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NUMERICAL SIMULATION OF DIFFERENT METHODS FOR ROAD EMBANKMENT STABILIZATION

Marwa Abdulkareem Mohammed AL-DULAIMI

Master`s Thesis

Supervisor

Asst. Prof. Dr. Mohsen SEYEDİ

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The thesis titled NUMERICAL SIMULATION OF DIFFERENT METHODS FOR ROAD EMBANKMENT STABILIZATION prepared by MARWA ABDULKAREEM MOHAMMED AL-DULAİMİ and submitted on 12 /04 /2023 has been **accepted unanimously** for the degree of Master of Science in Civil Engineering.

____

Asst. Prof. Dr. Mohsen SEYEDİ

Supervisor

Thesis Defense Jury Members:

Asst. Prof. Dr. Mohsen SEYEDİ	Department of Civil Engineering, Altınbaş University	____________________
Assoc. Prof. Dr. Sepanta NAIMİ	Department of Civil Engineering, Altınbaş University	____________________
Asst. Prof. Dr. Kaveh DEHGHANIAN	Department of Civil Engineering, Istanbul Aydin University	____________________

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ABSTRACT

NUMERICAL SIMULATION OF DIFFERENT METHODS FOR ROAD EMBANKMENT STABILIZATION

AL-DULAIMI, Marwa Abdulkareem Mohammed

M.Sc., Civil Engineering, Altınbaş University,

Supervisor: Asst. Prof. Dr. Mohsen SEYEDİ

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After the increase in urban development and the expansion of the road network, having sufficient knowledge and information about the various methods of improving the current surface soils for use in various construction projects is an essential issue for a Civil Engineer. The technology for soil improvement is one of the most trustable and practical ways. It is economically viable to increase the resistance of soil, soil strength, soil permeability as well as to limit water absorption, control soil erosion, losing water, and soil settlement, Solid waste materials such as construction waste are used for this intended purpose with or without lime or cement. Disposal of these waste materials is essential as these are causing hazardous effects on the environment. Literature review was undertaken on utilization of recycling concrete aggregate RCA and geogrid materials for the stabilization of soils and same is presented here.

The purpose of this study is to determine total displacement value as well as the vertical displacement and the lateral displacement to numerically investigate the performance of geogrid and recycled concrete aggregate (RCA) in stabilizing road embankments. The stability analysis has been done by finite element method using PLAXIS2D V21 , in this study, five types of sequence modeling were performed. First, the road embankment is stabilized without any reinforcement The results were analyzed in the program, The modeling was for the other four models to investigate the stability of the reinforced embankments model by using geogrid, (RCA) recycling concrete aggregate change their position in the soil and analyzing the results to reach the highest compressive resistance and the best properties of the soil.

The result of this study from the lateral and vertical displacement graphs, the Recycled concrete aggregated, and geogrid models showed lower displacement than other models. The model with geogrid in the center and only Embankment showed the worst behavior. The effect of using the geogrid does not depict much change.

Keywords: Road Embankment, Soil Stabilization, PLAXIS2D, RCA, Geogrid.

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ABBREVIATIONS

γsat	:	Saturated Unit Weight
$\gamma unsat$	:	Unsaturated Unit Weight
E	:	Young modulus
C	:	cohesion
φ	:	Angle Of Internal Friction
Ψ	:	Dilation Angle
SF	:	Safety Factor
$Stotal$	:	Total Settlements
Si	:	Immediate or distortion settlement
Sc	:	Consolidation Settlement
Ss	:	Secondary compression settlement

1. INTRODUCTION

1.1 RESEARCH BACKGROUND

As a result of recent urbanization and the increase in the volume of road traffic burden in Iraq, many roads embankment have been built on soft clay soil. This pattern is expected to continue. In this case, civil engineers face such usual difficulties as large settlements in road embankment and slope instability. There are different improvement methods in the literature to enhance the engineering properties of soils (e.g., [1]).Several studies have shown that terrestrial synthetic materials can be used as reinforcement in road embankment built on soft clay soil. The soil will be stabilized by geotextiles as well as concrete residues. Concrete is the most widely used man-made material, with concrete used twice as much as wood, steel, plastic, and aluminum combined. Due to its local availability, ease of configuration, durability, and energy efficiency, a person in many cases may need to modify or remove it, and disasters and conflicts can often lead to the appearance of large amounts of waste that have a negative impact on the surrounding environment. This topic acquires exceptional importance for countries suffering from wars and crises.

Which produces tons of construction and demolition waste. Building demolition products are considered a type of waste, and there are no global statistics on the amount of waste in the world, including building demolition waste, but they usually range from 20% to 80% of the total amount. The amount of waste generated by facilities and building demolitions is estimated at about 900 million tons per year in the United States of America, Europe, and Japan alone, and because of the liberation of areas, large amounts of damaged concrete are generated, and the products of building demolition are considered a type of waste, according to the statistics of the Central Bureau of Statistics on the amount of waste resulting from facilities and the demolition of buildings, which is about 8.2 million tons per year in Iraq.

Figure 1.1: Old Roads Problems[2] .

Geotextiles are increasingly being used to support road embankment in loose clay soils. Permeable synthetic geotextiles are permeable synthetic geotextiles made entirely from building material waste, according to ASTM D4439. The main objective of this study is to provide reinforcement in road embankments to modify the optimal tensile strength of geotextiles or concrete residues, taking into account the permissible safety and displacement factors. Finite Element Bridge Stability Analysis Performed Using PLAXIS2D Version 21 [2,3].

1.2 ROAD EMBANKMENTS

The construction of road embankments of varying heights is ongoing. Typically, embankments are built over somewhat incompressible soft soil consistency that must be altered to lessen the hazards of a slope sliding both internally and in terms of overall stability. The landslide might have been triggered by embankment weights, slope embankments, or traffic loads across road embankments. According to experience and observations, slope instability manifests itself in most cases as a sliding mass of soil, the sliding body, on a straight or curved sliding surface. due to top pressures and limited soil strength, especially in fine-grained soil [5].

Figure 1.2: Road embankments [6].

An opening crack forms, which appears as a scarp on the surface depending on the direction of motion. The appearance of such a crack is a strong sign of slope instability in its early stages. The crack appears to be extending through the new sliding surface. A landslide is defined as the area surrounding the sliding body and its surroundings. Slope slips can happen fast, with significant displacements arriving in a short period of time, after which the sliding mass remains in the new equilibrium position. Sliding, on the other hand, can be risky. a time-consuming and complex process that occasionally influences changes in the form of the landslide [4].

1.3 EXECUTION OF EMBANKMENTS FOR THE ROAD

Earthworks are divided into road construction projects for: [7]

a. Excavation work

b. Backfill work.

The excavation and backfilling work to build a road are variable in their quantities according to the required road level and in the following cases:

i. Either drilling is done to reach the required level.

ii. Or an earthen ramp or embankment is constructed (and at a variable height according to the areas, there must be a balance between excavation backfill the work section earthen.

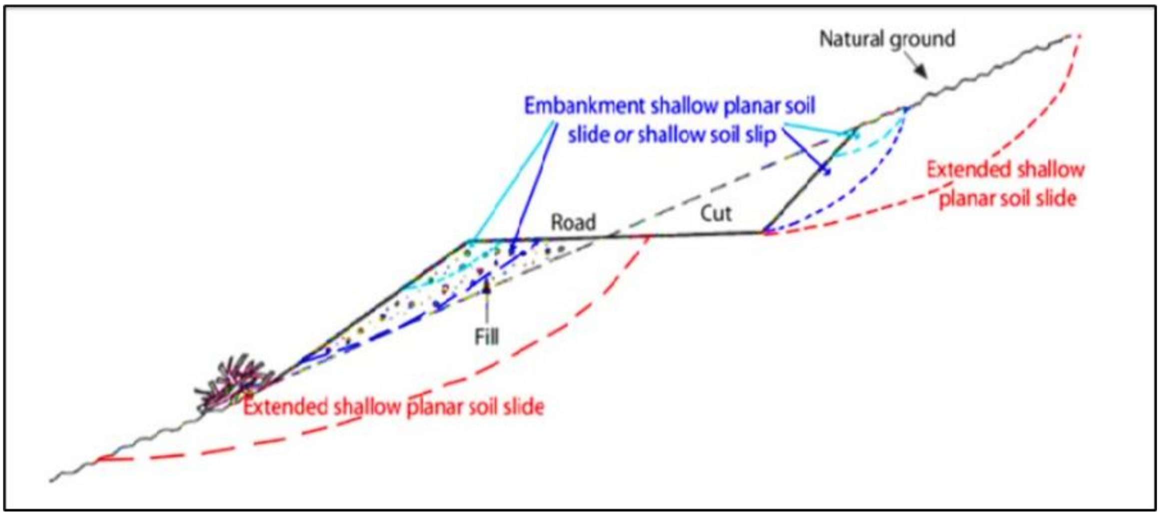

Figure 1.3: Cut & Fill of Road Embankment [8].

1.4 EMBANKMENTS AND SOIL COMPACTION

For the purpose of raising the road embankment level to a certain level, [9]

a. The surface soil should be scraped with a thickness of about 15 cm to remove traces of plants and organic matter and to reach a layer of soil with good tolerance.
b. After that, the soil that will be used in the backfilling work is spread, and it must be clean, free of organic matter, and have suitable engineering properties.
c. The clay soil mixed with a small percentage of sand, as well as a mixture of gravel and natural sand from soils suitable for this purpose.
d. Backfilling is done by brushing layers of soil with moisture content specified with a thickness not exceeding 15 cm (after stacking).

The main purpose of soil compaction is to give it a certain strength and make it capable of resisting the loads imposed on it by an acceptable amount of compression. Therefore, the soil must be of good quality and with a certain humidity close to what is called "moisture with dry density." Optimum and compact until obtaining the required density, which is measured. Also, A unique laboratory test determines the optimum moisture and dry maximum density for each type of soil. On the site, 90-100 percent of the dry maximum density is determined according to the type of origin and its importance. It is carried out in large and wide areas, such as yards. Roads and airports use large tractors to compact the soil, such as:[10]

i. Rollers with flat steel wheels.

ii. Lamb's ribs
iii. Axles with rubber tires

1.5 ROADS, ROAD PLANNING AND EMBANKMENTS WORKS

Roads are classified according to their importance, capacity, and uses. Know the different parts and elements that make up the road. Determine the factors by which the engineering design of the road is affected, and know the foundations and steps of the engineering design of roads [11].

a. Highways

   They are arterial roads dedicated to serving longitudinal transit between medium cities and major cities, in which high speeds of vehicles are allowed and the volume of traffic is very high, and surface intersections with these types of roads are often prevented, as well as direct contact with neighbouring properties, and entry is determined.

b. Main roads

   They are arterial highways that are used for longitudinal transit between different regions and cities and where surface intersections and direct contact with neighbouring properties are allowed.

c. Streets of assembly

   These roads are used to connect the main road networks with the local streets.

d. Local streets

   They are methods that are mainly used to serve local traffic and to connect the sites of housing, businesses, or neighbouring properties.

1.6 TRAFFIC VOLUME MEASUREMENT

The number of cars that travel past a particular location or station along a roadway throughout a given amount of time is used to calculate the traffic volume on that roadway. It is considered to be one of the primary variables that determine the engineering design of roads, provided that it takes into account both the existing traffic volumes as well as the anticipated traffic volumes in the future [12], The volume of traffic is not the same as the traffic density, which refers to the number of cars moving along a roadway at a specific distance from the roadway [13].

1.6.1 Concepts for Structural Design of Roads

a. Annual average daily traffic volume (ADVT) daily average annual traffic volume It is calculated by dividing the number of cars that travel through a specific piece of road in a year by the numbers of the days in this year [11].

$$\mathbf{AADT = Total\ traffic\ volume\ passing\ through\ the\ year\ /\ 365} \qquad (1.1)$$

b. The average daily traffic volumes are the number of vehicles that pass through a specific section of the roads in a period greater than a day and less than a year divided by the number of measurement days.

$$\mathbf{ADT = Total\ measured\ traffic\ volume\ /\ number\ of\ measured\ days} \qquad (1.2)$$

c. Design throughput It is the amount of traffic that was considered when two-lane roads were being designed and is typically expressed as a percentage of either the average daily traffic volume in the year AADT or the average daily traffic volume ADT.

$$\mathbf{DHV = K.AADT = K.ADT} \qquad (1.3)$$

Where: K= (0.15 - 0.2)

$$\mathbf{no\ of\ lanes = DHV/Capacity\ of\ lane} \qquad (1.4)$$

Table 1.1: Road Capacity According to AASHTO Specifications [14].

Road type	Capacity (private car / hour
Highway	2000 (per lane)
Two lanes road	3000 (total in both directions)
Three-lane Road	4000 (total in both directions)

d. Directional Distribution Coefficient direction distribution factor (D)l

$$\mathrm{Maximum\ traffic\ volume\ in\ one\ direction\ /\ traffic\ volume = total\ D\ in\ both\ directions} \qquad (1.5)$$

1.7 ROAD EMBANKMENT STABILITY

It's the final layer to which surface loads are transmitted. The earthen foundation layer is usually the exposed natural soil at the formation level. Sometimes the soil properties are improved by sand or stabilization, or the soil is also replaced with other soil with better properties supplied from another site. (This step will be explained in detail in chapter two). The role of the earth dictates Taking care in preparing the soil of the path well helps to establish it-in addition to its role as a carrier soil, the following [15].

a. Giving a homogeneous surface to the sub-base layer and thus achieving a homogeneous surface in it.
b. Reducing workshop stops as a result of climatic changes such as rain and others.
c. Allowing better movement of light and heavy workshop mechanisms.
d. Protecting the earthen floor between the period of completion of earthworks and the period of building paving layers.

If the geotechnical properties of the water soil are not capable of meeting these requirements, it is preferable to treat and stabilize it by the well-known methods of adding asphalt or hydraulic bonds or using a chemical stabilizer[16].

1.8 TYPES OF SOIL TESTING FOR ROADS EMBANKMENTS

A site study is required to identify the soil profile before performing any type of soil testing on a road embankment. For road construction, subgrade soil quality is crucial. Soil classification, particle size distribution, moisture content measurement, specific gravity, liquid limit, and plastic limit tests are all part of routine road construction soil testing. Tests on soils for moisture content, particle size, and specific gravity are used to determine soil properties, such as the degree of saturation. Testing of the soil might be done on-site or in a lab. To assess the particle size and moisture content of each sample, laboratory tests should be performed on them. Soil Testing Methods for Roads Construction The numerous kinds of soil testing for pavement construction are as follows: The soil moisture content test is performed in a laboratory. It is represented as a proportion of the soil's dry mass to its water content [17] , Numerous soil characteristics, such as compaction, permeability, particle size, etc., are represented by the moisture content of the soil. [18].

a. The weight of soil in a given volume of air at a particular temperature divided by the weight of distilled water in the same air at the same temperature is known as the specific gravity of soil. This examination is also performed in a lab.
b. Small Particle Dispersion (By wet sieving & pipette method) This test measures the soil's particle size distribution, which spans from coarse sand to fine clay. The results of the particle size distribution test are used to assess the soil's appropriateness for various

projects, including the development of airports and roads. This test can be used to forecast soil water flow, even though permeability tests are more frequently utilized.

c. Exam proctor - compact the maximum dry density is obtained at the ideal moisture content according to the Proctor test, which measures the mass of dry soil per cubic meter when the soil is compacted throughout a range of moisture contents. As a result, this test illustrates how different soils' compaction properties change as their moisture content does. Densifying the soil by removing air pockets does this. The dry density of the soil determines the degree. The dry density is greatest at the ideal water content.
d. CBR Exam (California Bearing Ratio) The California Bearing Ratio test is performed in a laboratory setting. This test measures the soil's resistance to load penetration. The CBR value is calculated when a cylindrical plunger is forced to penetrate the soil at a specific rate by examining the connection between force and penetration. Road and pavement subgrade strength is evaluated using the CBR test. The thickness of the pavement and its individual layers are calculated using empirical curves and the CBR value from this test. The most popular technique for constructing flexible pavement is this one. Even if installing subsurface drains reduces the impact of water on the subgrade, thoroughly saturated CBR testing is still advised for road-building projects. The following factors should be considered while doing soil testing for road construction.

Testing and sampling: An expert engineer must carefully sample soil for laboratory or in-situ testing. The specification and standard codes must be followed for varying mass and volume of soil at different places of a road project, all soil samples and test data must be logged by qualified personnel who are familiar with soil attributes and test findings. Testing Frequency: The soil testing frequency must determine by engineer input. The choice of the frequency of testing is generally made based on the results of prior tests.

1.9 ANALYSIS ROAD EMBANKMENT STABILITY

The problem of premature collapse in the flexible sidewalks is one of the main problems that failed in the paving layers because of its direct impact on the design life and performance of the Iraqi road network due to the excessive loads of uncontrolled load vehicles and the failure to operate weighing stations at border ports and city entrances and near quarries and sources of building materials [19].

The mechanical-experimental method is, based on the evaluation of stresses, strains, and deformations generated in flexible asphalt layers at each design stage. It is one of the most important and widely used asphalt pavement design methods. In Iraq, the road system is in a critical condition, not only because of the excessive traffic loads but also because of environmental conditions such as temperatures, where temperature changes not only lead to shrinkage of materials but also lead to a change in the properties of the viscoelastic materials of the asphalt mixture. Unfortunately, most practitioners do not currently take any of these phenomena into their design [20],paving structures. Therefore, the effects of traffic loads were studied: high on the permanent damage represented by the failure of exhaustion and erosion of the layers; flexible paving with viscoelastic properties; and analysis of the damage generated to determine the design life of the paving.

1.9.1 Analysis of Road Embankment Under Overload

The road design accounts for the influence of soft subsurface cumulative settling because vehicle overloading can result in a severe cumulative settlement. Keeping loaded vehicles under control is essential to reducing cumulative settling. It has been demonstrated that when vehicle loads grow, cumulative settlement of embankments accelerates. The cumulative settlement rises 33% greater when the vehicle load is between 0 and 40 kN than when it is 200 kN. This indicates that vehicle overloading can result in significant cumulative subsoil settling, causing structural damage to embankments and pavement. To decrease cumulative settlement and lengthen the lifespan of the road, it is crucial to reduce the number of cars that are overloaded. When compared to settlement caused by the dissipation of cumulative pore pressure, the undrained settlement caused by traffic loads accounts for the majority of the total cumulative settlement. [21].

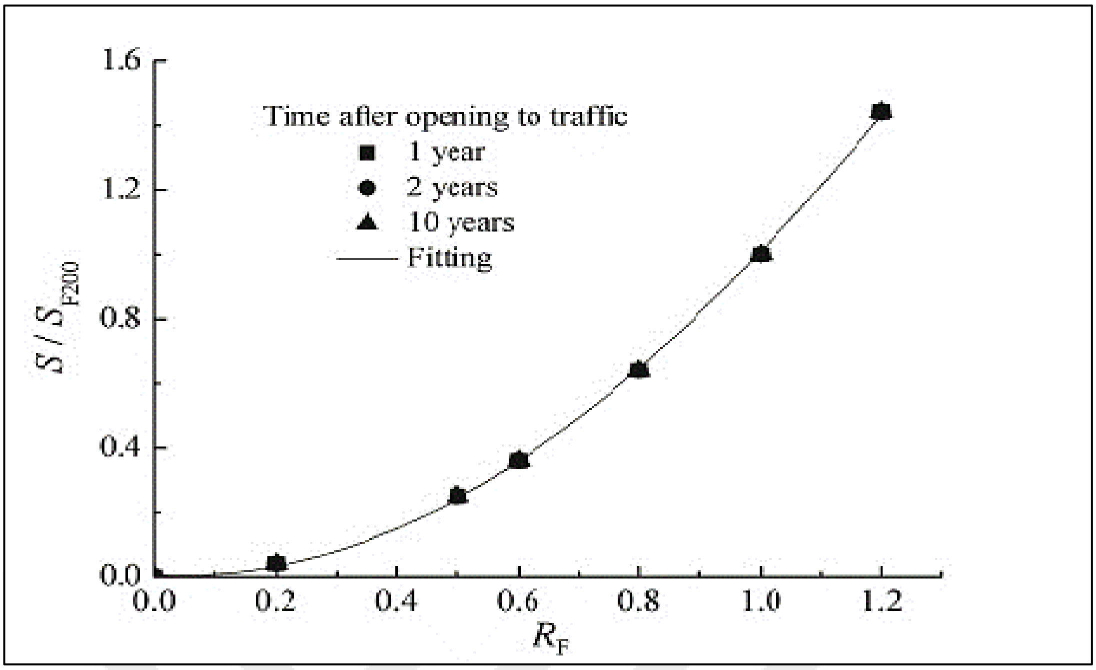

Figure 1.4: Damage Effect Due Temperature and Traffic Loading [22].

1.9.2 Damage Effect Due Temperature and Traffic Loading

The behaviour of coupled thermal loading conditions and traffic volume in relation to rutting damage on flexible pavement at high temperatures. The results demonstrated that both heat and traffic loading conditions had a substantial impact on the rutting damage to flexible pavement, with greater temperatures causing, respectively, deeper ruts in the asphalt layer, base layer, and subgrade layer. Heat and traffic load coupled to produce vertical strain inside the flexible pavement. The road's resistance to rutting failure is reduced when traffic and heat are present. Increasing the local temperature on the flexible pavement's surface to about 45 C decreases the maximum number of repetitions necessary to induce rutting by roughly three times less than the model of traffic loads alone. High temperatures and traffic loads can influence the resilience of flexible pavement to rutting. [22].

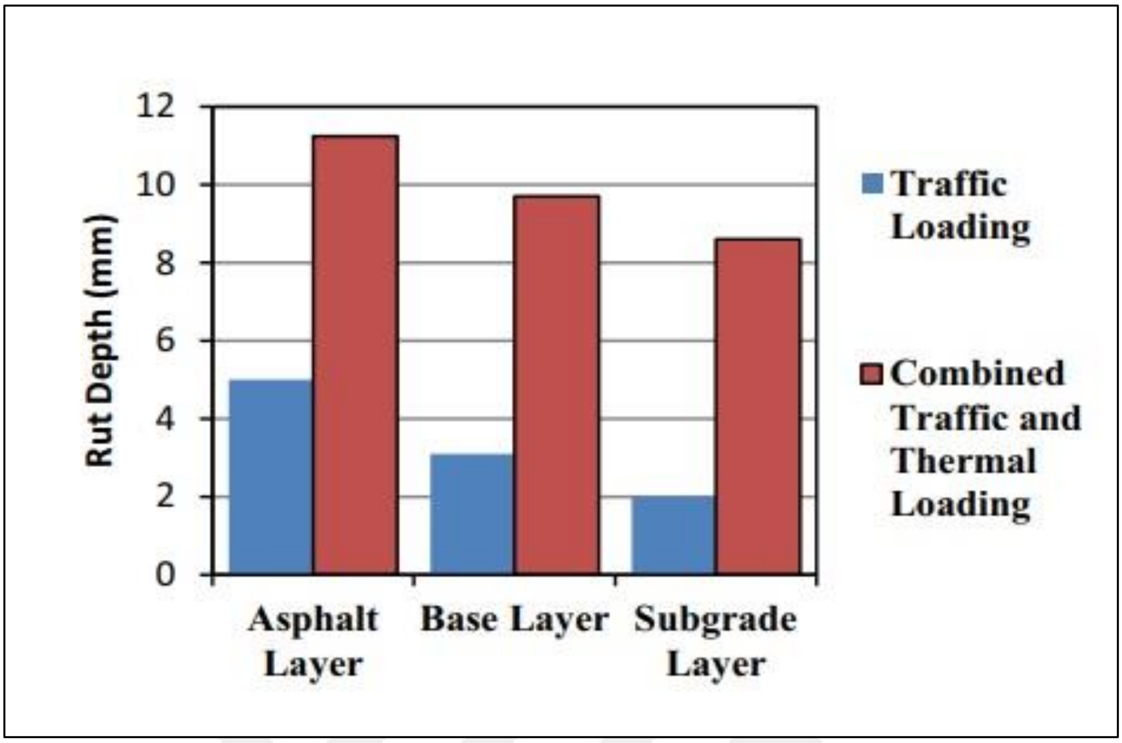

Figure 1.5: Damage Effect Due Temperature and Traffic Loading [22].

1.10 GEOGRID

A long-standing practice is soil improvement. In Mesopotamia, not far from the modern city of Baghdad, the Sumerians under King Kurigalzu I built the temple of Aqar Quf some 3,500 years ago. They realized that masonry and soil had very little tensile strength and that reinforcing components were needed to bring tensile stresses into their constructions for stability, therefore they used reed mats to reinforce the foundations and brick walls. It's worth noting that the Romans used a precursor to modern concrete called Opus Cementitious to construct the Pantheon over 1500 years ago [23].

Since the 1970s, road and rail construction has used nonwoven and woven textiles to separate weak, fine-grained subsoils. They prevent coarse granular material from mixing with finer-grained subsoil during base course construction. Like tie rods, they minimize soil deflection and sinking. Geosynthetic stiffness is important. The bigger the impact, the stiffer the geosynthetic. Composite materials made of nonwoven fabric and a genuine reinforcing component, like a geogrid, reduce settlements. High-strength geogrids allow the construction of 10-meter-high slopes. Geogrid soil reinforcement is a network of integrally linked polymer tensile components with large holes (greater than 0.25 inches) that mechanically interlock with the surrounding soil, aggregate, or other material. The geogrid reinforcements' structure must be dimensionally stable and able to preserve its geometry during construction loads, as well as resistant to construction damage, ultraviolet deterioration, and chemical and biological degradation in the reinforced soil [24].

