An Investigation of the Impact of Geogrid on the Stability of an Embankment by using PLAXIS 2D.

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This Report Presented in Partial Fulfillment of the Requirements for the Degree of **Bachelor of Science in Civil Engineering**

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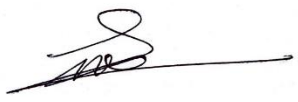

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ABSTRACT

Geosynthetic material use has increased dramatically in recent years in civil engineering applications such as reinforced earth barriers, slope stability, transportation, reinforced embankments, etc. The purpose of embankments is to raise the surface height over that of the surrounding land. Many infrastructure projects are being constructed on embankments, and infrastructures that are resting on embankments may collapse as a result of embankment failure. This could cause fatalities, financial losses, and interruptions to any services that the projects provide; the loss of these things could take years to be made up for. The performance of the embankment with and without the usage of geogrid was evaluated using the Analytical Method and the Finite Element Method (FEM). This work uses numerical simulations in PLAXIS 2D to examine the effect of geogrid reinforcement on embankment stability. The analysis compares embankments with and without geogrid reinforcement, focusing on important factors such as the factor of safety (FOS), displacement (both horizontal and vertical), and stress distribution. With a discernible rise in FOS and decreases in both vertical settlement and horizontal displacement, the results show a considerable improvement in stability for reinforced embankments. Stress concentrations and failure risk were decreased in geogrid-reinforced embankments due to their more uniform stress distribution. Geogrid reinforcement has been shown to be very successful in difficult situations, such as unstable soils and steep inclines. For this reason, it is a crucial instrument in contemporary geotechnical engineering for augmenting the resilience and security of embankments. This study highlights the advantages of geogrid as an affordable way to reduce the risks of deformation and collapse, providing important insights for the design of safer and more durable embankment constructions.

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CHAPTER 1
INTRODUCTION

1.1 General

An old type of civil engineering construction, embankments have been used for transportation purposes such as road, railway, and airport embankments, as well as for flood control dykes along river banks and reservoirs. The embankment's performance requirements are mostly based on its intended function. Fill and foundation are the two main parts of an embankment. Building embankments has become a necessary part of infrastructure development and is frequently seen in many infrastructure projects. One of the main responsibilities of civil engineers is to estimate slope stability accurately. Many issues are commonly encountered during and after the construction of an embankment during its service life, such as the inadequate bearing capacity of the foundation soil, slope instability of the embankment, settlement, etc. These issues can cause the embankment to collapse, which could then cause the infrastructure that is resting on it to collapse. Consequently, it is crucial to evaluate the embankment's performance both during construction and after an appropriate ground improvement approach has been used. The purpose of this work is to examine the performance of a 4-meter-high embankment both as it is constructed and after geogrid has been added as reinforcing material. Both numerical modeling based on FEM and an analytical computational model were used in the design process. The internal stability estimate served as the basis for determining the tensile forces of geogrids.

This research aims to examine and evaluate the performance of embankments during construction, as well as to design the ideal geogrid tensile strength and spacing for use in embankments as a ground improvement technique to increase their stability. Afterward, the safety factor of the embankment will be ascertained following its reinforcement with geogrid.

1.2 Background Study

In the construction of infrastructure, embankments are crucial because they provide the support required for major buildings like railroads, roadways, and flood control systems. In order to keep a smooth and secure surface for traffic, these man-made slopes are built to raise a road or railroad above the naturally occurring ground level. The stability of these embankments is crucial because if they break, it might have disastrous effects like the collapse of railroads, roadways, or other important infrastructure. Such malfunctions can seriously endanger both human life and the environment in addition to causing traffic disruptions. Even though they work well in many situations, traditional embankment designs can present serious difficulties, especially when built on or in poor soil conditions. Poor shear strength or high compressibility are examples of intrinsic weaknesses in the soil that can cause problems including excessive settlement, unstable slopes, and even total structural failure. The stresses operating on the embankment can change quickly in areas experiencing high rainfall or seismic activity, which makes stability even more compromised. Furthermore, it has been demonstrated that geogrid reinforcement reduces a number of typical problems with conventional embankment designs.

1.3 Problem Statement

In the field of civil engineering, embarkations are extremely important for the purpose of supporting infrastructure throughout time. Nevertheless, its stability can be jeopardized by variables such as soil that is insufficient or weak, situations that involve excessive loading, and environmental concerns. Under the weight of the embankment, soils that have conditions such as low shear strength, high compressibility, or poor drainage qualities have the potential to deform or settle, which can result in cracking and uneven settling. The presence of high loads can worsen the properties of the soil, which in turn increases the likelihood of slope instability or settlement. A soil's behavior can also be influenced by environmental elements such as fluctuations in temperature, seasonal shifts in moisture content, and the presence of groundwater. Because it provides additional tensile strength and enhances soil shear strength, geogrid reinforcement has emerged as an efficient way for improving the stability of embankments. It is necessary, however, to do in-depth research into the efficiency of the product in a variety of circumstances. For geogrid-reinforced embankments, the finite element analysis program known as PLAXIS 2D can be of assistance in determining design parameters that are ideal as well as probable constraints or failure causes.

1.4 Scope and Objectives

This work focuses on embankments that have been examined with PLAXIS 2D, considering various soil types, loading scenarios, and slope angles. Through a series of simulations, the influence of geogrid reinforcement is evaluated, and the outcomes are verified against case studies and available literature.

The objectives of the study are as follows:

1. To find the displacement, mesh, and stress before and after installing geogrid.
2. To determine the factor of safety, between before and after installing geogrid.

CHAPTER 2
LITERATURE REVIEW

2.1 General

The entire body of knowledge that forms the basis for the analysis of embankment stability, the function of geogrid reinforcement, and the use of PLAXIS 2D for numerical modeling in geotechnical engineering are explored in this chapter. The chapter highlights the interaction between theoretical notions, experimental research, and practical applications in order to give a solid basis for comprehending the complexity and developments in these areas. It does this by evaluating the material that has already been published. It is commonly known that while soil can withstand pressure and shear loads, tensile stress causes the soil to become unstable. The study's conclusions demonstrated that building an embankment presents a number of issues, including soil carrying capacity, slope stability, and settlement (Mamat, 2019). Accordingly, earlier studies found that one reliable and efficient way to improve and treat soil qualities is to reinforce the soil (Majedi, 2017). The study came to the conclusion that there are four ways in which geogrids can enhance soil performance: they can avoid local soil shearing, enhance load distribution across the soil, reduce or realign shear stresses in the soil, and provide a tensioned membrane effect (Moayedi, 2009). Research revealed that tensile reinforcement resulted in decreased shear stress and strain magnitudes, plastic deformations in the foundation, and higher embankment stiffness (Bonaparte R. , 1987).

According to the analysis's findings, the reinforcement lessens lateral spreading and embankment settling because of undrained constant-volume distortion. Additionally, previous research found that geogrids improve soil mechanical characteristics by strengthening soil bonding as a result of soil particles interlocking with reinforcement apertures and by increasing shear resistance based on the orientation of the reinforcement relative to the failure plane (Rahman, 2004). Previous studies have demonstrated that the use of geogrid improves the mechanical qualities of soil by minimizing lateral deformations and raising lateral stress (Broms, 1977).

2.2 Embankment Stability

In the field of civil engineering, embankment stability is an extremely important topic since embankments are used to support infrastructure such as roads, trains, and dams. For example, the stability of an embankment can be affected by the qualities of the soil, the geometry of the slope, the amount of water present, the loading conditions, and environmental variables. For the purpose of comprehending and forecasting the behavior of embankments, several theoretical frameworks have been established. Both the limit equilibrium approach and the factor of safety (FOS) are examples of traditional slope stability theories that are used to guide the design and study of embankments. These theories assist engineers in evaluating the potential for failure and putting in place the appropriate reinforcing measures. In addition to this, the chapter discusses experimental investigations that were conducted to determine the stability of embankments (Sarada K. Sarma, 1979). These studies frequently involved physical modeling and large-scale laboratory experiments. The findings of this study offer significant insights into the factors that cause embankment failure as well as the efficiency of various stabilization method approaches.

2.2.1 Key Factors Influencing Embankment Stability

- **Soil Properties**: The stability of an embankment is significantly influenced by the characteristics of the soil that was used in its construction. Generally speaking, soils that have a high shear strength, such as gravels and sands, contribute to the stability of embankments. Clays and silts, on the other hand, have lower shear strengths and are more prone to deformation, which can lead to instability. The degree to which the soil is compacted, the amount of moisture it contains, and whether or not it possesses cohesive or frictional qualities are all essential aspects that need to be properly analyzed.

- **Slope Geometry**: An embankment's stability is directly impacted by the geometry of the slope, which includes the slope's height, angle, and form. " Because of the more difficult conditions, slopes that are steeper are more prone to undergo collapse. To strike a balance between the demand for space efficiency and the necessity for stability, engineers need to carefully design the geometry of the slope. Stability can be improved by either leveling out the slope or adopting designs that have stepped surfaces.

- **Water Content and Pore Water Pressure**: Stability may be considerably affected by the amount of water that is present within the embankment as well as the soil that is around it. Through the process of raising pore water pressure, water has the ability to decrease the strength of the soil. This can result in circumstances such as liquefaction in saturated, cohesionless soils or a weakening of the cohesive forces seen in clays. It is vital to have drainage systems that are in good working order in order to control water levels and prevent the accumulation of pore water pressure, which can lead to slope collapses.

- **Loading Conditions**: The soil can be stressed and its stability can be affected by the stresses that are applied to an embankment. These loads might come from traffic, building operations, or other structures that are placed on the embankment. Dynamic loads, which include those that are caused by earthquakes or heavy machinery, can be especially hazardous, since they can result in unexpected and catastrophic failures if they are not correctly accounted for in the design.

- **Environmental Factors**: Additional environmental elements that can have an impact on the stability of an embankment include precipitation, fluctuations in temperature, and vegetation. Heavy rainfall can produce surface erosion or interior erosion through pipes, and freeze-thaw cycles can cause soil expansion and contraction, which can contribute to instability. Both of these types of erosion can be caused by the same thing. The presence of vegetation may either contribute to the instability of an embankment by modifying the moisture content or it can help to stabilize the embankment by strengthening the soil with roots.

2.3 Geogrid Reinforcement

Geogrid reinforcement is a significant innovation in geotechnical engineering that improves the stability of embankments by giving greater tensile strength compared to traditional reinforcing methods. Polymeric materials are utilized for the purpose of reinforcing soils, which results in an increase in load-bearing capacity and a decrease in the likelihood of failure or deformation. The chapter discusses the many forms of geogrid reinforcement, as well as their material qualities and the methods by which they interact with soil. It also analyzes the development and implementation of geogrid reinforcement. In addition to this, it investigates the aspects that influence its efficacy, such as the kind of soil, the location and orientation of the geogrid, and the nature of the load. Experimental investigations that evaluate the performance of geogrid-reinforced embankments are also discussed in this chapter. These studies typically incorporate both laboratory testing and field trials conducted in the field. Significant advantages of geogrid reinforcement are demonstrated by the findings, which include an increase in shear strength, a decrease in settlement, and an improvement in slope stability.

2.4 Types of Geogrids

In geotechnical engineering, synthetic materials called geogrids are used to increase soil stability, strengthen soils, and stop deformation in structures like retaining walls, embankments, and roads. Geogrids come in various varieties, each with unique characteristics and uses. The intended use, production method, and material composition of these types vary. Uniaxial, biaxial, and triaxial geogrids are the three main varieties of geogrids (Bonaparte R. H., 1987). They are categorized according to the direction and geometry of their tensile strength.

1. Uniaxial Geogrid

    - Definition: The primary purpose of uniaxial geogrids is to offer high tensile strength in a single direction, typically the longitudinal or machine direction. Long, stretched strips arranged in a single direction make up the grid pattern, which helps to support the soil along that axis.

    - Material: Extrusion is a common method used to create uniaxial geogrids from polypropylene (PP) or high-density polyethylene (HDPE). To boost the polymer's tensile strength, it is extruded and then stretched in a single direction.

    - Advantages: Strong tensile in a single direction. Perfect for buildings (such as steep slopes and retaining walls) where stresses are applied mostly in one direction.

2. Biaxial Geogrid

    - Definition: Biaxial geogrids are engineered to yield exceptional tensile strength in both the longitudinal (machine) and transverse directions, which are perpendicular to one other. Apertures or openings in the grid structure enable efficient interaction with soil particles in both directions.

    - Material: Polypropylene (PP) or polyester (PET) are commonly used to create biaxial geogrids through the processes of extrusion and stretching. Two directions are used in the stretching process to give equal strength along both axes.

    - Advantages: It is appropriate for multi-directional loading since it offers tensile reinforcement in both directions. Enhances the distribution of weight on broad surfaces, such as road bottoms.

3. Triaxial Geogrid

    - Definition: Triaxial geogrids, which have a triangle grid structure, offer reinforcement in three dimensions and multidirectional strength. In comparison to uniaxial or biaxial geogrids, the grid pattern creates equilateral triangles, which improve load distribution in various directions.

- Material: Triaxial geogrids, whose triangle aperture design ensures more efficient weight distribution through the soil, are usually produced from polypropylene (PP) using a sophisticated extrusion method.

- Advantages: The triangular grid construction allows for superior load distribution in every direction. Greater resistance to deformation both vertically and laterally, which makes it appropriate for heavy-duty applications including railroads, runways, and roadways.

4. Welded Geogrid

- Definition: Geogrids that are welded or bonded are created by attaching individual polymer ribs together at their junction locations, frequently with the use of heat or glue. Throughout the whole construction, these grids provide constant strength.

- Material: Usually composed of polymers like polyester or polypropylene, welded geogrids have joints that are bonded or welded together to create a sturdy grid.

- Advantages: Durability under conditions of high load is ensured by strong connections. provides a wide range of soil types with consistent performance and excellent rigidity.

5. Woven Geogrid

- Definition: The process of knitting or weaving synthetic fibers usually polyester or polypropylene into a grid design creates knitted or woven geogrids. It is possible to create a flexible yet robust reinforcing material using knitting.

- Material: High-strength polyester (PET) or polypropylene (PP) fibers are typically used to create these geogrids, which are then knitted or woven into a structure resembling a mesh.

- Advantages: High flexibility makes installation simple, especially in challenging terrain. Comparable to biaxial geogrids, offers robust tensile reinforcement in both directions.

6. Extruded Geogrid

- Definition: A polymer sheet is extruded and then stretched to create an even grid structure, which is known as an extruded geogrid. The tensile strength is improved by stretching in either or both directions (uniaxial or biaxial).

