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Study of the Effect of Geogrid on the Stability of Embankment

Tanoj Dulal [a], Santosh Kumar Yadav [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE,Tribhuvan University, Nepal*
Corresponding Email: [a] dulaltanoj@gmail.com, [b] yadavsantoshkr@ioe.edu.np

Abstract
Embankments are built to increase the height of the surface compared to the height of the surrounding area. Various infrastructures are being built on embankment and infrastructures resting on embankment may collapse due to embankment failure which may result in loss of human lives, financial loss and disruption of any services provided by infrastructure projects, the loss of which may takes years to be compensated. Analytical Method and Finite Element Method (FEM) were used to assess the performance of the embankment with and without use of geogrid. The factor of safety of embankment without geogrid and after using geogrid of certain tensile strength was determined to check the stability of the embankment. It was found that with the use of geogrid, the displacement parameters of embankment; horizontal displacement, vertical displacement and total displacement of the embankment decreased and the stability of the embankment was enhanced. Also, the stress parameters i.e. total principal stress, effective principal stress and pore water pressures tend to increase with the use of geogrid through limiting lateral deformations. The purpose of this study is to evaluate the usefulness of geogrid on the embankment to enhance its stability.

Keywords
Embankment, Geogrid, Stability

1. Introduction

Embankment as an ancient form of civil engineering structures has been used as embankment dams for reservoirs, as flood control dykes along river banks and airport, road and railway embankment in transportation. The requirement of performance of embankment is mainly dependent on the purpose for which it is used. Generally, embankment consists of two components; fill and foundation.

Construction of embankment has become inevitable during development of infrastructure and is often encountered in various infrastructure projects and the prediction of slope stability with accuracy is one of the major tasks of Civil Engineers. Various problems like inadequate bearing capacity of foundation soil, slope instability of embankment, settlement etc. are often encountered during and after the construction of embankment during its service life which may cause collapse of embankment leading to the collapse of infrastructure resting on it. Therefore, it is highly important to assess the performance of the embankment as it is built and also, to assess the performance of the embankment after suitable ground improvement technique has been applied. This paper intends to study the performance of the 25 m high embankment as it is built and also, the performance of the same embankment after it has been reinforced with geogrid as reinforcing material. The design was done using analytical computational model and the numerical modeling, based on FEM. The tensile forces of geogrids were decided based on the internal stability calculation.

The objective of this study is to study and analyze the performance of embankment as it is built and to design the optimum tensile strength and spacing of geogrid to be used in embankment as ground improvement technique to enhance the stability of embankment and then, determining the factor of safety of embankment after it has been reinforced with geogrid.

2. Literaure Review

It has been well established that the soil can bear pressure and shear loads but is not stable when tensile force is applied on it. Findings of study showed that settlement, slope stability and soil bearing capacity are all challenges to construction of embankment [1] .

Hence, Previous research concluded that reinforcing soil is one of effective and trustable method for improving and treatment of soil properties[2] . It was concluded that geogrids can improve the performance of the soil through four mechanisms; prevention of local shearing of the soil, improvement of load distribution through the soil, reduction or reorientation of shear stresses in the soil, and tensioned membrane effect [3]. Study showed that the effects of tensile reinforcement included increased embankment stiffness and reduced shear stress and strain magnitudes and plastic deformations in the foundation [4]. Analysis results showed that the reinforcement reduces embankment settlement and lateral spreading due to undrained constant-volume distortion. Also, the past studies concluded that the geogrids enhance the mechanical properties of soil by enhancing bonds in the soil due to interlocking of soil particles with reinforcement apertures and by shear resistance depending on the direction of the reinforcement with failure plane[5] . Past research showed that the use of geogrid upgrade mechanical properties of soil by increasing lateral stress through limiting lateral deformations[6].

The present study aims to study the effect of geogrid on the stability of embankment using analytical calculation and numerical modeling so that the further parametric study regarding the optimization of geogrid design in embankment can be carried out further to achieve better design of embankment in terms of stability and cost.

3. Methodology

In order to assess the stability of the embankment, the data for the study was arbitrarily assumed taking into consideration the site of Sinamangal area where the foundation material was generalized to be homogeneous with the physical properties of soil as listed in Table 1. Similarly, the embankment was generalized to be homogeneous made of single backfill material with the physical properties of embankment material as listed in Table 1.

