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NUMERICAL ANALYSIS OF THE GEOSYNTHETIC REINFORCED EMBANKMENT CONSTRUCTED ON A SOFT FOUNDATION

Shams Amer AL-RAWE

Master's Thesis

Supervisor

Assoc. Prof. Dr. Sepanta NAİMİ

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The thesis titled NUMERICAL ANALYSIS OF THE GEOSYNTHETIC REINFORCED EMBANKMENT CONSTRUCTED ON A SOFT FOUNDATION prepared by SHAMS AMER AL-RAWE and submitted on 22/12/2022 has been **accepted unanimously** for the degree of Master of Science in Civil Engineering.

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I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Shams Amer AL-RAWE

Signature

DEDICATION

I would like to take the opportunity to thank God first for everything and help me to write the thesis. I owe my gratitude and thanks to my supervisor, Assoc. Prof. Dr. Sepanta NAIMI for the invaluable guidance and encouragement he has given me. I would like to thank the members of the discussion committee. I would like to thank and appreciate Assis Prof. Dr. Ahmed Hazem Abdul-Karim at the College of Engineering at the University of Anbar, for his scientific advice and for the advice and guidance he gave me, who devoted an effort to this research. I would also like to thank and praise my family for their patience and support. I would also like to thank everyone who supported me with all my gratitude to all.

ABSTRACT

NUMERICAL ANALYSIS OF THE GEOSYNTHETIC REINFORCED EMBANKMENT CONSTRUCTED ON A SOFT FOUNDATION

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Embankments and other structures on soft clay soils continue to be a geotechnical engineering challenge. The problems resulting from deformation are extensive on the embankment and cause failure, which leads to great instability or slippage due to insufficient shear strength and to address the resulting problems, the cost of time delay, non-service period and high maintenance cost. Therefore, the current study aimed to solve the issues by creating an improved model for the analysis and design of embankments supported by the geogrid of origin on soft clay soils under the influence of traffic loads through reinforcement with geogrid and supported by stone columns for the purpose of improving the foundation soil. Plaxis 3D 2020 was the Mohr-coulomb model, which was adopted for the soil and was used for this research. Using a set of numerical analyses, the effect of important design parameters like the position of the reinforcement, the number of layers, and the type of geogrid was studied on a geogrid-reinforced embankment. The results of the models showed for a geogrid-reinforced embankment, the reinforced embankment's lateral deformation, the improvement value in the construction phase was (45.2%) and the loading phase was (40.8%) the unreinforced embankment in the case type (GGIII) and with four layers of geogrid. In the case of vertical displacement, the improvement value in the construction phase was

(15%) and in the loading phase was (18.1%) the unreinforced embankment in the type (GGIII) and with four layers. For the purpose of improving the foundation soil, stone columns reinforced with geogrid were placed. The results were compared in the case of a geogrid-reinforced and reinforced embankment with stone columns reinforced with geogrid of the type (GGIII) than those not supported by stone columns, and the improvement value in the case of horizontal displacement was (71%) in the construction phase and (12.7%) in the loading phase of the embankment that is without support from stone columns. In the case of vertical pressure, the improvement in the state of the embankment reinforced by geogrids and reinforced by stone columns reinforced with geogrid was (50%) in the construction phase and (61%) in the loading phase compared to the embankment without support from stone columns. A slope of 1:1.5 recommends choosing a geogrid of the type (GGIII) with four layers as the most efficient combination.

Keywords: Reinforced Embankment, Geogrid, Finite Element Analysis, Soft Foundation, PLAXIS 3D, Stone Columns.

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ABBREVIATIONS

FEA	:	Finite Element Analysis.
GGI	:	Geogrid type I.
GGII	:	Geogrid type II.
GGIII	:	Geogrid type III.
HDPE	:	High Density Polyethylene
PLAXIS	:	Plane Strain and Axial Symmetry
H	:	Horizontal.
3D	:	Three-dimensional.
2D	:	Two-dimensional
V	:	Vertical
MD	:	Machine Direction.
XMD	:	Cross-Machine Direction
MC	:	Mohr Coulomb
N	:	Northing.
PVC	:	Polyvinyl Chloride

LIST OF SYMBOLS

ψ	:	Angle of dilatancy.
ϕ	:	Angle of internal friction
γ	:	Bulk unit weight.
υ	:	Poisson's ratio.
γ_{sat}	:	Saturated unit weight.
γ_{dry}	:	Dry unit weight.

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The industry's fast expansion population and the unprecedented demand for the increase and development of infrastructure and the massive expansion of construction projects at present and proximity to rural and urban areas lead to a shortage of buildable land, highways, and railways, which led to the construction sector to implement projects in places where they are available tracts of land [1]. Road bridges and other construction on soft natural clay remains a geotechnical engineering challenge. And some issues arise as a result deformation is fairly common ، embankments can fail leads to slippage due to insufficient tensile strength, and as a consequence of the increasing demand for construction works such as road networks and structures built on soil, it must be accompanied by construction supervision and quality and as a result of urgent and increasingly urgent need finding solutions to the structural problems of soil that accompany buildings, bridges, and other facilities, and as a result of these problems, geotechnical engineers face many challenges during construction on soft soils, so failures must be mitigated. This strategy has several drawbacks. As a result of mitigation, infrastructure is temporarily destroyed. such as the line for distributing water, a cable made of electricity, a telecommunications fiber optical line, as well as so on. Thus, the time delay cost, non-service period, and maintenance cost are high. The result of bearing failure and soil instability is the result of constructing an embankment constructed on soft clay soils with low strength and high compressibility, and instability of slopes. To make it safer, a reinforcement layer must be placed at the bottom of the embankment. A variety of geosynthetic materials with properties have been developed to suit different uses. Reinforcing synthetic materials perform key functions in engineering applications in terms of reinforcement, separation, filtration, and moisture retention, using a layer of geogrid .The purpose of improvement is to modify the soil reinforcement and its engineering properties, so there are several methods for improving the soil, either the use of additives or pressure or chemical stabilization so [2]. formulated in the modern concept of reinforced soil, use of metal tapes for reinforcement using polymer technology, for the ability of soil to withstand pressure or shear forces, so the use of cladding materials as reinforcing elements ،that can improve the building height well and reduce horizontal displacement and uneven settlement clay soil and fast pore water pressure dissipation [3,4]. Soil reinforcement can be defined as the introduction of reinforcement between soil layers such as geotextile materials or made of polymer or polypropylene, the purpose of the use is to improve stability, increase capacity and reduce lateral deformation [5]. Figure (1.1) different geosynthetics types.

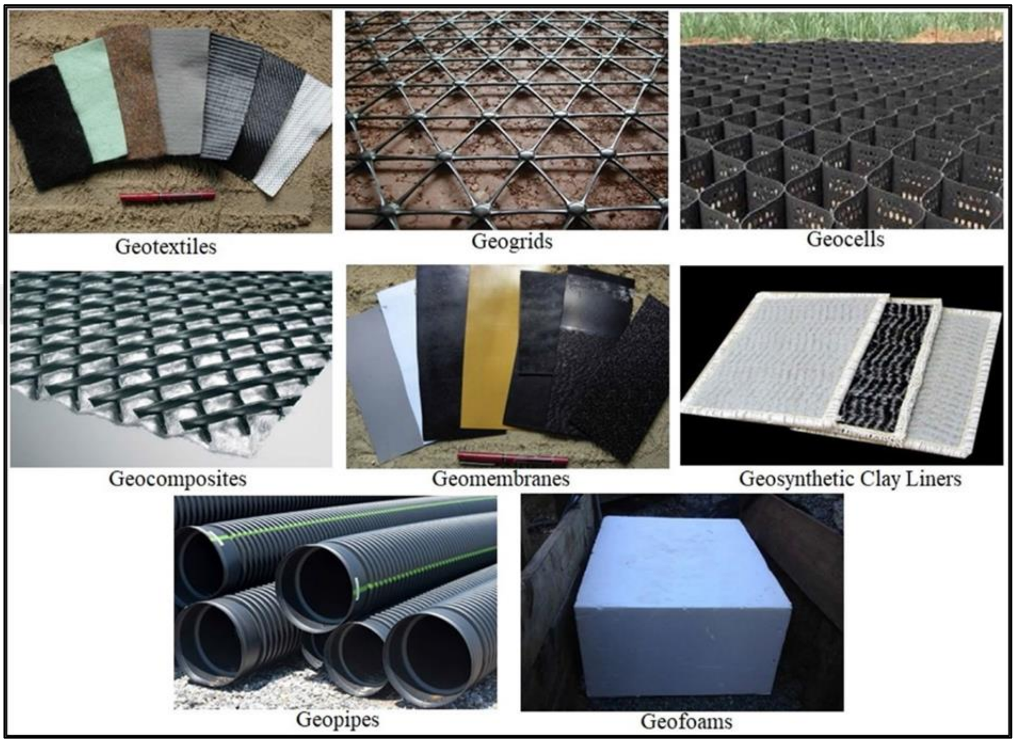


Figure 1.1: Different Geosynthetics Types.

Therefore, the steps of optimization techniques for soil behavior and characteristics depending on the soil type and the requirements for design [6,7,2]. Because of its simplicity and economic aspects, it has good tensile strength and hardness in the soil as reinforcement, studies have shown its use as reinforcement layers in the soil [8,9,10]. The research aims to get a better understanding of the reinforced embankment's performance on clay with low strength soil, so data was used based on laboratory tests and the use of materials as input. Numerical modeling based on finite element three-dimensionality was used. Several three-dimensional numerical analyzes were performed to analyze stability and deformation as a basic criterion in the embankment. The purpose of building the embankment to raise the road's height over that of the surrounding area ،it’s a type of structure that's used in the construction majority of project-related engineering applications and infrastructure and depends on two factors (the foundation and the filling) [11,12]. These two sources are essential in the analysis to find the failure slope and to understand the behaviors of components such as the deformation mechanism that fails, the dictation must be appropriate for the required engineering performance [13]. The degree of pressure and factors affecting to obtain better results to soil [14]. Lightweight filling materials [15]. It has suitable anti-saturation properties [16] and pressure properties [17] and compressibility [18] and shear strength [19].Therefore, the properties must be appropriate to avoid instability if it is built on soft foundations.

1.2 STATEMENT OF THE PROBLEM

Structures and others that are installed on soil with strength low continues to be a challenge ‹geotechnical engineers faced challenges to find method innovative and cost-effective to improvements the soil such as increasing soil shear strength, (wear resistance), (resistance to deformation) , and other properties with the aim of treatment to improve sustainability‹Shear strength, reducing the compaction, and controlling water absorption for improved soils[20] , so various soil improvement methods must to be utilized in the stabilization of soft clay soils to increase their bearing capacity while lowering their weight soil stability [21]. suggested the use of metal tapes for reinforcement using polymer technology[22]. For soil ability to withstand pressure or shear forces, so the use of cladding materials as reinforcing elements. Soil reinforcement can be defined as inserting reinforcement between soil layers such as geotextile materials made of polymer or polypropylene, the purpose of the use is to improve stability, increase capacity and reduce lateral deformation. The deformation causes a variety of issues numerous and may cause failure that may lead to great instability or slippage due to insufficient shear strength. The soil on which the origin is built could be from different types of soils located below the embankment site or were in different places due to changing climatic conditions, which leads to the movement of soil associated with a under infrastructures [23] , as a result of this movement, cracks occur in the surfaces, which leads to the rehabilitation and maintenance of highways in addition to the high cost, so the maintenance method leads to the destruction of infrastructures such as water distribution lines, electrical cables, and telecommunication fiber lines, in addition to the cost of the factor of time delay and the high cost of maintenance in addition to the delay in non-service during the maintenance period, geogrid was employed as a reinforcing material the accompanying problems during the movement of the soil [4] . Therefore, it is necessary to develop and contributed to the structure by strengthening the layers of geogrids and integrate‹ study aims to treat by creating a better model for the design and analysis of the bases that have been strengthened of the geogrid under traffic loading impact. Among the techniques available to improve soft soils by employing stone columns, an effective technique for improving soil variables such as settlement and bearing capacity, representing sustainable solutions for foundations. The process of improving the soil using the stone column helps to an extent large soft-soil cohesion in the construction [24] therefore, impact adding stone columns to soft soil to reinforce it for improvement purposes.

1.3 THE OBJECTIVES AND AIM OF STUDY

a) The study's goal is to find out more about the numerical analysis of a geogrid or geotextile is used to provide stability for an embankment constructed on soft clay soils.

b) Using an element-based program to determine the deformation and stability of the embankment due to the strengthening of the geogrid.

c) The embankment is placed on clay soil to obtain the optimal application of embankment.

d) Develop the behavior of reinforced soft soils is better understood.

e) Studying the soil's shear strength and behavior in terms of deformation. Soil deformation can be defined as the expansion of the soil ،the goal is to investigate the shear resistance and expansion of the soil.

f) Examination of shear resistance and deformation in the case of geogrid-reinforced soils. That is, the shear strength of the reinforced soil is affected by the armament account as well examination behavior of deformation of soil reinforced by geogrids, considering ،extension in the soil ،shape, and pattern of deformation close to the reinforcement ،displacements, and distribution of forces in the reinforcement and calculation of the stress between soil and reinforcement.

g) linked between shear strength and deformation in the material reinforced soil.

h) Calculation of effects on the reinforced soil's shear strength and deformation, such as pressure on the soil and density and increasing shear strength.

i) Studying the results of constructing an embankment on soft soils without improvement (without supports or soil reinforcement), supported by stone columns, to assess lateral deformation and pressure. The results are compared in the case of the embankment reinforced and reinforced with stone columns than in the case of unreinforced stone columns through the results of finite element analysis (FEA).

1.4 THE STUDY'S PURPOSE

The research's scope depends on the numerical analysis of the kind of reinforcement with the most effective effect by determining the embankment's deformation and changing the specified soil embankment specifications (slop the side ‹geogrid layer, the type and the number of reinforcing layers have been used in this research PLAXIS 3D). The purpose of the study is to add geogrid layers to improve engineering characteristics of the embankment and raise the safety factor to prevent failure and reduce the horizontal and vertical displacement, stone columns were added for comparison and to improve the soil's engineering characteristics and prevent the soil from failing.

1.5 THE STUDY'S SIGNIFICANCE

This work is anticipated to contribute a great deal of importance

a) Develop and understand the behaviour of soft clay soils on which is built a reinforced embankment.

b) Contribution to other future works by applying the best technology to improve soft soil layers and contribute to achieving optimal results in the construction sector.

1.6 THESIS ORGANIZATION

There are five chapters in the thesis.

The first part of the writing contains a high-level overview of the study goals, their importance, and their purpose. The second chapter is about summarizes some of the literature related to the embankment reinforced by a percentage of geogrids in terms of past study, historical progress, and construction methods. The third section introduces the materials and soil approved in the examination and the generation of specific elements using the Plaxis 3D 2020. The fourth chapter presents a summary of the result and discussion. The fifth final chapter presents the conclusions drawn from this study as well as suggestions for future studies.

1.7 THESIS LIMITATIONS

There are some key design elements characteristics, and their impacts are a thorough examination, however, there are still others touching issues that must be addressed, the material parameter of the profile of the soil was adopted only for the fundamental property, where additional characteristics, such as toughness properties as well as toughness properties are related to the basic properties and were used as programming input.

2. LITERATURE REVIEW

2.1 INTRODUCTION

A system of roads is the most important prevailing situation in the transportation of goods and passengers, so it is considered a very important part of the economy of the country, this needs compliance with the basic design, construction and upkeep standards. A high level of services is available [23] . Suggested that transportation means such as roads, railways and air routes, so there must be roads developed to enable them to withstand traffic loads, therefore, soil improvement techniques are required to increase shear strength and stabilize the soil. The estimation of slope stability has been an important problem for technologists who have drawn the attention of researchers for a long time. The stability calculation was carried out to ensure the man-made or natural design that is safe slopes such as embankment. The term the resistance to change is known as stability the inclined surface the failure that occurs by slipping or collapse. The determination of stability is known as stability analysis against slope failure considering possible failure modes[25].

2.2 EMBANKMENT

An embankment can be defined as filling the land to confine water or reinforce roads and it is man-made. Embankment built on soft soils can face problems during loading and stability, there are many techniques for the problems faced by geotechnical engineers to address the problems they face such as preloading or Phased construction or the use of lightweight grouting, excavation and replacement, ground reinforcement or column techniques [26].

Ground reinforcement is a widely used technique, this entails the installation of artificial ground reinforcements at the embankment base to enhance the bearing capacity, enhance stability and lowering differential subsidence i.e. Reducing differential settlement, it is also known as fundamental reinforcement. This application employs high-strength uniaxial geogrid. Embankments with artificial reinforcement can be regarded as acceptable and cost-effective, especially when constructed on weak foundations with little regard for time and settling. Stability reduction can be thought about broadly in the case of using columns under the embankments reinforced with artificial soil, as well as using various filler materials like sand, gravel and clay to build the embankments, as well as using a lightweight filler if the soil is very soft or the need for rapid construction. Numerical analysis can be defined as the branch of mathematics and computer science concerned with creating algorithms and analyzing and solving chronic mathematical issues. Problems often arise from algebra, geometry or calculus applications and are dependent on continually changing variables،because the embankments reinforced with artificial soil are considered a complex problem as a result of the interaction between soil and structure, so numerical approaches have been utilized to design piled embankments because they are a strong tool for decreasing uncertainty [27].

2.3 GROUND IMPROVEMENT TECHNIQUES

As a result of the increase in construction sites during the urban progress, engineers had to deal with many different soils, and among the soils that were dealt with during construction were soft and weak soils, so it was important to improve the soil strength through techniques of improving and strengthening of the soil such as soil replacement and intensification on the site filling, pre-loading, and stabilization with additives.

The objective of improving the soil is to raise the soil's bearing capacity, decrease its instability and enhance its characteristics and because the improvement techniques take longer and are not economical, so steel fibers and glass were used to improve and strengthen the soil and the use of different polymers within the reinforcing , the emergence of geosynthetic layers is a revolution in improving soil properties are usually used as protection and reinforcement or filtering and containment.

2.4 GROUND REINFORCEMENT

The increase in the volume of traffic and in most cases ,the construction of highways and railways resulted in embankments above, this soil being subjected to pressure, lateral movements, slope, and failure to bear, which leads to delays in construction work and maintenance works, it is known that drilling or research pits to be carried out in the field increase the cost and require time [38] , that are costly [28]. Therefore, it is necessary can alleviate these issues and improve vehicle safety single alternatively, numerous layers of the geogrid were employed to maintain the embankments over soft soil , geotechnical analysis that confirms the existence of different stages and the risk of slippage in a practical situation [39]. Geogrid-made of Polymer composition has a significant impact on the embankment's performance. Geogrids can be placed in single or many levels to increase load transfer and reduce settlements, both the total and the differential [29,30,31,32,33,34,35,36,37]. Reinforcement can be defined as a composite building material that combines soil, as well as reinforcement. This content has tensile and compressive strength that is unrivaled and is obtained either by mixing the impurities of the reinforcement, it is called reinforced soil or by combining the fibers separately and randomly and it is with fiber reinforcement [23]. The soil preparation method reinforcement it was cost-effective and time-efficient among the applications in geotechnical and highway engineering of successful structures that are both temporary and permanent through adhesion, friction, entanglement or captivity, as a result, improving the soil mass's stability [23].

2.4.1 Principles

To compute the tensile strength, certain concepts have been devised and reinforced embankment in the past periods [40,41,42,43,44,37]. As a result of the complexity, it is necessary to rely on hypotheses that lead to conflicting results, especially those related to pregnancy and stress that have been developed [45,46,47,48,36]. Shed a light on the finite point method, which is considered as one of the best methods to be used for solving problems [49]. Multiple layers of geogrid were recommended to boost bearing capacity, which may be regarded as a strong reinforcement for composite soil [50], it has increased bearing capacity which can be considered as strength reinforcement for geogrid soil and is characterized by low tensile strength but strong compressive strength [26]. Strengthening is the objective the soil's function is to absorb loads and tensile forces when there is no soil reinforcement, shear failure occurs due to deformation, but when a load is placed on the it creates axial compressive forces in reinforced soil. stress as well as lateral tensile stress, if axial tensile strength was more than that of the soil, the soil's lateral movement does not happen until it moves about the soil's movement reinforcement. As for the reinforcing layer, it will cause in soil shear stress, thus the shear stress is distributed as a result of internal tension, so this pressure within the fortified soil will be less than the stress in unreinforced soils, provided that the surface is rough to prevent relative movement δhr <h ‹δvr <v for the same value of pressure where in the case of reinforcement, the axial tensile stiffness is greater than the soil stiffness and as a result of absorbing loads, shear strength of the soil and roughness of the reinforcing are both

responsive to stress, so the reinforcement maintains the load during the life of the design without rupture or deformation limited [23].

2.5 MATERIALS USED FOR REINFORCEMENT

Reinforcement is often galvanized steel sheets or strips oriented horizontally or in directions where undesirable soil tension exists in most civil engineering applications [5].

2.6 SYNTHETIC GEOSYNTHETICS

Earth materials employed in different civil engineering applications are giving way to geosynthetic materials. There are many polymers (plastics) that are used in daily life and used in synthetic building materials. Polyolefin and polyester are the most prevalent, rubber, fiberglass and natural materials are also used. Therefore, geotextiles can be utilized as a separator, filter, flat drainage, reinforcement, cushioning or liquid-gas barrier [51].

2.6.1 Geogrids

Geogrids are a network-like formation that contains large openings used in forms of reinforcement, widely used in strengthening retaining walls and sub-bases or sub-soil under the structure or road [51]. It is a matrix-like material that contains openings with large open areas ranging from (10 to 100) mm between Longitudinal and transverse sides, respectively.

The ribs can be built of various materials and the methods for attaching the cross ribs or joining the joints vary, so the main function is the reinforcement, it’s also called a geosynthetic since it's made up of a regular network of integrally linked components with holes larger than 6.35 mm (1/4 inch) to let adjacent soil interlock with it rocks and other nearby materials to serve largely as reinforcement. According to the manufacturer, the other types of geogrids are either in the machine (MD) or directing it (XMD). It is considered an intersection with the point where the sides of the geogrid are joined to provide structure and dimensional stability. They are stiff or flexible polymeric mesh-like sheets with wide apertures that are mostly utilized for soil stabilization and strengthening. Unidirectional, bidirectional, and geogrid extruded, the most prevalent geogrid types are linked geogrid and geogrid weaved [51].

