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Evaluation of PET and PP geotextile reinforced embankment on soft soil

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Abstract

Parametric study is carried out to investigate the applicability of limit equilibrium method for analyzing reinforced embankment on soft soil with the use of *GEO5* software in this paper. The effect of vertical spacing of geotextile layers, slope inclination, and tensile strength of *PET* (Polyester) and *PP* (Polypropylene) geotextile on the behavior of reinforced flyash+clay embankment on soft clay is determined. Results divulge that use of full length of geotextile covering whole width of embankment can increase factor of safety at stiffer slope inclination. Decreasing the slope and vertical spacing can also give safer design. Reinforced embankment with *PET* geotextile can also gives safer design compared to *PP* geotextile when considering creep phenomenon. here and insert a concise and factual abstract of this paper.

Keywords: Reinforced earth embankment, geotextile, numerical analysis, *PET* (polyester), *PP* (Polypropylene)

Nomenclature

c_{ef}	cohesion (kPa)
q	surcharge (kPa)
R_t	tensile strength of geotextile (kN/m)
S_v	vertical spacing of geotextile (m)
B	crest width of embankment (m)
H	height of embankment (m)
L	length of geotextile

Greek symbols

γ	unit weight (kN/m ³)
γ_{sat}	saturated unit weight (kN/m ³)
β	slope angle (°)
ϕ_{ef}	angle of internal friction (°)

Subscripts

ef	effective shear parameters
t	tensile strength
v	vertical
sat	saturated

1. Introduction

Reinforced embankment structures are cost-effective alternatives over reinforced earth wall for new construction and reconstruction where the cost of fill, right-of-way, and other considerations may make a steeper slope desirable.

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Reinforcement is used to construct an embankment at an angle steeper that could otherwise be safely constructed with the same soil. The increase in stability allows for construction of steepened slopes on firm foundations for new highways and as an alternative to flatter unreinforced slopes and for retaining walls. Roadways can also be widened over existing flatter slopes without encroaching beyond existing right-of-ways. In the case of repairing a slope failure, the new slope will be safer, and reusing the slide debris rather than importing higher quality backfill may result in substantial cost savings.

Analyses must be based upon a model that accurately represents site subsurface conditions, ground behavior, and applied loads considering environment in life time for structures. Judgments regarding acceptable risk or safety factors must be made to assess results of analyses. Soil with greater shear strength if at all it exists nearby is a better solution. Sand and other good soil in future will be not possible for all site condition. Overall all industrial byproducts such as fly-ashes provide a good construction material for many geotechnical applications. The design mix of available cheap soil to flyash (byproduct of industry) will be only available option. They can be beneficially utilized resulting in lot of savings and eliminating environmental problems and effective utilization. For these applications, the physical, chemical and engineering properties of Ukai flyash and their behaviour were also analyzed [1]. Flyash has lower compressibility and design mix has better shear parameters & permeability when compared with other structural fill material used and it is proposed for foundation & reinforced fill material. [2], analyzed slope stability of weathered clay.

Embankment slope stability analysis using computers is an easy task for engineers when the slope configuration and the soil parameters are known [3-4-5-6]. However, selection of slope stability analysis method is not an easy task and effort should be made to accumulate the field conditions and the failure observations in order to understand the failure mechanism, which determines the slope stability method that should be used in the analysis. Therefore, the theoretical background of each slope stability method should be investigated in order to properly analyze the slope failure and assess the reliability of the analysis results. Among available analysis methods are the limit equilibrium methods of slices, boundary element methods [7], finite element methods [8], and neural network methods [9]. In method of analysis if an effective stress analysis of slope is to be made, the effective stresses must be determined around the failure surface. In practice this is achieved if the failure mass of the soil is divided into a number of slices. For that non linear method are [10-11-12], Corps of Engineers Method, Friction Circle Method, Swedish Circle Method, Taylor's stability number Method.

Creep is more pronounced in *PP* (polypropylene) than it is in *PET* (polyester). It is established that geosynthetics are made of *PET* rather than *PP*. For the economy point of view especially for earth retaining structures, woven geotextile will performed better than geogrids with cohesive backfill as well [13]. The replacement of *PP* woven geotextile by *PET* woven geotextile reinforcing element is suggested in this paper. Up-till now geogrid is widely used for reinforcement application in reinforced earth retaining structures but as use of geotextile in reinforcement is growing, this paper is an attempt to investigate the applicability of embankment slope stability analysis considering Indian major geological formation using *GEO5* version 12 software for analyzing reinforced embankment slopes over the reinforced earth retaining wall on under laying soft soil. [14-15], also analyzed field evaluation of geotextile reinforced soil walls and describe use of geotextile's benefits over the use of other types of reinforcement, such as metallic strips or geogrids, like, ease of construction, expediency, and significant cost reduction.

