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# AN INVESTIGATION ON THE STABILITY OF A SLOPING EMBANKMENT REINFORCED AT THE BASE UNDER THE INFLUENCE OF A SLANTING LOAD

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## Abstract

Many studies have shown that basal reinforcement using geosynthetics improves embankment slope stability on soft soils. Horizontal axial pullout force in the reinforcement and complete mobilisation of frictional resistances on the reinforcement layer are used to analyse slope stability in the literature. The reinforcing layer dragged by the sliding mass is inclined during failure. At the failure wedge-reinforcement layer junction, transverse deformation occurs. The sliding mass's angle of rotation at the failure circle centre determines transverse displacement. This research considers the geometry of the reinforcement during failure to determine the stability of a basal reinforced embankment.

**Keywords:** Embankment, Reinforcement, Stability, Axial, Transverse Pull

## 1. Introduction

### 1.1 Basal Reinforced Embankments on Soft Soils

Reinforced soil idea employing geosynthetics was the greatest way to improve soil strength and deformation in tough conditions. An embankment on soft ground has geosynthetic reinforcement at the bottom. Reinforcement improves embankments in soft soils. It was recognised that lateral earth pressure in the embankment over a soft cohesive foundation causes shear strains in the foundation soil. The tensile force in reinforcement opposes outward forces, improving stability. Reinforcement tensile forces and shear strength at the fill-reinforcement ground interface depend on its effective length.

The effective length determines whether the geosynthetic layer is extendable or inextensible. Extensible and inextensible sheets vary solely in effective length throughout full shear stress mobilisation. In extensible sheets, just the extended region is functional, whereas inextensible sheets consider the whole length. Jewell states that basal reinforcement may resist ground pressure in the embankment and foundation lateral deformations, enhancing bearing capacity and stability.

To assess embankment stability for internal and exterior collapse modes, a systematic design method is needed. Reinforced embankments collapse via lateral sliding over the base reinforcement layer. Foundation extrusion (bearing capacity failure), global stability analysis, reinforcement breakdown or withdrawal, excessive displacement. To prevent this failure mechanism, consider (i) the reinforcement–soil interface shear strength when the reinforcement is pulled out from the soil above and below it, (ii) its tensile strength, and (iii) its stress–strain characteristics relative to the foundation soil.

## 1.2 Methods of Analysis of A Geosynthetic – Reinforced Embankment

Limit equilibrium and finite element approaches are examples of research methodologies. Limit equilibrium techniques have been widely utilised to evaluate the short-term (undrained) stability of reinforced embankments on soft foundation soils (Zheng G, Yu X, Zhou H, Yang X, Guo W, Yang P.). These approaches were utilised to test bearing capacity, lateral sliding, and slip circle failure mechanisms' equilibrium.

Common limit equilibrium technique, slide circle failure mechanism, addresses moment equilibrium around circle centre. Stability comes by overturning and restoring moments. The overturning moments, lateral pressures in fill, and resistive forces along failure surface are part of soil weight and fill shearing strength. Finite element techniques accommodate for deformations that limit equilibrium methods do not. Foundation soil, fill, and reinforcement make up reinforced embankments. Their performance depends on internal interactions and deformations.

Since its inception, the finite element approach has been effective in evaluating slopes and embankments. Many studies have used these methods to understand reinforced embankment field behaviour (Gourc, J.P., Ratel, A. and Delmas, P, Bergado and Chai). In analysing time-dependent reinforced embankment behaviour, these methods have shown versatile (Ma H, Luo Q, Wang T, Jiang H, Lu Q.

## 2. Kinematics of Reinforcement-Backfill Response

Figure 1 shows how deformation kinematics causes reinforced soil structure collapse. Soil mass failure pulls reinforcement. Figure 2 shows that most design techniques use the axial pullout mechanism Jewell. As gravity loads stay normal on sheet reinforcement, shear resistance mobilised at the contact is proportionate to these stresses.

Figure 3 shows oblique pull on reinforcement near to the failure surface during failure. As the reinforcement deforms transversely under oblique force or displacement, the soil underneath mobilises additional normal stresses. Thus, reinforcement applied to axial force may mobilise varying shear resistance. Gourc, J.P., Ratel, A. and Delmas, P evaluated oblique deformation and reinforcement pullout.

