DESIGN AND ANALYSIS OF REINFORCED SLOPE USING GEOGRID

Major Project II submitted for the fulfillment of the requirement for the award of Master of Technology

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CANDIDATE'S DECLARATION

I Minilik Tamene Damtie, Roll No. 2K17/GTE/20, student of M.Tech Geotechnical Engineering hereby declare that the project Dissertation titled "Design and Analysis of Reinforced Slope Using Geogrid" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I certify that all the analytical or experimental work presented in this project entitled "**Design and Analysis of Reinforced Slope using Geogrid**" for the fulfillment of Major Project II in Geotechnical Engineering, Civil Engineering Department, Delhi Technological University, Delhi is an authentic record of my work carried out in the third semester of M-Tech programme under the guidance and supervision of Prof. Kongan Aryan.

To the best of my knowledge, this work has never been submitted or presented anywhere for an award of any other degree or diploma.

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Prof. Kongan Aryan

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ABSTRACT

This study investigated the use of geogrids for ground improvement based on numerical analysis using Plaxis and Geostudio software. Owing to the low shear strength and excessive settlement of the sandy soil, geogrids materials were used to reinforce the soil taking advantage of their good tensile strength. Geogrids were applied in three layers after the design output. The reinforced mechanism of geogrids was analyzed based on modelling outputs and results. Output results from the Plaxis and Geostudio software showed a significant decrease in displacement and increase in factor of safety after reinforcing the soil with geogrids materials. The total displacement in the unreinforced slope is 670.67 mm which reduced to 19.30 mm when reinforced with geogrids. This reduction is over 900 % of the original total settlement.

The slope was also analyzed for different amounts of surcharge in both reinforced and un-reinforced case. The effect of groundwater fluctuation and rapid drawdown of water were analyzed. The influence of rainfall intensity and duration is also analyzed. The factor of safety results after the analysis are compared with different parameters. Based on the results of this study, it was concluded that geogrids could be used as soil reinforcement materials to improve the shear strength of the soil and reduce its settlement potential significantly.

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List of Symbols, Abbreviations and Nomenclature

FEM = Finite Element Method

2D = Two Dimensional

3D = Three Dimensional

RSS = Reinforced Soil Slope

FOS = Factor of Safety

CG = Centre of Gravity

RM = Resisting Moment

MD = Driving Moment

D = Depth of slope

FSR = Factor of safety required

FSU = Factor of safety utilized

Ts = Tensile strength

Tmax = Maximum Tensile strength

Tult = Ultimate Tensile strength

C= cohesion

Φ = Angle of internal friction of the soil

σv = Vertical stress

H’ = Equivalent height

H = Height of slope

q = Surcharge load

KN = Kilo Newton

mm = millimeter

ɣ = Unit weight

R_{CR} = Reduction factor for creep

R_{ID} = Reduction factor for installation damage

R_{FD} = Reduction factor for duration

CHAPTER 1
INTRODUCTION

Soil is a weak structural material in tension. Reinforced soil is a generic term that describes structures or systems which are constructed by using reinforcing elements (such as, steel strips, geogrids, or geotextile sheets) in the soil to have improved tensile resistance. Reinforced soil structures are cost-effective because of readily availability of the reinforcements and the concept has appeared as one of the most innovative civil engineering technologies in the recent times [1].

Geogrid is a type of geo synthetic material which is used as reinforcement in different construction works. Geogrids are categorized as geo synthetic materials used in the construction work as a reinforcing material. It can be used in the soil reinforcement or used in the reinforcement of retaining walls and even different applications of the material are on their way to being flourished. The high demand and the application of Geogrids in construction are because of the fact that it's good in tension and has a higher capacity to distribute the load across a large area. They are made of polymer materials, such as polyester, polyvinyl alcohol, polyethylene or polypropylene. They may be plain-woven or unwoven from yarns, heat-welded from strips of fabric, or created by punching an everyday pattern of holes in sheets of fabric, then stretched into a grid.

In this study, the slope is modelled by Plaxis software program which works based on finite element method. It was used to calculate the deformation and stress results for different cases of the analysis. Also, Geostudio is used to calculate the factor of safety of the slope under different cases. The results from these two softwares are used to assess the stability of the slope.

Plaxis 2D is a finite element bundle utilized for the two-dimensional investigation of deformation and stability in geotechnical designing. It uses propelled soil constitutive models for the reproduction of the non-direct, time needy and anisotropic conduct of soils and shakes. Plaxis 2D models the geogrids, the dike soil and the connection between geogrid structure and the soil.

Geostudio is also another software which has different tools to analyze the slope by using both limit equilibrium and finite element methods.

Soil and foundation parameters are inserted into Plaxis and the development stages, loads and boundary conditions are assigned in an officially characterized geometry cross-segment containing the soil model. Then the Plaxis consequently creates the unstructured 2D limited component networks with alternatives of global and local mesh refinements.

By using its calculation procedures, Plaxis 2D will undertake the calculation process and display the results of the calculation and model outputs which are accessible in animation scheme and/or numerical forms Plaxis 2D manual 2012.

Fig. 1.1: Embankment model without reinforcement

1.1 Objective of the study

To design the reinforced slope for appropriate number of geogrid layers.

To analyze the slope for the effect of geogrid reinforcement.

To analyze the slope for the effect of groundwater in reinforced and un-reinforced condition.

To analyze the slope for the effect of surcharge load.

To analyze the slope for the effect of seepage from rapid drawdown of water.

To analyze the slope for the effect of rainfall intensity and duration.

CHAPTER 2
Literature Review

Reinforced soil dividers and slopes are savvy soil holding structures which can endure a lot bigger settlements than reinforced solid dividers. By setting elastic strengthening components (considerations) in the soil, the quality of the soil can be improved altogether to such an extent that the vertical essence of the dirt/fortification framework is basically self-supporting. Utilization of a facing framework to avoid soil raveling between the reinforcing components permits exceptionally steep slants and vertical walls to be securely developed. At times, the incorporations can likewise withstand bending or shear stresses giving extra dependability to the framework [1].

Geosynthetics has been characterized by Holtz [2] as a planar item made from a polymeric material utilized with soil, rock, earth, or other geotechnical-related material as a fundamental piece of a structural building undertaking, structure, or framework. Most regular kinds of geosynthetic incorporate; geotextiles, geomembranes, geogrids, geocomposites, geofoams, geocells and geotubes. Geosynthetics have been progressively utilized in geotechnical and ecological building throughout the previous four decades [3]. Throughout the years, these items have helped designers and contractual workers to take care of a different kinds of building issues where the utilization of traditional development materials would be limited or impressively costly. There is countless geosynthetic types and applications in geotechnical engineering.

There are typically 2 varieties of analysis that are utilized in industry: 2-D modelling, and 3-D modelling. While 2-D modelling conserves simplicity and permits the analysis to be run on a comparatively traditional pc, it tends to yield less correct results. 3-D modelling, however, produces a lot of correct results whereas sacrificing the flexibility to run on virtually the quickest computers effectively. Within every of those modelling schemes, the engineer will insert various algorithms (functions) which can build the system behave linearly or non-linearly. Linear systems are way less advanced and customarily don't take under consideration plastic deformation.

Non-linear frameworks do represent plastic distortion, and numerous likewise are fit for testing a material right to fracture [4]. Small-scale model footing tests manufacture higher values for the bearing capacities than those of theoretical equations and thus they ought to not be utilized for the look of complete footings without a reduction [5].

The distinction in performance between the particular massive and/or full scaled soil footings and also the model footing tests ought to be thought of. The connection between the tests with little and enormous scaled footing is known as the "scale effect" in geotechnics. The scale impact is the variety in the bearing capacity attributes with the variety in the footing size.

The requirement for high devotion and for modelling of huge three-dimensional (3D) spatial designs is rousing this bearing of research. Finite element method (FEM) comprises of a PC model of a material or plan that is stressed and analyzed for explicit outcomes.

It is utilized in new product design, and existing item refinement. The job of modelling inside geotechnical designing practice was unmistakably outlined by [6].

The plan and construction of embankments on delicate foundation soils is a difficult geotechnical issue. As verified by [7], effective activities require a careful subsurface examination, properties assurance, and settlement and soundness investigation. On the off chance that the settlements are excessively huge or insecurity is likely, at that point some sort of establishment soil improvement is justified. Customary soil improvement techniques incorporate preloading/surcharging with channels; lightweight fill; uncovering and substitution; profound soil blending, bank heaps, and so forth, as examined by [2]. Today, geosynthetic fortification must al so be considered as a plausible treatment elective. In certain circumstances, the most prudent last plan might be a mix of a customary establishment treatment elective together with geosynthetic support.

Similarly as with conventional embankments on delicate soils, the fundamental structure approach for reinforced embankments is to design against failure. The manners by which dikes developed on delicate establishments can come up short have been depicted by Terzaghi among others.

The three potential methods of failure show the sorts of stability analysis that are required for structure. Bearing capacity of the embankment should be satisfactory, and the reinforcement ought to be sufficient to resist rotational failure at the edge. Lateral spreading failures can be forestalled by the advancement of sufficient shearing obstruction between base of the embankment and the reinforcement. Furthermore, an analysis to reduce geosynthetic deformations must be done. At long last, the geosynthetic strength prerequisites the longitudinal way, normally the transverse seam strength, must be resolved.

Discussion of these design concepts and also detailed design procedures are provided by [1], [8], [2], and [7].

The estimations required for stability and settlement use regular design techniques altered uniquely for the nearness of the support. Since the most basic condition for embankment soundness is toward the finish of construction, the total analysis of stress is normally performed, which is traditionalist since the investigation for the most part expect that no strength addition happens in the soil. It is constantly conceivable obviously to ascertain effective stress as far as successful estimate gave that compelling pressure shear quality parameters are accessible and a precise gauge of the field pore pressure can be made amid the task configuration stage. Because the expectation of in situ pore pressure ahead of time of construction isn't simple, it is basic that the foundation be instrumented with brilliant piezometers amid construction to control embankment filling. Preloading and staged dike construction are explained in detail by [9].

At the point when appropriately structured and chose, high - quality geotextiles or geogrids can give satisfactory embankment fortification. The two materials can be utilized similarly well, if they have the imperative structure properties. There are a few contrasts by the way they are introduced, particularly as for seaming and field workability. Likewise, at some exceptionally delicate locales, particularly where there is no root tangle or vegetative layer, geogrids may need a lightweight geotextile separator to allow filtration and counteract pollution of the embankment fill. Be that as it may, a geotextile separator isn't required if the fill can sufficiently channel the foundation soil.

A detailed explanation of geosynthetic properties and specifications is provided by [2] and [10] so only additional comments are stated below.

The selection of appropriate fill materials is also a vital aspect of the design. As long as possible, granular fill is preferred, particularly for the first few lifts right above the geosynthetic.

Environmental Considerations

For most embankment support circumstances, geosynthetics have a high protection from chemical and organic attack; along these lines, chemical and biological compatibility is normally not a worry. Be that as it may, in strange circumstances, for example, low (i.e., < 3) or extremely high (i.e., > 9) pH soils, or other unusual substance conditions (for instance, in mechanical territories or close to mine or other waste dumps), compound compatibility with the polymer(s) in the geosynthetic ought to be checked. It is imperative to guarantee it will hold the design strength in any event until the subsoil underneath is sufficiently able to help the structure without reinforcement.

Constructability (Survivability) Requirements

Notwithstanding the structure strength prerequisites, the geotextile or geogrid should likewise have adequate strength to endure construction. On the off chance that the geosynthetic is tore, punctured, torn or generally harmed amid construction, its strength will be decreased and failure could result. Constructability property prerequisites (These are likewise called survivability necessities.)

See [1] for explicit property prerequisites for strengthened embankment construction with changing subgrade conditions, development hardware, and lift thicknesses. For every critical application, high to exceptionally high survivability geotextiles and geogrids are prescribed.

Stiffness and Workability

For very delicate soil conditions, geosynthetic firmness or workability might be a significant thought. The workability of a geosynthetic is its capacity to help work people amid starting situation and seaming activities and to help construction equipment amid the primary lift position. Workability is commonly identified with geosynthetic firmness; be that as it may, solidness assessment procedures and relationships with field workability are extremely poor. See [10] for suggestions on solidness.

Construction

The significance of appropriate development strategies for geosynthetic reinforced embankments can't be overemphasized. A particular development grouping is typically required so as to maintain a strategic distance from failures amid construction. Suitable site readiness, low ground pressure equipment, small initial lift thicknesses, and partially loaded transporting vehicles might be required. Clean granular fill is prescribed particularly for the initial couple of development lifts, and appropriate fill arrangement, spreading, and compaction techniques are significant. A point by point dialog of construction methods for strengthened dikes on extremely delicate foundations is given by [1] and [11].

It ought to be noticed that all geosynthetic creases must be emphatically joined. For geotextiles, this implies se wing; for geogrids, some kind of positive clasping game plan must be utilized. Cautious review is basic, as the creases are the "powerless connection" in the framework, and crease failures are basic in inappropriately developed dikes. At last, delicate ground construction extends more often than not require geotechnical instrumentation for legitimate control of construction and fill situation; see [2] for proposals.

Reinforced steep slopes

The principal utilization of geosynthetics for the adjustment of soak inclines was for the restoration of fizzled slants. Cost reserve funds came about on the grounds that the slide flotsam and jetsam could be reused in the fixed slant (together with geosynthetic fortification), instead of bringing in select materials to recreate the incline. Regardless of whether foundation conditions are agreeable, expenses of fill and right-of - route in addition to different contemplations may require a more extreme slant than is steady in compacted dike soils without support, numerous layers of geogrids or geotextiles might be set in a fill incline during construction or reproduction to reinforce the soil and give expanded slope stability.

Most steep incline fortification activities are for the development of new dikes, options in contrast to holding dividers, augmenting of existing banks, and fix of fizzled slants. Another utilization of geosynthetics in slants is for compaction helps.

In this application, tight geosynthetic strips, 1 to 2 m wide, are set at the edge of the fill incline to give expanded sidelong control at the slant face, and hence expanded compacted thickness over that typically accomplished. Indeed, even humble measures of support in compacted slants have been found to counteract sloughing and lessen slant disintegration. Now and again, thick nonwoven geotextiles with in-plane seepage abilities take into consideration fast pore weight dissemination in compacted strong fill soils.

The general design prerequisites for fortified inclines are like those for unreinforced slants - the factor of wellbeing must be satisfactory for both the short-and long - term conditions and for every single imaginable modes of failure. These include: (1) inward - where the failure plane goes through the fortifying components; (2) outside - where the failure surface goes behind and underneath the fortified mass; and (3) compound - where the failure surface goes behind and through the strengthened soil mass.

Strengthened slopes are investigated utilizing changed forms of old style limit equilibrium slant stability strategies [9]. Potential round or wedge-type failures surfaces are accepted, and the connection among driving and opposing forces or moments decides the factor of safety. In view of their tensile capacity and direction, fortification layers meeting the potential failures surface increment the moment or force. The tensile capacity of a fortification layer is the base of its reasonable pullout resistance behind, or before, the potential failure surface as well as its long - term design elasticity, whichever is littler. An assortment of potential failure surfaces must be considered, including profound situated surfaces through or behind the strengthened zone, and the critical surface requiring the greatest sum support dissuade mines the incline factor of safety.

The reinforcement format and separating space might be fluctuated to accomplish an ideal design. PC projects are accessible for fortified incline design which incorporate looking routines to help find critical surfaces and proper thought of fortification strength and pullout limit, [1].