2. Analysis method

Although there are methods available to design reinforced slopes which account for cohesion and/or soil pore pressures, those commonly used for walls are for drained granular soils only. None of the methods explicitly address the stiffness of the foundation soils or the rigidity of the wall facing, both of which may have significant effects on the performance of a wall. The majority of design methods available for reinforced soil walls/slopes are for granular backfill soils prescribed by [16]. [3-4], said that embankment slope stability analysis using computers is an easy task for engineers when the slope configuration and the soil parameters are known. It was shown by [17], that none of the methods accurately predicted the quantity and strength of reinforcement required for a limiting equilibrium condition and, furthermore, there is significant variation among the predictions obtained using the various methods. Due to an increasing demand for structures constructed using indigenous soils, [18], focused on the fundamental understanding of the problem, and a consistent design methodology for walls and embankments with poorly draining backfills should be formulated. Experience by [19] shows that safe reinforced structures are produced using simple limit state approach, and if safety factors satisfy typical design criteria, the displacement will likely be within tolerable limits. However, selection of slope stability analysis method is not an easy task and effort should be made to accumulate the field conditions and the failure observations in order to understand the failure mechanism, which determines the slope stability method that should be used in the analysis. Among available analysis methods are the limit equilibrium methods of slices, boundary element methods [7] finite element methods [8], and neural network methods [9]. The most commonly used methods of slope stability analysis are the limit equilibrium methods. Stress-deformation analysis, using the finite element method, is performed more rarely, especially in the case of major

projects. [10], method was used for analysis of embankment slope in this study. Although the simplified Bishop method does not satisfy complete static equilibrium, the procedure gives relatively accurate values for factor of safety. The Simplified Bishop method is more accurate than Ordinary Method of Slices, especially for effective stress analysis with high pore water pressure. [20], also have shown that factor of safety calculated by the Simplified Bishop method agrees favorably (within about 5%) with factor of safety calculated using finite element procedures. The primary limitation of Simplified Bishop method is that it is limited to circular slip surface.

3. Analysis method

For analyzing the model initial step, is creating the geometry of the model. The geometry characteristics such as embankment height, slope, and crest width. The other geometry which should be defined is under laying soil profile such as thickness of the soft layer (foundation of embankment). The second step is to provide the material properties of the embankment and the under laying soil.

For present investigation the main model with 8 m height, 20 m crest width of embankments with slopes as 58° , 64° , 72° , and 78° are placed on a 2 m of embankment foundation & below that relatively soft layer of 5 m thickness was being investigated in this study. This embankment was reinforced by layers of geotextile having variable length from top to bottom covering whole width of embankment. The vertical spacing of geotextile is varied from 2, 1, 0.5 and 0.4 m. A nominal surcharge of 50 kPa has been used for modeling the traffic load as commonly adopted in practice [21]. In order to determine the effect of *PET* and *PP* geotextile in reinforced embankments, the same model is analyzed by taking two different woven geotextile samples of *PET* 100 and *PP* 100, having tensile strength 40kN/m and 10 kN/m respectively, as considering creep phenomenon. Also it was assumed that each layer of geotextile has same tensile strength & placed horizontally.

Based on the assumption that foundation soil is strong enough to receive the load from upper structure, slope or shallow slope failure will occur in the embankment structure [22-23]. In this study, the analytical modeling of geotextile-reinforced slopes is performed using the *GEO5* – slope stability software version 12 [24]. The geometry is presented in Fig. 1.

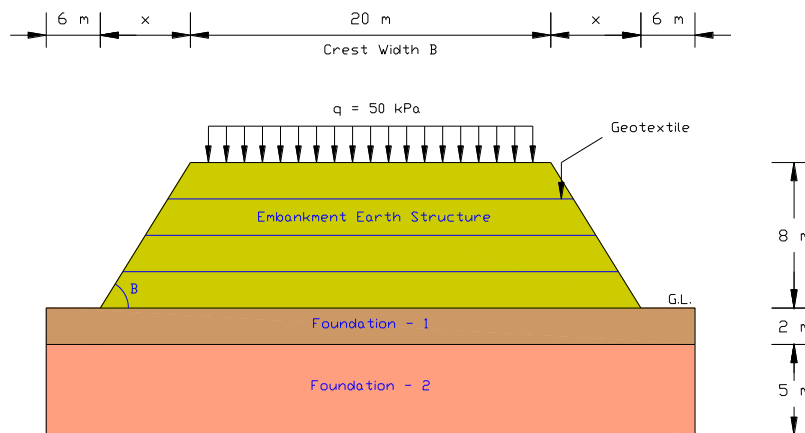


Fig. 1. Geometry of models

3.1. Material properties

The consolidation and time relative behavior of this soft layer must be considered in analyses of the model, because under laying layer is relatively soft in monsoon. The material properties used for the model was flyash + *CH* clay (80:20) described by laboratory test by [1]; are presented in Tables 1.