- Material: Typically made from polypropylene (PP) or high-density polyethylene (HDPE).
- Advantages: high strength because of the process of stretching. Depending on the application can be produced to offer reinforcement in one or two directions.

Uniaxial geogrid is best for applications where reinforcement is needed primarily in one direction, such as retaining walls, steep slopes, and embankments with unidirectional loads. So uniaxial geogrid is used in this paper.

2.5 Previous Studies on Geogrid-Reinforced Embankments

Extensive studies have been conducted on the use of geogrid reinforcement in the building of embankments, which has resulted in the discovery of significant insights into the efficiency of this technique in a variety of different situations. The purpose of this research was to investigate the performance of geogrid-reinforced embankments under a variety of soil conditions, loading regimes, and environmental variables. The findings of these studies contributed to a more nuanced knowledge of the advantages and disadvantages of this reinforcing approach (Dulal, 2021).

2.5.1 Benefits of Geogrid Reinforcement

Geogrid reinforcement is a crucial component in enhancing the stability of embankments, as it significantly increases the factor of safety (FOS), a key factor in assessing slope failure likelihood. Geogrids improve soil shear strength, reducing slope instability, especially in weak or compressible soils. Especially in soils that are weak or compressible, geogrids enhance soil shear strength, which in turn reduces slope instability. They also distribute loads more uniformly over the soil mass, which significantly reduces the danger of localized collapse and minimizes the concentration of stress at certain spots. The reduction of deformation under load is another benefit of geogrid reinforcement, particularly in circumstances that involve dynamic loads such as seismic activity or traffic. Geogrids are able to regulate soil displacement, so preventing excessive settlement and safeguarding the integrity of embankments. This is accomplished by adding extra tensile strength. Geogrid reinforcement also improves the resistance of embankments to environmental elements such as erosion and water infiltration, which results in an extension of the embankment's lifespan. It assists in preserving the structure's shape and strength even when subjected to harsh circumstances, hence lowering the expenses of maintenance and the frequency with which repairs are required.

2.5.2 Limitations and Challenges of Geogrid Reinforcement

The use of geogrid reinforcement is a technology that is widely acknowledged for enhancing the stability of embankments; nevertheless, the efficiency of this method is contingent upon a number of elements. There are a number of factors that can influence its performance, including the kind of soil, which can be sandy or gravelly, as well as the location and orientation of the geogrid within the embankment, which can also have an effect on its efficiency. This can result in inferior performance, which in turn reduces the predicted improvements in stability and deformation control. Incorrect installation or inadequate coverage might also contribute to this scenario.

One of the limitations of geogrid materials is their long-term durability, which may not be able to endure harsh environmental conditions for lengthy periods of time. This is especially true in situations that are characterized by hostile chemical environments or continual cyclic loads. The tensile strength of the geogrid can be decreased by a number of factors, including exposure to ultraviolet light, chemical deterioration, and mechanical wear. This causes the geogrid's reinforcing capacities to decrease. Due to the fact that geogrid reinforcement might lead to an increase in building expenses, its use may not always be justified in some circumstances. This is because the economic benefits of geogrid reinforcement may not always justify its usage. Therefore, when selecting geogrid reinforcement, it is required to do a thorough cost-benefit analysis, taking into consideration a variety of aspects including the availability of materials, the circumstances that are peculiar to the site, and the needs for long-term maintenance.

2.5.3 Case Studies and Practical Applications

The implementation of geogrid reinforcement in embankment projects that are based in the real world has been the subject of a number of case studies that have offered practical insights. This type of research frequently involves the meticulous monitoring of embankment performance over a period of time, which provides empirical proof of the benefits and limits that were addressed before.

One case study, for instance, showed how the application of geogrid reinforcement greatly decreased settlement and increased the soil's ability to support loads. The project involved the placement of multiple layers of geogrid at strategic intervals, which effectively distributed loads from the road surface and prevented the clayey subsoil from experiencing excessive deformation (Ramadhan, 2022).

An additional case study concentrated on building railroad embankments in seismically active areas. According to the study, the embankment's resistance to seismic forces was increased via geogrid reinforcement, which decreased the chance of failure during an earthquake. The embankment received extra lateral support from the geogrid layers, which helped keep it stable and in form even under situations of dynamic stress.

Not every case study, meantime, has shown consistently favorable outcomes. The expected advantages of geogrid reinforcement were not always achieved, either as a result of site-specific difficulties or inadequate design and installation techniques. For example, research conducted on an embankment built in a flood-prone location discovered that although the geogrid reinforcement helped to some extent to limit erosion, it was unable to stop serious damage during a big flood event. This demonstrated the necessity of designing embankments holistically, including additional stabilizing and protective measures in addition to geogrid reinforcement.

2.6 Finite Element Analysis

The process of predicting and comprehending how an object can react under various physical conditions is known as Finite Element Analysis (FEA), and it involves computations, models, and simulations. FEA is a tool used by engineers to identify weaknesses in their design prototypes. A prototype dry excavation system underwent a series of two-dimensional Finite Element Analyses (FEA) to better understand the trends in soil mass deformation. The PLAXIS software package, a finite element tool, was utilized to do the analysis (Brinkgreve, 2002). Numerous geotechnical issues, including deep excavations, tunnels, and earth constructions like retaining walls and slopes, can be handled by PLAXIS. Three or five- node beam elements and six or fifteen-node triangular plane strain elements for the soil, as well as three or five-node elastic elements for the geotextile components, can be automatically generated by the software. Creating the model's geometry is the first step in the analysis process. The dimensions of the excavation, including its breadth and height.

2.7 Finite Element Modeling

Sand's non-linear behavior was studied using the hardening soil model, an Elastoplast hyperbolic stress-strain model based on friction and hardening plasticity. The foundation was modeled as elastic beam elements using Mindlin's beam theory, with significant flexural rigidity (EI) and normal stiffness (EA). The hyperbolic model relies on stress to determine soil stiffness. Geogrid-soil interaction is modeled using interface components, resulting in lower wall friction relative to soil friction. The limiting state of stress is described by secant Young's modulus, tangent stiffness modulus for primary compression, Poisson's ratio, effective cohesion, angle of internal friction, angle of dilatancy, failure ratio, and interface reduction factor. The modeled boundary conditions assume free vertical and confined horizontal bounds, with a fixed bottom horizontal boundary. The software automatically generates six node triangular plane strain elements for soil and three node beam elements for geogrid. Reinforced tests use 250 elements, while unreinforced tests include 160. FEM is widely used in various fields, including structural analysis, heat transfer, fluid dynamics, electromagnetics, and more (Brinkgreve, 2002).

2.8 The Hardening Soil (HS) Model

"Schanz" (Schanz, 1999) discussed the verification and formulation of this model. This cutting-edge model simulates and models soil behavior. The Mohr-Coulomb method explains the limiting state value of stress using three parameters: angle of friction (phi), cohesion (c), and angle of dilatancy (psi). The HS model explains soil stiffness more accurately by using three additional input stiffnesses: triaxial stiffness (Eref), triaxial unloading stiffness (Eur), and oedometer loading stiffness (Eoed).

The HS model is also recognized for its stress-dependent stiffness modulus. This explains all. Stiffnesses grow under pressure. Therefore, all three input stiffness parameters correspond to a reference stress. Usually taken as 100 kPa (1 bar) wherever necessary. assume. Besides the many model parameters as noted above, initial soil conditions, such as Pre-consolidation are critical in the majority of Soil deformation difficulties. This could be a modern phenomenon considered in the first stress. The major load, which generates both stretchy (recoverable upon unloading) and plastic Deformations that cannot be recovered by unloading has been described in this approach that utilizes the important modulus of unloading and reloading is also Compression modulus. The current relationship is the Hyperbolic relationship between vertical strain (ε1) and deviatoric stress.

2.8.1 Features of the HS Model

The Hardening Soil model, also called as HS standard was explained by (Schanz, 1999), (Addenbrooke, 1997) to modify the important phenomena which are exhibited by soils such as:

1. Densification is defined as a decrease in void volume in soil caused by plastic deformations, which also reduces the void ratio.

2. Stress-dependent stiffness is a technology that increases stiffness as confining stress increases.

3. Soil stress history provides insight into the pre-consolidation process and its repercussions.

4. Plastic yielding is crucial for preventing irreversible stresses and achieving yield targets.

5. Dilatancy refers to negative volumetric stresses during shearing.

“Truty A” (Truty, 2008) explained this model which is known to be a concept that is simple and effective for addressing tiny strain stiffness. It uses two plastic mechanisms: shear and volumetric. Compared to other material models like the cap or modified cam clay, this model accurately models soil deformations, stresses, and forces using three input stiffness parameters: triaxial loading stiffness (E50), triaxial unloading-reloading stiffness (Eur), and oedometer loading modulus.

2.9 Numerical Modeling with PLAXIS 2D

In the field of geotechnical engineering, numerical modeling is an essential technique that enables engineers to simulate intricate interactions between layers of soil and structures. To represent geotechnical issues in two dimensions with a high degree of precision, PLAXIS 2D is a well-known and widely used software program. The purpose of this chapter is to discuss the application of PLAXIS 2D in the modeling of embankment stability and geogrid reinforcement. Particular attention is paid to the sophisticated soil constitutive models, the capability to simulate complicated loading circumstances, and the modeling tools for soil-reinforcement interchanges. In addition to this, it examines examples of research projects and case studies in which PLAXIS 2D was utilized to model geogrid-reinforced embankments. These examples demonstrate how numerical modeling may be utilized to anticipate performance, optimize design parameters, and evaluate probable failure risks. In order to emphasize the benefits and drawbacks of numerical modeling in this context, the chapter performs a comparison between the outputs of PLAXIS 2D simulations and the experimental data and real-world outcomes (Pamuk, 2015).

2.10 Limited Use of PLAXIS 2D in Geogrid Research

Numerous methodologies, including laboratory tests and more conventional analytical procedures, have been utilized in the substantial research that has been conducted on geogrid reinforcement. PLAXIS 2D is a strong piece of software that serves as a finite element analysis (FEA) tool; yet, its applicability has not been completely explored. The current body of literature has not completely achieved its potential, despite the fact that it has the capability to represent the particular impacts that geogrid reinforcement has on embankments (Park, 2007). Empirical techniques or simpler analytical models are frequently the focus of current research on geogrid reinforcement. These approaches may not be able to represent the entire complexity of soil behavior and reinforcement interactions under a variety of scenarios. The enhanced soil models, staged building processes, and specific boundary conditions that are included in PLAXIS 2D have the potential to give more in-depth insights into these seemingly complicated phenomena.

CHAPTER 3
METHODOLOGY

3.1 General

PLAXIS 2D is a well-known finite element analysis (FEA) program that was used to model the behavior of geogrid-reinforced embankments. Finite element methods are now used in commercial software. PLAXIS has been used to analyze structural components that need excavation procedures. Nevertheless, earlier missteps indicated that selecting the constitutive model to describe soil behavior and the related soil parameters was essential for a productive study that made use of the codes. A variety of element types, including the anchors that support the retaining wall, different wall types, like diaphragm and sheet pile walls, different kinds of loads behind the wall, and elements that serve as an interface between the soil and the anchored retaining wall, can all be modeled using PLAXIS (F. H. Chehade, 2008). The analysis was conducted using the 15-noded triangular elements of the PLAXIS 2D finite element program. To understand how different parameters affect the behavior of the wall as mentioned above, all of the modeled and studied cases had their total displacement, wall bending moments, stresses, and wall shear forces examined (PLAXIS2D, 2002).

3.2 Model Details

Due to the limited capabilities of existing software and computational resources, a significant number of 2D simulations have been used during the design process and for research. Since PLAXIS was selected for this project, I will be examining its constitutive soil models. The more comprehensive details. The engineering soil simulation program PLAXIS employs parameters to characterize soil attributes quantitatively and numerical soil models to reflect the behaviors of the soil qualitatively. With just one integrated application, PLAXIS 2D is an easy-to-use finite-element tool that allows modeling of various geotechnical issues. Examine how projects including tunneling, mining, geomechanics, embankments, foundations, and excavations deform and stabilize. All of the necessary features to do routine deformation and safety analyses for rock and soil without taking into account creep, steady-state thermal or groundwater flow, consolidation analysis, or any time-dependent effects are included in PLAXIS 2D (PLAXIS2D, 2002). PLAXIS 2D, a finite element software tool for geotechnical engineering and rock mechanics, examines two-dimensional deformation and stability. Geotechnical structures, such as excavations, dams, embankments, and tunnels, can be represented using the software. The software can calculate 2D plane strain, axisymmetric deformations, soil stresses, water flow, pressures, and structural, and thermal forces. Various soil models are used to account for the behavior of different soil types, including clay, sand, and rock, as well as loading, unloading, and reloading. In addition, PLAXIS 2D offers a CAD-like environment for quick and efficient model creation, allowing users to focus on analyzing results.

3.3 Soil Parameters

The soil profile was analyzed using feasibility study results from past mega-projects. However, due to the unavailability of some attributes, empirical correlations have been utilized (Taher, 2022). Soil parameters used in the model have been shown in Table 3.1.

Table 3.1: Properties of Materials Used in Modeling

Parameter	**Name**	**Dense sand**	**Loose sand**	**Unit**
Material model	**Model**	HS	HS	
Soil unit weight above phreatic level	**γ**	17.5	17	kN/m^3
Soil unit weight below phreatic level	**γ(sat)**	18	18	kN/m^3
Young's modulus	**Eref**	37	20	Mpa
Tangent stiffness for primary oedometer loading	**Eoed**	29	16	Mpa
Unloading/reloading stiffness	**Eur**	90	60	Mpa
Cohesion	**c(ref)**	5	2.5	kN/m^2
Friction angle	**Φ**	41	34	°
Dilatancy angle	**Ψ**	14	0	°
Strength reduction factor inter.	**Rinter**	0.65	0.7	-

3.4 Model Geometry

This section has provided a comprehensive explanation of the geometry of the model. This study developed a model of an embankment that has a height of 4 meters, a top height of 10 meters, and a base height of 30 meters. As can be seen in Figure 3.1, the width of the rigid pavement over the top of the embankment is anticipated to be 10 meters. On the assumption that the pavement is located on the top of the embankment, as seen in Figure 1, the whole static uniform load is considered to act on the top of the embankment. 3 geogrid layers are included in the model, and they are positioned at regular intervals throughout the embankment's height. The stiffness and tensile strength of the geogrid are carefully chosen in accordance with industry standards and the particular needs of the embankment. From the analytical calculation that serves as the basis for the model's execution, the stiffness of the geogrid, as well as its position and spacing, have been determined.

