Assessment of reinforced embankment on soft soil with PET and PP Geotextile

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ABSTRACT

A parametric study is carried out to investigate the applicability of limit equilibrium method for analyzing reinforced embankment on soft soil in this paper. The effect of vertical spacing of geotextile layers, slope inclination, and tensile strength of PET (Polyester) and PP (Polypropylene) geotextile behavior on reinforced flyash and clay mixed embankment, over a soft clay layer is studied. For present investigation study, a 8 m high embankment with 20 m crest width and slopes of 58°, 64°, 72°, and 78° are considered. Analysis was performed using the GEO5 – slope stability software version 12 after modeling the above standard geometry. Results divulge that use of full length of geotextile covering whole width of embankment can increase factor of safety (F.S) at steeper slope inclination. Also decreasing the slope inclination and vertical spacing of geotextile gives safer designs. From this study it is seen that reinforced embankment with PET geotextile gives economical and safe design, compared to PP geotextile when the creep phenomenon is considered as a governing factor.

Keywords: Reinforced earth embankment, geotextile, Numerical analysis, PET (polyester), PP (Polypropylene).

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. 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 the 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 their 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 of selected backfill may result in substantial cost savings (FHWA, 2009).

Analyses must be based upon a model that accurately represents site subsurface conditions, ground behavior, and applied loads considering environment/durability aspects in its 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. Availability of sand and other good soil, in future will not be a possibility for all site conditions. Overall, industrial byproducts such as fly-ashes provide a good alternative construction material for many geotechnical applications. A perfect design mix of available Natural soil with flyash (byproduct of industry) will be the only viable option in places where soil of required quality is not abundant or easily available. They can be effectively utilized.
resulting in lot of savings monetarily and eliminating environmental problems. For the beneficial applications of flyash, the physical, chemical and engineering properties of Ukai flyash and their behaviour were also analyzed (Vashi et al., 2011). Flyash has many favorable properties like light weight, lesser pressure on sub-soil, high shear strength, low compressibility & low strain to shear failure, pozzolanic nature, additional strength due to self-hardening, amenable to stabilization, ease of compaction, high permeability, non plastic, faster rate of consolidation and low compressibility, can be compacted using vibratory or static roller etc. Also flyash can give better friction co-efficient with geotextile and improves the stiffness of reinforcement embankment when mixed with soil, when compared with other structural fill material used and it is proposed for foundation & reinforced fill material.

Creep is more pronounced in PP (polypropylene) than it is in PET (polyester) (Greenwood & Myles, 1986). PET geotextile have higher tensile strength and lower creep when compared to PP geotextile having lower tensile strength and more creep. This leads to a long term safer and economical design. 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 (Vashi et al., 2011). The replacement of PP woven geotextile by PET woven geotextile reinforcing element is suggested in this paper. Untill now geogrids were widely used for reinforcement application in reinforced earth retaining structures. But as use of geotextiles as reinforcement is growing, this paper is an attempt to investigate the applicability of the same in embankment slope stability analysis considering major Indian geological formation.

For this purpose a running pilot model of reinforced embankment slopes over the reinforced earth retaining wall on under laying soft soil was selected for analysis, using GEO5 version 12 software. Benjamin et al., 2007; also analyzed field evaluation of geotextile reinforced soil walls and describes the 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 BS 8006:1995. Bathurst & Simac, 1993; and Chandra, 2002; 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 Claybourn & Wu, (1991a, 1993b); 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, Mitchell & Zornberg, 1995; 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 Dov Leshchinsky, 2009; 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. 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 (Jiang, 1990) finite element methods (Matsui and San, 1992); and neural network methods (Jaritngam et al., 2001). 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 Bishop's Method 1955, Janbu's Simplified method 1973, Spencer’s Method 1967, Morgenstem and Price’s Method 1965, Corps of Engineers Method, Friction Circle Method, Swedish Circle Method, Taylor’s stability number Method.