2.6.2 The Effect of Geo-Grid Properties.

Durability and strength (low creep tendency) and simplicity are the key qualities of reinforcing materials are a high coefficient of friction or ease of handling adhesion to the soil at a reasonable price with easy access. The textile test must be based on the appropriate fabric properties [52]. Geogrid tests are unique compared to geotextiles. Geogrids provide the primary role of reinforcement, as a result, separation, filtration, drainage and barrier properties are not considered [52].Three key features of geogrids are significant effective qualities (Physical, mechanical qualities, and loading characteristics). Geogrid physical properties can be measured directly, weight (mass), structure type, rib dimensions, hole size and thickness [52]. Geogrid mechanical characteristics like stiffness, modulus of elasticity, strong tensile strength, high and low yield strength, tensile strength, inappropriate and total stretching strength, fracture elongation, maximum load elongation and total elongation are all tests that may be done on a material [52].

The overall strength varies from 20 to 250 kN/m^2, used in the construction of reinforced roads and slopes, so the geogrids are classified into two categories. Mostly solid geogrid (HDPE), geogrid with elasticity, mostly of polyethylene terephthalate with polyvinyl chloride or acrylic paint with longitudinal and transverse components mechanically coupled (PVC). The computation is one of the most important needs of geogrid employed in soil constructions of different failure modes, which leads to the demand for the geogrid's axial tensile strength and maximum stress requirements are designed [52].

Therefore, geogrids are made by stretching and coating high-density polyethylene or polypropylene yarns or by weaving or knitting high-strength polyester yarns. They can be one or more layers. they are especially useful as soil and aggregate reinforcement thanks to geogrid [52]. To strengthen the soil, the interaction must be an effective reinforcement for absorption, which may cause failure. The final stage of collapse can be where the deformation of the reinforcement is due to the soil and reinforcement interacting or failure's connection between the soil as well as reinforcement. If it is the soil of little cohesion, the resistance of the bond will be friction and depends on the soil's surface roughness, but if the soil is cohesive, then the adhesive stress will be the binding.

2.7 ROAD EMBANKMENT

When constructing an embankment, the embankment should sustain the pavement or railway structure and transmit stresses more uniformly to the sidewalk or railway structure beneath without revealing unacceptable big deformations. Variable building materials to be applied and sub-soil layers. Many elements influence the embankments stability, including the road's structural design. pavement or the railway structure. Therefore, the negative effects are reduced through solid structural design and appropriate construction. Settlements occur as a result of the embankment's construction on soft soil whose size depends on the loading volume, the embankment static weight and the subsoil's deformation properties because there are some variances in the subsoil loading volume and deformation characteristics, so they are not uniform. When shear stresses form at contact points, the stress pressure increases, causing the pore size to shrink and the number of contact points between the particles to grow until they find equilibrium. Secondary due to the additional heavy load of the embankment [53].

2.7.1 Stability of Road Embankment

The stability and bearing capability of the lateral slope must be taken into consideration when designing embankments. When building an embankment over soft soil such as clay and low strength such as silt. Filling materials at the embankment. Dynamic forces can result in embankment failure slopes resulting or when the foundation soil is subjected to high stress during or after construction, a failure in the rotating or sliding mass occurs. From earthquakes, explosions or the displacement of the piles. The embankment on cohesive soils frequently has more short-term stability results from the foundation soil's increased shear strength as pore space increases expands, rather than long-term stability size increases and pressure dissipates [54]. The embankment may fail due to:

a) Failure of rotational slip and circular slip formed inhomogeneous, anisotropic and non-circulating soils formed in heterogeneous soils.

b) Compound slip occurs if the base layer has characteristics and strengths that are noticeably different [55].

some of the following major issues must be addressed before starting a stability analysis:

a. A phased stability analysis is required if the site is bordered by fine silt or mud. Are there any technical or site restrictions that need higher embankment slopes, is the embankment temporary or permanent if it is necessary to evaluate the slope's stability to assess the different alternatives ,the temporary embankment's safety factors might be 1. 5H:1V, depending on site constraints and material availability [54].

As a result of the experience and observations of the failure of the embankment, which was established on deep deposits of soft soil, the embankment settles in the case of failure, the surrounding soil rises and the collapsed surface travels in a circular arc. Failure of the slip in an embankment circuit might be a basic circuit, a toe circuit, or a slope circuit. In the case that the thickness of the soft soil foundation is large, and the basic slip circuit develops، the failure arc's base is tangent to the weak layer's base and the arc spends a considerable a part of its length in the soft soil. Within the embankment, the slip circuit develops and intersects with the slope. In the embankment, the toe slip cycle develops and at the toe, intersects when the embankment becomes saturated and fails, this happens.

The following are the driving factors and resistance in the case of failure:

a) The movement of the driving forces caused by the body's weight is the product of the embankment's weight operating via its center of gravity times the horizontal separation between the gravity and rotational centers (Lw).

b) The resistance force equals the total shear force on the sliding plane. The moment of resistance is calculated by multiplying the resistance force by the radius of the circle (ls).

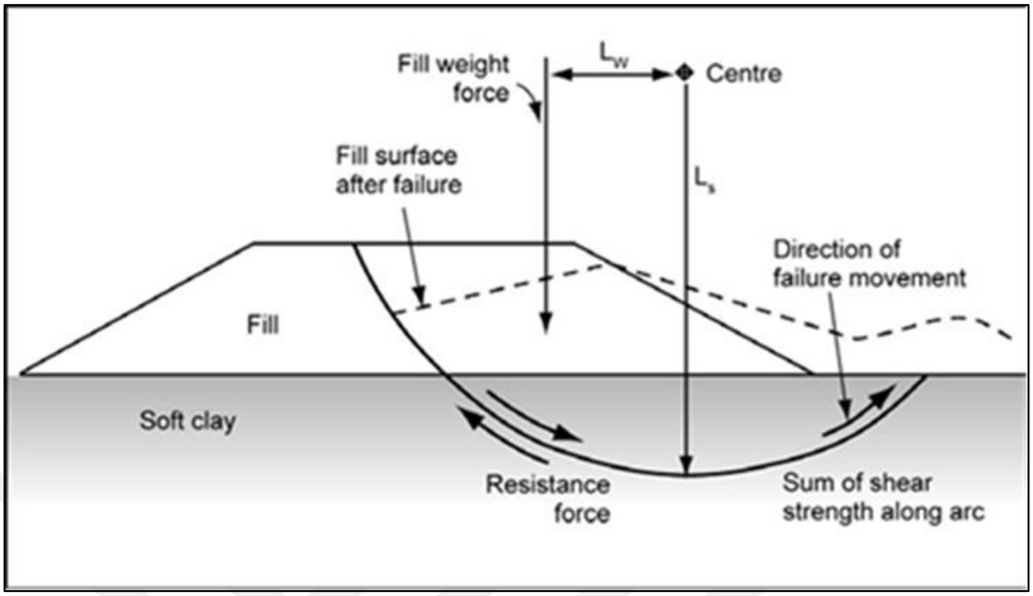


Figure 2.1: Illustration of Embankment Failure and Stability [54].

So the typical approach to preserving long-term stability requires side slopes must have a safety factor of at least 1.3 for any road embankment، damage-causing slopes to non-critical structures, an embankment must be 1.3 as a minimum safety factor. The safety factor in design should be increased from 1.3 to 1.5 for failures slopes near embankment abutments, major highways and retaining structures. Embankments that sustain the safety factor for structures should be 1.5 and failures and property damage causes are classed critical structures. If springs or seeps are discovered near the embankment, appropriate expenses must be provided to collect the flow [54].

2.7.2 Base Reinforcement

The usage of base reinforcement enhances safety factors against ramp failure. The base can be strengthened by installing a geotextile or geogrid at the embankment's base. Before constructing the embankment, the base must be reinforced especially if the soil is soft below the embankment site. A strong foundation because of creep and durability. The foundation reinforcement is designed comparable to a strengthened slope, as a result, it employs balanced slope stability methods to calculate the needed strength for the safety factor. As a result, the foundation reinforcement material placed longitudinal, continuous strips. parallel to the major reinforcement. Connections between geogrid or geotextiles components must be avoided all seams in geotextiles must be perpendicular to the slope and in the force direction. stitched rather than rolled and geogrid must be sewed rather than rolled and geogrid must be fastened with pins rather than simply overlapped. When utilizing basic reinforcement, gravel borrowing regions may be employed instead of appropriate soil elements to boost the embankment shear strength [54].

2.8 SOIL STABILIZATION BY GRANULAR PILES

2.8.1 General

Improvement strategies can be used to provide a stable ground for weak soils [56]. Provide techniques such as mechanical properties insufficient to load the installation, load the infrastructure to be built, inflation, shrinkage, foldability of soft soils, organic and coarse soils, karst sediments with drains, landfill and sanitary landfill formations and foundations, dredged materials for foundations, and hazardous materials in contact with soil, when the site is facing difficult conditions, the possible solutions are to avoid the analysis of the finite elements of embankment supported by stone columns ، not recommended, replacing unsuitable soil or costly soil amendment, foundation design that is cost-effective using improvement approaches, minimizing the consequences of polluted soil and ensuring sustainability in construction projects [56] .

2.8.2 Granular Piles

Stone piles are granular piles made up of stone aggregates (20-75 mm) pressed into a vertical hole (with a diameter ranging from 0.6 - 1 m, depth of 15-20 m) [57].

Explain that improvements such as granular piles/stone columns partial replacement of soil in the site to provide and increase the bearing, a considerable reduction in instability and a rise in resistance to liquefaction a circular hole is dug in soft soil and filled natural stone, sand, or stone chips as granular materials form granular piles/stone columns[58]. When 10-35 % of the unstable piles are built when soil is removed and replaced with granular material , the soils carrying capacity improves, stability decreases and the ground is usable for structural support [59].

2.8.3 Granular Piles Function

Granular piles perform fundamental reinforcing and drainage tasks, as well as enhancing the soft soil strength and deformation characteristics throughout the stages of post-consolidation and reconsolidation. That is, it increases the mass of the unit by replacing and lowering the pore pressure as a result. Acts as strong, tough and withstands the highest surface stress, it is formulated in many types of soil, from loose sand to fine clay soil and organic soil and granules are cost-effective [60]. Three factors influence the stone columns efficiency in improving soft soils :

a) The first component is to amend soft soil with a thicker column substance (such as crushed stone and gravel).

b) The second aspect is that during installation, the stone columns were surrounded by soft soil.

c) The third factor is vertical drainage using stone pillars [61].

Stone columns may modify both the qualities of the materials and the state of stress in the block's treated soil , thus they are not only a replacement procedure [62].

2.8.4 Advantages of Granular Piles Supported Embankments

a) There is no reason to delay the integration procedure should be finished prior to beginning embankment construction.

b) Suitable for quick follow-up construction, especially in the event of time constraints to complete the project.

c) Reducing the pressure exerted on the soil allows for a reduction in total and differential settlement within the embankment.

d) In the situation of uncertain ground conditions, this strategy is more trustworthy than other soft soil improvement strategies.

e) There is little maintenance needed.

2.9 SIGNIFICANCE OF GEOSYNTHETIC REINFORCEMENT IN EMBANKMENT CONSTRUCTION

To strengthen the stability of embankments built on soft soils , geosynthetic soil layers are added [63].Layers might be in pile-supported structures and one or more geosynthetic reinforcements are added embankment to increase the transfer of weight to piles and reduction of needed area [64].

Polymer materials are used to make geosynthetic materials and most of them have elastic behavior that varies in load, rate of loading, duration and temperature, geosynthetics include geotextiles, geogrids and membranes.

Geotextiles are textiles woven with geosynthetic fibers on conventional machinery (woven geotextiles) or randomly constructed (random geotextiles) (nonwoven geotextiles). Nonwoven geotextiles are utilized for filtration, drainage, separation and reinforcing, however, because they are nonwoven tightly as geotextiles, we only use them as reinforcing materials. Geogrids are polymers. In a setup comparable to an open network, it was formed. Geomembranes are rubber or plastic sheets that are impermeable and are utilized as linings and coverings for liquid and solid storage facilities.

Geotextiles and geogrids may be used to reinforce column-reinforced tanks while also providing embankment support over soft soils[65]. According to Priyanath Udayanga Ariyarathne, artificial soil support materials are employed to accomplish the following benefits [66]:

a) The heaps there is no need to separate them.

b) They can be piles of covers

c) There is no need to place broken piles along the embankment's edge.

d) Reduces soil lateral movement.

e) Land usage is little.

2.10 ANALYSIS MODEL BY FINITE ELEMENT METHOD

2.10.1 General

In the study of mathematics and computing, numerical analysis studies and uses methods to solve numerical issues that occur continually, including constantly changing variables. These problems exist in all various fields. The beginning was in the forties, a period of growth in digital power. In evolution, there may be a need to solve more accurate and complex models in various formal academic fields of numerical analysis in theory for mathematical study purposes of computer science involving computer effects and programs that specialize in implementing specific algorithms.

2.10.2 Numerical Analyses of Geosynthetic Reinforced

To evaluate embankment portions and determine improvements, many numerical studies were conducted on artificial ground reinforcement. The FE approach was used to conduct the research. The model that best represents the pressure and deformations in the reinforced embankment was chosen from many options. Plasticity models with isotropic stiffness bases can forecast stress throughout a single cycle of the applied load. During the first load cycle, applying pressure at the same amount repeatedly results in elastic behavior without stress accumulation. Plasticity-based material models with kinetic stiffness bases must forecast persistent stress development. When recurring traffic loads are applied in layers.

Models of plasticity are better used by kinetic stiffness bases with the growth of permanent deformation of the surface. Models of this type were available during the seventies when they were recently applied [67].

Relate the findings of triaxial stress testing to a model of developed surrounding surface plasticity[68].

The encircling surface idea allows to include any kind of formula for the surface of the product that represents the maintenance of the surrounding surface[69].

The FEA results indicated that the value of the bearing value rise as the reinforcing stiffness increased, but the rise in the base layer's thickness resulted in a decrease. Between the base layer's bottom portion and1/3 of the base layer, the size of the ideal section of the reinforcement was established.

The reinforced and unreinforced embankment were subjected to FEA and the findings were compared with experimental measurements of 35 % as determined by testing[70].

A FE program was employed for doing on the model a three-dimensional finite element analysis soil supported embankment, according to the findings of this study, the usage of reinforcement has improved. the substrate's bearing capability and lowered shear stresses and pressure on the layer, as well as reducing vertical displacement by 15- 20% due to the overlapping geosynthetic reinforcement, the longevity of reinforced portions was expected to be 2-2.5 times that of unreinforced portions[71].

To maintain the geogrid pavement foundation a model with finite elements and a finite element analysis software program was employed. The investigation's conclusions were matched to the material attributes of unreinforced embankment sections[72]. The installation of the geogrid decreased the distortions by 20% during one loading cycle, according to the comparisons. This improvement was attributed to the bending stiffness of the geosynthetic flooring because of the authors' model presentation [73].

A numerical analysis investigation of an unstressed reinforced structure using FE software embankment previous work by the researchers was utilized to verify a finite element model created for embankment reinforced with geosynthetic floors[74].

As the coefficient to the bottom layers from total layer ratio reduced, performance of the reinforced section improved. For a geogrid with a greater geogrid coefficient or a better soil interface, the embankment reaction was dramatically decreased[75].

The study findings highlighted the benefits of developing a restricted model of elastic soil components strengthened with geogrids by inserting geogrids at the base layer interface, it is possible to correctly predict the concentration above the geogrid reinforcement due to residual stresses. Low residual stress concentrations are seen around the geogrids[76].

Using the PLAXIS 2D software suite, developed a finite model. Finite element analysis was done on several portions of the unsupported embankment to reduce the effect of putting reinforcements inside the base layer on the reaction of the embankment. The findings demonstrated the modified critical state biplane model's capacity to effectively forecast the reaction of the examined basic cycle material when subjected to periodic and constant loads under ideal circumstances. The results showed that the FEA that strengthens the artificial soil has reduced lateral stresses in the fundamental layers and sublayers and that the incorporation of the artificial soil layer reduces anchoring stresses and shear in the top regions of the substratum significantly[77].

2.11 SUMMARY

According to literature reviews, the benefits of reinforcing the geogrids base layer are depending on several things, includes the foundation layer thickness, position of the geogrid layer and substrate's hardness, as well as the geometric characteristics of the geogrids. The smaller the coagulation rate, the weaker the bottom layer, according to published research and there was a slight improvement [78,79].

The advantage of geogrid is decreasing as the thickness of the core plasticity increases, eventually becoming inconsequential when the core route is too thick [80],Geogrid placement within the embankment core layer is crucial for reinforcement [79]. The ideal position for the geogrid is determined by the base layer's thickness and substrate strength. If the foundation layer is weak, positioning the geogrid near the base layer's interface improves performance. In the top 1/3 of the basic layer is where it should be positioned [82,83]. When a single layer of geogrid was put up in the thick basal path's base layer or in the middle of it , there were no expected benefits [82].There is no clear data on the link between the base reinforcement performance of geogrids and the aperture, stability modulus, stiffness, flexural or tensile modulus of the geogrid [84] .These traits are thought to combine to define geogrid performance and no one attribute can accurately represent geogrid performance.

3. FINITE ELEMENT MODELING AND METHODOLOGY

3.1 GENERAL

This chapter represents the construction and development of a model to simulate an embankment supported by a geogrid placed on soft clay soils. In this chapter, the study area was described, the material parameters because of choosing the study area, and the material parameters of the soil from the tests conducted within the study area. Provide geogrid information. Based on a criterion, basic models representing road embankment behavior, geogrid, and soft soil materials will also be used to create a realistic representation of a road embankment reinforced with geogrids built on soft soils, modeling procedures must include the appropriate approach to simulation, model dimensions, mesh geometry, boundary sites and a realistic representation of a road embankment reinforced with geogrids built on soft soils model that represents studied soil, additionally the fact that finite element analysis (FEA) it is a suitable technique and many tests must be carried out to ensure accurate numerical analysis.

3.2 PLAXIS PROGRAM

PLAXI 3D three-dimensional finite element program [85] ,created in geotechnical engineering for the investigation of deformation, stability, and water flow, is a member of the PLAXIS group, which is a collection of finite elements utilized in the world. The original goal was to create a simple 3D finite element model, but in recent years it has been expanded to include all other areas of geotechnical engineering for other growing activities. PLAXIS3D is a program that simulates realistic construction in stages and combines an easy-to-use interface with 3D modeling facilities. It was released in 2010.

3.2.1 Nodes and Finite Elements

To solve geotechnical issues accurately, there are several components and nodes in a program that contains the types of analysis that are used now [86].

3.2.1.1 Soil Elements

Soil contains the three-dimensional finite element's fundamental elements, the 10-node tetrahedral element makes up the 3D finite element mesh, shown in Figure (3.1) tetrahedral element coordinates (ζ, η and ξ). The form function Ni has the property that the function value at node I is unity, whereas it is 0 at the other nodes[85].

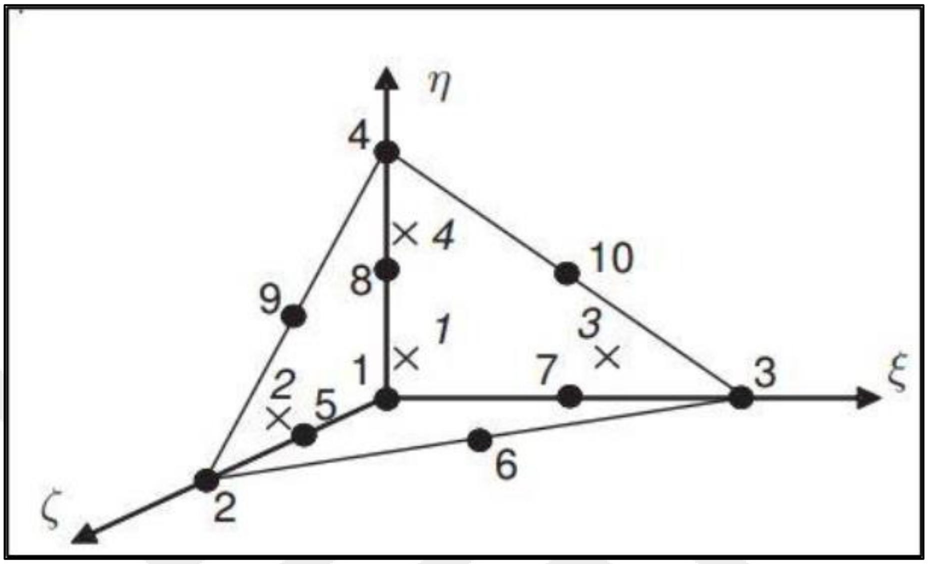


Figure 3.1: Local Numbering and Placement of a Ten-Node Tetrahedral Element's Nodes (•) And Integration Points (X) [85].

Trigonometric coordinates are used to describe the tetrahedron. Ni (I:) is the unit node, and

$$N1 = (1 - \xi - \eta - \zeta)(1 - 2\xi - 2\eta - 2\zeta) \tag{3.1}$$

$$N2 = \zeta(2\zeta - 1)$$

$$N3 = \xi(2\xi - 1)$$

$$N4 = \eta(2\eta - 1)$$

$$N5 = 4\zeta(1 - \xi - \eta - \zeta)$$

$$N6 = 4\xi\zeta$$

$$N7 = 4\xi(1 - \xi - \eta - \zeta)$$

$$N8 = 4\eta(1 - \xi - \eta - \zeta)$$

$$N9 = 4\eta\zeta$$

$N10 = 4\,\xi\eta$

In each node, there are three degrees of freedom in soil. For the soil constituents ($u_{x\,,}u_{y,}u_{z}$) a new form function matrix, Ni, is now known as

$$Ni = \begin{bmatrix} \mathrm{Ni} & 0 & 0 \\ 0 & \mathrm{Ni} & 0 \\ 0 & 0 & \mathrm{Ni} \end{bmatrix} \qquad (3.2)$$

V is the nodal displacement vector, and it's written like this

$$V = [\mathrm{V_{ix}} \quad \mathrm{V_{iy}} \quad \mathrm{V_{iz}}]^{\mathrm{T}} \qquad (3.3)$$

3.2.1.2 Plate Elements

The plates are a structure used for three-dimensional thin modeling with great flexural stiffness (bending stiffness) consisting of a triangular plate consisting of 6 nodes with 6 degrees of freedom, each node has 3 a range of possibilities ($u_{x\,,}u_{y,}u_{z}$) three rotating axes (x, y and z)

3.2.1.3 Interface Elements

Available at the soil interface in the program PLAXIS 3D ‹interfaces are elements that are added to panels or geogrids to allow them to be extended to model the interaction of soil structure, modeling the interplay of smooth and rough surfaces side surfaces soil and geogrid the user interface strength is connected cohesiveness and the soil's friction angle the strength of shear between the soil and the reinforcement is determined[9]. It can be utilized to imitate say the thin zone of intense shear materials in contact between clay and surrounding soils, interfaces can be constructed alongside plate elements or a geogrid between two soil volumes, the stiffness matrix the triangular interface components are based on the material data's finite characteristics set obtained utilizing 6 integration points, the exact (pressure points) are selected for the linear pressure distributions RINTR=0.9, Figure(3.2) shows interface element. Figure (3.3) shows interface element's relative stiffening values of interface components provided by [85].