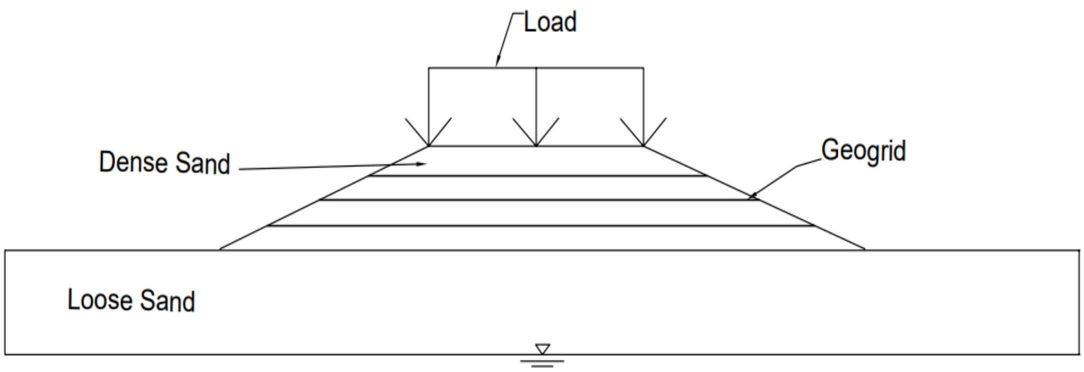

Figure 3.1: Geometry of the Model

Through the utilization of PLAXIS 2D, this all-encompassing model configuration offers a solid foundation for conducting an investigation into the impact that geogrid reinforcement has on the stability of embankments. The study can offer relevant insights into the behavior of reinforced embankments, which contributes to the creation of geotechnical solutions that are more effective and trustworthy. This is made possible by the carefully designed geometry, loading circumstances, and reinforcing method.

3.5 Flow Condition

Finite element modeling is performed with the assumption that the water table is located four meters below the surface of the ground. This is done because the water table has the potential to have a major influence on the shear strength of soil. Due to the fact that there is a comparable portion in the other half of the boundary, the groundwater flow has been limited in the x(min)=0 section during the modeling process. On the other hand, the groundwater flow is permitted in the other borders.

CHAPTER 4
RESULTS ANALYSIS

4.1 Introduction

The results of the numerical simulations using PLAXIS 2D to assess the effect of geogrid reinforcement on embankment stability are showcased in this chapter. Crucial factors that are the subject of the investigation include displacement (both horizontal and vertical), stress distribution inside the embankment, and factor of safety (FOS). To evaluate the efficacy of geogrid reinforcement under variations in soil types, slope angles, and stress situations, both without geogrid and with geogrid embankment models were simulated. The significance of geogrid reinforcement for the embankment's stability will be ascertained by analyzing the simulation results. With an emphasis on lowering deformation and enhancing safety margins, a comparison of without geogrid and with geogrid embankments will shed light on the advantages of geogrid reinforcement.

4.2 Factor of Safety (FOS)

4.2.1 FOS without Geogrid Embankments

An important metric for assessing the stability of embankments is the Factor of Safety (FOS), which is the ratio of driving forces to resisting forces, which prevents collapse and encourages it. When the embankment was built on flimsy soils or had steeper slopes, the simulations for the without geogrid embankment model showed that the FOS was below permissible norms in several circumstances. The soil's incapacity to adequately withstand shear stresses in these situations indicated a greater chance of failure for the without geogrid embankment.

An embankment that was not strengthened may fall soon if it has a steep slope and weak clayey soil, as indicated by an FOS of less than 1.5. This outcome is in line with established geotechnical principles, which state that embankments constructed without reinforcement on cohesive, weak soils are more likely to collapse and become unstable. After the embankment had been erected, the safety factor for slope stability was assessed to be 1.3, which is a rating that cannot be considered acceptable.

4.2.2 FOS with Geogrid Embankments

The geogrid embankment models, on the other hand, showed a notable increase in FOS. By adding greater tensile strength and dispersing the loads more uniformly across the soil, the geogrid reinforcement strengthened the resisting forces inside the embankment. The minimal criterion for safe embankment design, which is widely thought to be 1.5, was regularly exceeded by the FOS in the reinforced models.

By adding geogrid layers, for instance, the FOS increased to 1.7 in the same steep slope situation with weak soil. This shows that the embankment is presently stable and that there is little chance of failure for it to safely withstand the imposed loads. In situations with poorer soils and steeper slopes, where unreinforced embankments would normally be in significant danger, the geogrid reinforcement was shown to be very efficient in reducing instability.

4.3 Displacement Analysis

4.3.1 Total Displacement without Geogrid Embankments

In the absence of geogrid reinforcement, the total displacement of an embankment is the sum of the effects of both the horizontal and vertical displacements that occur as a result of the loads that are applied. The absence of geogrid results in increased lateral movement and settlement, which in turn leads to a larger total displacement. This is because there is no tensile reinforcement in the soil if geogrid is not there. In the model, the total displacement is $5.004*10^{-2}$ m which is shown in Figure 4.1.

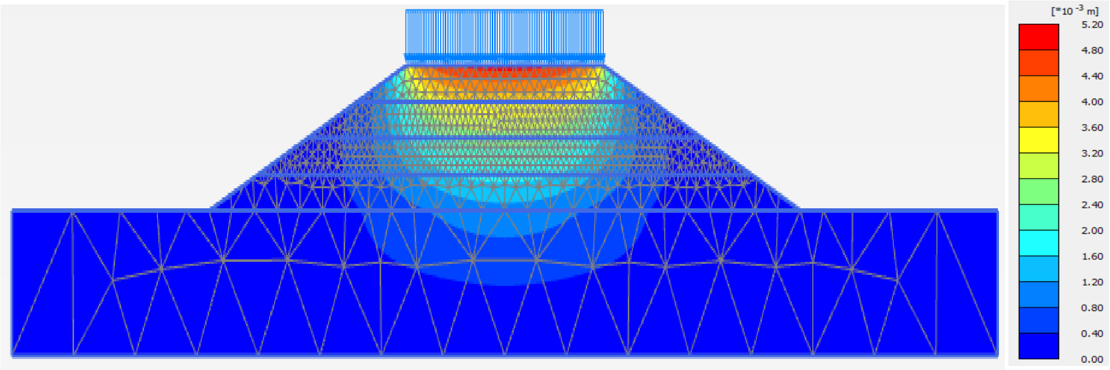

Figure 4.1: Without geogrid total displacement

4.3.2 Total Displacement with Geogrid Embankments

In geogrid-reinforced embankments, the total displacement is the sum of the horizontal and vertical displacements that occur following the incorporation of geogrid layers to sustain the embankment. By providing tensile strength, optimizing load distribution, and resisting lateral and vertical motions, geogrid is able to drastically minimize total displacement in comparison to embankments that are not reinforced. In the model, the total displacement with geogrid is $5.010*10^{-3}$ m which is shown in Figure 4.2.

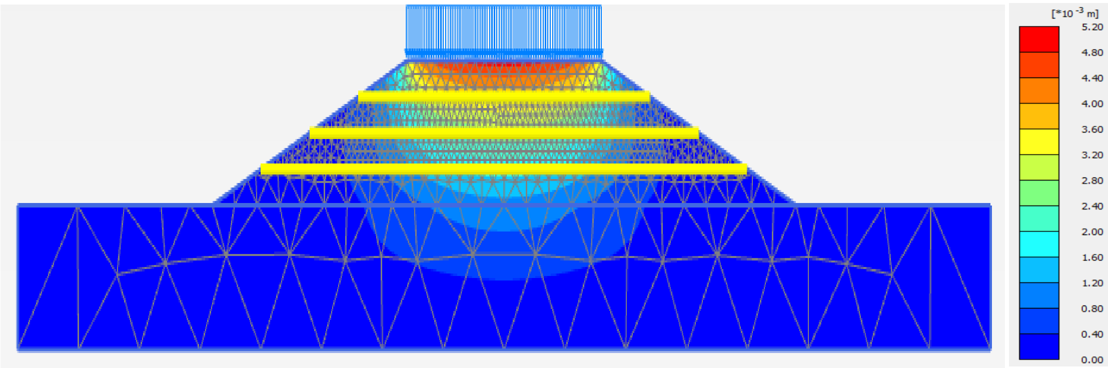

Figure 4.2: With geogrid total displacement

In Figure 4.3, the number of geogrids is increased by one for better analysis. When a number is increased, it is seen that its total displacement does not change. The total displacement with 4 geogrids layer is $5.010*10^{-3}$ m.

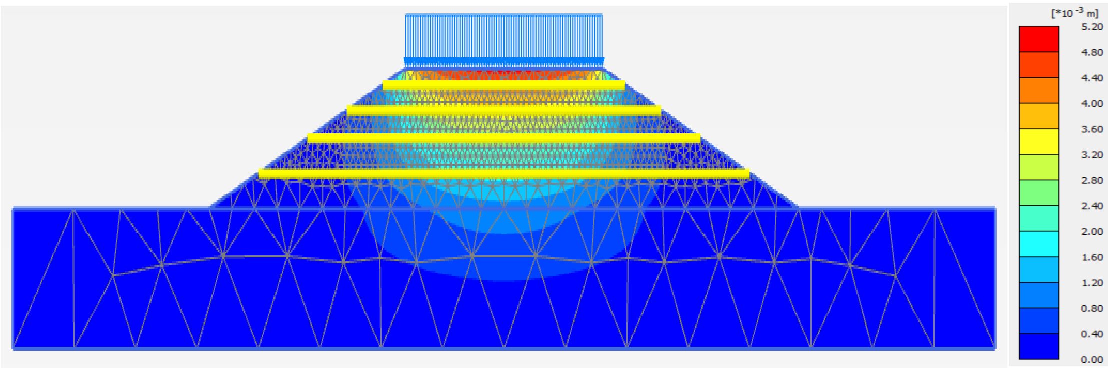

Figure 4.3: With 4 geogrid layer total displacement

4.3.3 Horizontal Displacement without Geogrid Embankments

One of the most important indicators of the shifting or sliding of the embankment is the horizontal displacement. Significant horizontal displacement was found in the models of the unreinforced embankment, particularly in situations involving soils that were on the weaker side or slopes that were steeper. The majority of these displacements took place in the middle and upper parts of the embankment, which is where the shear forces expressed themselves the most clearly. As seen in Figure 4.4, the horizontal displacement is shown. In terms of horizontal displacement, the value is $1.017*10^{-2}$ m.

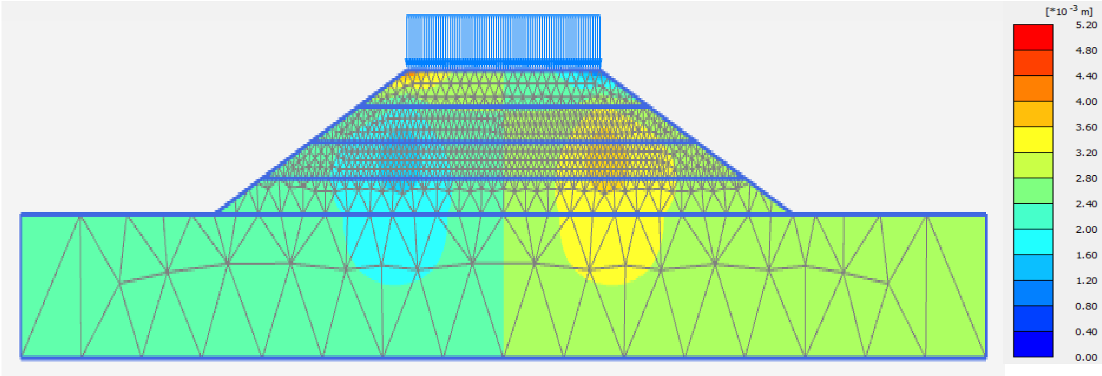

Figure 4.4: Without geogrid horizontal displacement

4.3.4 Horizontal Displacement with Geogrid Embankments

Every single model experienced a considerable reduction in horizontal displacement as a result of the implementation of geogrid reinforcement. By providing extra tensile strength and resistance against lateral stresses, the geogrid layers prevented the movement of soil particles, hence reducing the amount of movement that occurred. When compared to the models that did not include reinforcement, the reinforced embankment models had a horizontal displacement reduction that was, on average, between sixty and seventy percent. As seen in Figure 4.5, the horizontal displacement with geogrid is shown. In terms of horizontal displacement, the value is $1.007*10^{-3}$ m.

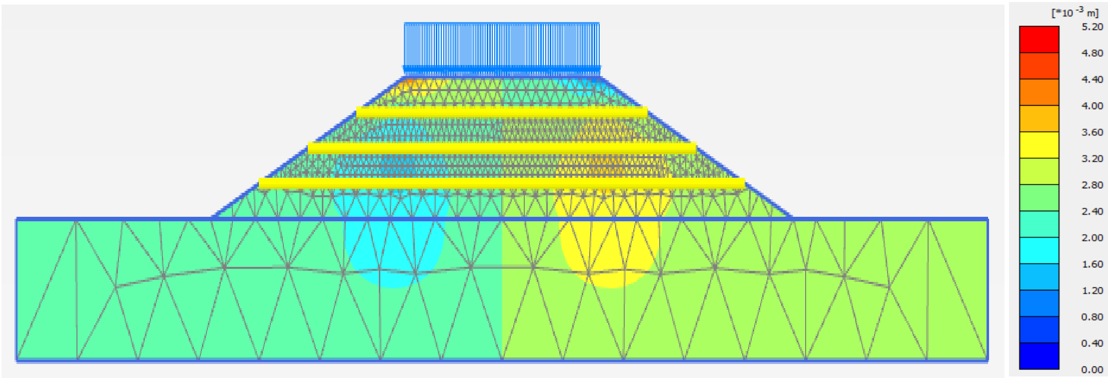

Figure 4.5: With geogrid horizontal displacement

In the case of horizontal displacement, it is seen that when the number of geogrids is increased, the displacement is reduced to some extent. As seen in Figure 4.6, the horizontal displacement with geogrid is shown. In terms of horizontal displacement, the value is $1.000*10^{-3}$ m.