Due to their consistently strong and great performance, simple and dependable application method, extended durability, and variety of solutions they may offer the usage of geosynthetics in transportation engineering projects are unavoidable nowadays. Geogrids are the most effective at strengthening soil. Geogrids are mostly utilized in transportation engineering to strengthen earth structures, resulting in increased bearing capacity and decreased deformability. The word "stabilization" was just formally established in geosynthetic engineering. This word is welcome because it distinguishes the scenario in which lateral (and vertical) deformations are restricted from the situation in which tensile tension ensures force balance (reinforcement). The following are the definitions of reinforcement and stabilization:

Reinforcement is defined as the use of a geosynthetic material's stress-strain behaviour to enhance the mechanical qualities of soil or other building materials.

Stabilization means improving the mechanical characteristics of an unbound granular material by including one or more geosynthetic layers to limit deformation under applied loads by decreasing soil particle mobility.

1.11 WASTE CONCRETE (RECYCLED CONCRETE AGGREGATE (RCA))

Concrete is the most used man-made material ever, as concrete is used in an amount equivalent to twice the use of wood, steel, plastic and aluminium combined.

Concrete is also an ideal material for construction because of the availability of its raw materials locally, ease of formation, durability and efficiency in the use of energy, but often a person may need to modify or remove it, Disasters and conflicts often result in significant volumes of waste that have an adverse effect on the environment, hence this topic attaches special importance to nations that experience wars and crises that generate tons of construction and demolition garbage.

Because of the liberation of areas, large results are generated from damaged concrete, and the products of building demolition are considered as a type of waste, according to the statistics of the Central Bureau of Statistics on the amount of waste resulting from facilities and the demolition of buildings by about 8.2 million tons annually.

Table 1.2: Recycled Concrete Aggregate (Ton/Year) [25].

Amount of waste	2017	2018	2019
Demolition and construction waste (tons/year) (RCA)	8.2	5.9	7.3
General Waste	53.1	61.1	60

Concrete presents several issues, mostly due to two factors. It is demanding to reuse, hefty, tough to carry, and difficult to smash. For various applications, different fractions (particle sizes) may be utilized. Starting with very small particles that can be utilized in the manufacture of concrete, moving on to regular fractions of 16–300 mm used to create new fills and fill the matting, and finally reaching very irregular combinations used to create stone columns using Impulse Compaction or Dynamic Replacement[26].

1.12 PROBLEM STATEMENTS

Due to the urban development and high traffic in Iraq, it has become necessary to establish an organized and extensive road network to control the population inflation that is occurring in the country, as well as to design roads and implement higher requirements, In this case, as a result of the expansion of the road construction network, as well as the large amount of concrete waste resulting from the liberation of Iraqi cities and the extensive reconstruction movement that the country is witnessing, road engineers tend to localize onto use local soil in road construction or a layer under the foundation, which often leads to grooves and deformations in the road due to the weakness of the load-bearing soil of the road as shown in Figure 1.5, and given that the use of improved or good soil transferred from other places may increase the cost of the road, it was necessary to use materials that help improve the performance of these roads and reduce the cost of construction and maintenance.

Figure 1.6: Cracks on Road [20].

1.13 OBJECTIVES AND SCOPES

a. To evaluate road construction performance based on time and cost.
b. To determine the time and cost involved in road construction projects, with a special focus on the use of software and analysis of results.
c. To analyze the stability of the soil by determining the relationship between the use of soil additives to improve its properties and reach the best stability state.
d. Achieve the best soil stability by analyzing the results before starting the implementation of the road on the ground.

1.14 THE PURPOSE OF THE RESEARCH

The problems of the road network are many and complex, and they require a large number of studies and research. This research is a modest contribution in the context of finding some practical solutions for a small part of it. This research focuses on the following points:

a. Clarify the importance of using geotextile networks as well as additives such as concrete waste in strengthening flexible pavement layers in paved roads. By studying the areas of stresses and deformations in road pavement layers, geological networks and additives play an important role in strengthening flexible pavement layers in paved roads.
b. The effect of placing the geotextile reinforcement layer or the concrete waste layer inside the base layer of the soil dictates that one must reach the permissible boundary deformations.

1.15 THE AIM OF THE RESEARCH

The main objective of the research is to determine the optimal place to place the geographical network as a reinforcement layer or the concrete waste layer, or both together, within the flexible paving layers of roads and to study the impact of natural soil durability on the contribution of the geographical network and the concrete waste layer and the limits of the geographical elasticity modulus that contribute to reducing vertical deformations.

1.16 RESEARCH CONTRIBUTION

a. Using soil reinforcement related to the topic of this thesis to apply best method of road embankment stabilization.
b. Reducing environmental pollution by reusing waste concrete to stabilize the soil.
c. We analyzed five models of road embankment and using two different types of reinforcement to reach the lowest displacement.
d. Achieve the best soil stability by use of local and available reinforcements, analyzing the models and get results starting the implementation before on of the road embankment on the ground.

1.17 ORGANIZATION OF THE THESIS

This study includes five chapters:

a. The first chapter is a general introduction, as well as the methods and their types, the effect of traffic loads on the stability of embankments (soft clay), and an introduction to geogrid and its use in soil stabilization.
b. Chapter two is an overview of:
   i. Flexible and rigid pavements layers and the function of each layer
   ii. Road embankments, embankment problems, and methods to improve embankment properties.
   iii. Geogrid, its functions, and mechanism of action.
   iv. Previous studies.
c. The third chapter contains a sectional analysis of the finite elements of a road embankment and includes:

i. Study the effect of geographic location within the gravel base layer.
ii. study of the effect of natural soil durability on the contribution of geogrids Concrete waste.
iii. Studying the effect of the geological elasticity modulus on improving performance.

d. The fourth chapter includes a presentation and discussion of the results. The fifth chapter contains the most important conclusions and recommendations for further studies in this field.

2. LITERATURE REVIEW

2.1 GENERAL

The use of paving layers in roads dates to the beginning of the construction of paving layers in the Roman era, about three thousand years ago. The process of paving roads developed significantly during the eighteenth century when the French and Americans used asphalt as a covering for granular materials. The design of layers of flexible paving on the roads was a very important factor in the great development in the size of the road network. And because of their diversity in terms of use, investment, loads, methods of design, and implementation, the study of roads was a great challenge to improve road performance and keep pace with the continued development of transportation under various conditions [16].

2.2 THE MAIN TYPES OF ROAD PAVEMENTS

Road Pavements are classified into two categories[27].

Figure 2.1: Type of Road Pavements [28].

2.2.1 Flexible Pavement

Vehicle load is conveyed to the subgrade via clinging contact of aggregate via the granular structure in the case of flexible pavements. These roads are flexible sheets with minimal flexural strength (as compared to bituminous roads). If rigid pavement, the flexural strength of the pavement transfers vehicle loads to the sub-grade soil, and the pavement functions as a rigid plate (as in cement concrete roads), mixed pavement, also known as semi-rigid pavement, is used. Hard pavement is covered with a thin layer of flexible pavement in this situation, resulting in the perfect pavement with the best attributes.[29].

However, because they are expensive and require extensive studies, these sorts of pavement combinations are rarely used in new construction. Grain-to-grain transmission through the granular structure transports wheel loads to the subgrade in flexible pavement. The wheel of vehicle load forces pressing on the layer pavement are scattered across a big larger area, and the tension decreases with depth. because of the weight distribution characteristics of the flexible pavements, it has numerous layers[30].

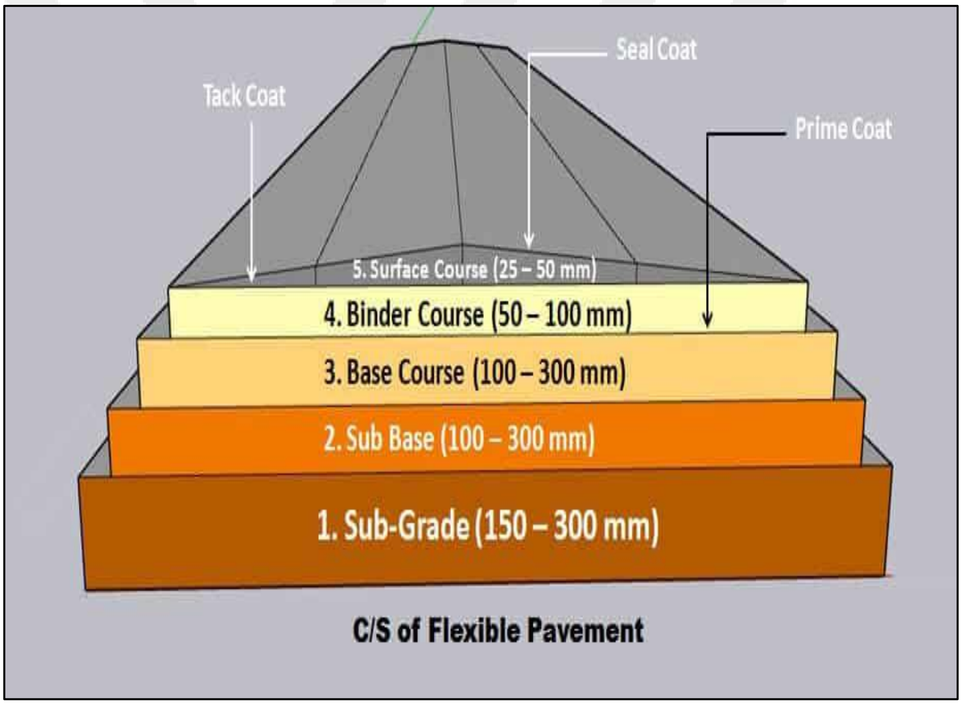

Figure 2.2: Layers of Flexible Pavement [31].

As a result, a flexible pavement design method employs a layered approach. This means that the flexible pavement needs to be of a higher grade in order to sustain both the maximum compressive force and wear and tear. Lower layers have a tolerable level of tension, allowing the use of inferior materials.

Bituminous materials are generally used in the construction of flexible highways. Defects in the flexible road may be seen on the lowest layer of settling's surface. When developing flexible pavement, the overall performance of the road is considered, and the stress levels should be kept considerably below the maximum permitted stress levels for each road layer.

2.2.2 Rigid Pavements

Rigid pavements have strong flexural strength and are used to distribute wheel weight over a larger surface. The layers of materials in the stiff pavement are not as thick as those in the flexible pavement. In rigid mode, it is immediately deposited on a subgrade that has been thoroughly compacted or a single layer of granular or stabilized material. The base or subbase course is named after the single layer that exists between the concrete and the subgrade [32] .

The road functions like an elastic plate resting on a viscous liquid as the load of the automobile traffic is transferred by slab action in stiff. It is constructed of standard cement concrete. Typically, plate theory rather than layer theory is utilized to investigate its design, with an elastic plate resting on a viscous foundation.

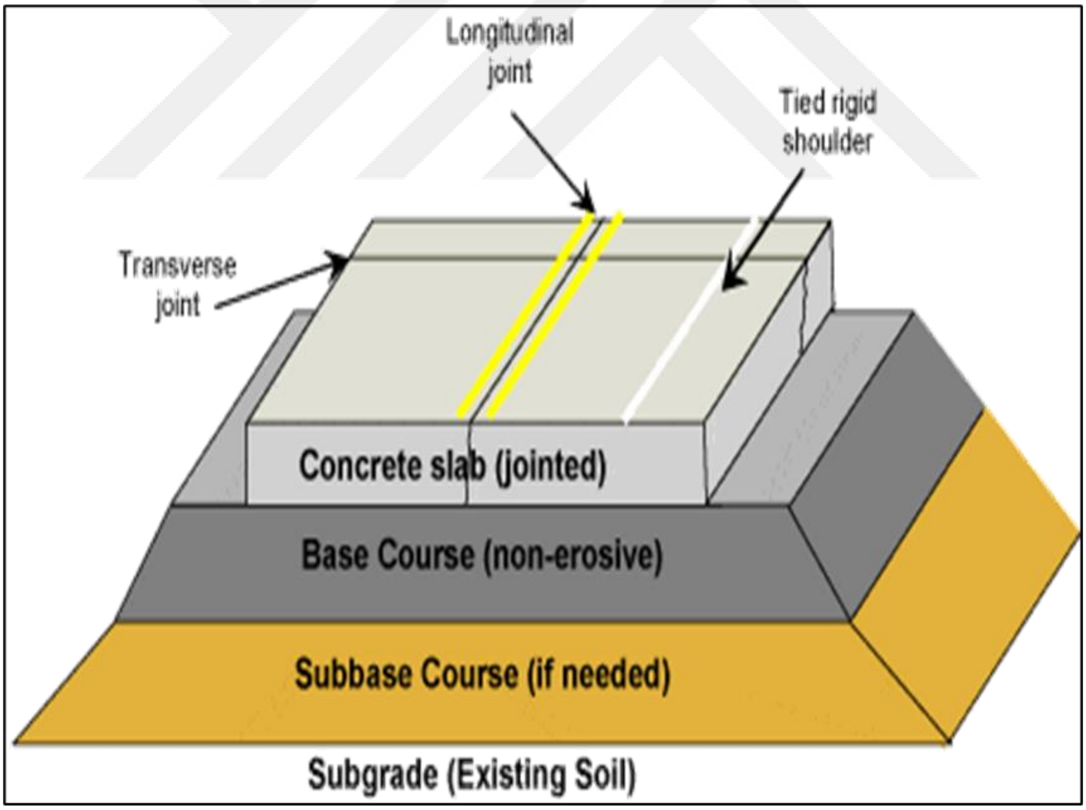

Figure 2.3: Layers of Rigid Pavement [33].

According to the plate theory, the road pavement slab is a medium-thick, plane plate that will stay that way after being loaded. Wheel load and temperature variations, as well as the consequent tensile and flexural stress, cause the pavement slab to bend.

2.3 ROAD EMBANKMENT

Building an embankment and filling it with acceptable material from reputable sources while adhering to these specifications as well as the lines, levels, grades, dimensions, and cross sections shown on the drawings, or as the engineer deems required, are all included in this task. There must be no sod, roots, or other potentially hazardous contaminants in any fill materials. All embankment materials must be approved by the contractor and engineer. Materials that must be rejected include those with a 4-day soaking CBR value of less than 3% when compacted to 95% of their maximum dry density.

a. The liquid limit of the soil fraction passing through the 0.425 mm filter must not exceed 50%.
b. The plasticity index of soil fractions passing through a 0.425 mm sieve must not exceed 25%.

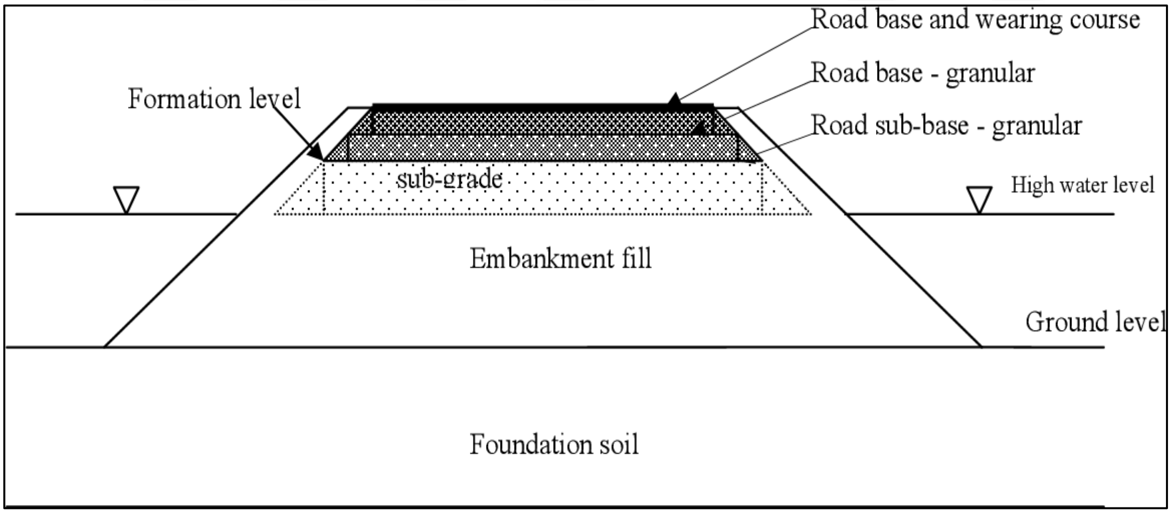

Figure 2.4: Road Embankments [34].

2.3.1 Construction Methods of Road Embankment

All clearing and grubbing works must be completed and excavation beneath carriageways must be carried out in compliance before putting any embankment on any land. The natural landscape should be altered as little as possible, except for levelling dikes, terraces, and abandoned ditches.

Embankments in wet areas must be constructed according to the plans and specifications, and any existing ditches or similar features must be filled up to the embankment. In the absence of specific instructions to the contrary from the Engineer, the Contractor shall excavate or otherwise displace marshland and replace the resulting void with river or beach sand.

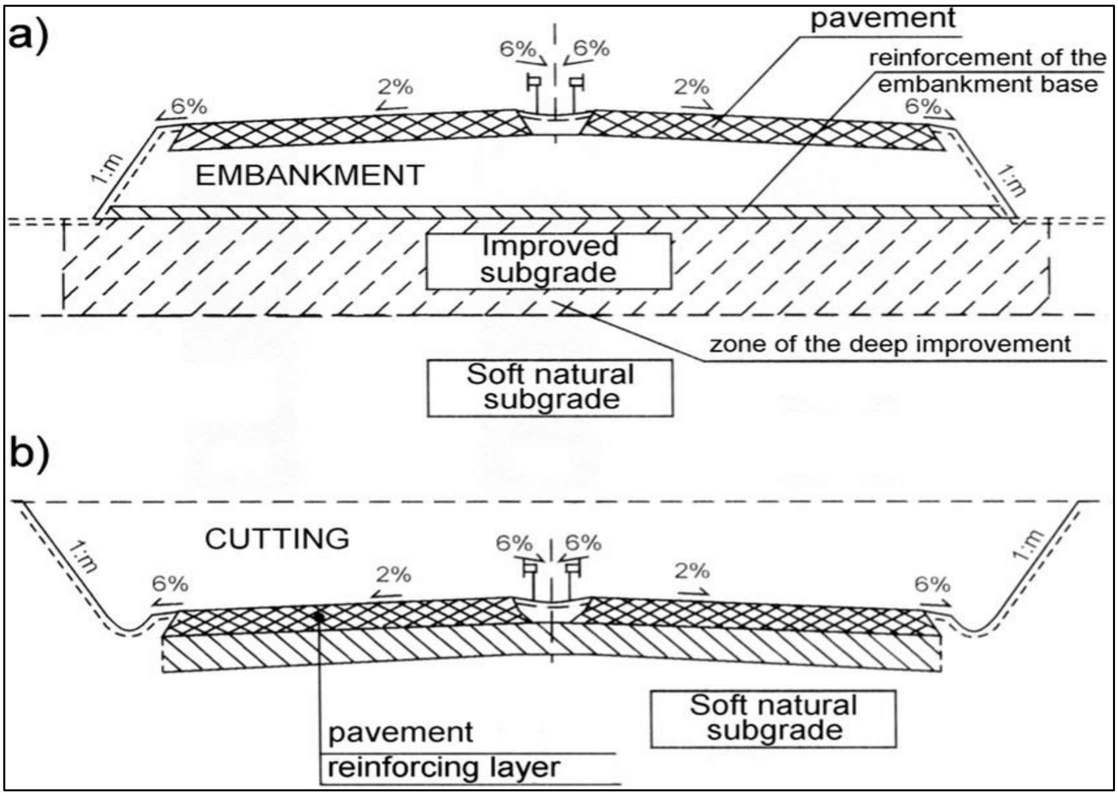

Figure 2.5: Construction of Road Embankments[35].

2.3.2 Compaction of Road Embankment.

The fill materials' moisture content must be less than 2% of the ideal moisture level, as measured by STP 4.3, before compacting (Standard Compaction). The dry density of the embankment should be greater than 95% of the initial objective after compaction. One density test will be conducted for every 1,000 square meters of a finished layer unless otherwise specified by the engineer. If tests show that the density is lower than required, the contractor must compact the area until it reaches the minimum standard. The engineer must sign off on each compacted layer before the contractor may move on to the next.

One Dynamic Cone Penetrometer (DCP) test for every 500 m of a finished layer may be utilized in place of the density test. The DCP test mm/blow shouldn't penetrate more deeply than 45 mm/blow in this case. Each layer must be combined with dry material or otherwise treated to bring the moisture content close to ideal before being compacted, allowing compaction to the necessary density. The material must be manipulated in such a way that the moisture content is consistent across the whole layer. With the use of adequate and appropriate compaction equipment, each layer of material must be consistently compacted. Along the embankment, compaction needs to be done longitudinally, beginning at the outside margins and progressing toward the centre in such a way that each section gets equal compaction force.

2.4 ROADS AND EMBANKMENT SOIL PROBLEMS

In road construction, challenging soil is any soil that influences the performance of a pavement due to induced stresses and strains generated by volume fluctuations in the subgrade components. Soils are soils that create extra engineering issues due to the circumstances of their composition or a change in environmental conditions[36].

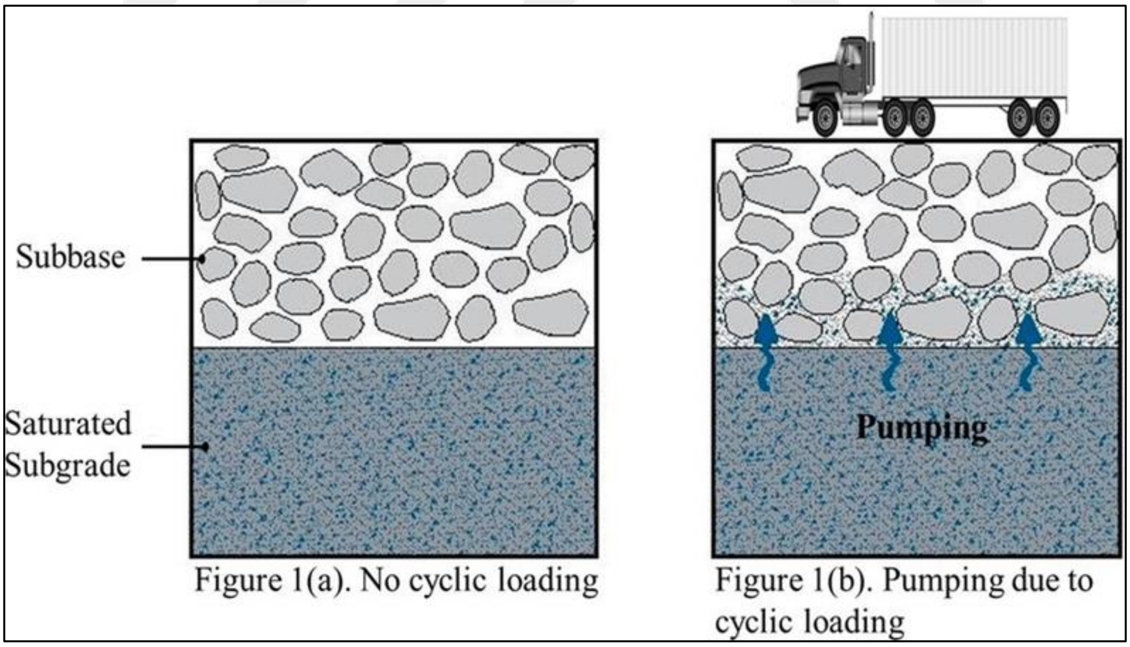

Figure 2.6: Load Analysis on Soil [37].

The Fairfax County code defines challenging soils as soils prone to landslides, shrinking, and swelling; soils with high water table conditions; soils containing hazardous materials, buried waste sites, uncompacted and undocumented man-made fills; and earthen structures requiring special precautions for safety during and after construction. Roads are a category of roads that form part of temporary and unpaved roads because of the lack of a long investment period, so the conditions required for the quality of materials that enter the structure of the paving layers are less stringent due to the cost and difficulty of securing high-quality materials. For roads and roads, the secondary is a layer of gravel placed directly on the soil of the natural soil, as shown in the figure below, where the gravel layer bears part of the load and transfers the other part to the soil, as shown in Figure 2.7.

So that the traffic loads move from the gravel foundation layer to the natural ground. Therefore, because of the traffic loads, sometimes excessive grooves appear on these roads that hinder the movement of machines when the grooves exceed the permissible limit, and a complete collapse may occur in the road structure, which may prevent movement completely, as in figure 13.

Figure 2.7: Settlement of Embankment Road [38].

2.4.1 Settlement of Embankment

New embankments, like practically any new building, increase the load on the underlying soils, causing them to settle. There are three potential components to the overall settlement:

1) immediate settlement, 2) consolidation settlement, and 3) secondary compression. All embankments will be examined for settlement. Even if the embankment has an appropriate overall stability factor, the significant differential settlement at the road surface might harm its performance.

