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# Finite Element Modeling of Geotextile Reinforced Embankments on Soft Clay

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## Abstract

The use of geotextiles as a reinforcement material for improving the factor of safety against slope failure in embankments built on soft clay is becoming a common practice. This work is intended to help understand the effect of the geotextile reinforcement has on such embankments and to provide a design aid for civil engineers that enables them to quickly estimate the factor of safety against slope failure. Seventy four different cases were modelled and analyzed using a finite element software, GeoStudio 2018 R2. The results showed that the optimum improvement was achieved when using a single layer of geotextile reinforcement placed at the base of the embankment, by which the factor of safety increased by up to 40%. Adding a second layer, a third layer and a fourth layer, increases the safety factor by 2.5%, 1% and 0.5% respectively. Different charts for different heights of embankments were presented to aid in finding the most suitable slope angle and number of reinforcement layers required to achieve a certain safety factor.

## Keywords

Reinforced Soil, Embankments, Soft Soils, Slope Stability

## 1. Introduction

Soil can resist pressure and compressive forces very well, but it is not able to tolerate tensile forces. Construction of embankments over weak soils is a commonly encountered problem in many geotechnical applications like highway and airport runway embankments, containment dikes, flood protection levees, earth dams and berms. Among various stabilization techniques available for embankments on soft soils, is the application of reinforcements to the soil.

Reinforced soil is a composite material that contains components that can easily stand tensile forces. Nowadays reinforcing materials are widely used to overcome technical problems. Reinforced soil is used in stabilizing embankments (slopes), fill dams, retaining walls, foundation and *in-situ* slope for increasing the shear resistance of soil layer in different earth structures and even on stabilization of soil layers under shallow foundations or embankments of roads. Concept of reinforced soil has been used by Henry Vidal [1], a French engineer in 1968. He used metal strips between compacted soil layers for increasing its strength and stability. Nowadays reinforced soils are used vastly because of economic reasons and easy applications in reinforcing structures like embankments, dams and slopes.

Geosynthetics recognized as synthetic materials are used in soil. The specific families of Geosynthetics are the following: Geotextiles, Geogrids, Geomembranes and Geocomposites. When synthetic fibers are made into a flexible, porous fabric by standard weaving machinery or are matted together in woven and nonwoven manner, the product is known as "Geotextile". Geogrids are plastics formed into a very open netlike configuration. Geotextiles and Geogrids are used usually as reinforcing material for soil improvement. Geosynthetics reinforcement has a special role in increasing the safety factor of slopes. Because of increasing traffic in recent years, many road embankments have been built on soft soils. At these conditions, engineers have been faced with different problems such as settlements and instability of slopes, and lots of studies have been done on geotextiles as a trustable material for reinforcing and improving soil properties [2] [3] [4] [5]. These reinforcing materials are not susceptible to corrosion, have relatively low stiffness and flexible enough to tolerate large deformation. These factors make them to be superior to steel reinforcing materials in soils. As the use of geotextile in reinforcing embankment is growing, this study will seek to analyze reinforced embankments on under laying soft soils.

Several previous studies have been done on this subject. M. Siavoshnia [6] studied the effect of the number of layers of reinforcing material and the effective length of the geotextiles on the horizontal and vertical displacements using finite element analysis. Full-scale test embankments, with and without geotextile reinforcement, were constructed on soft Bangkok clay. The performances of these embankments were valuated and compared with each other on the basis of field measurements and FEM analysis [7]. Yet, all those studies considered a specific embankment height and a specific slope, and thus the need for a wider study that can touch different slopes, and different reinforcement arrangements.

The main aim of this proposed study is to model the response or stability of geosynthentic reinforced embankment slopes underlain by soft clay. Finite element method [8] was employed as the numerical tool for modelling.

The specific objectives include:

i) Determination of embankment deformation and factor of safety against slope failure upon variation of embankment slope, embankment height, number of layers of geotextile reinforcement, properties and distribution using finite element analysis.

ii) Obtaining a design methodology and design charts for quick design of geotextile reinforced embankments built on soft clays.