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. Bishop 1955, 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. Wright et al., 1973; 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. Model Generations for Analysis

The initial step for analysis using a computer software program is to model the structure geometry in the software interface. The geometry characteristics such as embankment height, slope angle, crest width, underlying soil profile such as thickness of soft soil layer (foundation of embankment) are defined. Reinforcement layer types (strength), its horizontal and vertical spacing’s and its location are also modeled. The second step is to provide the material soil characteristics of the embankment and the under laying soil.

In the present investigation, main model with 8 m high embankment, a crest width of 20 m and having slope angles of 58°, 64°, 72°, and 78° are followed. The embankment is placed over a 2 m thick embankment foundation overlying a relatively soft layer of 5 m thickness. A nominal height of 8 m is considered, based on commonly adopted industry practice of vertical clearance required for flyover openings, which is 6m as per IRC: 6-2000. The horizontal crest width of 20 m was used considering a four lane highway each of 7.5 m wide carriageway with 2 m wide median at center and walkways of 1.5 m on either side of the highway.

The range of slopes 58° to 78° was selected by running pilot model on soft soil for factor of safety, with different spacing and type of geotextile. Also in regular practice, we encounter slopes that are steeper than 26.57° (2H:1V) or 45° (IH:1V). This study covers practical ranges successfully.

The 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 m, 1 m, 0.5 m and 0.4 m. A nominal surcharge of 50 kPa has been used for modeling the traffic load as commonly adopted in practice (IRC: 6-2000).
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, PET 100 and PP 100, having tensile strengths of 40kN/m and 10kN/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 withstand the loads from embankment structure, occurrence of only slope or shallow slope failure is possibility in the embankment structure (Das, 1994). In this study, the analytical modeling of geotextile-reinforced slopes is performed using the GEO5 – slope stability software version 12. The geometry followed is presented in Figure 1.

![Figure 1: Geometry of models](image)

### 3.1 Materials properties

The consolidation and time relative behaviour of this soft underlying layer shall be considered in analyses of the model, because under laying soil layer (clay) is relatively soft in monsoon and rigid in summers. The embankment material properties used for the model are flyash + CH clay (80:20), proportion prescribed as per laboratory test results by Vashi et al., 2011; presented in Table 1. The layers of geotextile are modeled in the embankment geometry. In GEO5 program the geotextile was introduced to software as a tension element and named as "Reinforcement Tensile Strength R_t". In this model 40 % of ultimate tensile strength R_t is considered as 40 kN/m, and 10 kN/m for polyester woven geotextile PET 100, and PP 100 respectively.

| Properties                  | Type                                          |
|-----------------------------|----------------------------------------------|
| Unit weight, γ (kN/m³)      | Earth structure and foundation - 1           |
| Saturated unit weight, γsat (kN/m³) | 19.06                                        |
| Cohesion, c_{ef} (kPa)      | Foundation - 2                               |
| Angle of internal friction, φ_{ef} (deg) | 30                                            |

Table 1: Properties of soil material (Vashi et al., 2011)
4. Results and Discussion

The factor of safety (F.S) for slope stability was taken from the critical surface requiring the maximum reinforcement. Detailed design of reinforced slopes was performed by determining the factor of safety with sequentially modifying the reinforcements until the target factor of safety was achieved. When factor of safety was equal to 1, the slope is in a state of impending failure. 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 used GEO5 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 were modeled with different slopes 58°, 64°, 72°, & 78°. Then vertical spacing of geotextile were varied from 2 m, 1m, 0.5 m and 0.4 m in the body of embankment above the base at equidistant spacing respectively (Figure 1). For this purpose, embankment model with full/continuous length of geotextile (Covering whole width of embankment) were considered. The results obtained from analyses are presented in Figures 2 (a & b) and 3(a & b) for normal and flooded conditions.

![Figure 2 (a): F.S for normal condition, R_t = 10 kN/m for PP 100](image-url)
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As creep in geotextile is an inherent material property, an advanced type of modeling was used for reinforcing material. As per BS 8006:1995, to assess the effect of creep, embankment models with geotextile covering full/continuous length (Covering whole width of embankment) for variable slopes 58° to 78° and variable reinforcement spacing of 2 m to 0.4 m was followed and analyzed. The results obtained from these analyses are presented in Figure 2 (a & b), for both normal and flooded conditions.