Firstly, with the available information, the stability factor of the embankment was calculated using stability analysis of simple slopes developed by Michalowski [7]. Also, the safety factor was calculated using Plaxis 2D software which carries out numerical modeling based on finite element method. In slope stability analyses, numerical methods can simulate accurately the stress field and the displacement field in a slope. Plane strain analysis was carried out using the Hardening soil model in the modeling of the soil behavior which better represents real elasto-plastic behaviour of the soil. If resulting factor of safey thus obtained is adequate, no reinforcement is required. However, if factor of safey is not adequate, then increase in FOS is achieved by introducing geogrid as reinforcement material in embankment. The geogrid as reinforcing material acts as a stabilizing tensile force at its intersection with the critical failure plane. For a given failure surface, resisting moments and driving moments are calculated. The additional resisting moment is introduced by the inclusion of geogrid in the embankment which contributes to the enhancement of FOS. It can be illustrated as:

$$FOS = \frac{M_{\mathrm{R}} + M_{\mathrm{G}}}{M_{\mathrm{D}}} \tag{1}$$

where, M_R=Resisting Moment, M_G=Additional Resisting Moment due to Geogrid and M_D=Driving Moment.

3.1 Description and Geometry of Embankment Model

At this part, geometry of model has been explained completely. The embankment modeled in this study has the height of 25 m, top and base of 50 m and 87 m, respectively. The embankment has a side slope of 1:1 (horizontal to vertical) in benching portion with 3m wide horizontal berm and if only the edge of top and toe is considered, then the slope angle of embankment is 37.14 . The width of the rigid pavement is assumed to be 40 m at the top of the embankment as shown in Figure 1. Total static load of 217 kPa is assumed to act on the top of embankment assuming the pavement lies on the top of embankment as shown in Figure 1.

Because of symmetric geometry of embankment, just half of it has been modeled and analyzed. For purpose of simulating construction of embankment, body of embankment has been divided to 5 layers with each of 5m thickness. The stiffness of geogrid and its position and spacing has been determined from the analytical calculation based upon which the model is run.

3.2 Flow Condition

Water table may have a significant impact on the shear strength of soil and this finite element modeling is

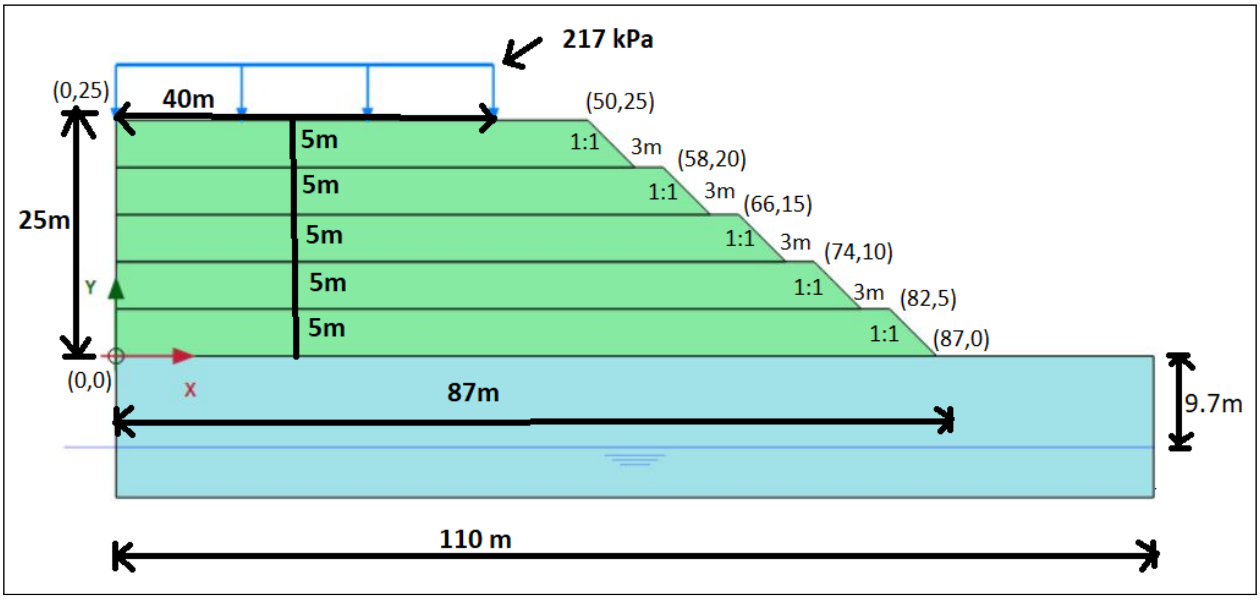


Figure 1: Geometry of the Model (without Geogrid)