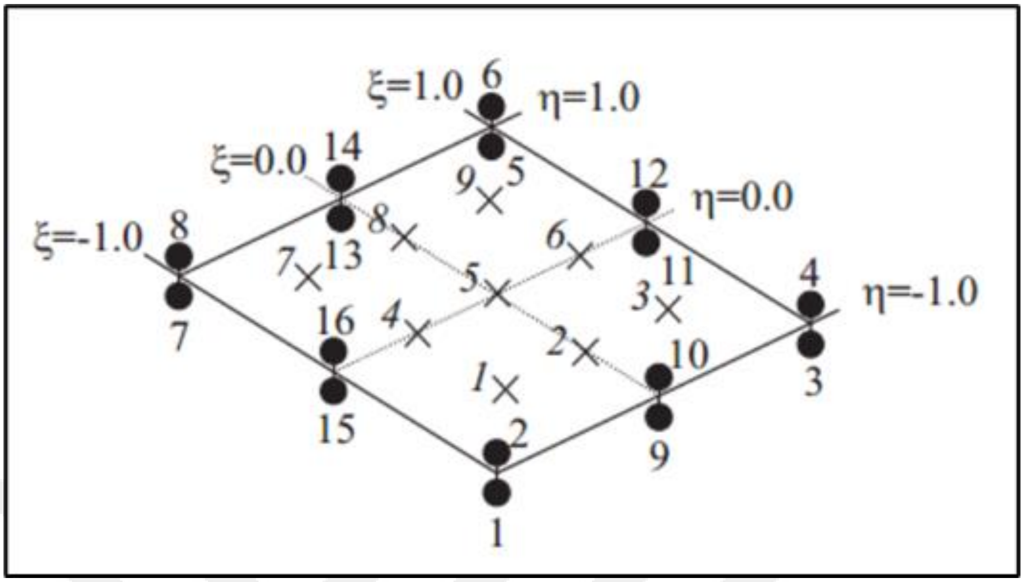


Figure 3.2: 16-Node Interface Element's in the Local Numbering and Placement of Nodes (•) And Points of Integration (X) [85].

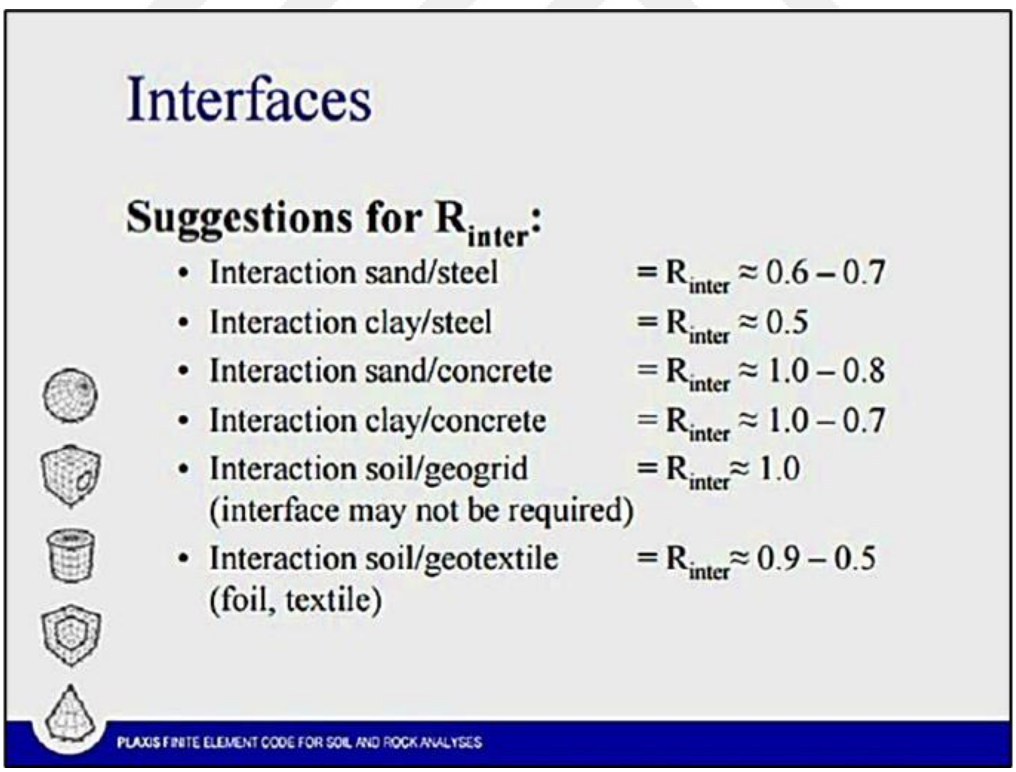


Figure 3.3: Shows the Values of the Interface Element[85].

To perform finite element analysis using the program PLAXIS 3D ،we define the attributes of materials and boundary conditions in a three-dimensional geometric model composed of points, lines, surfaces, sizes, etc. In the beginning, this is done, tabs using the input program's software. The remaining tabs (calculation method) of the input program were used to create the geogrid and define the starting account.

3.3 GEOLOGY OF THE SITE

Habbaniyah is located in Anbar Governorate. It is characterized by the slope of its lands towards depressions such as Habbaniyah, Al-Razzaza, and Al-Tharthar. The project consists of the Habbaniyah Bridge and embankment linking the old and new cities.

3.3.1 The Research Area's Description

3.3.1.1 The Geographical location

Al-Habbaniyah is a city located 85 kilometers (53 miles) west of Baghdad in the Anbar province Governorate.

It lies within latitude (43° 35′ 0″ E ,33° 23′ 0″ N) are the latitude and longitude. Figure (3.4) and Figure (3.5) and Figure shows the Al-Habbaniyah location. Figure (3.6) show location of boreholes.

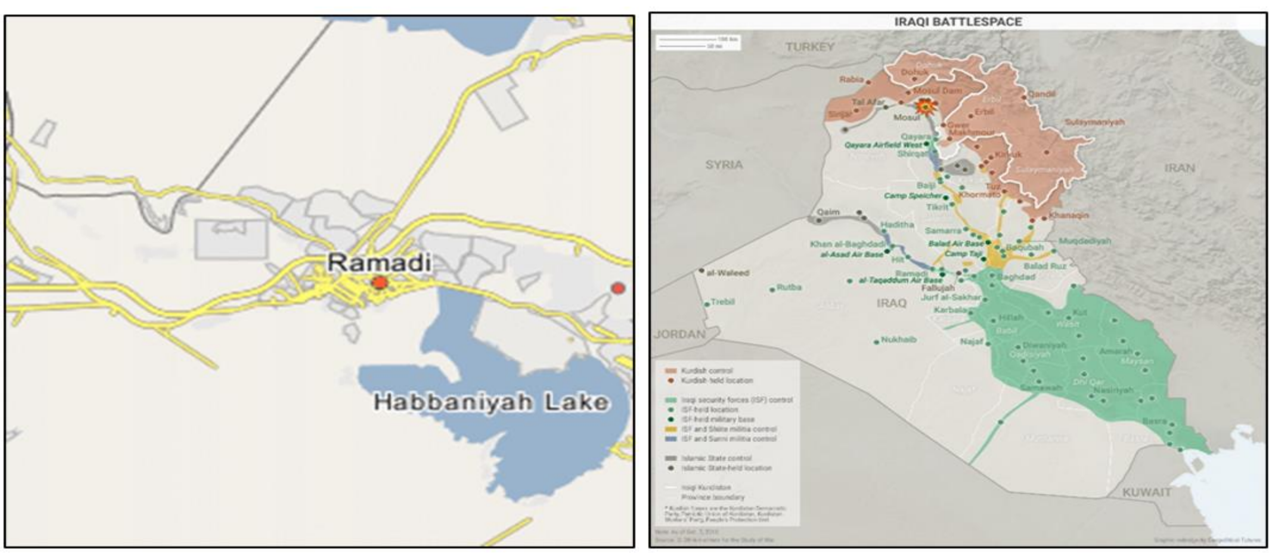


Figure 3.4: Al-Habbaniyah Location

Figure 3.5: Al-Habbaniyah Location.

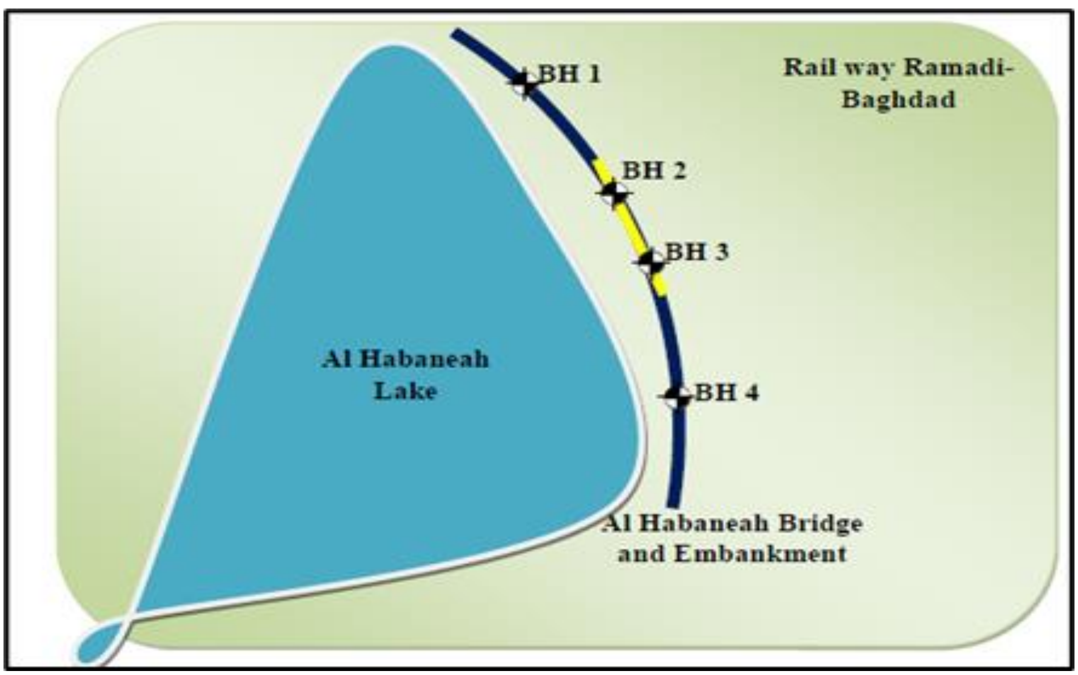


Figure 3.6: Location of Boreholes.

3.3.2 Geotechnical Characteristics

The properties that soil must have in general simulation according to a model Mohr- Coulomb ,(Ɣ ,kN/m3) bulk unit weight , (γ_{sat}, kN/m3) saturated unit weight , the coefficient of rest for horizontal soil stress (normal consolidation) (k_o) ، using the index property correlation recommended by [87].

$$\gamma_{sat} = \gamma_d(1 + w) \tag{3.4}$$

$$k_0 = 1 - \sin\varphi \tag{3.5}$$

3.3.3 Strength Characteristics

Strength characteristics include soil simulation according to a model Mohr- Coulomb ، effective cohesion ($c^{'}$, kN/m2), internal friction's effective angle $\varphi' = 0$, initial inclination expansion (Ψ, o), the value of effective cohesion has been correlated C' experimentally with the effective friction angle as recommended by φ' [88].

3.4 INPUT SOFTWARE

To study the finite elements using PLAXIS 3D we must define the attributes of the materials and the boundary conditions for a three-dimensional geometric a point model, lines, surfaces, there are different sizes. In the beginning, this is done through tabs using the input program's software. The remaining tabs (calculation method) of the input program were used to create the network and define the starting account.

3.4.1 Modeling The Behavior of Soil

Under the effect of a load, including soil and rocks that respond in a non-linear manner. It is possible to represent non-linear stress behavior on various levels. The number of variables in the model increases to run various models, the PLAXIS may be used as a simulator of soil behavior. Mohr- Coulomb models are used in the current study.

3.4.1.1 Model of Mohr- coulomb

Well-known: linear elasticity uses an ideal plastic model as a preliminary approximation to the behavior of the soil. It is advised to utilize the model for preliminary analysis. The average soil stiffness is estimated. Because of this continuous stiffness, it represents the calculations until they are relatively fast. Preliminary results for it are possible to obtain deformations. The elasticity parameter E is one of the five inputs. An approximation of the (first degree) behavior of soil or rocks is provided by, C, φ, soil plasticity, and expansion angle Ψ so recommends the usage of in the case of conducting a preliminary analysis of soil to consider the problem of each layer, the average constant stiffness is estimated and increases linearly with depth, so calculations tend to be quick and preliminary estimates of distortions can be obtained.

A. The Young's modulus (E)

In the Mohr- Coulomb linear model, PLAXIS employs Young's modulus as the primary stiffness parameter.

B. The Poisson Ratio (v)

If the models are elastic or the Mohr- Coulomb model is utilized for gravity loading. Poisson's ratio may be tested easily so it must give a realistic ratio of k_o, which is the ground lateral pressure coefficient Ko = σh/σv. where gives the percentage of elasticity, as a result, the Poisson's ratio may be easily calculated σh/σv= ν (1- ν) thus, they are matched in many cases, ranging in value from k_o (0.35 -0.495) .

C. The Cohesion (C)

In a Mohr- Coulomb model, the cohesive force has stress dimensions, the cohesion parameter, as well as the effective and realistic friction angle, can be used to approximate effective cohesion c of the soil.

D. Angle of Friction ($\varphi^{'}$)

The friction angle, which is measured in degrees, is commonly used to simulate the soil's actual friction and cohesion. Figure (3.7) shows stress circles at yield [85]. Figure (3.8) the failure surface in the major stress [85].

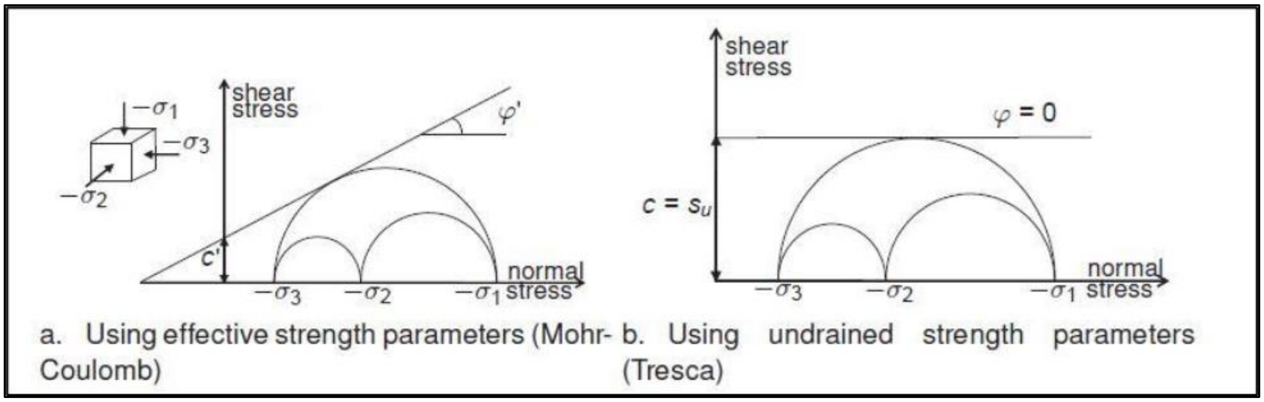


Figure 3.7: Shows One of the Stress Circles at Yield Hits Coulomb's Envelope, As Seen in the Figure [85].

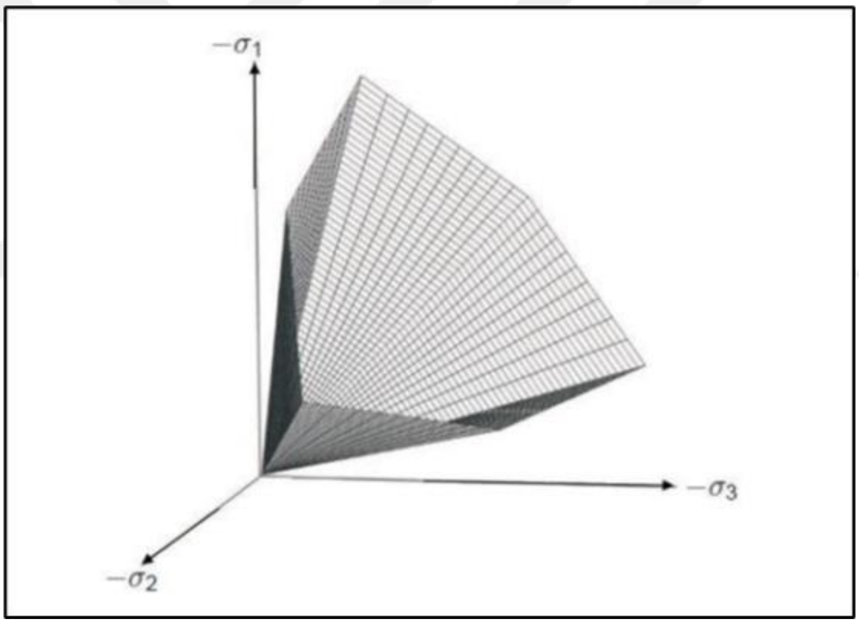


Figure 3.8: The Failure Surface in the Major Stress Space of A Cohesionless Soil is Seen in the Figure [85].

The author will do an effective pressure analysis and instead simulate the strength of the soil PLAXIS allows the coefficient of cohesion equals the strength of the uncast soil in combination with drained, so the failure criterion φ = 0 will be reduced to the Mohr- Coulomb. criterion known. High friction angle can be obtained for dense sand, the plastic calculation effort increases dramatically, and the calculation time increases or decreases several times with the angle of friction. When using friction angles caution should be used making the initial calculations for a particular project, angles greater than 35 degrees were used. Shear strength is a big factor in the friction angle. using circles [86]. Mohr stress (Fig. 3.7) represents the failure criterion, as the best way to describe soil strength in terms of general stress conditions Drucker-Prager.

3.4.2 Embankment

The embankment was represented in the program using Mohr- Coulomb. The soil element is tetrahedral elements with Mohr- Coulomb, according to the mentioned characteristics. It consists of 4 layers of sand soil with a height of 4 meters, each layer with a height of 1 meter, interspersed with a geogrid layer by 4 layers, the first intersecting the soil with the embankment and the other layers according to the layers of the embankment. Table (3.1) shows of embankment properties.

Table 3.1: Shows of Embankment.

Parameter	Embankment Fill
Unit Weight (KN/m3)	19
Young’s Modulus(MPa)	35
Poisson’s Ratio,V	0.4
Cohesion, C (Kpa)	0
Friction Angle, ϕ, (degree)	35
Dilatancy Angle, Ψ (degree)	0

3.4.2.1 Drainage type

All parameters of the PLAXIS model aim as a visual representation of the soil's effectiveness that is the link between pressure and strains linked to the soil structure, the presence of pore water greatly affects the response of the soil. Long-term or short-term response without considering how pore pressure changes over time. Pore pressure is a result of variations in stress (loading and unloading). The uniformity calculation may analyze the pore pressure dissipation, therefore, the application offers a variety of drainage options.

3.4.2.2 Drained behavior

Using these settings, there is no pore pressure, so are dry soils, as well as complete drainage, which has high permeability (sand and crushed stone), the program in the study of stone columns and embankment filling, this form of modeling is used to simulate the behavior of soil.

3.4.2.3 Undrained behavior

Used in saturated soils pore water cannot readily run through the soil structure, at times, water may be overlooked because of its limited permeability (clay) or high loading rate, all groups identified as behaving in an unrestricted manner.

Types of undrained condition:

Three different methods distinction is made between of modeling undrained soil behavior

A. Soil Behavior Undrained (A)

Effective strength, along with effective stiffness, is included in this material stress analysis. The pore pressure may be predicted using this approach. An examination of uniformity can be performed after the study has been completed. Instead of being an input parameter, the undrained shear force (s_u) is a model parameter. Shear strength should be examined to determine the kind of analysis, and option(A) must be chosen.

B. Undrained (B)

The undrained shear strength (s_u) is the input parameter that will give pauses to the pore stresses when applied to the stiffness and strength parameters. the uniformity analysis is followed. The shear strength is not updated to consider this type of analysis should be selected (B).

C. Undrained (c)

For soft clay soil materials, the stress analysis with all parameters gives a slow pore pressure, as a result, doing a uniformity analysis is pointless. The input parameter is shear strength (s_u), and type (c) must be chosen.

3.4.3 Model Generation

Soil elements were used to simulate the surrounding soil and soil embankment by the Mohr-Coulomb model.

3.4.4 Generation of Mesh

PLAXIS 3D uses an unstructured geogrid automatically generated for optimization, the program provides five options in terms of network density from coarse to very fine, the geogrid is used and refined in areas with high pressures, and Table (3.2) shows values of element roughness [85].

Table 3.2: Shows Values for Relative Element Size Factors Based on Element Roughness[85].

Element coarseness	**The relative element size factor**
Very coarse	2
Coarse	1.6
Medium	1
Fine	0.7
Very fine	0.5

3.5 CALCULATION

After creating the specified element model, the calculation must be implemented and the type of calculation must be determined, so it can be divided into several sequential stages, each according to the stage corresponding to the loading or a specific building. The stages of construction can be determined.

3.5.1 Types of Analysis

The PLAXIS analysis is to calculate the type of loading. The available options are a procedure K0 for the initial step, gravity loading is used for subsequent phases, plastic, uniformity, safety, and dynamism are used.

3.5.1.1 Initial stress generate

Many analysis problems in geotechnical engineering require a set of initial stresses (σ'_v,0)

The effective pressure (σ'_h ، 0) the lateral soil pressure component is related to the initial vertical effective stress. k_o، (σ'_h ,0 = k_o . σ'_v ,0) in for Plaxis the initial stresses can be established using the $k_o$procedure or using gravity loading.

3.5.1.2 Plastic calculation (elasto – plastic)

The calculation can be performed for elastic deformation of plastic analysis in which no change in pore pressure is required. Process although a period is specified, the plastic calculation considers time effects.

3.5.1.3 Consolidation calculation

The consolidation is calculated in the case of development and dissipation of pore pressure in saturated clay soils. PLAXIS software allows consolidation analysis of flexible plastic. Therefore, Consolidation analysis was used in this study.

3.5.2 Loading Types

loading type should be selected to perform consolidation analysis

3.5.2.1 Staged construction

The feature of the program is to control the loading by canceling or activating groups of the body and structural objects, the phased construction produces a realistic simulation of the varied loads and building conditions, drilling and operations process precisely, as well as the data set, is reset. Are important certain things being necessary to develop a geometric model that incorporates all the parts that are needed in the computations that must be deactivated, the construction phase can be carried out with a plastic account or a uniformity analysis.