Extra data on fortified incline design is accessible in [1], [2] and [12]. For slide fix applications, it is significant that the reason for unique failure is tended to so as to guarantee that the new strengthened soil incline won't have similar issues. Specific consideration must be paid to drainage. In regular soil slants, it is additionally important to distinguish any feeble creases that could influence stability.

Geosynthetic properties required for strengthened slants are like those recorded previously. Properties are required for structure (stability), constructability, and strength. Admissible rigidity and soil - geosynthetic friction are most significant for stability plan. As a result of vulnerabilities in creep strength, compound and bio coherent degradation impacts, installation harm, and joints & connections, a reduction factor is prescribed. A definitive wide width strength is diminished for these different variables, and the decrease relies upon how much data is accessible about the geosynthetics at the season of design and selection.

Insights concerning the assurance of the suitable geosynthetic elasticity are given [2]. They additionally depict how soil - geosynthetic grating is estimated or assessed.

An innate bit of leeway of geosynthetic support is their life span, particularly in ordinary soil conditions. Ongoing investigations have shown that the foreseen half - life of support geosynthetics in the middle of 500 and 5000 years, in spite of the fact that strength attributes may must be changed in accordance with record for potential debasement in the particular ecological conditions.

Any soil appropriate for embankment development can be utilized in a fortified slant framework. From a support perspective alone, even lower-quality soil than customarily utilized in unreinforced slant development might be utilized. Be that as it may, higher - quality materials offer less strength concerns, are simpler to place and compact, which will in general accelerate development, and they have less issues with seepage. See [2] for discourse of soil degree, compaction, unit weight, shear quality, and synthetic piece.

Also to fortified dikes, legitimate development is imperative to safeguard satisfactory execution of a strengthened incline. Contemplations of site planning, support and fill arrangement, compaction control, face development, and field assessment are given by [2] .

CHAPTER 3
Materials and Methods

3.1 Materials

Embankment fill parameters: A dike for the most part alludes to an earthen structure that is utilized to raise the height of the encompassing zone. For these investigations, dike is done on a slant to reinforce the basic point at a few spots. Dikes are normally worked by compacting earthen materials set up, so the compaction properties of the soil are significant for steadiness and execution. The compressibility and shear strength are likewise significant measures for the compacted material.

The bank fill was thought to be an absolutely frictional granular soil with an angle of friction, ϕ is 30°, dilatancy angle is 0° and a unit weight is 20 KN/m^3. The friction angle of the fill material affects a definitive tallness of the dike yet a lower friction angle would have almost no impact on the time subordinate deformation of the dike and support since the wet blanket distortions are represented by the viscoelastic behavior of the geosynthetics and the establishment soils. The table below demonstrates the properties of sand utilized in the bank.

Table 1.1: Embankment fill properties

PARAMETERS	VALUES
Unsaturated Unit Weight	17 kN/m^3
Saturated Unit Weight	20 kN/m
Permeability horizontal and vertical	1 m/day
Reference Young's Modulus	1300 kN/m
Poisson's Ratio	0.3
Cohesion	5 kN/m
Friction Angle	30^0
Dilatancy Angle	0^0
Interface Strength	0.8

Geosynthetic: The geosynthetic utilized for the development of embankment was a geogrid, which are principally utilized for support; they are framed by a standard system of tractable components with openings of adequate size to interlock with encompassing fill material. The geogrid has axial stiffness properties of 80 kN/m.

3.2 Methods

Numerical modelling: In this study, establishment settlement was displayed by the utilization of Plaxis programming system dependent on finite element technique. Plaxis 2D is a finite element bundle utilized for the two-dimensional investigation of disfigurement and stability in geotechnical designing. It uses propelled soil constitutive models for the reproduction of the non-direct, time needy and anisotropic conduct of soils and rocks. Plaxis 2D models the geogrids, the bank soil and the connection between the geogrid structure and the soil.

The accessible hypothesis for flexibility was created and set up based on homogenous and isotropic conduct of construction materials like steel, iron, elastic (Sinha, 2013). The solid ionic bond in the middle of the particles holds the flexible property inside as far as possible. Soil, then again, is an anisotropic, non-homogenous, three-stage material, where a little cohesive soil) or no (granular) holding power in the middle of the particles exists. Accordingly, the conduct of soil mass, which is a mix of various discrete particles, can't be displayed by the unadulterated elastic or plastic speculations.

Subsequently, the soil pressure strain constitutive conduct is spoken to by methods for elastoplastic constitutive model (adjusted Mohr-Coulomb model), which is the mix of the elastic and plastic hypotheses got from mechanics of material. The proper elastoplastic constitutive law for the soil continuum, the geometric modelling of the contact zone and different parts alongside the numerical well-ordered simulation, are the significant pieces of the numerical models.

At the point when the geometry model is finished, the finite element mesh can be created. Plaxis takes into consideration a completely programmed mesh generation methods, in which the geometry is consequently separated into component of the fundamental component type and good basic components (for example geogrids). The mesh generation assesses the situation of focuses and lines in the geometry model, with the goal that the accurate position of layers, loads and structures is reflected by the finite element mesh. The generation procedure depends on a powerful triangulation rule that looks for streamlined triangles, which results in an unstructured work. The dike models are appeared in Figures beneath.

The main results from finite element calculation are the displacement values at the nodes and the stresses at stress points. The finite element models also include structural elements in which structural forces are calculated. Different output results for the unreinforced and reinforced embankments which includes stresses and displacements are appeared in figures below.

CHAPTER 4

DESIGN OF REINFORCED SLOPE

4.1 Reinforced Soil Slopes (RSS)

A type of stabilized slope which has incorporated reinforcing components like anchors, nails, geotextiles, and geogrids inside the soil is called reinforced slope. The objective is to increase the stability and to decrease surface sloughing by improving compaction at the edge.

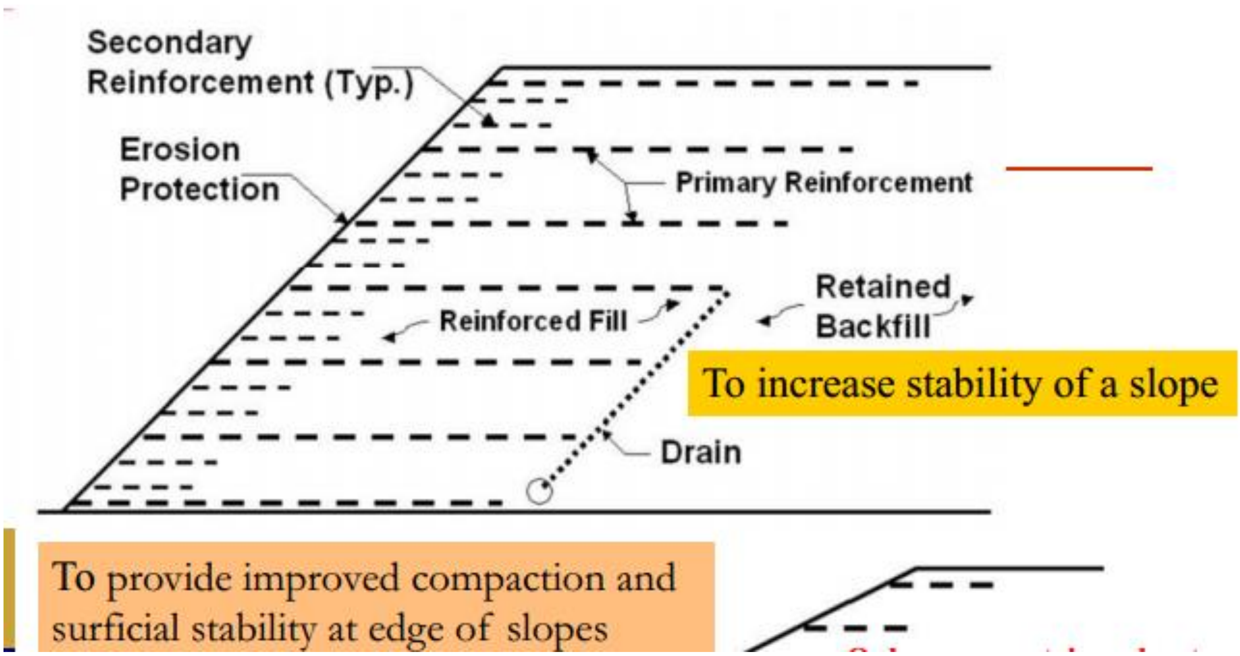

Fig. 4.1: reinforced slope [13]

Strengthened soil frameworks comprise of planar reinforcements organized in almost even planes in the fortified fill to oppose outward development of the strengthened fill mass. Support of fill materials Include fill materials, new or replaced, by fortification which is set on a level plane inside the compacted layers of fill. Confronting or facing materials extends from vegetation to adaptable Protection frameworks are connected to forestall unwinding and sloughing off the face.

As slope failure would be the result of reinforcement failure, the design needs critical consideration. The reinforcement of the slope increases lateral resistance and confinement of the soil. It also reduces erosion and sloughing of the slope. Geosynthetics performs well for cohesive soils whereas geogrids are recommended for granular soils. In this study, the fill material property is sand hence geogrid is designed for stabilizing the embankment.

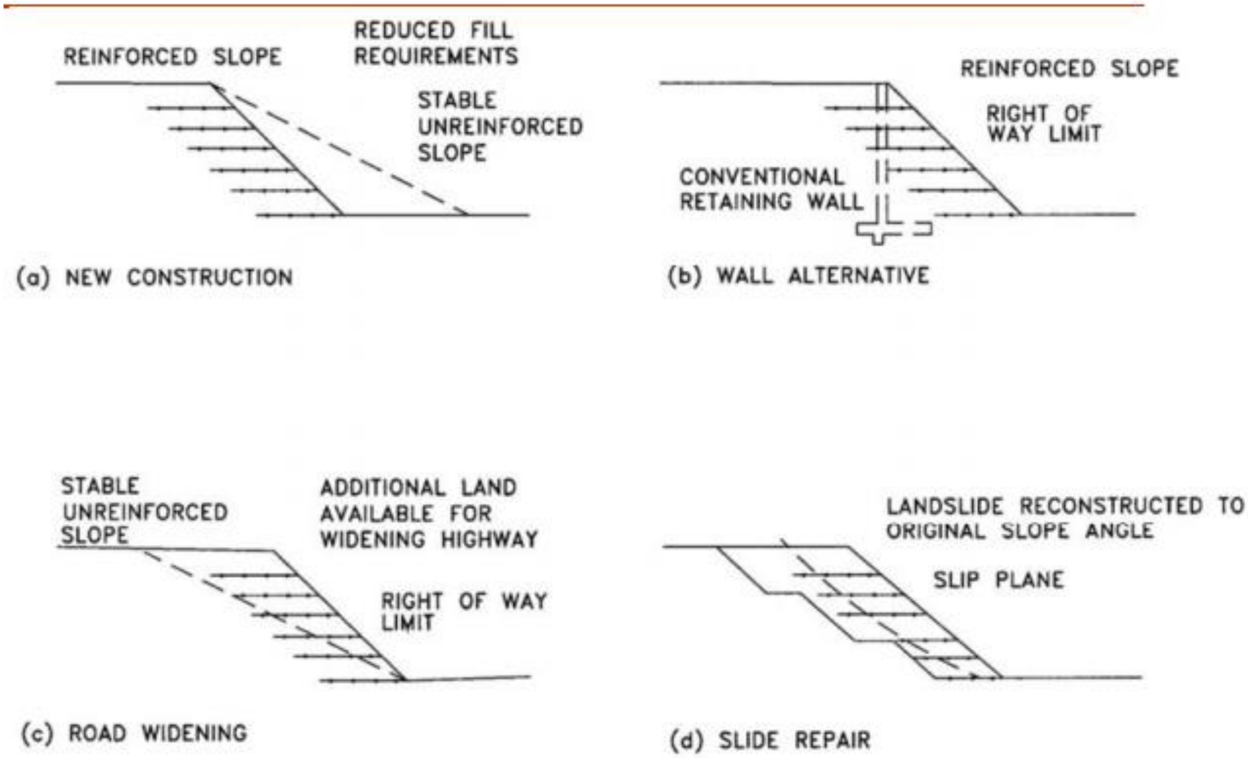

Fig. 4.2: applications of reinforced slope [13]

4.2 Design Approaches

The design approaches basically assume the slope will be established on a stable foundation. Circular or rotational failure surface is also assumed to occur in the reinforced slope. The design life expected to be more than 3 years.

There are three modes of failure; internal failure which implies that the failure is passing through reinforcing materials. External, when the failure surface is underneath or behind the slope mass. Compound, when it is passing through the soil mass and also behind it. The design will be performed by using different reinforcement capacities and/or layouts until the predetermined factor of safety is gained. The effect of the reinforcement will be checked by stability analysis using different computer programs.

There are two approaches for the design:

- General approach and
- Chart approach

Both methods are used to design the slope in this study.

Design of the reinforced embankment was carried out by changing the tensile strength of the reinforcement until the recommended value of factor of safety (1.5) is acquired.

Geostudio is used to analyze the FOS. The result of geogrid reinforced embankment analysis using PLAXIS 2D and Geostudio by applying different values of tensile strength to obtain the FOS and displacement is mentioned in Table 4.2.

Factor of safety increases with the increase of tensile strength of geogrid reinforcement. In Fig. 4.3, it is shown that by increasing the tensile strength of geogrid, the factor of safety is increased until a certain value and then reduced. It shows that it is recommended to determine the acceptable tensile strength of geogrid.

In this study, the recommended value for tensile strength of geogrid reinforcement is 80 kN/m by assessing the factor of safety. The increase in the tensile strength of geogrid reduced the displacement insignificantly. As the displacement don't show significant impact while increasing the tensile strength of geogrid, it won't be used to determine acceptable value for tensile strength of geogrid in this study.

Table 4.2: Tensile strength versus factor of safety and displacement

Tensile strength (KN/m)		Factor of safety		Displacement (mm)	
60		1.391		19.33	
70		1.461		19.31	
80		1.582		19.30	
100		1.633		19.29	
150		1.681		19.29	
200		1.684		19.29	
300		1.689		19.29	
400		1.672		19.28	
500		1.670		19.27	

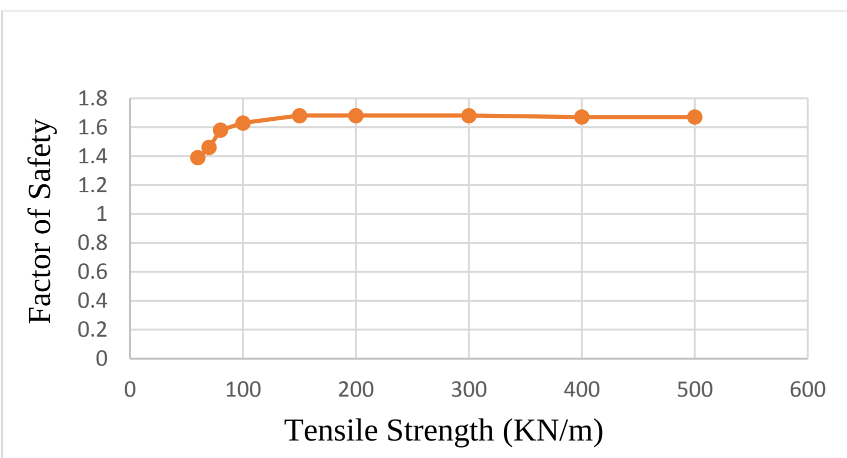

Fig. 4.3: Factor of safety analysis

4.2.1 General Approach

Critical failure surface is considered for the unreinforced slope. Calculate the values for driving and resisting moments. Evaluate the factor of safety and if it's less than FOS required (commonly 1.5), reinforcement design will be computed.