A layer of geotextile is modeled in the embankment. In *GEO5* the geotextile is introduced to software as a tensile element and named as "Reinforcement Tensile Strength R_t ". In this model 40 % of ultimate tensile strength R_t is considered 40, and 10 kN/m for polyester woven geotextile *PET* 100, and *PP* 100 respectively.

Table 1. Properties of soil material

Properties	Earth structure and foundation - 1	Foundation - 2
Unit weight, γ (kN/m ³)	14.12	20.5
Saturated unit weight, γ_{sat} (kN/m ³)	19.06	25
Cohesion, c_{ef} (kPa)	15	5
Angle of internal friction, ϕ_{ef} (deg)	30	15

4. Result and discussion

The factor of safety (*F.S*) for slope stability is taken from the critical surface requiring the maximum reinforcement. Detailed design of reinforced slopes is performed by determining the factor of safety with sequentially modified reinforcement until the target factor of safety is achieved. When factor of safety is equal to 1, the slope is in a state of impending failure. Generally, a value of 1.5 for the factor of safety with respect to strength is acceptable for the design of a stable slope as per software.

For optimized reinforcement design, assessment of effect of geotextile reinforced with two different polymeric material say *PET* 100 and *PP* 100 were studied.

4.1. Effect of Polymeric Material on Reinforced Embankment

To assess the effect of polymeric material on reinforced embankment, initially four types of embankments are modeled with different slopes 58°, 64°, 72°, & 78°. Then different vertical spacing of geotextile are varied from 2, 1, 0.5 and 0.4 m is introduced in the body of embankment above the base at equidistant respectively (Fig. 1). For this purpose, embankment models with full/continuous length of geotextile (Covering whole width of embankment). The results obtained from analyses are presented in Figs 2 and 3 for normal and flooded conditions.

As creep in geotextile is an advanced type of modeling used for reinforcing material. As per [16], to assess the effect of creep, embankment models with full/continuous length (Covering whole width of embankment) for variable slopes 58° to 78° and variable spacing of 2 to 0.4 m were analyzed. The results obtained from analyses are presented in Fig 2, for both normal and flooded conditions.

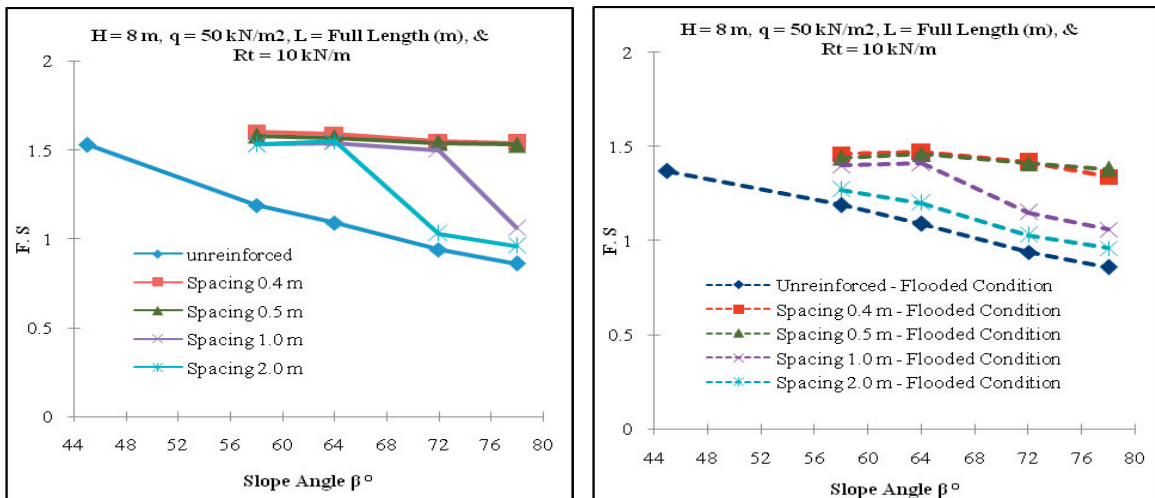


Fig. 2. (a) F.S for normal and flooded condition for $R_t = 10$ kN/m for *PP* 100

Considering creep for full/continuous length of reinforcement having $R_t = 10$ kN/m geotextile tensile strength for *PP*100, *F.S* is not satisfied for all embankment slopes at all spacing for flooded conditions and at 2 & 1 m spacing *F.S* is not satisfied for all embankment slopes for normal condition, whereas at 0.5 and 0.4 m spacing's *F.S* is just satisfied for all embankment slopes for normal conditions (Fig 2).