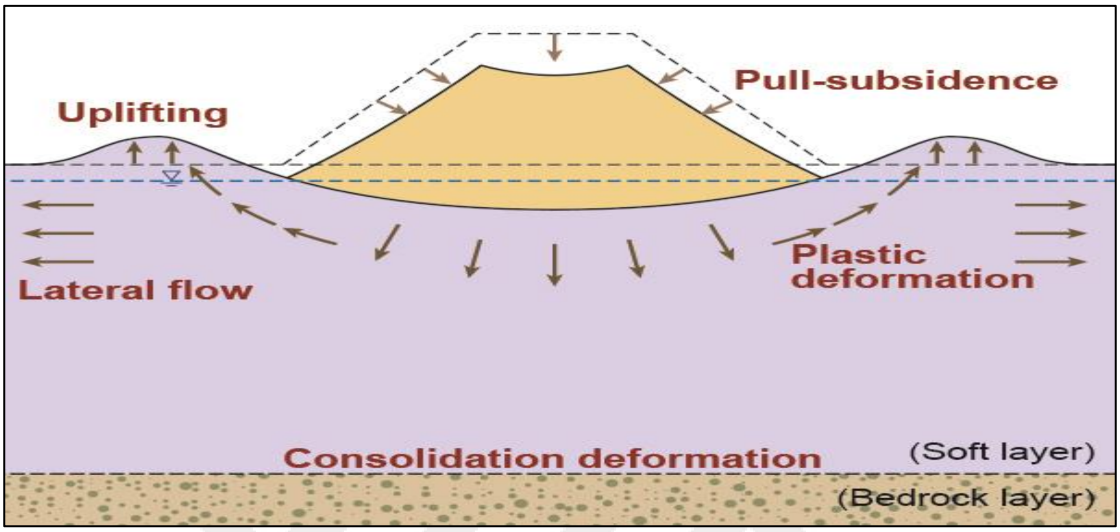

Figure 2.8: Type of Settlement[39].

The use of compression index values is essential when evaluating the settlement of embankments on soft soils. Fine-grained soils are the most typical source for these features, and conventional one-dimensional oedometer measurements are used to extract them. For granular soils, these values can be estimated empirically. At least three but ideally four points on the virgin consolidation curve should be used in oedometer testing, with the pressure increased to at least twice the reconsolidation pressure (i.e., at stresses higher than the reconsolidation pressure). The coefficient of consolidation value in the virgin curve may be 10 times higher than the experimental results at or below the reconsolidation pressure [40]. Settlement is the accumulation of movements in the direction of (vertical direction and is defined as (St) or (ΔH). Some settlement is inevitable and, depending on the situation, some settlements are tolerable. For structures like fills, road embankment, braced sheeting, and retaining walls, a larger tolerance for settlement error is typically acceptable. A larger margin of error in the settlements may typically be permitted for structures like fills, road embankment, braced sheets, and retaining walls.

2.4.2 Type of Settlement of Embankment

The estimation of vertical displacement is a fundamental aspect of a foundation or earth structure design. Typically, the total settlement of the foundation consists of three components:

a. Immediate or distortion settlement Si
b. Consolidation settlement Sc
c. Secondary compression settlement Ss

$$Stotal = Si + Sc + Ss \tag{2.1}$$

2.4.2.1 Immediate or distortion settlement Si

Soil's initial reaction to load is usually not elastic. (Fang, 1991)[41]. The calculation of immediate settlement is based on elastic theory and is derived from the non-elastic characteristics of soil. Consolidation and secondary compression settlement are phenomena that arise from the expulsion of water from the soil skeleton under compressive forces. During the period of consolidation settlement, the soil's load is borne by water, and this period persists until the excess hydrostatic pressure reaches zero. The conditions for secondary compression settlement are evaluated under zero excess hydrostatic pressure, as the soil framework bears the entire load under constant effective stress.

$$Si = Cs\, qB\, (1 - v\, 2\, /Eu\,) \tag{2.2}$$

Schmertmann [42] The author devised a frequently employed methodology for resolving issues related to coarse-grained soil, which was founded upon the subsequent observations .[41] This study examines the distribution of vertical strain beneath a uniformly loaded area at the surface of an elastic half-space.

$$\varepsilon z = (\Delta p/\, E)\, Iz \tag{2.3}$$

where Δp = intensity of the uniform load distribution, and Iz = strain influence factor.

The strain distribution in linear-elastic media demonstrates analogous behavior to that observed in nonlinear materials, contingent upon the displacement outcomes obtained from both finite element analysis and model foundation. According to Schmertmann, the settlement of coarse-grained soil is the integration of strain.

$$S_i = \Delta p \int_0^{2B} \frac{I_z}{E} d_z \tag{2.4}$$

Then, the settlement of coarse-grained soil can be computed from

$$\mathrm{S_i} = \mathrm{C_1 C_2 \Delta p} \sum_{\mathrm{i=1}}^{\mathrm{n}} \left(\frac{\mathrm{I_z}}{\mathrm{E}}\right)_{\mathrm{i}} \Delta \mathrm{z_i} \tag{2.5}$$

$$C_1 = 1 - 0.5 \left(\frac{\sigma_p'}{\Delta p}\right) \geq 0.5 \tag{2.6}$$

$$C_2 = 1 + 0.2 log \left(\frac{t}{0.1}\right) \tag{2.7}$$

Iz strain influence factor

E Young's modulus at the middle of the ith layer of thickness

$\Delta\ zi$ are correction factors.

($C1$ & $C2$)

$C1$ = correction for depth of the foundation

$C2$ = correction for creep or time-related settlement

Δp is net footing pressure.

Δz thickness of each soil layer

$\sigma\ '\ p$ effective stress at depth m

t is time from load application.

The settlement of the footing may exhibit a relatively smaller magnitude in coarse-grained soil in comparison to fine-grained soil. This settlement phenomenon can be attributed to two factors: (1) the shear strain that alters the shape of the soil following loading and (2) the volume change, which can either be dilation or compression. This can be expressed mathematically using the appropriate equation.

$$C1 = 1 - 0.5 \left(\sigma\ '\ p / \Delta p \right) \geq 0.5 \tag{2.8}$$

2.4.2.2 Consolidation settlement

The assessment of total settlement in fine-grained soil involves the consideration of consolidation settlement as its subsequent component. Applied loads are transferred to the subsoil, which causes a volumetric strain to increase relevance to the increase in pore water pressure. The expulsion of pore water from soil voids results in a reduction in volume that is dependent on the dissipation of pore water pressure and the consequent increase in effective stress. The analysis of consolidation settlement assumes that both strain and loading are confined solely to the vertical direction. The assumption facilitates the assessment of consolidation and is deemed rational for unidirectional loading, compression, and consolidation of soil with fine particles. The computation of consolidation settlement is contingent upon the soil characteristics and can be determined through various techniques. In cases where the soil deposit is in a state of normal consolidation, the formation of a structure under additional stress, denoted as $^{\sigma}$v0, is considered alongside the pre-existing vertical overburden stress, σ'vo, in order to calculate the consolidation settlement. The equation exhibits the consolidation settlement and void ratio variation of normally consolidated soil.

$$S_c = \sum_{i=1}^{n} \Delta s_c = \Delta e_0 \frac{H_i}{1+e_o} \tag{2.9}$$

$$\Delta e_0 = C_C \, log\left(\frac{\sigma_v' + \Delta\sigma_v}{\sigma_{v_0}'}\right) \tag{2.10}$$

where,

Cc compression index.

e_0 the initial void ratio at the middle of the i-th layer.

$\sigma v_0{}'$ initial vertical effective stress.

H clay layer thickness.

Δσv applied vertical stress by structure.

2.4.2.3 Secondary compression settlement Ss

In most soil types, secondary compression is a minor component of overall settlement and is considered insignificant when compared to consolidation settlement. However, it should be noted that secondary consolidation may hold greater importance for organic soils. (Holtz, Kovacs and Sheahan, 1981; Day, 1999). The secondary settlement of WTG systems is typically insignificant as they are typically erected on non-organic soil formations.

$$Ss = C\alpha \, Ho \, \Delta \, logt \tag{2.11}$$

Cα secondary compression ratio

Ho the initial thickness of the fine-grained soil layer.

$\Delta \, logt$ change in the log of time from the end of primary consolidation to the end of the design life of the structure.

2.4.3 Causes of Settlement in Embankment Roads.

a. The main advantage of soil compaction in road construction is that it reduces settlements caused by the consolidation of the soil. So, the bulking factor is normally between 25 and 35 percent, resulting in settlements in the future[43].
b. The size of the total voids in the soil body is reduced by compacting the soil particles well.

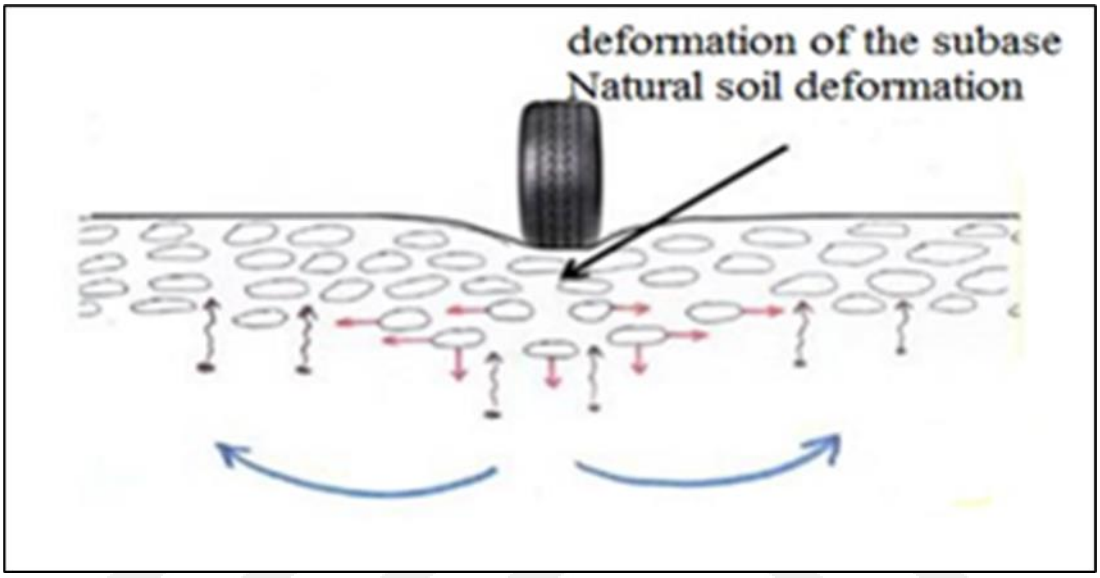

Figure 2.9: Deformation Transition From Subbase to Embankment [44].

Also, this change in the size of the voids in the soil has a clear and significant effect on the movement of water on the surface of the soil, as the well-compacted embankments will resist water entering them during rainy periods.

2.5 METHODS USED TO IMPROVE THE SOIL PROPERTIES OF THE SITE

It is difficult to build roads in soft clay zones due to their compressibility and low strength, since this may result in early deformation and consequent loss of bearing capacity. Addressing this problematic character is, therefore, implicit in fighting potential failures.

2.5.1 Improving of Embankment

When dealing with difficult sites and weak soils for roads, the traditional practice was either to replace the unsuitable soil or use additives to improve these soils, which are expensive or difficult to implement, such as: [45].

a. Improving soil with cement

b. Improving the soil with lime
c. Strengthening the soil with bitumen
d. Reinforcing the soil with silicates
e. Soil replacement

All of this was an impetus to find new techniques to improve road performance. The use of the geogrid network to improve pavement performance was an innovative way to address soil-related problems, which proved to be the most effective and least costly method for improving the site's soil.

2.5.2 Recycled Concrete Aggregate R.C.A for Embankment

Environmental attributes are being used more and more to evaluate building materials. By employing the easily accessible concrete as a source of aggregate for new concrete or other purposes, recycling of concrete preserves natural resources and removes the need for disposal. States that employ recycled concrete aggregate (RCA) in new construction report that the performance of concrete using RCA is on par with that of concrete made with natural aggregates. The majority of agencies stipulate employing the material in the project that is being rebuilt directly. Concrete recycling is a rather straightforward procedure. It entails dismantling, removing, and crushing pre-existing concrete to create a product of a certain size and caliber, for further details on creating recycled concrete aggregates from old concrete. The final concrete's quality is significantly influenced by the quality of the recycled materials used. Avoiding items like roofing materials, asphalt, dirt and clay balls, chlorides, glass, gypsum board, sealants, paper, and plaster is essential. Remove all imbedded materials, including any steel used for reinforcement. The potential utilization of recycled concrete aggregates is being evaluated by the O'Hare Modernization Project. (OMP). The laboratory tests utilizing a two-stage mixing technique indicate that the use of RCA from Chicago O'Hare International Airport results in a reduction of bleeding and segregation, while producing coarse aggregate that exhibits comparable workability, compressive strength, and shrinkage to virgin aggregates. Upon conducting a comparative analysis, it has been ascertained that the concrete material obtained from the demolition of the airport was utilized in the construction of the RCA facility located on the same premises. The supplier of pre-mixed concrete utilized recycled concrete aggregate (RCA) as a substitute for conventional, heavier materials, thereby achieving a one-step mixing process. According to the contractors who installed the RCA concrete, the material exhibited comparable performance to virgin aggregate concrete and achieved a satisfactory finish. The operational status of the installation was achieved within a timeframe of approximately four days. During the pouring of the concrete, sensors were incorporated to monitor the temperature, relative humidity, and lift-off of the slab from the permeable foundation coated with cement. The regular practice was to observe joint width and other attributes, such as surface appearance. After a period of five months of observation, the statistical data indicates that there is no significant difference in behavior between the RCA concrete and virgin aggregate concrete used in the two concrete lanes. It can be inferred that construction waste management practices have contributed to this outcome. It is given out if building, demolition, and land clearing trash is diverted from landfill disposal by at least 50% by mass. Concrete is a rather heavy building material that is commonly recycled to create aggregate for use as fill or road bases.

Figure 2.10: Recycled Concrete Aggregate [46].

2.5.3 Embankment Reinforcement Using Geosynthetics

All these ancient soil stabilization techniques have a variety of applications, but they are undesirable because they are costly, time-consuming, or both. Therefore, it is vital to discover fast and efficient solutions in soil stabilization treatment.

Soil reinforcement using geosynthetics is an alternate way of addressing the inadequacy associated with road building in soft clays. As essential planar reinforcement components.

a. Geogrid
b. Geotextiles.

2.6 GEOGRID AND ITS FUNCTIONS

The process of strengthening the soil, or what is called civil engineering "reinforcement", has a long history, dating back to 3500 years ago, and in the process of building, they used mats made of reeds, to ensure the stability of what was being built. From the brick walls, they seem to have realized that elements such as bricks and soil cannot withstand tensile forces and need to be reinforced to ensure their stability. Engineers are always confronted with the challenge of maintaining and improving pavement infrastructure while working with limited budgetary resources. Traditional pavement design and building procedures need the use of high-quality materials to meet construction requirements.

Figure 2.11: Geogrid with Soil [47].

Quality materials are either unavailable or scarce in many parts of the globe. Engineers are often pushed to explore alternate solutions employing poor materials, commercial construction aids, and novel design approaches because of these restrictions. Geosynthetics are a kind of commercial construction assistance. Geosynthetics are a wide range of polymer-based compounds used to improve geotechnical and transportation projects. Separation, reinforcement, filtration, drainage, and containment are all functions of geosynthetics. One kind of geosynthetic geogrids, is gaining popularity in road building. constructive suggestions a geosynthetic material called a geogrid is constructed of connected parallel sets of tensile fibers. The ribs' apertures are big enough to let the surrounding soil, stone, or other geotechnical material pass through them. Extruded geogrids are offered commercially. Geogrids, woven geogrids, welded geogrids, and geogrid composites are all examples of geogrids. Extruded geogrids are made from a polymer sheet that has been pierced and drawn in one or two directions. engineering property enhancement. Woven geogrids are made by weaving polymer strands, commonly polypropylene or polyester, which may be coated for abrasion resistance. Welded geogrids are created by joining together woven pieces of extruded polymers. When geogrids are merged, geogrid composites are generated. combined with additional items to create a composite system capable of solving a specific application. When compared to other forms of pavement geogrids, extruded geogrids have performed well. Based on their structure and concept, geogrids may be split into two basic kinds. uniaxial and biaxial application Extruded geogrids with a single direction of tension are used. Uniaxial geogrids are often utilized in geotechnical engineering projects, including retaining walls and reinforced earth. Geogrids that have been extruded and pre-tensioned in two directions.

In the last decades and since the seventies of the last century in particular, types of woven and non-woven fabrics have been used in road and railway facilities to strengthen weak soils.

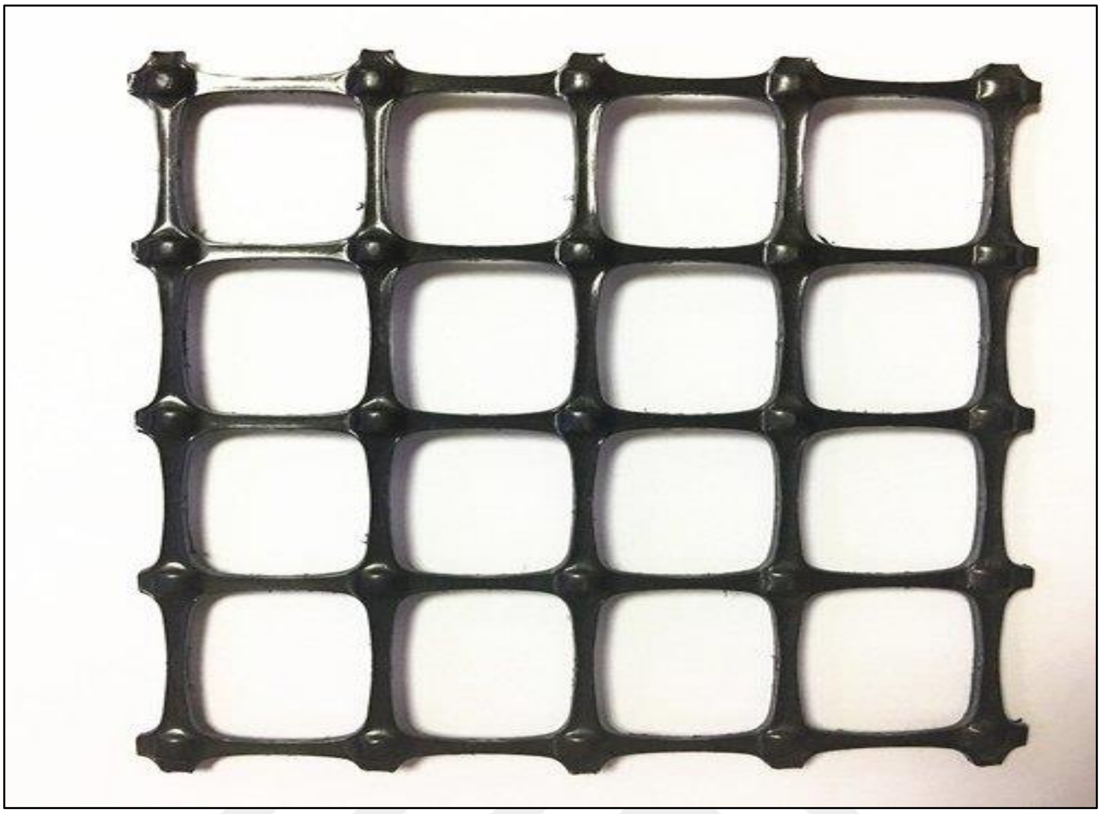

Figure 2.12: Type of Geogrid [48].

What gives this material an effective role in installations in general and in road and railway facilities, is its hardness in resisting tensile forces, as its resistance to tensile forces increases with the increase in its hardness, which allows it to be used in constructing and strengthening steep slopes of high altitude[49].

a. The high tensile strength can be heated by traffic loads.
b. The shape of the special geogrid is through the holes in it, which have different models as well as shapes, it secures the interference between the
c. The geogrid and the soil particles act as a buffer between the geogrid and the soil particles, which increases the hardness of the gravel layer.

2.6.1 The Mechanism of Action of the Geogrid in Improved Methods

Geogrid is one of the most modern geosynthetic products made of polymeric materials with high elastic modulus. It is a mesh with holes in different shapes between the formed ribs that are characterized by high tensile resistance. It is processed according to demand. It works on tension in one or two directions (biaxial-uniaxial) to improve the performance of the paving layers. inroads for reinforcement.

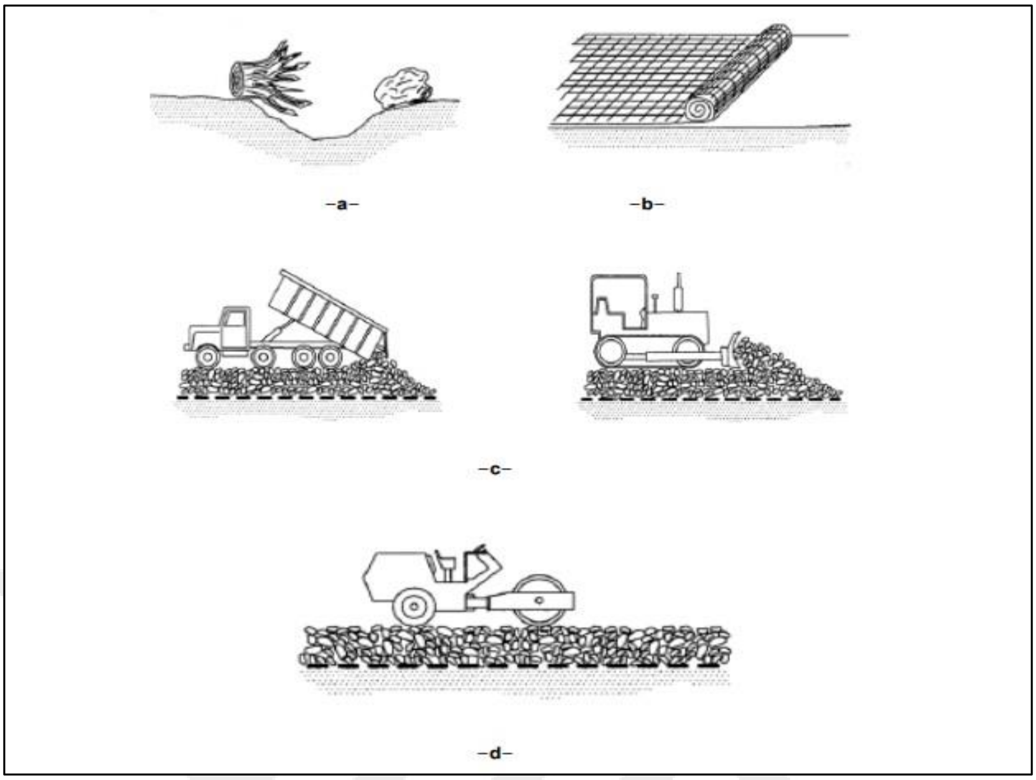

Figure 2.13: Method of Using Geogrid [50].

The geogrid is in the form of rolls and various lengths, characterized by its light weight and ease of transportation to the site, and it is also characterized by the ease of putting it into practice by laying it directly on the soil and then spreading gravel on it.

and stacking them, which contributes to reducing the time required to carry out the work. The stages of laying the geogrid within the flexible pavement layer can be seen in the figure below. The implementation stages during the process of reinforcement of the paving with the geogrid network consist of [51].

a. The construction site needs cleaning and levelling.
b. Laying the reinforcing mesh on the surface of the natural soil.
c. Paving the road with a layer of sub-base.
d. Levelling the layer of the sub-base and levelling it.

2.6.2 Reinforcement Mechanism in Flexible Pavement Layers

Flexible paving systems consist of the surface layer, the base layer, and the sub-base layer that are based on natural soil, where the surface layer is usually asphalt, while the base layer and the sub-base consist of gravel, and the natural soil is sand or clay. Researchers have carried out many studies and research to study the effects of geosynthetics when they are used as reinforcement materials within the gravel layer of flexible pavement. These studies concluded that the performance of flexible paving has improved when using geogrid as a reinforcement material. composition and thickness.

asphalt layer, natural soil type and durability, and the volume and frequency of applied loads. The advantages that are obtained using geogrid as a reinforcement material are:

a. The separation between natural soil and gravel granules to prevent interference between them is a secondary task of the geogrid.
b. Reinforcement of flexible pavement layers is the main task of the geogrid.

And some practical designs showed a decrease in the rate of cracks and grooves because of reinforcement with geogrid effectively, as shown in the figure below, so that the geogrid contributes to reducing the amount of stress transferred to the natural land from traffic loads when we compare it with layers of flexible pavement that are not reinforced with geogrid.

2.7 GEOTEXTILES

Geotextiles were among the earliest textile items developed by humans. Excavations at ancient Egyptian sites reveal the usage of grass and linen mats. Geotextiles were utilized in road building during the Pharaohs' reign to stabilize highways and their margins. These early geotextiles were formed of natural fibres, cloths, or plants combined with soil to enhance road conditions, especially on unstable terrain. Geotextiles have just lately been utilized and tested for contemporary road building. Geotextiles are highly developed items that must meet a variety of criteria. Appropriate equipment is required to make tailor-made industrial textiles. For almost 30 years, geotextiles have been utilized effectively in road building. Their main purpose is to isolate the sub-base from the subgrade, resulting in better road construction. This role is played by the geotextile, which provides a dense mass of fibres at the interface of the two layers [52].