Reinforcement shall be provided by taking into consideration the required additional RM to get FSR. The distance between the centre of rotation and CG of reinforcement should be maintained while choosing the location and spacing of reinforcement members. Length of the reinforcement is determined by using the pullout FOS and computing the pullout resistance.

Below is the design of the reinforced slope computed by using the general approach.

$$T_S = (FS_R - FS_U)\frac{M_D}{D} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Table 4.1 design of reinforced slope

Given			
FOS -R	1.5		
Driving Moment	72000	kN.m	
Restoring Moment	78000	kN.m	
Lever arm distance	20	m	
Tensile Strength of geogrid	80	kN/m	
Depth of slope	15	m	
Friction angle	30		
Unit wt	20	kN/cu.m	
Co eff of friction	0.15		
Solution			
FOS (UR)	1.24		$T_S =$
Tension required	936	kN	
Reduction factor for HDPE biaxial geogrid	3	creep	from
Reduction factor for HDPE biaxial geogrid	1.3	Installation damage	graph
Tensile Strength of geogrid	20.51	kN/m	
Tensile force available in each layer	307.69	kN	
Number of layer	3.04	nos	

$L_e = T_{max} * FS$ / Pull out Resistance

Where:
Pullout resistance = $2\mu * (c + \tan \phi * \sigma_v)$ ……………(2)

FOS (UR) = M_R/M_D ………………..(3)

Ts = Tension required = $(FS_R\text{-}FS_U)*M_D$ / lever arm distance…….(4)

Tensile strength of geogrid (reduced) = Tensile strength of geogrid / $(RF_{CR}*RF_{ID})$…….(5)

Tensile force available in each layer = Tensile strength of geogrid (reduced)*depth of slope….(6)

Number of layers = Tensile force available in each layer / Tension required………(7)

4.2.2 Chart Approach (after Schmertmann et al. 1987)

Assumptions in this approach:

Slopes are comprised of uniform and cohesion less soil, C=0, ϕ. Pore water pressure and seismic loading are not considered.

Extensible reinforcement members are used. Horizontal layer of reinforcement having a coefficient of interaction=0.9.

Level foundation and uniform surcharge at the top. Horizontal crest and flat face of slope are considered.

Below is the design for the RSS using this approach.

Step 1: equivalent height

$H' = H + \frac{q}{\gamma}$ …………..(8)

$H' = 20m + \frac{40\ KN/m2}{20\ \mathrm{KN/m3}}$

H' = 22m

Step 2: factored friction angle

$\phi_f = \tan^{-1} \dfrac{\tan \phi}{FS}$ ....(9)

$\phi_f = \tan^{-1} \dfrac{\tan 30}{1.5}$

$\phi_f = 21.05^0$

Step 3: obtain K from chart

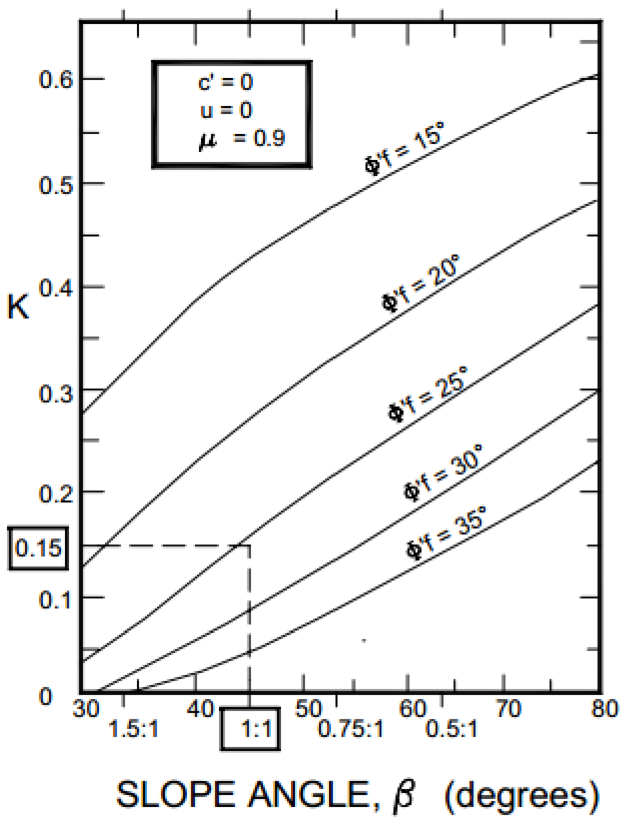

Fig. 4.4: Schmertmann chart

K = 0.13 for $\phi_f = 21.05^0$ and slope angle = 31^0

Step 4: total geogrid force

$$T_{\max} = 0.5 \times K \times \gamma \times (H')^2 \quad \text{................(10)}$$

Tmax = 0.5*0.13*20*(22)^2

Tmax = 629.2 KN/m

Step 5: Long term design strength (LTDS)

$$LTDS = \frac{T_{ult}}{RF_{CR} \times RF_{ID} \times RF_D} \quad \text{.................(11)}$$

$$= \frac{380}{1.6*1.1*1.1}$$

$$= 196.28$$

Number of layers:

$$N = \frac{T_{\max}}{LTDS} \quad \text{................(12)}$$

$$= \frac{629.2}{196.28}$$

= 3.2

3 layers of geogrid will be used

Pullout resistance (P):

Geogrid 1 at 15m, P = 2μ*(c+σ*tanϕ) = 2*0.1(5+17*15*tan30^0) = 30.4 kpa

Geogrid 2 at 10m, P = 2μ*(c+σ*tanϕ) = 2*0.1(5+17*10*tan30^0) = 20.6 kpa

Geogrid 3 at 5m, P = 2μ*(c+σ*tanϕ) = 2*0.1(5+17*5*tan30^0) = 10.8 kpa

CHAPTER 5
ANALYSIS OF REINFORCED SLOPE

5.1 Analysis of the RSS without surcharge

The analysis involves both limit equilibrium and finite element methods. Plaxis for analyzing deformation and stress whereas Geostudio offers the safety factor result.

The unreinforced slope is 670.67 mm which reduced to 19.30 mm when reinforced with geogrids. This reduction is over 900 % of the original total settlement. This shows that the use of geogrids could be very useful in reducing settlement of embankment of slopes and geosynthetic materials can complement soils that are weak in tension. The FOS also increases from 1.376 to 1.582. Geogrid reinforces the soil along potential sliding zones or planes.

Table 5.1: summary of analysis outputs

	Un-reinforced	Reinforced
Displacement	670.67 mm	19.30 mm
Factor of safety	1.376	1.582
Shear strain	9.43 %	38.07 %
Total stress	-342.91 KN/m^2	341.05 KN/m^2
Effective stress	-290.12 KN/m^2	-296.91 KN/m^2
Excess pore pressure	-52.79 KN/m^2	-44.14 KN/m^2

Soil shearing resistance stems from frictional contact between soil particles subject to effective compressive stress. The effective stress is the portion of the total stress transmitted through the particle contacts rather than through the pore water pressure. Soil deforms when it is loaded in shear. In addition to any elastic distortion of the soil particles themselves, shear deformation occurs as soil particle contacts realign to mobilize shearing resistance. The deformation is observed as an overall strain in the soil, and both compressive and tensile strains usually develop when soil shears.

A reinforced soil mass is somewhat analogous to reinforced concrete in that the mechanical properties of the mass are improved by reinforcement placed parallel to the principal strain direction to compensate for soil's lack of tensile resistance. The improved tensile properties are a result of the interaction between the reinforcement and the soil. The composite material has the following characteristics:

- Stress transfer between the soil and reinforcement takes place continuously along the reinforcement.
- Reinforcements are distributed throughout the soil zone with a degree of regularity. Localized.

Stresses are transferred between soil and reinforcement by friction and/or passive resistance depending on the reinforcement geometry. Friction develops at locations where there is a relative shear displacement and corresponding shear stress between soil and the reinforcement surface. Reinforcing elements dependent on friction should be aligned with the direction of soil reinforcement relative movement. Examples of such reinforcing elements are steel strips, longitudinal bars in grids, geotextile, geosynthetic straps, and some geogrid layers.

Passive resistance occurs through the development of bearing type stresses on "transverse" reinforcement surfaces normal to the direction of soil reinforcement relative movement. Passive resistance is generally considered to be the primary interaction for bar mat, wire mesh reinforcements, and geogrids with relatively stiff cross machine direction ribs, the transverse ridges on "ribbed" strip reinforcement also provide some passive resistance.

The contribution of each transfer mechanism for a particular reinforcement will depend on the roughness of the surface (skin friction), normal effective stress, grid opening dimensions, thickness of the transverse members, and elongation characteristics of the reinforcement. Equally important for interaction development are the soil characteristics, including grain size, grain size distribution, particle shape, density, water content, cohesion, and stiffness.

The primary function of reinforcements is to restrain soil deformations. In so doing, stresses are transferred from the soil to the reinforcement. These stresses are resisted by the reinforcement tension and/or shear and bending.

Tension is the most common mode of action of tensile reinforcements. All "longitudinal" reinforcing elements (i.e., reinforcing elements aligned in the direction of soil extension) are generally subjected to high tensile stresses. Tensile stresses are also developed in flexible reinforcements that cross shear planes.

Shear and Bending. "Transverse" reinforcing elements that have some rigidity, can withstand shear stress and bending moments.

