Numerical Analysis of a Landslide Affected Site at Koottickal, Kottayam

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Abstract. In recent years, Kerala is facing heavy rainfall and due to that landslides and floods are occurring frequently. In 2021, heavy landslides occurred at Koottickal, Kottayam and life of the local people and embankments were in critical conditions. To suggest solutions for the problem, stability analyses were conducted. Field studies are time consuming and not feasible with the altered topography, hence numerical analysis plays a major role in the embankment studies. Finite element method by PLAXIS 3D is used in the numerical analysis of slope stability of embankment. The ground improvement techniques play a crucial role in the stability of embankments. The present study relates with the determination of stability of embankment according to the factor of safety and deformations with and without geogrid for toe angles 30^0,45^0 and 60^0.The factor of safety is increased by twice the initial value when the geogrid is placed into the embankments. Hence it is concluded that geogrid can be effectively used to prevent the slope failure due to frequently occurring landslides.

Keywords: Deformations, Embankment, Factor of Safety, Landslide, Slope Stability.

1 Introduction

Since the country's infrastructure is heavily dependent on its road system, the design and construction of the road sub-grade are extremely important to the stability of the roadway. These roadways are frequently built on embankments with varying heights, slopes, and soil types. Therefore, a key factor in the resilience of the roadways is the stability of such embankments. Safety factor (SF), the key design criterion used in stability analysis calculations, can be determined using a variety of techniques, including the limit equilibrium method (LEM) and the finite element method (FEM). It becomes a significant problem with the selection of methods needed in analysis because the stability analysis is heavily dependent on certain methodologies. In recent years, stability-related issues have been studied using FEM. Stability analysis is crucial to the development of natural resources, including surface mining, waste management, earth dams, as well as many other human activities including building construction and excavation. Examples of these activities include the construction of roads, railroads, and canals. Failures of slope in various applications may be caused by changes in the naturally occurring slope, changes in the cut or fill that was made by humans, or a combination of the two. The stability of man-made slopes is significantly influenced by the quality of the subsoil and fill soil. In the current study, lateritic clay was detected in the Koottickal, Kottayam region, and slope stability studies on embankments were conducted using Plaxis-3D. study.

2 Validation

The paper published by "Kumar, A., George, V., Marathe, S.,(2017),titled “Stability Analysis of lateritic soil Embankment sub-grade using plaxis-2D”, International Journal for Research in Civil Engineering, vol 2,1- 8" was used to validate the PLAXIS 3D programme. For the purpose of this study, a model embankment with a width of 4.5 m, varied heights of 3m, 4 m, and 5 m, and various toe angles of 30, 45, and 60 degrees is taken into consideration. Wheel loads of 5100 kg are placed on the pavement built on the embankment during modelling.

Table 1. Validation Results

	From Kumar, A., et al. (2017)	From PLAXIS 3D software
Mesh	Medium Mesh	Medium Mesh
Max. Deformation	2.52×10^{-3} m	2.617×10^{-3} m
Effective Principal Stress (max.)	53.4×10^{-3} kN/m^2	51.5×10^{-3} kN/m^2
Effective Principal Strain (max.)	1.35×10^{-3}	1.315×10^{-3}

Kumar, A., et al. (2017) results and PLAXIS 3D software results are compared and medium mesh is used in both. It is evident that the variation in the results obtained for deformed mesh during validation was 3.7%, effective principal stress (max.) was 3.68% and effective principal strain (max.) was 2.66% which are acceptable.

3 Numerical Modelling

The soil was first classified based on sieve analysis, hydrometer analysis and also using the liquid limit and A-line charts. The strength and other properties of soil for analysis was obtained through different laboratory tests including modified proctor test, triaxial compression test, test for specific gravity and moisture content and the properties obtained along with the other parameters are used for modelling in PLAXIS 3D and summarized in the below Table 2.

Table 2. Properties of soil.

