ISSN (Print) : 2347-6729
ISSN (Online) : 2348-3105

International Journal on Recent Researches in Science, Engineering & Technology (IJRRSET)

A Journal Established in early 2000 as National journal and upgraded to International journal in 2013 and is in existence for the last 10 years. It is run by Retired Professors from NIT, Trichy. Journal Indexed in JIR, DIIF and SJIF.

Available online at: www.jrrset.com

Volume 8, Issue 1
January 2020.
JIR IF : 2.54
SJIF IF : 4.334
Cosmos: 5.395

Received on: 04.12.2019 **Published on:** 21.01.2020 **Pages :** 67-75

SLOPE STABILITY ANALYSIS OF BASAL REINFORCED EMBANKMENT SUBJECTED O SLANTED LOADS

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Abstract

Many studies have shown that the stability of embankments on soft soils may be improved by using geosynthetics for basal reinforcement. The literature examines the stability of slopes by analysing the horizontal axial pullout force acting on the reinforcement layer, taking into account the complete mobilisation of frictional resistances on the surface of the reinforcement. However, during the failure, it is found that the reinforcing layer is inclined rather than being horizontal due to the pulling force exerted by the sliding mass. Transverse deformation will occur at the junction point of the failure wedge and the reinforcing layer during failure. The magnitude of lateral displacement is contingent upon the rotational angle of the sliding mass located at the centre of the failure circle. Therefore, this work examines the stability of a basal reinforced embankment by taking into account the reinforcement's shape at the point of failure.

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

1. Introduction

1.1 Basal Reinforced Embankments on Soft Soils

The idea of reinforced soil, introduced by Vidal in 1969, has shown that the application of geosynthetics is the most effective way for improving the strength and deformation characteristics of soil under challenging conditions. A geosynthetic reinforcing layer is added at the bottom of an embankment that is built on a soft foundation. In 1988, Jewell provided a description of the process via which reinforcement may enhance the performance of embankments built on soft soils. This entails acknowledging that the sideways pressure exerted by the soil in the embankment on a soft cohesive base causes shear stresses on the foundation soil. The tensile force in reinforcement counteracts the outer forces, so enhancing stability. The tensile forces in the reinforcement are determined by the effective length of the reinforcement, whereas the shear strength is mobilised at the contact surface between the fill and the reinforcement-ground interface. The classification of the layer of geosynthetics as either extensible or inextensible material is determined by its effective length. The distinction between extensible and inextensible sheets lies only in the effective length over which shear forces are fully mobilised. For extensible sheets, only the extended section is considered effective, but for inextensible sheets, the complete length of the sheet is taken into account. According to Jewell (1988), the basal reinforcement may help withstand the earth pressure in the embankment and prevent the foundation from deforming laterally. This improves the bearing capacity and stability of the structure. The evaluation of embankment stability in relation to internal and external failure modes requires the use of a systematic design methodology. The failure mechanism of reinforced embankments is the lateral sliding of embankments over the base reinforcement layer. The issues to be considered are: (i) foundation extrusion due to bearing capacity failure, (ii) global stability analysis, (iii) breaking or withdrawal of reinforcement, and (iv) excessive displacement. To prevent this failure mechanism, it is important to consider the shear strength at the interface between the reinforcement and the soil, particularly when the reinforcement is being pulled out from the soil above and below it. Additionally, the tensile strength of the reinforcement and its stress-strain characteristics relative to those of the foundation soil should be taken into account.

1.2 Methods of Analysis of A Geosynthetic – Reinforced Embankment

The literature has several examples of researchers illustrating the use of approaches such as the limit equilibrium approach and the finite element approach. The short-term (undrained) stability of reinforced embankments erected on soft foundation soils has been widely evaluated using limit equilibrium techniques. This approach has been documented in several studies, including those by Jewell (1988), Rowe and Soderman (1984), Rowe and Li (2005), and Bergado et.al (2002). These methodologies have been used to analyse the stability of bearing capacity failure mechanism, lateral sliding mechanism, and slip circle type failure mechanism. The slip circle failure mechanism, which is a commonly used limit equilibrium approach, addresses moment equilibrium around the middle of the circle. The stability of the system is derived from the opposing forces of overturning moments and restoring moments. The overturning moments consist of the weight of the soil, the lateral pressures inside the fill, and the resistive forces that are a result of the weight and shearing strength of the ground and fill along the failure surface. Finite element approaches include deformations that are not taken into consideration in limit equilibrium methods. Reinforced embankments are a composite structure including three components: the foundation soil, the fill, and the reinforcement. Their performance is heavily reliant on the interactions and deformations occurring inside them. The efficacy of the finite element approach in assessing slopes and embankment behaviour has been well-established since its inception. Many studies have used these methodologies to analyse the behaviour of reinforced embankments in the field (Rowe et. al 1984, Bergado and Chai 1994). The adaptability of these methodologies has been shown in analysing the time-dependent behaviour of reinforced embankments (Rowe and Li, 2005).

