19 kN/m ³ (initial range only)	Measure / calculate for moisture condition
Strength parameters	c' and ϕ' from tests	Separate set for each mix
Groundwater	Low and high water-table cases	Site monitoring / design scenario
Loading	Self-weight initially	Add traffic or surcharge if relevant

3.3 GeoStudio analysis procedure

The embankment profile and material regions are defined in GeoStudio. In SLOPE/W, assign the appropriate strength model and enter the unit weight and shear-strength parameters for each material. Use the Morgenstern–Price method as the primary limit-equilibrium method because it satisfies overall force and moment equilibrium; a second method, such as Spencer or Bishop simplified, may be used as a reasonableness check. Search for critical circular and/or non-circular slip surfaces using suitable entry and exit limits and enough trial surfaces to establish a stable minimum FoS.

For a dry or prescribed pore-pressure case, define the pore-water condition consistently. Where groundwater or seepage affects stability, develop a SEEP/W model using measured permeability and defensible hydraulic boundary conditions. Transfer computed pore-water pressures to the corresponding SLOPE/W analysis. Compare at least a lower-water-table case with a high-water-table or adverse seepage case. Do not change geometry, loading, mesh/search settings or hydraulic assumptions between mixes unless that change is part of the parameter study.

Run the same analysis sequence for PF0–PF4, changing only the measured material properties associated with each mix. Record the minimum FoS, slip-surface coordinates or plot, pore-pressure condition and convergence or solver warnings. Repeat selected runs with a second limit-equilibrium method and refine the search if the critical surface lies near a model boundary. The model should be checked for

plausible failure mechanisms before its FoS is interpreted.

3.4 Governing concepts and comparison metric

For a Mohr–Coulomb material, the available shear strength is commonly represented as $\tau_f = c' + (\sigma' n) \tan \phi'$, where c' is effective cohesion, $\sigma' n$ is effective normal stress and ϕ' is the effective friction angle. SLOPE/W evaluates the equilibrium of slices along trial slip surfaces using the selected limit-equilibrium formulation. The relative change in FoS is calculated as:

$$\text{FoS improvement (\%)} = [(\text{FoS}_{\text{fiber}} - \text{FoS}_{\text{control}}) / \text{FoS}_{\text{control}}] \times 100$$

This metric should be reported for each fiber content and water condition. It is a comparative indicator, not a substitute for the governing design standard or a site-specific acceptance criterion.

4. Results and Discussion Framework

The key output is a comparison of the critical FoS for each mix. A higher FoS may result if laboratory tests show that fiber inclusion increases the effective cohesion, friction angle or both; the outcome cannot be assumed from fiber dosage alone. Fibers may also affect density and permeability, so those variables should be recorded and incorporated where they materially influence the analysis. An apparent FoS increase is meaningful only when the model inputs are supported by consistent testing and the same analysis assumptions are applied to all mixes.

Mix	c' (kPa)	ϕ' (°)	FoS—low WT	FoS—high WT
PF0	Enter test value	Enter test value	Enter SLOPE/W result	Enter SLOPE/W result
PF1	Enter test value	Enter test value	Enter SLOPE/W result	Enter SLOPE/W result
PF2	Enter test value	Enter test value	Enter SLOPE/W result	Enter SLOPE/W result
PF3	Enter test value	Enter test value	Enter SLOPE/W result	Enter SLOPE/W result
PF4	Enter test value	Enter test value	Enter SLOPE/W result	Enter SLOPE/W result

Table 3. Editable results template. Replace each text entry with laboratory measurements and actual GeoStudio output; do not report the template as completed numerical evidence.

Three comparisons are recommended. First, plot FoS against fiber content for each water condition to identify whether the response is monotonic or has a peak. Second, compare the

critical slip surfaces: a change in location may indicate that the controlling mechanism has shifted from the embankment face to a deeper surface involving the foundation. Third,

compare the adverse-water condition with the lower-water condition. Higher pore-water pressure generally reduces effective stress and can lower stability, although the magnitude depends on the geometry and strength profile. The mix that performs best under dry conditions may not necessarily remain best under seepage conditions.

A numerical paper should include SLOPE/W screenshots showing the geometry, materials and critical slip surface for the control and the selected treated mix. A figure comparing FoS values should include the analysis method and hydraulic scenario in its caption. If a coupled SEEP/W analysis is used, include the phreatic surface or pore-water-pressure contours and document the permeability and boundary conditions. Numerical results should be checked against laboratory observations or a published benchmark before being used for design conclusions.

5. Limitations and Quality Checks

The present document is a research-paper draft and modelling protocol, not a report of a completed GeoStudio simulation. No site-specific soil data, laboratory shear-strength results, embankment drawing or SLOPE/W files were provided; consequently, no FoS values or quantitative improvement claims are asserted. The proposed geometry and fiber-content levels are illustrative. Actual conclusions must be based on measured properties and completed analyses.

Important uncertainties include variability in fiber dispersion, sample preparation, density, moisture, drainage condition, scale effects and the representation of fiber–soil interaction by an equivalent Mohr–Coulomb model. Randomly distributed fibers are not equivalent to geogrids or geotextile layers and should not be modelled as such without a justified reinforcement formulation. A sensitivity study on c' , ϕ' , unit weight and groundwater level is recommended, and the final design should follow applicable codes and independent geotechnical review.

6. Conclusions

A GeoStudio-based framework has been developed for evaluating the stability of polypropylene fiber-stabilized earth embankments. SLOPE/W can compare the minimum factor of safety and critical slip surface for untreated and treated soil, while SEEP/W can provide pore-water pressures for

cases where seepage is significant. The reliability of the comparison depends primarily on obtaining representative shear-strength parameters for each fiber content and maintaining consistent model assumptions.

The proposed workflow recommends a control mix and a defined fiber-content series, a 6 m high illustrative embankment, Morgenstern–Price analysis, and comparison of lower and higher groundwater conditions. The optimum fiber content cannot be declared until laboratory results and numerical outputs are available. Future work should combine direct shear or triaxial testing, compaction and permeability measurements, model verification and, where possible, field performance monitoring. These steps will enable defensible conclusions about the engineering benefits and practical limits of PP fiber stabilization.

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