ANALYSIS OF SLOPE STABILITY ON BASAL REINFORCED EMBANKMENT WITH SLANTING LOAD

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Abstract

Slope stability of embankments on soft soils can be enhanced by providing basal reinforcement with geosynthetics proved by many researchers. In the literature the stability of the slopes analyzed by considering horizontal axial pullout force in the reinforcement upon with full mobilization of frictional resistances on the surface of the reinforcement layer. But during the failure the reinforcement layer is pulled by the sliding mass is observed to be inclined not in horizontal. During the failure transverse deformation will occur at the intersection point of failure wedge with reinforcement layer. The amount of transverse displacement depends on the angle of rotation of the sliding mass at the center of the failure circle. Hence in this paper stability of a basal reinforced embankment by considering the geometry of the reinforcement during the failure.

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

1. INTRODUCTION

Basal Reinforced Embankments on Soft Soils

Reinforced soil concept (Vidal, 1969) using geosynthetics proved as the best technique, which can be used to enhance the strength and deformation behavior of soil in difficult situations. An embankment constructed on soft foundation is designed with a layer of geosynthetics reinforcement at its bottom. Jewell (1988) described the mechanism by which reinforcement could improve the performance of embankments on soft soils. This involved the recognition that the lateral earth pressure within the embankment over a soft cohesive foundation imposes shear stresses on the foundation soil. The tensile force in reinforcement resists the driving outward forces thus adding stability. Tensile forces mobilized in the reinforcement based on the effective length of reinforcement, shear strength mobilized at the contact surface of fill-reinforcement ground interface. Based on the effective length the layer of geosynthetics can be termed either extensible/ inextensible material. The difference between extensible and inextensible sheet being only effective length over full mobilization of shear stresses occurs. In the case of extensible sheet only the elongated portion is considered as effective while, total length of sheet is considered in the case of inextensible sheet. The basal reinforcement can serve to resist some or all of the earth pressure within the embankment and to resist the lateral deformations of the foundation, thereby increasing bearing capacity and stability, Jewell (1988). A systematic design approach is to be followed to evaluate the embankment stability with respect to internal and external failure mechanisms. The failure mechanism of reinforced embankments are (i) lateral sliding of embankments over the base reinforcement layer, 9ii) Foundation extrusion (bearing capacity failure), (iii) global stability analysis (iv) breakage or pullout of reinforcement (v) Excessive displacement. In order to prevent this failure mechanism, consideration must be given to (i) the reinforcement–soil interface shear strength under conditions where the reinforcement is pulled out from the soil above and below it, (ii) the tensile strength of the reinforcement and (iii) the stress–strain characteristics of the reinforcement relative to those of the foundation soil.

Methods of Analysis of A Geosynthetic – Reinforced Embankment

Limit equilibrium approach and finite element approach are few of the methods illustrated in literature by many researchers. Limit equilibrium methods have been used extensively to assess the short-term (undrained) stability of reinforced embankments constructed on soft foundation soils (Jewell 1988, Rowe and Soderman 1984, Rowe and Li 2005, Bergado et.al, 2002). These methods have been used to examine equilibrium of bearing capacity failure mechanism, lateral sliding mechanism and slip circle type failure mechanism. Commonly used limit equilibrium method i.e. the slip circle failure mechanism considers moment equilibrium about the circle centre. The stability is obtained from the overturning moments and restoring moments. The over turning moments include part of weight of soil, lateral pressures within fill and resisting forces are part of weight and shearing strength of ground and fill along failure surface. Finite element methods consider the deformations also which are not accounted in limit equilibrium methods. Reinforced embankments are composite system consisting of three components: the foundation soil, the fill and the reinforcement. Their performance is highly dependent up on interactions and deformations within them. The finite element method has been proven to be a powerful technique in the evaluation of slopes and embankment behavior since its use. Numerous researchers have employed these techniques to interpret field behavior of reinforced embankments (Rowe et. al 1984, Bergado and Chai 1994). These techniques have also proven their versatility in analyzing time dependent behavior of reinforced embankments (Rowe and Li, 2005).