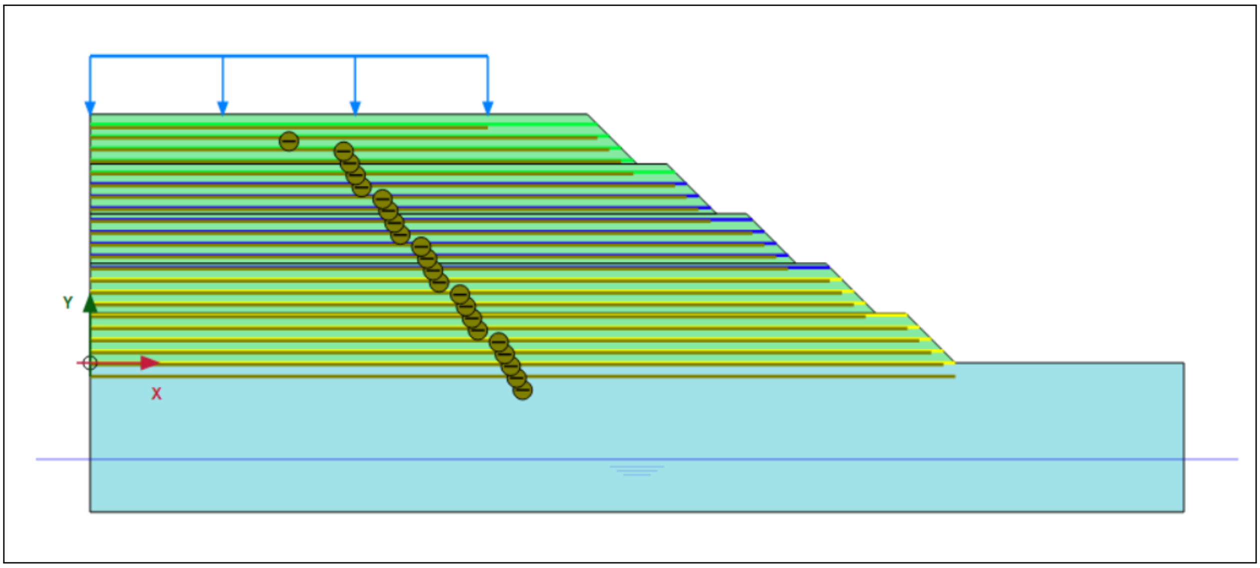


Figure 2: Geometry of the Model (with Geogrid)

Table 1: Physical Properties of Materials used in Modelling

Parameter	Embankment (Fill)	Foundation soil	Unit
Material Model	Hardening Soil Model	Hardening Soil Model	
Soil unit weight above phreatic level	18	15	kN/m^3
Soil unit weight below phreatic level	20	18	kN/m^3
Secant Stiffness in standard drained triaxial test	30,000	30,000	kN/m^2
Tangent Stiffness for primary oedometer loading Eoedref	30,000	30,000	kN/m^2
Unloading/Reloading Stiffness	90,000	90,000	kN/m^2
Power for stress-level dependency of stiffness	1	0.5	-
Cohesion	5	1	kN/m^2
Friction Angle	35	35	degree
Dilatancy angle	5	5	degree

done considering water table to be 9.7 m below the ground surface. While modeling, the ground water flow has been restricted in the x_{min}=0 section as there lies similar section in other half and no ground water flows across it while in other boundaries, the ground water flow is allowed.