2. Kinematics of Reinforcement-Backfill Response

The typical failure of reinforced soil structures is determined by the kinematics of the deformation, as seen in Figure 1. When the soil mass fails, the reinforcement experiences tension. Figure 2 demonstrates that the majority of design methodologies now in use only include the axial pullout mechanism, as stated by Jewell (1992). The gravitational loads exerted on the sheet reinforcement will result in normal stress. As a result, the shear resistance mobilised at the interface is directly proportional to these stresses. Nevertheless, as seen in Figure 3, when failure occurs, the reinforcement located next to the failure surface experiences oblique tension (Bergado et al., 2000). When subjected to a diagonal force or movement, the soil under the reinforcement generates extra perpendicular strains when the reinforcement undergoes lateral deformation. Consequently, the amount of shear resistance that is activated may vary significantly when reinforcement is exposed to axial force. Gourc et al. (1986) conducted a study on the oblique deformation and pull out of reinforcement.

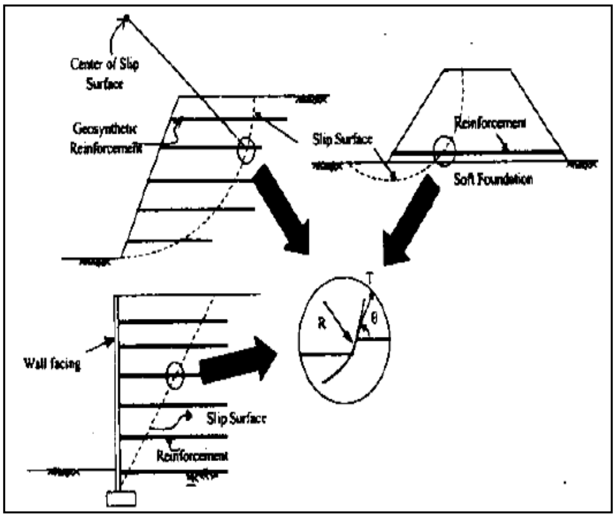


Figure 1 Kinematics of Reinforcement and Soil Interaction

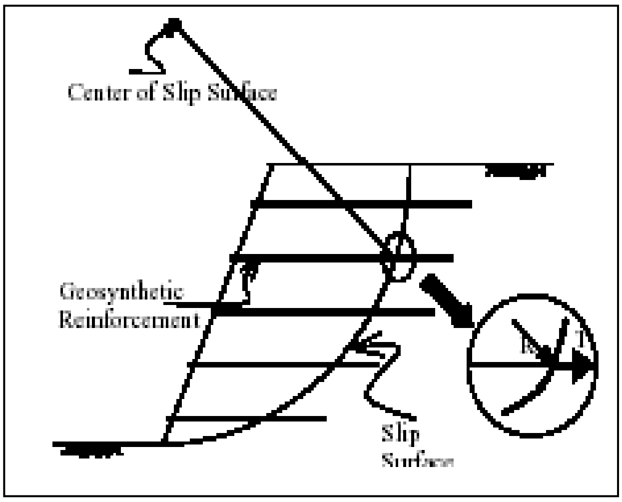


Figure 2 Horizontal Pullout Force

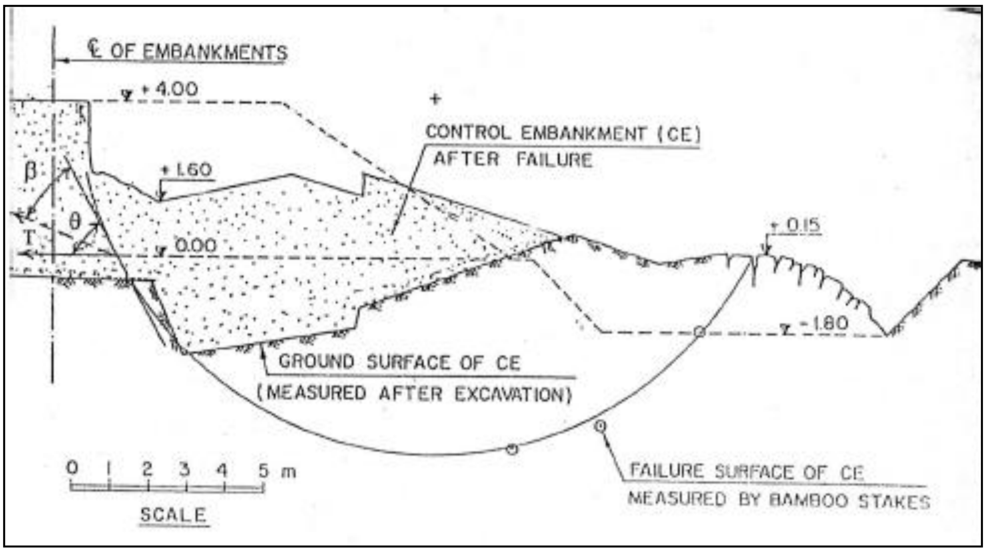


Figure 3 Cross section of Failed Embankment showing Obliquity of Reinforcement Force

2.1 Sheet Reinforcement Subjected To Transverse Downward Force/ Displacement

The presence of transverse pull or transverse displacement causes the development of extra normal stresses on the geosynthetic reinforcement at the point where it intersects with the failure surface. This, in turn, leads to an increase in frictional resistance. Giroud (1995) established a correlation between geosynthetic strain and deflection on a worldwide level. However, there is currently no research that combines both normal and axial displacements of reinforcement. between their studies conducted between 2003 and 2005, Madhav and Umashankar examined how geosynthetic reinforcement responds to transverse force and displacement. They specifically investigated both linear and non-linear responses of the subgrade.

3. Statement of Problem and Analysis

The analysis focuses on a granular fill embankment with a certain shape that is placed on a uniformly consistent soft clay substrate. Geosynthetics layer is used to reinforce the interface between the foundation and the fill by placing it with little embedding into the fill material. Figure 4 displays the diagram of the embankment. The study is conducted using limit equilibrium techniques. The Bishop's simplified technique is used to analyse the factor of safety. The Geoslope programme is used for the generation of the critical failure circle and the calculation of the factor of safety. Tables 1 to 4 provide specific information on the geometry of the embankment, ground, and characteristics of the fill, ground, and reinforcement.