Properties	Values
Type of soil	Clay
Material model	Mohr-Coulomb

Drainage type	Undrained
γ_{unsat} (kN/m^3)	17
γ_{sat} (kN/m^3)	18.5
E (kN/m^2)	3200
N	0.3
c (kN/m^2)	52
Φ	3.2°
Ψ	0°

4 Embankment Study

For the present study embankment models are considered of width 4.5m, height 5m and various toe angles 30, 45 and 60 degrees respectively. Wheel load of 52.5kN is applied over the pavement constructed on the embankment in the modelling. Consider shoulder as 3.5m, top width as 0.5m and carriage way as 0.5m. A total of six models are to be developed in order to accomplish the objectives of the study. The models are developed with varying toe angles to 30^0 , 45^0 and 60^0. Toe angles are selected in the basics of the variations between 0 to 90 degrees and each case consider the variations in deformations in the embankment study. Here, the reinforcement is modelled using PLAXIS 3D's "build geogrid" tool, where geogrid can be stiffened to 50 kN/m. The desired length and position of the reinforcement are chosen. The qualities of the reinforcement are then assigned. The stiffness value is taken as 50 kN/m into account when conducting the analysis.

4.1 Embankment study without Geogrid

4.1.1 Model 1 : Toe angle with 30^0

For the embankment modelling coordinates, a surface is created with coordinates (0,0,0), (8.66,0,5), (13.16, 0, 5), (21.82,0,0) and the surface is extruded to 6m in y direction and for surface loading coordinates , a surface is created with coordinates, (8.66,0,5), (8.66,6,5), (13.16, 6, 5), (13.16, 0, 5) for 30^0 toe angle.

4.1.2 Model 2 : Toe angle as 45^0

For the embankment modelling coordinates, a surface is created with coordinates (0,0,0), (5,0,5), (9.5, 0, 5), (14.5,0,0) and the surface is extruded to 6m in y direction and for surface loading coordinates , a surface is created with coordinates, (5,0,5), (5,6,5), (9.5, 6, 5), (9.5, 0, 5) for 45^0 toe angle.

4.1.3 Model 3 : Toe angle as 60^0

For the embankment modelling coordinates, a surface is created with coordinates (0,0,0), (5.77,0,5), (10.27, 0, 5), (16.04,0,0) and the surface is extruded to 6m in y direction and for surface loading coordinates , a surface is created with coordinates, (5.77,0,5), (5.77,6,5), (10.27, 6, 5), (10.27, 0, 5) for 60^0

4.2 Embankment study with Geogrid

4.2.1 Model 1 : Toe angle with 30^0

For the embankment modelling coordinates with geogrid, a surface is created with co-ordinates, (2.5,0, 2.5), (2.5,6,2.5), (12, 6, 2.5), (12, 0, 2.5) for 30^0 toe angle.

4.2.2 Model 2 : Toe angle as 45^0

For the embankment modelling coordinates with geogrid, a surface is created with co-ordinates, (4.33,0, 2.5), (4.33,6,2.5), (17.49, 6, 2.5), (17.49, 0, 2.5) for 45^0 toe angle.

4.2.3 Model 3 : Toe angle as 60^0

For the embankment modelling coordinates with geogrids, a surface is created with co-ordinates, (1.44,0, 2.5), (1.44,6,2.5), (8.82, 6, 2.5), (8.82, 0, 2.5) for 60^0 toe angle.

5 Results and Discussion

In this section, the results of analyses are presented and discussed. The figures showing deformed mesh, effective principal stresses, effective principal strain and factor of safety for toe angle 30^0 without geogrid are given below.