4. Results and Discussion

Safety factor for slope stability calculated after embankment has been constructed is 0.945 which is an unacceptable value. Also, the safety factor was determined using Plaxis 2D as numerical modeling software which is based on finite element analysis method which shows that the stability factor of 25 m high embankment as 0.9682. In order to obtain the safety factor of 1.5 for the embankment, geogrid was designed in the embankment using analytical method which showed that the three different types of geogrid can be used in the embankment to achieve the FOS of 1.5. The required lengths, strengths and spacings of geogrids were determined based on the internal stability criteria. It w as determined that the 8 layers of geogrid of tensile strength of 80 kN/m to be used at spacing of 1.2 m starting from the base of the embankment to the height of 8.4 m. Similarly, 7 layers of geogrid of tensile strength of 55 kN/m to be used at spacing of 1.2 m starting from 9.6 m height to the height of 16.6 m. Lastly, 6 layers of geogrid of tensile strength 25 kN/m at spacing of 1.2 m to be used from 17.8 m height of embankment to the top of the embankment. The embedment length of the geogrid in this modeling is kept throughout the embankment section. These design parameters were used to model the embankment in Plaxis 2D and the interface was created to simulate the interaction between soil and structure. The geogrids were designed to transfer the tension load. After reinforcing of soil using geogrid, tensile strength of soil is increased due to which horizontal displacement of soil is decreased, so stability of slope is increased. Horizontal displacement showed decrease of about 85% after using geogrid as per design in embankment and accordingly, it led to increase in safety factor to 1.328 after the geogrids designed from analytical calculation were introduced which showed that both the results are in agreement & the introduction of geogrid in embankment enhances the stability of embankment.

Table 2: Summary of Output of Modeling in Plaxis 2D with & without geogrid

Parameters	Unit	Embarkment without Geogrid	Embarkment with Geogrid
Safety Factor	-	0.9682	1.328
Horizontal Displacement	m	2.072 (max.) -0.0605 (min.)	0.2952 (max.) -0.0958 (min.)
Vertical Displacement	m	0 (max.) -1.247 (min.)	0 (max.) -0.922 (min.)

The variation of FOS and horizontal displacement of embankment with and without geogrid is illustrated by graph in Figure 3 and Figure 4.

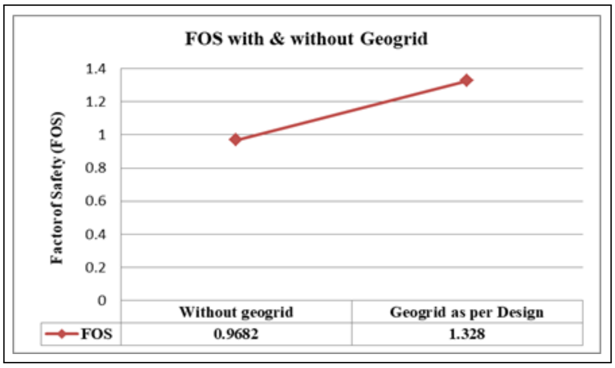


Figure 3: Variation of FOS of Embankment with and without Geogrid

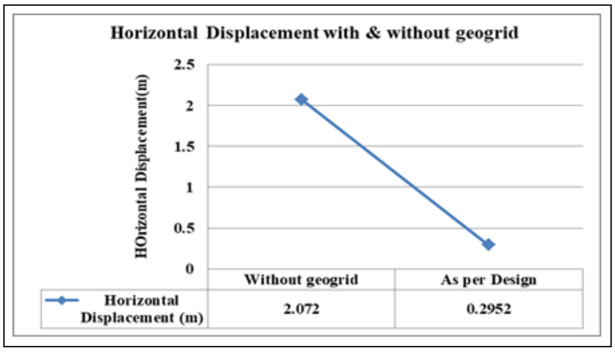
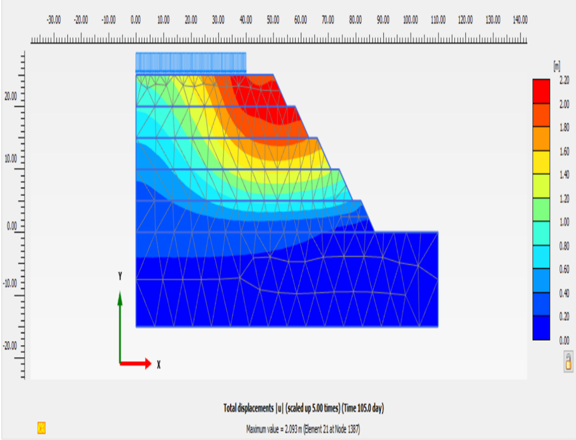