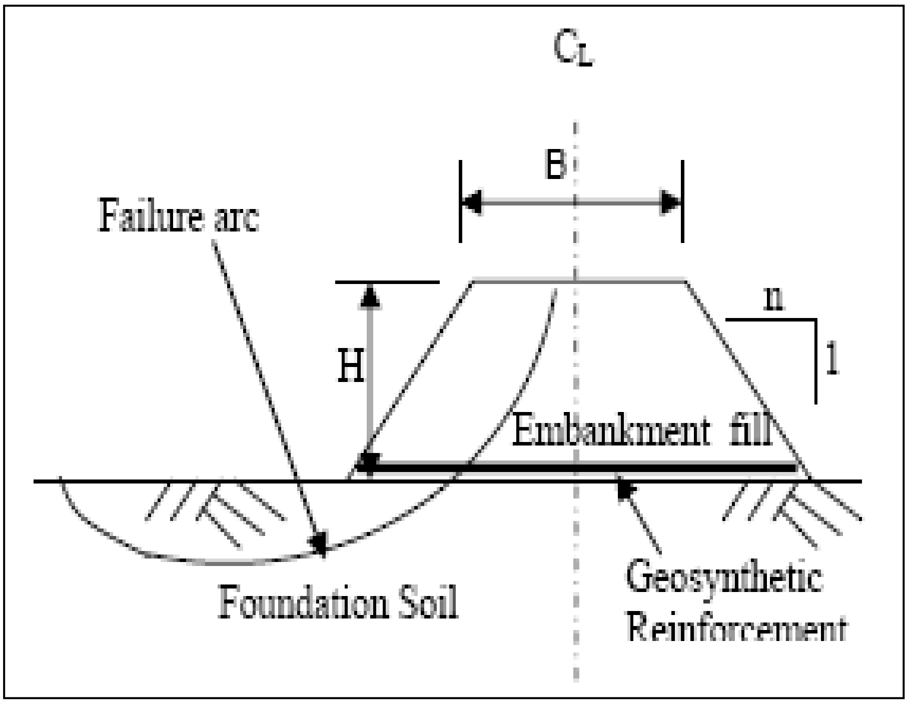


Figure 4 Definition sketch

3.1 Stability from Rotational Failure

The driving and resisting moments at the base of the chosen sliding wedge are calculated by considering the normal and tangential components of the trial failure surface. The factor of safety is calculated by dividing the resisting moment by the driving moment. The resisting force is comprised of cohesive resistance that extends over the whole length of the failure surface. A slip circle surface with the lowest factor of safety has been discovered. The Geoslope programme is used to generate the crucial slip surface.

3.2 Stability of Embankment with Basal Reinforcement - Horizontal Pull

Figure 5 illustrates the placement of geosynthetic reinforcement in a horizontal manner between the foundation soil and embankment fill. The layer is expanding to cover the whole breadth and length of the embankment. It is assumed that the shear resistance along the surface of the basal reinforcement is fully mobilised.

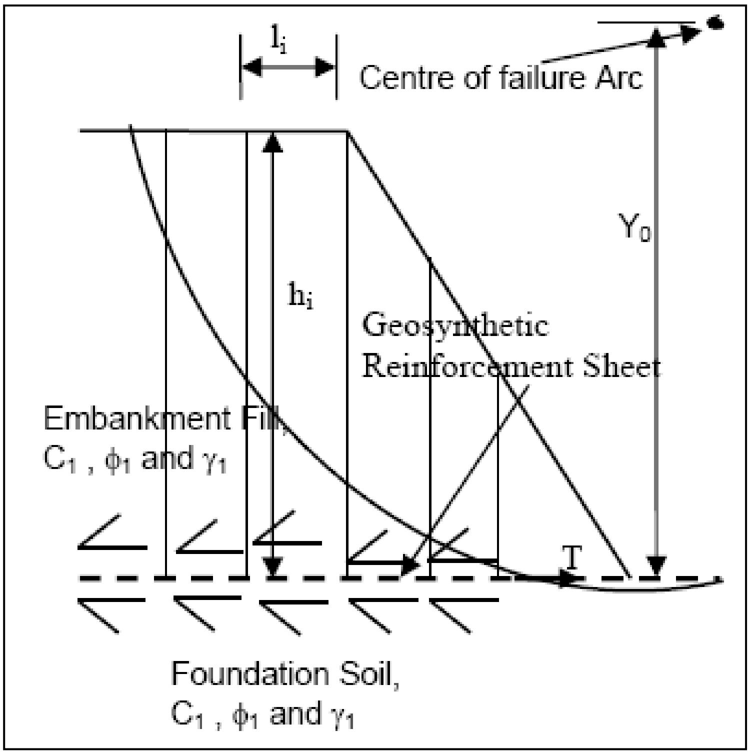


Figure 5 Horizontal pull in reinforcement layer

3.3 Stability of Embankment with Basal Reinforcement - Transverse Pull

Figure 6 shows that the failure surface crosses the reinforcement at an oblique angle at the point of failure. When the sliding mass becomes too heavy, it causes the reinforcing layer to fail, resulting in the development of a tensile force, T. This force is inclined at an angle of 'θ' with respect to the horizontal direction. The transverse pullout force in reinforcement at failure is calculated using the methodology described in the next section.