This study centers on modelling the stability of embankment slopes on soft clay soils. GeoStudio 2018 R2 finite element tool was used for analyzing the geosynthetic reinforced embankment slopes underlain by soft clay soil. Other numerical methods have been adopted in soil stability and embankment studies [9] [10]. Material properties of the embankment and the underlying soil were determined from standard experimental procedures. The geometry characteristics of the embankment such as the height, crest and slope were defined. Furthermore, the geometry characteristics of the underlying soft soil such as its thickness were also clearly defined. The ground water conditions were clearly defined.

## 2. Methodology

### 2.1. Materials

Geotextiles were used in this study as the geosynthetic material for reinforcement of the embankment dam. Several Geotextiles with varying properties were used and the properties were obtained from the manufacturer's product data sheets.

### 2.2. Soil Properties

The selected sample site studied was Tema-Ifoko road/Bridge in Asari/Toru Local Government Area (LGA), Rivers state, Nigeria. Deep soil investigation was performed in June 2018, for the purpose of getting the soil properties to enable the design of deep foundations for the proposed bridge structure and the high embankments for bridge approach.

The soil strata consisted of an 8 m deep layer of soft, grey, high to low plasticity clay with shear strength parameters of ($C_u$ = 15 KN/m$^2$ and $\phi = 0$), underlain by Medium dense grey silty sand with SPT value varying from 11 to 25.

The area is a swampy area, where tidal activities influence the depth of the water table which ranges from ground surface to 1m above ground water table.

The embankment material to be used is dredged sharp river sand. Sands with friction angle of 30 is assumed to be used in the construction of the embankment.

### 2.3. Modeling and Analysis

Initial step for analyzing the model, was to create the geometry of the model. The geometry characteristics such as embankment height, slope and crest width are to be defined. The other geometry property that should be defined is under laying soil profile such as the thickness of the soft layer. The second step is to provide the material properties of the embankment and the under laying soil. For present investigation the main model has 11 m crest width, varying heights, varying slopes and varying number of reinforcement layers and properties, and is placed on the soft clayey layer of 8m thickness. As the model is symmetric with respect to the center line, half of the embankment was modeled for analysis. GeoStudio 2018 R2 software wasemployed for performing the analyses. The **Figure 1** represents a typical mode in GeoStudio software. First the drawing extents were defined, keeping the x axis extending to 30m to account for possible extension of failure surface. For the y axis, the grid was selected to extend from −8 m to 7 m. Ground surface is assumed at y = 0.

The first step in modeling is to create the geometry objects. 2 geometry objects were created: One for the soft clay base material (identified as zone 1) and which is defined by 4 points: (0, 0), (0, −8), (30, −8) & (30, 0). The second geometry object created was for the sand fill, (identified as zone 2) and this geometry varied with varying heights and varying slope angle.

The second step was identifying material properties. The soft clay was defined as undrained (Phi = 0) material, with undrained cohesion $c_u$ = 15 KPa and unit weight = 18.5 $KN/m^3$ (Saturated unit weight assumed). The sharp sand fill was defined as Mohr-Coulomb material, with unit weight of 19 $KN/m^3$, friction angle Phi = 30˚, and cohesion c = 0 Kpa.

The third step was to define the pore water pressure conditions, and for this a piezometric line running at y = 0 level was drawn. This implies that the ground water table is at the ground surface. (Represented by the blue dotted line in the **Figure 1**).

The fourth step was to identify the slip surfaces, and entry and exit method was used. The slip surface entry was defined as the embankment surface at y = H, while the slip surface exit was defined at y = 0 starting from the end of the embankment. The entry and exit lines are represented by the red lines in **Figure 1**.

Two properties of the geotextile reinforcement were defined: the tensile strength, or tear strength, and the pullout resistance which was automatically