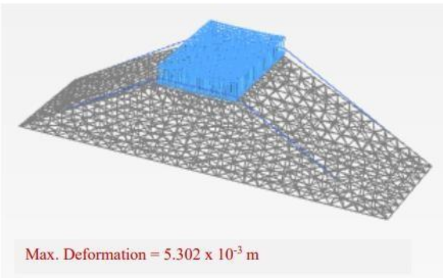

Fig 1. Deformed mesh

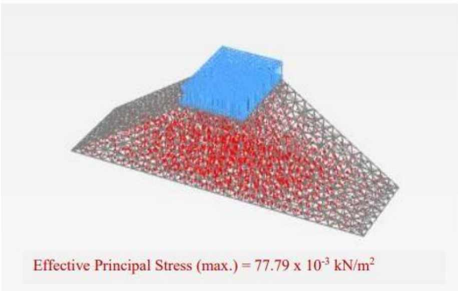

Fig 2. Effective Principal Stress

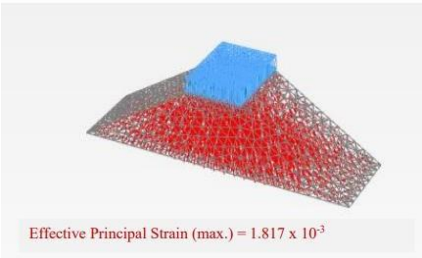

Fig 3. Effective Principal Strain

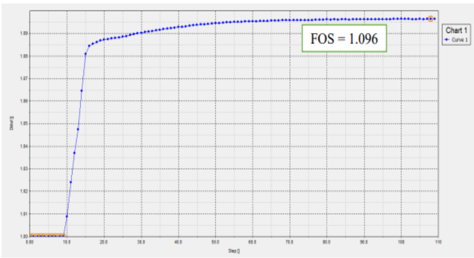

Fig 4. Factor of Safety

Table 3. Result summary without Geogrid

Toe angle	30^0	45^0	60^0
Max. Deformation	5.302×10^{-3} m	5.304×10^{-3} m	5.306×10^{-3} m
Effective Principal Stress (max.)	77.79×10^{-3} kN/m^2	77.00×10^{-3} kN/m^2	77.58×10^{-3} kN/m^2
Effective Principal Strain (max.)	1.817×10^{-3}	1.790×10^{-3}	1.798×10^{-3}
Factor of Safety	1.096	1.181	1.121

From the Table 3, it is observed that, when the toe angle is 45^0, the value of effective principal stress (max.) and effective principal strain (max.) were found to be the least and when the toe angle is 30^0 , the value of effective principal stress (max.) and effective principal strain (max.) were found to be the maximum. The factor of safety is maximum when the toe angle is 45^0 and hence the stability is more for the embankment with 45^0 toe angle.

The figures showing deformed mesh, effective principal stresses, effective principal strain and factor of safety for toe angle 30^0 with geogrid are given below.

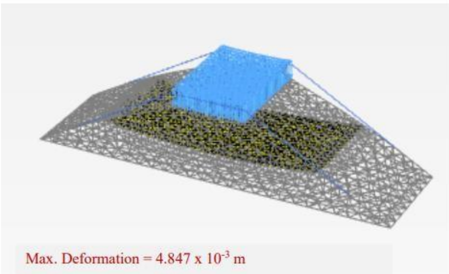

Fig 5. Deformed mesh

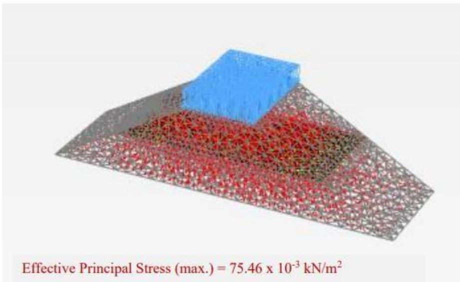

Fig 6. Effective Principal Stress

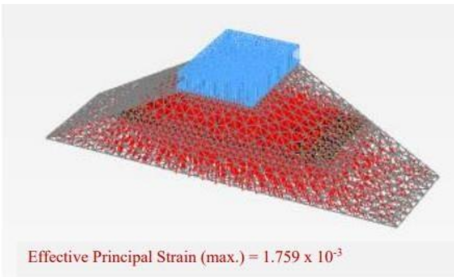

Fig 7. Effective Principal Strain

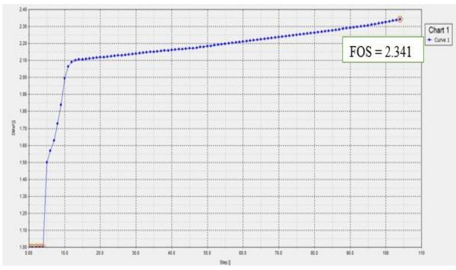

Fig 8. Factor of Safety

Table 4. Result summary with Geogrid

Toe angle	30^0	45^0	60^0
Max. Deformation	4.847 x 10^{-3} m	4.954 x 10^{-3} m	4.855 x 10^{-3} m
Effective Principal Stress (max.)	75.46 x 10^{-3} kN/m^2	74.28 x 10^{-3} kN/m^2	74.85 x 10^{-3} kN/m^2
Effective Principal Strain (max.)	1.759 x 10^{-3}	1.735 x 10^{-3}	1.748 x 10^{-3}
Factor of Safety	2.341	2.959	2.593