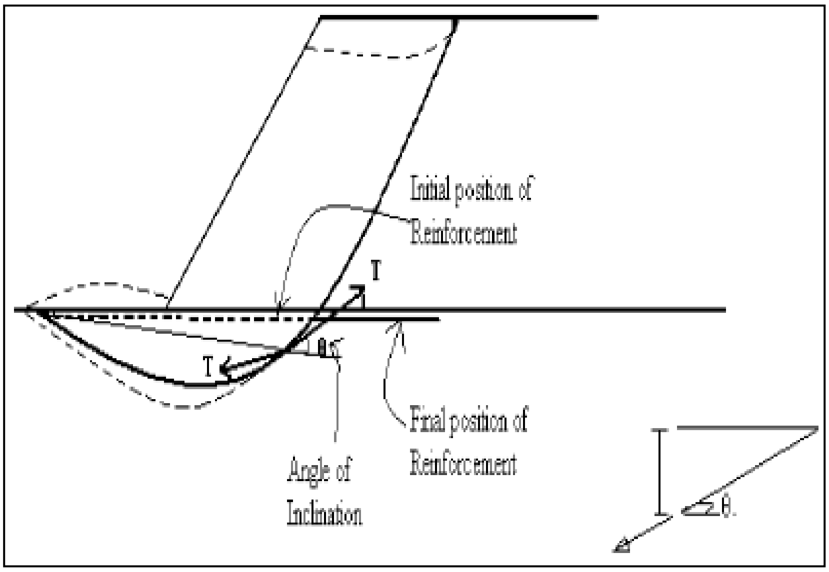


Figure 6 Basal reinforced embankment with oblique failure

3.4. Analysis for transverse pull in reinforcement:

Figure 7 depicts the placement of a flexible sheet reinforcement with a length, L, at a depth, d, in a soil with a unit weight, γ. The interface shear resistance between the reinforcement and the soil is determined by the angle, Φr (which is less than or equal to Φ, the angle of shearing resistance of soil). The transverse force, P, applied at point B may be used to calculate the displacement profile and the tension mobilised in the reinforcement. Alternatively, the displacement profile and the transverse force mobilised may be calculated by using the provided transverse displacement, wL, of point B.

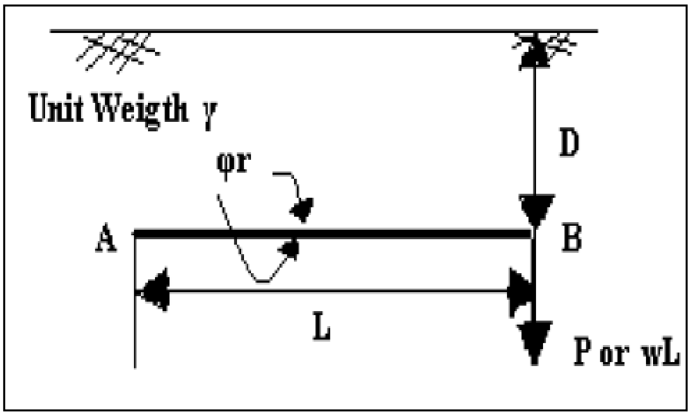


Figure 7 Definition sketch of transverse pull

3.5 Problem Considered

The embankment under consideration in this research is seen in Figure 8.