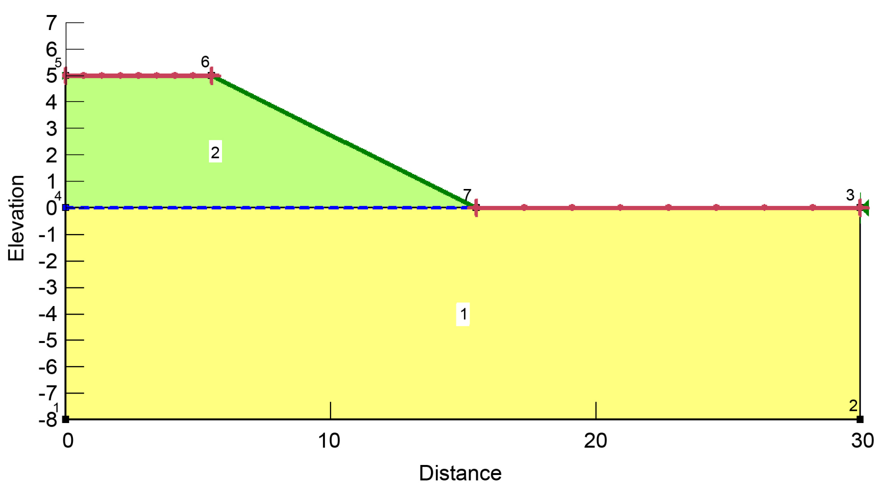


**Figure 1.** Basic model.

calculated based on the overburden pressure and the soil-geotextile friction angle (taken as 25˚).

Morgenstern-Price method was selected as the best method to use in analyzing the slope stability model.

Morgenstern-Price [11] is a general method of slices developed on the basis of limit equilibrium. It requires a satisfying equilibrium of forces and moments acting on individual blocks, and it provides a more accurate factor of safety compared to the Bishop simplified method [12].

A summary of the input data is presented in **Table 1**.

## 3. Results and Discussions

### Analysis results

The analysis was performed for embankments of heights H = 2 m, 3 m, 4 m, 5 m & above 5 m. For each of the heights, 4 different slopes were modeled: 1:1 slope ($\beta$ = 45˚), 1:2 slope ($\beta$ = 27˚), 1:3 slope ($\beta$ = 18˚), & 1:4 slope ($\beta$ = 14˚). For each of those slopes, the model was analyzed without reinforcement, with one layer of reinforcement and with several layers of reinforcements (See **Figures 2-4**). A total of 74 basic models were created and analyzed, in addition to several other models tested for other purposes.

Different tensile strengths were tried, ranging from 100 KN to 1000 KN. It was

**Table 1.** Summary of input data.

| | |
|---|---|
| SETTINGS: | |
| Analysis method | Morgenstern-Price |
| PWP conditions from | Piezometric Line |
| Unit weight of water | 9.807 KN/m$^3$ |
| SLIP SURFACE: | |
| Direction of movement | Left to right |
| Slip surface option | Entry and exit |
| Tension crack option | No tension crack |
| MATERIALS | |
| *MATERIAL* 1: *SOFT CLAY* | |
| Material model | Undrained (Phi = 0) |
| Unit weight | 18.5 KN/m$^3$ |
| Cohesion | 15 Kpa |
| *MTERIAL* 2: *SAND FILL* | |
| Material model | Mohr-Coulomb |
| Unit weight | 19 KN/m$^3$ |
| Cohesion | 0 Kpa |
| Phi | 30˚ |

found that for all models, when the tensile strength of the geotextile material was equal or exceeded 200 KN, the pullout resistance governed the mode of failure. This applied for all heights of embankments and all slopes. It is thus assumed that our analysis applied to geotextile reinforcements of tensile strength of 200 KN and above.

Figures 2-4 are examples of the output data for an embankment of height H = 2 m and a slope angle of 45˚. The program solves all possible slip surfaces and automatically selects the most critical. The embankment had a factor of safety of 1.325 when modeled without any reinforcement, 1.909 when 1 reinforcement layer was used and 2.311 when 2 reinforcement layers were used.

The results are summarized in Table 2, showing the factor of safety against slope failure upon varying the embankment height, slope angle and number of geotextile layers used.