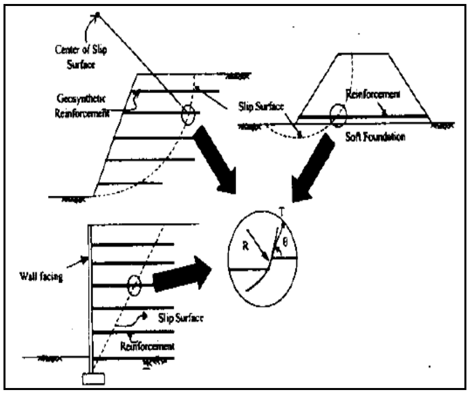


**Figure 1 Modelling the Interaction Between Reinforcement and Soil**

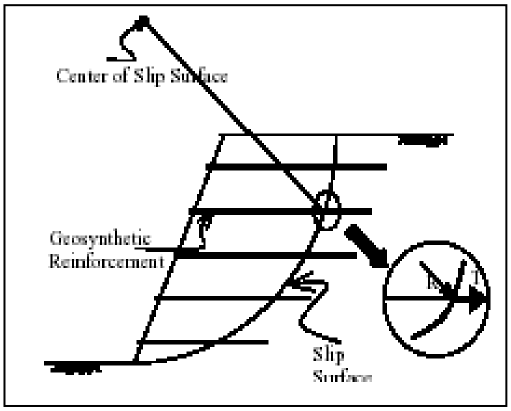


**Figure 2 Force acting horizontally**

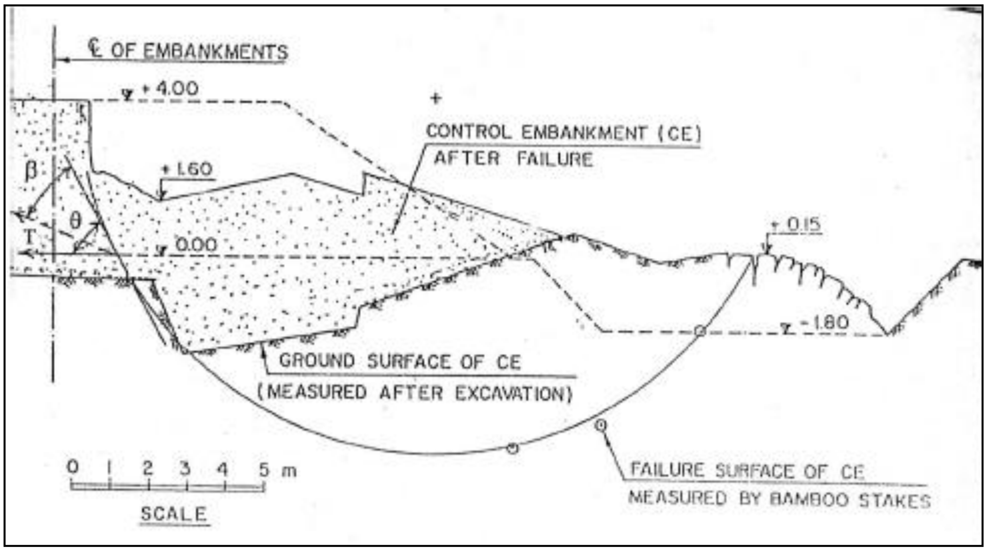


**Figure 3 Obliquity of Reinforcement Force in a Cross-Section of a Failed Embankment**

### 2.1 Sheet Reinforcement Subjected To Transverse Downward Force/ Displacement

Additional normal stresses arise at the interface between the failure surface and the geosynthetic reinforcement as a result of transverse strain or displacement. These additional normal stresses subsequently elevate the frictional resistance of the reinforcement. Giroud (1995) established a global relationship between geosynthetic strain and deflection; however, there is currently no analysis that combines the axial and normal displacements of reinforcement. Madhav and Umashankar (2003) and 2005, respectively, assessed the transverse force/displacement response of geosynthetic reinforcement in the presence of a linear and nonlinear subgrade response.