3.5.2.2 Minimum pore pressure

It is the criterion for completing the uniformity analysis. When the pore pressure hits a particular value, the analysis will be stopped.

3.5.2.3 Degree of consolidation

It is an alternate criterion for completing the uniformity analysis,the computation finishes when it is less than the of uniformity value.

3.6 OUTPUT

The output program shows the findings after the computations are complete. A finite element may provide a wealth of information. Pressure, pore pressure and soil displacement are all considered in the computations.

3.7 CURVES

For each iteration, step or time in the subprogram curves, there is a pre-selection of model points that may be presented in a file or a plotted curve table for the points provided such as displacement and pressure.

3.8 SOIL PROFILE

Generally, the subsoil surface shows the following layers:

a) The first layer consists of soft clay and extends from the natural ground surface to the 6m.

b) The second layer is a stiff clay layer that stretches from 6m to 20 m below of natural ground.

The source of this information is (the Engineering Consulting Bureau Geotechnical Investigation report - University of Anbar -Engineering College). Table (3.3) shows a summary of soils properties.

Table 3.3: Summary of the Soil Properties.

Parameter	Embankment Fill	Soft Clay Layer	Stiff Clay Layer
Unit Weight (KN/m^3)	19	17	17.5
Young's Modulus(MPa)	35	7.4	15.7
Poisson's Ratio,V	0.4	0.49	0.49
Cohesion, C (Kpa)	0	47	116
Friction Angle, ϕ, (degree)	35	0	0
Dilatancy Angle, Ψ (degree)	0	0	0

3.9 GEOGRID

There is very little (less than one percent) strain created in geogrid material, and this is regarded to be within the linear elastic range of geogrid. The influence of tensile strength of geogrids on embankment and performance was examined using finite element modeling with three distinct geogrids with different equivalent elastic moduli. The characteristics were chosen based on the Tables shown (3.4)and based on the characteristics of the source. The material property of geogrid after [86].

Table 3.4: Geogrid Material Properties After [86].

Geogrid type	Reference Name	Elastic Modulus (Kpa)	Area (m)	EA(KN/m)
Geogrid Type I**	GGI	585,100	0.06	35,000
Geogrid Type II**	GGII	860,000	0.06	52,000
Geogrid Type III**	GGIII	950,000	0.06	57,000

3.10 NUMERICAL MODELING

In this section, we will go through the specifics of the numerical model and the approach used to simulate the embankment using the finite element method. The composition was determined for the embankment analyzed, the soil profile was approved, the 4m height of the embankment was determined and 10 m width with a slope of 1:1.5 a traffic load of 50 Kpa for this analysis was adopted, which was considered based on the [54] recommendations for all subsequent FEA. The geogrid that reinforces the embankment was placed in different layers and a parametric study was carried out to determine the best reinforcement layer. The (GGIII) geogrid was considered adapted for simulation, so it was studied based on the stiffness properties. The analysis was conducted for half of the model to reduce the size of the model and reduce the time it takes to perform the analysis . Figure (3.9) the section of the embankment with the loads and the soil on which it is based.

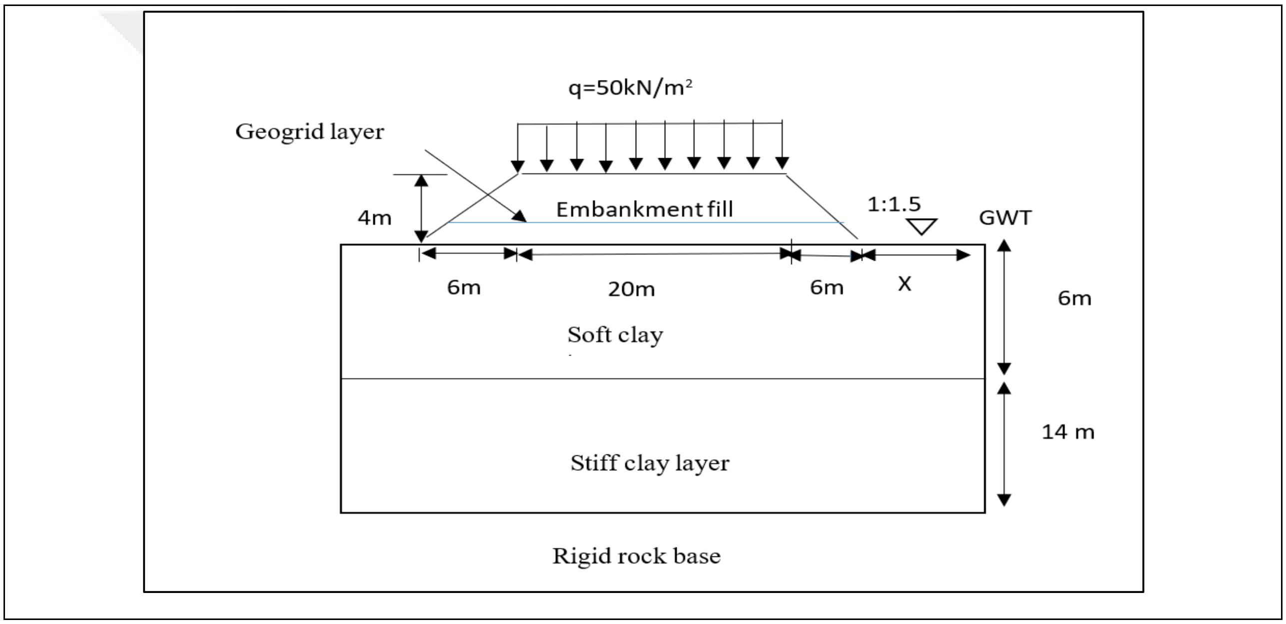


Figure 3.9: The Section of the Embankment with the Loads and the Soil on Which It is Based.

3.10.1 Site Condition of Embankment Geometry

3.10.1.1 Geogrid reinforced embankment

The study aims to implement a three-dimensional element to model a road line and discuss the addition of geogrid to the behavior of the embankment. The analysis was chosen, using two basic layers of soil, Figure (3.10) the cross-section shows the embankment. The soil profile is composed of two layers of soil, the first of which is soft clay 6 m thick, followed by stiff clay 14 m thick, with the property of different materials based on a stone foundation. The embankment extends in the longitudinal direction (0.5B+4H), Table (3.4) summarizes the embankment information above the soft layer was a layer of geogrids 0.5 cm thick geogrid layers of different types were placed between the layers of the embankment with a thickness of 1m, as shown in Figure (3.10), Figure (3.11).

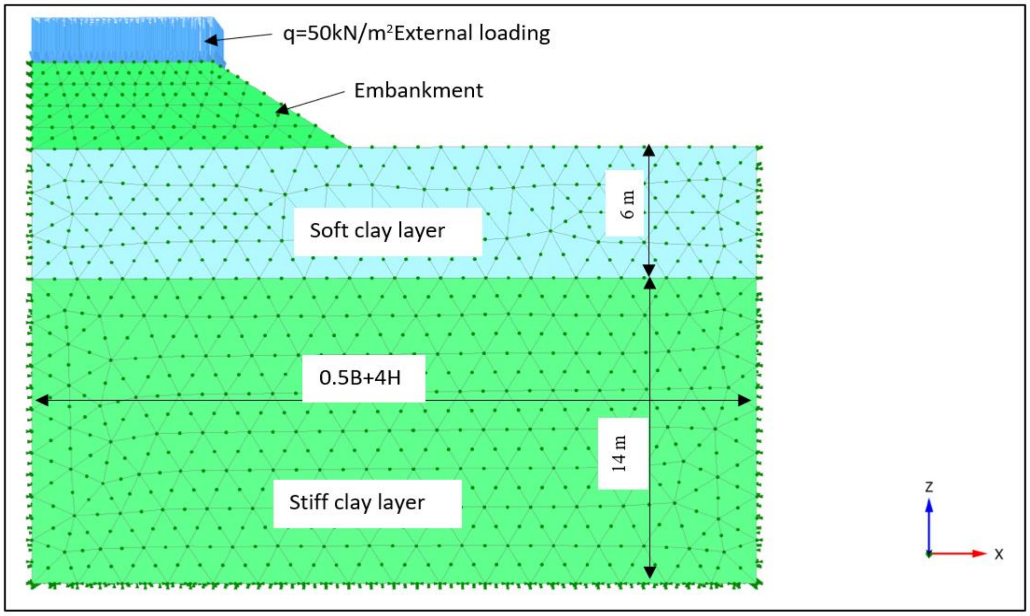


Figure 3.10: Cross-Section Shows the Embankment.

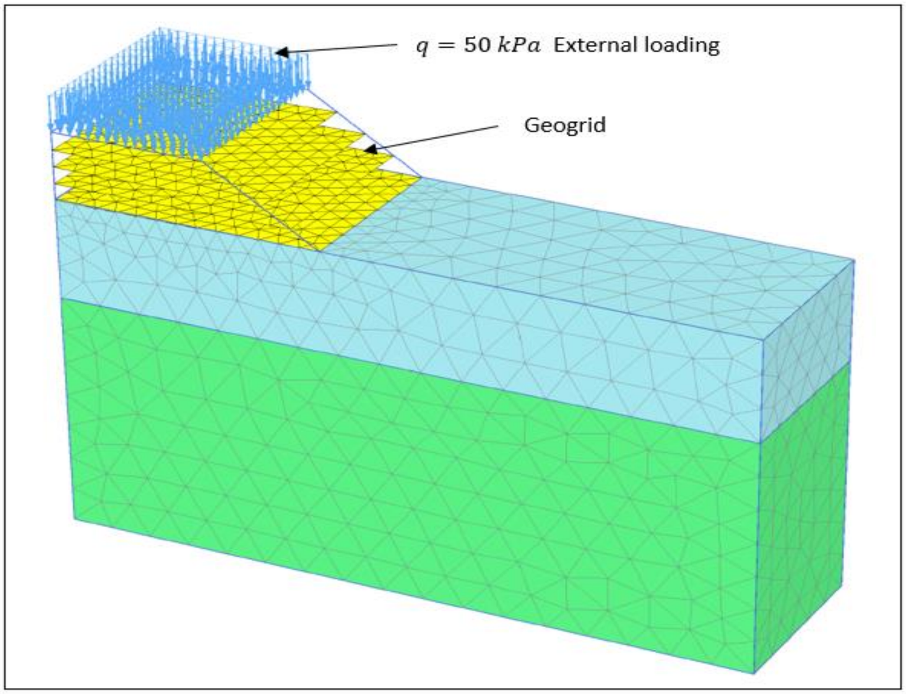


Figure 3.11: Cross-Section Shows the Thickens Embankment with Geogrid.

3.10.1.2 Geogrid reinforced pile-supported embankment

Determining a three-dimensional model of the embankment and describing how adding pile supports and geogrid affects the behavior of the embankment are the major goals of this study. The soil profile consists of two layers of soil based on a rocky base, the first layer is a soft clay layer 6 m thick, followed by another stiff clay layer 14 m thick with the property of different materials based on the rock foundation. The embankment extends in the longitudinal direction, width (0.5B+4H) lateral slope 1:1.5, the total filling height of the embankment is 4m. It consists of gravel mixed with sand. Table (3.5) summarizes the piles' information above the soft clay layer were 4 layers applied. geogrid 0.5cm thickness, the piles used here are piles supported by the Stone column (crushed stone). Figure (3.12) shows cross-section geogrid reinforced stone columns.

Table 3.5: Geogrid Reinforced Pile-Supported Embankment

Embankment Height (m)	Pile Length (m)	Pile Spacing(S) (m)	Pile Diameter(d) (m)
4.0	20	2	0.8

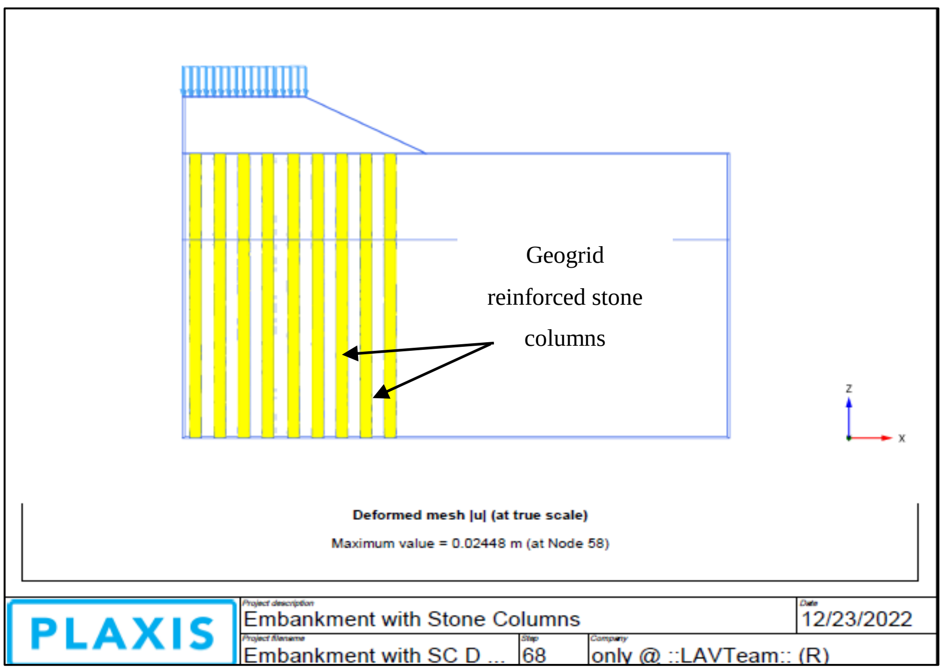


Figure 3.12: Cross-Section Shows Geogrid Reinforced Stone.

3.10.2 Material Model and Parameters

To calculate the properties of the materials when developing the model, the behavior of the path infrastructure must be designed. Mohr- Coulomb criteria changing the parameters of the layers is important to consider Table (3.6) show Parameters used for embankment fill material and clay foundation.

Table 3.6: Show Parameters Used for Embankment Fill Material and Clay.

Material	**Density (Kg/m^3)**	**Elastic Modulus, E(MPa)**	**Poison̓s ratio, *V***	**C (Kpa)**	**Angle of internal friction, φ**
Embankment	0	35	0.4	0	35
Geogrid Type I Geogrid Type II Geogrid Type III		585 860 950	0.5 assumed	0	0
Soft clay layer	0	7.4	0.49	47	0
Stiff clay layer	0	15.7	0.49	116	0
Stone column (Crushed stone)	21	100	0.3	0.2	41

Model material used to model the granular filler to embankment layer, the filling layer is a linear model of a flexible plastic material with a Moher- Coulomb failure, where the modulus of elasticity E, is the effective cohesion C̓, the friction angle φ', the expansion angle is the Poisson's ratio Ψ . The piles are designed by utilizing the properties of linear elastic materials, (Young's modulus and Poisson's ratio). A composite geosynthetic layer was used to monitor the effect of adding the geogrid layer. The geogrid layer was modeled with a linear elastic material like the piles.

3.11 FINITE ELEMENT ANALYSIS MATRIX

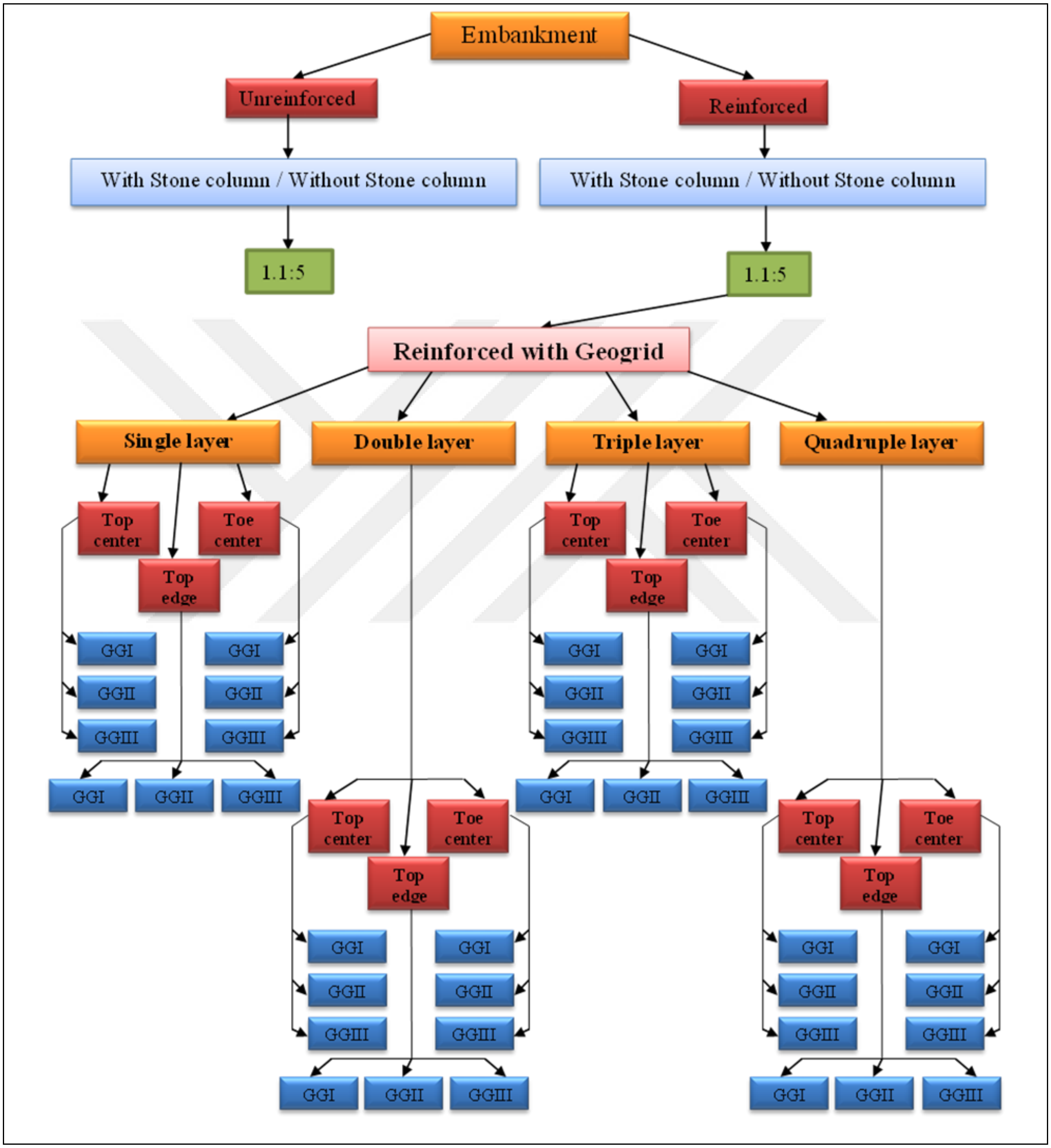


Figure 3.13: Schematic Illustration of FEM Matrix.

4. RESULTS AND DISCUSSION

4.1 INTRODUCTION

Several models have been made using FEA to know the value of horizontal, vertical displacement and safety factors of road embankments placed on soft soils with different characteristics, using code PLAXIS 3D 2020. This study's main goal is to learn about the geogrid effects on soft clay soils and their behavior effectiveness on the embankment. The geogrid-reinforced embankment's load levels were used most in the parametric study (ie, traffic). This chapter outlines more information about the results of the analysis, the effect of design parameters and the investigation of FEA results, and a discussion of the results.

4.2 MODEL DEVELOPMENT

4.2.1 Effect of Model Size on The Soil Behavior

The outer boundary is represented by representations of real forces, and the output of the FE model. A true output of a mass of soil cannot be included, so the FE code ،the boundary of the reaction can be used as constraints, displacement, and other forces. Thus, the user can select PLAXIS 3D effects. Assigning it to the model on which the study is prepared and with the least impact on the model's precision. Results from FE simulations can be drastically impacted by boundary limitations because the interaction forces generated and the displacement in these limits can affect the boundary constraints on the results of finite element simulation. Because the interaction forces generated and displacement affect the effect of the applied forces, so the user must determine the location of the boundary far enough from any area of interest, but at the same time, it must be considered not far because it costs the analysis process more time[89]. The dimensions of the model were chosen by studying the effect of the dimensions of the model on the horizontal displacement to choose the appropriate model for conducting the analysis. It was form created completed a symmetrical model with a width of 10 m from the width of the embankment was taken and the impact of the model's length on the results was studied. The length of the model was linked to the height of the embankment the width of the model was take from the centre to the inclined sides. The model's impact on horizontal displacement was studied, and the real length of the model was reached through the displacement behavior and the size of the model. For the model to reach close results, a model with dimensions [0.5B+4H] was optimum to facilitate the analysis of the model. Unreinforced models without geogrids are adopted [90]. Table (4.1) shows choosing the optimal model for analysis. Figure (4.1) Horizontal displacement [mm] from PLAXIS 3D at a slope of 1:1.5. Figure (4.2) shows choosing the optimal model for analysis[90].