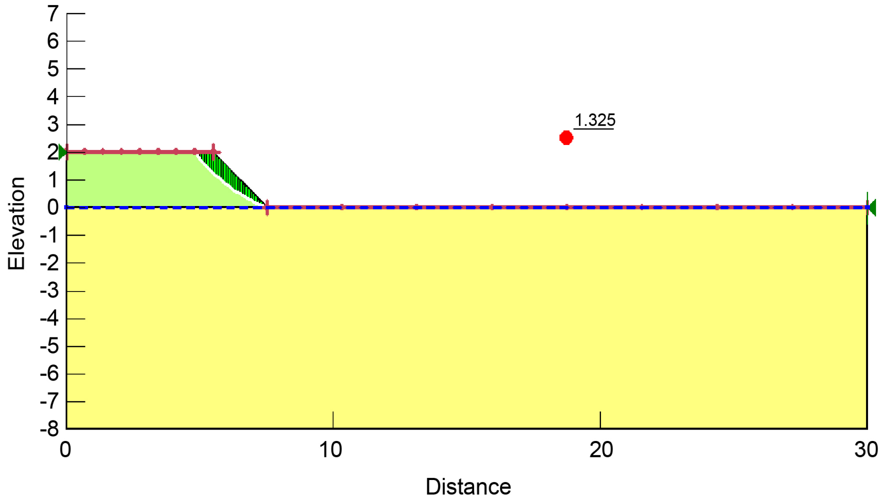


Figure 2. H = 2 m, $\beta$ = 45˚, No Reinforcement.

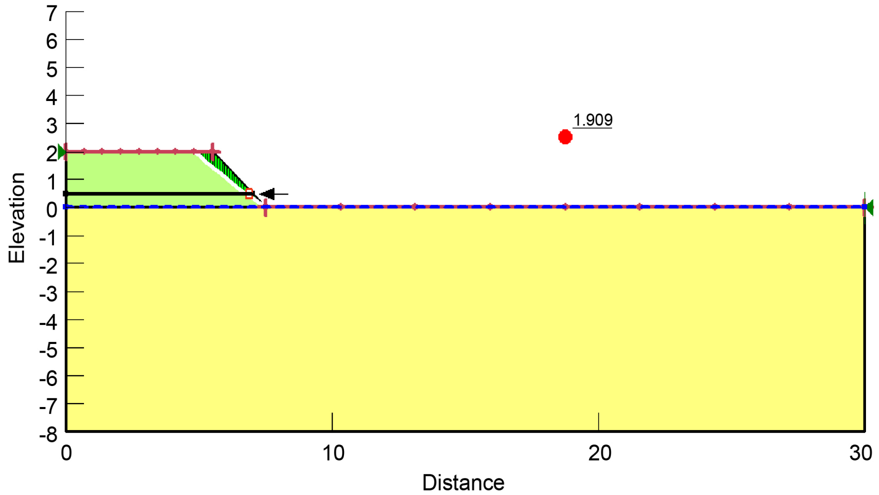


Figure 3. H = 2 m, $\beta$ = 45˚, 1 Layer of Reinforcement.