2. KINEMATICS OF REINFORCEMENT-BACKFILL RESPONSE

Kinematics of the deformation dictates typical failure of reinforced soil structures is shown in Figure 1. At failure of soil mass the reinforcement is subjected to pull. As shown in Figure 2, almost all the available design methods incorporate only the axial pullout mechanism Jewell (1992). Here the gravity stresses will remain as normal stress on sheet reinforcement, consequently, the shear resistance mobilized at the interface is proportional to these stresses. However, as shown in Figure 3, at failure, the shape of reinforcement adjacent to the failure surface is subjected to oblique pull (Bergado et al. 2000). Under the action of oblique force or displacement, the soil beneath the reinforcement mobilizes additional normal stresses as the reinforcement deforms transversely. As a result, the shear resistance mobilized could be considerably different in case of reinforcement subjected to axial force. Oblique deformation and pull out of reinforcement was studied by Gourc. et al. (1986),

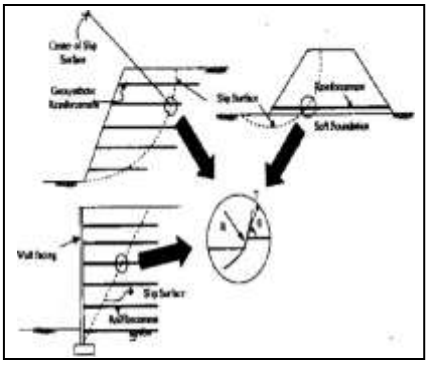

Figure 1 Kinematics of Reinforcement and Soil Interaction

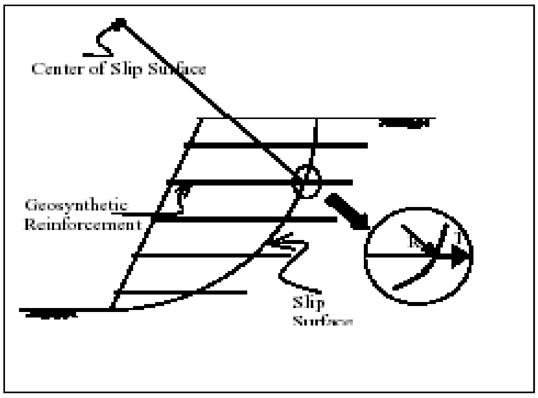

Figure 2 Horizontal Pullout Force

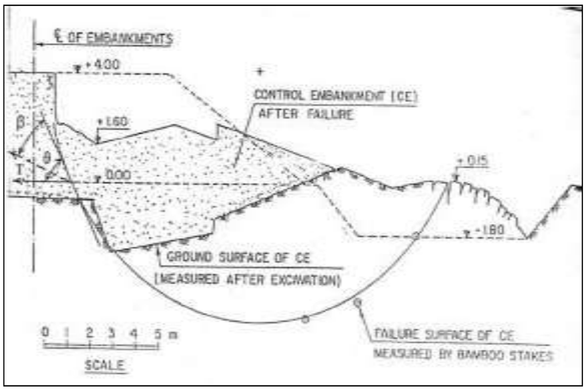

Figure 3 Cross section of Failed Embankment showing Obliquity of Reinforcement Force

Sheet Reinforcement Subjected To Transverse Downward Force/ Displacement

Due to transverse pull/ transverse displacement additional normal stresses develop over geosynthetic reinforcement at the intersection of the reinforcement and the failure surface, which in turn increases frictional resistance. Giroud (1995) related geosynthetic strain to deflection on a global scale but, no analysis is available that couples normal and axial displacements of reinforcement. Madhav and Umashankar (2003 & 2005) evaluated the response of geosynthetic reinforcement to transverse force/displacement under linear response and non linear response of sub grade.

3. Statement of Problem and Analysis

A granular fill embankment of given geometry is considered on soft clay bed homogeneous in nature. Reinforcement in the form of geosynthetics layer is provided at the foundation-fill interface with little embedment in to fill. The sketch of embankment is shown in Figure 4. The analysis is carried out by limit equilibrium methods. Bishops simplified method is used for analyzing factor of safety. Geoslope package is used to generate the critical failure circle and to compute factor of safety. The geometry of embankment, ground and properties of fill, ground and reinforcement are detailed in Tables 1 to Table 4.