For continuous length of reinforcement having 40 kN/m geotextile tensile strength of *PET* 100, *F.S* is not satisfied for all embankment slopes at 2 m spacing for both normal and flooded conditions and at 1m spacing *F.S* is just satisfied for all embankment slopes except 78° for normal condition but are not satisfied for flooded condition, whereas at 0.5 and 0.4 m spacing's *F.S* is favorably satisfied for all embankment slopes for both normal & flooded conditions (Fig 3).

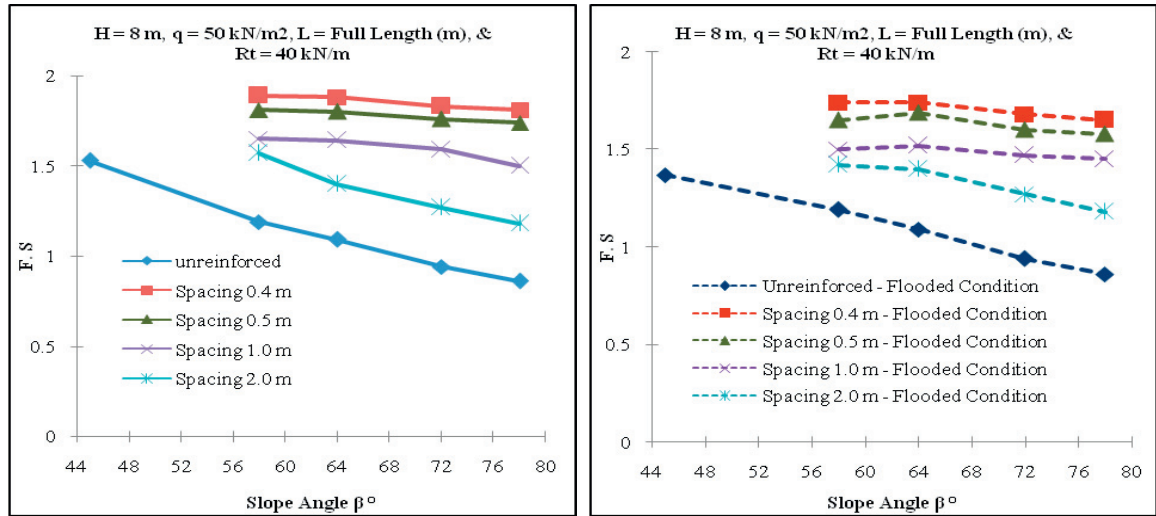


Fig. 3. (a) *F.S* for normal and flooded condition for $R_t = 40$ kN/m for *PET* 100

If the fabric is *PET* 100 (Fig.3) rather than *PP* 100 (Fig.2), shows $F.S > 1.5$ for all slopes at spacing $S_v = 1.0$ m or less. Thus use of *PET* is safer and better than *PP* [13].

5. Concluding Remarks

The analysis of model incorporating national major geology for subsoil and environmental factors for long life structures, adopting locally available by product and soils (Including cohesive soil treated if needed) and geotextile woven fabric & polyester (normally *PP* fabric of geogrid are used) having low creep established feasibility of adopting steep reinforced slopes as alternative to CC block facing reinforced vertical wall commonly practiced today.

In this study, factor of safety tended to increase linearly with increases in reinforcement strength R_t , and decreasing vertical spacing S_v of reinforcement & embankment slope β . For all the cases it is found that because of the flooded condition there is a decrease in the slope stability which might lead to instability as it does not have minimum level of safety against failure. The economical design of *PET* over *PP* woven geotextile reinforced embankment is recommended in this study.

The design of full length of geotextile-reinforced embankments with the optimum embankment slope of 58° to 64° at 0.4 m to 0.5 m vertical spacing and 40 kN/m ultimate tensile strength of reinforcement (*PET* 100) meets the minimum safety factor requirement of 1.5 from *USACE* recommendation [25] and is suggested for the following advantages: increase of reliable factor of safety, favorable stress distribution to the soil, low creep material, allowance for use of soil with average mechanical properties, the entire system lead to a more cost-effective design of embankment.

The various design methods yield widely varying results. To some extent, the differences in results are a result of obvious differences in the analytical methods that the design methods are based on. However, the more prominent differences in the design results are due to significant disparity in defining allowable reinforcement strength and safety factors.

Further study by means of test structures and monitoring of production structures should lead to more consistent design methodologies, and ultimately in more economy and confidence in geotextile reinforced soil structures. In many situations, the economy of a geotextile reinforced structure may be entirely dependent on whether or not it can be constructed with the on-site soils.

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