Table 4.1: Shows Choosing the Optimal Model for Analysis

Length of model	Parametric results
(L=0.5B+H)	14.16
(L=0.5B+2H)	30.13
(L=0.5B+3H)	35.96
(L=0.5B+4H)	39.10

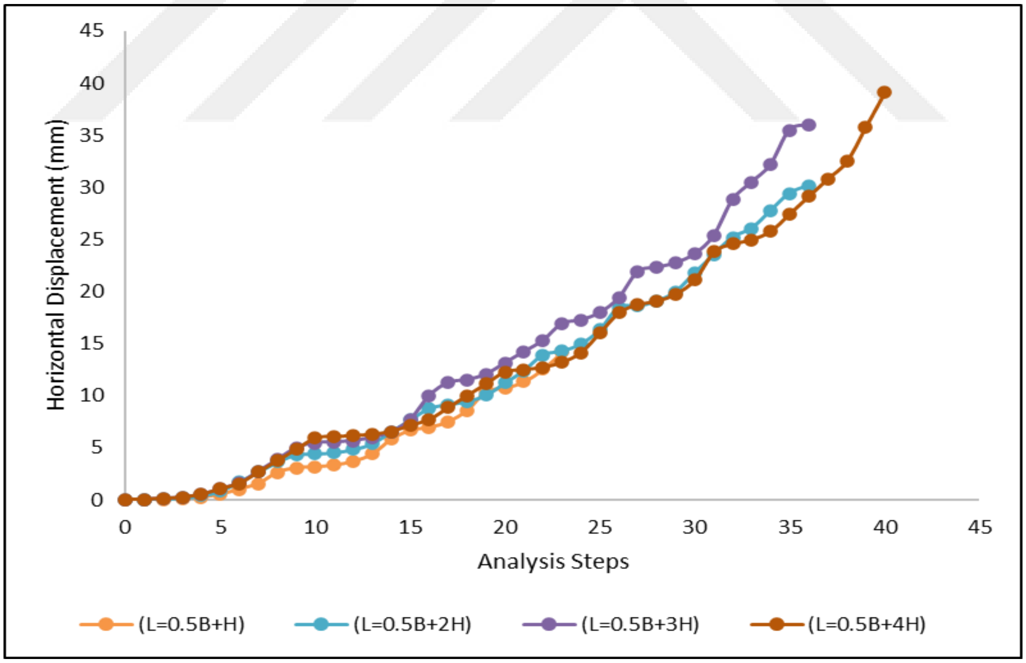


Figure 4.1: Horizontal Displacement [mm] from PLAXIS 3D at a Slope of 1:1.5

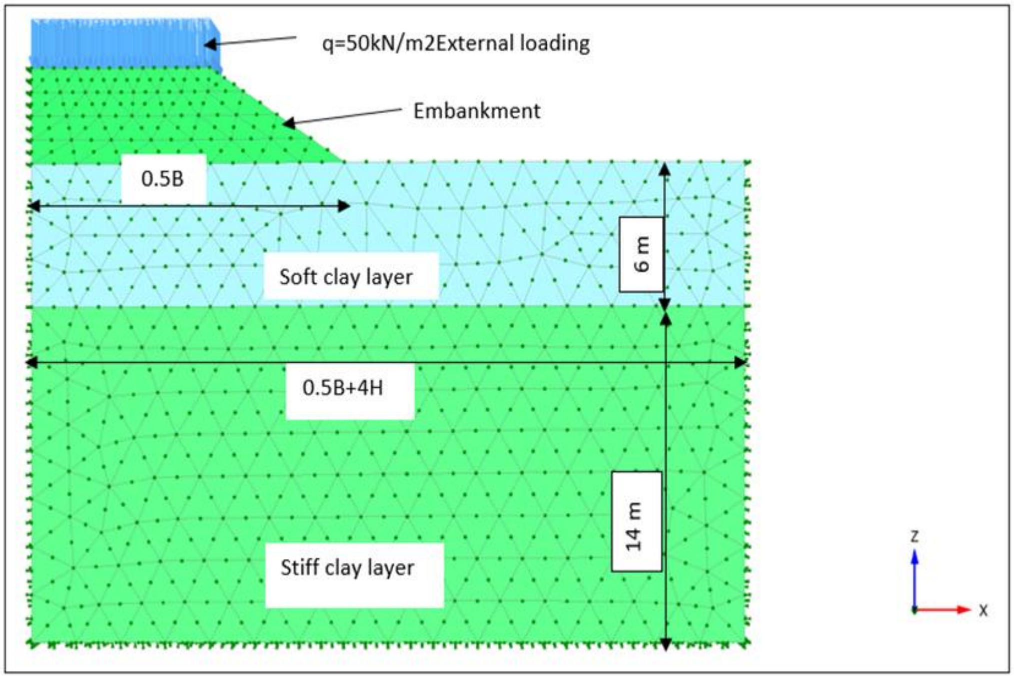


Figure 4.2: Shows Choosing the Optimal Model for Analysis [90]

4.3 DETAILED RESULTS OF FINITE ELEMENT ANALYSIS

FEA was done with the PLAXIS 3D code to examine basic parameters of the geogrid that affected the soil's properties. Finite element analyzes were carried out on reinforced and unreinforced clay soils to assess the impact of several parameters numerous on the performance examined and reinforced soils. The geogrid layer is one of the variables examined in this study, the geogrid type, the number of reinforcement layers for each case, deformation loads, and constriction, it was obtained by finite element modeling and was used to calculate the horizontal, vertical displacement and safety factor. Table (4.2) shows a summary of the results of the Plaxis 3D FEA. The model's output for road embankments with reinforced and without reinforcement at a 1:1.5 slope is the maximum value of the horizontal displacement, vertical displacement, and safety factor. The negative sign in Table (4.2) indicates the upward movement of the soil.

4.4 SAFETY ANALYSIS IN PLAXIS

a) Strength reduction method: Phi/c reduction

b) Same numerical tool as for serviceability design

c) Automatically detects most critical failure mechanism

4.4.1 Safety Analysis

a) Phi/c reduction:

b. Reduction of strength parameters until failure is reached.

Using effective strength

$$\sum Msf = \frac{\tan\varphi}{(\tan\varphi)_{reduced}} = \frac{c}{c_{reduced}}$$

Using undrained shear strength

$$\sum Msf = \frac{s_U}{s_{U,reduced}}$$

ΣMsf = strength reduction factor

4.4.2 Safety Analysis in PLAXIS

Notes on the Safety calculation:

a) During a Safety calculation all advanced soil models reduce to

  a. Linear Elastic-Perfectly Plastic with stiffness based on the starting stress state.

  b. Safety calculation also reduces *Tension cut-off* stress

  c. *Residual strength* for interfaces and structural elements is not taken into account

  d. Soil models for which strength is not based on φ and c (for instance the Hoek-Brown model) an equivalent method is used to reduce strength in a Safety calculation

4.4.3 Safety Analysis in PLAXIS - Calculation

A. Strength reduction with a predefined factor (Target Σ-*Msf*)

a) Create a Safety phase:

  a. Set *Loading input* to *Target Σ-Msf*

  b. Specify a target reduction factor

b) Calculate

B. *Note: Plaxis will calculate until failure occurs to check* Target Σ-Msf < FoS [85].Table(4.2) Summarizes the Findings from the Plaxis 3D Finite Element Analysis at a Slope of 1:1.5 and safety factor.

Table 4.2: Summarizes the Findings from the Plaxis 3D Finite Element Analysis at a Slope of 1:1.5 and safety factor.

<table>
<tr><th rowspan="2">Slop V: H</th><th rowspan="2">Reinforcement</th><th colspan="2">Reinforcement Layer</th><th colspan="3">Parameter Results</th></tr>
<tr><th>Layer</th><th>At</th><th>Horizontal Displacement (mm)</th><th>Vertical Displacement (mm)</th><th>Safety Factor</th></tr>
<tr><td rowspan="15">1.1:5</td><td rowspan="3">Unreinforced</td><td rowspan="3">-</td><td>Top Center</td><td>0</td><td>92</td><td rowspan="3">1.4</td></tr>
<tr><td>Top edge</td><td>2.6</td><td>53.0</td></tr>
<tr><td>Toe Center</td><td>43</td><td>-14</td></tr>
<tr><td rowspan="12">Reinforcement with GGI</td><td rowspan="3">Single</td><td>Top Center</td><td>0</td><td>82</td><td rowspan="3">1.4</td></tr>
<tr><td>Top edge</td><td>-2.4</td><td>51.6</td></tr>
<tr><td>Toe Center</td><td>32</td><td>-13</td></tr>
<tr><td rowspan="3">Double</td><td>Top Center</td><td>0</td><td>80</td><td rowspan="3">1.5</td></tr>
<tr><td>Top edge</td><td>-4.4</td><td>49.2</td></tr>
<tr><td>Toe Center</td><td>28</td><td>-14</td></tr>
<tr><td rowspan="3">Tripartite</td><td>Top Center</td><td>0</td><td>79</td><td rowspan="3">1.7</td></tr>
<tr><td>Top edge</td><td>-5.2</td><td>48.8</td></tr>
<tr><td>Toe Center</td><td>28</td><td>-14</td></tr>
<tr><td rowspan="3">Quadrilat eral</td><td>Top Center</td><td>0</td><td>79</td><td rowspan="3">2.16</td></tr>
<tr><td>Top edge</td><td>-5.5</td><td>48.4</td></tr>
<tr><td>Toe Center</td><td>28</td><td>-14</td></tr>
</table>

Table 4.2: Summarizes the Findings from the Plaxis 3D Finite Element Analysis at a Slope of 1:1.5 and safety factor. "Table Continued"

	Reinforcement with GG	Single	Top Center	0	80	1.4
			Top edge	-3.7	50.0	
			Toe Center	28	-13	
		Double	Top Center	0	77	1.5
			Top edge	-6.4	48.1	
			Toe Center	25	-13	
		Tripartite	Top Center	0	77	1.7
			Top edge	-6.3	49.6	
			Toe Center	23	-13	
		Quadrilateral	Top Center	0	77	2.16
			Top edge	-6.7	47.6	
			Toe Center	24	-13	
	Reinforcement with GGIII	Single	Top Center	0	79	1.4
			Top edge	-4	49.7	
			Toe Center	28	-13	
		Double	Top Center	0	76	1.5
			Top edge	-6.7	47.9	
			Toe Center	24	-13	
		Tripartite	Top Center	0	76	1.7
			Top edge	-6.6	49.3	
			Toe Center	23	-13	
		Quadrilateral	Top Center	0	77	2.16
			Top edge	-7	47	
			Toe Center	24	-13	

As shown in Figure (4.2) the value result of the model. Figures (4.4) and (4.5) show the model of the road embankment's horizontal and vertical displacement built on soft soil with a 1:1.5 side slope, and Figure (4.3) shows the location of the points selection.

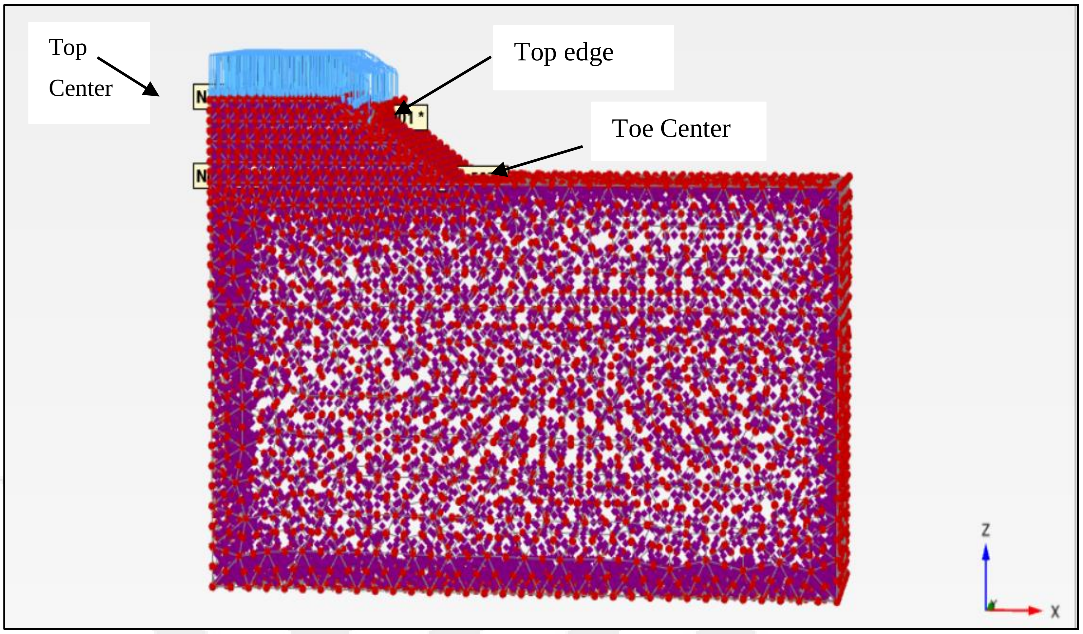


Figure 4.3: Showing the Location of the Points Selection.

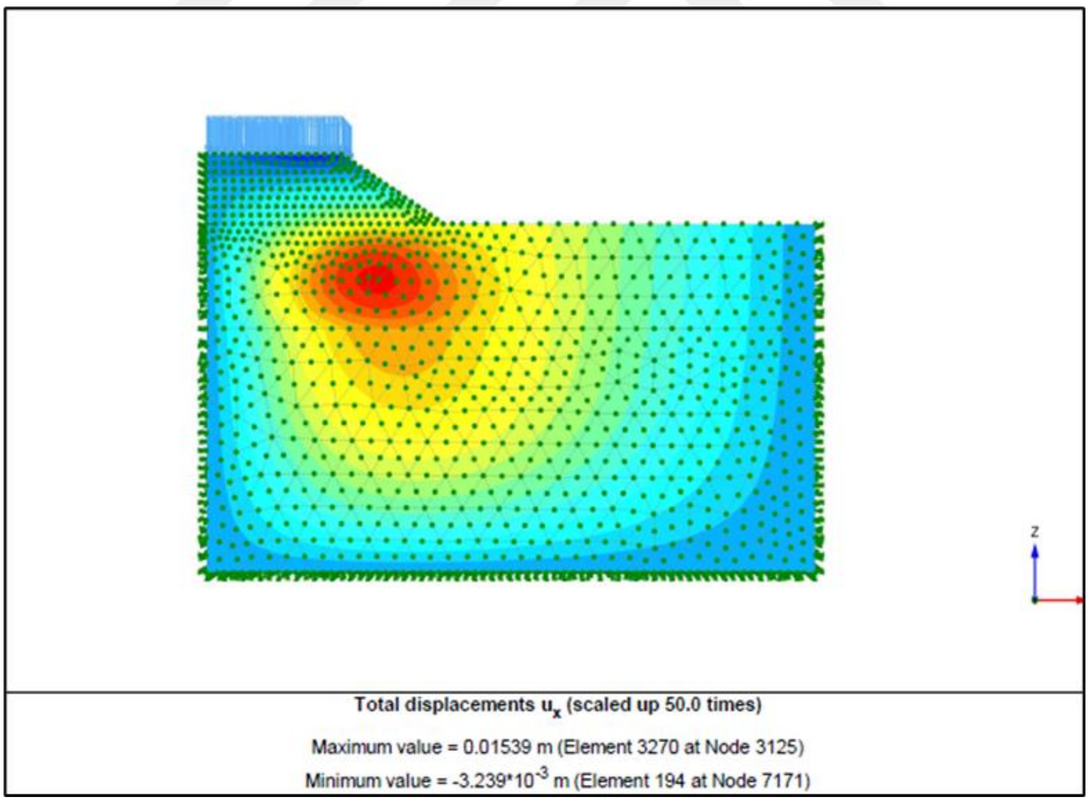


Figure 4.4: Model's Horizontal Displacement (PLAXIS 3D 2020).

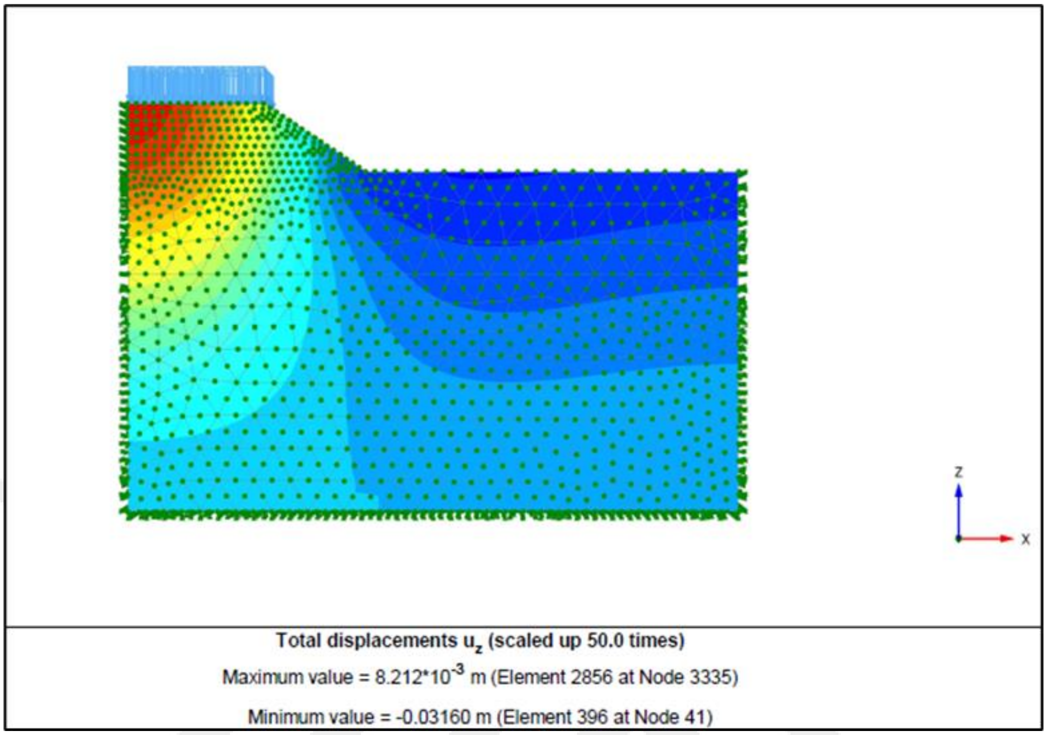


Figure 4.5: Model's Vertical Displacement (PLAXIS 3D 2020).

4.5 PARAMETRIC STUDY

Design criteria that may affect road embankment performance ‹this study include study included the impact of geogrid type and layer count on embankment behavior.

4.5.1 Effect of Geogrid (Layers and Type)

Considering the impact of geogrid reinforcement used in road embankments, in the FE model, the effect of the layer where the geogrid is added on the performance of the road embankment is shown by vertical settlement, horizontal displacement, and safety factor. Geogrid is laid on the bottom in single, double, triple, and quadruple layers .The results were obtained for the loading and construction phases. Figure (4.6) shows layers of geogrid (PLAXIS 3D 2020).

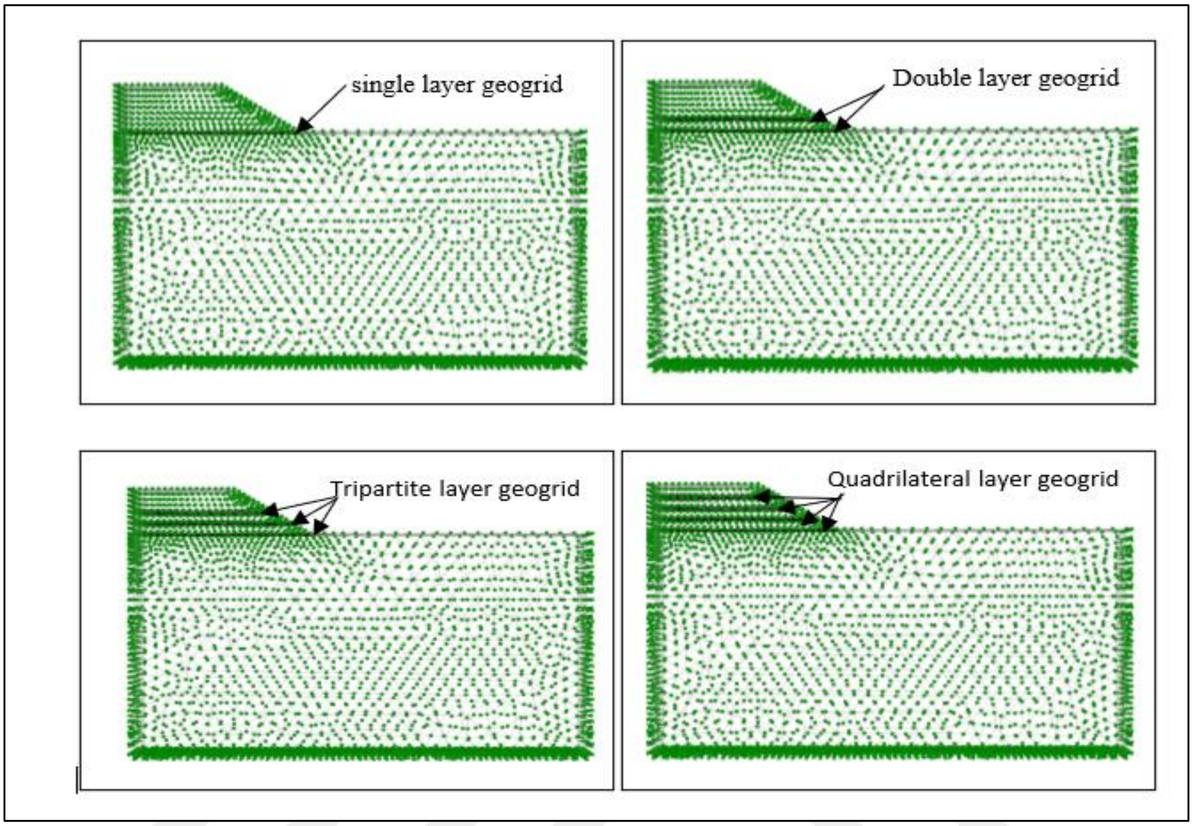


Figure 4.6: Show Layers Geogrid (PLAXIS 3D 2020).

4.5.1.1 Effect of geogrid on embankment deformation

Site in Table (4.2) the possible deformation that can occur in the model is divided into two types vertical (settlement) deformation and horizontal (lateral) deformation.

A. With Respect to Horizontal Displacement

The impact of the four reinforcing layers of geogrid was applied to model an embankment ،points have been selected in the (Top center) (Top edge) (Toe center), to know the values of deformations and draw deformation curves for the embankment. reinforcement by single-layer, double-layer, three-layer, and four-layer. Table (4.2) shows the number of layers and the impact of geogrids on the horizontal value because of loading and construction. When the number of layers is increased and the kind of geogrid is changed, there is a decrease in the displacement value, the deformations decrease and there is an improvement in the value of lateral displacement from the unreinforced soil. The third and fourth layers. It can be noted that there is no noticeable difference in the reduction of deformation. The results indicate that the reinforcement with four layers (Toe center) and the type of geogrid (GGIII) may reduce the horizontal displacement more than the reinforcement of the rest of the layers. Table (4.3) shows the percentage of improvement in the value of horizontal displacement in the case of reinforced soil, to the unreinforced soil in the construction and loading phase. Figure (4.7) horizontal displacement of the geogrid-reinforced embankment (GGI) as a result of the construction and loading of the layers. Figure (4.8) horizontal displacement of the geogrid-reinforced embankment (GGII) because of the construction and loading of the layers. Figure (4.9) horizontal displacement of the geogrid-reinforced embankment (GGIII) because of the construction and loading of the layers.

Table 4.3: Shows The Percentage of Improvement in the Value of Horizontal Displacement.