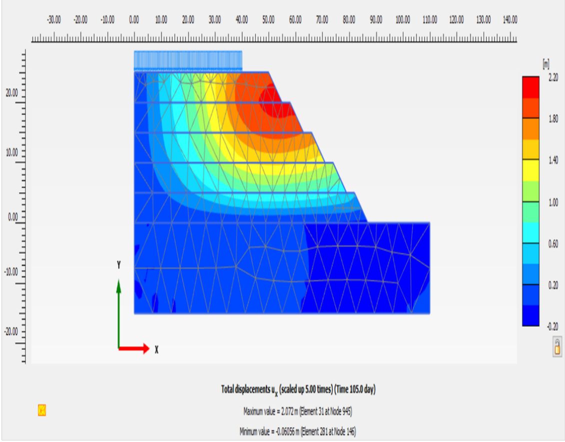
Figure 4: Variation in Horizontal Displacement of Embankment with and without Geogrid

The output generated by the finite element modeling software (Plaxis 2D) is illustrated in the Figure 5 and Figure 6.

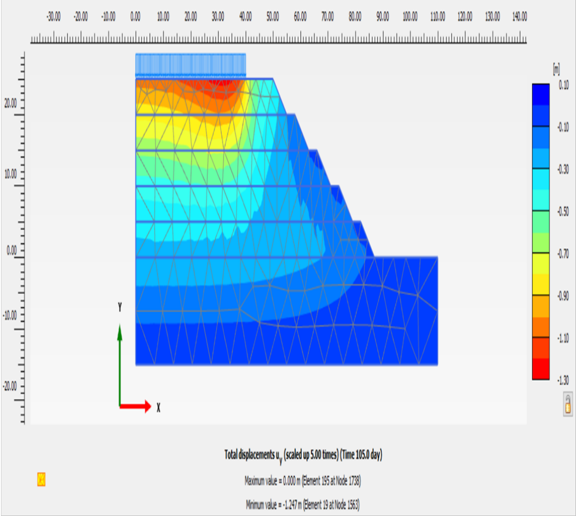
Case 1: Embankment (without Geogrid)



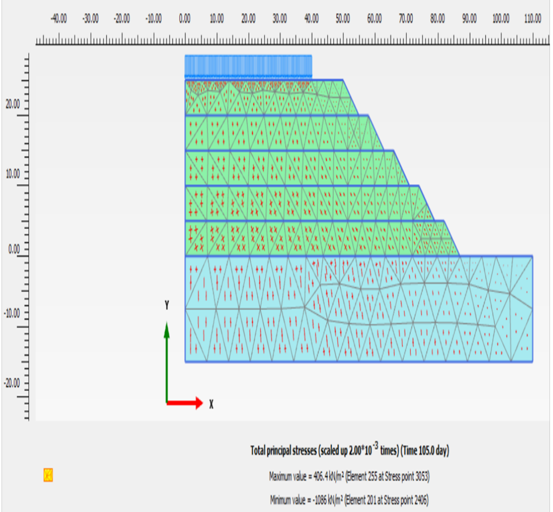
a) Total Displacement [u = 2.093m]



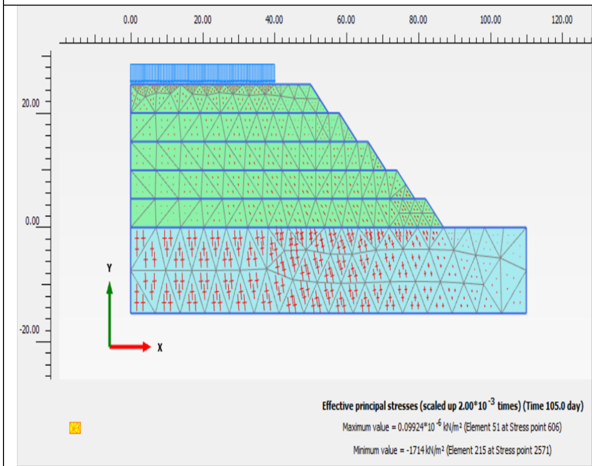
b) Horizontal Displacement [u_x = 2.072m (max.)]