Output for Un-reinforced embankment

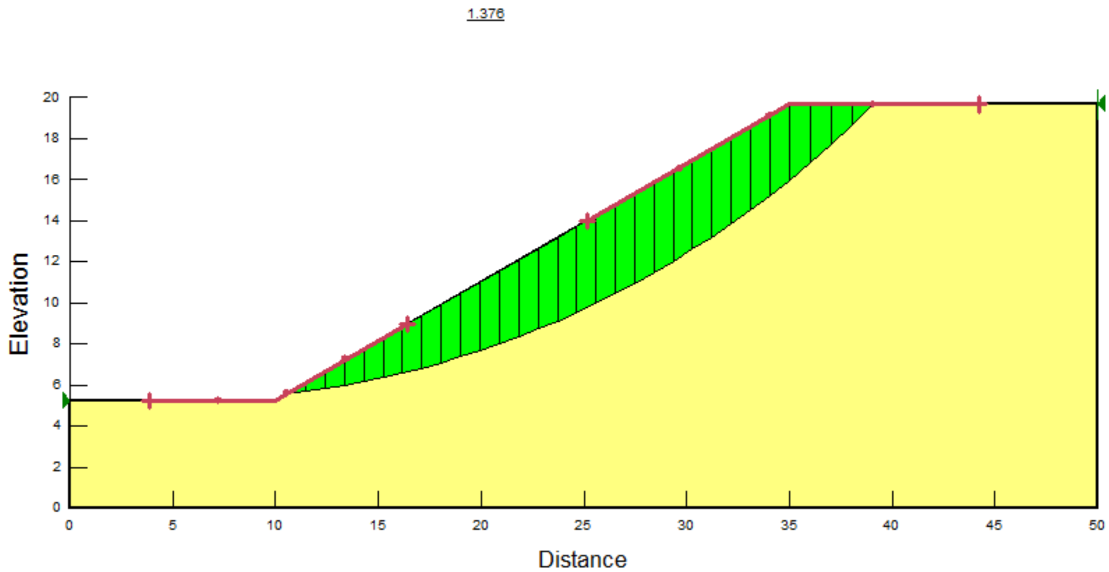

Fig. 5.1: factor of safety of the un-reinforced slope

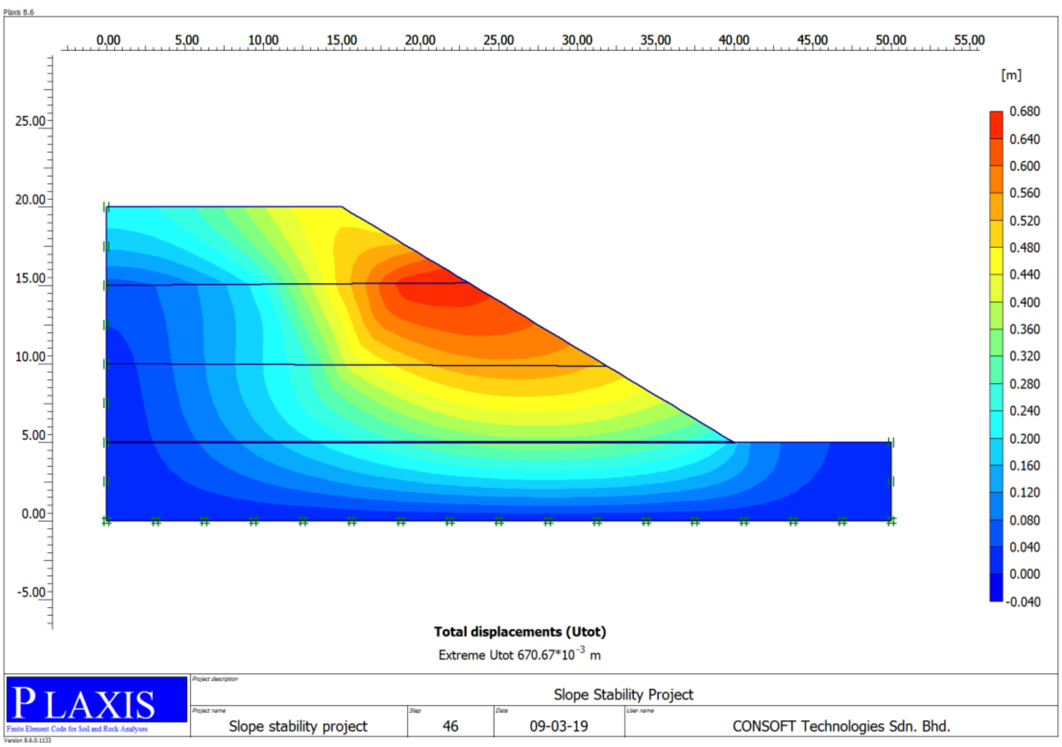

Fig. 5.2: Total displacement of the un-reinforced slope

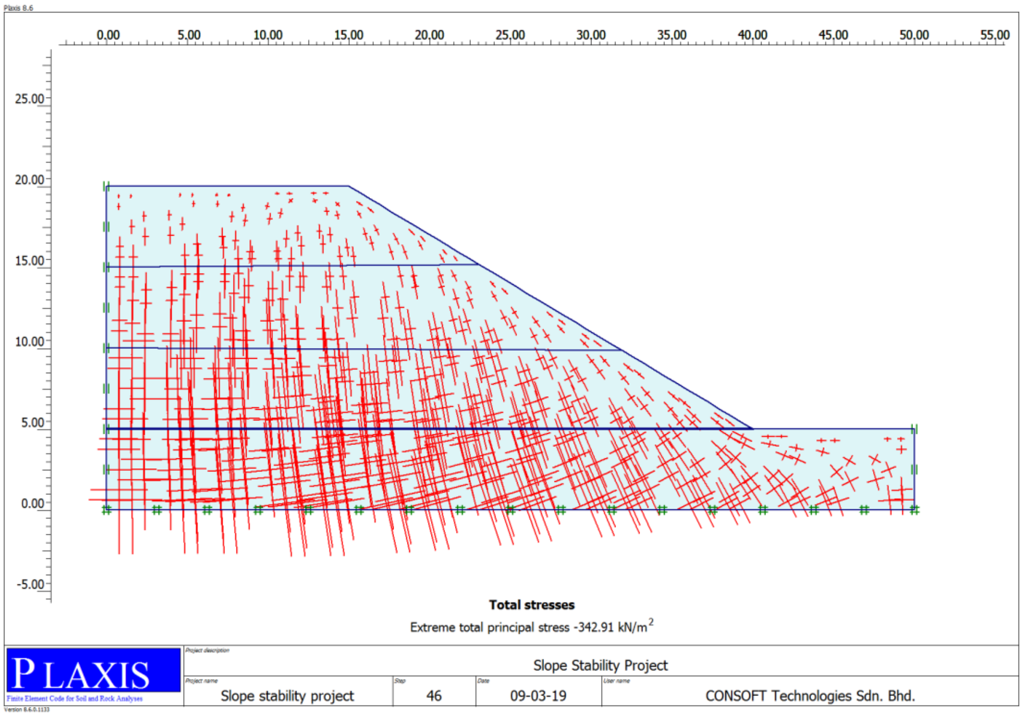

Fig. 5.3: total stress of the un-reinforced slope

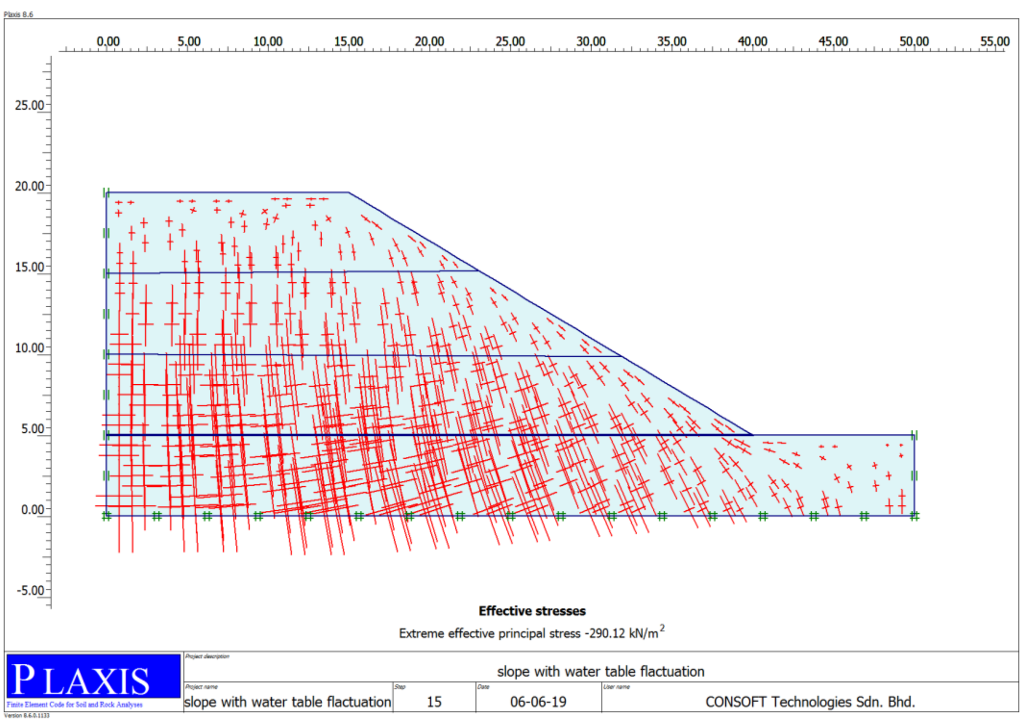

Fig. 5.4: effective stress of the un-reinforced slope

Output for Reinforced embankment

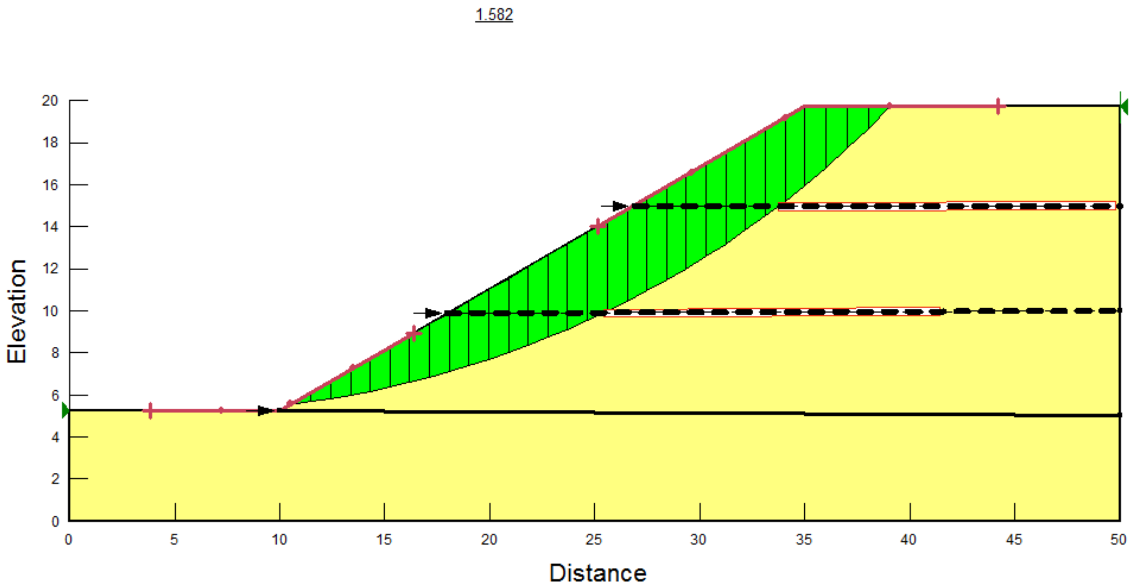

Fig. 5.5: factor of safety of the reinforced slope

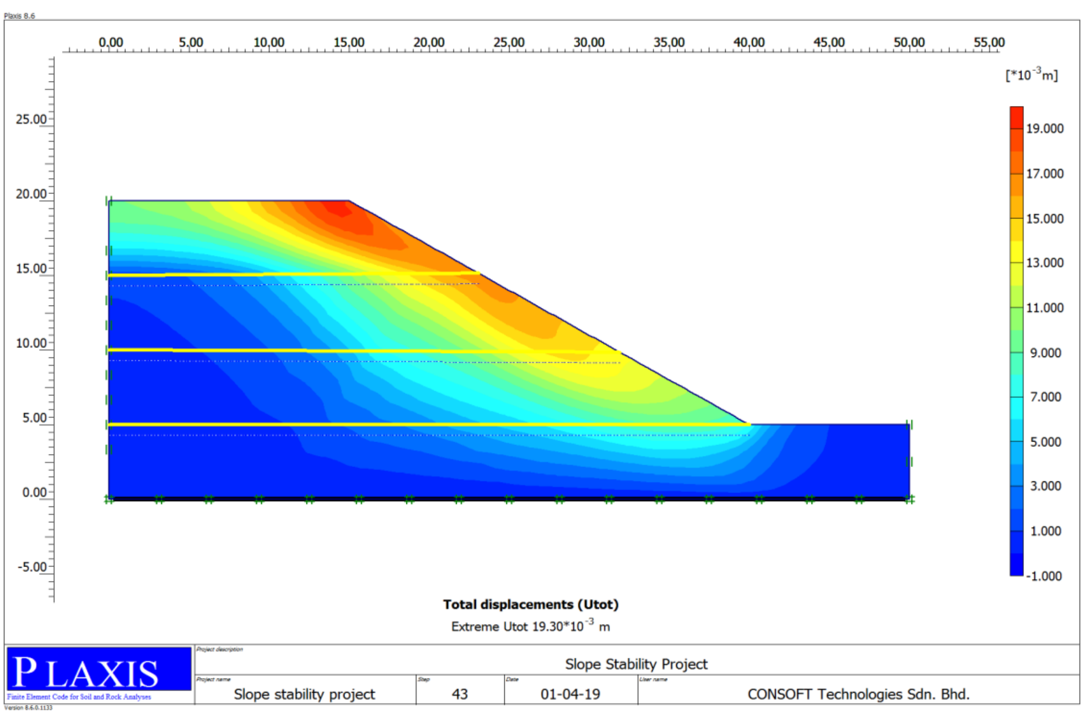

Fig. 5.6: total displacement of the reinforced slope

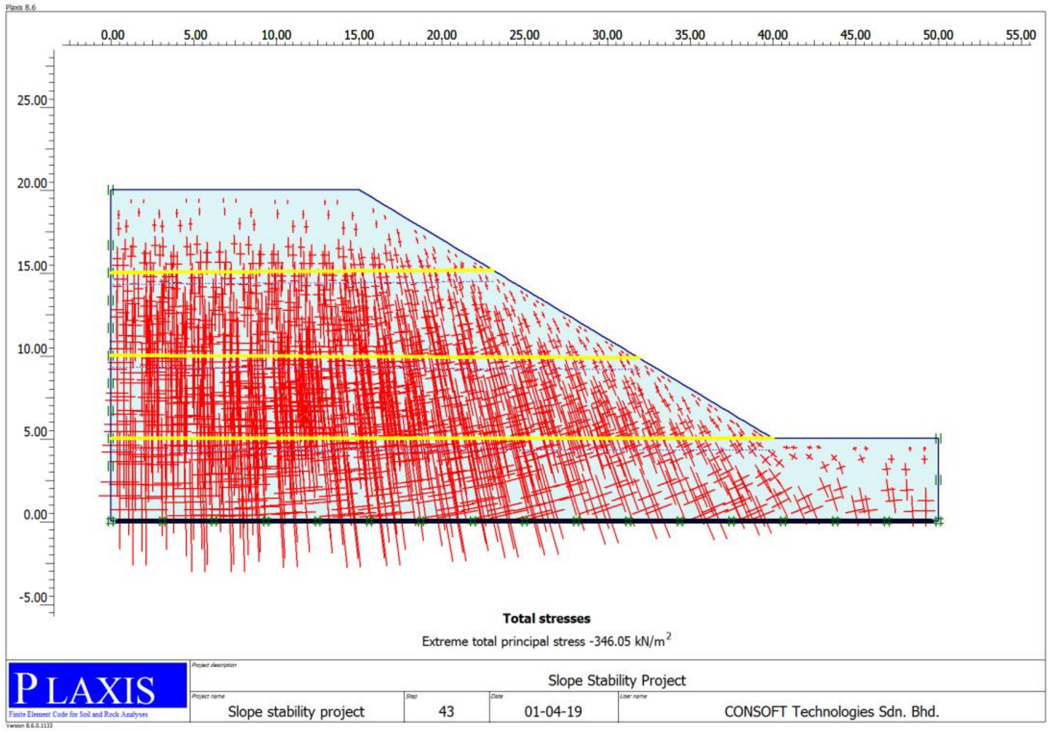

Fig. 5.7: total stress of the reinforced slope

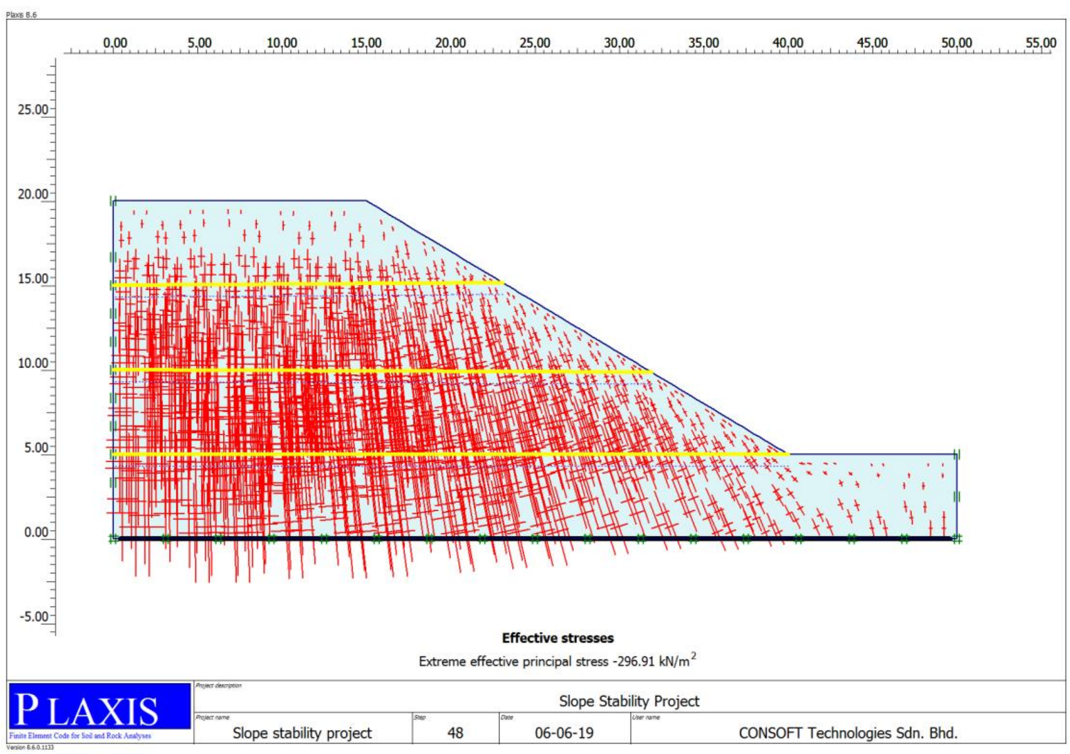

Fig. 5.8: effective stress of the reinforced slope

When reinforcement is placed in soil it can develop bond through frictional contact between the soil particles and the planar surface areas of the reinforcement, and from bearing stresses on transverse surfaces which exist in grids or ribbed strips. Deformation in the soil causes tensile or compressive force to develop in the reinforcement, depending on whether the reinforcement is inclined in a direction of tensile or compressive strain in the soil. The mobilized reinforcement force, ultimately limited by the available bond, acts to alter the force equilibrium in the soil.

Fundamental studies have shown that reinforcement is most effective when aligned in a direction of tensile strain in soil, so that tensile reinforcement force develops (McGowan et al., 1978). This tensile force, acting across a potential rupture surface, (a) directly supports some of the applied shear loading, and (b) increases the normal stresses in the soil on the rupture surface, thereby allowing greater frictional shearing resistance to be mobilized.

The reinforcement stiffness properties int1uence the soil shear deformation required to mobilize the reinforcement force. The maximum possible tensile strain in the reinforcement is equal to the tensile strain in the adjacent soil in the direction of the reinforcement. Thus reinforcement orientated in the direction of maximum tensile strain will experience the greatest elongation for any given shear deformation in the soil.

It is useful to consider the amount of tensile strain which develops in the soil and the reinforcement in order to assess the equilibrium in reinforced soil. This helps ensure that (1) the design values selected for the reinforcement force and the soil shearing resistance can realistically be mobilized together, and that (2) the equilibrium can be achieved with acceptable deformation in the structure.

Tensile axial force in reinforcement improves the shearing resistance of soil, and reinforcement acts most effectively when placed in a direction in which tensile strain develops in the soil.

The load-elongation properties of the reinforcement influence the rate at which force can be mobilized as the soil deforms. The mobilized reinforcement force must remain in equilibrium with the surrounding soil, otherwise the reinforcement pulls out when the bond stress is exceeded.