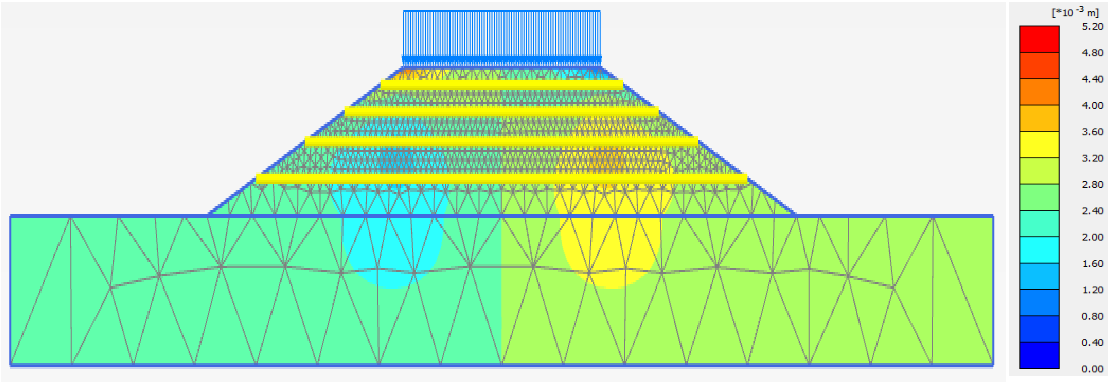

Figure 4.6: With 4 geogrid layer horizontal displacement

4.3.5 Vertical Displacement without Geogrid Embankments

The vertical displacement, also known as settlement, is another significant component that has an impact on the stability of an embankment over the long run is settlement. There was a substantial amount of vertical settlement seen in the models that were not reinforced, particularly in situations where the foundation soils were poorer or the loads were higher. Within the vicinity of the top and middle of the embankment, which was the location where the load concentration was the largest, the settlement was most noticeable. In the model, the vertical displacement is $2.044*10^{-2}$ m which is shown in Figure 4.7.

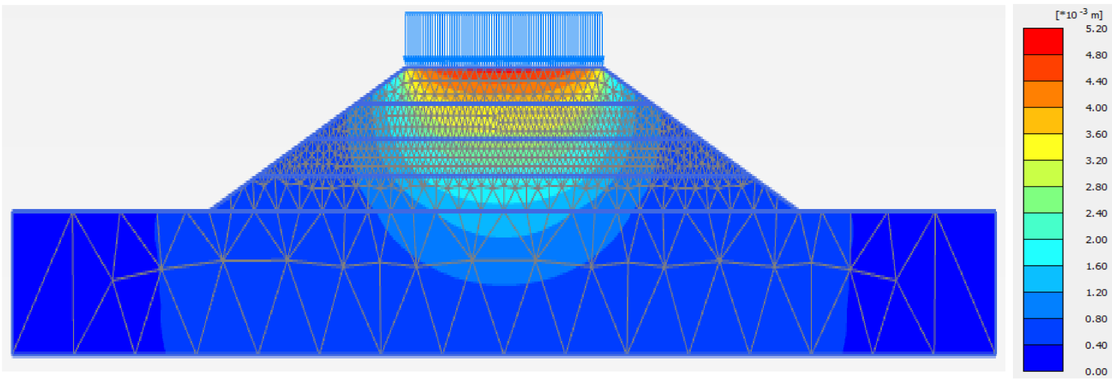

Figure 4.7: Without geogrid vertical displacement

4.3.6 Vertical Displacement with Geogrid Embankments

The embankment saw a significant reduction in vertical displacement as a result of the incorporation of geogrid reinforcement. The layers of geogrid served to distribute the load more uniformly throughout the embankment, which prevented localized settlement and reduced overall deformation. Both of these goals were achieved. The vertical displacement was decreased by roughly fifty percent in the reinforced models, with the exact amount of reduction depending on the soil type and load circumstances. As seen in Figure 4.8, the vertical displacement is shown. In terms of vertical displacement, the

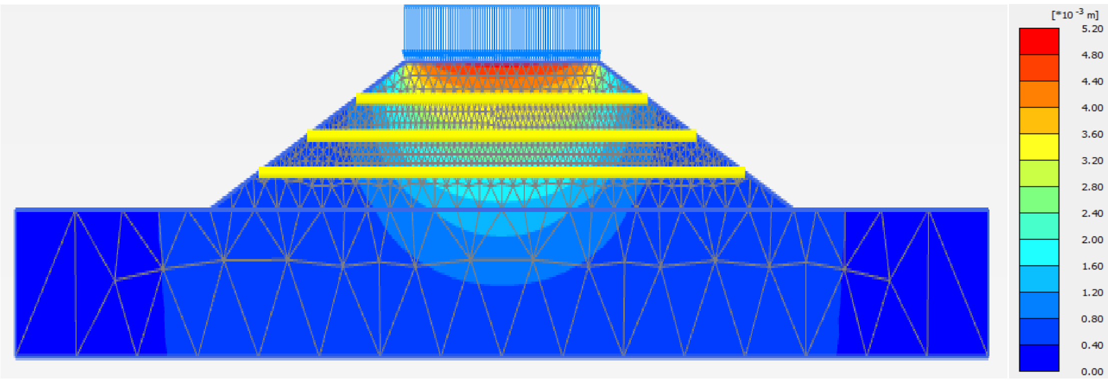

Figure 4.8: With geogrid vertical displacement

value is 2.037*10^{-3} m.

In the case of vertical displacement, it is seen that when the number of geogrids is increased, the displacement is reduced to some extent. As seen in Figure 4.9, the vertical displacement with geogrid is shown. In terms of vertical displacement, the value is 2.030*10^{-3} m.

4.4 Stress Distribution

Stress distribution inside embankments is an important component that plays a significant role in determining the stability and performance of these structures over the long term. An embankment's self-weight, applied loads, and external effects like as water pressure all contribute to the stress distribution, which characterizes the manner in which internal forces, also known as stresses, are distributed across the soil mass of

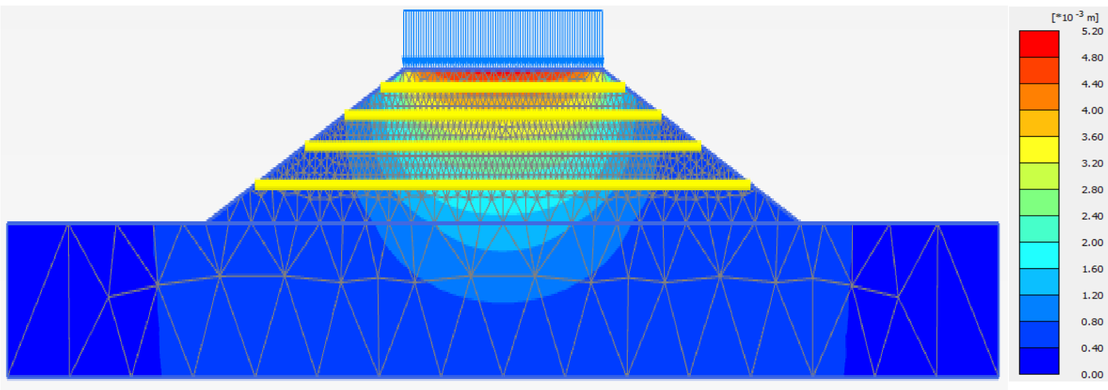

Figure 4.9: With 4 geogrid layer vertical displacement

the embankment. It is helpful for engineers to have an understanding of the pattern of stress distribution because it allows them to evaluate probable failure zones, deformation behavior, and the overall safety of the embankment.

4.4.1 Stress Distribution without Geogrid Embankments

Stress tends to be distributed unevenly in embankments that do not have geogrid reinforcement, which can result in stress concentrations that affect the stability of the structure. When it comes to unreinforced embankments, the major stresses that are present are shear stress, vertical stress, and horizontal stress. Each of these stressors has an impact on the behavior of the embankment as well as the possibility that it would break. When reinforcement is not there, the natural propensity of the soil to deform when subjected to stress is accentuated. This is especially true in soils that are weak or prone to compress. As seen in Figure 4.10, the total stress is shown. In terms of total stress without geogrid, the value is -0.04740 kN/m^2.

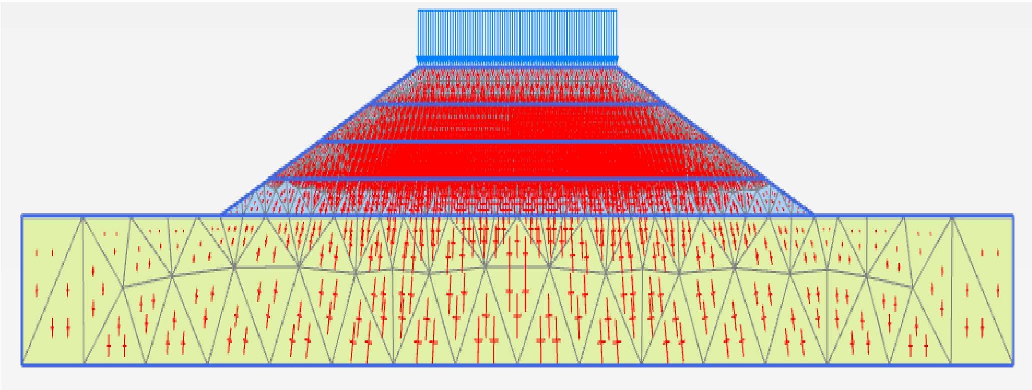

Figure 4.10: Without geogrid total stress

4.4.2 Stress Distribution with Geogrid Embankments

In embankments, the introduction of geogrid reinforcement causes a considerable shift in the distribution of stress, which ultimately leads to an internal stress state that is more uniform and balanced. An increase in the embankment's overall stability can be attributed to the tensile strength and load-distributing qualities that geogrid reinforcement offers. Because of the primary influence that this reinforcement has on shear stress, vertical stress, and horizontal stress, the danger of failure and deformation is significantly decreased. In geogrid-reinforced embankments, the stress distribution is more uniform and balanced due to the geogrid's ability to:

- Reduce vertical stress at the base.
- Resist horizontal stress and prevent lateral spreading.
- Mitigate shear stress along potential failure planes.
- Enhance effective stress in the presence of pore water pressure.

As seen in Figure 4.11, the total stress is shown. In terms of total stress with geogrid, the value is -0.05856 kN/m^2.

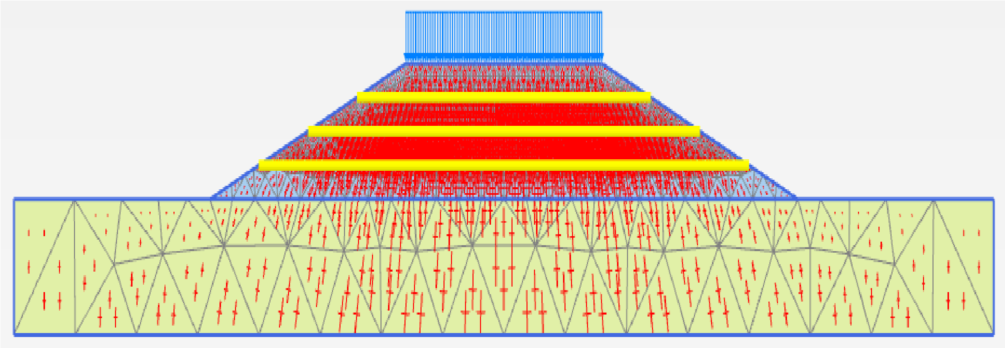

Figure 4.11: With geogrid total stress

In the case of total stresses, it is seen that the stress value has decreased. As seen in Figure 4.12, the total stress is shown. In terms of total stress with geogrid, the value is -1.44*10^{-15} kN/m^2.

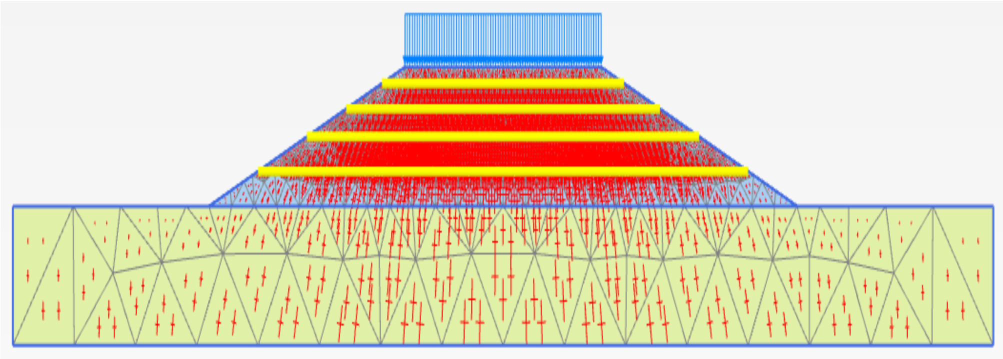

Figure 4.12: With 4 geogrid layer total stress

Geogrid reinforcement has been shown to greatly increase embankment stability over a wide variety of situations, as demonstrated by the results of the numerical simulations. All of the reinforced models saw a rise in the factor of safety, while both the horizontal and vertical displacements were significantly decreased. Within the reinforced embankments, the distribution of stress was more uniform, which resulted in a reduced probability of collapse. It has been demonstrated that geogrid reinforcement is an efficient way to enhance the stability of embankments, particularly in difficult situations such as soils that are weak or slopes that are steep. These findings offer important insights that may be utilized in the planning and building of embankments that are both more secure and more resistant to damage.