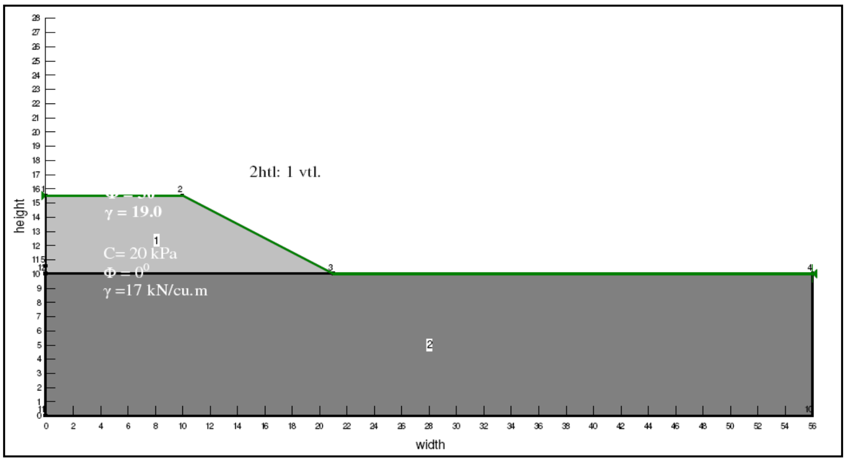


Figure 8 Cross-section of embankment considered

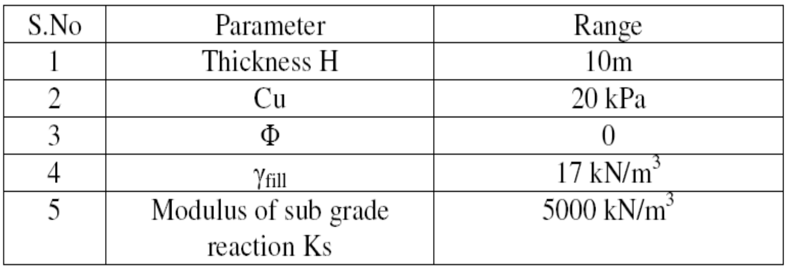
Table 1 Geometry Ranges for study

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

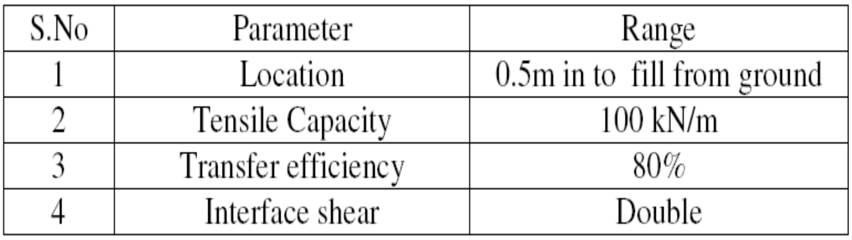
S.No	Parameter	Range
1	*Ce*	0 kpa
2	Φe	24, 28 and 32
3	γfill	20 kN/cu.m

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

3.6 Stability Analysis

3.6.1 Stability of Unreinforced Embankment and Reinforced Embankment with Axial Pull

Geoslope is used to do stability analysis for both unreinforced embankment and reinforced embankment, taking into account axial pull. The critical slip circle is formed and the factor of safety is calculated using the search function in Geoslope. This function identifies the slip surface that corresponds to the lowest factor of safety. The programme calculates the geometry of the slip surface and the centre of the slip circle.

3.6.2 Stability of Reinforced Embankment with Oblique Pull

The oblique pull is calculated using the slip circle that was previously determined for the embankment with axial pull. Oblique pull is determined by doing calculations based on the given information, including the geometry, centre of the slip surface, depth of reinforcement embedment, slip circle radius R, and the point of junction of axial reinforcement.

4. Results

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 where the reinforcement intersects the slip surface. This calculation is done for the same critical circle obtained in the axial case, taking into account the length of reinforcement (Le) and the moment centre. The factor of safety is calculated for the given rotations and the results are shown in Figure 9 and Figure 10.

4.1 Effect of Angle of Internal Friction of Embankment

Figure 9 illustrates the relationship between the factor of safety and the friction angle of the embankment soil for both unreinforced and reinforced embankments. The factor of safety for both unreinforced and reinforced embankments is shown to increase as the friction angle, Φ, increases. An increment from 1.02 to 1.05 is found for unreinforced embankment, from 1.12 to 1.15 for reinforced embankment, and from 1.21 to 1.25 with oblique pull as phi increases. This phenomenon occurs due to an increase in the frictional angle of the embankment soil. As the friction between the embankment soil and the reinforcement layer grows, it leads to an increase in the stress exerted on the reinforcement. Consequently, this results in an increase in the factor of safety.

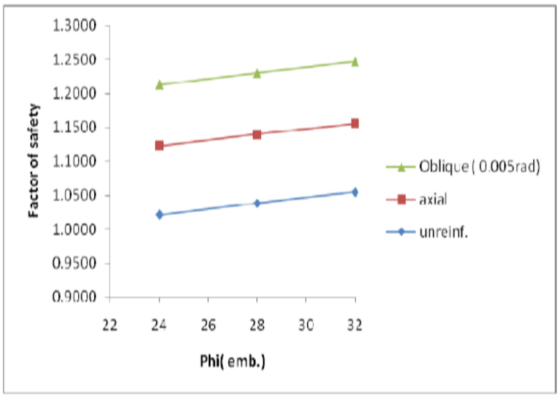


Figure 9 Variation of FS with various forces in reinforcement

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

Figure 10 illustrates the relationship between the factor of safety and oblique pull. It has been noticed that the factor of safety increases linearly with rotation and the angle of internal friction. Observations reveal an upward shift in values from 1.12 to 1.21 for phi 28, 1.14 to 1.23 for phi 32, and 1.16 to 1.25 for different oblique pressures resulting from rotation. Oblique pull results in a 30% increase in factor of safety compared to axial pull, regardless of the phi values.