Geotextiles are one of the most adaptable and cost-effective ground improvement products. Their use has spread fast across practically all disciplines of civil, geotechnical, environmental, coastal, and hydraulic engineering. Along with geogrids, geomembranes, and recomposites, they are the most crucial elements in the subject of geosynthetics. According to ASTM, geotextiles are essential parts of any civil engineering project, structure, or system that meet soil, rock, earth, or any other geotechnical-related material. (1994).

For plants to thrive, geotextiles must provide material exchange between air and soil, be permeable to roots, and for rainwater to seep into the soil from the outside as well as excess water to drain out of the earth without eroding the soil. To achieve all these features in geotextiles, the proper textile fiber selection is essential. Although natural fibers like ramie, jute, and others may also be used, geotextiles commonly use synthetic fibers like nylon, polyester, and polypropylene. [53].

2.7.1 Geotextiles' Important Characteristics

Geotextile properties are roughly classed as follows:

a. Specific gravity, weight, thickness, stiffness, and density are examples of physical qualities.
b. the qualities of tenacity, tensile strength, bursting strength, drapability, compatibility, flexibility, tearing strength, and frictional resistance.
c. Porosity, permeability, permittivity, transitivity, turbidity/soil retention, and filtration length are examples of hydraulic properties.
d. Properties of deterioration: degradation brought on by rat, termite, and other pest infestations include biodegradation, hydrolytic degradation, photodegradation, chemical degradation, mechanical degradation, and other degradation.
e. Endurance features such as elongation, abrasion resistance, clogging length, and flow, among others.

2.7.2 Type of Geotextile

a. Weaved geotextiles are constructed by interlocking fabric strips that provide strength and stability for projects that need geotextiles, Woven geotextiles are constructed from polypropylene strips that can endure high stress, because they are practically impermeable.

Figure 2.14: Woven Geotextile[54].

they are perfect for separation and reinforcing, Woven geotextiles may be formed of a variety of materials, the most common of which is a weave or yarn-blend. The materials seem to be plastic sheets, with the weaving discernible only upon scrutiny.

b. Non-Woven Geotextiles: Short-staple fibers or continuous filament yarn are used to make nonwoven geotextiles. The fibers are frequently attached by thermal, chemical, mechanical, or a mix of two or all of these techniques. Although chemically bonded non-woven geotextiles are capable of having a thickness of up to 3mm, mechanical or thermal geo-fibers normally have a thickness of 0.5 to 1mm. They are mostly utilized for separation, protection, and filtration in highway, railroad, and landfill projects, as well as civil and environmental projects, to assure the use of high-quality materials, the production technique employs a process with infinite filaments. Non-woven geotextiles are impervious to all chemicals and biological mediums found in soil and building materials, Water cannot dissolve the substance, making it safe for groundwater. They also include a U-stabilizer to give further protection from direct sunlight.

c. Knitted Geotextile: Knitted geotextiles are created by interlacing a succession of yarn loops. All knitted geosynthetics are created utilizing a knitted process in combination with another geosynthetic producer method, such as weaving. Aside from geotextiles, additional geosynthetics include geonets, geogrids, geo-cells, geomembranes, composites, and so on. Each has its own set of characteristics, uses, and applications.

Figure 2.15: Knitted Geotextile [55].

2.7.3 Geotextile Uses

a. Road Construction: The basic ideas behind the design of reinforced concrete with steel bars and the placement of geotextiles within a soil mass are the same. In places of the earth's bulk where shear stress would result, the textiles are used to provide tensile strength. Furthermore, to enable quick dewatering of the roadbed, the geotextiles must retain their permeability while maintaining their separating roles. Mechanical stress must not appreciably affect its filtering properties.
b. Paved and unpaved airport roads will be improved.
c. On landfills and stone foundation courses.
d. filling land gaps with tiny geotextile pieces.
e. Under the parking lots and curb sections, under the walkways and sand drainage layer:

i. To improve the greenery and leisure amenities collected on the retaining wall construction,
ii. improved soil capping as a result of reinforced and pipe trenches.

2.8 PREVIOUS REFERENCE STUDIES

Numerical studies have been conducted for several types of research to calibrate laboratory and field experiments and understand the mechanism of load transfer between the reinforcing mesh and the different paving layers. It is noteworthy that the mechanism of action of the reinforcing mesh depends mainly on reducing the lateral movement of the gravel base because a load of vehicles applied on the surface generates lateral movement within it, where lateral tensile stresses are generated in the base below the applied load, causing movement of the grains away from the loads downward and outward, so the geogrid reduces this lateral movement as a result of the overlap between its holes and soil particles. It also raises the coefficient of the gravel base layer and reduces the vertical distortions as a result of the phenomenon of membrane tension.

2.8.1 Analysis Using PLAXIS2D

Analysis and study of soil and rock deformations under the influence of different loads, in addition to studying the various soil structures. The program (PLAXIS2D) consists of four main subprograms, which are as follows:[56]

a. Input program the first working stage within this program is the pre-processing stage, which is used to enter the basic data necessary to describe the problem under study and includes determining the dimensions and shape of the geometric model.

b. calculation program, and processing program. It is possible to model the different stages of project creation accurately and accurately, which helps to calculate the stresses and distortions of each stage separately.

c. The output program, which is a post-processing stage concerned with outputting the results of the calculations, displays the distortions of the studied finite element network model and the stresses affecting it in various forms.

d. Curves program A program is used to display the curves of the relationship between loads and deformations, stresses and relative deformations, and stress and deformation trajectories at selected points of the geometric model, in addition to the possibility of displaying the distribution of groundwater pressures [57].

2.8.2 Field Experiments

a. S. S. Mukthar V Basheer, Rajat Ravi, Sreedevi, In this research, three distinct models were utilized to demonstrate the soil's stability and to determine the greatest appropriateness for the packing materials accessible locally.

a. Sand
b. Peat
c. Clay

These are the materials employed in this investigation, Model 1 is made up of four layers. The first two layers are made of sand, while the third layer is made of peat. The bottom layer is made of clay, whereas Model 2 has four layers, the first two of which are made of peat. The next layer is sand, while the lowest layer is filled with clays. Model 3 likewise has four layers. The first two layers are made of clay, followed by a layer of peat, and the last layer is made of sand. The properties of the materials used in the models were as in the Figure 2.16.

Parameter	Peat	Sand	Clay
Material model	Mohr coulomb	Mohr coulomb	Mohr coulomb
Material type	Undrained	Drained	Undrained
General Properties V unsaturated V saturated	8.000KN/m3 11.000KN/m3	16.000KN/m3 20.000KN/m3	15.000KN/m3 18.000KN/m3
Permeability	Kx = 2.000E0.3m/day Ky = 1.000E0.3m/day	Kx = 1.000m/day Ky = 1.000m/day	Kx = 1.000E0.4m/day Ky = 1.000E0.4m/day

Figure 2.16: Soil Properties [58].

The overall displacement, vertical tension, and pore pressure are calculated using several embankment models. Model 1 has the most total displacement or deformation when compared to the other two models. When de-saturated soil gets wetter, the volume and shear strength of the soil vary owing to an increase in pore pressure. The greatest surplus pore pressure occurred five days into construction. The measurement of excess pore pressure may then approach zero, indicating that the soil is entirely consolidated. Model 2 is better since it has less displacement. Models 2 and 3 are appropriate since they satisfy the provided requirement [58].

b. In this work, P. S. Wulandari and D. Tjandra The tensile strength of geotextile as an embankment reinforcement varies from 100 to 1000 kN/m. The road embankment's stability was analyzed with PLAXIS2D and finite elements. Figure 8 shows a model of 2H:1V embankments. 0.00 water level. The fill and soil were modelled as Mohr-Coulomb. This study used three sequence modelling types. First, road embankment stability without strengthening was analysed. The second model was to establish geotextile reinforcement length considering model road embankment stability. Last, the model reinforced embankment's stability was tested with different geotextile tensile strengths.

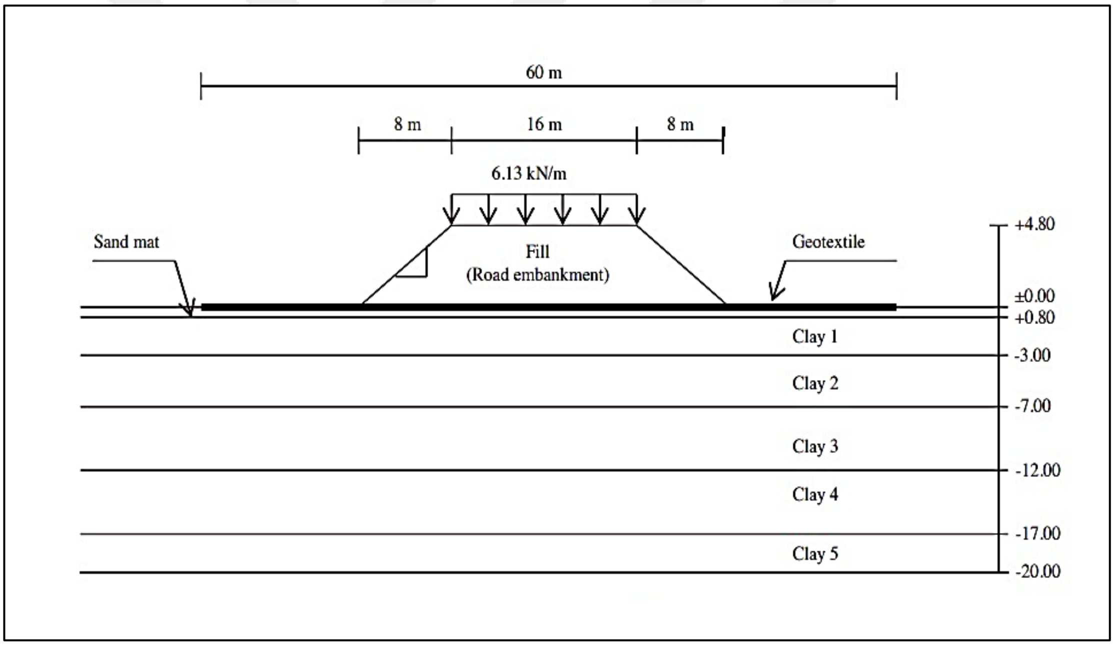

Figure 2.17: Geometry Model [59].

The safety factor increases with geotextile reinforcement tensile strength. Because displacement has no significant effect on geotextile tensile strength, this parameter may be neglected for determining ideal strength. In this study, the safety factor greatly affected the ideal tensile strength of geotextile-reinforced embankment [59].

c. Z. T. Han, H. N. Htun, and K. S. Tint, The researcher used many models to achieve the best soil stabilization; he used a model with different additives, a model by changing the deviation, and a model with a different level of groundwater, The issue of soil selection is critical in settling situations. The primary goal of this research is to assess the pavement's stability in terms of safety and deformation. Slope stability was predicted in three situations in this research (different fills, different slopes, and different levels of the water table). PLAXIS2D employed the finite element approach in the numerical slope analysis. The findings of this research demonstrated the feasibility of soil infill in embankment buildings based on a comparative examination of deformations and the safety factor. Sandy loam soils (Fill 2) are more suited for road backfill embankment in the filled aggregate soils [60].

d. S. K. Ahirwar and J. N. Mandal , A finite element model was used using the PLAXIS2D program to analyze the behavior of flexible asphalt pavement when exposed to a static load to investigate the effects of geogrid flexibility, natural soil strength, and foundation thickness on the behavior of reinforced flexible pavement, where the Mohr-coulomb model criterion for soil collapse was used, while the geogrid flexibility criterion was used, and the analysis was done in both cases of reinforcement and non-reinforcement as, The researcher used typical boundary conditions, which allow the vertical movement of the sides of the model and constrain the lower bound. After loading, it was found that the subsidence of the pavement surface decreases with the increase of the geogrid coefficient, and the performance is affected by the bearing capacity of the soil [61].

e. E. M. Ibrahim, S. M. El-Badawy, M. H. Ibrahim, A. Gabr, and A. Azam, They studied the effect of placing the geogrid reinforcing mesh between the layers of the pavement on the improved performance by using a numerical study in PLAXIS2D software according to axisymmetric 2d loading to determine, The responses as a result of static loading are shown in the results from the model parametric analysis. When the geogrid reinforcement is put at the bottom of the bituminous concrete layer, it results in the greatest reduction in horizontal tensile strain, ranging from 14.96 percent to 22.35 percent under dynamic and static loading conditions, respectively. Thus, geosynthetic reinforcement has a high potential for reducing fatigue strain in pavements. Under dynamic stress, there is no discernible difference in residual vertical surface deflection between unreinforced and geogrid-reinforced pavement. When installed between the base course and the subgrade layer, the geogrid reinforcement capability for reducing vertical strain (amounting to

11.80 percent) is more obvious under dynamic loading conditions. Pavement with geogrid reinforcement at the bottom of the bituminous concrete layer has shown significant improvement in pavement service life under variable load, where fatigue life is the dominating criterion in service life prediction [62].

f. S. A. Khan and S. M. Abbas, This study aimed to perform slope stability analysis on a highway embankment using FEM-based software. An embankment with a crest width of 8.5 meters and side slopes of 2:1 was selected for this investigation. The embankment is four meters high. The soft clay layer is supposed to be entirely soaked, followed by a well-graded sand layer. A 30 kN/m2 overburden pressure The Mohr-Coulomb soil model was used to simulate the embankment, which is made up of various elements, as well as the foundation soil, which is made up of soft clay and well-graded sand. Maximum horizontal displacement was determined to be 0.12 mm in fly ash fill reinforced with geogrid embankment, resulting in a 99.42 percent reduction from regular soil embankment (25 mm). The smallest value of maximum vertical displacement in fly ash fill reinforced with geogrid embankment was determined to be 1.67 mm, representing a 97.91 percent reduction from regular soil embankment (80 mm). The typical soil fill augmented with geogrid embankment showed the greatest percent decrease in stress, 44.44 percent. In the case of standard soil fill augmented with geogrid, the highest FOS against slope collapse was recorded [63].

g. R. C. Mamat, A. Kasa, and S. F. Mohd Razali , The study was conducted as part of plans to build new roads in Yan, Kedah, Malaysia. This construction site is primarily a farming area where paddy is grown. Engineers have proposed two methods for soil improvement at this site due to the soft soil: piles and PVDs with a surcharge. A total of 12 separate locations along a 5.5 km-long track were used to install the PVDs. In this study, a numerical exercise was conducted at one of these locations. The ground foundation is composed of two meters of clay silt followed by five meters of silty clay, according to the site survey. The next stratum is composed of 3 m of soft clay, 9 m of silty clay, and roughly 18 m of clayey silt. 2.3 meters below the surface of the earth is the groundwater level. In order to determine the parameters needed for the simulation in the FEM analysis, the observed settlement and pore water pressure measurements were compiled and interpreted. The construction of work platforms, the creation of embankments, and the installation of PVDs are among the site work projects for this research. A sand cushion is a work platform that is constructed from two levels of compacted sand. The FEM research was successful in forecasting the behavior of soft ground with improved PVD. Because of this, the main goal of this study is to evaluate how well the permeability ratio smear effect performs in FEM calculation prediction. Additionally, the comparison of the coefficient of determination between field observations and computational FEM results demonstrates that FEM is capable of making accurate predictions for values of settlement and pore water pressure. The results of this study also showed that using the recommended equivalent permeability, the settlement and pore water pressure predicted by FEM analysis correlate quite well with field measurements. [64].

h. D. Tsige, S. Senadheera, and A. Talema, Tensile strength and soil characteristics of the roots were measured using tensile strength testing and triaxial compression tests, respectively. The slope's safety factor was calculated using the PLAXIS2D program. According to the research, when the slope was strengthened with plant roots, the factor of safety (FOS) increased from 22 to 34 percent. When soil moisture rose, the influence of plants on slope stability decreased. The sensitivity analysis also revealed that: the influence of vegetation on the slope increased as plant spacing decreased. Slope angle change using a plant root combination had a considerable influence on slope stability. Salix subserrata was the most promising plant species for slope stabilization among the five tested plant species, exhibiting the best root mechanical characteristics. The study's results may be Among the five evaluated plant species, Salix subserrata was the most promising for slope stabilization, with the best root mechanical qualities. The findings of the study may be stated as follows: The slope that was initially unstable without plant root support became safe when plant roots were introduced for similar geometric slope configurations. Plant roots have a vital role in preventing shallow slope collapse on road-cut slopes. In general, as the value of root cohesion and the effective depth of the root zone has increased, so has the slope's stability [65].

i. PLAXIS2D The settling behavior of both unstabilized and stabilized soils under different widths of strip foundations was investigated. According to load settlement research, raising GBFS concentration raises net permissible pressure, which climbs even more with the addition of lime to soil stabilized with appropriate GBFS. When weak soils, such as lethargic clay, come into contact with water, they cause serious problems, and the absence of stronger fill materials nearby to replace them makes foundation engineers' jobs difficult. This study aims to improve the strength of lithomargic clay by chemical stabilization using lime and granulated blast furnace slag (GBFS). The disposal of massive amounts of industrial waste, GBFS) has become an environmental concern, and utilizing it for soil stabilization would be a long-term solution. Laboratory studies on lithomargic clay were conducted to optimize lime consumption and understand the process underlying the increase in strength by substituting varied amounts of GBFS and adding different percentages of lime. Lime and GBFS concentrations of 4% and 20% were determined to be ideal. Further optimization was carried out by mixing lethargic clay with 4% lime and 20% GBFS, resulting in a significant increase in strength. SEM and XRD analyses were performed on the stabilized soil and the increase in strength [66].

j. In this work, the researchers used a two-dimensional finite element simulation to discover the elements that govern the performance of the geogrid-reinforced asphalt overlays and their impact on the response of the flexible pavements. By comparing the computational predictions of the finite element model to the actual results obtained in the large-scale accelerated stacking models, the computational predictions of the finite element model are confirmed. A series of parametric assessments of the finite element is performed by varying the stiffness of both the geonetwork and the substrate materials. Static loading is also used to investigate stresses mobilized inside a geogrid. According to numerical projections, the inclusion of geogrids has a significant impact on the structural behavior of the pavement, as assessed by reduced vertical displacements and stresses but unaffected by the increase in geographic stiffness. Pavement strains are minimized, primarily in the substratum layer. According to metric analyses of finite components, geogrids inserted within asphalt layers can boost the overall bearing capacity of the paving system, even in scenarios with poor subgrades. Finally, structural reinforcing mechanisms may be coupled to the numerically predicted geo-network strain distribution, which has been demonstrated to be highly consistent with experimental results [67].

k. To analyze modeling in this study, the researcher used the following model: an embankment model with a width of 4.5m, heights of 3m, 4m, and 5m, and toe angles of

30, 45, and 60 degrees, respectively. In the modeling, a wheel load of 5100kg is placed on the embankment pavement, and the safety factor (SF) is the primary design criteria in stability analysis computation, which may be computed using a number of methodologies, including the limit equilibrium method (LEM) and the finite element method (FEM). Because stability analysis is strongly dependent on certain processes, it becomes a major issue in the selection of techniques required in the analysis. FEM has been used to study stability difficulties in recent years. The present research focuses on the stability of embankments utilizing PLAXIS2D for lateritic soils found in the Dakshina Kannada region. According to the PLAXIS2D research results, the lateritic soil in this site is exceptionally stable and may be used efficiently in the construction of embankments as Sub-grade [68].

l. M. Kianimehr, P. T. Shourijeh, S. M. Binesh, A. Mohammadinia, and A. Arulrajah , The researcher studed the effectiveness of recycled concrete aggregates (RCA) in enhancing the shear/compressive strengths and deformation characteristics of clay soils is examined in this experimental investigation. On properly proportioned combinations of RCA and a clay soil, a thorough set of compaction, uniaxial compression, and direct shear tests were conducted. According to test findings and observations, adding RCA to clay soils causes a decrease in dry density and an increase in unconfined compressive strength (UCS), which rises with moist curing. In comparison to the parent clay soil, clay soils mixed with RCA exhibit stronger shear strengths and higher inclinations for dilative behavior (during shear). Stronger, stiffer, and less compressible blends are produced when RCA is combined with clay soils; these blends are especially well suited for construction tasks like sub-base/subgrade of road pavements[69].

m. V. G. Havanagi, A. K. Sinha, V. K. Arora, and S. Mathur , To determine if certain waste materials were suitable for use in embankments, the outcomes of studies on physical, chemical, geotechnical, and other engineering features were conducted ,Waste materials have CBR values greater than 30% ,In comparison to local soil, all waste materials have greater frictional properties, which leads to better shear strength. The high angles of internal friction values demonstrated the viability of these waste materials for embankment building ,The viability of using these waste products in place of fine aggregate while building road embankments[70].

3. PROPOSED METHODOLOGY

3.1 INTRODUCTION

This chapter describes the procedures conducted to achieve the objectives of the study. The research is carried out to overcome slope failure, and the aim is to analyses the natural slope using suitable methods according to the site condition. The method chosen will stabilize the slope prior to the excavation works carried out at the toe of the slope. There will also be a description of the site included in this chapter and the software input procedure to achieve this study's purpose.

3.2 SOIL INVESTIGATION

One of the essential studies that need to be carried out on a construction site prior to any work is to study the soil properties and behavior. During the initial stage of construction, the slope was considered stable as the natural slope was not disturbed. The soil investigation was carried the soil type and based on the Soil Investigation Report, the water table is located at the ground level.

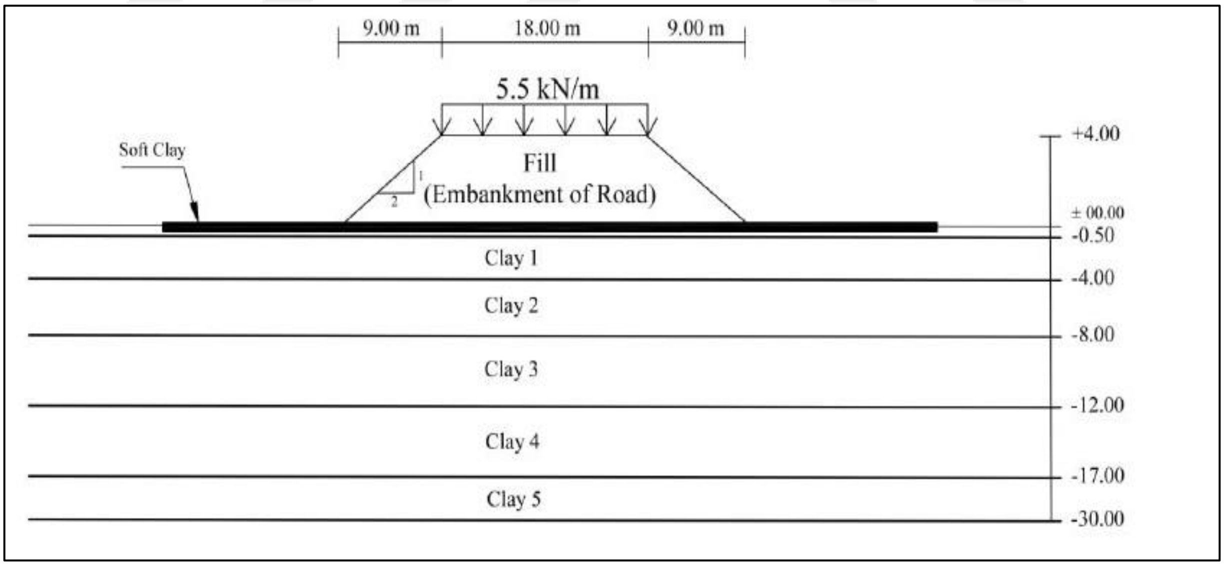

Figure 3.1: Geometrical Design[71].

The water table is considered at ground level to make it less complicated (see Table 3.1).

Table 3.1: Configuration Parameters Used.

Name	Material model	Drainage type	γ_unsat	γ_sat	E (kN/m2)	C’	φ	R_inter
Soft clay	Mohr-Coulomb	Undrained (A)	18	23.50	30E3	10	25	0.70
Clay1	Mohr-Coulomb	Undrained (A)	16.50	17.50	2000	33	1	0.70
Clay2	Mohr-Coulomb	Undrained (A)	16.50	17.50	2000	12	1	0.70
Clay3	Mohr-Coulomb	Undrained (A)	16.50	17.50	2000	47	1	0.70
Clay4	Mohr-Coulomb	Undrained (A)	16.50	17.50	2000	119	1	0.70
Clay5	Mohr-Coulomb	Undrained (A)	16.50	17.50	2000	164	1	0.70
Fill	Mohr-Coulomb	Drained	18	18	50000	10	28	0.70
Recycled concrete aggregate (RCA)	Linear elastic	Non-porous	24	24	26000	-	-	0.70

3.3 NUMERICAL MODELLING

The mass being considered is represented by an arrangement of components connected at a limited number of nodal points using the finite element method (FEM) [72] The primary distinction between conventional methods and finite element methods is that linear elastic behavior of materials is frequently calculated using conventional methods. Because of the nonlinear elastoplastic behavior of soil, finite element method-based computer programs are advised. The fundamental idea behind this technique is that a complex model of a body or structure is broken down into several smaller components. Then, nodes join those components together. The number of functions is described by one or more degrees of freedom at each node.

3.3.1 Plaxis2d

A finite element-based numerical program for two-dimensional analysis is called PLAXIS 2D. It is particularly useful for constructing geotechnical structures as well as for analysing soil deformations and groundwater movement. The application can be used to analyze things like groundwater movement, consolidation, and deformations. A plane strain or an axisymmetric model can both be used to simulate real-world conditions. A fast geometry model and finite element mesh can be quickly generated using the program's easy graphical user interface using a realistic vertical cross-section of the current scenario. Only the two-dimensional variant has been examined for examination in this thesis[73].