4.5 Graph

The image shown in Figure 4.13 a graph comparing the Factor of Safety (FOS) with and without the use of geogrid, which is a synthetic material used in construction to reinforce soil. Here's a breakdown of the graph:

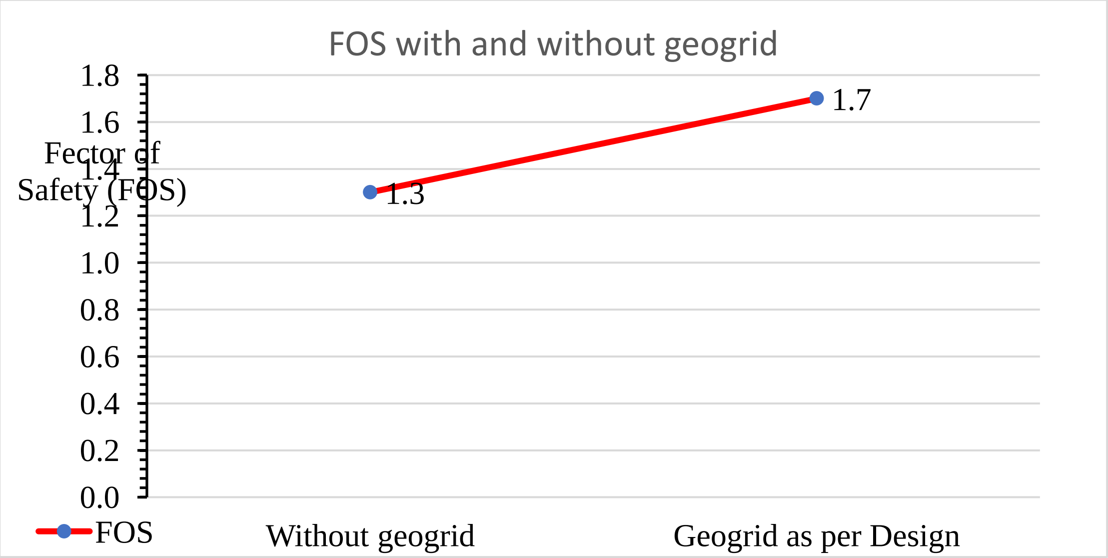

Figure 4.13: Variation of FOS of Embankment with and without Geogrid

1. Factor of Safety (FOS): According to the FOS, a structure's level of stability or safety may be evaluated. In the field of engineering, it is utilized to show the degree to which a system is much more robust than the minimum necessary for stability. The higher the FOS, the bigger the margin of safety that the structure possesses, and the lower the likelihood that it would fail.
2. Without Geogrid: The FOS is 1.3 in the scenario where geogrid is not present. This indicates that the structure is just thirty percent stronger than what is required for the fundamental stability of the thing. It does not give a significant margin of safety, despite the fact that it is greater than 1.0, which is the minimum necessary for stability requirements.
3. With Geogrid: Additionally, the FOS rises to 1.7 when geogrid is used into the design. Considering that the system is now 70 percent stronger than the minimal stability criterion, this demonstrates a substantial improvement. This greater FOS suggests that the structure is more secure and less likely to fail, both of which are indicators of improved safety and stability.

4. Significance of Geogrid: By reinforcing the soil and increasing its strength, geogrid is a material that is utilized in the building industry. For the purpose of stabilizing the ground and more efficiently distributing loads, it is frequently utilized in the construction of retaining walls, slopes, and foundations. The fact that the FOS has increased from 1.3 to 1.7 in this graph demonstrates that the geogrid is a significant contributor to the overall improvement in the system's safety.

Using geogrid in buildings has a number of beneficial effects, which are shown in the graph. As a result of the incorporation of geogrid, the structure becomes more trustworthy, and the safety margin improves dramatically, as seen by the increase in FOS.

4.6 Mesh Analysis

4.6.1 Deformed Mesh without Geogrid Embankments

Finite Element Analysis (FEA) mesh analysis is a useful tool for assessing the structural behavior of embankments without geogrid reinforcement. Grasp how embankments function in terms of displacement, stress distribution, and possible failure zones especially in difficult soil conditions or under the influence of outside factors like traffic or seismic loads requires a grasp of this concept. Without geogrid, the embankment's ability to withstand deformation and failure is entirely dependent on the soil's inherent strength, which frequently results in increased instability. As seen in Figure 4.14, the deformed mesh is shown. In terms of deformed mesh with geogrid, the value is 7875 m.

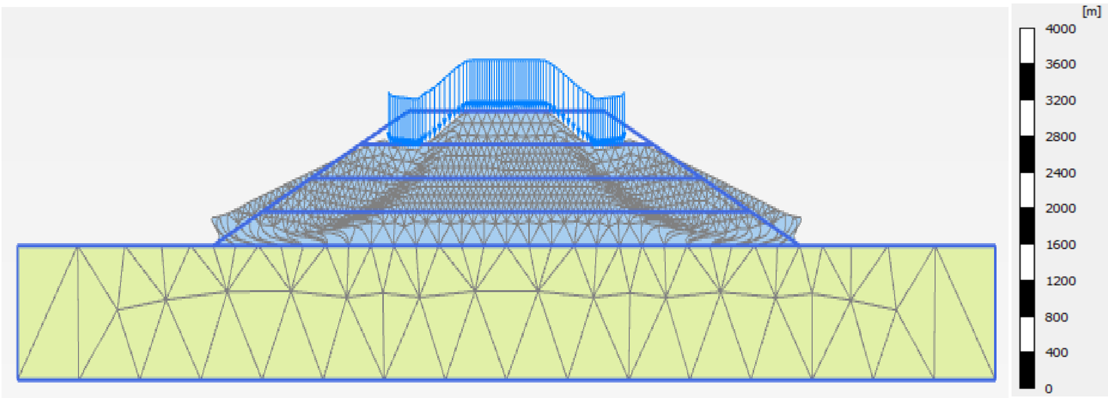

Figure 4.14: Without geogrid deformed mesh

4.6.1 Deformed Mesh with Geogrid Embankments

The mechanical behavior of an embankment reinforced with geogrid can be comprehensively assessed using mesh analysis utilizing Finite Element Analysis (FEA) to determine the impact of the geogrid. The influence of geogrid layers on soil to alter stress distribution, lessen deformation, and enhance overall stability is investigated in this investigation. By adding to the embankment's tensile strength, the geogrid is able to counteract failure processes including lateral spreading and settlement, which can cause the embankment to slip and fail. As seen in Figure 4.15, the deformed mesh is shown. In terms of deformed mesh with geogrid, the value is 190.6 m.

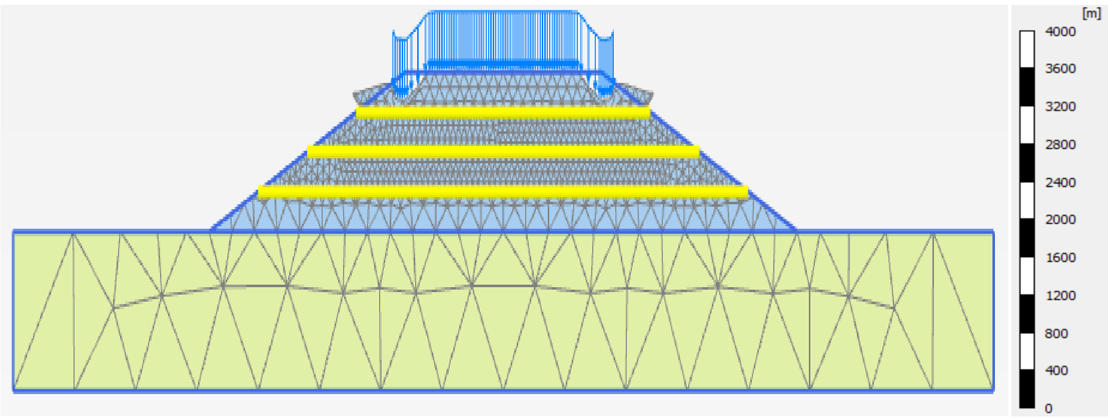

Figure 4.15: With geogrid deformed mesh

In Figure 4.16, the number of geogrids is increased by one for better analysis. When a number is increased, it is seen that its total mesh changes a lot. The total mesh with 4 geogrids layer is 47.67 m.

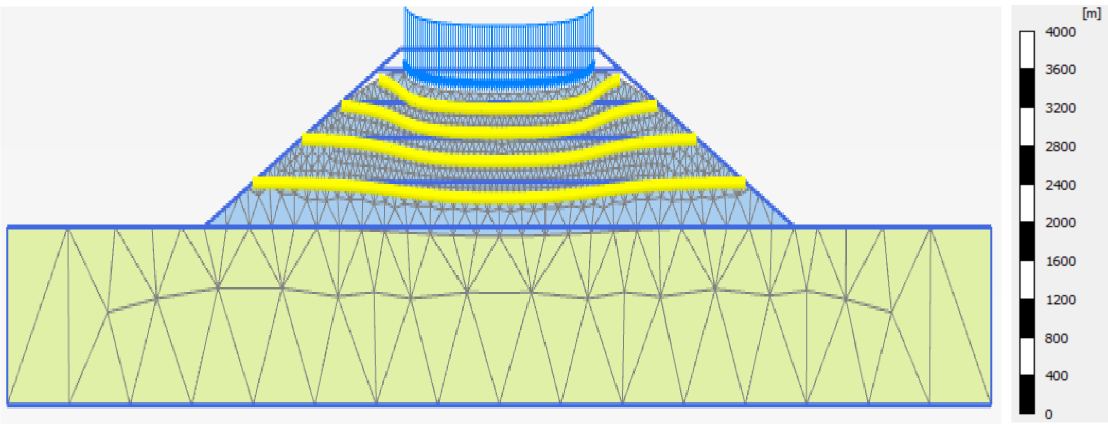

Figure 4.16: With 4 geogrid layer deformed mesh

4.7 Displacement Analysis for 6 m Embankment

Geogrids are geosynthetic materials designed to reinforce the soil and improve its mechanical properties. By incorporating geogrids into the embankment, the overall stability is enhanced, which helps reduce settlement, increase slope stability, and control lateral displacement. For a more in-depth look, the embankment has been analyzed by creating a model using 3 geogrids for 6m.

4.7.1 Total Displacement without Geogrid Embankments

The overall displacement of an embankment in the absence of geogrid reinforcement is the result of the combined impacts of the horizontal and vertical displacements brought about by the applied loads. There is more lateral movement and settlement when there is no geogrid, which increases overall displacement. This is because, in the absence of geogrid, there is no tensile reinforcement in the soil. In the model, the total displacement is 3.706*10^{-2} m which is shown in Figure 4.17.

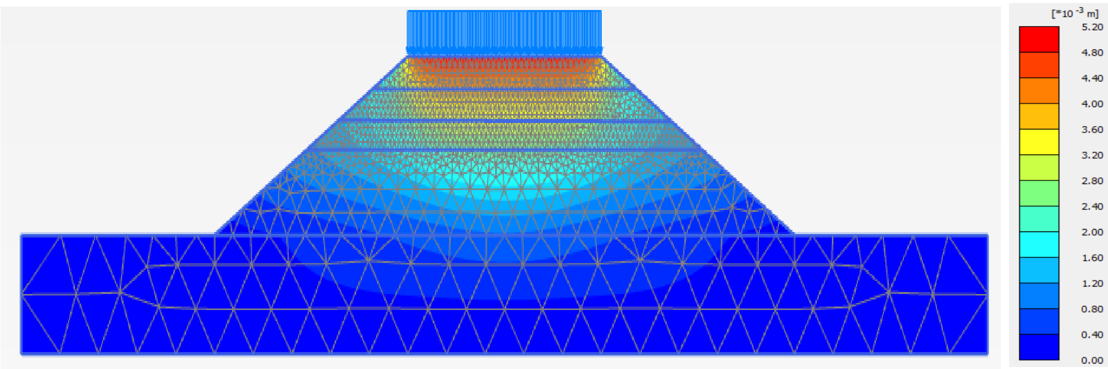

Figure 4.17: Without geogrid total displacement

4.7.2 Total Displacement with Geogrid Embankments

soil or ground material's total movement or deformation within a geogrid-reinforced embankment. In order to improve the stability and load-bearing capacity of an embankment, geogrids are artificial materials, usually composed of polymers, that are used to strengthen soils by giving them tensile strength. When loads, like traffic or building on the embankment, as well as natural pressures, such as settlement and erosion, are applied, these reinforcements aid in controlling and reducing displacements. In the model, the total displacement with geogrid is 3.665*10^{-2} m which is shown in Figure 4.18.

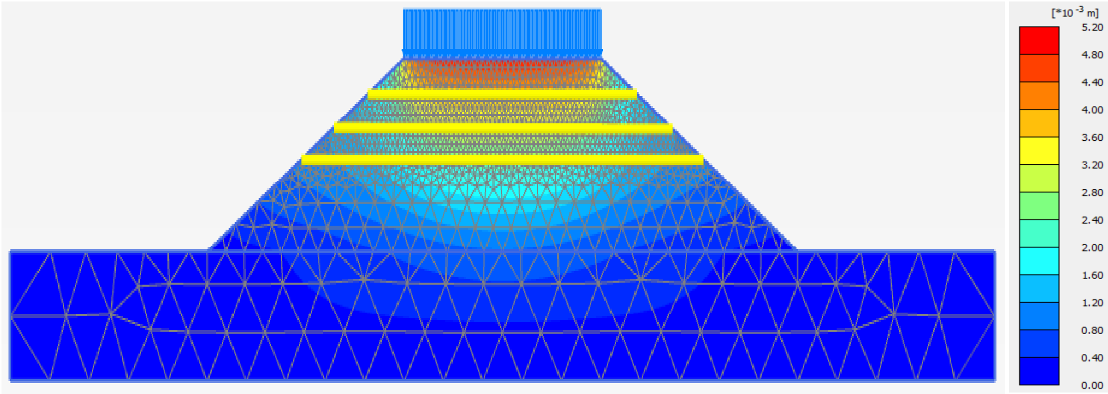

Figure 4.18: With geogrid total displacement

4.7.3 Horizontal Displacement without Geogrid Embankments

The displacement of the embankment horizontally is one of the most significant symptoms of its shifting or sliding. In the models of the unreinforced embankment, significant horizontal displacement was seen, especially when steeper slopes or weaker soils were included. The middle and top portions of the embankment saw the bulk of these displacements, and here is also where the shear pressures were most noticeable. As seen in Figure 4.19, the horizontal displacement is shown. In terms of horizontal displacement, the value is $9.183*10^{-3}$ m.