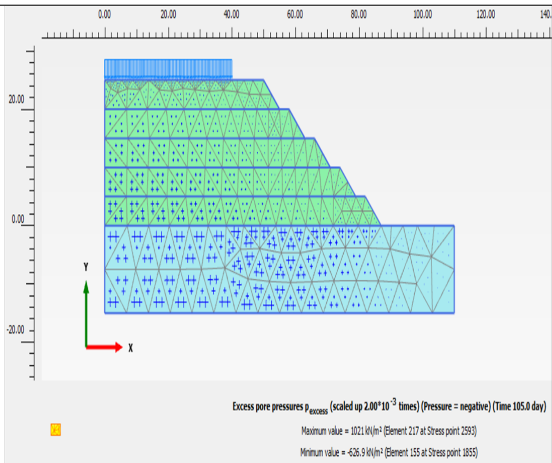
c) Vertical Displacement [u_y = 0 m (max.)]



d) Total Principal Stresses [406.4 kN/m^2 (max.)]



e) Effective Principal Stresses [0.09924*10^{-6} kN/m^2 (max.)]



f) Excess Pore Pressures [1021 kN/m^2 (max.)]

Figure 5: Deformations and Stresses (Embankment without Geogrid)

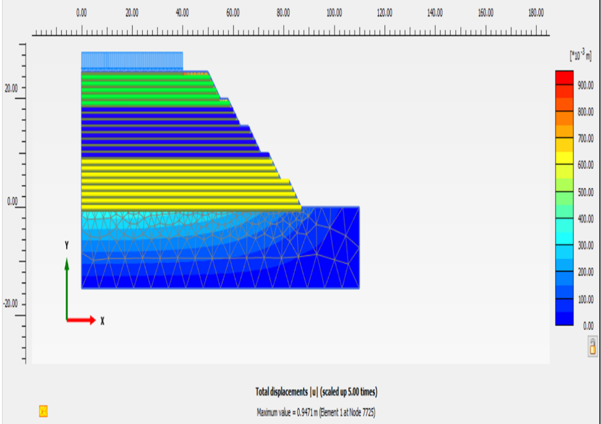
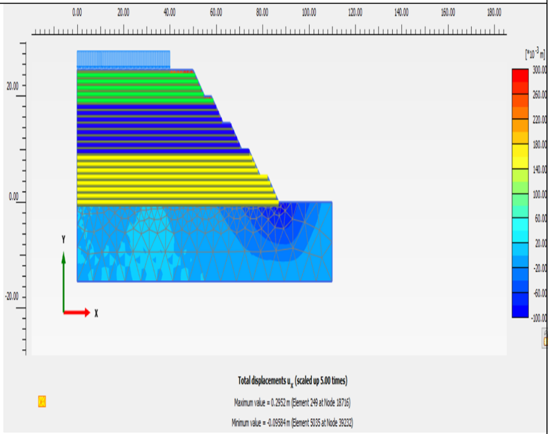
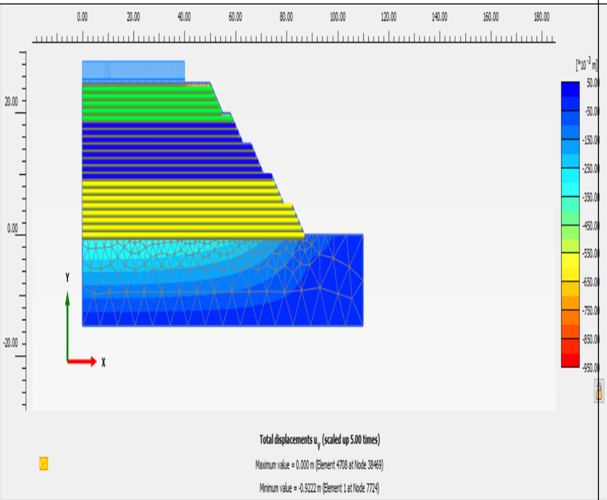
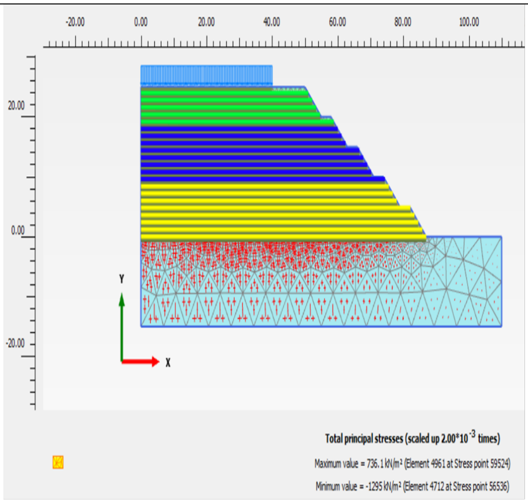
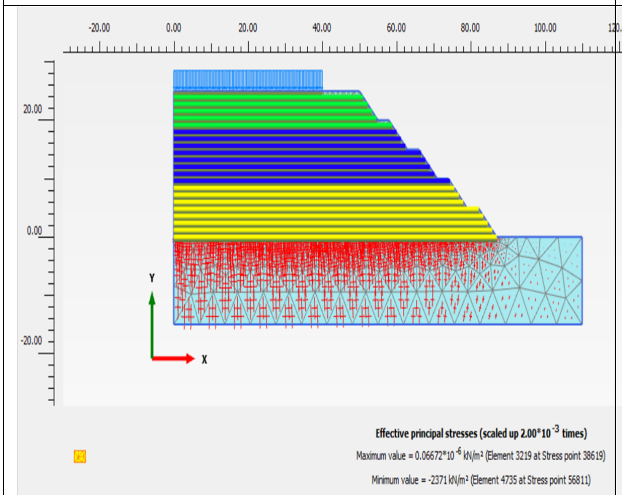
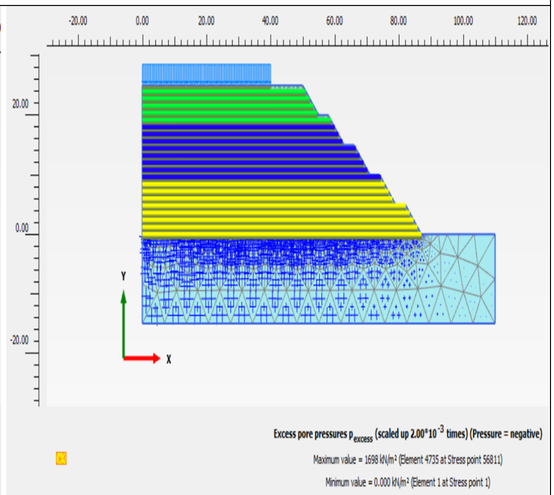
Case 2: Embankment (with Geogrid of 80 kN/m, 55 kN/m and 25 k/m)	
	