3.3.2 PLAXIS3D's constitutive model definition

For use in PLAXIS2D, a constitutive model of soil was established. In general, the study was conducted using the MC, HS, and HS small model. Site particularity is used to define the water table height. Additionally, the following factors for the soil below were taken into account: The clayey soil is classified as an Undrained A condition in the PLAXIS2D software. Following are descriptions of the conditions for undrained A and B based on [73].

a. Undrained A

Stiffness and strength are characterized in terms of their respective effective qualities in the context of undrained or short-term material behaviour. To render the soil incompressible, a significant bulk stiffness for water is automatically given. (Excess) pore pressures are then estimated, even above the phreatic surface.

b. Undrained B

Undrained shear strength is described as short-term or undrained material behaviour, where stiffness is characterized in terms of effective characteristics. To render the soil incompressible, a significant bulk stiffness for water is automatically given. (Excess) pore pressures are then estimated, even above the phreatic surface."

3.3.3 Finite Element Quality and Efficiency Analysis in Plaxis2d

a. Analysis of boundary: Every analysis was checked to make sure the boundary line wouldn't be interfered with by the supplied boundary limit.

b. Meshing Generation (Simple case): To assure the speed and accuracy of finite element analysis, the results of various mesh qualities (number of elements) were compared to the results of each pile. This study primarily focused on the deformation outcomes.

3.4 DESCRIPTION OF MODELS

The geotechnical investigation result of numerical modeling by using the finite element program PLAXIS2D to estimate and predict the settlements. [74]

Technical, financial, and morphological variables are the key determinants of an embankment's alignment. The alignment that can be built with the least amount of land needed to be acquired, utilizing materials that are readily available locally and that are acceptable, and enclosing as much land as feasible is the one that is most favorable economically.

In this investigation, the 4 m of embankments with slopes of 2H: 1V shown in Figure 3.1 Deformed Mesh for Model-I were examined. The water was at its lowest point, 0.00. Modeling of the traffic load has been done using a nominal surcharge of 5.5 kN/m' , A layer of reinforcement are placed between the base of embankment and the soft clay layer , We obtained the lowest displacement [74].

Table 3.2: Geogrid Properties.

Table Specifications	Standard	Standard Type (value)
Type of mesh		Rectangular apertures
Standard color		Black
type of Polymer	Iso 9864	Polypropylene
Aperture size mesh	strain Iso 10,319	41 mm
Mass per unit area	strain Iso 10,319	250 g/m2
Strength at 2%	Iso 10,319	7 kN/m
Strength at 5%		14 kN/m
Peak tensile strength		20 kN/m

Five different models were analyzed:

a. Modelling only with embankment (only with the Road Embankment)
b. Embankment with the addition of geogrids (Road Embankment + Geogrid (between the first soil layer and embankment))[74]
c. Embankment with geogrids at different levels (Road embankment + geogrids in the middle)
d. Embankment with recycled concrete aggregate (Road embankment + recycled concrete aggregate)

e. Embankment with recycled aggregate and geogrids (Road embankment + recycled aggregate +geogrids)

3.5 STAGED CONSTRUCTION

Staged construction-wise, projects are divided into phases; similarly, to numerical calculation in PLAXIS2D, the calculation is divided into phases. In staged construction, loading activation at a particular time is adapted to simulate the construction stages. Nonlinear soil behaviour requires the loadings to be applied in small proportions, in PLAXIS2D, called steps. Stage-zero's first stage is the initial phase calculated using gravity loading or K0. For the cases in this study, the slope stability, thus initial phase is selected for calculation type of gravity loading for a non-horizontal layer (slope). It is a type of plastic calculation where initial stresses are generated based on the volumetric weight of the soil. In which the soil self-weight is applied in the first calculation. As the initial stress is set up by gravity loading, the displacement is zero at the following calculation phase. Thus, the stress remains, but the effect of initial stress generation is removed from the analysis of the following phase. The following staged construction applies the plastic calculation to the soil body. The modelling is done using the soil profile given in above. Following stages of construction are defined in PLAXIS2D.

4. EXPERIMENTAL RESULTS & DISCUSSION

4.1 INTRODUCTION

The main objective of this study is to evaluate the stability of the investigated embankment. Utilizing a limit equilibrium analysis is a typical method of determining the embankment's stability. Different potential failure surfaces must be considered while analyzing the stability of the embankment. The following requirements should be met while designing a roadway embankment:

a. Set a reasonable sum as the maximum settlement.
b. Shorten the period necessary for an appropriate consolidation settlement.
c. Offer sufficient stability.
d. Construct a platform for the paved road.

4.1.1 Output

Numerous road embankments have been constructed on soft ground as a result of the rise in traffic worldwide in recent years. (Loose sand, etc.,). In metropolitan areas, the construction of new highways makes it necessary to build road embankments over already-existing subsurface facilities. Being that most of these structures are ancient. Large settlements and slope instability are two common issues that geotechnical engineers encounter in this scenario. Five distinct models with various features were examined:

a. Modelling only with embankment.
b. Embankment with the addition of geogrids.
c. Embankment with geogrids at different levels.
d. Embankment with recycled concrete aggregate.
e. Embankment with recycled aggregate and geogrids.

4.1.1.1 Model-I (only Embankment)

Stages of Construction

a. Initial Phase
   i. Installation of Embankment
   ii. Application of cyclic loads (-5.5 kN/m)

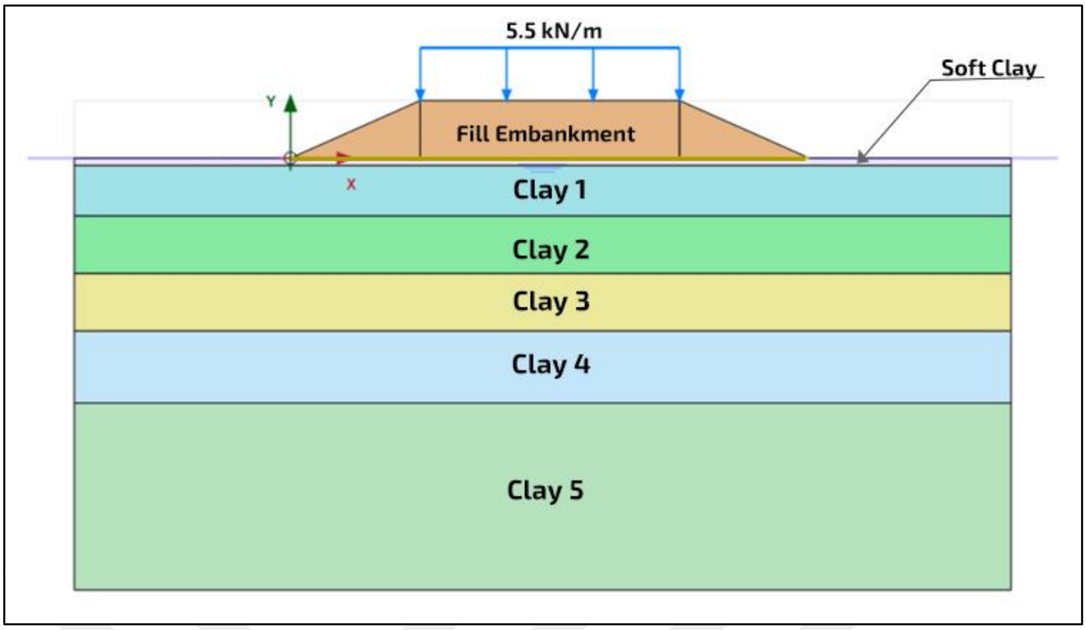

Figure 4.1: Soil and Loading and Deformed Mesh for Model -I.

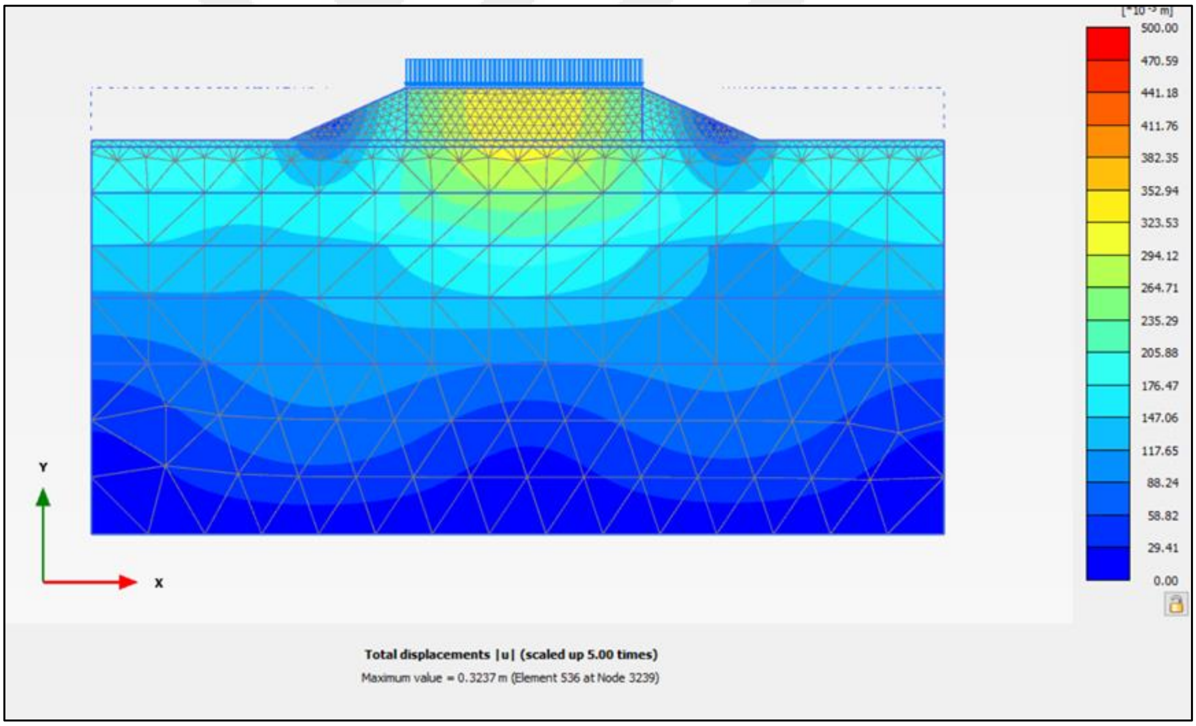

Figure 4.2: Total Displacement for Model I.

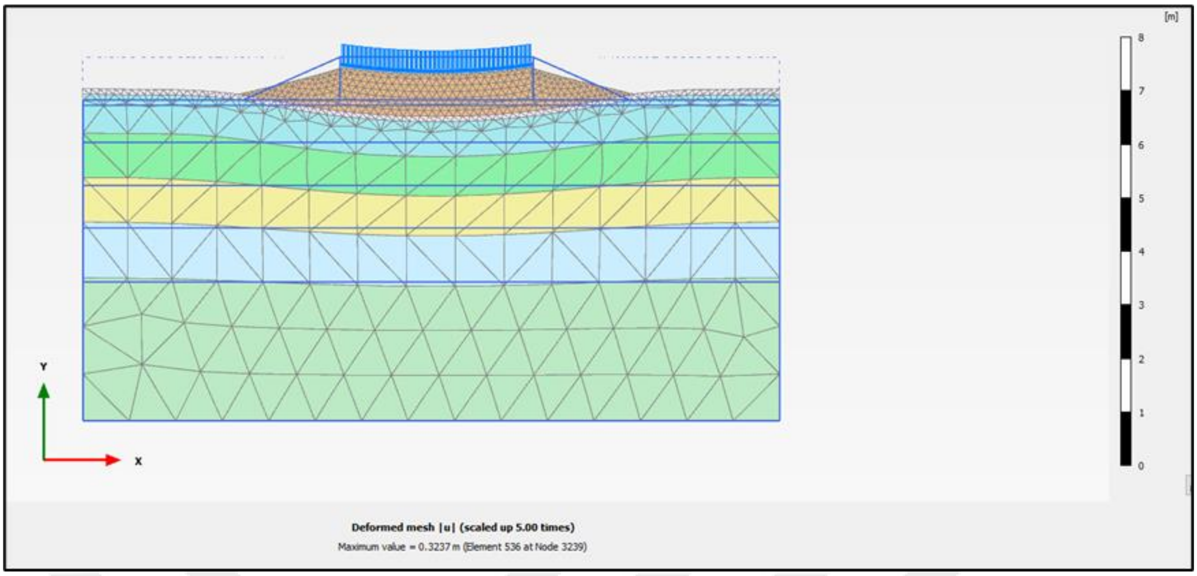

Figure 4.3: Deformed Mesh for Model I.

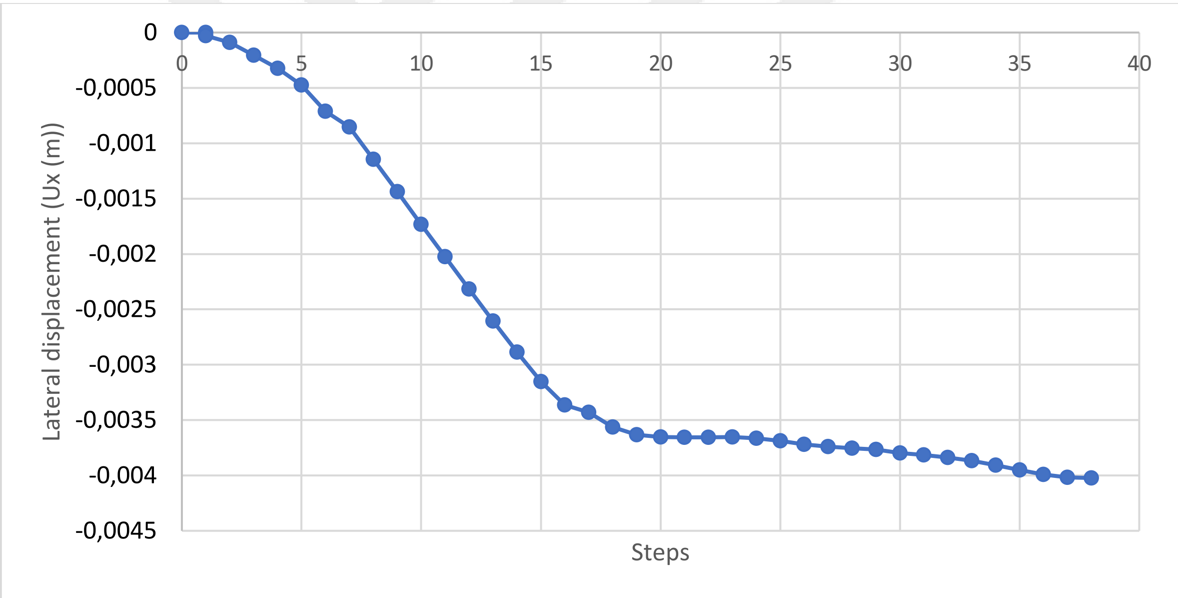

Figure 4.4: Lateral Displacement for Bottom Node.

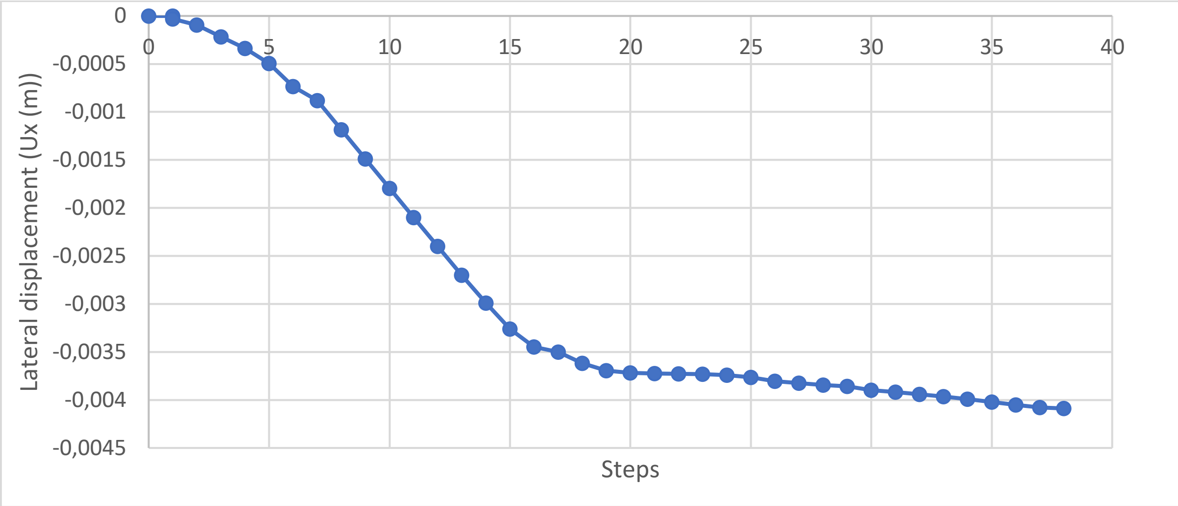

Figure 4.5: Lateral Displacement for Top Embankment Node.

Table 4.1: Lateral Displacement for Bottom Node.

Point	Step	Step []	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	-0.00002926
3	2	2.00	-0.00008808
4	3	3.00	-0.00020573
5	4	4.00	-0.00032369
6	5	5.00	-0.00047461
7	6	6.00	-0.00071010
8	7	7.00	-0.00085245
9	8	8.00	-0.00114368
10	9	9.00	-0.00143716
11	10	10.00	-0.00173148
12	11	11.00	-0.00202491
13	12	12.00	-0.00231540
14	13	13.00	-0.00260456
15	14	14.00	-0.00288633
16	15	15.00	-0.00315383
17	16	16.00	-0.00336408
18	17	17.00	-0.00342890
19	18	18.00	-0.00356248
20	19	19.00	-0.00363406
21	20	20.00	-0.00365431
22	21	21.00	-0.00365610
23	22	22.00	-0.00365475
24	23	23.00	-0.00365328
25	24	24.00	-0.00366478
26	25	25.00	-0.00368696
27	26	26.00	-0.00372051
28	27	27.00	-0.00373942
29	28	28.00	-0.00375313
30	29	29.00	-0.00376632
31	30	30.00	-0.00379678
32	31	31.00	-0.00381607
33	32	32.00	-0.00383860
34	33	33.00	-0.00386653
35	34	34.00	-0.00390669
36	35	35.00	-0.00395154
37	36	36.00	-0.00399073
38	37	37.00	-0.00401708
39	38	38.00	-0.00402319

Table 4.2: Lateral Displacement for Top Embankment Node.

Point	Step	Step []	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.000000
2	1	1.00	-0.000031
3	2	2.00	-0.000093
4	3	3.00	-0.000216
5	4	4.00	-0.000339
6	5	5.00	-0.000494
7	6	6.00	-0.000734
8	7	7.00	-0.000883
9	8	8.00	-0.001185
10	9	9.00	-0.001490
11	10	10.00	-0.001796
12	11	11.00	-0.002100
13	12	12.00	-0.002401
14	13	13.00	-0.002700
15	14	14.00	-0.002991
16	15	15.00	-0.003260
17	16	16.00	-0.003449
18	17	17.00	-0.003501
19	18	18.00	-0.003618
20	19	19.00	-0.003694
21	20	20.00	-0.003718
22	21	21.00	-0.003723
23	22	22.00	-0.003726
24	23	23.00	-0.003731
25	24	24.00	-0.003742
26	25	25.00	-0.003766
27	26	26.00	-0.003803
28	27	27.00	-0.003826
29	28	28.00	-0.003843
30	29	29.00	-0.003860
31	30	30.00	-0.003898
32	31	31.00	-0.003918
33	32	32.00	-0.003940
34	33	33.00	-0.003963
35	34	34.00	-0.003990
36	35	35.00	-0.004020
37	36	36.00	-0.004050
38	37	37.00	-0.004078
39	38	38.00	-0.004089

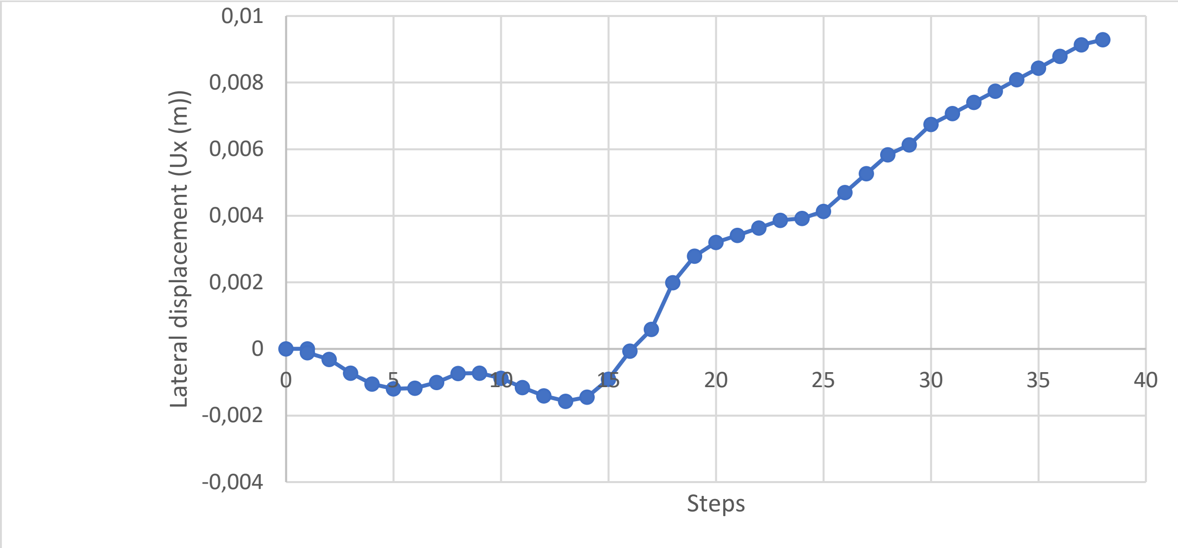

Figure 4.6: Lateral Displacement for Face Embankment Node.

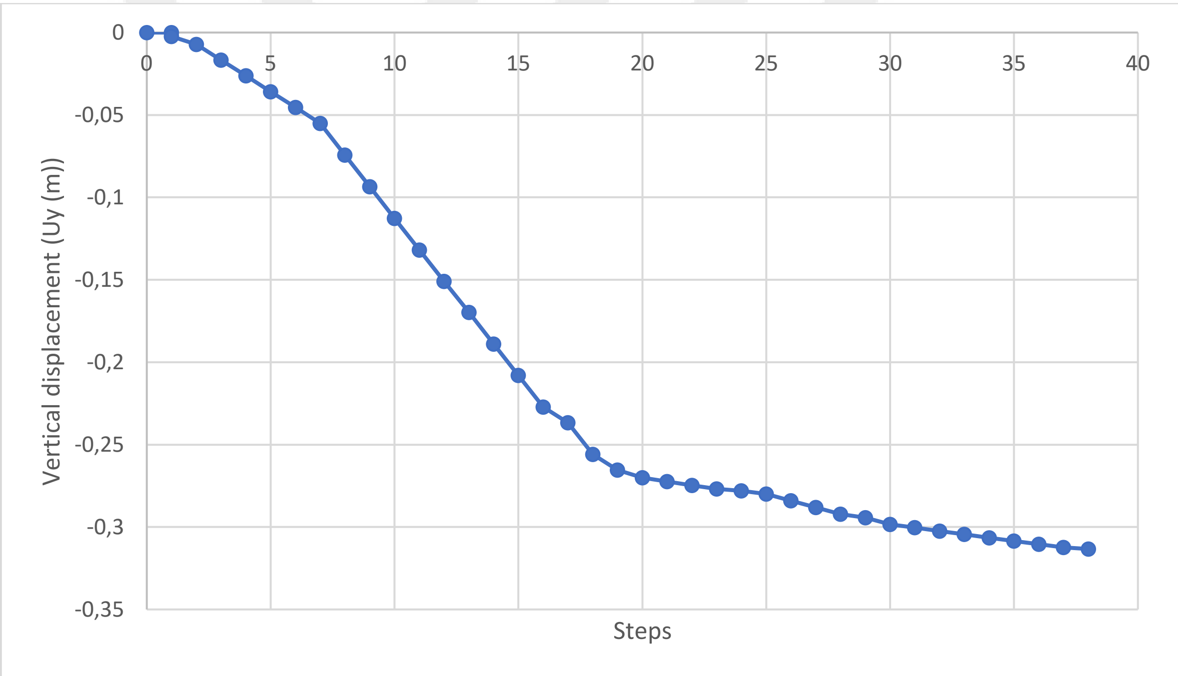

Figure 4.7: Vertical Displacement for Bottom Embankment Node.

Table 4.3: Lateral Displacement for Face Embankment Node.