The shear strength of reinforced soil is determined jointly by the mobilized shearing resistance in the soil and the mobilized tensile force in the reinforcement. The relative magnitude of these mobilized resistances depends on the deformation properties of the constituent soil and reinforcement materials. The question of strain compatibility between the soil and reinforcement materials must be considered so that appropriate combinations of resistances can be chosen for use in design analysis. The inclusion of reinforcement in soil introduces the possibility of new failure mechanisms involving direct sliding across the surface of a reinforcement layer.

5.2 Analysis of the RSS with surcharge

The analysis was done by applying different values of surcharge on the slope. The results obtained are as follow.

Table 5.2: factor of safety for different surcharge loads

Surcharge load (KN/m^3)	Factor of safety	
	Un-reinforced	Reinforced
30	1.376	1.496
50	1.325	1.416
70	1.269	1.351
100	1.200	1.273

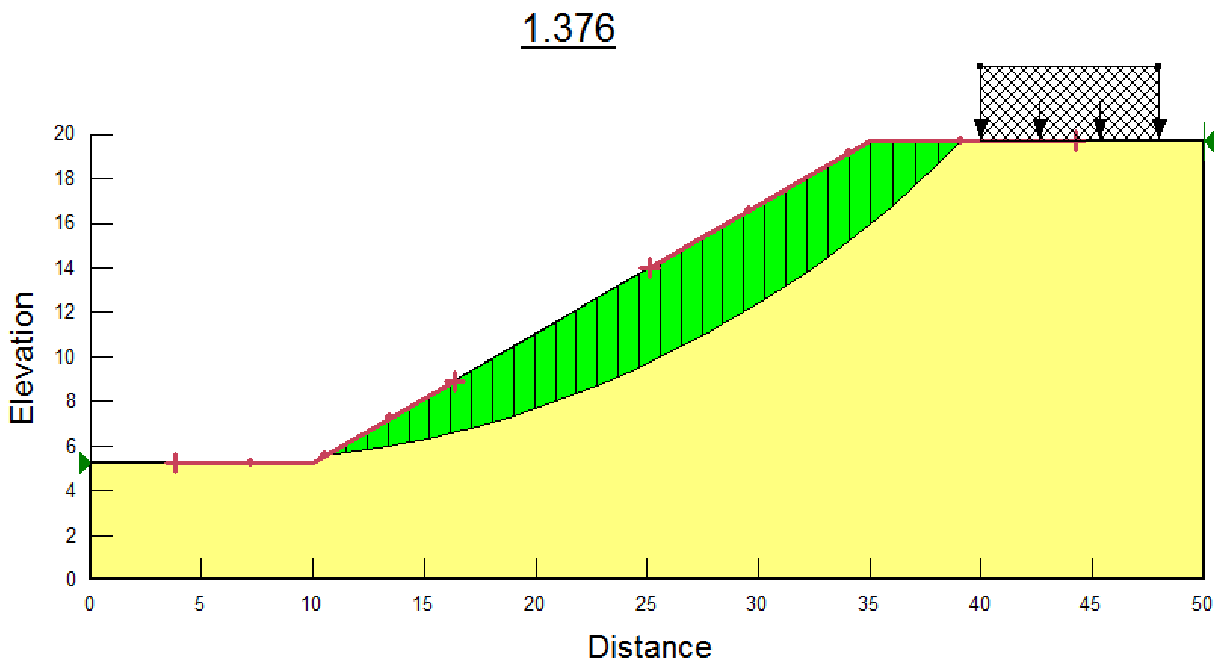

Fig. 5.9: Un-reinforced slope with 30 KN/m^3 surcharge

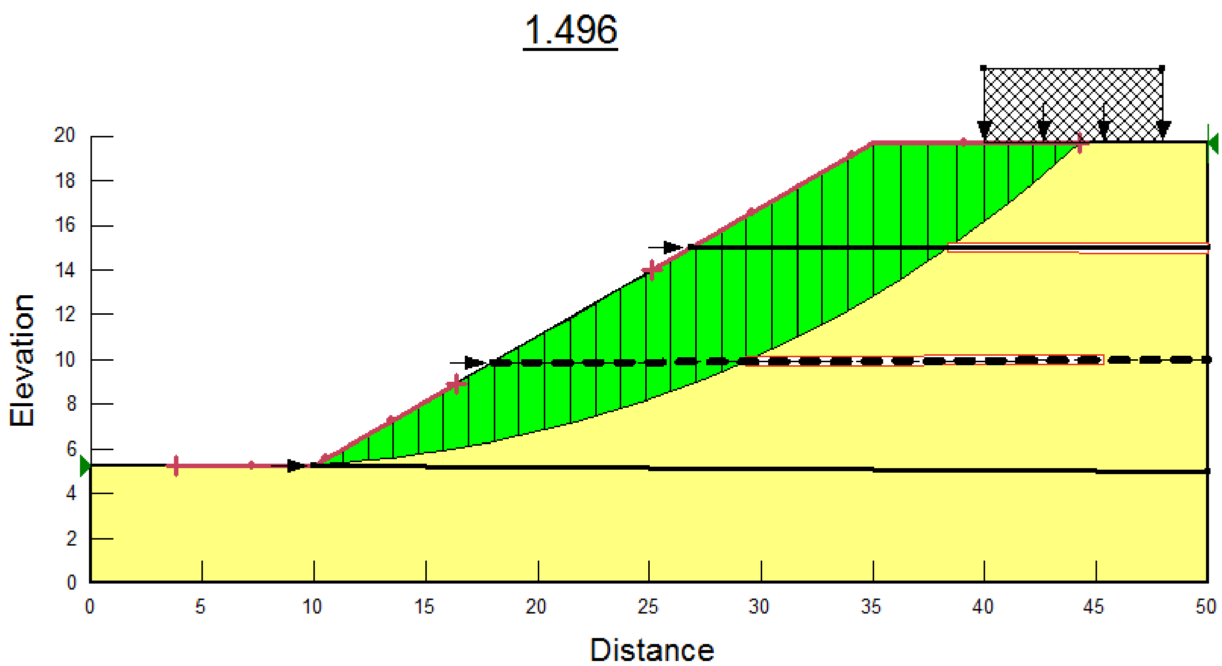

Fig. 5.10 Reinforced slope with 30 KN/m^3 surcharge

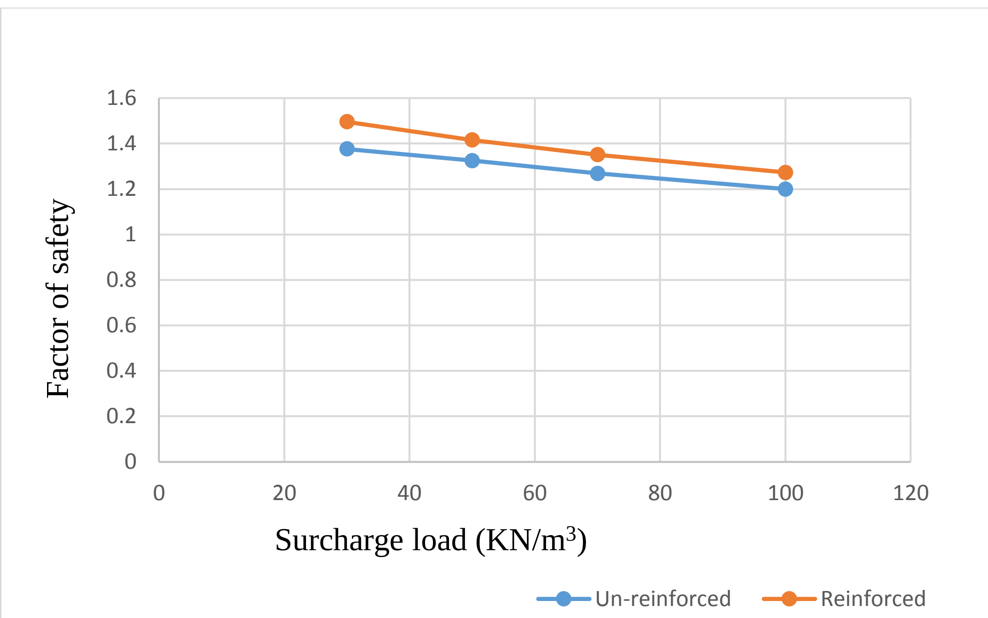

Fig. 5.11: factor of safety under surcharge load for both cases

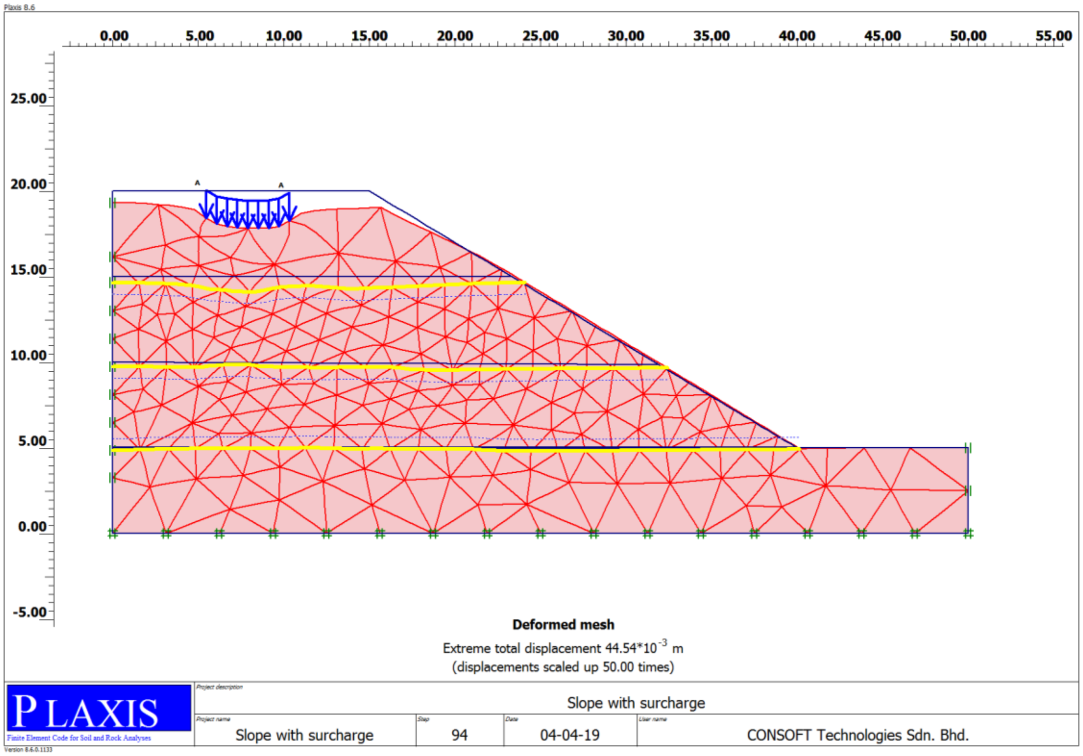

Fig. 5.12: deformed mesh under surcharge load for reinforced slope

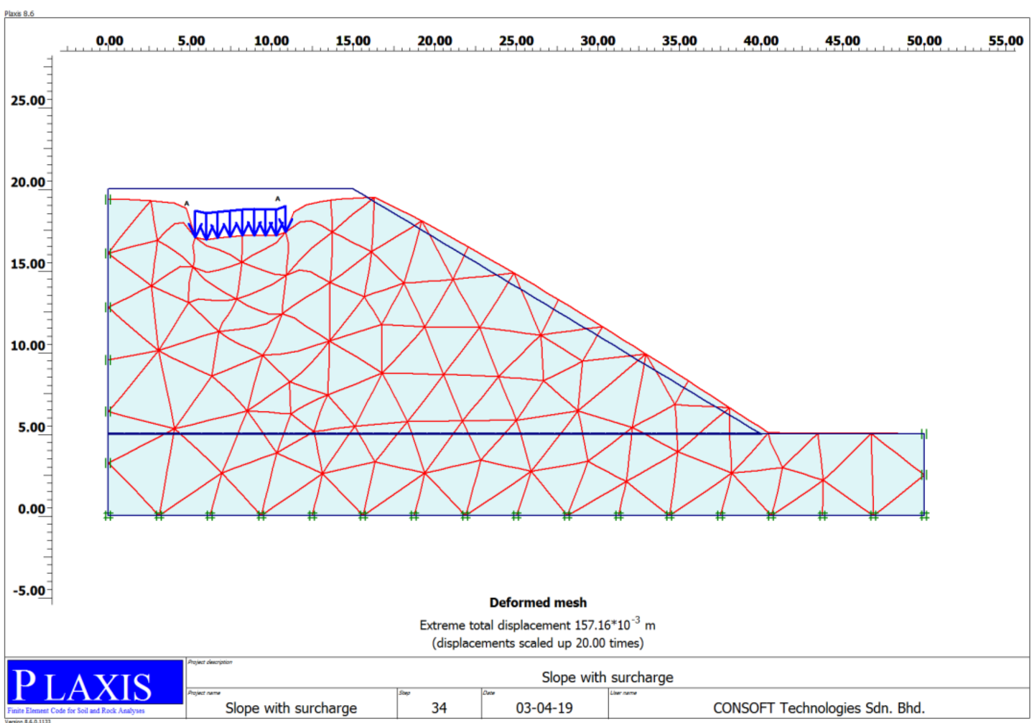

Fig. 5.13: deformed mesh under surcharge load for un-reinforced slope

Table 5.3: Analysis outputs with 100 KN/m^2 surcharge

	Un-reinforced	Reinforced
Displacement	157.16 mm	44.54 mm
Total stress	-351.77 KN/m^2	-348.34 KN/m^2
Effective stress	- 338.42 KN/m^2	-335.42 KN/m^2
Excess pore pressure	-13.35 kN/m^2	-12.92 KN/m^2
Shear strain	6.05 %	27.75 %

Different amounts of surcharge were applied on the embankment and the results were obtained both on Plaxis and Geostudio. The results from Geostudio depict that the safety factor increased for the reinforced slope and also upon increment of the surcharge loads, the safety factor was reduced significantly. The reinforcement plays a great role for the stability of the slope.

Table 5.4: Axial force before and after surcharge

Elevation (m)	Axial force (slope without surcharge) (KN/m)	Axial (slope with surcharge of 100 KN/m^2) (KN/m)
15	$11.12*10^{-6}$	$328.67*10^{-3}$
10	$21.24*10^{-6}$	$49.05*10^{-3}$
5	$7.63*10^{-3}$	$13.59*10^{-3}$

The axial force results increased in the case of embankment with a surcharge load of 100 KN/m^2. However, it has different pattern of increment with respect to elevation.

In the case of the slope without the surcharge, axial force increases as the elevation go down. Whereas it decreased down to the lowest elevation level when it was loaded with a surcharge load of 100 KN/m^2.

CHAPTER 6
SEEPAGE ANALYSIS

6.1 Groundwater Analysis

The safety factor was computed by fluctuating the groundwater level at different elevations of the slope. The values are higher for the reinforced one. The factor reduced upon higher water table. As the water table reduces the safety factor increases because of less pore pressure.