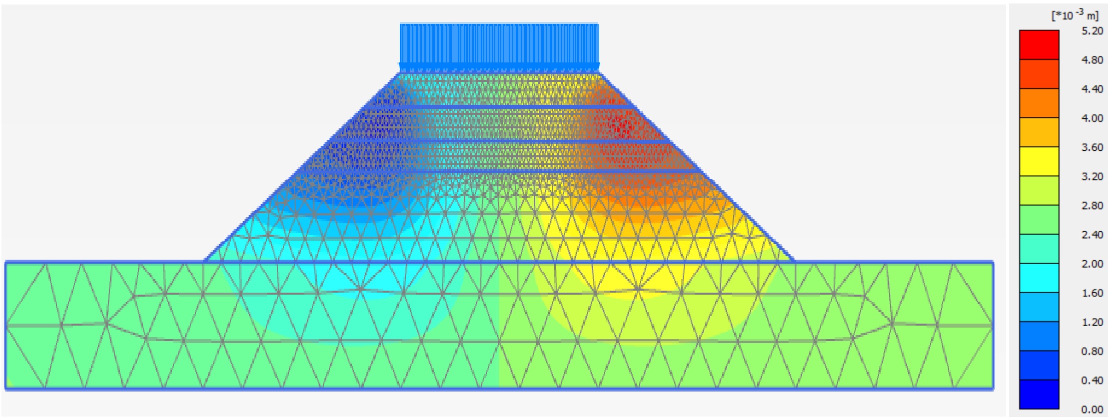

Figure 4.19: Without geogrid horizontal displacement

4.7.4 Horizontal Displacement with Geogrid Embankments

The application of geogrid reinforcement resulted in a significant decrease in horizontal displacement for all models. The geogrid layers reduced the amount of movement by preventing soil particle movement and offering additional tensile strength and resistance against lateral stresses. The reinforced embankment models showed an average horizontal displacement decrease of sixty to seventy percent when compared to the non-reinforced versions. As seen in Figure 4.20, the horizontal displacement with

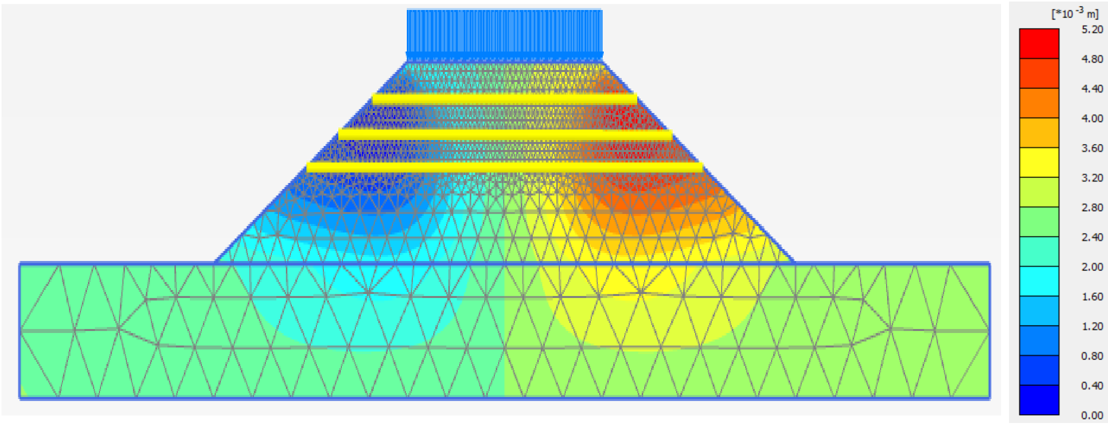

Figure 4.20: With geogrid horizontal displacement

geogrid is shown. In terms of horizontal displacement, the value is 7.541*10^{-3} m.

4.8 Stress Distribution

For a more in-depth look, the embankment has been analyzed by creating a model using 3 geogrids for 6m. The distribution of stress inside embankments is a crucial factor that affects how stable and effective these structures will be in the long run. The stress distribution, which describes how internal forces, also known as stresses, are distributed throughout the soil mass of an embankment, is influenced by the self-weight of the embankment, applied loads, and external factors like water pressure. Understanding the pattern of stress distribution is useful for engineers as it enables them to assess the embankment's overall safety as well as likely failure zones and deformation behavior.

4.8.1 Stress Distribution without Geogrid Embankments

In embankments without geogrid reinforcement, stress is more likely to be distributed unevenly, which can lead to stress concentrations that compromise the integrity of the structure. Shear stress, vertical stress, and horizontal stress are the main stresses that are present in unreinforced embankments. Every one of these stresses affects the way the embankment behaves and increases the likelihood that it may fail. The inherent tendency of the soil to distort under stress is amplified in the absence of reinforcement. This is particularly true for weak or easily compressed soils. As seen in Figure 4.21, the total stress is shown. In terms of total stress without geogrid, the value is 0.08974*10^{-6} kN/m^2.

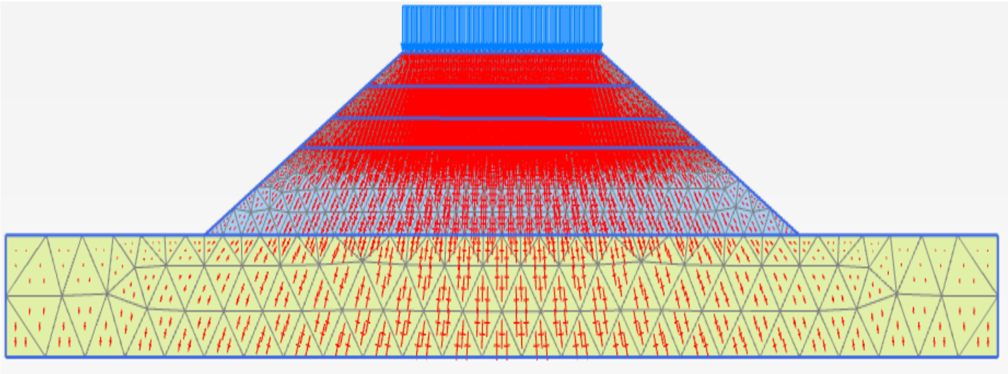

Figure 4.21: Without geogrid total stress

4.8.2 Stress Distribution with Geogrid Embankments

The installation of geogrid reinforcement in embankments results in a significant change in the stress distribution, which eventually produces a more uniform and balanced internal stress condition. The tensile strength and load-distributing properties that geogrid reinforcement provides result in an increase in the overall stability of the embankment. The principal effect of this reinforcement on shear stress, vertical stress, and horizontal stress reduces the likelihood of failure and deformation considerably. As seen in Figure 4.22, the total stress is shown. In terms of total stress with geogrid, the value is 0.06111*10^{-6} kN/m^2.

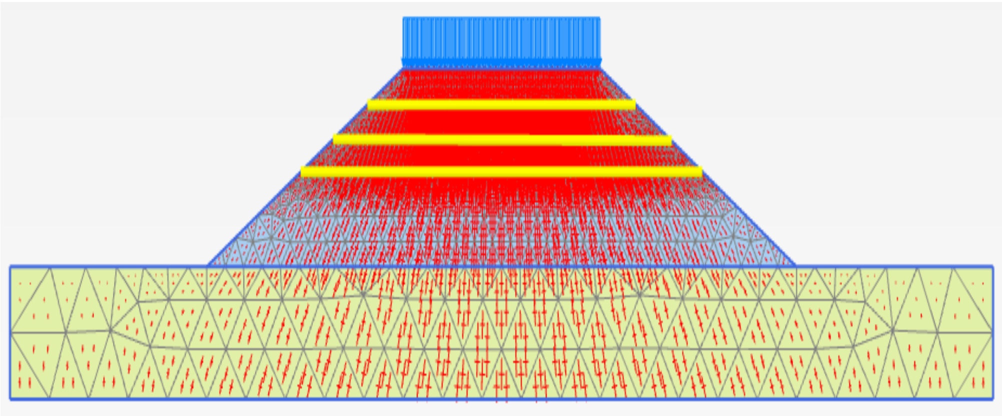

Figure 4.22: With geogrid total stress

4.9 Graph for 6 m Embankment

An important indicator of an embankment's stability under the forces pressing upon it is its Factor of Safety (FOS), which is measured for a 6-meter embankment. It may be defined as the ratio of the driving forces (which cause failure) to the resisting forces (which prevent failure). The weight of the embankment itself, external loads like traffic or structures, and the characteristics of the underlying soil are some of the load situations that this ratio helps engineers assess for the danger of structural collapse or instability. A graph comparing the Factor of Safety (FOS) with and without the usage of geogrid is displayed in Figure 4.23.

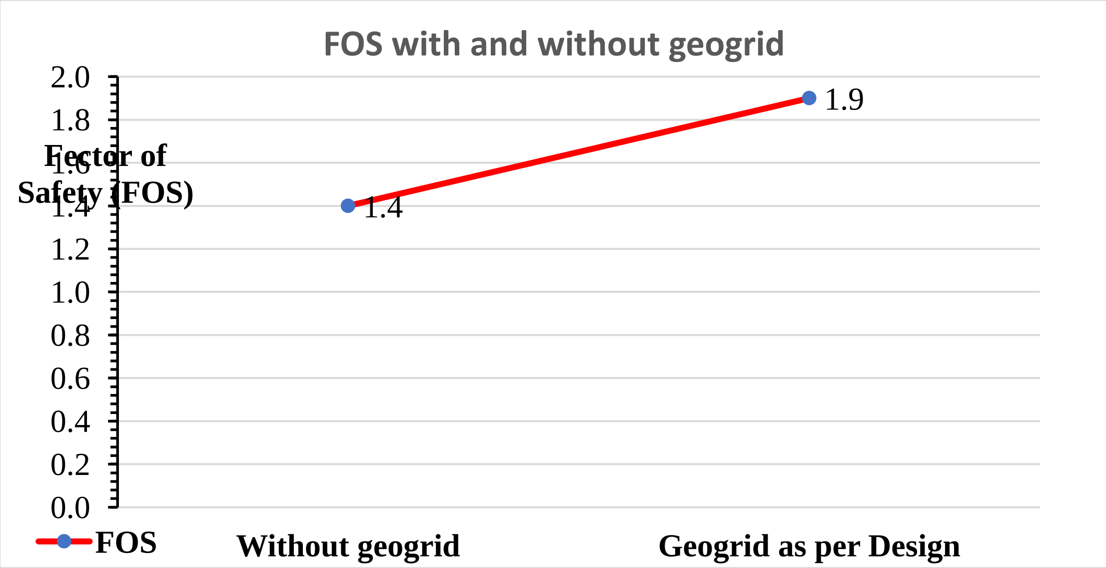

Figure 4.23: Variation of FOS of Embankment with and without Geogrid

For a 6-meter embankment, the Factor of Safety is essential to guarantee the stability and long-term functionality of the construction. Engineers can build safe, dependable embankments that can endure operational and environmental challenges by striking a balance between resisting and driving forces.

4.10 Mesh Analysis

4.10.1 Deformed Mesh without Geogrid Embankments

An effective method for evaluating the structural behavior of embankments without geogrid reinforcement is mesh analysis using Finite Element Analysis (FEA). Understanding this idea is necessary to understand how embankments work in terms of displacement, stress distribution, and potential failure zones, particularly in challenging soil conditions or when external forces like traffic or seismic loads are at play. Without geogrid, the intrinsic strength of the soil determines how resistant the embankment is to deformation and collapse, which typically leads to greater instability. As seen in Figure 4.24, the deformed mesh is shown. In terms of deformed mesh with geogrid, the value is 0.03706 m.

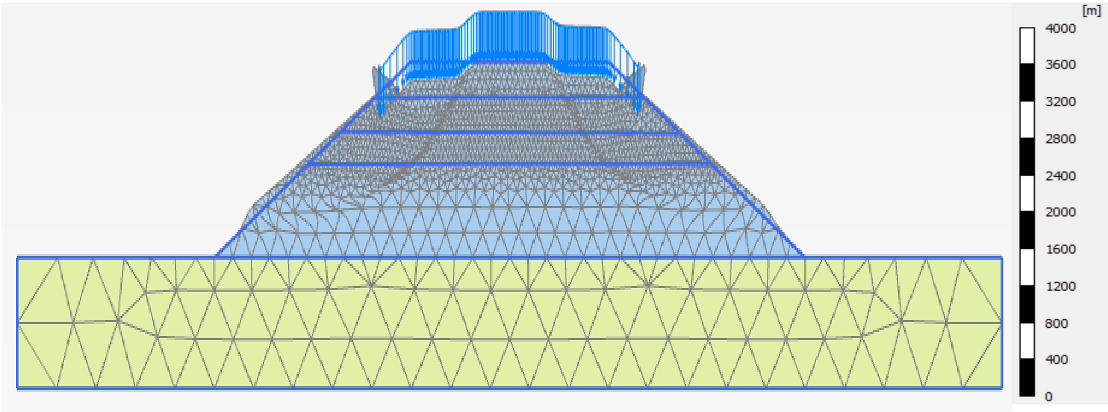

Figure 4.24: Without geogrid deformed mesh

4.10.2 Deformed Mesh with Geogrid Embankments

Finite Element Analysis (FEA) may be used to do a thorough assessment of the mechanical behavior of an embankment reinforced with geogrid in order to ascertain the influence of the latter. This inquiry explores the impact of geogrid layers on soil to modify stress distribution, reduce deformation, and improve overall stability. The lateral spreading and settlement processes that might lead to the embankment collapsing are countered by the geogrid by strengthening the embankment's tensile strength. As seen in Figure 4.25, the deformed mesh is shown. In terms of deformed mesh with geogrid, the value is 0.004813 m.

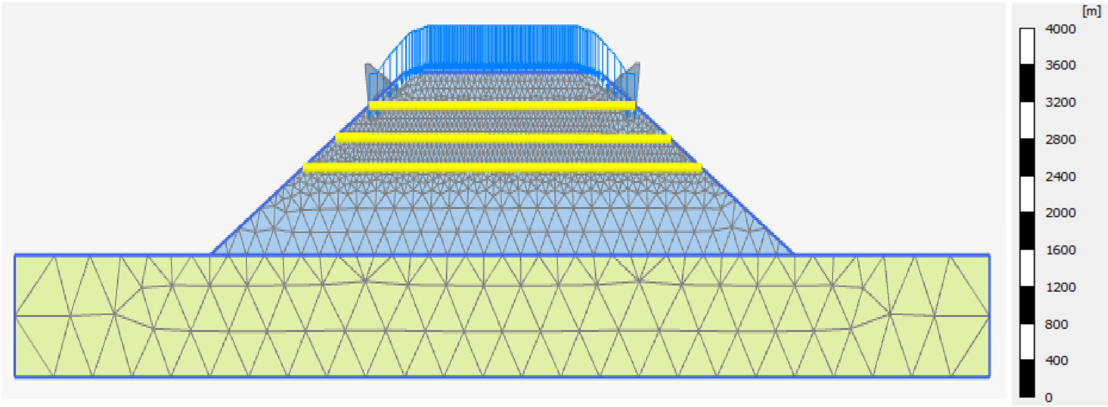

Figure 4.25: With geogrid deformed mesh

4.11 Displacement Analysis for 6 m Embankment

Geogrids are geosynthetic materials designed to reinforce the soil and improve its mechanical properties. By incorporating geogrids into the embankment, the overall stability is enhanced, which helps reduce settlement, increase slope stability, and control lateral displacement. For a more in-depth look, the embankment has been analyzed by creating a model using 1.5 spacing 3 geogrids for 6m.

4.11.1 Total Displacement without Geogrid Embankments

When applied loads are applied, the combined effects of the horizontal and vertical displacements cause an embankment's total displacement in the absence of geogrid reinforcement. When there is no geogrid, there is more lateral movement and settlement, which raises the total displacement. This is due to the lack of tensile reinforcement in the soil when geogrid is not there. In the model, the total displacement is $3.706*10^{-2}$ m which is shown in Figure 4.26.