## 3. Statement of Problem and Analysis

A granular fill embankment, with a specified geometry, is deemed to be situated on a homogeneous soft clay substrate. At the interface between the foundation and the fill material, a geosynthetics layer is utilised to provide reinforcement with minimal embedment in the fill. The embankment design is illustrated in Figure 4. The analysis is conducted utilising methodologies of limit equilibrium. The simplified technique of Bishop is utilised to analyse the factor of safety. In order to compute the factor of safety and generate the critical failure circle, the geoslope package is utilised. Tables one through four provide descriptions of the fill, ground, and reinforcement properties, as well as the geometry of the embankment and ground.

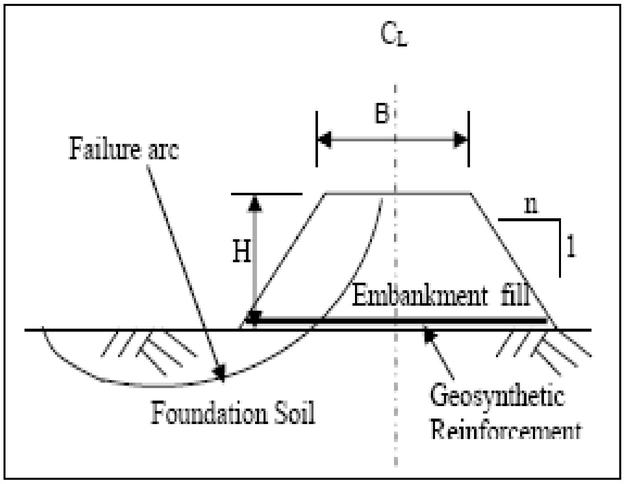


Figure 4 Definition sketch

### 3.1 Stability from Rotational Failure

The driving and resisting moments originating from the tangential and normal components at the base of the selected sliding wedge are calculated for a trial failure surface. The factor of safety is calculated by dividing the drive moment by the resisting moment. Cohesive resistance is a component of the resisting force along the fault surface's extent. The identification of a critical slip circle surface with the lowest factor of safety occurs. Geoslope is a software application utilised to produce the critical slide surface.

### 3.2 Stability of Embankment with Basal Reinforcement - Horizontal Pull

Figure 5 shows horizontal geosynthetic reinforcement between foundation soil and embankment fill. Layer spans embankment width and length. Fully mobilising shear resistance at the basal reinforcement surface is assumed.

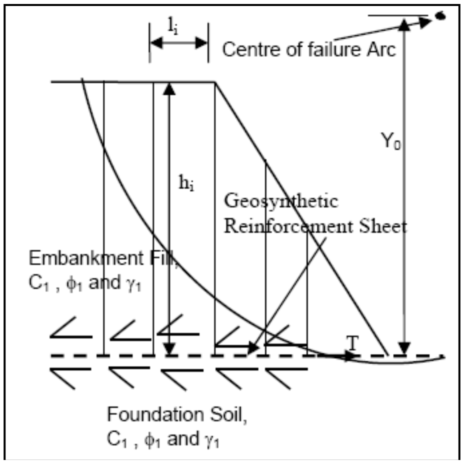


**Figure 5 Horizontal pull in reinforcement layer**

### 3.3 Stability of Embankment with Basal Reinforcement - Transverse Pull

As can be seen in Figure 6, the failure surface passes through the reinforcement at an angle that is perpendicular to the direction of the failure. In the event of failure caused by the weight of sliding mass, the reinforcing layer experiences the development of a tensile force, denoted as T. This force is exerted at an angle of θ with respect to the horizontal. Calculating the transverse pullout force in reinforcement at failure is accomplished by the use of the analysis, as will be discussed in the following section.