Table 6.1: Groundwater effect on safety factor

	Factor of safety	
Elevation (m)	Un-reinforced	Reinforced
0	1.925	2.093
1	1.876	2.044
3	1.778	1.943
5	1.654	1.77
8	1.418	1.623

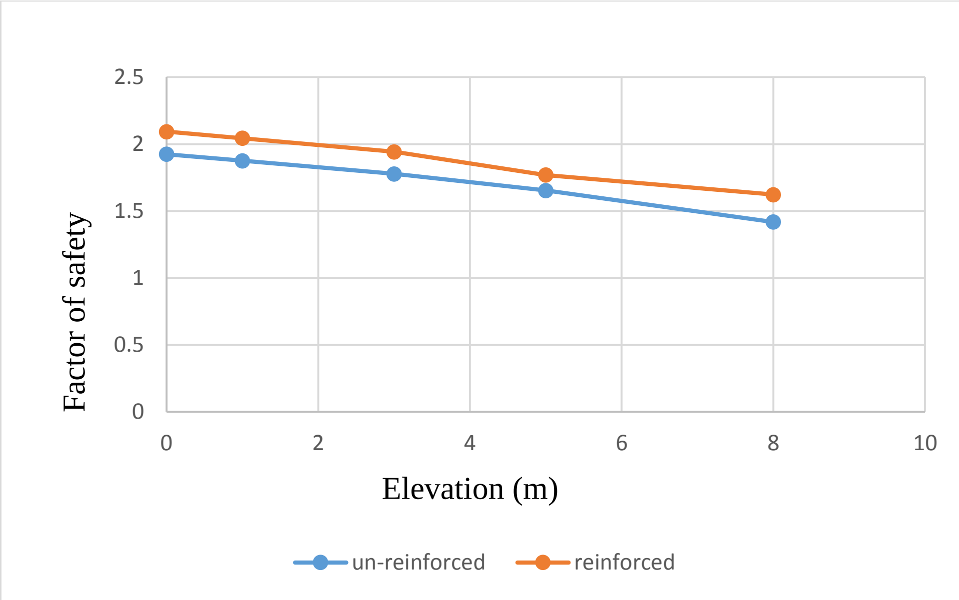

Fig. 6.1: Groundwater effect on safety factor

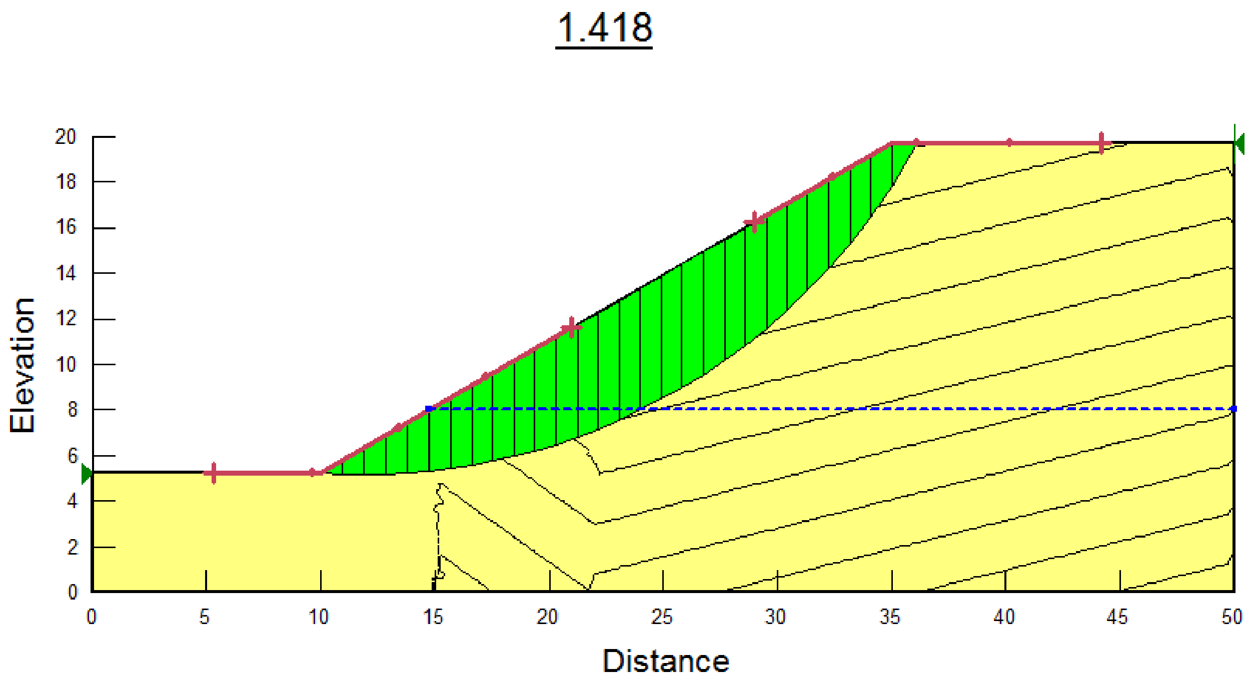

Fig. 6.2: FOS at 8m of GWT for un-reinforced slope

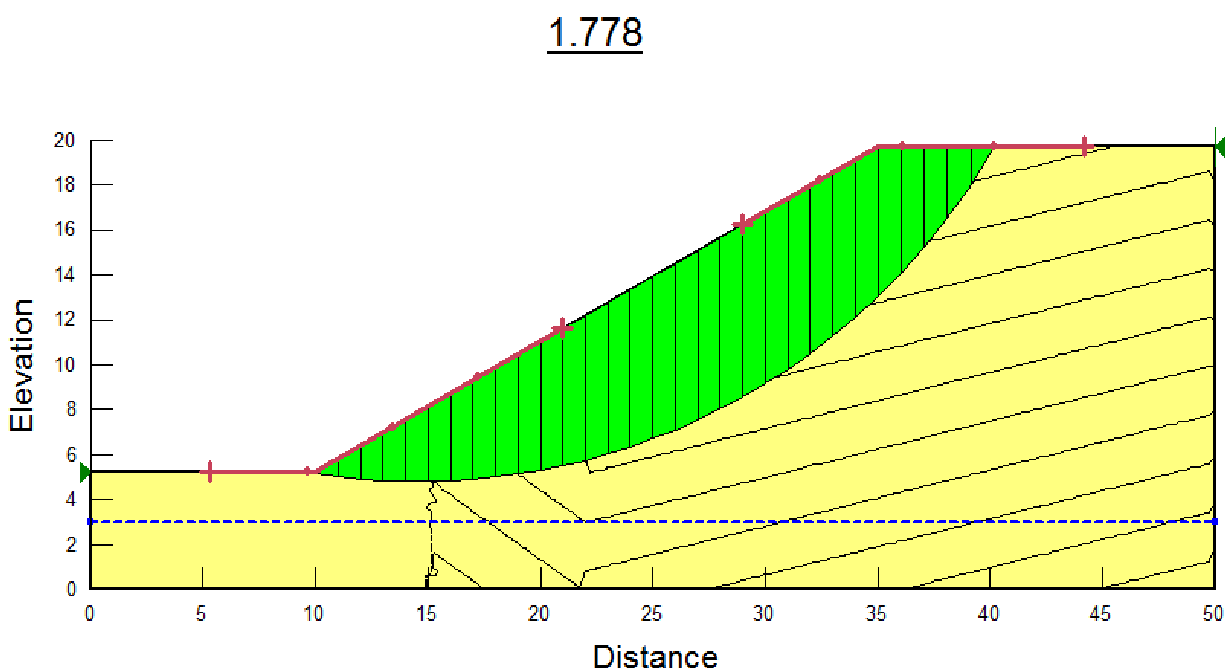

Fig. 6.3: FOS at 3m of GWT for un-reinforced slope

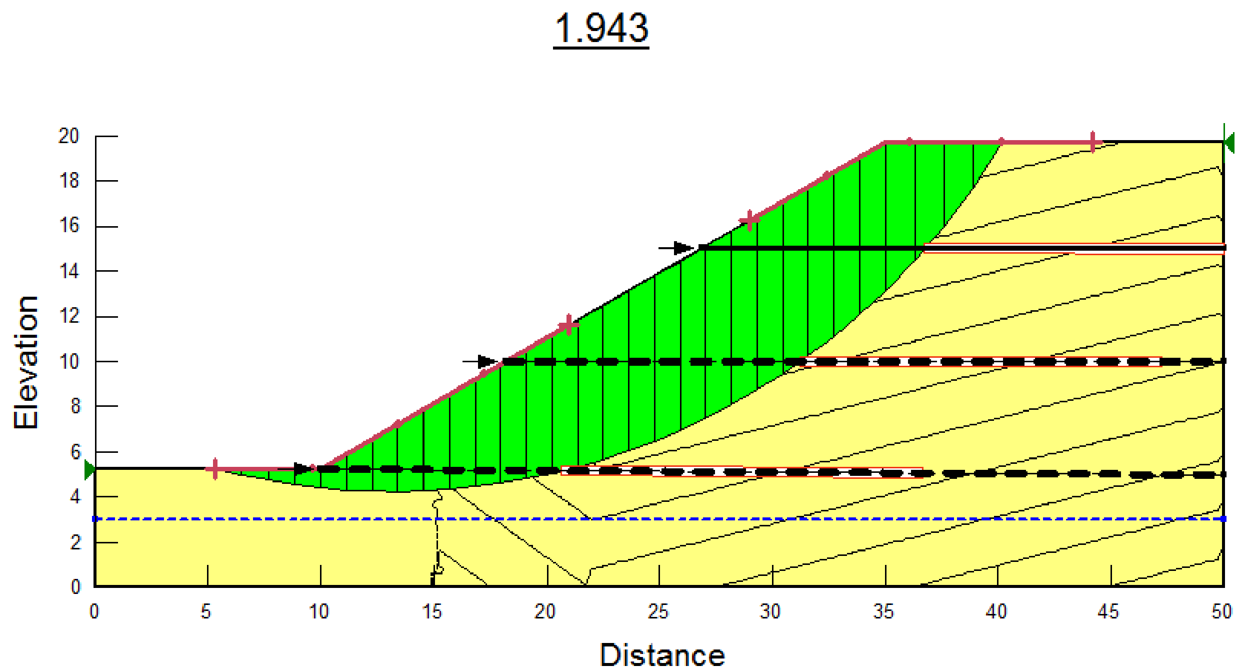

Fig. 6.4: FOS at 3m of GWT for Reinforced slope

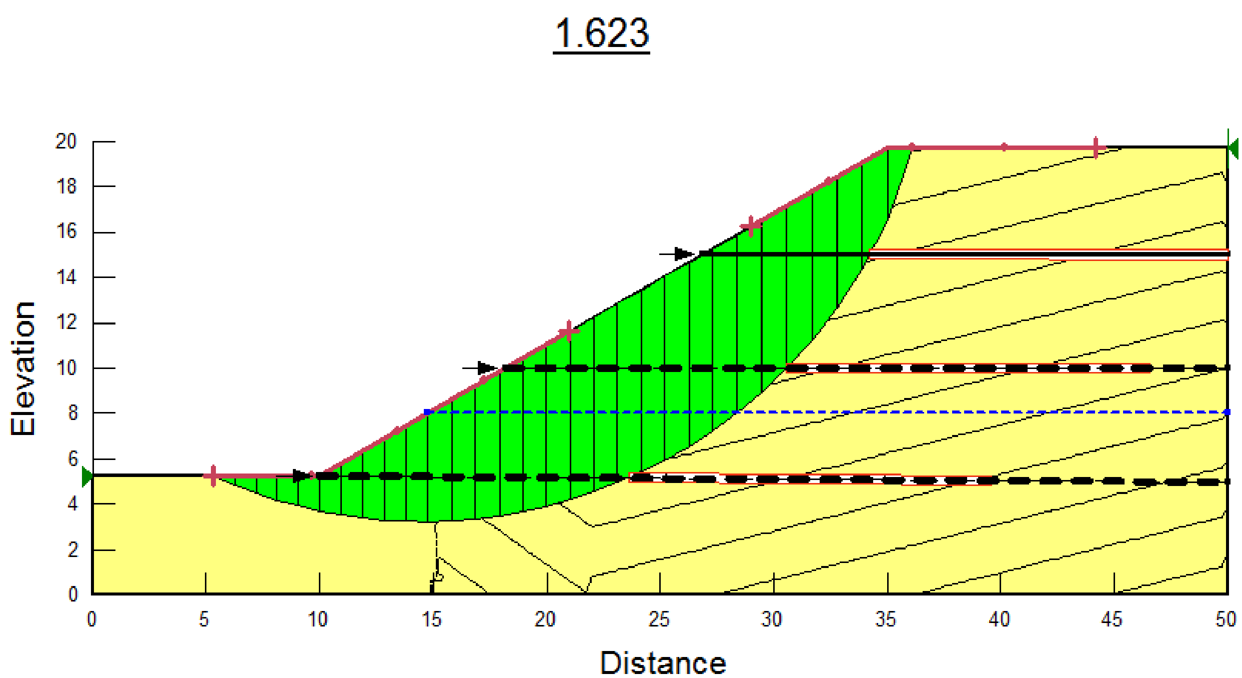

Fig. 6.5: FOS at 8m of GWT for Reinforced slope

Geostudio was used to compute the safety factor for different cases of groundwater table. As the water table elevation decreases, the factor increases in both reinforced and unreinforced slopes. It shows that the water table saturates the soil and decreases the shear strength of the soil which in turn reduces stability of the slope.

The rise of water table analyzed here doesn’t include piping or uplift and other vibrations. It increases pore pressure and reduces effective stress of the soil.

6.2 Transient drawdown of water analysis

This analysis was done to consider the rapid drawdown of water incase flooding occurs. It's performed by using steady and transient analysis for a duration of 5 days. The following results from Geostudio represents the output from the drawdown of water in different intervals of time.

The steady state analysis was carried out initially to simulate constant drawdown of water with time and after that a transient analysis was performed to represent the removal of water over a period of five days. The analysis also continued for thirty days until the water is dissipated from the embankment.

After the analysis was done different graphs were obtained from the result regarding to change of factor of safety with time; pore water pressure in relation to time and also the upstream deformation in reference to time were depicted and discussed below.

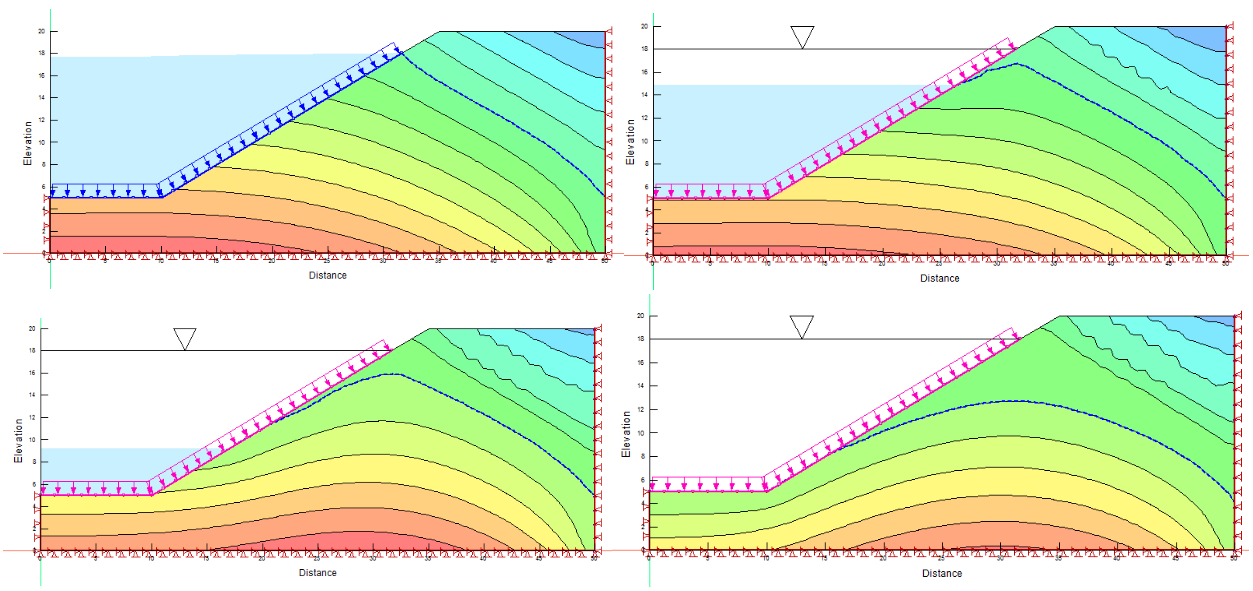

Fig. 6.6: Drawdown of water

The analysis starts from creating the geometry of the slope by checking the units and scales convenient for use. After that the material properties should be defined as per the parameters which are stated at the beginning for the embankment and then it will be assigned to the regions in the geometry of the slope. The boundary conditions also assigned to perform the analysis. In this case, the reservoir level with a total head of 18 meters is assigned to the inclined slant surface. Fixed supports were also assigned to the sides and the bottom of the geometry of the slope.