Point	Step	Step []	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.0000000
2	1	1.00	-0.0001134
3	2	2.00	-0.0003153
4	3	3.00	-0.0007249
5	4	4.00	-0.0010557
6	5	5.00	-0.0011956
7	6	6.00	-0.0011816
8	7	7.00	-0.0010019
9	8	8.00	-0.0007362
10	9	9.00	-0.0007241
11	10	10.00	-0.0008822
12	11	11.00	-0.0011545
13	12	12.00	-0.0014039
14	13	13.00	-0.0015702
15	14	14.00	-0.0014485
16	15	15.00	-0.0009055
17	16	16.00	-0.0000645
18	17	17.00	0.0005908
19	18	18.00	0.0019951
20	19	19.00	0.0027846
21	20	20.00	0.0031979
22	21	21.00	0.0034138
23	22	22.00	0.0036360
24	23	23.00	0.0038659
25	24	24.00	0.0039255
26	25	25.00	0.0041372
27	26	26.00	0.0046968
28	27	27.00	0.0052623
29	28	28.00	0.0058334
30	29	29.00	0.0061288
31	30	30.00	0.0067485
32	31	31.00	0.0070724
33	32	32.00	0.0074043
34	33	33.00	0.0077439

Table 4.4: Vertical Displacement for Bottom Embankment Node

Point	Step	Step []	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.0000000
2	1	1.00	-0.0023888
3	2	2.00	-0.0071679
4	3	3.00	-0.0167257
5	4	4.00	-0.0262980
6	5	5.00	-0.0358975
7	6	6.00	-0.0455066
8	7	7.00	-0.0551163
9	8	8.00	-0.0743354
10	9	9.00	-0.0935550
11	10	10.00	-0.1127770
12	11	11.00	-0.1318908
13	12	12.00	-0.1508986
14	13	13.00	-0.1698435
15	14	14.00	-0.1888806
16	15	15.00	-0.2080115
17	16	16.00	-0.2271587
18	17	17.00	-0.2367608
19	18	18.00	-0.2559568
20	19	19.00	-0.2653514
21	20	20.00	-0.2700043
22	21	21.00	-0.2723152
23	22	22.00	-0.2746245
24	23	23.00	-0.2769409
25	24	24.00	-0.2779855
26	25	25.00	-0.2800369
27	26	26.00	-0.2841063
28	27	27.00	-0.2881899
29	28	28.00	-0.2922778
30	29	29.00	-0.2943168
31	30	30.00	-0.2983858
32	31	31.00	-0.3004130
33	32	32.00	-0.3024358
34	33	33.00	-0.3044523
35	34	34.00	-0.3064589
36	35	35.00	-0.3084532
37	36	36.00	-0.3104428
38	37	37.00	-0.3124296

Table 4.5: Vertical Displacement for Top Embankment Node.

Point	Step	Step []	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.0000000
2	1	1.00	-0.0024107
3	2	2.00	-0.0072318
4	3	3.00	-0.0168739
5	4	4.00	-0.0265325
6	5	5.00	-0.0362164
7	6	6.00	-0.0459081
8	7	7.00	-0.0556003
9	8	8.00	-0.0749838
10	9	9.00	-0.0943676
11	10	10.00	-0.1137531
12	11	11.00	-0.1331582
13	12	12.00	-0.1525892
14	13	13.00	-0.1720346
15	14	14.00	-0.1915711

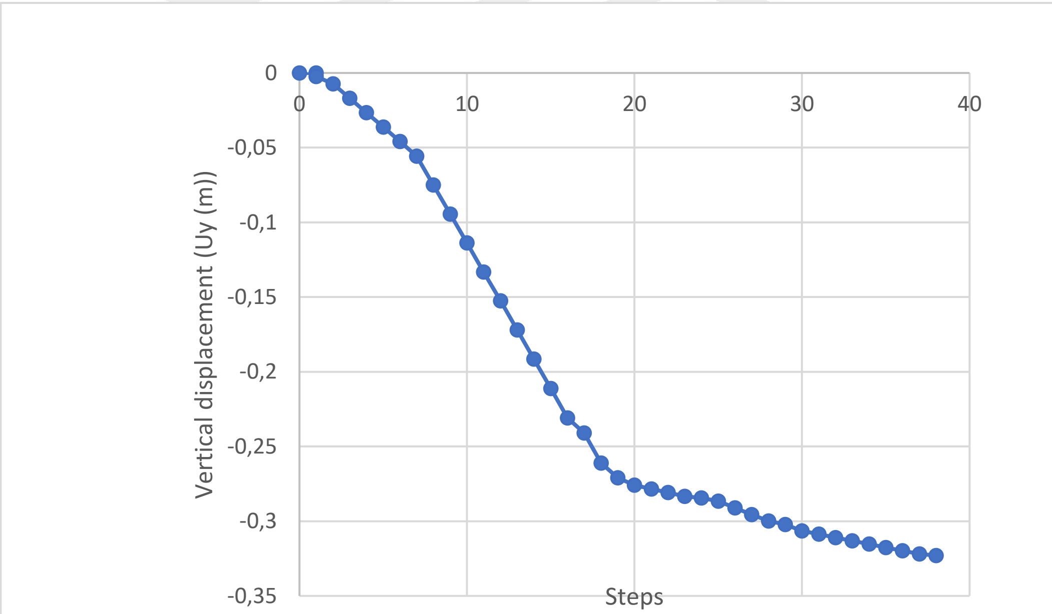

Figure 4.8: Vertical Displacement for Top Embankment Node.

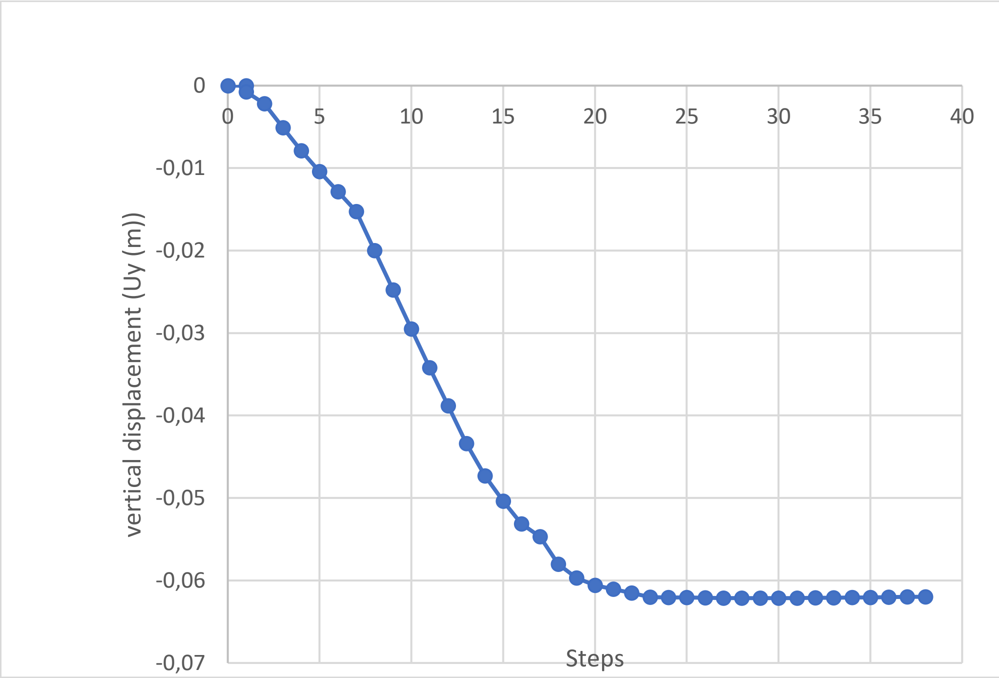

Figure 4.9: Vertical Displacement for Face Embankment Node.

Table 4.6: Vertical Displacement for Face Embankment Node.

Point	Step	Step []	u_y [m]
0	0	0.0	N/A
1	1	1.0	0.000000
2	1	1.0	-0.000739
3	2	2.0	-0.002197
4	3	3.0	-0.005117
5	4	4.0	-0.007894
6	5	5.0	-0.010414
7	6	6.0	-0.012860
8	7	7.0	-0.015255
9	8	8.0	-0.020010
10	9	9.0	-0.024759
11	10	10.0	-0.029507
12	11	11.0	-0.034209
13	12	12.0	-0.038826
14	13	13.0	-0.043400
15	14	14.0	-0.047312
16	15	15.0	-0.050382
17	16	16.0	-0.053116
18	17	17.0	-0.054688

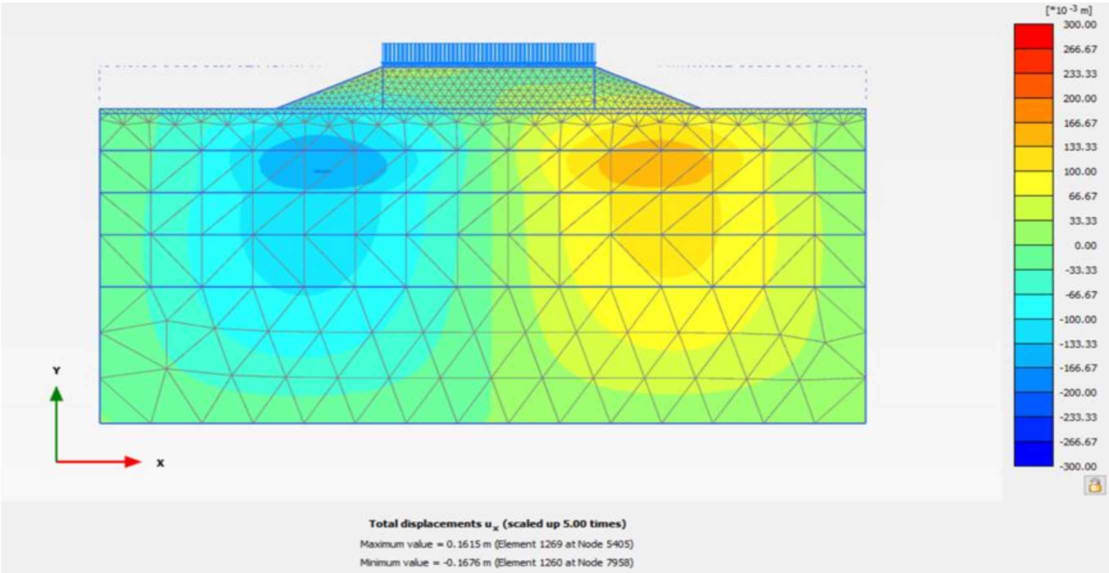

Figure 4.10: Total Horizontal Displacement for Model I.

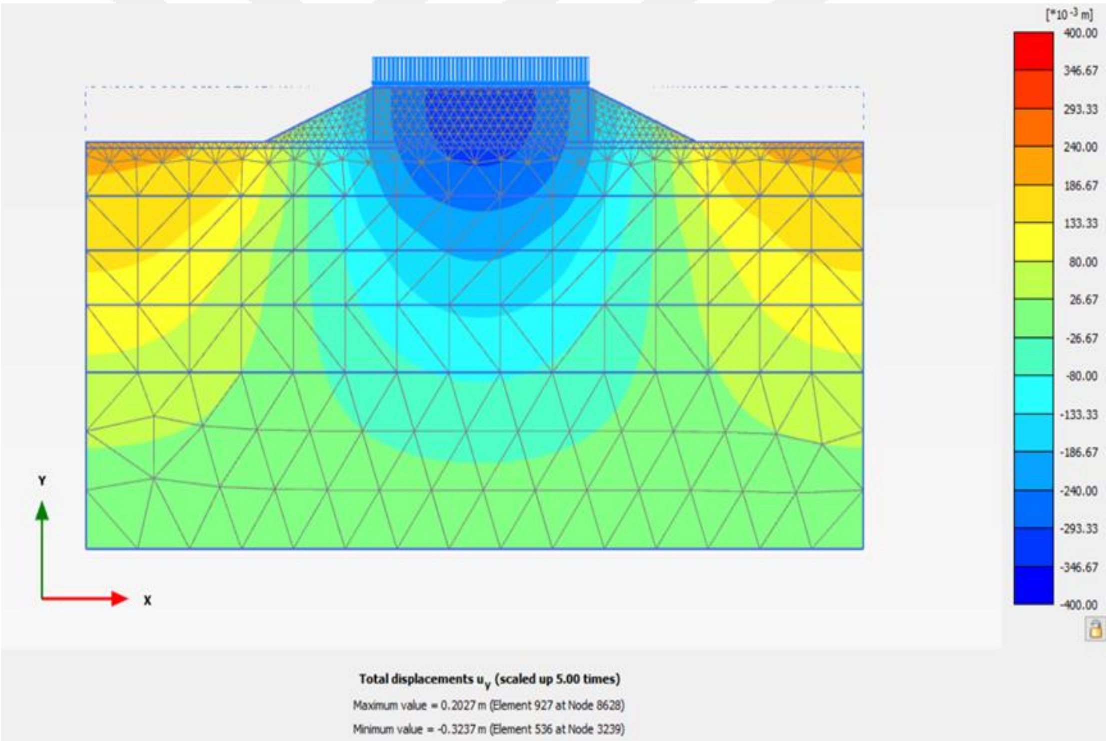

Figure 4.11: Total Vertical Displacement for Model I.

4.1.1.2 Model-II (only with geogrid)

Stages of Construction

a. Initial Phase

i. Installation of geogrid

ii. Installation of Embankment

iii. Application of cyclic loads (-5.5 kN/m)

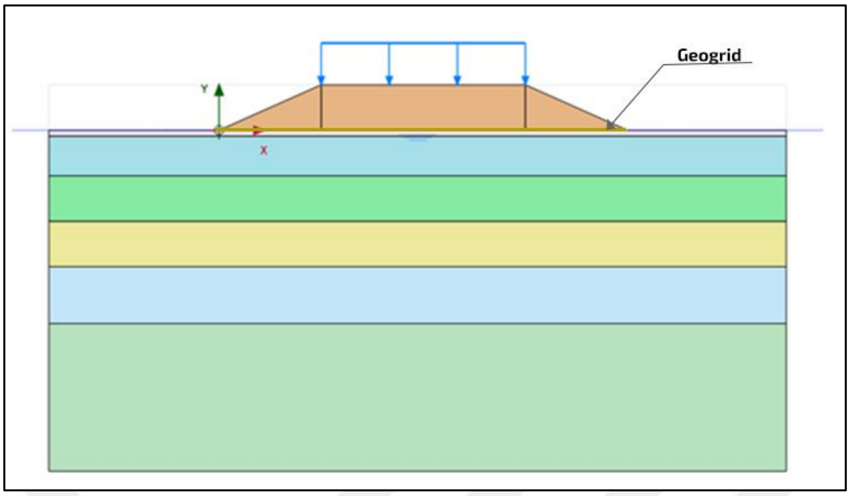

Figure 4.12: Input Soil and Loading Model II.

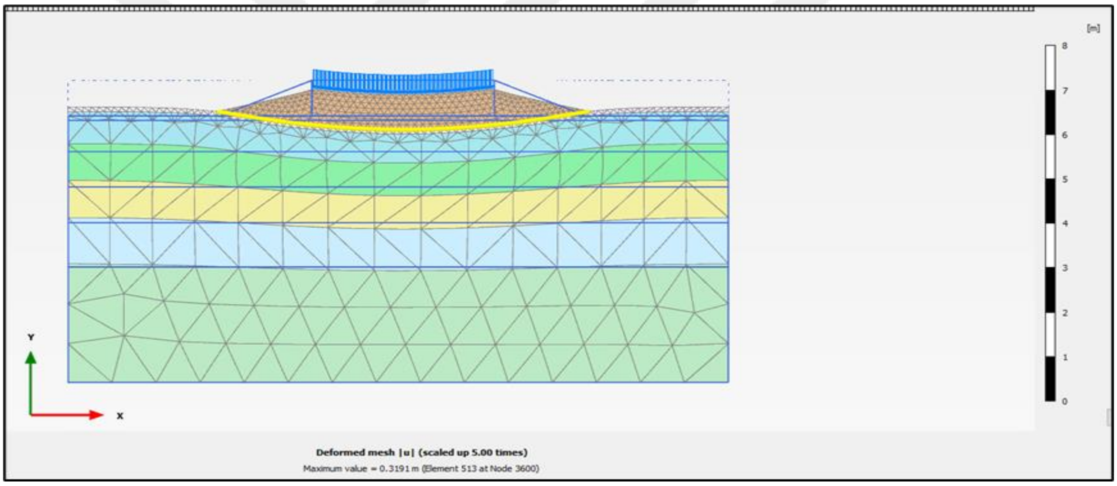

Figure 4.13: Deformed Mesh for Model-II.

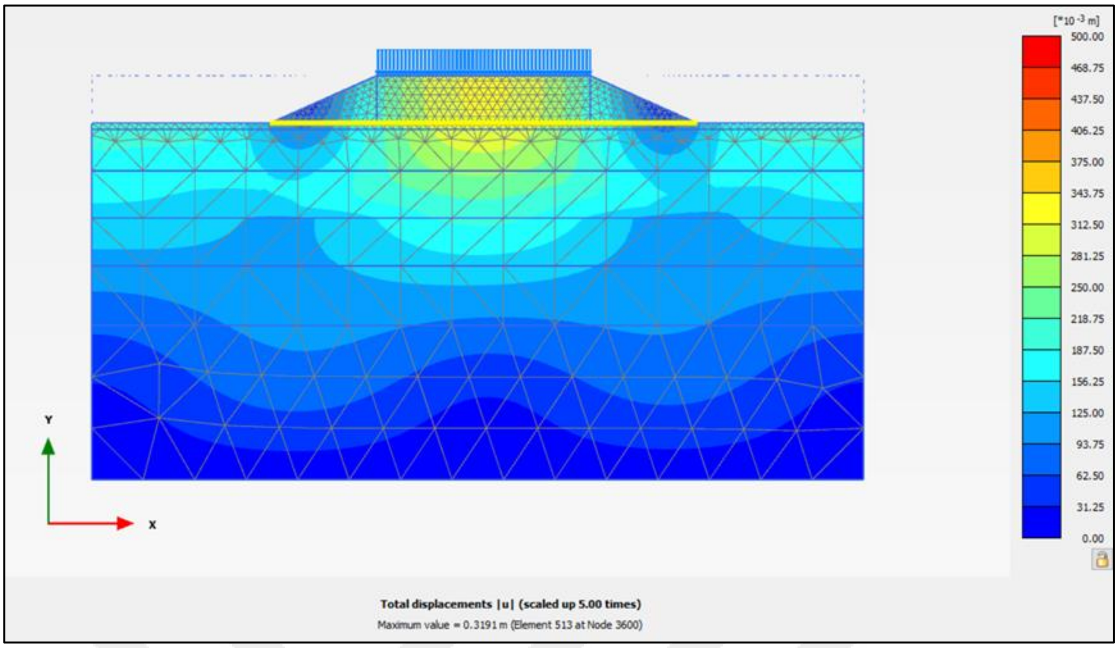

Figure 4.14: Total Displacement for Model-II.

Table 4.7: Lateral Displacement for Bottom Embankment Node.

Point	Step	Step []	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	0.00000000
3	2	2.00	0.00000000
4	3	3.00	-0.00002970
5	4	4.00	-0.00008938
6	5	5.00	-0.00020876
7	6	6.00	-0.00032844
8	7	7.00	-0.00048454
9	8	8.00	-0.00072260
10	9	9.00	-0.00086760

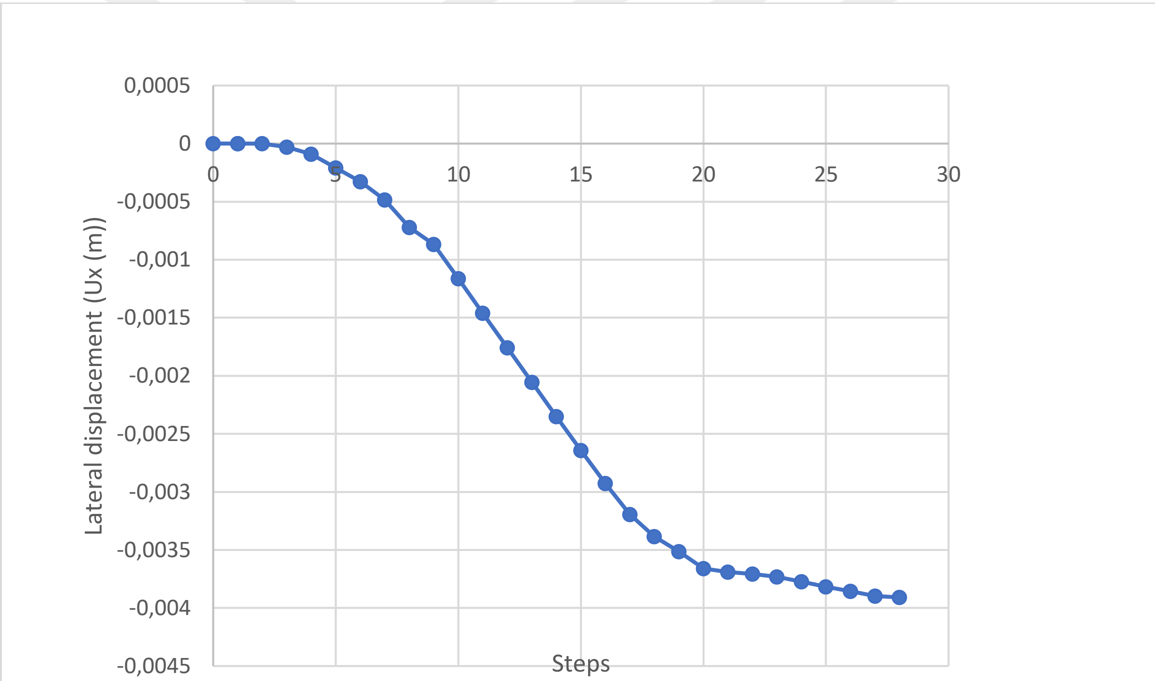

Figure 4.15: Lateral Displacement for Bottom Embankment Node.

Table 4.8: Lateral Displacement for Top Embankment Node.

Point	Step	Step []	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	0.00000000
3	2	2.00	0.00000000
4	3	3.00	-0.00003132
5	4	4.00	-0.00009410
6	5	5.00	-0.00021962
7	6	6.00	-0.00034439
8	7	7.00	-0.00050491
9	8	8.00	-0.00074767
10	9	9.00	-0.00089887

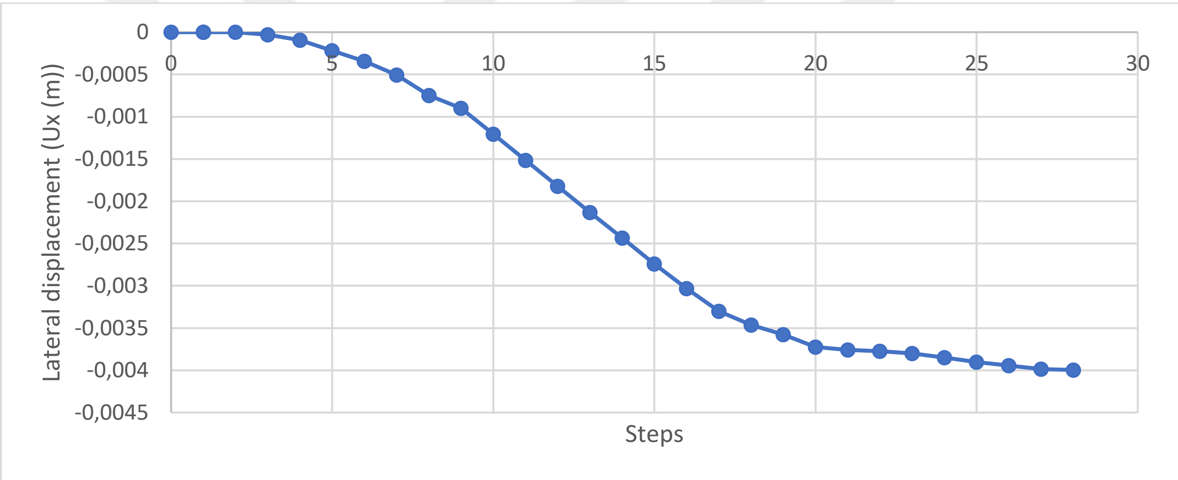

Figure 4.16: Lateral Displacement for Top Embankment Node.

Table 4.9: Lateral Displacement for Face Embankment Node.

Point	Ste p	Step []	u_x [m]
0	0	0.0	N/A
1	1	1.0	0.00000000
2	1	1.0	0.00000000
3	2	2.0	0.00000000
4	3	3.0	-0.00011882
5	4	4.0	-0.00033233
6	5	5.0	-0.00076536
7	6	6.0	-0.00112030
8	7	7.0	-0.00129215
9	8	8.0	-0.00131039
10	9	9.0	-0.00118207

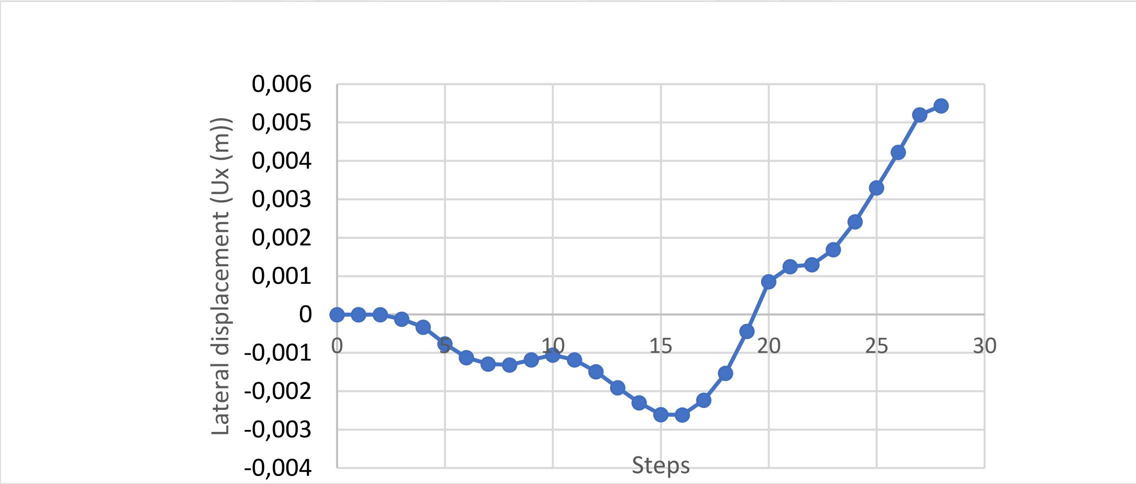

Figure 4.17: Lateral Displacement for Face Embankment Node.