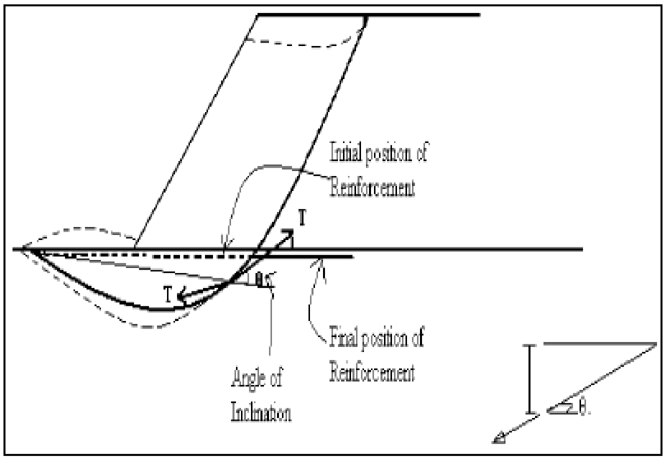


**Figure 6 Basal reinforced embankment with oblique failure**

## 3.4. Analysis for transverse pull in reinforcement:

A soil with a unit weight of γ is represented in Figure 7, which depicts an extensible sheet reinforcement with a length of L that is buried at a depth of d. Φr, which stands for the angle of shear resistance of the soil, is the angle that is used to characterise the interface shear resistance between the reinforcement and the soil. A computation may be made to determine the displacement profile as well as the tension that has been mobilised in the reinforcement by using the transverse force, P, that is applied at point B. You also have the option of computing the displacement profile and the transverse force mobilised by using the transverse displacement, wL, of the point B that is provided to you.

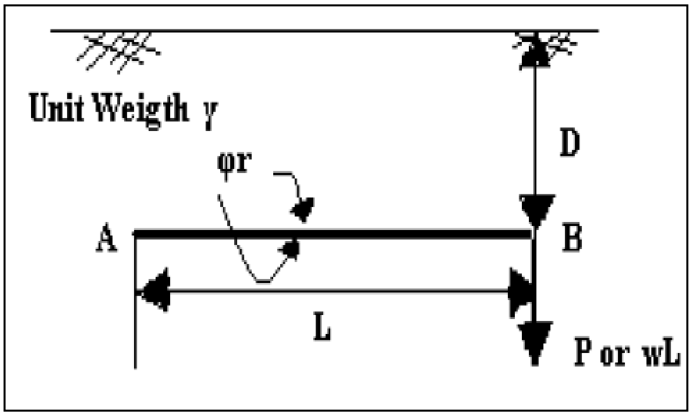


**Figure 7 Definition sketch of transverse pull**

## 3.5 Problem Considered

The embankment considered for present study is shown in Figure 8.

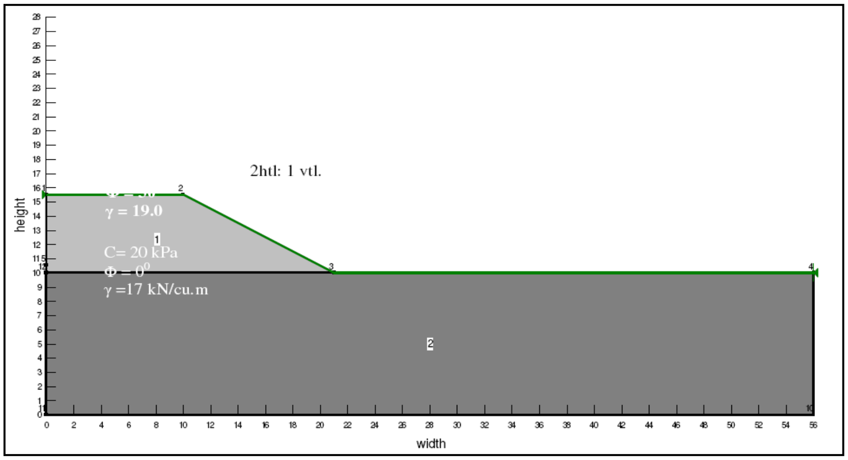
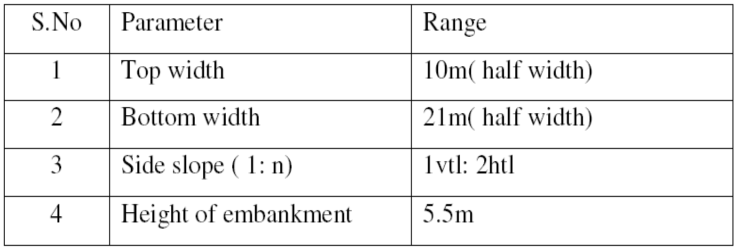