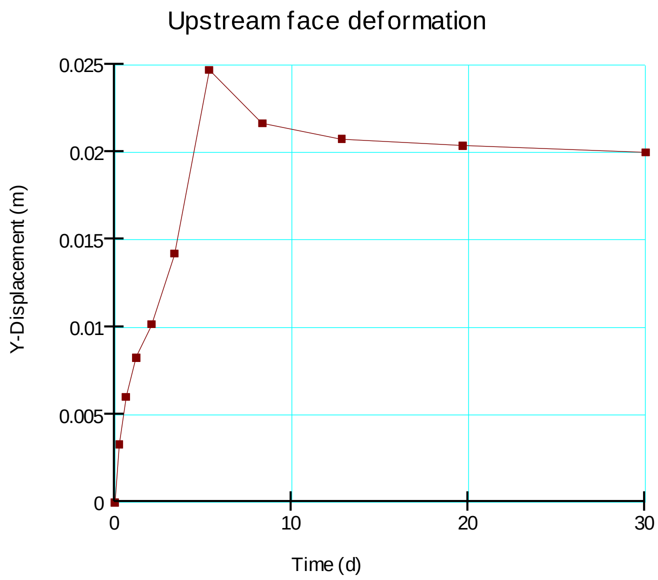

Fig. 6.7: Upstream face deformation

The graph in the above shows that the soil is rebounding upon the removal of the water from the embankment surface until 5 days and then the graph declines after dissipation of the pore water pressure from the soil; deformation of the soil reduced.

The face deformation of the slope continued for five days because of the removal of weight of the water as the graph shows and then the soil settles back down after five days.

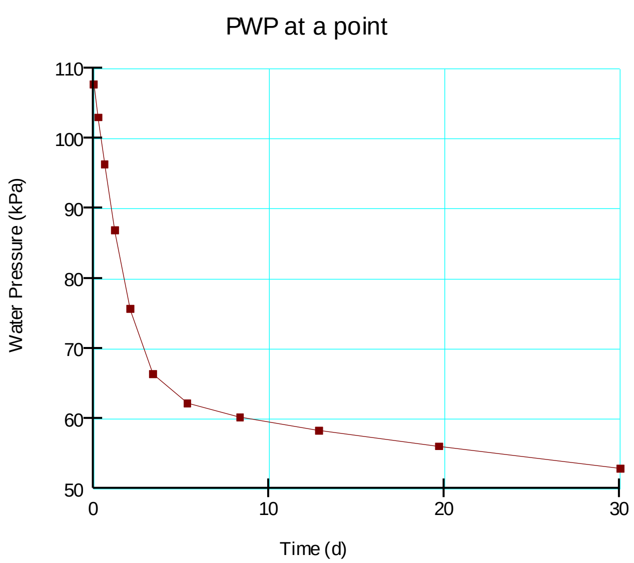

Fig. 6.8: Pore pressure at a point (15,5)

The pore water pressure as shown in the graph declines drastically until five days upon the removal of the water and then continued to decrease for thirty days until the pore water is fully dissipated from the embankment.

As long as rapid drawdown of water is considered there will only be a decline in the value of the pore water pressure which varies upon the time specified for the water to be removed.

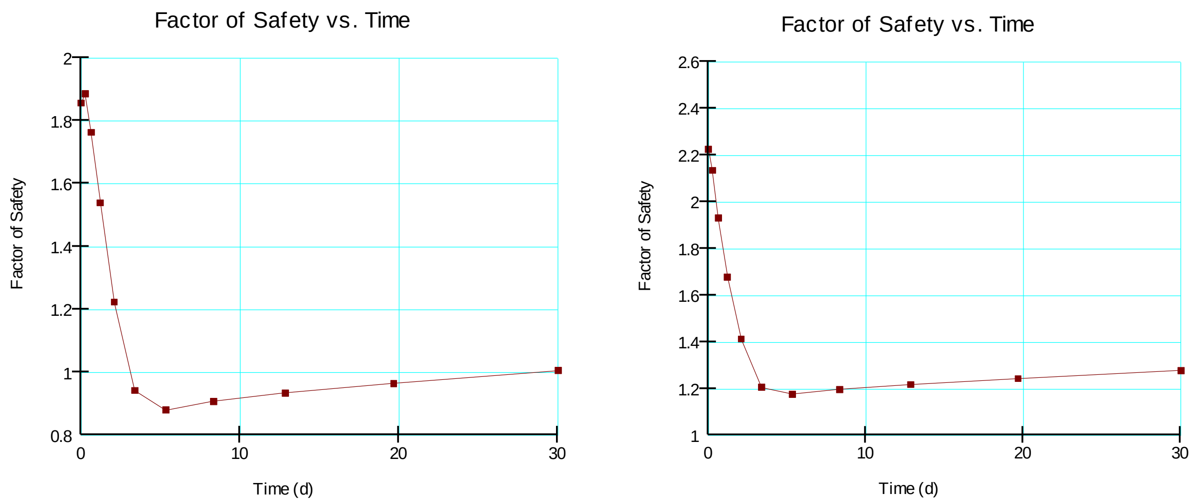

Fig. 6.9: factor of safety with time for un-reinforced (left) and reinforced case (right)

As we can see from the graph, the factor of safety was very high under static condition but then with the slow drawdown of the reservoir the safety factor diminishes. After the reservoir from flooding is gone and pore pressure dissipates the factor of safety again increases. This is because the weight of water used as a stabilizing agent at first and then its removal reduced the safety factor.

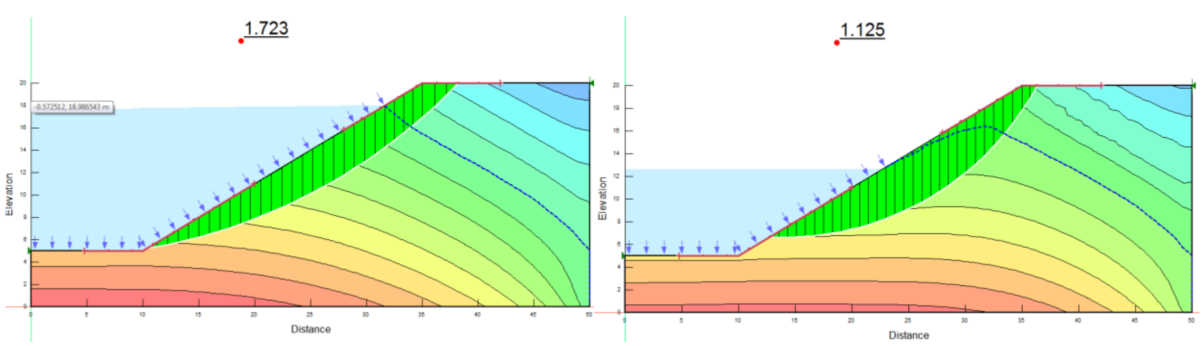

Fig. 6.10: factor of safety at 0 day and 2.08 days

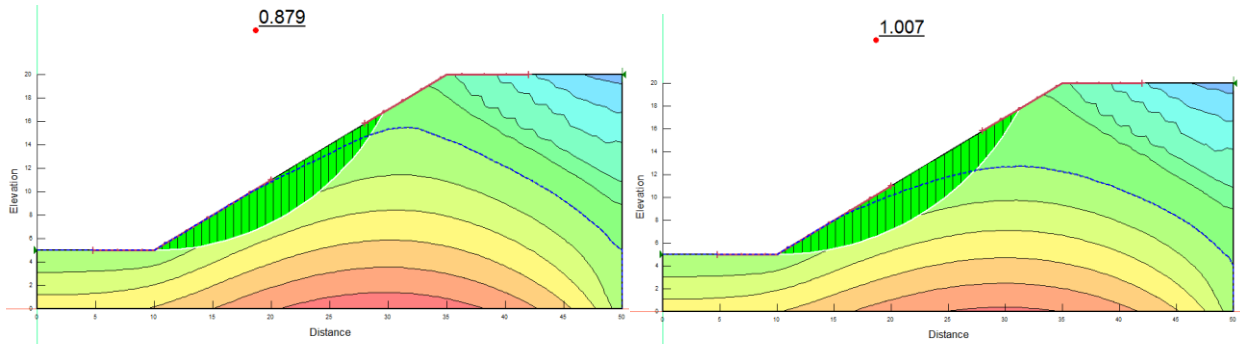

Fig. 6.11: factor of safety at 5.33 days and 30 days

The safety factor shows higher results in case of reinforced embankment as it’s also the case for different type analysis performed above. The following are the results obtained from Geostudio for the reinforced embankment case. The safety factor reduces as the water is removed from the slope surface but then it increase as the pore water is removed from the embankment.

Outputs for reinforced embankment:

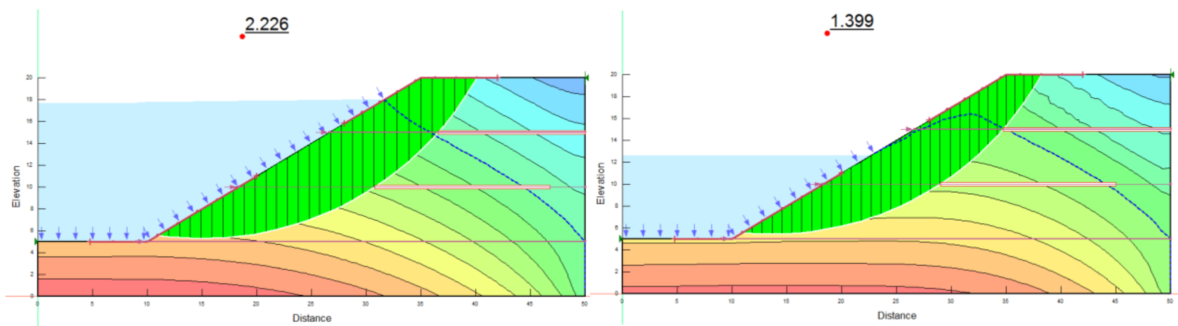

Fig. 6.12: factor of safety at 0 day and 2.08 days (reinforced)

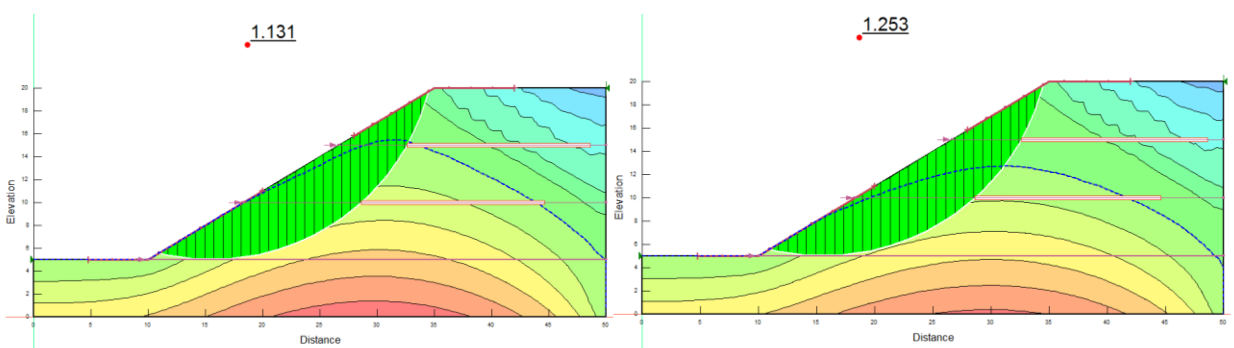

Fig. 6.13: factor of safety at 5.33 days and 30 days (reinforced)

Table 6.2: factor of safety with time for un-reinforced and reinforced cases

Days	**Un-reinforced FOS**	**Reinforced FOS**
0	1.723	2.226
0.25 (6 hours)	1.662	2.136
0.625 (15 hours)	1.515	1.932
1.21	1.333	1.679
2.08	1.125	1.399
3.38	0.930	1.172
5.33	0.879	1.131
8.33	0.908	1.157
12.8	0.934	1.182
19.7	0.966	1.212
30	1.007	1.253

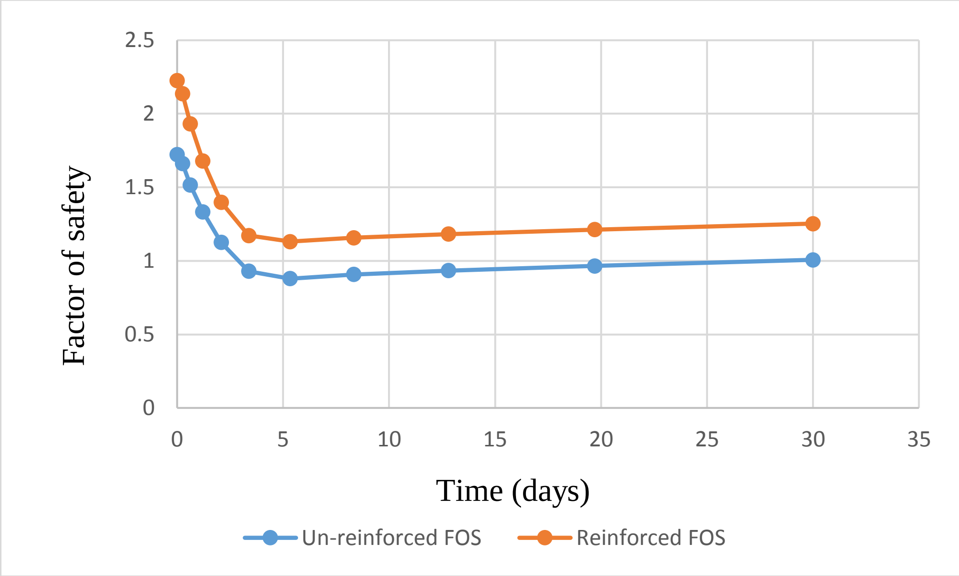

Fig. 6.14: factor of safety with time for un-reinforced and reinforced cases

As we can see both from the table and the graph, the safety factor initially got reduced as the water level decreased from the embankment but then it starts to increase upon the removal and dissipation of the pore pressure from the embankment.

The factor of safety for the reinforced embankment is higher than the one for un-reinforced case. It shows that the reinforcement has a significant effect to maintain or increase the stability of the embankment. So far the geogrid reinforcement has shown its positive impact on the embankment for different types of analysis performed earlier in this study.