Reinforcement	**Reinforcement layer**	**Improvement Ratio**	
		Horizontal Displacement Loading(mm)	**Horizontal Displacement Construction Embankment (mm)**
GGI	Single	20	27.1
	Double	30.8	35.2
	Tripartite	33.3	37.7
	Quadrilateral	33.3	37.3
GGII	Single	28.3	35
	Double	38.3	43
	Tripartite	40.8	45.6
	Quadrilateral	40.8	45.2
GGIII	Single	30.1	36.9
	Double	40.8	44.9
	Tripartite	43.3	47.1
	Quadrilateral	40.8	45.2

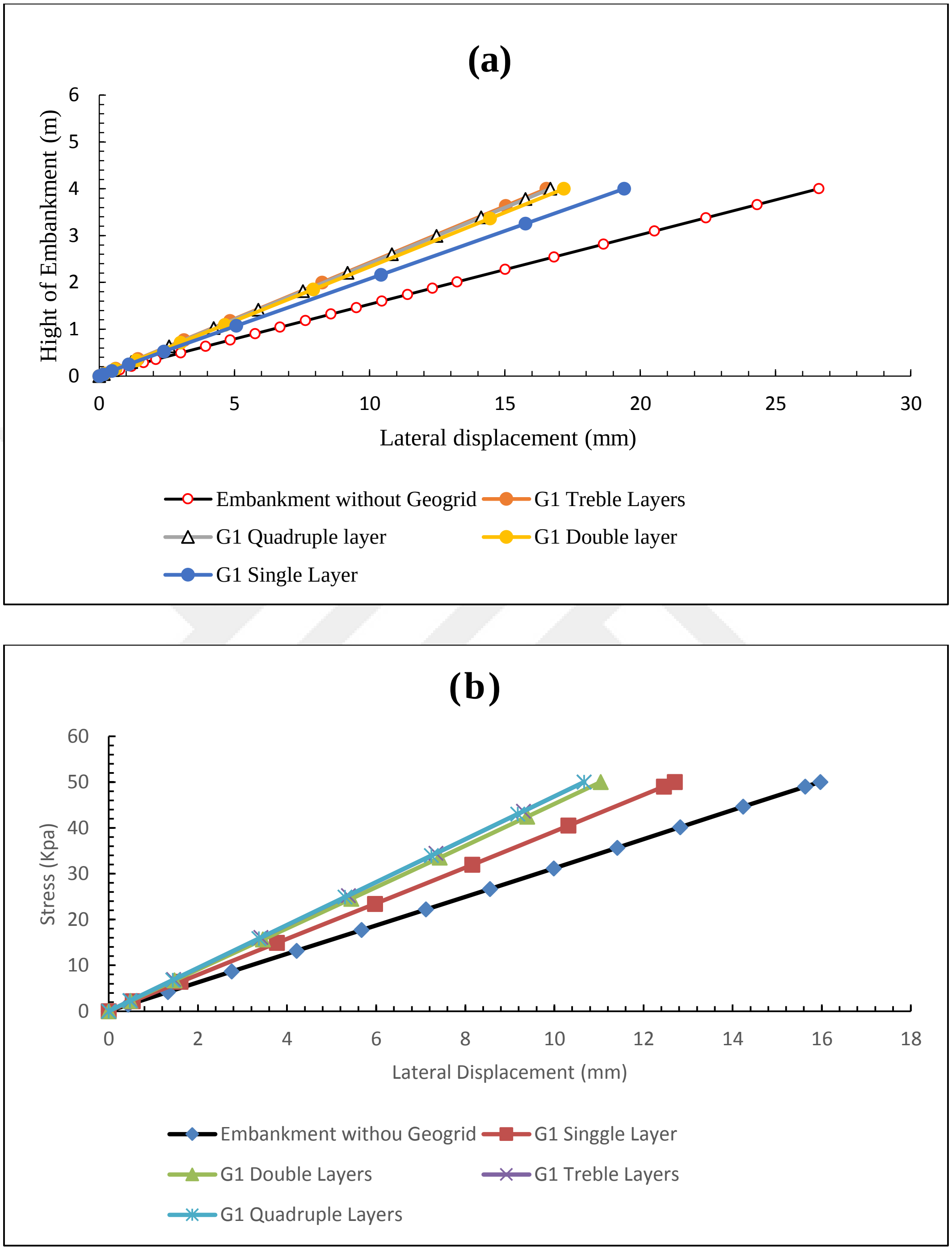


Figure 4.7: (a) Horizontal Displacement of the Geogrid-Reinforced Embankment (GGI) as a Result of the Construction Layer, (b) Horizontal Displacement of the Geogrid-Reinforced Embankment (GGI) as a Result of the Loading Layer.

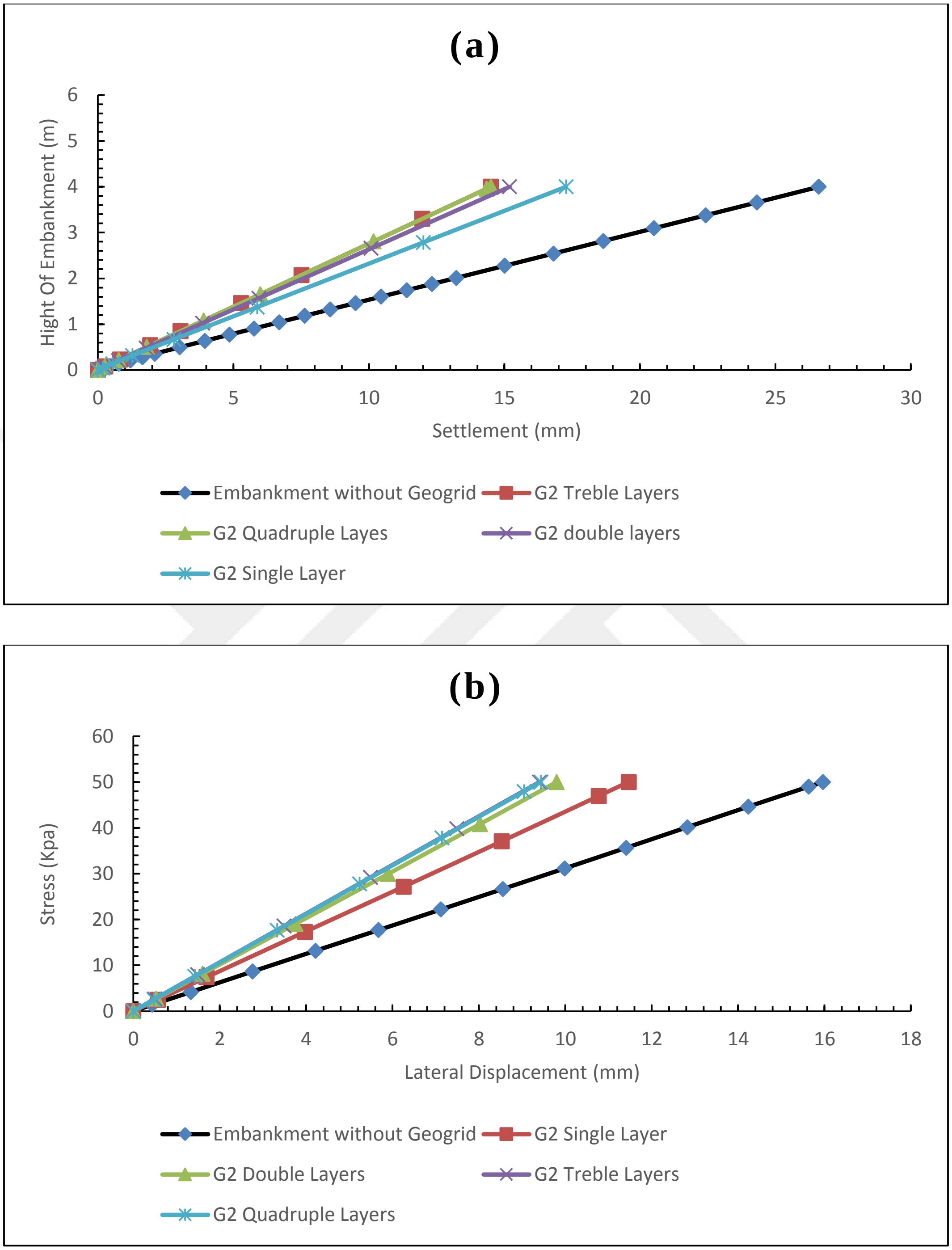


Figure 4.8: (a) Horizontal Displacement of the Geogrid-Reinforced Embankment (GGII) as a Result of the Construction Layer, (b) Horizontal Displacement of the Geogrid-Reinforced Embankment (GGII) as a Result of the Loading Layer.

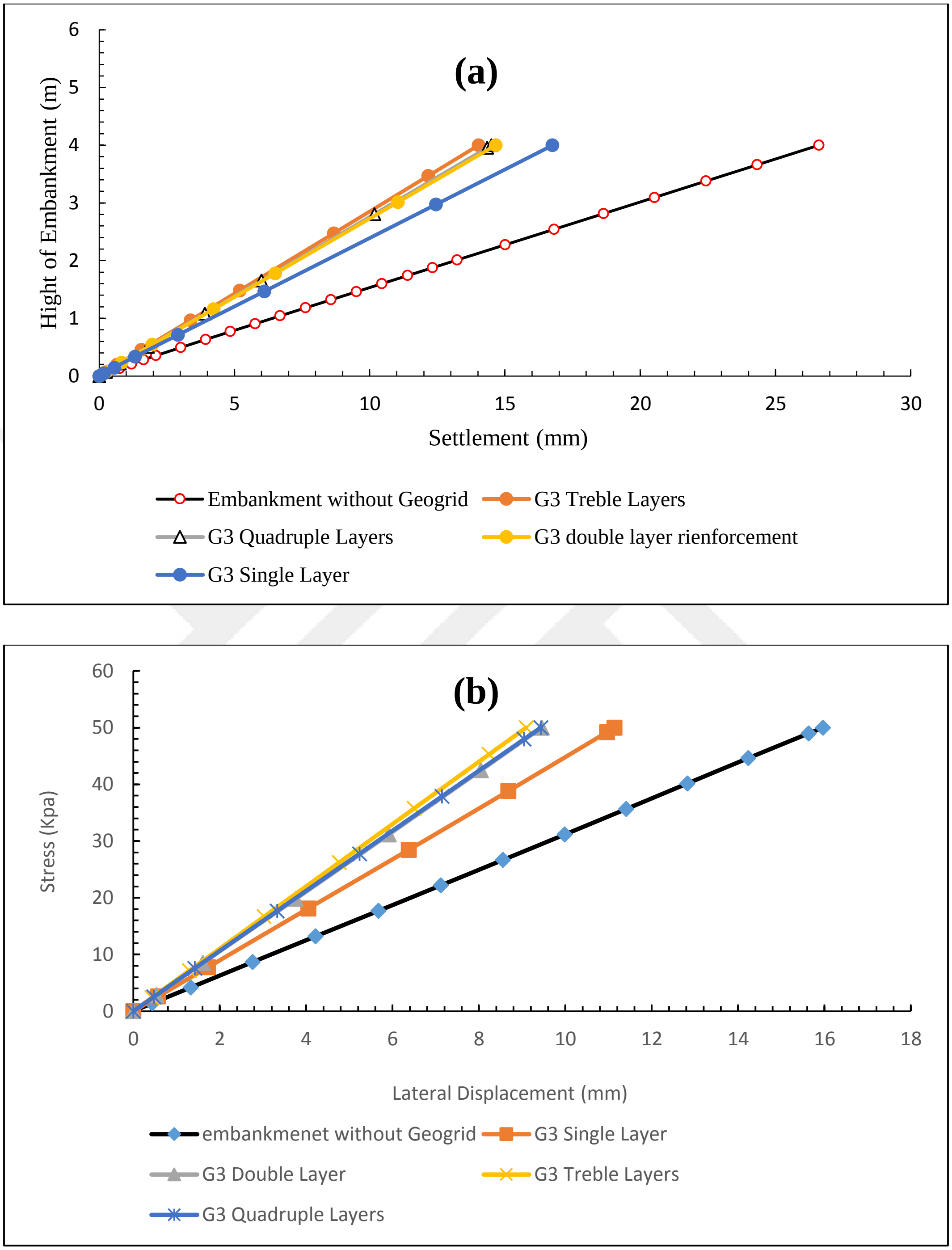


Figure 4.9: (a) Horizontal Displacement of the Geogrid-Reinforced Embankment (GGIII) as a Result of the Construction Layer: (b) Horizontal Displacement of the Geogrid-Reinforced Embankment (GGIII) as a Result of the Loading Layer.

B. With respect to vertical displacement

The impact of reinforcement position on single, double, triple, and quadruple reinforcement's vertical displacement is shown in its classification layer Figure (4. 4) as shown in Figure, the result indicates that the value of deformation occurred in the (Top center). The results depended on the program outputs during the loading and constriction. It can be concluded that it can be adding two layers because the improvement gave the same values. There is a difference in the improvement only when adding the geogrid to the first and second layers. Figure (4. 10) vertical displacement of the geogrid-reinforced embankment (GGI) due to layer construction and loading. Figure (4.12) vertical displacement of the geogrid-reinforced embankment (GGII) due to layer construction and loading. Figure (4. 13) vertical displacement of the geogrid-reinforced embankment (GGIII) due to layer construction and loading.

Table 4.4: Shows the Percentage of Improvement in the Value of Vertical Displacement.

Reinforcement	**Reinforcement layer**	**Improvement Ratio**	
		Vertical Displacement loading(mm)	**Vertical Displacement construction embankment (mm)**
GGI	Single	10.8	9
	Double	14.5	12.2
	Tripartite	15	12.8
	Quadrilateral	15.2	12.8
GGII	Single	14.2	11.8
	Double	17.8	14.7
	Tripartite	18.1	15
	Quadrilateral	18.1	15
GGIII	Single	15	14.3
	Double	18.6	15.2
	Tripartite	18.9	15.6
	Quadrilateral	18.1	15

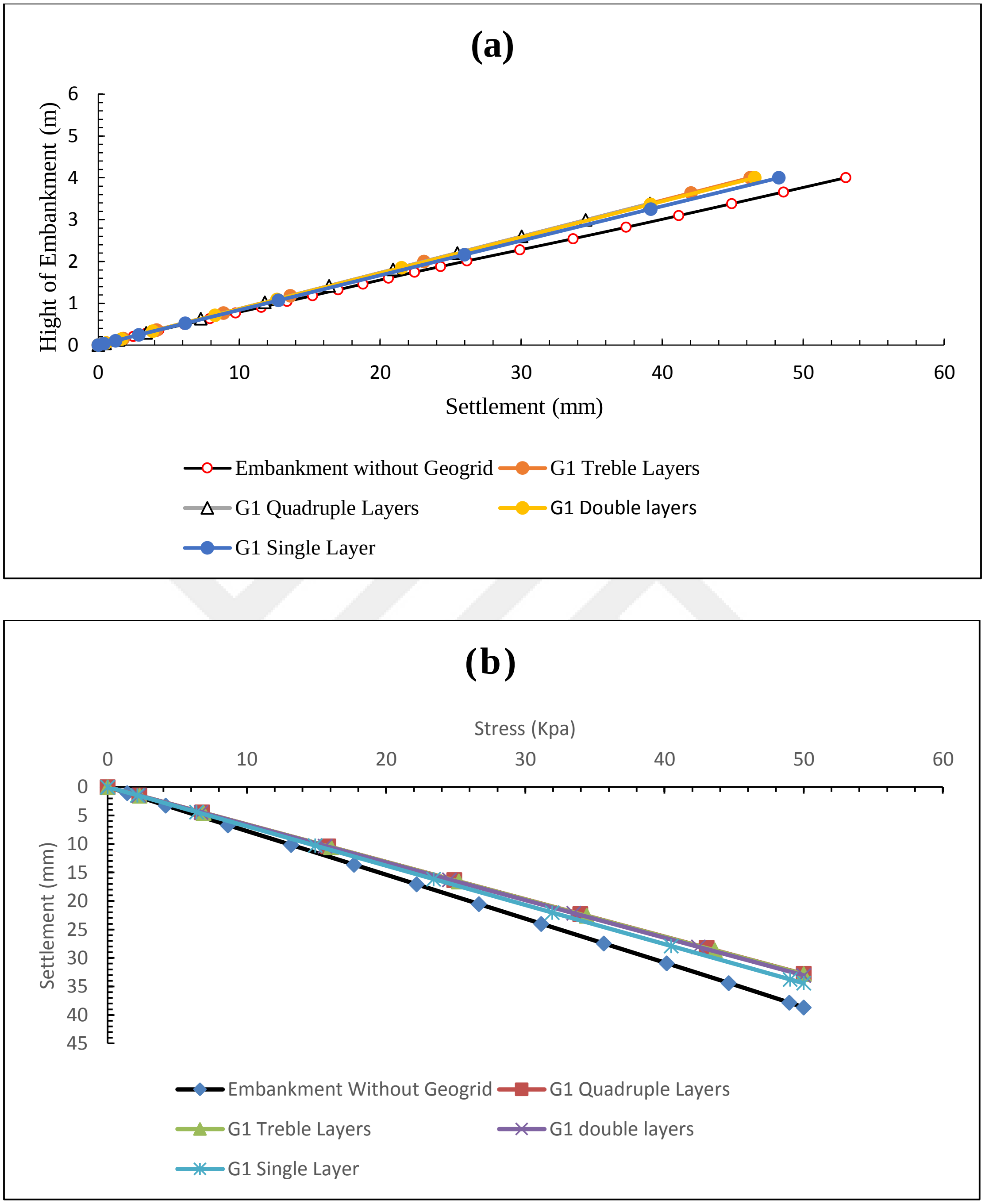
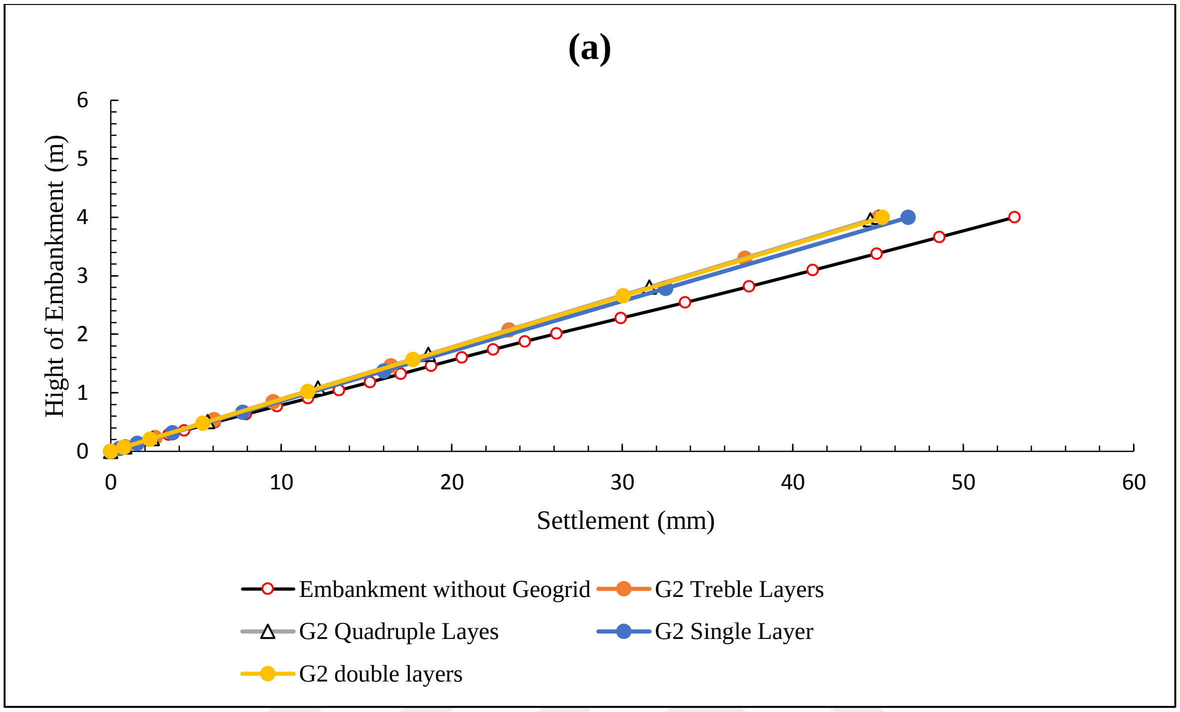


Figure 4.10: (a) Vertical Displacement of the Geogrid-Reinforced Embankment (GGI) Due to Layer Construction, (b) Vertical Displacement of the Geogrid-Reinforced Embankment (GGI) Due to Layer Loading.



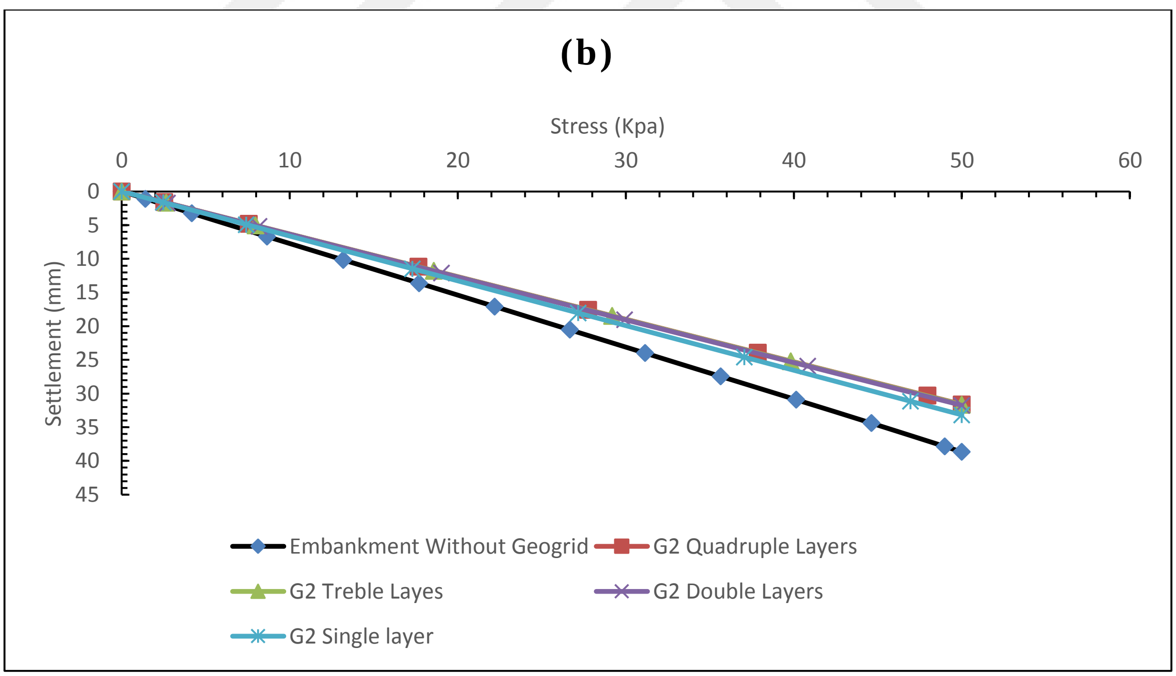


Figure 4.11: (a) Vertical Displacement of the Geogrid-Reinforced Embankment (GGII) Due to Layer Construction, (b) Vertical Displacement of the Geogrid-Reinforced Embankment (GGII) Due to Layer Loading.