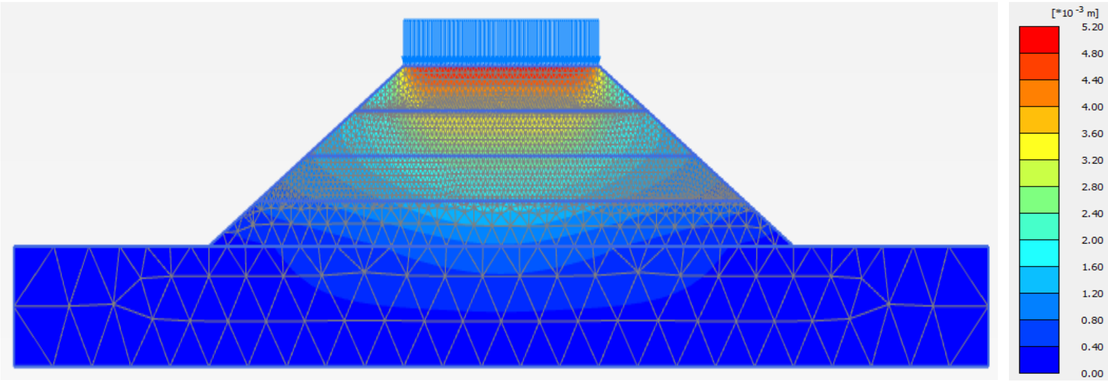

Figure 4.26: Without geogrid total displacement

4.11.2 Total Displacement with Geogrid Embankments

Complete movement or deformation of soil or ground material inside an embankment supported with geogrid. Geogrids are man-made materials, often made of polymers, that are used to provide soils tensile strength in order to increase their stability and load-bearing capability. These reinforcements help regulate and reduce displacements when natural forces like erosion and settlement, together with loads like traffic or building on the embankment, are applied. In the model, the total displacement with geogrid is $3.665*10^{-2}$ m which is shown in Figure 4.27.

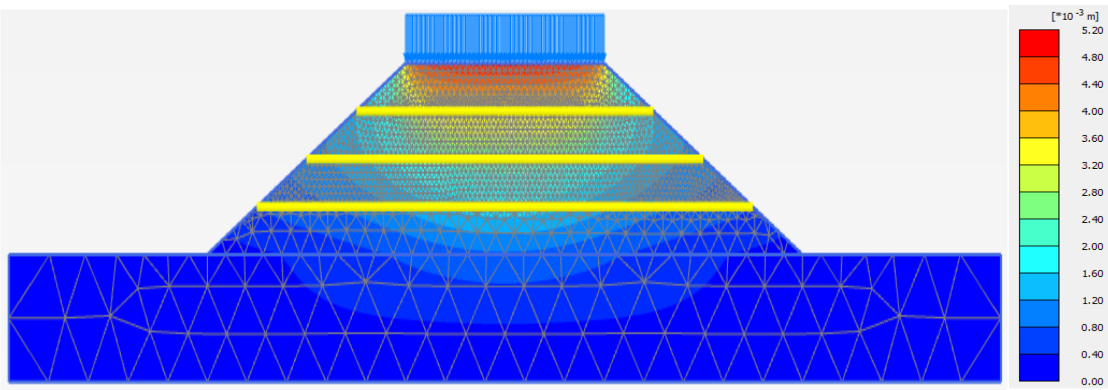

Figure 4.27: With geogrid total displacement

4.11.3 Horizontal Displacement without Geogrid Embankments

One of the most important signs that the embankment is moving or sliding is the displacement of the embankment horizontally. Significant horizontal displacement was seen in the unreinforced embankment models, particularly when steeper slopes or weaker soils were incorporated. The majority of these displacements and the strongest shear pressures were observed in the middle and upper sections of the embankment. As seen in Figure 4.28, the horizontal displacement is shown. In terms of horizontal displacement, the value is 9.157*10^{-3} m.

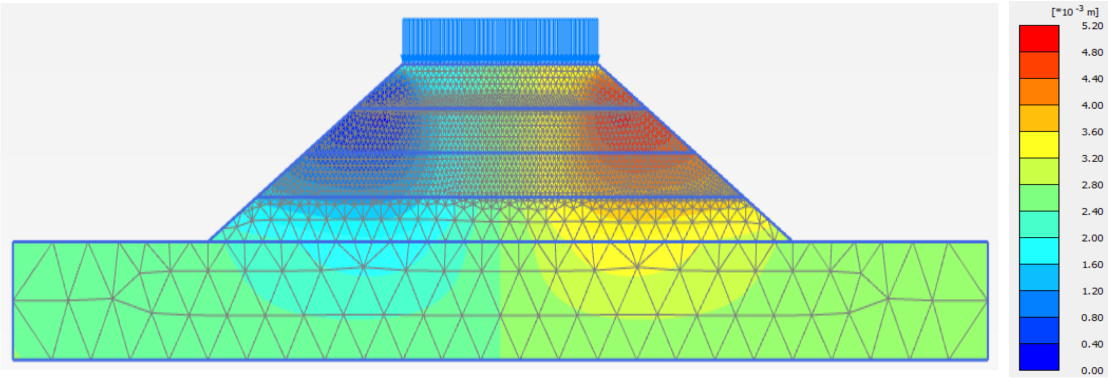

Figure 4.28: Without geogrid horizontal displacement

4.11.4 Horizontal Displacement with Geogrid Embankments

For all models, the horizontal displacement was significantly reduced upon the introduction of geogrid reinforcement. By stopping the movement of soil particles and providing more tensile strength and resistance against lateral stresses, the geogrid layers lessened the amount of movement. The reinforced embankment models demonstrated an average horizontal displacement decrease of sixty to seventy percent as compared to the non-reinforced equivalents. As seen in Figure 4.29, the horizontal displacement with geogrid is shown. In terms of horizontal displacement, the value is 7.861*10^{-3} m.

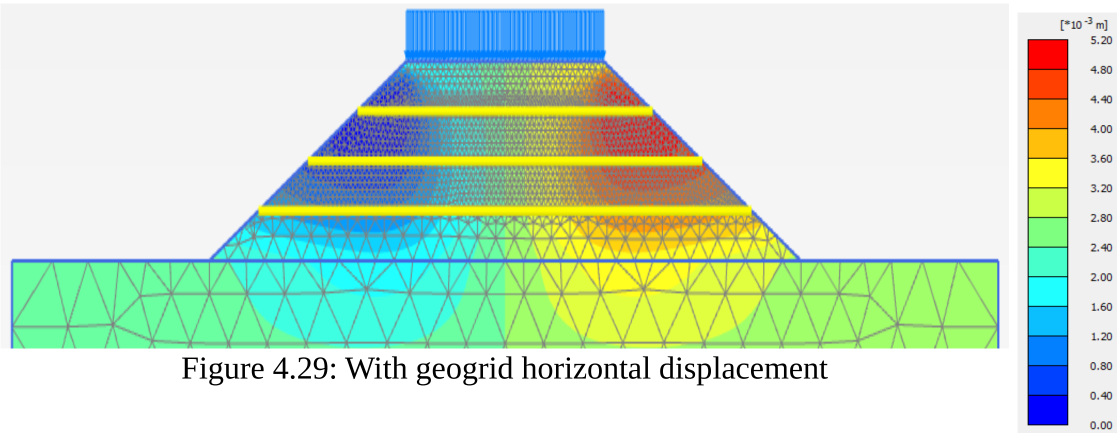

Figure 4.29: With geogrid horizontal displacement

4.12 Stress Distribution

For a more in-depth look, the embankment has been analyzed by creating a model using 1.5 spacing 3 geogrids for 6m. The distribution of stress inside embankments is a crucial factor that affects how stable and effective these structures will be in the long run. The stress distribution, which describes how internal forces, also known as stresses, are distributed throughout the soil mass of an embankment, is influenced by the self-weight of the embankment, applied loads, and external factors like water pressure. Understanding the pattern of stress distribution is useful for engineers as it enables them to assess the embankment's overall safety as well as likely failure zones and deformation behavior.

4.12.1 Stress Distribution without Geogrid Embankments

Stress distribution is more likely to be unequal in embankments lacking geogrid reinforcement, which might result in stress concentrations that jeopardize the structural integrity of the embankment. The primary stresses seen in unreinforced embankments are shear, vertical, and horizontal stresses. Each of these stressors has an impact on the embankment's behavior and raises the possibility that it may fail. Without support, the soil's innate propensity to sag under load is exacerbated. This is especially true for soils that are readily compacted or weak. As seen in Figure 4.30, the total stress is shown. In terms of total stress without geogrid, the value is 0.09012*10^{-6} kN/m^2.

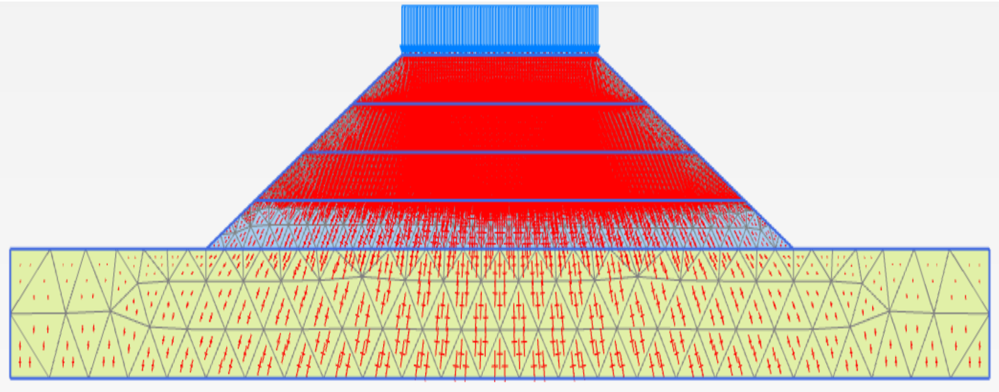

Figure 4.30: Without geogrid total stress

4.12.2 Stress Distribution with Geogrid Embankments

An internal stress state that is more uniform and balanced is ultimately produced by the installation of geogrid reinforcement in embankments, which causes a major shift in the stress distribution. The total stability of the embankment is increased by the tensile strength and load-distributing qualities that geogrid reinforcement offers. This reinforcement primarily lowers the chance of failure and deformation by reducing shear

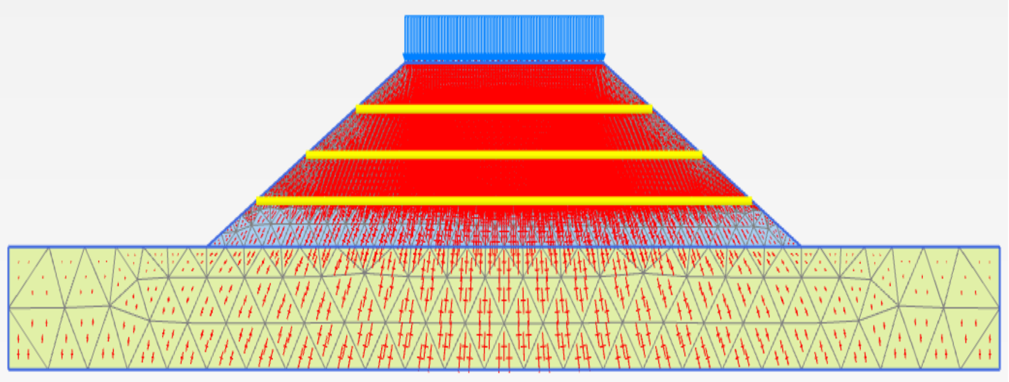

Figure 4.31: With geogrid total stress

stress, vertical tension, and horizontal stress. As seen in Figure 4.31, the total stress is shown. In terms of total stress with geogrid, the value is 0.05188*10^{-6} kN/m^2.

4.13 Mesh Analysis

4.13.1 Deformed Mesh without Geogrid Embankments

Finite Element Analysis (FEA) mesh analysis is a useful technique for assessing the structural behavior of embankments without geogrid reinforcement. Comprehending this notion is vital to comprehend the functioning of embankments concerning displacement, distribution of stress, and possible zones of failure, especially under difficult soil circumstances or when extraneous factors such as traffic or seismic loads are involved. Without geogrid, the embankment's resistance to deformation and collapse is determined by the soil's intrinsic strength, which usually results in increased instability. As seen in Figure 4.32, the deformed mesh is shown. In terms of deformed mesh with geogrid, the value is 0.03706 m.

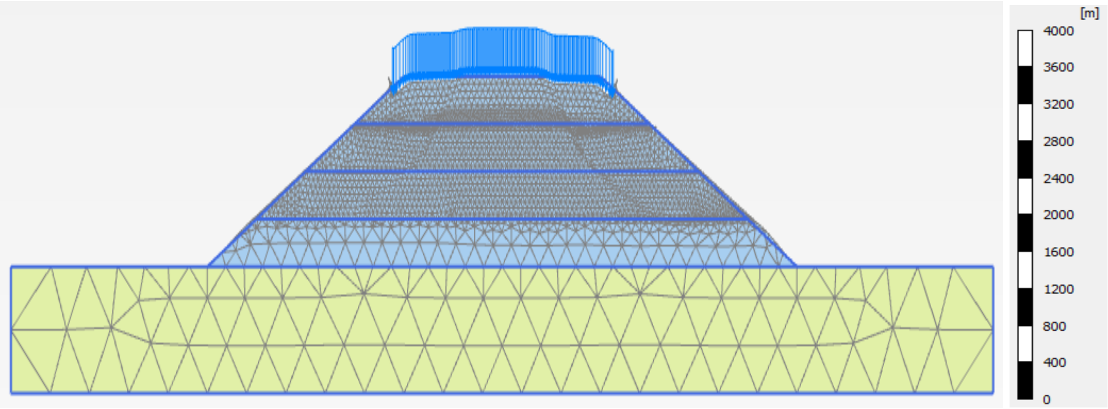

Figure 4.32: Without geogrid deformed mesh

4.13.2 Deformed Mesh with Geogrid Embankments

The mechanical behavior of an embankment reinforced with geogrid may be thoroughly evaluated using Finite Element Analysis (FEA) to determine the impact of the latter. In order to alter stress distribution, lessen deformation, and enhance overall stability, this investigation looks at the effects of geogrid layers on soil. The geogrid prevents the embankment from collapsing by fortifying its tensile strength against lateral spreading and settling processes. As seen in Figure 4.33, the deformed mesh is shown. In terms of deformed mesh with geogrid, the value is 0.03667 m.