Considering creep effect of geotextile, for continuous length of reinforcement having $R_t = 10$ kN/m i.e.; geotextile tensile strength for PP100, required F.S was not satisfied for all embankment slopes at all reinforcement spacing, especially in flooded conditions. At 2 m & 1 m reinforcement spacing F.S was not satisfied for all embankment slopes for normal condition. At 0.5 m and 0.4 m reinforcement spacing’s F.S was just satisfied for all embankment slopes in normal conditions (Figure 2 a & b).

The result obtained for 1m and 2 m spacing are inconsistent as the reinforcement effect for the tensile fabric is used. It may not have adequate effect of creating stiffness and interface friction element, as a result and requirement of construction 0.3 and 0.4 m spacing of geotextile were adopted. It is also seen that the F.S for reinforcement Spacing 2 m at 64° and reinforcement Spacing 1 m at 72° doesn’t have visible difference (Figure 2a). Also the results for reinforcement Spacing of 1 m at slope 64° is very close to unreinforced flooded condition (Figure 2b).

Similarly for continuous length of geotextile reinforcement having 40 kN/m tensile strength for PET 100, F.S is not satisfied for all embankment slopes at 2 m reinforcement spacing in both normal and flooded conditions. At 1 m reinforcement spacing F.S is just satisfied for all embankment slopes except 78° in normal condition but F.S was not satisfied for flooded condition. At 0.5 m and 0.4 m reinforcement spacing’s F.S is favorably satisfied for all embankment slopes in both normal & flooded conditions (Figure 3a & b).

Figure 2 (b): F.S for flooded condition, $R_t = 10$ kN/m for PP 100

![Figure 2 (b): F.S for flooded condition, $R_t = 10$ kN/m for PP 100](image)
If the fabric is PET 100 (Figure 3 a & b) rather than PP 100 (Figure 2 a & b), shows F.S > 1.5 for all slopes at reinforcement spacing $S_v = 1.0$ m or less. Thus use of PET is safer and better than PP (Vashi et al., 2011).

5. Concluding Remarks

The analysis of model, incorporating 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 Cement Concrete block/panel facing reinforced vertical wall commonly
practiced today was carried out. The model has been validated with the work of Rowe et al. (1995) and observed 4.25% error in both results.

The present studied approach is to design 4 lane road with traffic and underpass of 8 m height (IRC: 6-2000) for the replacement of conventional reinforced wall/structures. The same approach for site specific data of fill material and geotextile can be adopted using GEO5 software for design of safe embankment with min earthwork. The technique of modeling, derivation of parameters for local soil and locally available geotextile for reinforced embankment has been illustrated will give site specific design for similar problem.

In this study, factor of safety tended to increase linearly with increase in reinforcement strength $R_t$, and decreasing vertical spacing $S_v$ of reinforcement & embankment slope $\beta$. 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. However, requirement of further studies in this regard.

The design of continuous length of geotextile-reinforced embankments with the optimum embankment slope of $58^\circ$ to $64^\circ$ at 0.4 m to 0.5 m reinforcement vertical spacing and 40 kN/m ultimate tensile strength of reinforcement (PET 100) meets the minimum safety factor requirement of 1.5. From USACE (2003), recommendation, it is suggested for the following advantages: (1) increased of reliable factor of safety, (2) favorable stress distribution to the soil, (3) low creep material, (4) allowance for use of soil with average mechanical properties, and (5) entire system leads to a more cost-effective design of embankment.

The various design methods yield varying results. To some extent, the differences in results are a result of obvious differences in the analytical procedures that these 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 approach to geotextile reinforced soil structures. In many situations, the economy of a geotextile reinforced structure may be entirely governed/dependent on whether or not it can be constructed with the on-site soils especially in Indian conditions.

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