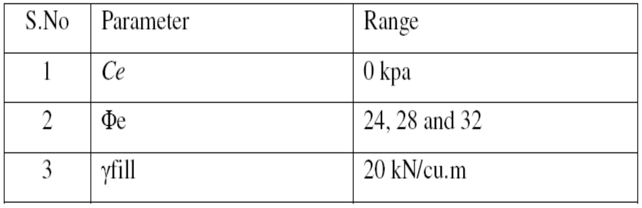
**Figure 8 Cross-section of embankment considered**

**Table 1 Geometry Ranges for study**



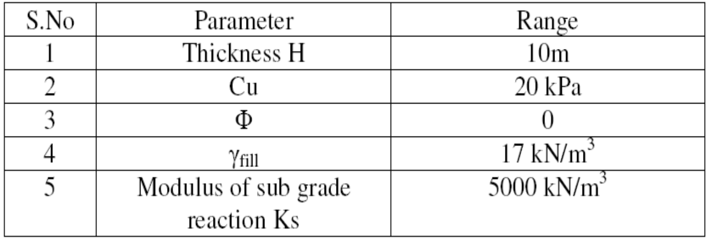
| S.No | Parameter | Range |
|---|---|---|
| 1 | Top width | 10m( half width) |
| 2 | Bottom width | 21m( half width) |
| 3 | Side slope ( 1: n) | 1vtl: 2htl |
| 4 | Height of embankment | 5.5m |

**Table 2 Embankments fill properties for study**



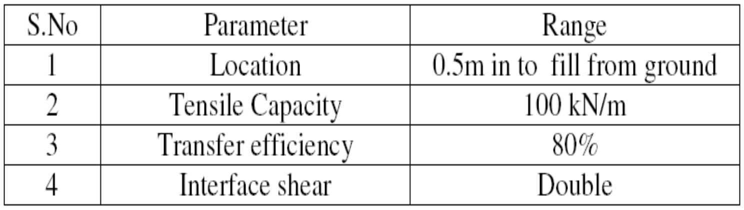
| S.No | Parameter | Range |
|---|---|---|
| 1 | *Ce* | 0 kpa |
| 2 | Φe | 24, 28 and 32 |
| 3 | γfill | 20 kN/cu.m |

**Table 3 Foundation soil properties for study**



| S.No | Parameter | Range |
|---|---|---|
| 1 | Thickness H | 10m |
| 2 | Cu | 20 kPa |
| 3 | Φ | 0 |
| 4 | $\gamma_{fill}$ | 17 kN/m$^3$ |
| 5 | Modulus of sub grade reaction Ks | 5000 kN/m$^3$ |

**Table 4 Reinforcement details**



| S.No | Parameter | Range |
|---|---|---|
| 1 | Location | 0.5m in to fill from ground |
| 2 | Tensile Capacity | 100 kN/m |
| 3 | Transfer efficiency | 80% |
| 4 | Interface shear | Double |

## 3.6 Stability Analysis

### 3.6.1 In the presence of axial pull, the stability of unreinforced embankment and reinforced embankment is analysed.

Geoslope is used in order to perform stability research on both unreinforced and reinforced embankments, taking into consideration the axial pull. While the critical slip circle is being formed, the factor of safety is being calculated using the search option in Geoslope. This results in the slip surface that corresponds to the minimal factor of safety. The programme is used to acquire the geometry of the slip surface as well as the centre of the slip circle.

### 3.6.2 Persistence of the Reinforced Embankment in the Presence of Oblique Pull

A computation is made for the oblique pull using the same slip circle that was obtained for the embankment with axial force. For the purpose of determining the oblique pull, calculations are carried out with the knowledge of the geometry, the centre of the slip surface, the depth of embedding of reinforcement, the slip circle radius R, and the point where the reinforcement of the axial case intersects.

## 4. Results

For the same critical circle that was obtained in the axial case, knowing the length of the reinforcement Le and the moment centre, the transverse force that is developed as a result of oblique pull is computed by taking into consideration a rotation of 0 (horizontal), 0.002, 0.004, 0.006, 0.008, and 0.01 radians at the point where the reinforcement intersects with the slip surface. It is possible to calculate the factor of safety using the rotations described above, and the results are shown in Figures 9 and 10.