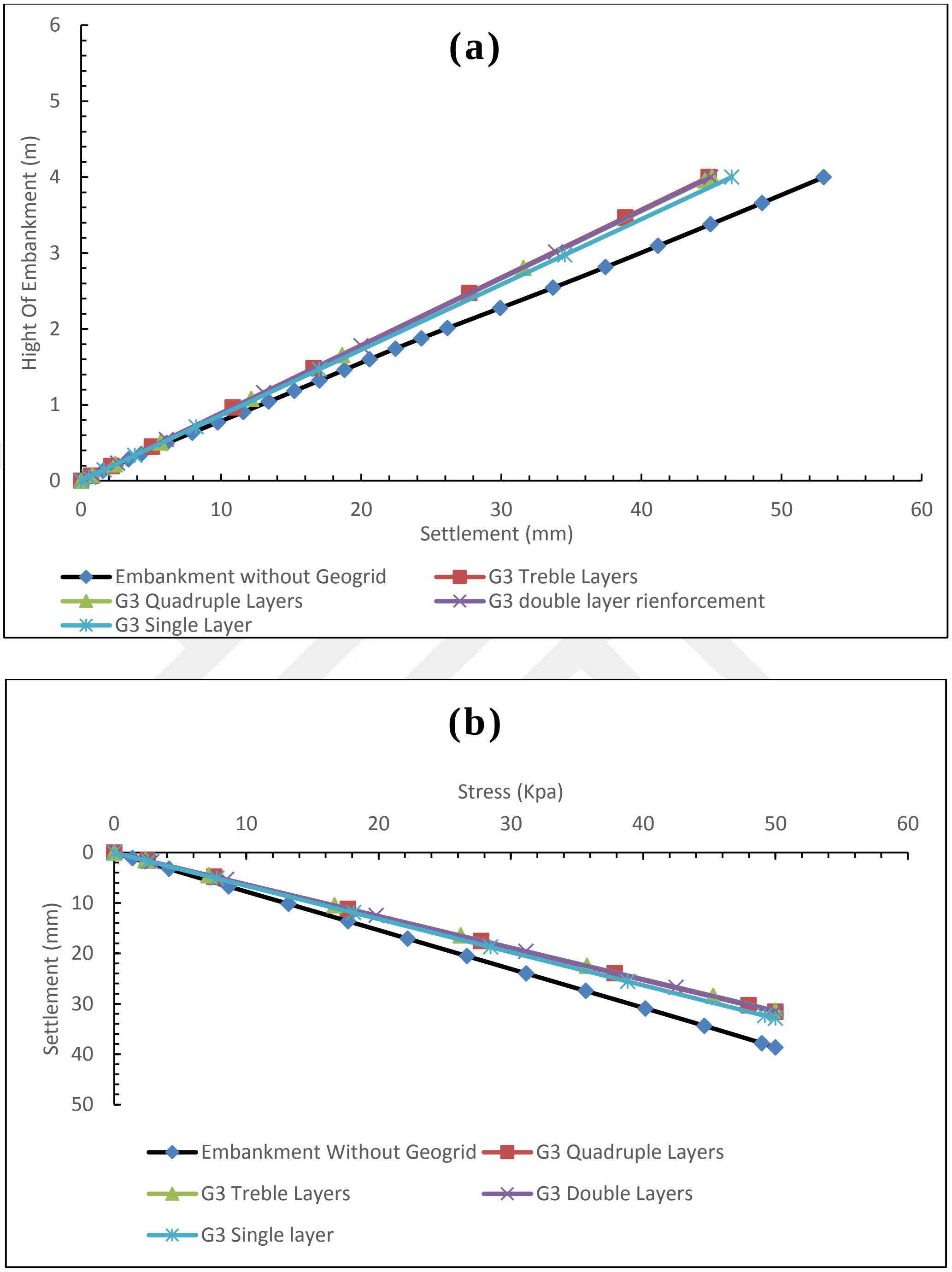


Figure 4.1: (a) Vertical Displacement of the Geogrid-Reinforced Embankment (GGIII) Due to Layer Construction, (b) Vertical Displacement of the Geogrid-Reinforced Embankment (GGIII) Due to Layer Loading.

4.5.1.2 Effect of geogrid reinforcement on the safety factor

The safety factor against slipping is calculated to prevent failure from happening. The influence of reinforcing layers and type on safety factor for different cases of single, double, triple, and quadruple reinforcement as shown in Figure (4. 13) to Figure (4. 15). This illustrates how the geogrid works when it is used at the base of an embankment. (Over clay soils) it may affect the performance of the road embankment. It can be noted that the value of safety factor has no effect in the case of one layer in the reinforcement soil on the unreinforced soil. When the four-layer geogrid is applied, it increases the safety factor and affects the performance of the road embankment. It can be concluding that the type of geogrid does not affect the safety factor, but its effect appears when the number of layers of geogrid is increased. It can be noted that the safety factor improvement increased by (50) % about the unreinforced embankment layer. Table (4. 5) shows the value of safety factors.

Table 4.5: Show Value of Safety Factor.

Reinforcement	**Reinforcement layer**	**The Safety Factor**
Reinforcement	**-**	1.4
GGI	Single	1.4
	Double	1.5
	Tripartite	1.7
	Quadrilateral	2.16
GGII	Single	1.4
	Double	1.5
	Tripartite	1.7
	Quadrilateral	2.16
GGIII	Single	1.4
	Double	1.5
	Tripartite	1.7
	Quadrilateral	2.16

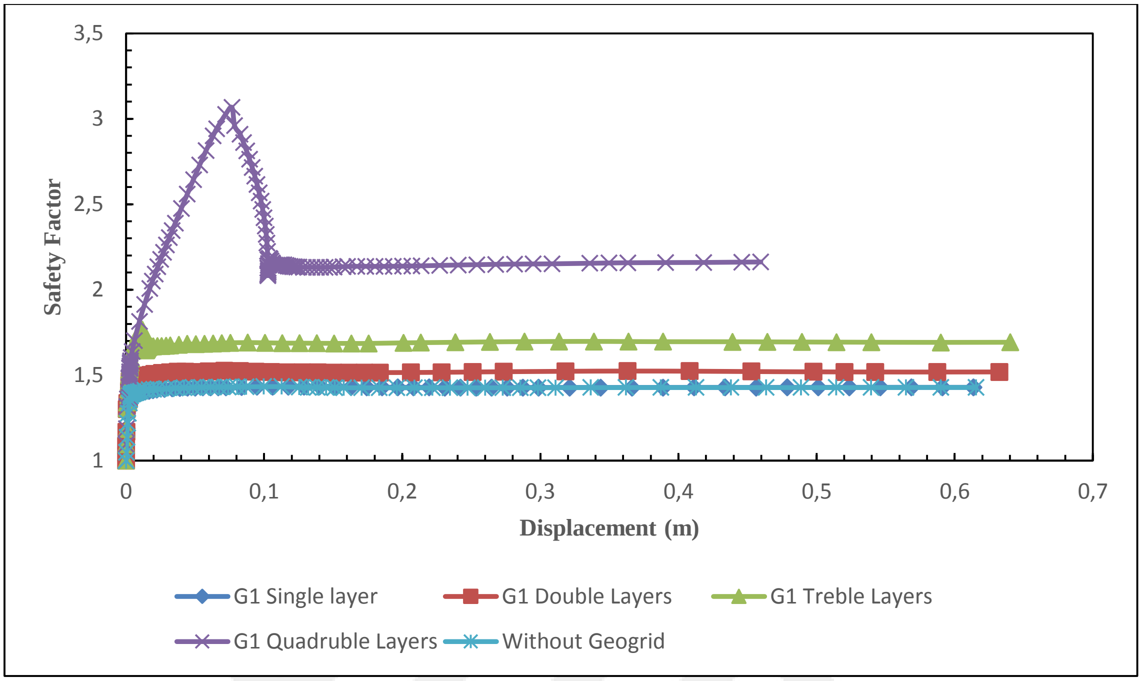


Figure 4.2: Show Effect of Geogrid Type (GGI) on the Safety Factor.

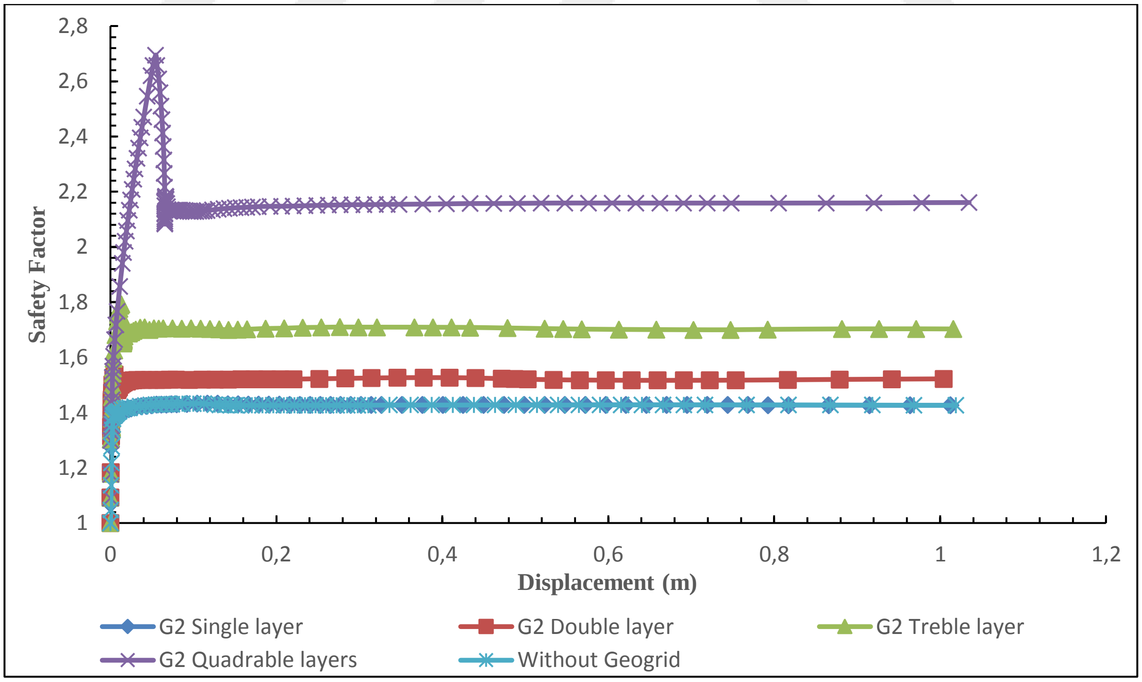


Figure 4.3: Shows Effect of Geogrid Type (GGII) on the Safety Factor.

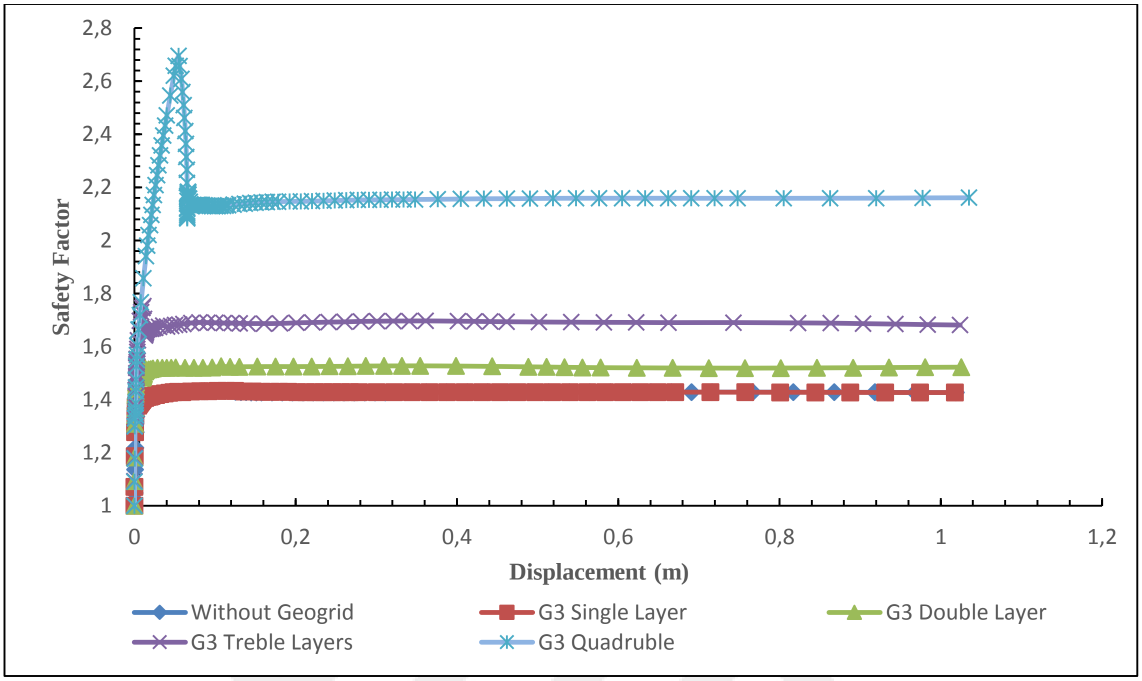


Figure 4.4: Shows Effect of Geogrid Type (GGIII) on the Safety Factor.

4.6 SUMMERY

A series of PLAXIS 3D FEA was conducted to investing the effect of design factors effect on a geogrid-reinforced road embankment's performance. The PLAXIS 3D FEA code simulated road embankment with a lateral slope of 1:1.5, the position of the geogrid layer, and the applied geogrid type were analyzed about parameters such as settlement (vertical displacement), lateral deformation (horizontal displacement), and safety factor. The study focused mainly on the road embankment leveling performance, as the foundation design is governed on soft soils by the stability condition due to its high compressibility, rather than the bearing capacity criterion and then the geogrids grading performance strengthened the pavement at critical work levels. Based on the parametric study, a geogrid road embankment was designed at the slope of 1:1.5 ، was selected as a type (GGIII) geogrid in the lower part of the embankment is recommended as more efficient. As shown by the performance of the road embankment before reinforcement with geogrid regarding the safety factor, the reinforcement increased the safety factor by (50%) more than the unreinforced. Reducing vertical and horizontal displacements can be accomplished by adding reinforcement under embankments but is generally more efficient in reducing horizontal movements. The soft clay layer's thickness and shear strength determine the degree to which displacements are reduced. Reinforcement improves shear stress resistance and as a result, embankment stability. [91] as well as may reduce differential lateral deformation and settlement [92].

4.7 STUDYING THE EFFECT OF (SOFT CLAY) IMPROVEMENT USING STONE COLUMNS

The numerical analysis investigated improving the soft clay foundation, by adding stone columns with geogrid, using the PLAXIS 3D program.

4.7.1 Various Cases Selected for Analysis

A simulation model was used for the numerical modeling of the stone columns, as explained previous chapter. The data is based on the source ([93] the results were compared. The first case is the problem of the embankment without a stone column Figure (4.22) shows an embankment without a stone column, a second case is the addition of a stone column and geogrid as shown in Figure (4.16) shows a stone column with geogrid (GGIII). The embankment fill was improved by using geogrids, and the results obtained were not sufficient for the improvement due to settlement in the foundation soil and not the embankment fill, except for the increase in the safety factor due to the addition of geogrid layers. To reduce the settlement that occurred in the foundation soil, the stone column improvement method was used, reinforced with type geogrids (GGIII). Two types used, the first type is without stone column, this type is weak because it depends on the strength of the soil adjacent to it and it occurs in the event of failure of the neighboring soil, which leads to the occurrence of curvature in the soil. The second type is with the stone column and with geogrid. The analysis was segmented to give the clearest effect i.e., embankment effect and geogrid effect. The results of settlement resulting from (constriction and loading) were adopted.

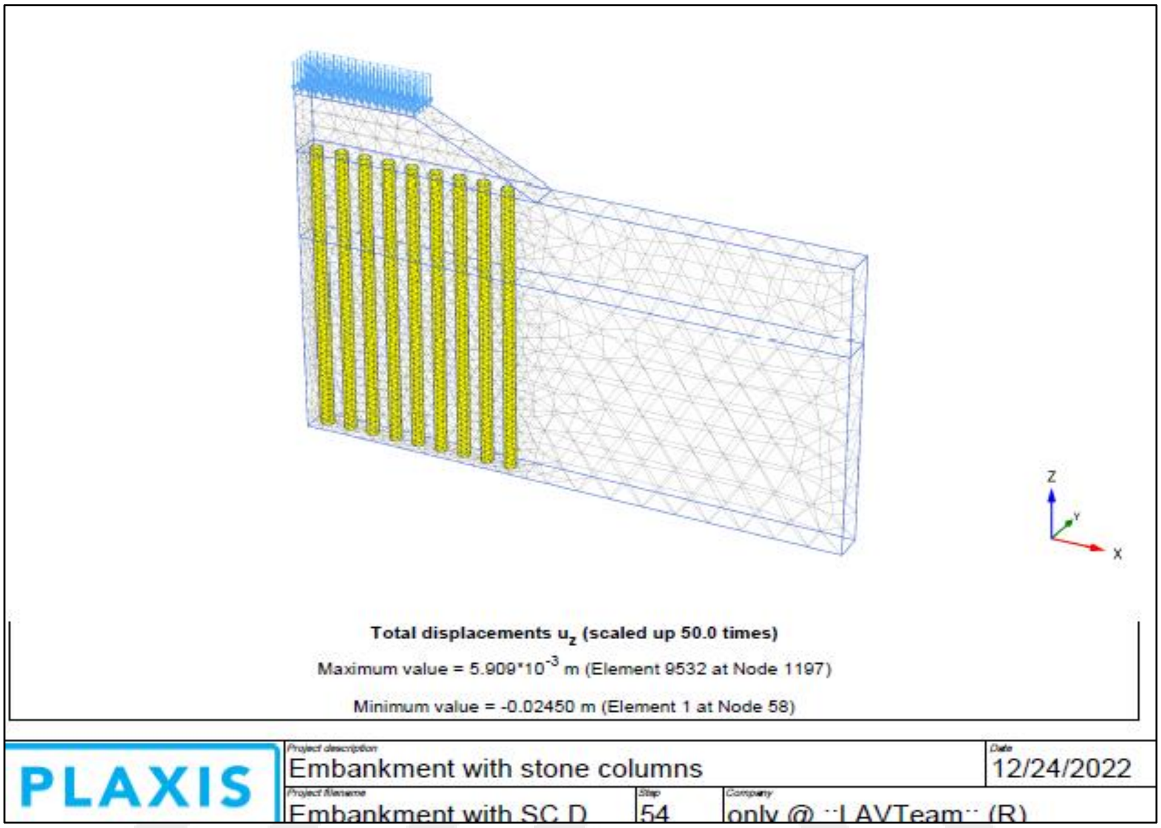


Figure 4.5: Show Stone Column with Geogrid (GGIII).

4.8 ANALYSIS OF THE RESULTS

The results obtained from the PLAXIS 3D program were discussed. The results were compared to the behavior of the embankment without stone columns and geogrid with the behavior of the embankment with the addition of stone columns and geogrid. (0-50) loading value, (0-4) value constriction embankment. Figure (4.17) show the geogrids tensile strength. Figure (4.18) show the result of displacement |u| arrow presentation in stone Columns.

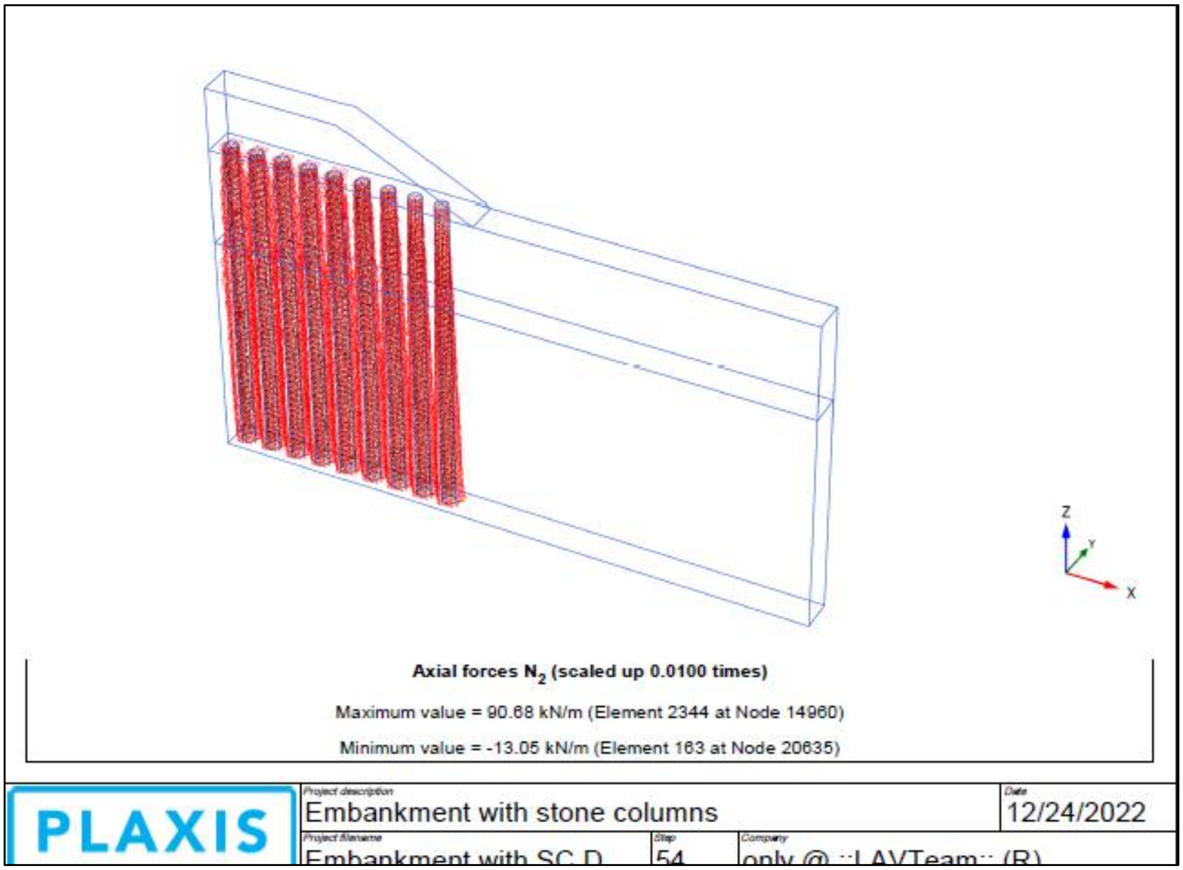


Figure 4.6: Show the Tensile Strength of the Geogrid Using a Stone Column.