Table 4.10: Vertical Displacement for Bottom Embankment Node.

Point	Step	Step []	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.0000000
2	1	1.00	0.0000000
3	2	2.00	0.0000000
4	3	3.00	-0.0024271
5	4	4.00	-0.0072827
6	5	5.00	-0.0169936
7	6	6.00	-0.0267183
8	7	7.00	-0.0364678
9	8	8.00	-0.0462268
10	9	9.00	-0.0559897

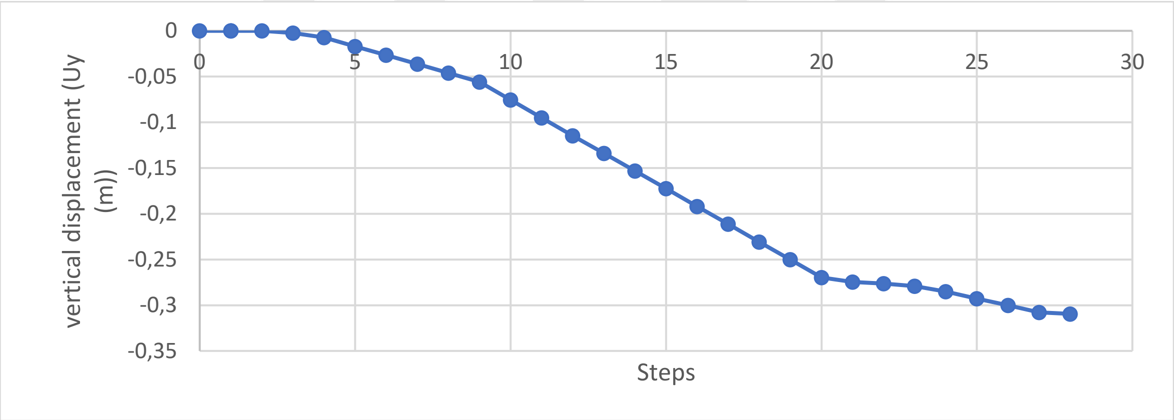

Figure 4.18: Vertical Displacement for Bottom Embankment Node.

Table 4.11: Vertical Displacement for Top Embankment Node.

Point	Step	Step []	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.000000
2	1	1.00	0.000000
3	2	2.00	0.000000
4	3	3.00	-0.002449
5	4	4.00	-0.007348
6	5	5.00	-0.017144
7	6	6.00	-0.026956
8	7	7.00	-0.036792
9	8	8.00	-0.046635
10	9	9.00	-0.056482

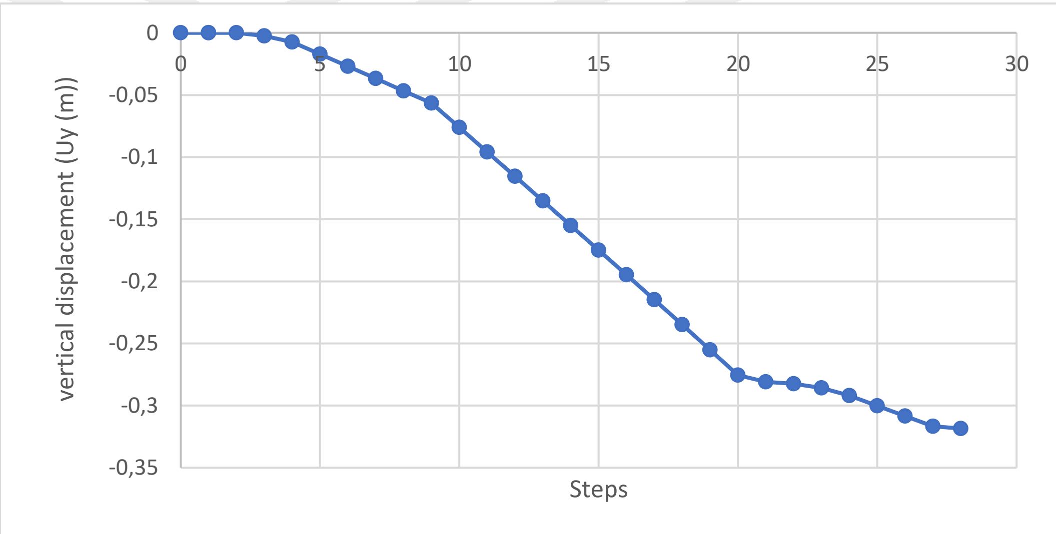

Figure 4.19: Vertical Displacement for Top Embankment Node.

Table 4.12: Vertical Displacement for Face Embankment Node.

Point	Step	Step []	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.0000000
2	1	1.00	0.0000000
3	2	2.00	0.0000000
4	3	3.00	-0.0007551
5	4	4.00	-0.0022448
6	5	5.00	-0.0052284
7	6	6.00	-0.0080726
8	7	7.00	-0.0106694
9	8	8.00	-0.0131935
10	9	9.00	-0.0156581

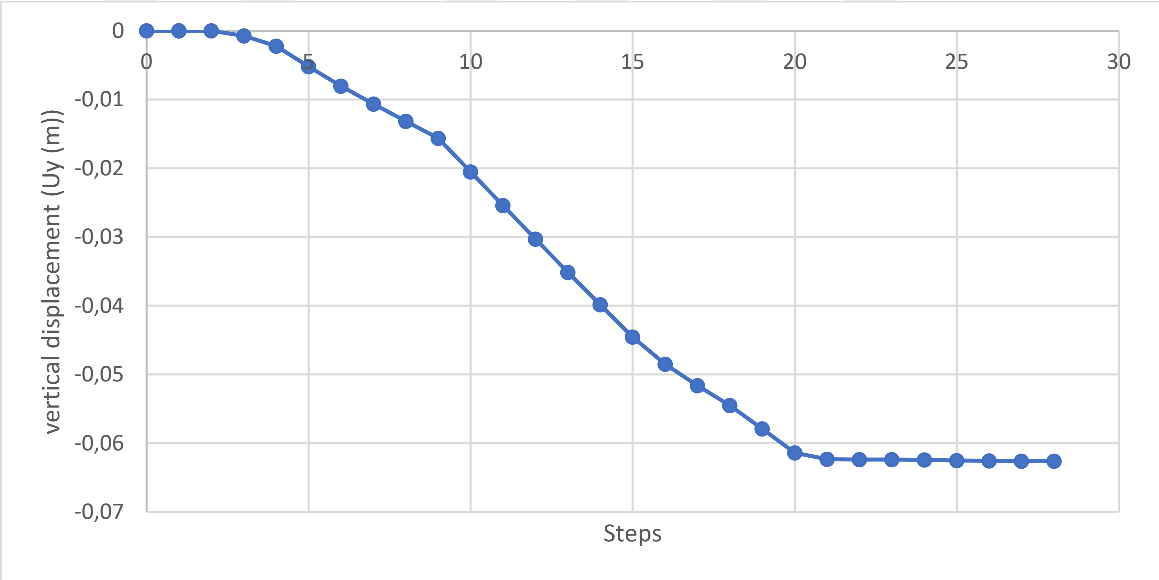

Figure 4.20: Vertical Displacement for Face Embankment Node.

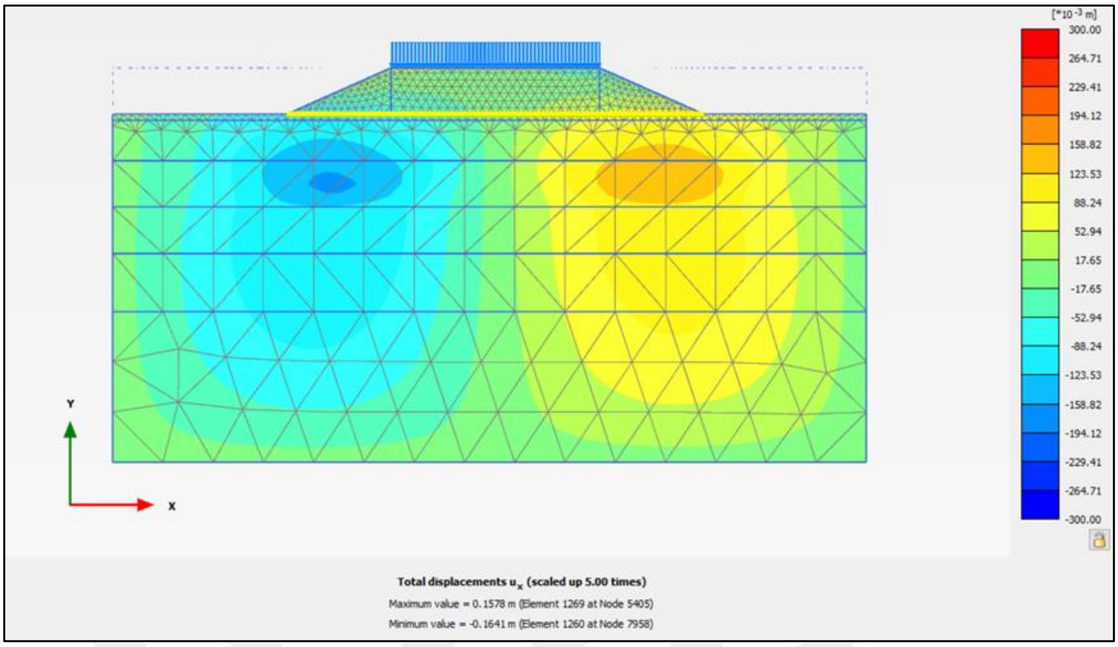

Figure 4.21: Total Horizontal Displacement for Model-II.

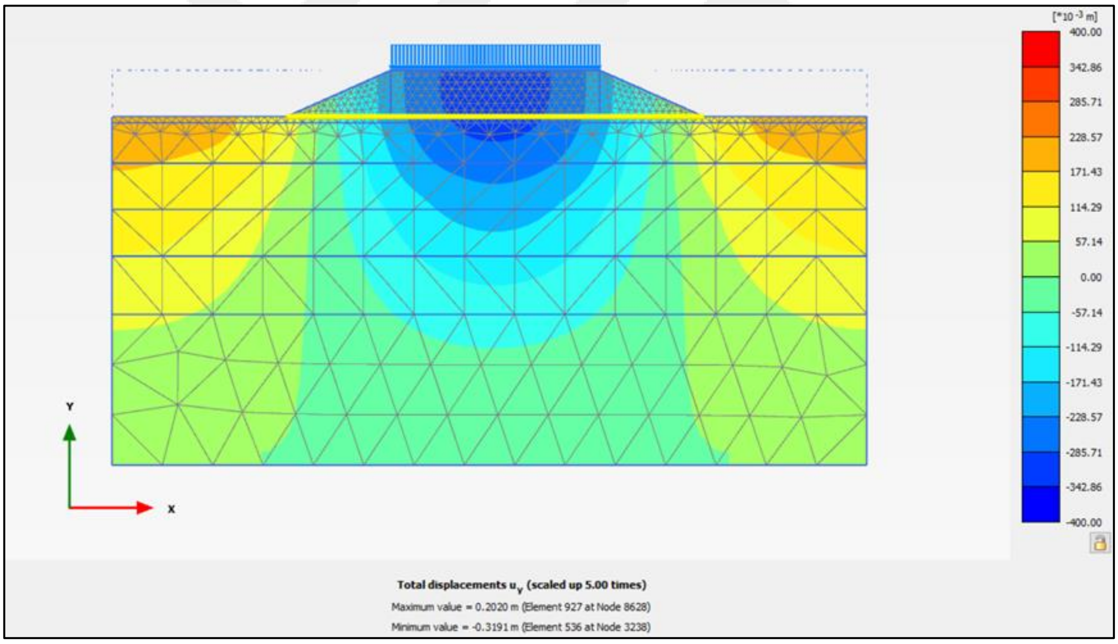

Figure 4.22: Total Vertical Displacement for Model-II.

4.1.1.3 Model-III (geogrid in the center)

Stages of Construction

a. Initial Phase

   i. Installation of half embankment

   ii. Installation of geogrid

iii. Installation of rest of the Embankment

iv. Application of cyclic loads (-5.5 kN/m)

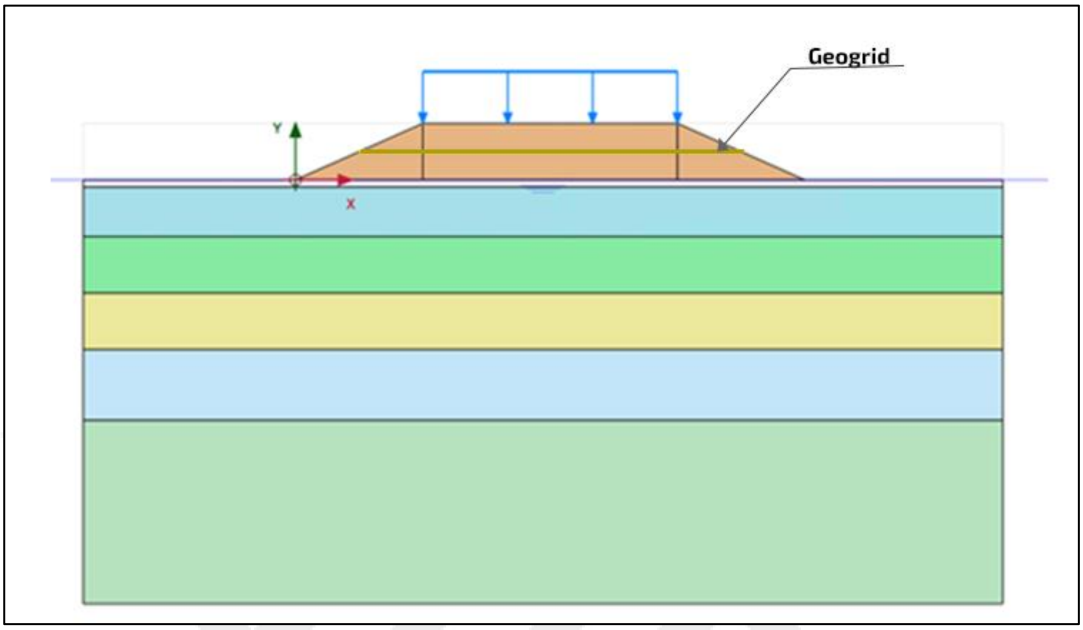

Figure 4.23: Input Soil and Loading for Model-III.

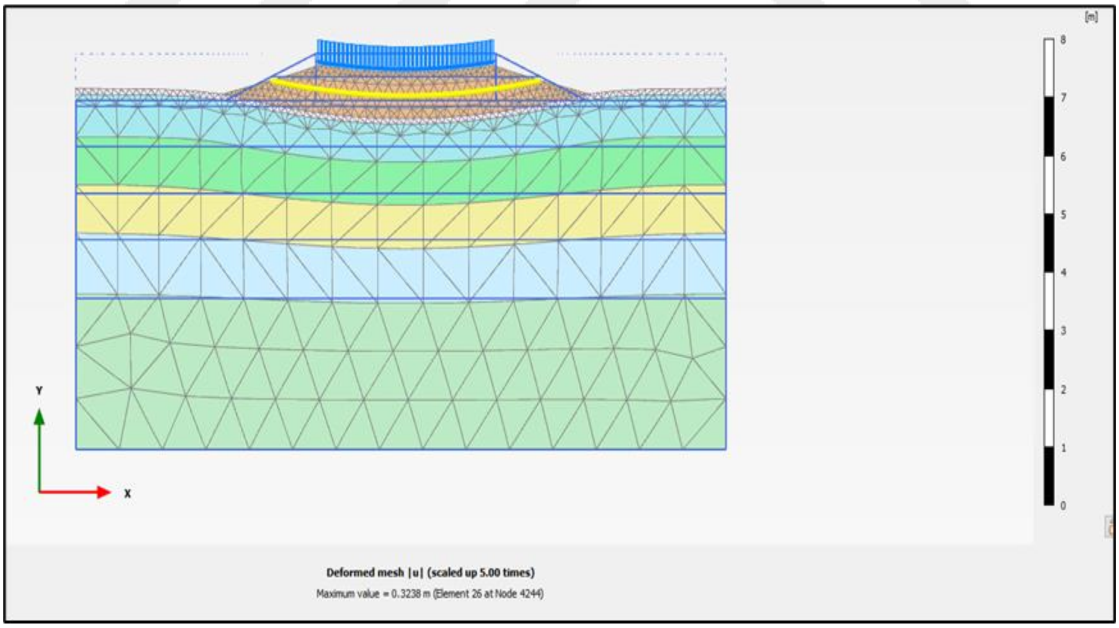

Figure 4.24: Deformed Mesh for Model-III.

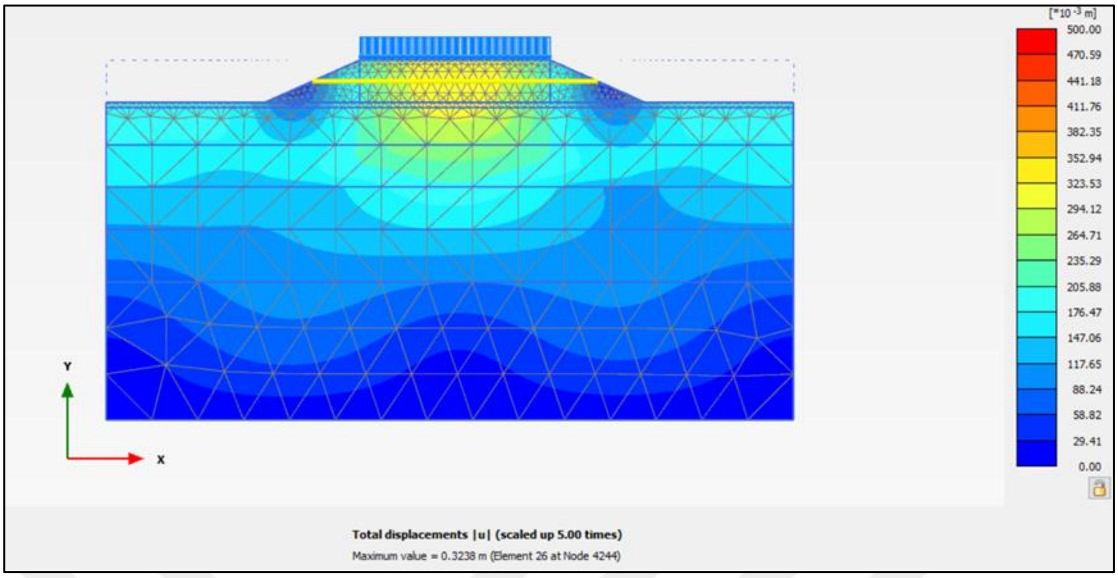

Figure 4.25: Total Displacement for Model-III.

Table 4.13: Lateral Displacement for Bottom Embankments Node.

Point	Step	Step []	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.000000000
2	1	1.00	-0.000029415
3	2	2.00	-0.000088372
4	3	3.00	-0.000206233
5	4	4.00	-0.000442199
6	5	5.00	-0.000848055
7	6	6.00	-0.001254472
8	7	7.00	-0.001612806
9	8	8.00	-0.001957118
10	9	9.00	-0.002104757

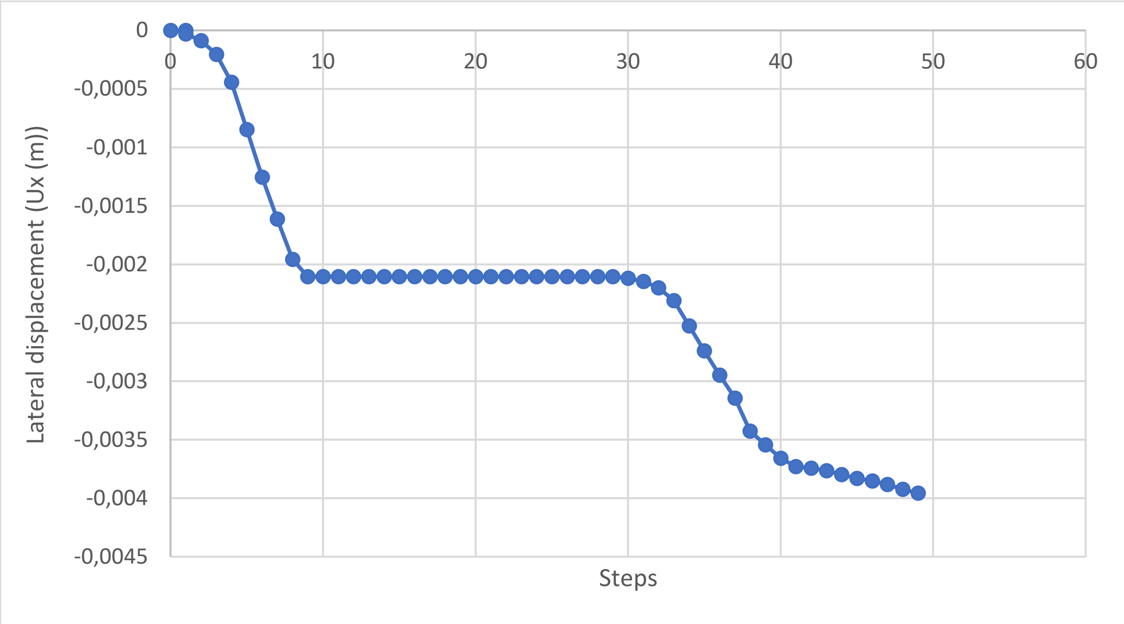

Figure 4.26: Lateral Displacement for Bottom Embankments Node.

Table 4.14: Lateral Displacement for Top Embankments Node.

Point	Step	Step []	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.000000000
2	1	1.00	0.000000000
3	2	2.00	0.000000000
4	3	3.00	0.000000000
5	4	4.00	0.000000000
6	5	5.00	0.000000000
7	6	6.00	0.000000000
8	7	7.00	0.000000000
9	8	8.00	0.000000000
10	9	9.00	0.000000000

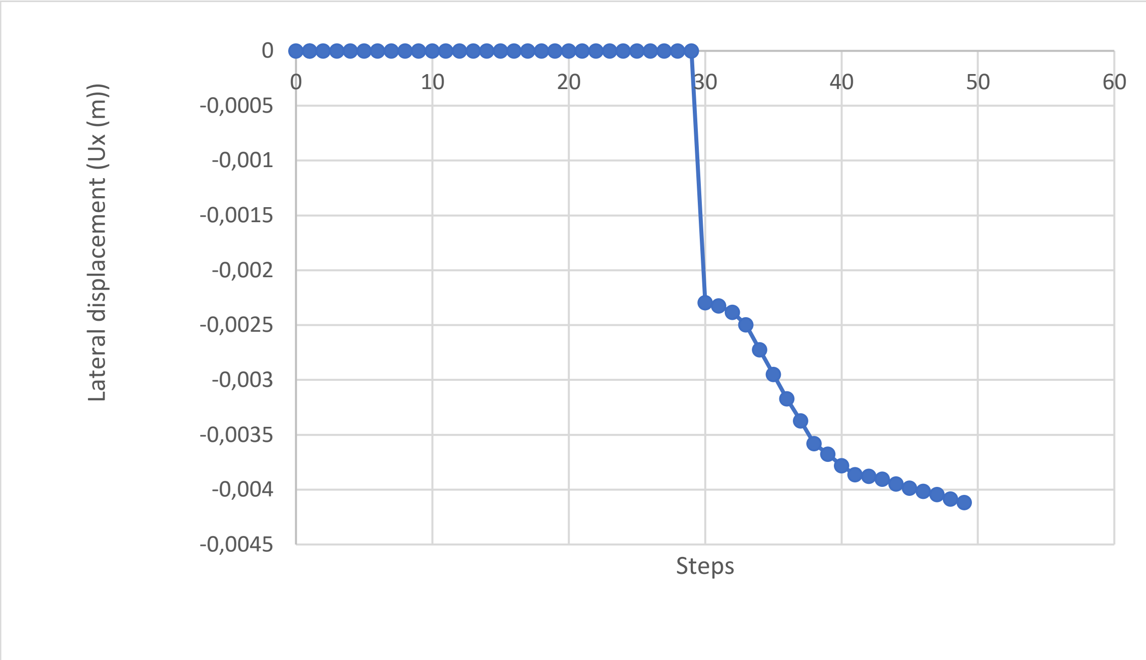

Figure 4.27: Lateral Displacement for Top Embankments Node.

Table 4.15: Lateral Displacement for Face Embankment Node.