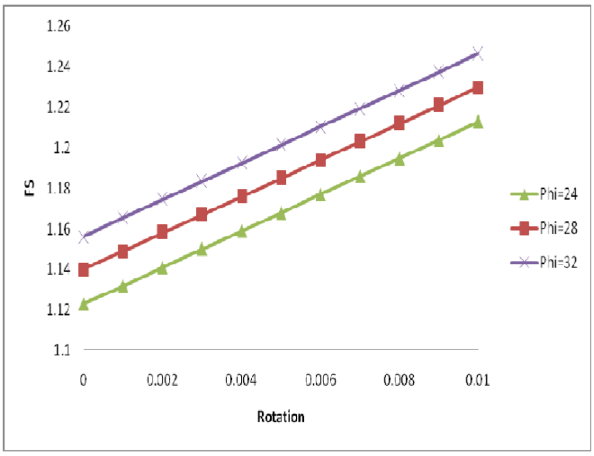


Figure 10 Variation of FS with various forces in reinforcement- effect of phi

5. Conclusion

Based on the study and findings, the following conclusions may be inferred.

- The angle of internal friction has a major impact on the Factor of Safety in both unreinforced and reinforced embankments.
- The factor of safety rises when subjected to axial tension. The magnitude of the increase is substantial when including oblique pull in reinforcement.
- The novel method highlights the need and significance of incorporating oblique pull force into stability analysis for the purpose of achieving efficient and optimum design.

8. References

[1]. Bergado, D.T. and Long, P.V., “LEM back-analysis of geotextile reinforced embankments on soft bangkok clay-A case study”, Geosynthetics International Journal, 9(3), 2002, 217-245

[2]. Bergado, D.T. and Chai, J.C., “Pullout force/displacement relationships of extensible grid reinforcements”, Geotextiles and Geomembranes, 13, 1994, 295- 316

[3]. Giroud, J.P., “Determination of geosynthetic strain due to deflection”, Geosynthetics Interntional, 2(3), 1995, 635-641

[4]. Van Eekelen SJ, Han J. Geosynthetic-reinforced pile-supported embankments: state of the art. Geosynthetics International. 2020 Apr;27(2):112-41.
[5]. Jewell, R.A., “The mechanics of reinforced embankments on soft soils”, Geotextiles and Geomembranes, 7, 1988, 237-273
[6]. Madhav, M.R. and Umashankar, B., “Analysis of inextensible sheet reinforcement subjected to transverse displacement/force: linear sub grade response”, Geotextiles and Geomembranes, 21, 2003,, 69-84
[7]. Madhav, M.R. and Umashankar, B., “Analysis of inextensible sheet reinforcement subjected to transverse displacement/pull”, Journal of South East Asian Geotechnical Society, 2005, 133-143
[8]. Rui R, Han J, Van Eekelen SJ, Wan Y. Experimental investigation of soil-arching development in unreinforced and geosynthetic-reinforced pile-supported embankments. Journal of Geotechnical and Geoenvironmental Engineering. 2019 Jan 1;145(1):04018103.
[9]. Rowe, R.K. and Li, L.L., “Geosynthetic-reinforced embankments over soft foundations. Geosynthetics International”, Special Issue on the Giroud Lectures, 12(1), 2005, 50-85
[10]. Vidal, H., “The principle of reinforced earth”, Highway Research Record 282, Highway Research Board, National Research Council, Washington D.C, 1969, 01-16
[11]. McGuire M, Sloan J, Filz G. Effectiveness of geosynthetic reinforcement for load transfer in column-supported embankments. Geosynthetics International. 2020 Apr;27(2):200-18.
[12]. Cengiz C, Kilic IE, Guler E. On the shear failure mode of granular column embedded unit cells subjected to static and cyclic shear loads. Geotextiles and Geomembranes. 2019 Apr 1;47(2):193-202.