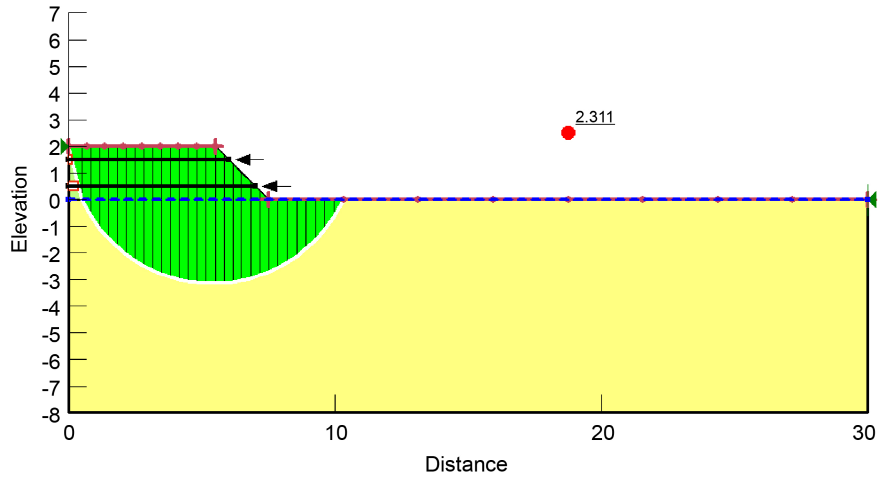


**Figure 4.** H = 2 m, $\beta$ = 45˚, 2 Layers of reinforcement.

**Table 2.** Summary of computer simulation.

| HEIGHT OF EMBANKMENT (H) | SLOPE ANGLE ($\beta$) | NUMBER OF GEOTEXTILE LAYERS ($n$) (T > 200 KN) | | | | | |
|---|---|---|---|---|---|---|---|
| | | $n$ = 0 | $n$ = 1 | $n$ = 2 | $n$ = 3 | $n$ = 4 | $n$ = 5 |
| $H$ = 2 m | 1:1 Slope ($\beta$ = 45˚) | 1.325 | 1.909 | 2.311 | N/A | N/A | N/A |
| | 1:2 Slope ($\beta$ = 27˚) | 1.897 | 2.316 | 2.333 | N/A | N/A | N/A |
| | 1:3 Slope ($\beta$ = 18˚) | 2.191 | 2.306 | 2.329 | N/A | N/A | N/A |
| | 1:4 Slope ($\beta$ = 14˚) | 2.251 | 2.327 | 2.348 | N/A | N/A | N/A |
| $H$ = 3 m | 1:1 Slope ($\beta$ = 45˚) | 1.231 | 1.644 | 1.701 | 1.731 | N/A | N/A |
| | 1:2 Slope ($\beta$ = 27˚) | 1.498 | 1.607 | 1.650 | 1.666 | N/A | N/A |
| | 1:3 Slope ($\beta$ = 18˚) | 1.553 | 1.655 | 1.701 | 1.718 | N/A | N/A |
| | 1:4 Slope ($\beta$ = 14˚) | 1.588 | 1.780 | 1.873 | 1.925 | N/A | N/A |
| $H$ = 4 m | 1:1 Slope ($\beta$ = 45˚) | 1.094 | 1.270 | 1.299 | 1.312 | 1.315 | N/A |
| | 1:2 Slope ($\beta$ = 27˚) | 1.143 | 1.223 | 1.251 | 1.264 | 1.267 | N/A |
| | 1:3 Slope ($\beta$ = 18˚) | 1.201 | 1.246 | 1.275 | 1.290 | 1.295 | N/A |
| | 1:4 Slope ($\beta$ = 14˚) | 1.239 | 1.290 | 1.311 | 1.321 | 1.324 | N/A |
| $H$ = 5 m | 1:1 Slope ($\beta$ = 45˚) | 0.914 | 1.092 | 1.153 | 1.177 | 1.182 | 1.183 |
| | 1:2 Slope ($\beta$ = 27˚) | 0.941 | 1.021 | 1.046 | 1.060 | 1.065 | 1.066 |
| | 1:3 Slope ($\beta$ = 18˚) | 0.981 | 1.012 | 1.030 | 1.041 | 1.045 | 1.045 |
| | 1:4 Slope ($\beta$ = 14˚) | 1.032 | 1.061 | 1.080 | 1.090 | 1.094 | 1.095 |

The simulated results are presented in graphical forms in Figures 5-8. Those charts can be used to quickly estimate the factor of safety against slope failure of sand embankments built on soft soils, or to determine the slope angle required and the number of geotextile layers required obtaining a certain value for the safety factor. The chart approach developed in this study is in consonance in that of Schmertmann *et al.* [13].

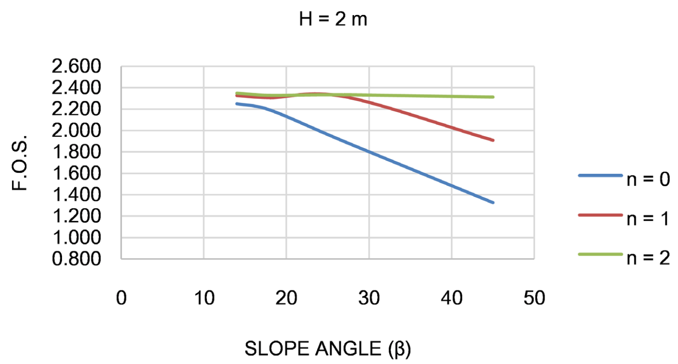


**Figure 5.** Variation of factor of safety with slope angle and number of geotextile reinforcement layers (geotextile tensile strength > 200 KN), for embankment height of H = 2 m.