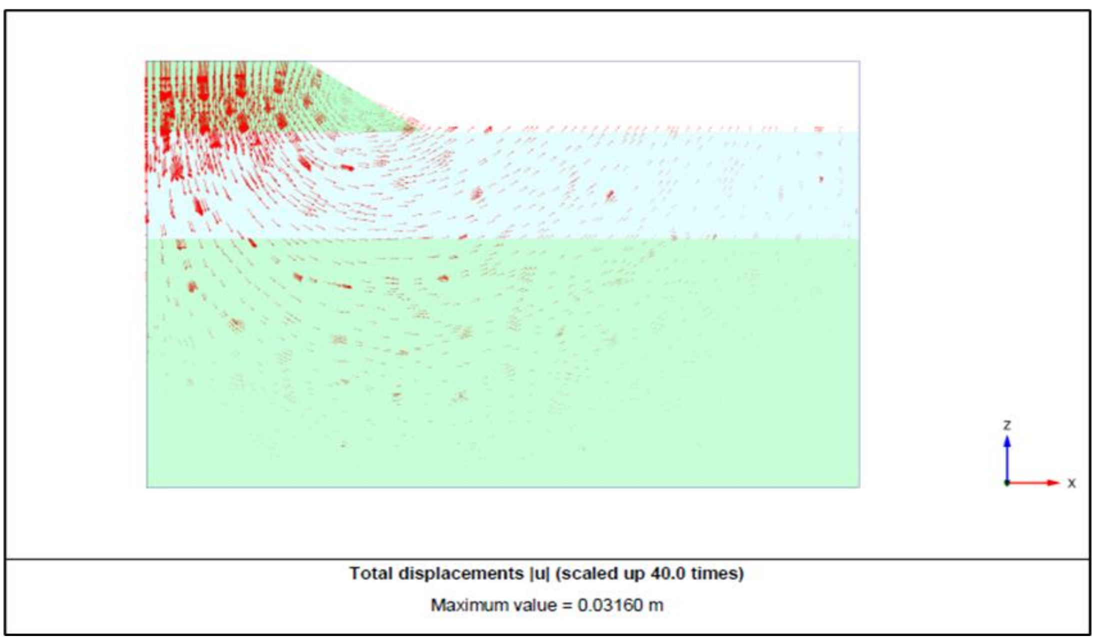


Figure 4.7: Show the Result of Displacement |U| Arrow Presentation in Stone Column.

A. Horizontal Displacement

The horizontal displacement of the (toe center) is compared to the embankment in the case of adding stone coulomb and geogrid of type (GGIII), The addition of the geogrid layer to the horizontal displacement in the case of stone columns reduced the deformation (71) % in the construction phase and (12.7) % in the loading phase. Figure (4.21) show an embankment with stone columns. Figure (4.22) show an embankment without stone columns. Table (4.6) shows the results of analysis. Figure (4.19) show settlement value constriction embankment. Figure (4.20) show settlement loading value.

Table 4.6: Shows the Results of Analysis.

Model	**Embankment without stone Colum**	**Settlement (mm)**	**Embankment with stone Column**	**Settlement (mm)**
(0.5B+4H)	(0-4) high Embankment	20.4	(0-4) high Embankment	5.9
	(0-50) Kpa Stress	11.8	(0-50) Kpa Stress	10.3

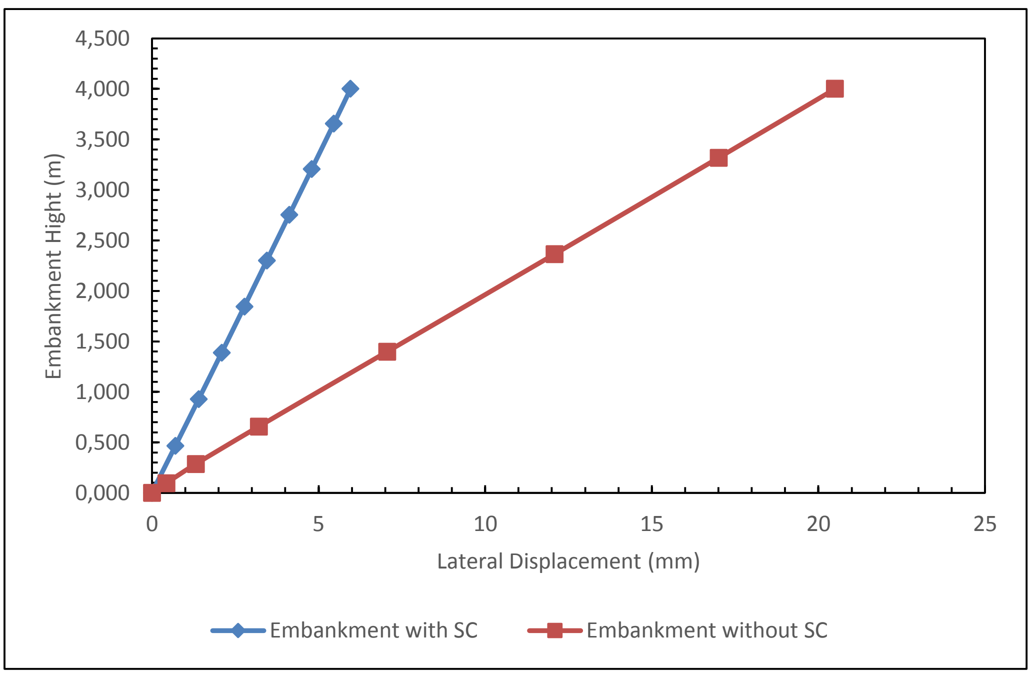


Figure 4.8: Show Settlement Value Constriction Embankment.

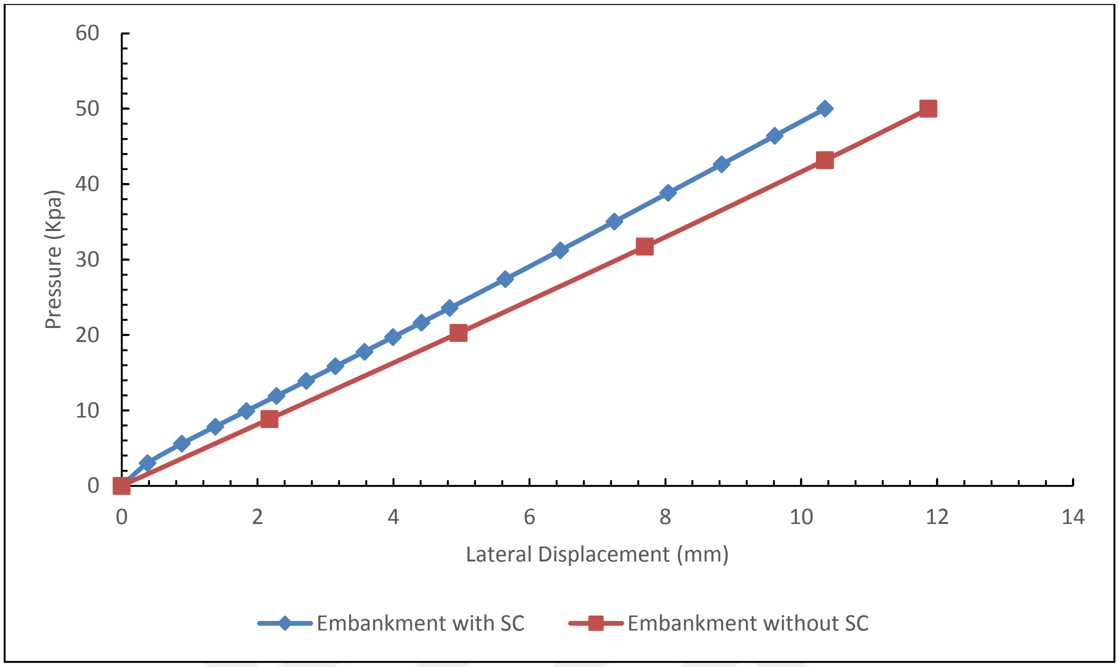


Figure 4.20: Show Settlement Loading Value.

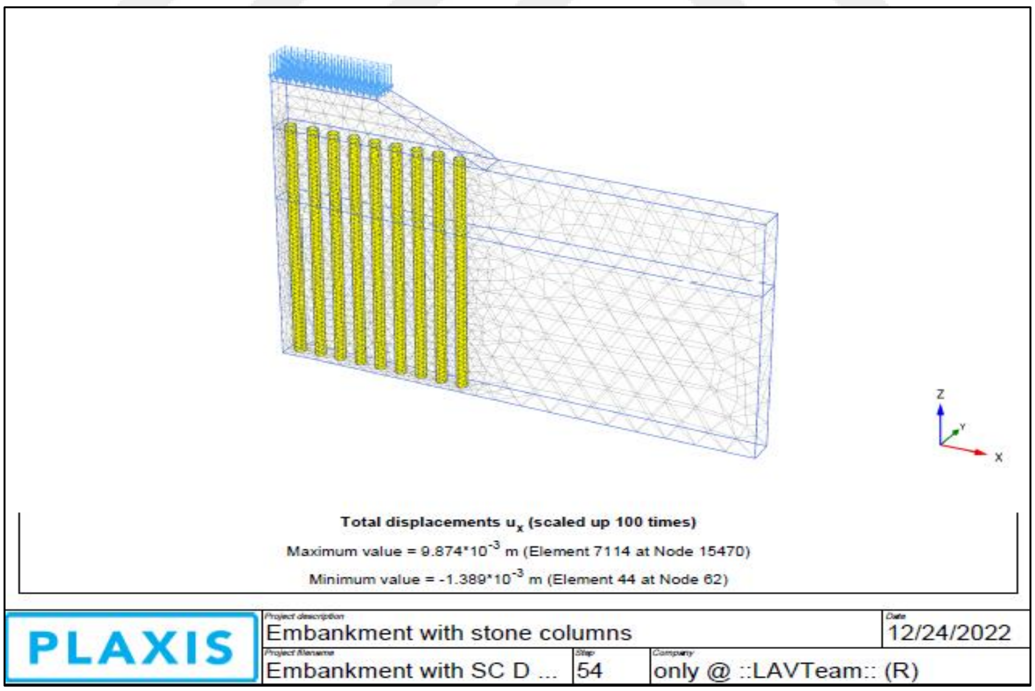


Figure 4.21: Show Embankment with Stone Columns.

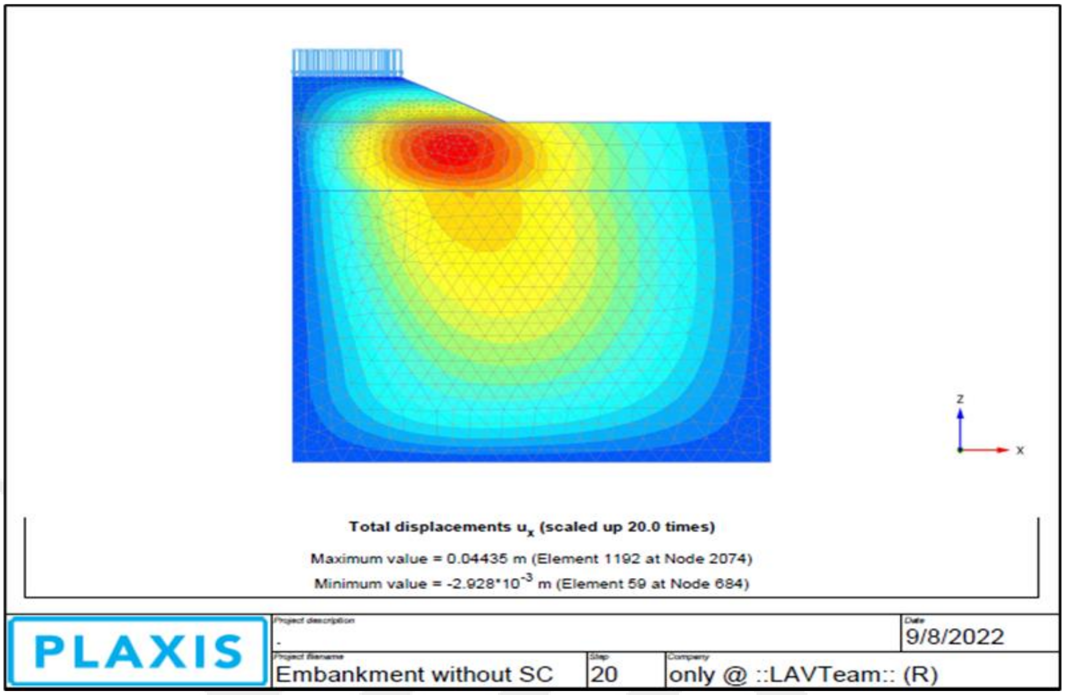


Figure 4.9: Show Embankment Without Stone Columns.

B. Vertical Pressures

The addition of the geogrid layer led causing a rise in the vertical pressure by(61) %. For loading and (50) % for constriction. By looking at Figures (4.24) and (4.25) shows settlement value constriction and loading embankment ،it can be proven that the addition of the geogrid layer to the embankment by the stone columns slightly increases the vertical pressure and the stress is transmitted to the stone column. The vertical pressure on the central stone column. The variation of the vertical pressure keeps the underlying soil increasing, meaning, that the increase is not as much as the increase of the piles, because a lot of pressure is transmitted to the stone columns because of soil curvature. Due to the presence between the stone columns was soft foundation soil, the soil between the stone columns will tend to settle more than the one directly above the stone columns. This load is transferred by a mechanism called soil curvature. Figure (4.23) show embankment without stone columns. Figure (4.16) show embankment with stone columns. Table (4.7) shows the results of analysis.

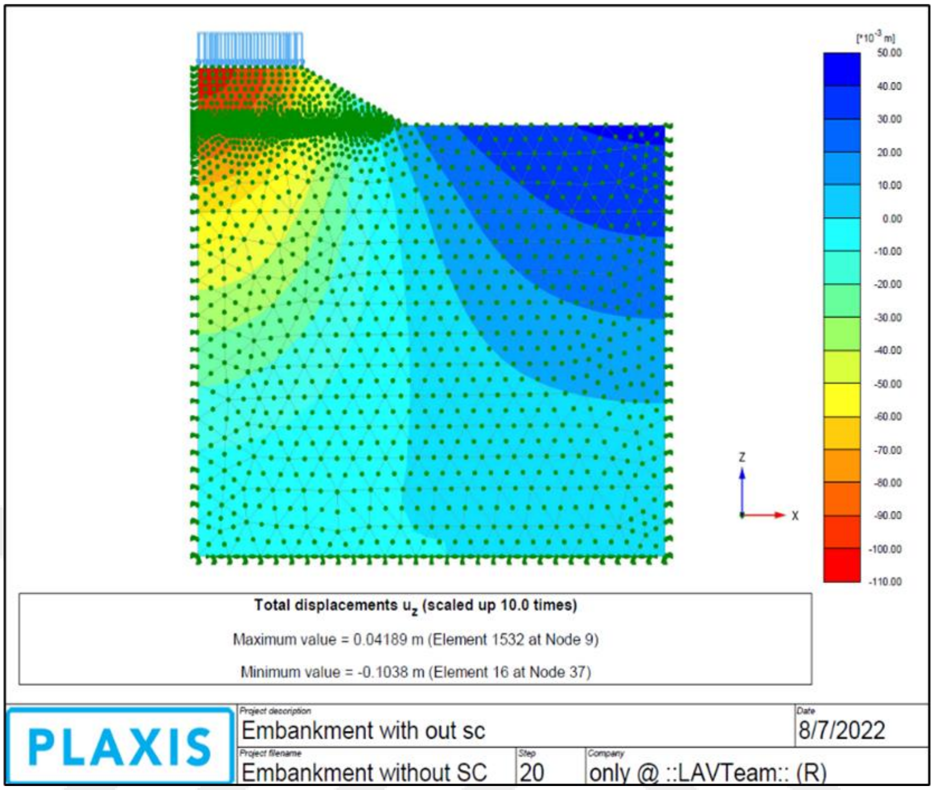


Figure 4.10: Show Embankment Without Stone Columns.

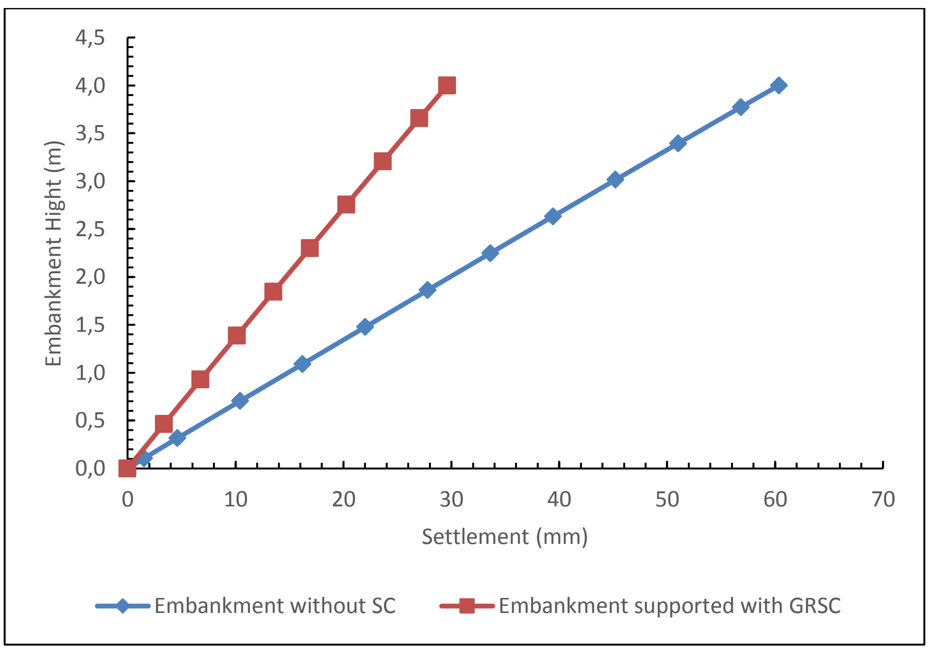


Figure 4.11: Show Settlement Value Constriction Embankment.

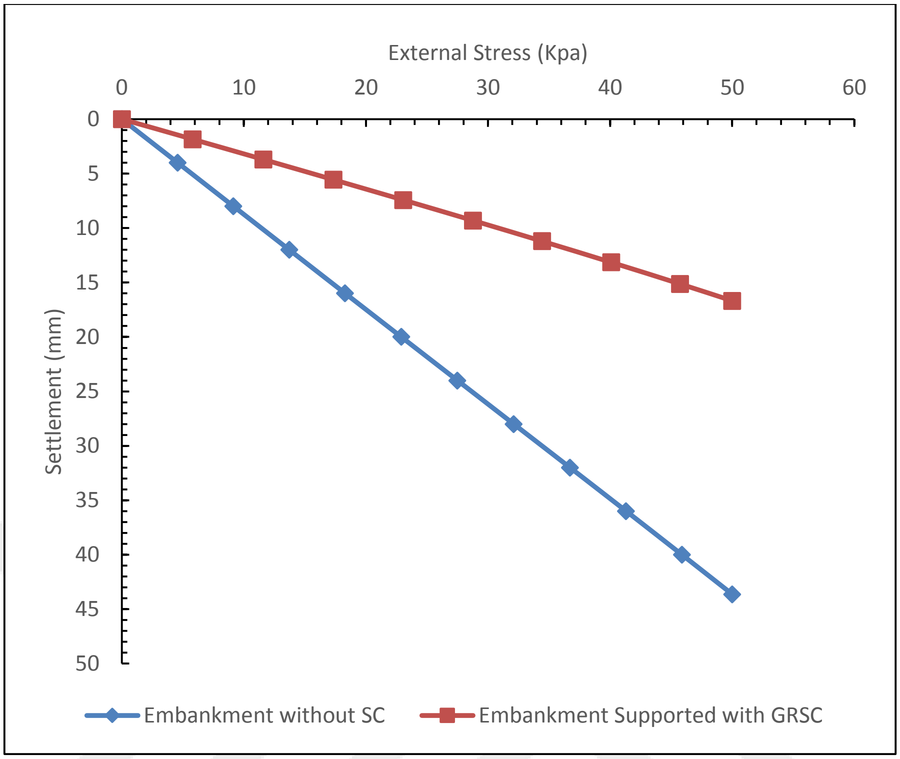


Figure 4.12: Show Settlement Loading Value.

Table 4.7: Shows The Results of Analysis.

Model	**Embankment without stone Column**	**Settlement (mm)**	**Embankment with stone column**	**Settlement (mm)**
(0.5B+4H)	high (0-4) Embankment	60	(0-4) high Embankment	29.6
	(0-50) Kpa Stress	44	(0-50) Kpa Stress	17

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this study, the (FEA) program used the PLAXIS3D model, and several analyses were carried out FEA and horizontal displacement values were obtained, vertical displacement and the safety factor. The FEA interface model was also presented to predict the behaviour of soft clay soils supported by stone columns under loads and construction. The embankment is designed over the natural soil numerically first without improvement on the soil. A comparison was made while using geogrid with stone columns, as well as when not using stone columns. With the results of the numerical modelling analysis of the bases reinforced by the geogrid for the embankment of a flexible paved road, the following conclusions can be drawn:

a) The reinforced embankment was made of geogrid and had a side slope of 1:1.5 relying on the parametric research., a type (GGIII) soil reinforced with four layers, which was selected and considered as the most effect in the improvement.

b) The lateral deformation performance of the geogrid-reinforced embankment is that the horizontal displacement of the reinforced embankment has been improved by about (40.8%) to the unreinforced embankment in the phase of loading and (45.2%) the improvement in the phase of construction, therefore the geogrids reinforcement leads to some reduction lateral displacements within the embankment and the underlying layers.

c) Increase in soil stability when the suitable geogrid is used to strengthen it, the vertical displacement of the reinforced embankment was improved by (18.1%) than the unreinforced embankment in the phase of loading, and the improvement in the phase of (15%) for construction.

d) The reinforcement under the embankment can be used to reduce vertical and horizontal displacements, but it is more effective in reducing horizontal displacements. The decrease in the displacements obtained is a function of the shear strength and the depth of the fine clay layer.

e) High vertical displacements due to load transfer by the curvature.

5.2 RECOMMENDATIONS

Based on the results of the study, which used a finite element model of a reinforced embankment to simulate a large-scale reinforced soil embankment and compare the results, the effects of some key design criteria have been looked at in detail, but there are still important points to talk about, like the hardness of the material, its strength characteristics, and the effect of the pavement structure. The spacing of the stone columns, a study of how static load affects how the stone columns behave.

5.3 FUTURE STUDIES

a) Studying the impact of stone column distance, length and diameter on improving embankment deformations

b) Studying the effect of the model used to represent soft clay soil and gravel soil of an embankment on the results of the analysis and comparing them with practical or laboratory studies

Verify the effect of dynamic load (machine vibration or seismic load) on the behaviour of the reinforced stone column.

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