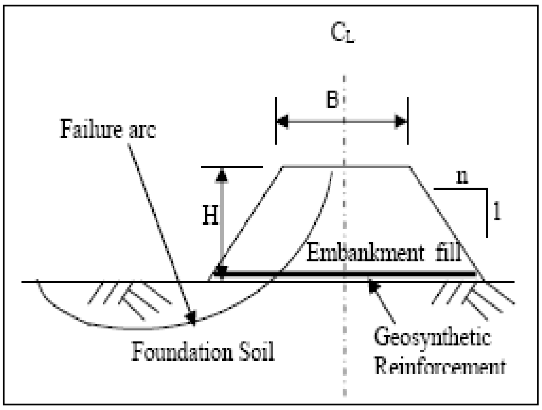

Figure 4 Definition sketch

Stability from Rotational Failure

For a trial failure surface, the driving and resisting moments from normal and tangential components at the base of sliding wedge (selected) are computed. Factor of safety is computed as a ratio of resisting moment to driving moment. Resisting force includes cohesive resistance along length of failure surface. A critical slip circle surface having least factor of safety is identified. Geoslope software is used for generating the critical slip surface.

Stability of Embankment with Basal Reinforcement - Horizontal Pull

Geosynthetic reinforcement is introduced horizontally between foundation soil and embankment fill is shown in Figure 5. The layer is extending to the full width and length of embankment. Full mobilization of shear resistance along the surface of the basal reinforcement is assumed.

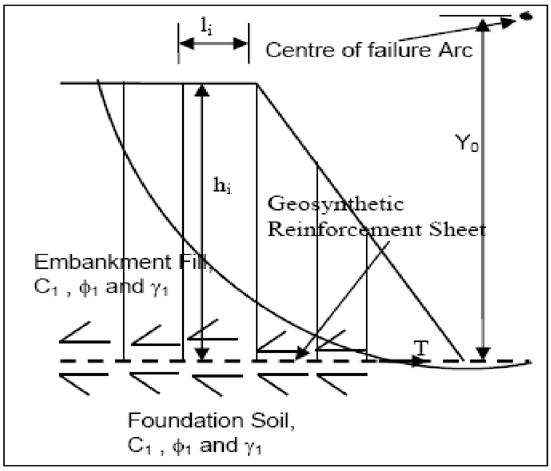

Figure 5 Horizontal pull in reinforcement layer

Stability of Embankment with Basal Reinforcement - Transverse Pull

As depicted in Figure 6, the failure surface intersects the reinforcement at an oblique angle at the failure. At failure due to weight of sliding mass, the tensile force, T, develops in the reinforcement layer and this force makes at an angle of 'θ' with the horizontal. The transverse pullout force in reinforcement at failure is computed with the analysis as explained in subsequent heading.

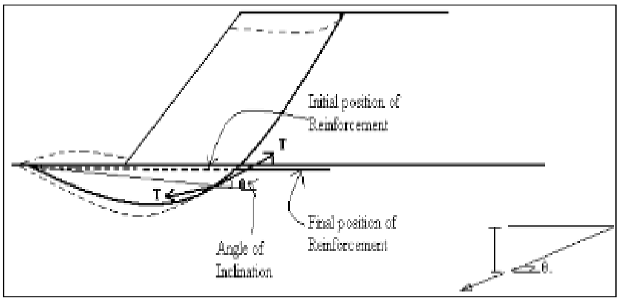

Figure 6 Basal reinforced embankment with oblique failure

3.4. Analysis for transverse pull in reinforcement:

An extensible sheet reinforcement of length, L, is embedded at a depth, d, in a soil of unit weight, γ, is shown in Figure 7. The interface shear resistance between the reinforcement and the soil is characterized by the angle, Φr (<=Φ, the angle of shearing resistance of soil). The displacement profile and the tension mobilized in the reinforcement can be computed with the transverse force, P, applied at point B. Alternatively, the displacement profile and the transverse force mobilized can be computed with the given transverse displacement, wL, of the point, B.

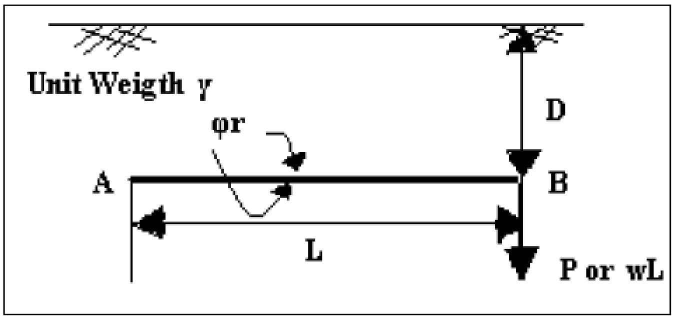

Figure 7 Definition sketch of transverse pull

Problem Considered

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

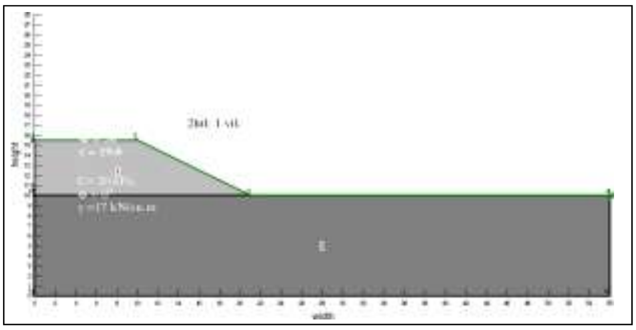

Figure 8 Cross-section of embankment considered

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	γ_{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