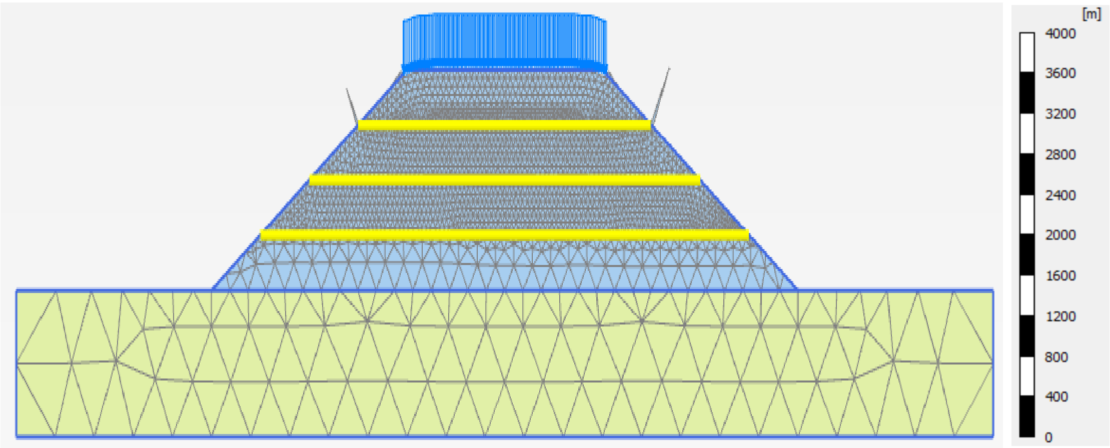

Figure 4.33: With geogrid deformed mesh

For more in-depth observation, three parameters are increased by 5%. Those parameters are cohesion, young's modulus. When cohesion increases, the displacement decreases in the without geogrid model. The total displacement is 3.421*10^{-2}m, Shown in Figure 4.34. Also, the displacement decreases with the geogrid model. The total displacement is 3.398*10^{-2}m, Shown in Figure 4.35.

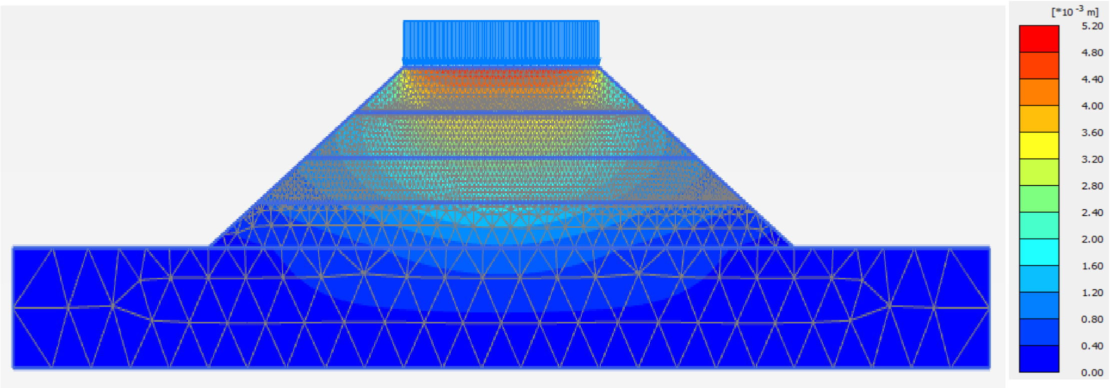

Figure 4.34: Without geogrid total displacement (Cohesion)

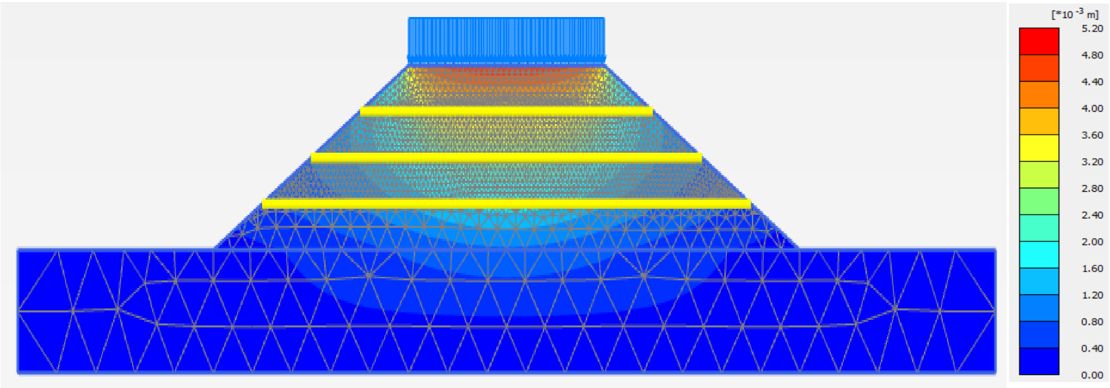

Figure 4.35: with geogrid total displacement (Cohesion)

When young's modulus increases, the displacement increases in the without geogrid model. The total displacement is 3.675*10^{-2}m, Shown in Figure 4.36. Also, the displacement increases with the geogrid model. The total displacement is 3.647*10^{-2}m, Shown in Figure 4.37.

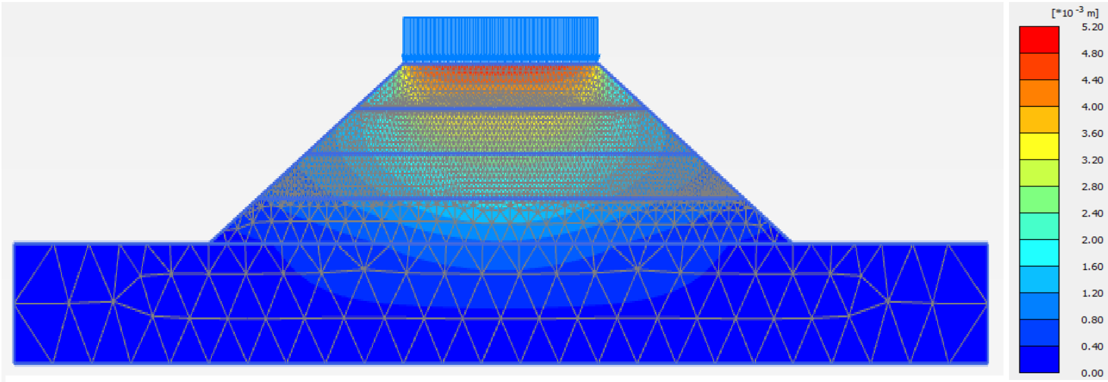

Figure 4.36: Without geogrid total displacement (Young's modulus)

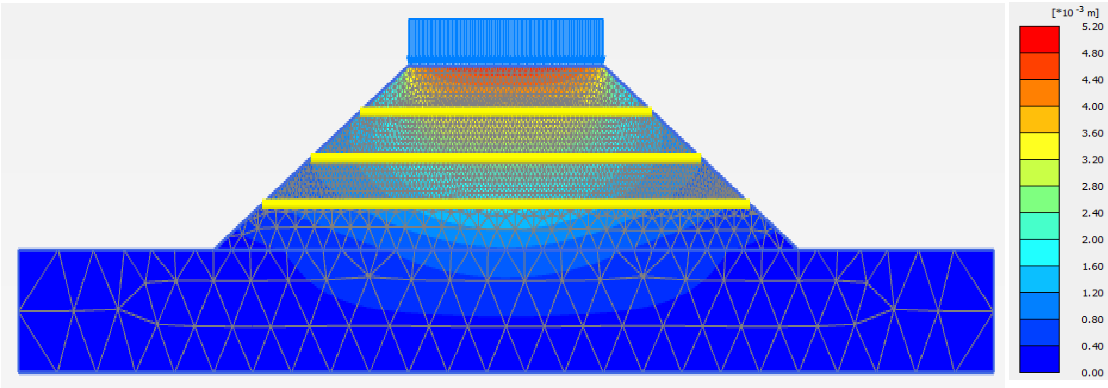

Figure 4.37: With geogrid total displacement (Young's modulus)

Three parameters are increased and decreased by 5%. Those parameters are cohesion, Young's modulus, and Reloading stiffness. Shown in Table 4.1, 4.2 and 4.3.

Table 4.1: Cohesion results differences

	Cohesion				
	Before installing geogrid		After installing geogrid		units
	increased 5%	decreased 5%	increased 5%	decreased 5%	
Total Displacement	$3.421*10^{-2}$	$4.481*10^{-2}$	$3.398*10^{-2}$	$4.193*10^{-2}$	m
Horizontal Displacement	$7.226*10^{-3}$	$1.503*10^{-2}$	$6.597*10^{-3}$	$1.203*10^{-2}$	m
Vertical Displacement	$3.421*10^{-2}$	$4.390*10^{-2}$	$3.398*10^{-2}$	$4.163*10^{-2}$	m
Stress Distribution	198.4	198.4	198.9	198.9	kN/m^2
Deformed Mesh	0.03421	0.04481	0.03398	0.04193	m

Table 4.2: Young's modulus results differences

	Young's modulus				
	Before installing geogrid		After installing geogrid		units
	increased 5%	decreased 5%	increased 5%	decreased 5%	
Total Displacement	$3.675*10^{-2}$	$3.816*10^{-2}$	$3.647*10^{-2}$	$3.693*10^{-2}$	m
Horizontal Displacement	$7.767*10^{-3}$	$1.160*10^{-2}$	$6.938*10^{-3}$	$9.317*10^{-3}$	m
Vertical Displacement	$3.675*10^{-2}$	$3.792*10^{-2}$	$3.647*10^{-2}$	$3.693*10^{-2}$	m
Stress Distribution	198.8	198.2	199.4	198.6	kN/m^2

Deformed Mesh	0.03675	0.03816	0.03647	0.03693	m

Table 4.3: Reloading stiffness results differences

	Reloading stiffness				
	Before installing geogrid		After installing geogrid		units
	increased 5%	decreased 5%	increased 5%	decreased 5%	
Total Displacement	$3.671*10^{-2}$	$3.741*10^{-2}$	$3.634*10^{-2}$	$3.696*10^{-2}$	m
Horizontal Displacement	$8.851*10^{-3}$	$9.450*10^{-2}$	$7.657*10^{-3}$	$8.068*10^{-3}$	m
Vertical Displacement	$3.669*10^{-2}$	$3.739*10^{-2}$	$3.634*10^{-2}$	$3.696*10^{-2}$	m
Stress Distribution	198.4	198.6	199	199.2	kN/m^2
Deformed Mesh	0.03671	0.03741	0.03634	0.03696	m

In this study, only three parameters-cohesion, young’s modulus, and reloading stiffness were systematically altered to examine their impact on the system's behavior. These parameters were individually increased and decreased by 5%, while all other variables were held constant to isolate their effects. Understanding the individual and relative contributions of three factors to soil-structure system performance can be achieved by isolating their unique impacts while keeping other parameters constant, thereby optimizing design tactics.

4.14 Summary

The numerical simulation findings show that embankment stability is greatly enhanced under a variety of situations by geogrid reinforcement. All reinforced models had higher safety factors, and there were significant reductions in both horizontal and vertical displacements. Because of the more even distribution of stress inside the reinforced embankments, there was less chance of failure. Enhancing the stability of embankments with geogrid reinforcement works well, especially in difficult situations like unstable soils or steep inclines. The study's conclusions offer insightful information for creating embankments that are safer and more durable. According to the findings, geogrid reinforcement considerably improves embankment stability by boosting the safety factor, lowering displacements in both the vertical and horizontal directions, and more uniformly dispersing stresses. Because of this, geogrid is a crucial technique for enhancing embankment performance, particularly in locations with poor soil or under high loads. These results provide valuable information that may be applied to the design and construction of embankments that are more safe and resilient to damage. The differences between three and four geogrids are negligible. displaying much the same outcomes. Using three geogrids is preferable as the outcomes are comparable. It will be less expensive.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Introduction

Geogrid reinforcement has been proven to be a highly effective method for improving the stability of embankments, particularly under conditions where unreinforced structures would be vulnerable to failure. The ability to reduce displacement, redistribute stresses, and increase the factor of safety makes geogrid reinforcement an essential tool in modern geotechnical engineering. This work used numerical simulations carried out in PLAXIS 2D to assess the effect of geogrid reinforcement on the stability of embankments. The analysis focused on crucial characteristics such as the factor of safety (FOS), displacement (both horizontal and vertical), and stress distribution. Several important results were reached by contrasting geogrid-reinforced and unreinforced embankments under varied circumstances, such as varied soil types, slope angles, and loading situations.

5.2 Conclusion

Due to soil particle interlocking and friction between geogrid layers and soil, geogrids create a steady force at the soil-reinforcement layer interface. Therefore, the reinforcement communicates the tensile strength to neighboring soils and disperses the applied load across a wide region from the soil. All things considered, the analysis's findings indicate that the usage of geogrid reduces the embankment's horizontal displacement and raises the safety factor. The following factors may contribute to an embankment's increased stability following geogrid:

1. The FOS of embankments is greatly increased by geogrid reinforcement, increasing their resistance to failure under various loading scenarios. Even in poorer soils and on steeper slopes, the models demonstrated that reinforced embankments regularly reached an FOS over the safety level, but unreinforced embankments frequently dropped below safe limits. Geogrid-reinforced embankments significantly reduce horizontal and vertical displacements, preventing deformation and preserving long-term stability, with a 60-70% decrease in horizontal displacement and a 50-60% drop in vertical settlement.

2. Stress concentrations at key places are decreased and the likelihood of structural failure is minimized by the uniform distribution of vertical, horizontal, and shear stresses provided by geogrid reinforcement. It offers a valuable solution in difficult geotechnical conditions because it works particularly well in weak or compressible soils, increasing load-bearing capacity, decreasing settlement, and minimizing the likelihood of deep-seated collapse.

All things considered, geogrid reinforcement has shown to be a very successful technique for enhancing the stability of embankments, especially in situations where unreinforced structures would be susceptible to failure. Geogrid reinforcement is a crucial tool in contemporary geotechnical engineering because of its capacity to decrease displacement, reallocate stresses, and raise the factor of safety.

5.3 Recommendations

Based on the findings of this study, the following recommendations are made for the design and implementation of geogrid-reinforced embankments:

- Geogrid reinforcement should be strongly considered for embankments constructed on weak or compressible soils, such as clays or silts. In these scenarios, the reinforcement not only enhances stability but also reduces long-term settlement, thereby extending the lifespan of the structure and reducing maintenance costs.

- The effectiveness of geogrid reinforcement depends on its proper placement within the embankment. It is recommended that geogrid layers be strategically placed at critical depths to intercept potential failure planes and evenly distribute loads. Simulations and field data suggest that multiple layers of geogrid, spaced evenly throughout the embankment, provide the best reinforcement.

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