From the Table 4, it is observed that, when the toe angle is 45^0, the value of effective principal stress (max.) and effective principal strain (max.) were found to be the least and when the toe angle is 30^0, the value of effective principal stress (max.) and effective principal strain (max.) were found to be the maximum. The factor of safety is maximum when the toe angle is 45^0 and hence the stability is more for the embankment with 45^0 toe angle.

From chart 1, it is observed that, the factor of safety is increasing when geogrid is placed at the middle height of the embankment. The factor of safety is more in the case of 45^0 toe angle with and without geogrid. Hence it is clear that the embankment with 45^0 toe angle is more stable. It may be due to more drainage of water compared with 30^0 toe angle.

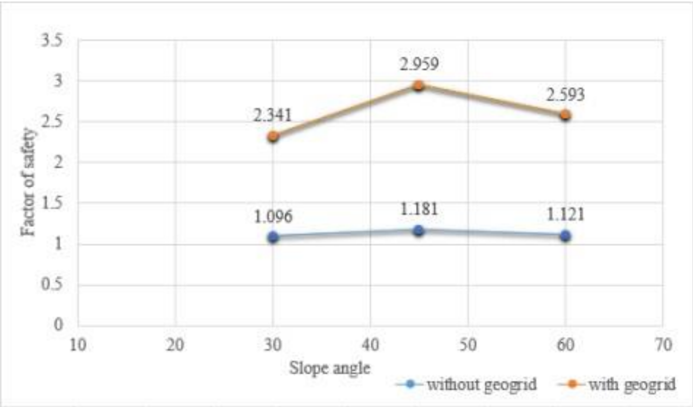

Chart 1. Graph showing slope angle v/s factor of safety

From the Table 5 it is observed that, the deformed mesh for toe angles 30^0,45^0 and 60^0 are 8.58%, 6.58 % and 8.49 % less respectively when geogrid is placed. The effective principal stress (max.) for toe angles 30^0,45^0 and 60^0 are 3.56%, 2.79 % and 4.23 % less respectively when geogrid is placed. The effective principal strain (max.) for toe angles 30^0,45^0 and 60^0 are 3.56%, 3.29 % and 3.21% less respectively when geogrid is placed. The factor of safety for toe angles 30^0,45^0 and 60^0 are 53.18%, 60.09 % and 5.66 % more respectively when geogrid is placed at the middle of the embankment. The deformed mesh, effective principal strain (max.) and effective principal stress (max.) are reducing when the geogrid is placed at the middle of the embankment and the factor of safety is increasing when the geogrid is placed. The presence of geogrid gives more stability and hence Geogrid can be effectively used to prevent the slope failure due to frequently occurring landslides.

Table 5. Result summary with Geogrid

Toe angle	30^0	45^0	60^0
Max. Deformation	8.58%	6.58%	8.49%
Effective Principal Stress (max.)	3.56%	2.79%	4.23%
Effective Principal Strain (max.)	3.56%	3.29%	3.21%
Factor of Safety	53.18%	60.09%	56.77%

6 Conclusions

- The stability of embankment is increased by 12.2 % as the toe angle varies from 30^0 to 45^0
- When the toe angle is further increased to 60^0, the stability of embankment is decreased by 5.68%.
- The values of deformed mesh, effective principal stress (max.) and effective principal strain (max.) are reduced when the geogrid is placed within the embankment.
- The factor of safety is increased by 60% when the geogrid is placed at the middle height of the embankment with toe angle 45^0.
- When the toe angle is 45^0, the values of effective principal stress (max.) and effective principal strain (max.) are least and factor of safety is maximum. Hence it is concluded that embankment with 45^0 is more stable when compared with 30^0 and 60^0 toe angles.
- Geogrid can be effectively used to prevent the slope failure due to frequently occurring landslides.

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