CHAPTER 7
RAINFALL ANALYSIS

Rainfall induces a major problem to the slope stability. The effect rainfall intensity and duration are investigated by transient analysis on Geostudio by assuming the ground water level at 5 meters. The infiltration from the rainfall increases the pore water pressure above the ground water level tends to slightly increase the water table as well.

The factor of safety obtained is compared with different values of rainfall intensity and duration without considering the geogrid reinforcement. Pore water pressures computed during the transient seepage analyses are used as input groundwater conditions for limit equilibrium analyses of the stability of the slope. It was found that the factor of safety not only depended on the intensity of rainfall and the initial groundwater table, but also on rainfall duration. A critical rainfall duration was identified, when the factor of safety was the lowest.

7.1 Influence of Rainfall Intensity

For investigation of the intensity of rainfall, four daily rainfall intensities with the same duration were considered. Then seepage analysis was done before the transient analysis. The safety factor also determined followed by the transient analysis which is later used to compare against the rainfall intensity. A certain section (a-a) was considered to assess the effect of the intensity. The results show that the factor of safety increases upon the rise of the rainfall intensity.

The water table slightly rises because of the rainfall and the matric suction or negative pore pressure decreases. The permeability of the soil also affects the rise of water table at shallow depth. It can be seen that for a given set of soil permeability, slope geometry and initial groundwater conditions, the factor of safety of the slope decreases as rainfall intensity increases. Based on research results published by Leach & Herbert (1982), the response to rainfall is a direct function of the ratio of the saturated soil permeability to the specific storage in a fixed slope geometry. The higher the value of the ratio, the faster the heads will rise and decay, and the shorter will be the response time of the system to storm events.

The decrease of the factor of safety was attributed to the reduction in effective stresses caused by the rise in pore water pressures. The effects of various rainfall intensities on the stability of the cut slope are shown below for four different daily rainfall intensities. Both positive and negative pore water pressures predicted by SEEP/W were used as input groundwater conditions for limit equilibrium analyses of the stability of the slope. The factor of safety was calculated using Bishop's simplified method, with modified Mohr-Coulomb failure criterion to allow for shear strength variation due to the presence of matrix suction.

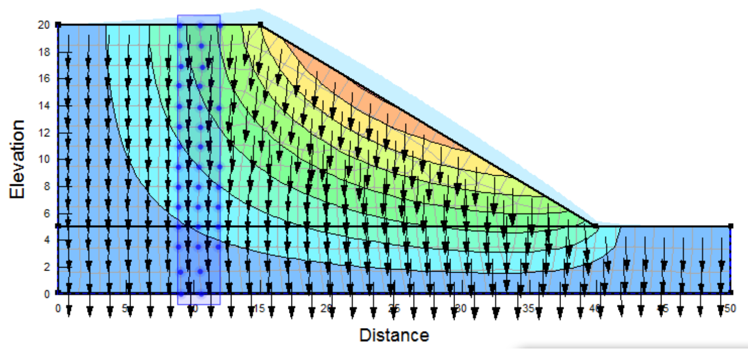

Fig 7.1: Section (a-a) for rainfall intensity analysis

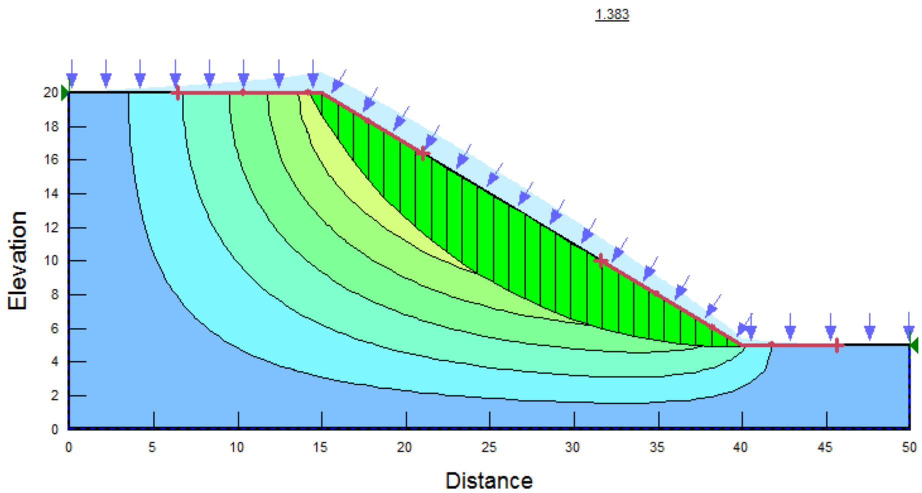

Fig 7.2: FOS for rainfall intensity of 250 mm/day

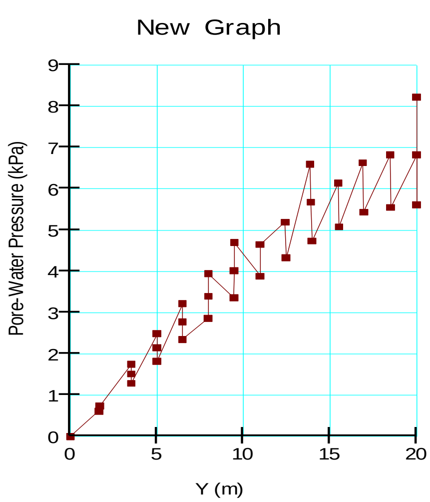

Fig. 7.3 Pore water pressure at section (a-a)

Table 7.1: FOS with respect to rainfall intensity

Rainfall intensity (mm/day)	Duration (hours)	Factor of safety (FOS)
0	-	1.412
250	24	1.383
320	24	1.361
400	24	1.332
480	24	1.305

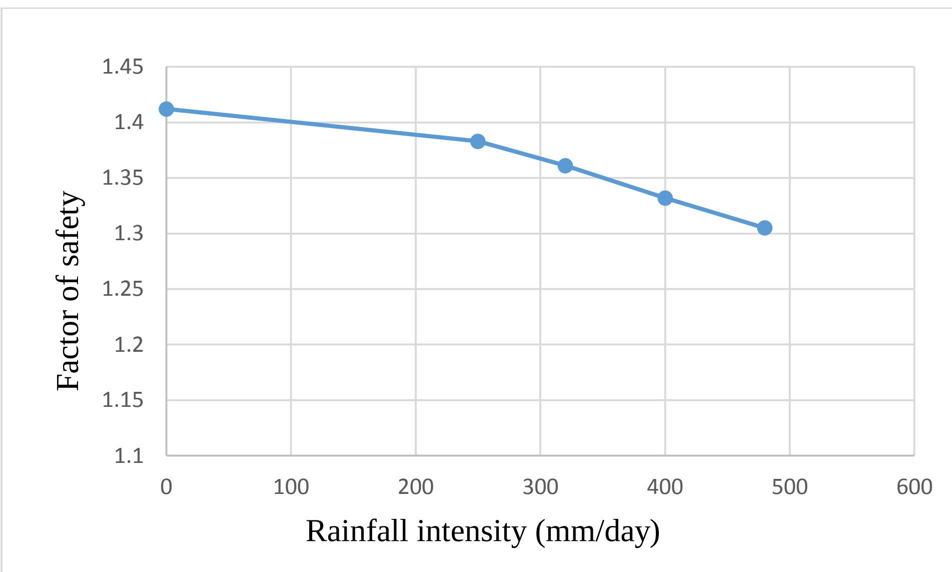

Fig 7.4: FOS with respect to rainfall intensity

The factor of safety decreases upon the increase of rainfall intensity as it induces a reduction of effective stress and shear strength of the soil because of infiltration.

7.2 Influence of Rainfall Duration

The influence of long periods of rainfall on slope stability has attracted considerable attention and debate over the years. The majority of landslides were induced by localized short duration rainfall events of high intensity. Other factors, such as local geological conditions and hydrological conditions, such as initial groundwater table were not taken into account. A constant rainfall intensity of 200 mm/day was considered to analyze the influence of the duration.

It can be seen that the rise of the main water table decreases slightly with increasing duration, because the rate of rainfall is smaller for longer rainfall duration. At first sight, prolonged rainfall does not seem to alter the main groundwater table significantly, nor the factor of safety of the slope. However, prolonged rainfalls alter the pore pressure regime above the main water table significantly and this alteration results in a noticeable fall in the factor of safety.

Based on the analyzed results, a critical rainfall duration exists, which leads to the lowest factor of safety. For the present investigation, the critical rainfall duration is found to lie between three and seven days. The concept of the existence of a critical duration is in fact consistent with field measurements of groundwater response at the mid-levels to rainfalls.

Typically the critical duration was found to lie between 3 and 7 days. Before reaching the critical duration, infiltration of rain water continues to increase the permeability of unsaturated soils, resulting in a rise of the main water table, until it reaches its maximum level at the critical duration. As average rainfall intensity decreases rapidly with time the main water table will not rise further for rainfalls with duration longer than the critical value. Instead, groundwater will be drained away by soils with sufficient high permeability after 'soaking'.

High-intensity rainfall may be a triggering factor for landslides but there are other factors such as the initial groundwater table and the duration of antecedent rainfall which are also important and contribute to the occurrence of landslides. The factor of safety decreases as the duration of rainfall increases, until a critical duration is reached. the critical duration is seven days when the factor of safety is lowest. For rainfalls longer than the critical duration, the factor of safety gently increases because the average rainfall intensity lessens.

Table 7.2: FOS with respect to rainfall duration

Duration (days)	FOS
0	1.412
1	1.405
3	1.297
7	1.29
14	1.359
21	1.373
30	1.395

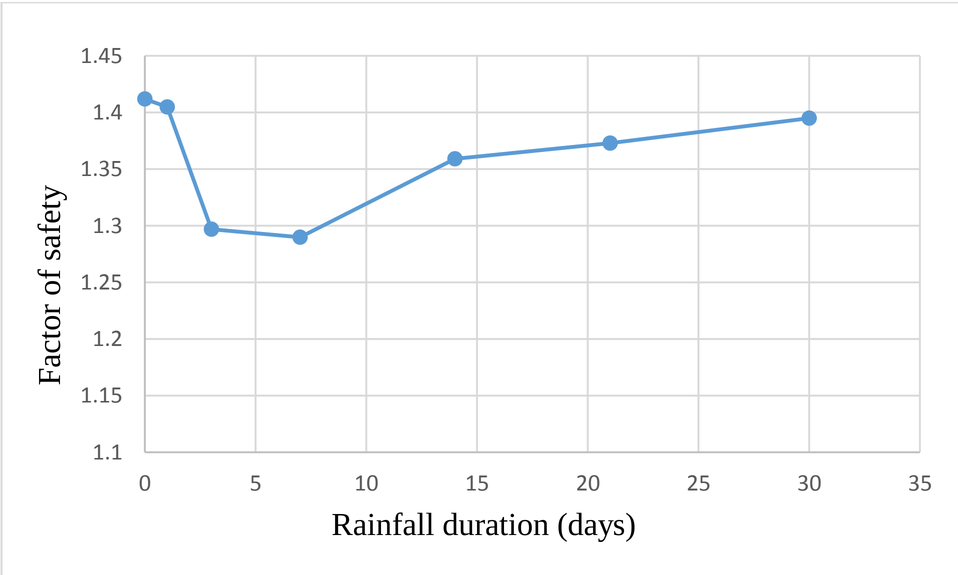

Fig. 7.5: FOS with respect to rainfall duration

The safety factor declines until critical duration and then starts to increase gently.

CHAPTER 8
CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

Embankment with geogrid reinforcement performs better than the one without it. The factor of safety was improved and the settlement decreases. It performs well under different conditions. The design procedure helped to choose the appropriate number of layers of geogrid to be used for ensuring the slope stability. Factor of safety increases with the increase of geogrid tensile strength but the displacement reduces slightly.

During surcharge loading, the reinforced slope performed well. The safety factor is higher and the displacement is lower. The axial force increases to the lowest elevation in case of unreinforced slope but it decreases down for the case of reinforced one.

As ground water level rises the pore pressure increases which reduces the effective stress and shear strength so that the factor of safety also declines.

Rapid drawdown of water reduces the safety factor as its weight of water has a stabilizing effect. But after five days the safety factor starts to rise upon dissipation of the pore water. The slope face deformation also increases when the water is removed but later the deformation reduces and the soil settles back down. The pore water pressure declines drastically upon removal of the water and then after five days it continue to decrease gently.

The rainfall is also a major problem to the slope stability. The influence of its intensity and duration were analyzed in this study. As the rainfall intensity increases the pore pressure above the ground water table increases and effective stress declines because of the infiltration which reduces the safety factor. The ground water table was static at 5 meters but there will be a slight rise because of the rainfall. Four different rainfall intensities which has the same duration were used for the analysis and the safety factor declines upon the increase of the rainfall intensity.

The rainfall duration also has effect to the slope stability. As it increases the safety factor declines until the critical duration between three and seven days and then it starts to rise gently. After a certain critical duration the pore water will be drained away by high permeability soils after soaking.

The geogrid reinforcement has shown its positive impact on the embankment for different types of analysis performed in this study.

8.2 Recommendations

Facing of the slope has also a positive effect for the slope stability and it could be analyzed as well.

Effect of water table on the rainfall analysis shall be investigated.

References

[1] B. R. G. S. A. G. J. P. J. I. M. J. K. S. F. a. Christopher, Reinforced soil structures design and construction guidelines, 1990.

[2] R. D. Holtz, "Geosynthetic for Soil Reinforcement," *The Ninth spencer J.,* 2001.

[3] E. M. T. F. B. R. J. S. Palmeira, "Geosynthetics Materials and Applications for Soil Reinforcement," *Electronic Journal of Geotechnical Engineering (EJGE),* 2008.

[4] P. Widas, Introduction to Finite Element, Virginia Tech Material Science , 1997.

[5] D. M. a. M. B. G. Dewaiker, "Computation of bearing capacity factor Nγ-Terzaghi’s mechanism," *International Journal of Geomechanics,* vol. 3(1), pp. 123-128, 2003.

[6] J. Burland, The Teaching of Soil Mechanics, 1987.

[7] S. Leroueil, "Natural slopes and cuts: movement and failure mechanisms," vol. 51:3, pp. 197-243, 2001.

[8] R. &. H. R. &. G. J. Bonaparte, "SOIL REINFORCEMENT DESIGN USING GEOTEXTILES AND GEOGRIDS," 1987, pp. 69-116.

[9] S. R. S. W. K. J. Yu H, "Limit analysis versus equilibrium for slope," *ASCE,* vol. 124(1), p. 1–11, 1998.

[10] D. J, "State of the art: limit equilibrium and finite element analysis of slopes," *ASCE,* vol. 122(7), p. 578–584, 1996.

[11] P. S. Wulandari, "Analysis of geotextile reinforced road embankment," in *The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5),* Surabaya, 2015.

[12] W. R. Clough R, "Analysis of embankment stresses and deformations," *ASCE,* vol. 4, p. 529–549, 1967.

[13] Office of Engineering and Highway Operations, FHWA-RO-89-043 PB91-1 912 69, Georgetown Pike McLean: Federal Highway Administration, 1998.

[14] L. F. D. G. &. B. S. L. LAM, " Transient seepage model for saturated-unsaturated soil systems," *Canadian Geotechnical Journal,* vol. 24, pp. 565-580, 1987.

[15] J. N. M. Labhane, "A procedure for the design and analysis of geosynthetic reinforced soil slopes," *Springer,* vol. 10, no. 4, p. 291–319, 1992.