a) Total Displacement [u = 0.9471 m]	**b) Horizontal Displacement [u_x= 0.2952m (max.)]**
	
c) Vertical Displacement [u_y=0 m (max.)]	**d) Total Principal Stresses [736.1 kN/m^2 (max.)]**
	
e) Effective Principal Stresses [0.06672*10^{-6} kN/m^2 (max.)]	**f) Excess Pore Pressures [1698 kN/m^2 (max.)]**

Figure 6: Deformations and Stresses (Embankment with Geogrid)

5. Conclusion and Recommendation

Geogrids provide a stable force at the reinforcement layers-soil interface due to friction action and interlocking between soil particles and geogid layers. Hence, the reinforcement distributes the applied load over a large area from the soil and transmits the tensile strength to surrounding soils. By considering all the results of analysis, it can be concluded that use of geogrid causes a decrease on horizontal movement of embankment and lead to an increase of safety factor.

Increased stability of embankment after geogrid may be caused due to following reasons:

- Confinement of fill material by geogrid may result in reduction in lateral spreading of the fill material.
- Confinement results an increase in lateral stress within embankment body, thereby increasing its stiffness.
- Improved vertical stress distribution due to which surface deformation will be less and more uniform.

It is recommended to carry out parametric study considering different conditions to optimize the design of embankment using geogrid to achieve the better performance of embankment in terms of stability and cost.

6. Limitations

Referring to the time constraint of study and the challenges associated with numerical modeling in the computer, a simple model was analyzed considering the single layer of foundation material and single embankment material which may not be the exact condition at the site. Some other limitations associated with the study are following:

- Soil properties are assumed isotropic and homogeneous which is impractical in real field.
- Only static loading has been considered.
- Study is limited to homogeneous soil condition under uniformly distributed vertical loading.
- The analysis performed is two dimensional finite element analysis using plaxis 2D as a tool. The interaction mechanism cannot be properly included in the analysis. For 3D models, further study is needed for the application of the proposed method.
- The creep behavior (secondary consolidation) is not studied using this constitutive model.
- Assumptions made in analytical calculation and numerical modeling using finite element analysis is inherently present in the outcomes of the study, thus limiting the applicability of study.

Apart from these, study is restricted to the limited range of parameters, which may not take into account the actual problems of field.

Acknowledgement

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