Stability Analysis

Stability of Unreinforced Embankment and Reinforced Embankment with Axial Pull

Stability analysis for both unreinforced embankment and reinforced embankment considering axial pull are carried out using Geoslope. Critical slip circle is generated and factor of safety is computed with search option in Geoslope giving slip surface corresponding to minimum factor of safety. The geometry of slip surface, slip circle center is obtained in the program.

Stability of Reinforced Embankment with Oblique Pull

Oblique pull is computed for the same slip circle obtained for the embankment with axial pull. Knowing the geometry, center of slip surface, depth of embedment of reinforcement, slip circle radius R and the point the intersection of reinforcement of axial case, computations are carried out for determination of oblique pull.

4. RESULTS

For the same critical circle obtained in axial case knowing length of reinforcement Le, moment center the transverse force developed due to oblique pull is computed by considering a rotation of 0 (horizontal), 0.002, 0.004, 0.006, 0.008 and 0.01 radians at the point of intersection of reinforcement with slip surface. Factor of safety with the above rotations are computed and the results are presented in Figures 9 and Figure 10.

Effect of Angle of Internal Friction of Embankment

Figure 9 shows the variation of factor of safety with change in friction angle of the embankment soil for unreinforced and reinforced embankments. It is observed that the factor of safety of both unreinforced and reinforced embankment is increasing with friction angle, Φ. An increase of 1.02 to
1.05 for unreinforced embankment, 1.12 to 1.15 for reinforced embankment 1.21 to 1.25 with oblique pull is observed for increasing phi. This phenomenon is observed, since with increasing frictional angle of embankment soil, the interfacial friction between the embankment soil and the reinforcement layer increases results in increase in mobilized tension in the reinforcement causes to increase in factor of safety.

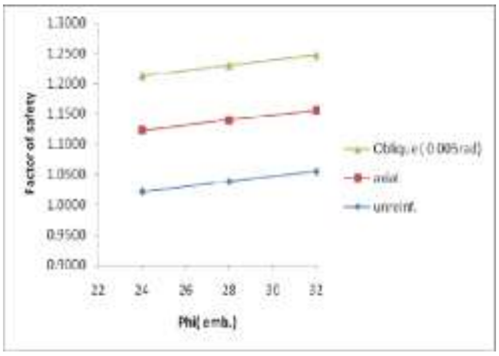

Figure 9 Variation of FS with various forces in reinforcement

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

The variation of factor of safety with oblique pull is presented in Figure 10. It is observed that factor of safety is increasing with rotation linearly and with angle of internal friction. An increase from 1.12 to 1.21 for phi 28, 1.14 to 1.23 for phi 32 and 1.16 to 1.25 is observed for various oblique forces developed due to rotation. An increase up to 30% in factor of safety is observed considering oblique pull compared to axial pull for all phi values.

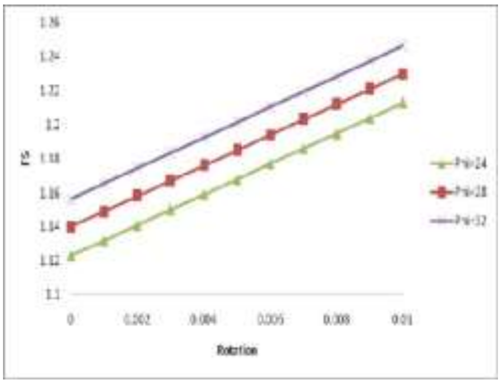

Figure 10 Variation of FS with various forces in reinforcement- effect of phi

5. CONCLUSION

From the analysis and results, the following conclusions are drawn.

- Effect of angle of internal friction is significant on Factor of safety in unreinforced or reinforced embankments.
- Under the axial pull the factor of safety increases. The same increases considerably for oblique pull in reinforcement.
- The new approach demonstrates the importance and significance of oblique pull force to consider in stability analysis for efficient and optimal design.

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