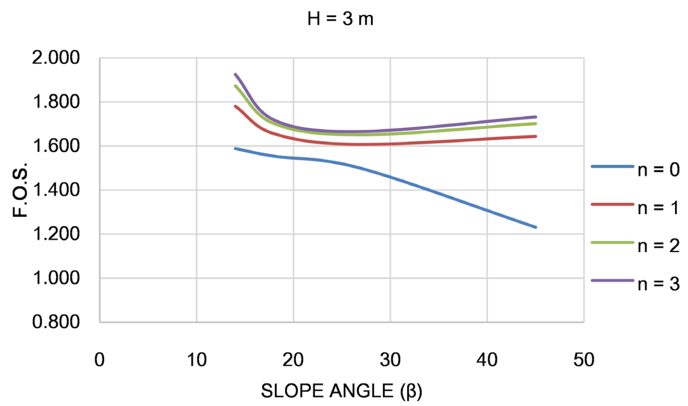


**Figure 6.** Variation of factor of safety with slope angle and number of geotextile reinforcement layers *(geotextile tensile strength > 200 KN), for embankment height of H = 3 m.

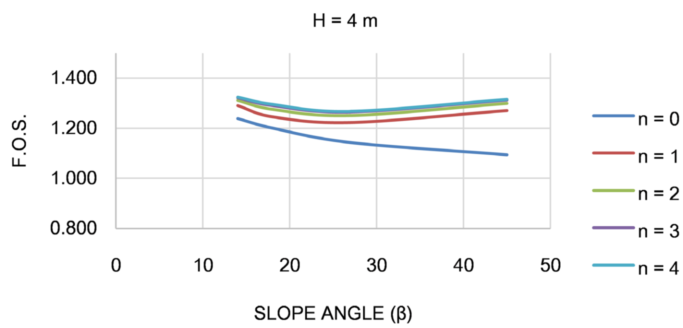


**Figure 7.** Variation of factor of safety with slope angle and number of geotextile reinforcement layers (geotextile tensile strength > 200 KN), for embankment height of H = 4 m.

Studying the effect of the positioning of the geotextile reinforcement was also a part of this research work. The embankment of 4m height, 1:1 slope ($\beta = 45^{\circ}$) was modeled with 1 layer of geotextile reinforcement at varying positions (h = 0.5, 1.5, 2.5, & 3.5 m). The results are summarized in **Table 3**. It can be seen that

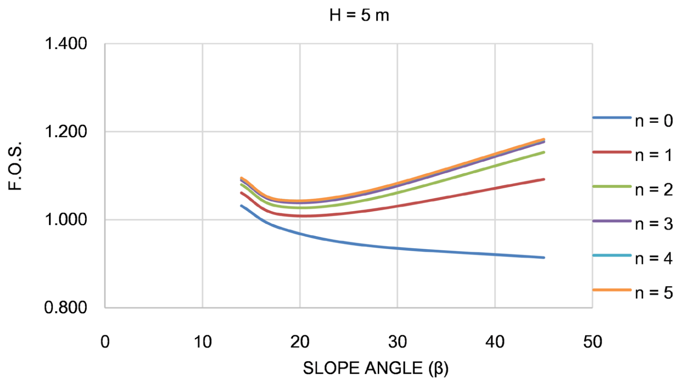


**Figure 8.** Variation of factor of safety with slope angle and number of geotextile reinforcement layers (geotextile tensile strength > 200 KN), for embankment height of H = 5 m.

**Table 3.** Variation of factor of safety (FOS) against slope failure for embankment height of 4 m, slope of 1:1, with varying position of geotextile reinforcement layer h.

| Position of geotextile reinforcement h | FOS |
|---|---|
| 0.5 | 1.270 |
| 1.5 | 1.159 |
| S2.5 | 1.105 |
| 3.5 | 1.097 |

the highest factor of safety was achieved when the geotextile layer was positioned closer to the base, with the factor of safety reducing as the position of the reinforcing layer is elevated.

Part of the contribution of this work is that we have translated the software solution into charts that can be easily used to assess the simple case of a reinforced embankment on soft soils. Those charts do not take into account some the of nature forces, like earthquakes and high rain intensity effects. Future works on this subject will begin by modifying the model to account for those natural forces and reflect the results in modified charts.

## 4. Conclusions

The results from the analysis of the 74 basic models of embankments having different heights, different slope angles and different number of geotextile reinforcement layers gave us a good understanding of the behavior of geosynthetic reinforced sand embankments built on soft clays.

From the results, it was found that adding a single layer of geotextile reinforcement improved the factor of safety significantly, while the improvement in adding additional layers of reinforcement being much less effective. The geotextile reinforcement performed best when it was positioned closer to the base of the embankment, and had the most effect in improving the factor of safety in steep slopes compared to the improvement in mild slopes.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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