### 4.1 Effect of Angle of Internal Friction of Embankment

For both unreinforced and reinforced embankments, the variation in the factor of safety is shown in Figure 9, which demonstrates how the factor of safety changes when the friction angle of the embankment soil changes. Both unreinforced and reinforced embankments have been seen to exhibit an increase in the factor of safety when the friction angle, denoted by Φ, increases. As the phi value increases, it is found that the unreinforced embankment experiences an increase of 1.02 to 1.05, the reinforced embankment experiences an increase of 1.12 to 1.15, and the oblique pull causes an increase of 1.21 to 1.25. Due to the fact that the interfacial friction between the embankment soil and the reinforcement layer rises as the frictional angle of the embankment soil grows, this phenomena is seen. This leads in an increase in the mobilised tension in the reinforcement, which in turn produces an increase in the factor of safety.

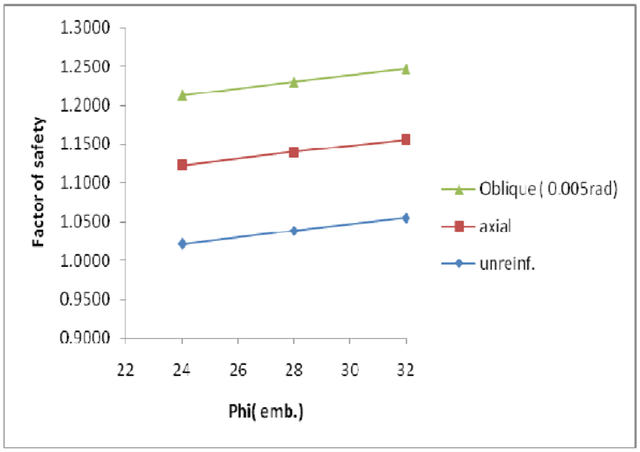


Figure 9 Variation of FS with various forces in reinforcement

### 4.2 Effect of Oblique Pull in the Reinforcement Layer on Factor of Safety

A representation of the change in the factor of safety with oblique pull may be seen in Figure 10. Based on observations, it has been established that the factor of safety increases in a linear fashion with rotation and with the angle of internal friction. It has been discovered that the different oblique forces that are created as a result of rotation experience an increase which ranges from 1.12 to 1.21 for phi 28, 1.14 to 1.23 for phi 32, and 1.16 to 1.25. It has been noted that when oblique pull is considered in comparison to axial pull, there is a factor of safety increase of up to thirty percent for all phi values.

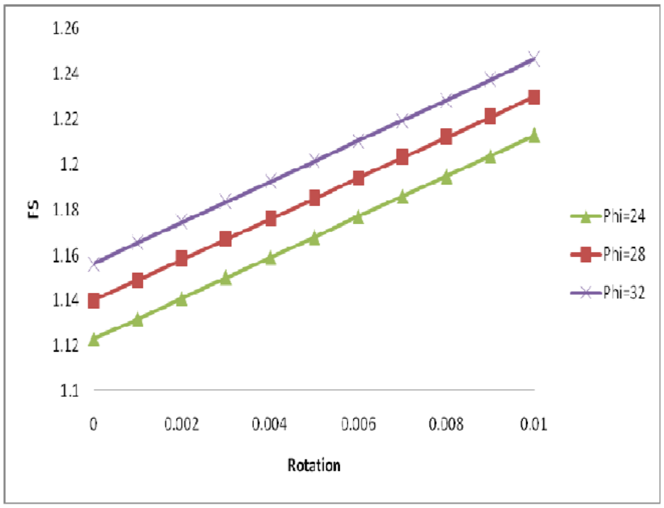


Figure 10 Variation of FS with various forces in reinforcement- effect of phi

## 5. Conclusion

Following are some conclusions that may be derived from the analysis and the outcomes in concern.

It is important to note that the angle of internal friction has a considerable impact on the factor of safety in both unreinforced and reinforced embankments. Additionally, the factor of safety rises when the axial pull is applied. The same goes for oblique pull in reinforcement, which may significantly enhance the amount. The newly developed method illustrates the relevance and value of taking into account the oblique pull force while doing stability analysis in order to generate an effective and optimum design.

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