Point	Step	Step []	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.000000000
2	1	1.00	-0.000335587
3	2	2.00	-0.001004780
4	3	3.00	-0.002343978
5	4	4.00	-0.005022593
6	5	5.00	-0.007697465
7	6	6.00	-0.009984964
8	7	7.00	-0.012125935
9	8	8.00	-0.014245784
10	9	9.00	-0.015143673
11	10	10.00	-0.015141322
12	11	11.00	-0.015137937
13	12	12.00	-0.015135494
14	13	13.00	-0.015132787
15	14	14.00	-0.015130600

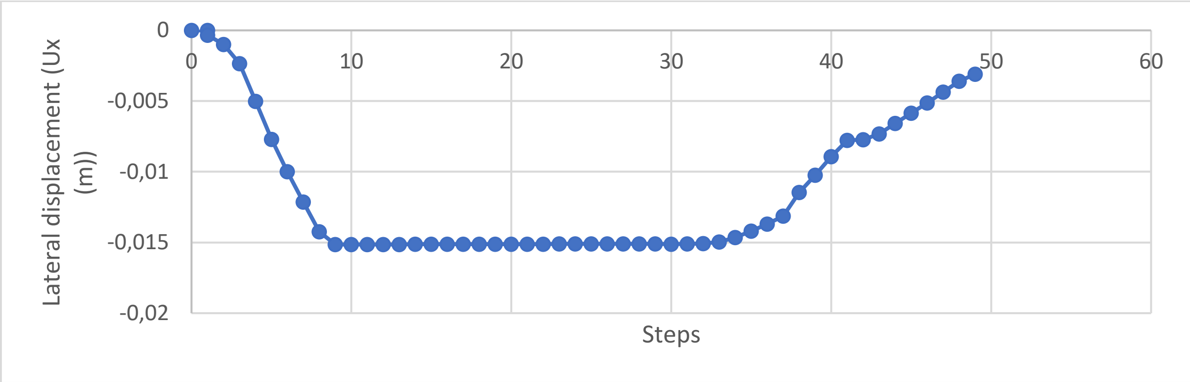

Figure 4.28: Lateral Displacement for Face Embankment Node.

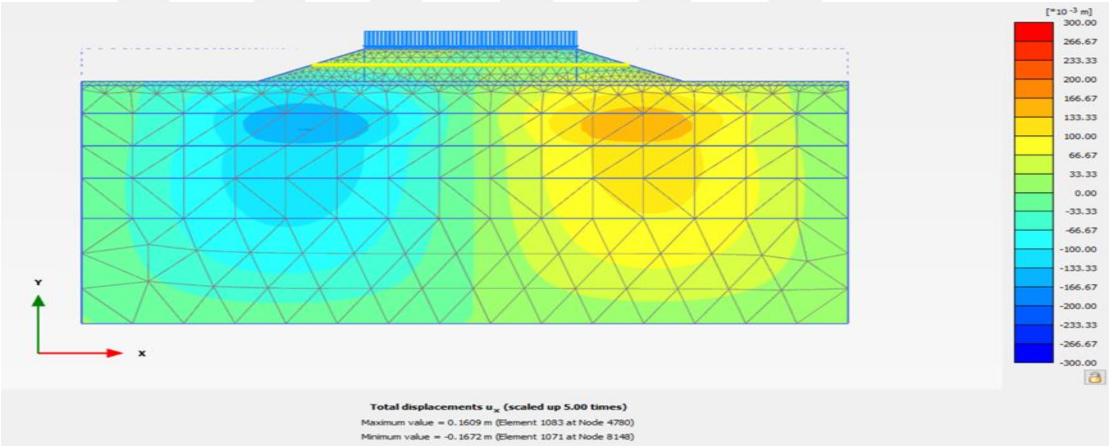

Figure 4.29: Total Lateral Displacement for Model-III.

Table 4.16: Vertical Displacements for Bottom Embankments Node.

Point	Step	Step []	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	-0.00242493
3	2	2.00	-0.00727404
4	3	3.00	-0.01697247
5	4	4.00	-0.03636823
6	5	5.00	-0.05557768
7	6	6.00	-0.07481115
8	7	7.00	-0.09418325
9	8	8.00	-0.11356804
10	9	9.00	-0.12193112

Table 4.17: Vertical Displacements for Face Embankments Node.

Point	Step	Step	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	-0.00089184
3	2	2.00	-0.00267484
4	3	3.00	-0.00623958
5	4	4.00	-0.01336750
6	5	5.00	-0.02063493
7	6	6.00	-0.02812233
8	7	7.00	-0.03575610
9	8	8.00	-0.04352582
10	9	9.00	-0.04691464
11	10	10.00	-0.04691895
12	11	11.00	-0.04692247
13	12	12.00	-0.04692651
14	13	13.00	-0.04692965
15	14	14.00	-0.04693333
16	15	15.00	-0.04693609
17	16	16.00	-0.04693978
18	17	17.00	-0.04694256
19	18	18.00	-0.04694541
20	19	19.00	-0.04694824
21	20	20.00	-0.04695107
22	21	21.00	-0.04695389
23	22	22.00	-0.04695672
24	23	23.00	-0.04695958
25	24	24.00	-0.04696249
26	25	25.00	-0.04696542
27	26	26.00	-0.04696839
28	27	27.00	-0.04697139
29	28	28.00	-0.04697442
30	29	29.00	-0.04697676

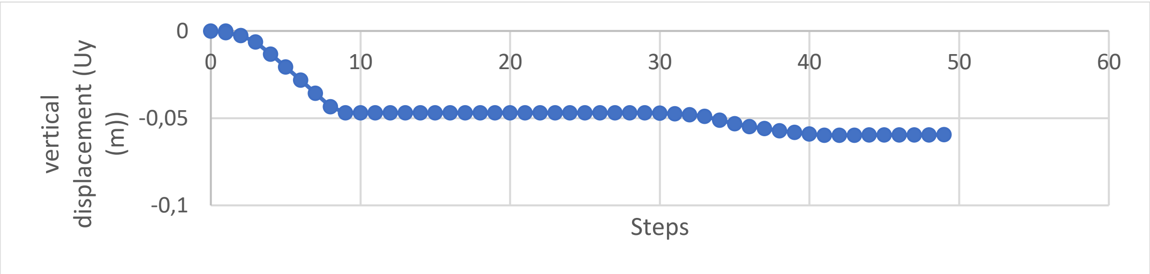

Figure 4.30: Vertical Displacements for Face Embankments Node.

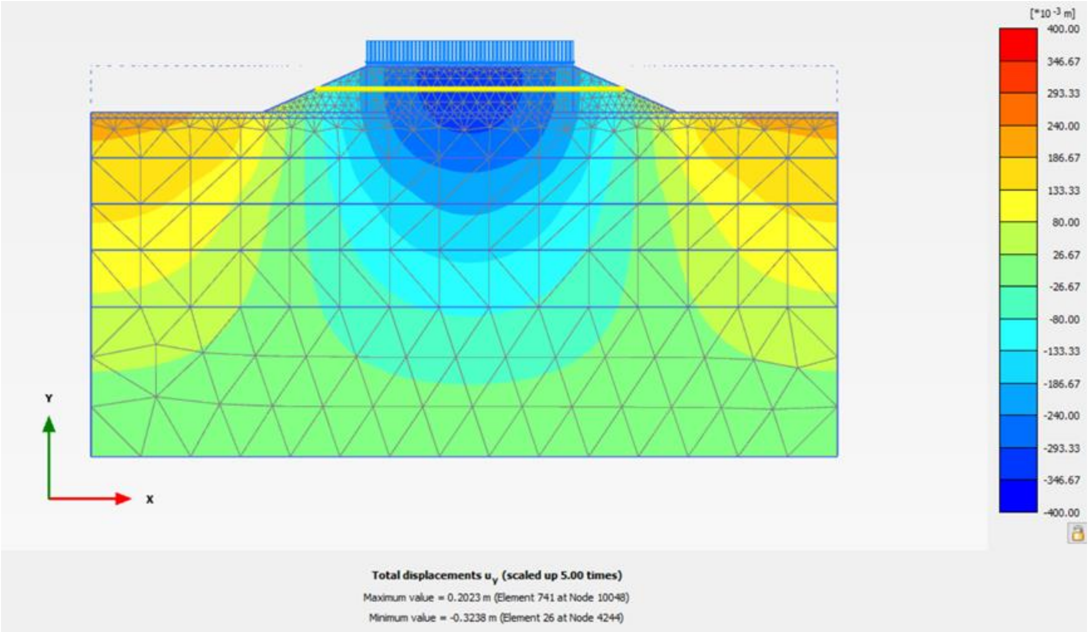

Figure 4.31: Total Vertical Displacement for Model-III.

4.1.1.4 Model- IV (only with recycled concrete)

Stages of Construction

a. Initial Phase

i. Installation of 0.5m concrete layer
ii. Installation of Embankment
iii. Application of cyclic loads (-5.5 kN/m)

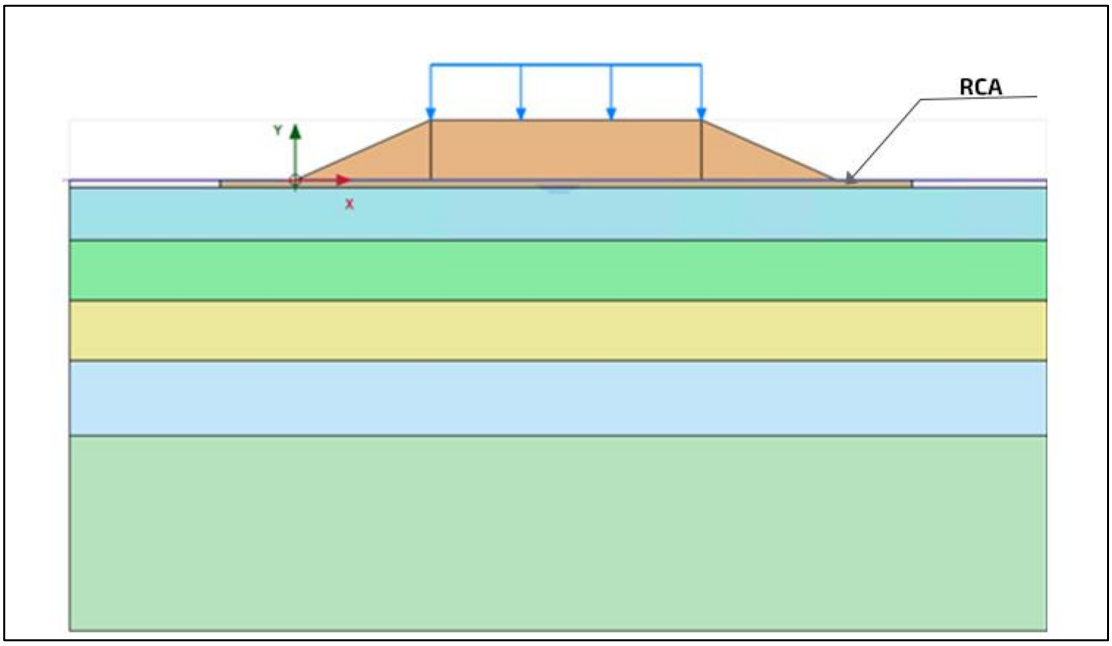

Figure 4.32: Input Soil and Loads for Model- IV.

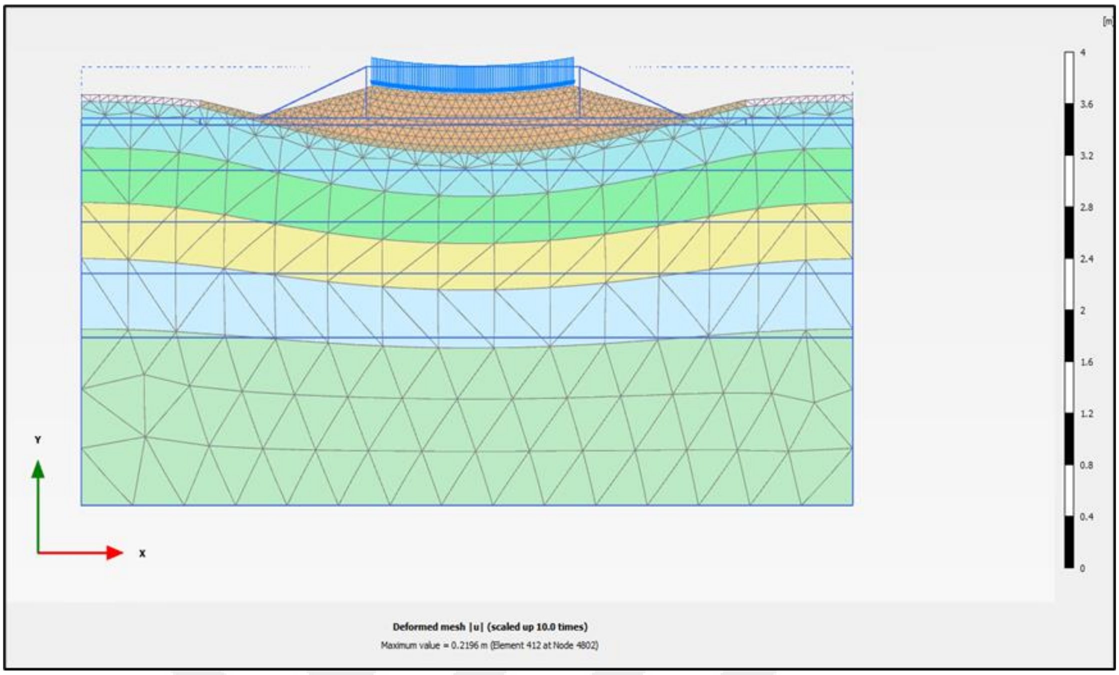

Figure 4.33: Deformed Mesh for Model-IV.

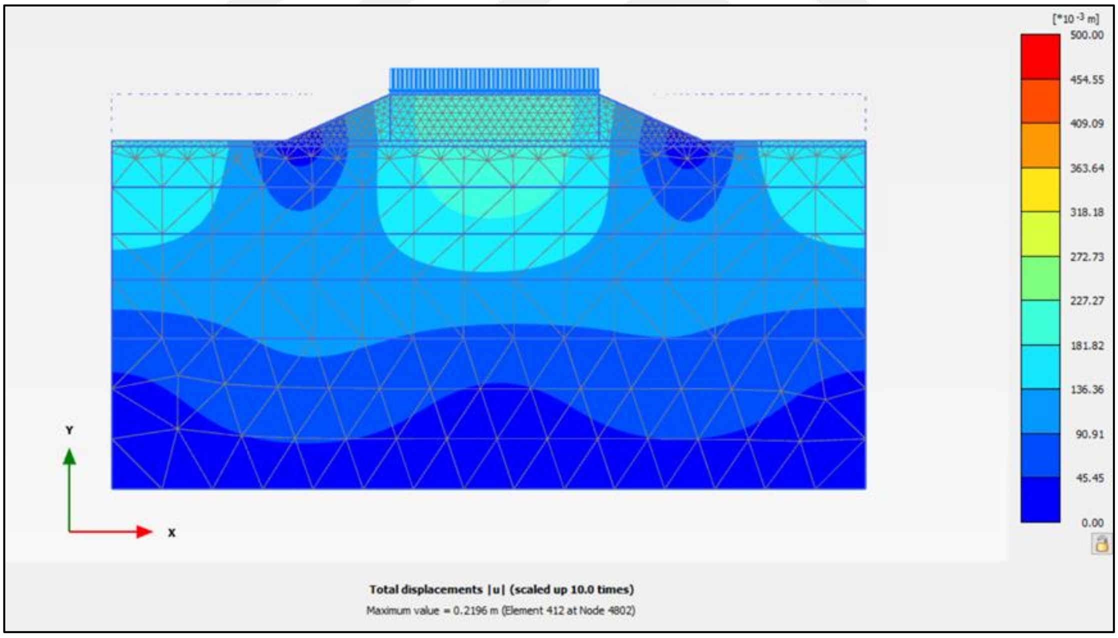

Figure 4.34: Total Displacement for Model-Iv.

Table 4.18: Lateral Displacement for Bottom Embankment Node.

Point	Step	Step []	U_X [M]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	-0.00000419
3	2	2.00	-0.00000839
4	3	3.00	-0.00014124
5	4	4.00	-0.00027534
6	5	5.00	-0.00041598
7	6	6.00	-0.00056735
8	7	7.00	-0.00071614
9	8	8.00	-0.00101957
10	9	9.00	-0.00132620
11	10	10.00	-0.00163971
12	11	11.00	-0.00200071
13	12	12.00	-0.00204783
14	13	13.00	-0.00211797
15	14	14.00	-0.00220751
16	15	15.00	-0.00222719

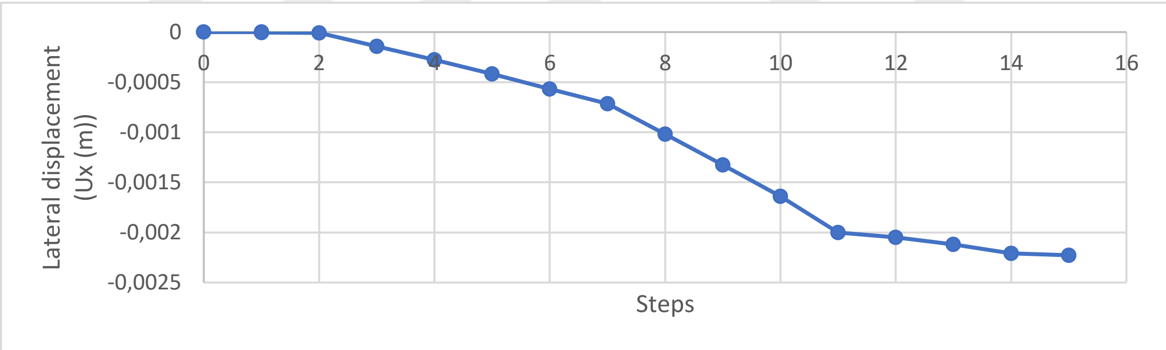

Figure 4.35: Lateral Displacement for Bottom Embankment Node.

Table 4.19: Lateral Displacement for Top Embankment Node.

Point	Step	Step []	u_x [m]
0	0	0.0	N/A
1	1	1.0	0.000000000
2	1	1.0	0.000000000
3	2	2.0	0.000000000
4	3	3.0	-0.000158862
5	4	4.0	-0.000309703
6	5	5.0	-0.000467440
7	6	6.0	-0.000635518
8	7	7.0	-0.000800935
9	8	8.0	-0.001136702
10	9	9.0	-0.001475127
11	10	10.0	-0.001819732
12	11	11.0	-0.002210160
13	12	12.0	-0.002260241
14	13	13.0	-0.002334047
15	14	14.0	-0.002427196
16	15	15.0	-0.002447581

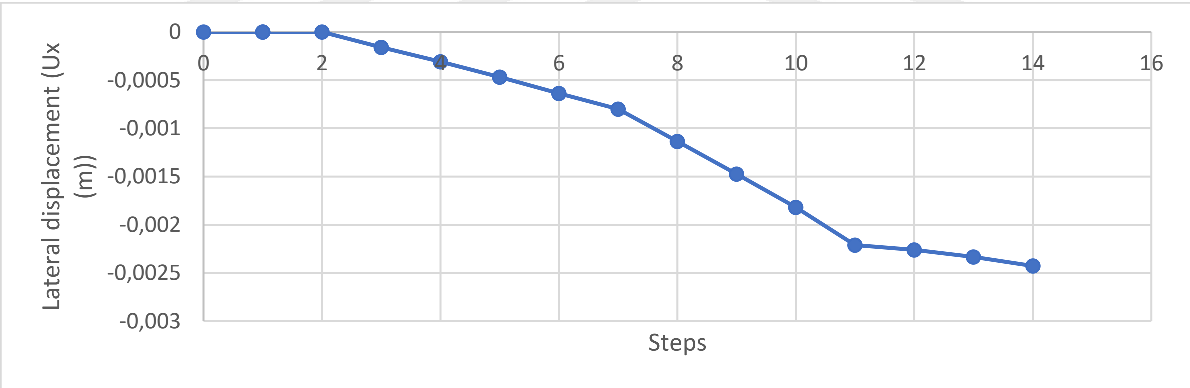

Figure 4.36: Lateral Displacement for Top Embankment Node.

Table 4.20: Lateral Displacement for Face Embankment Node.

Point	Step	Step	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.000000000
2	1	1.00	0.000000000
3	2	2.00	0.000000000
4	3	3.00	-0.002781420
5	4	4.00	-0.005506386
6	5	5.00	-0.008404714
7	6	6.00	-0.011436549
8	7	7.00	-0.014486766
9	8	8.00	-0.020533003
10	9	9.00	-0.026467535
11	10	10.00	-0.032334034
12	11	11.00	-0.038191234
13	12	12.00	-0.038885055
14	13	13.00	-0.039934167
15	14	14.00	-0.040994975
16	15	15.00	-0.041216141

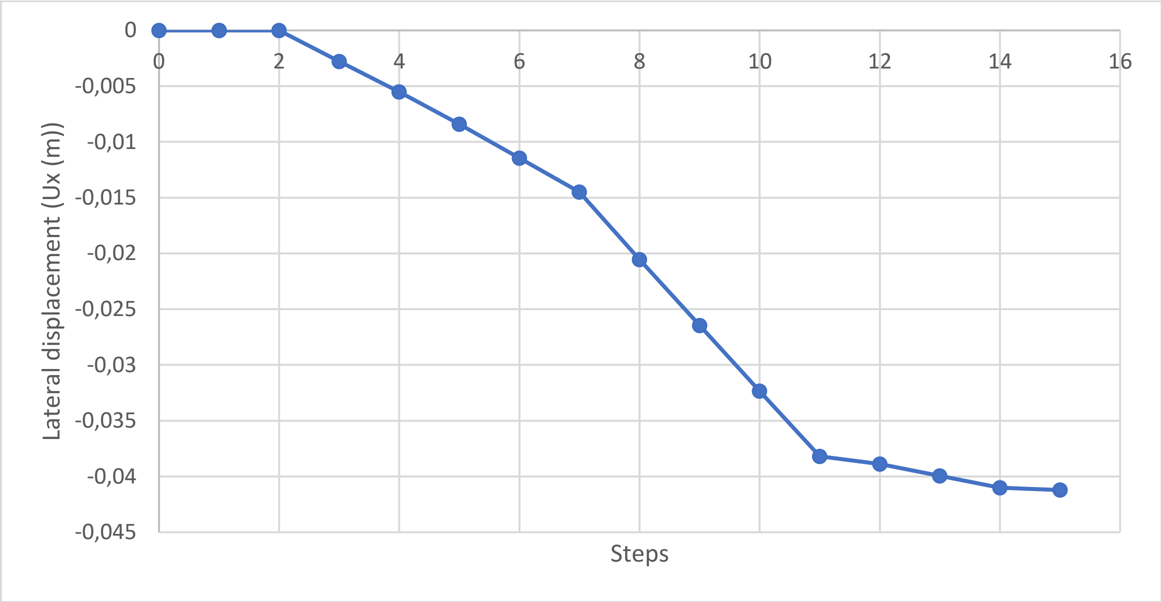

Figure 4.37: Lateral Displacement for Face Embankment Node.

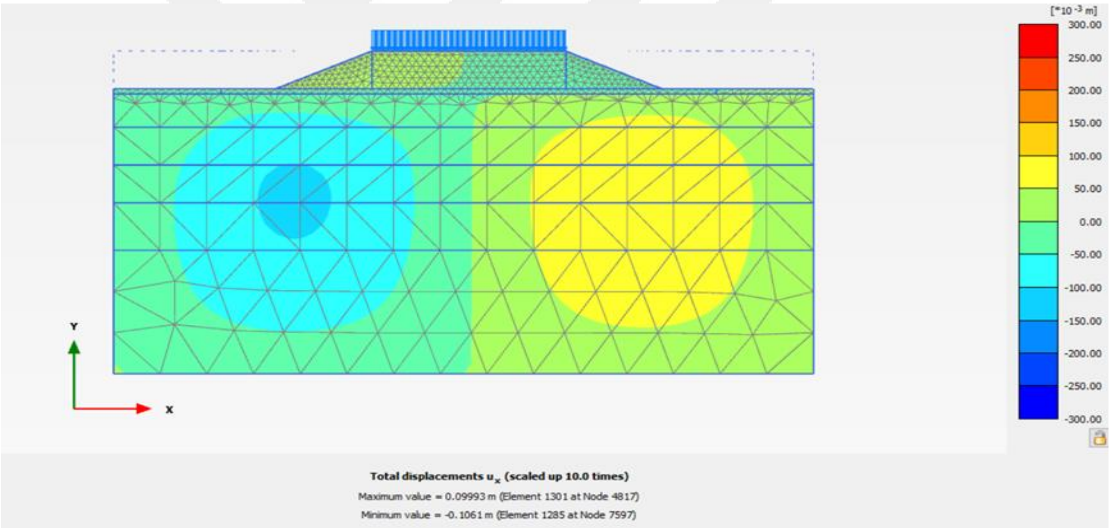

Figure 4.38: Total Lateral Displacement for Model IV.

Table 4.21: Vertical Displacement for Top Embankment Node.

Point	Step	Step	u_y [m]
0	0	0.0	N/A
1	1	1.0	0.00000000
2	1	1.0	0.00000000
3	2	2.0	0.00000000
4	3	3.0	-0.01583324
5	4	4.0	-0.03120282
6	5	5.0	-0.04669356
7	6	6.0	-0.06225883
8	7	7.0	-0.07785063
9	8	8.0	-0.10903832
10	9	9.0	-0.14020217
11	10	10.0	-0.17136463
12	11	11.0	-0.20254130
13	12	12.0	-0.20621901
14	13	13.0	-0.21214204
15	14	14.0	-0.21808108
16	15	15.0	-0.21927335

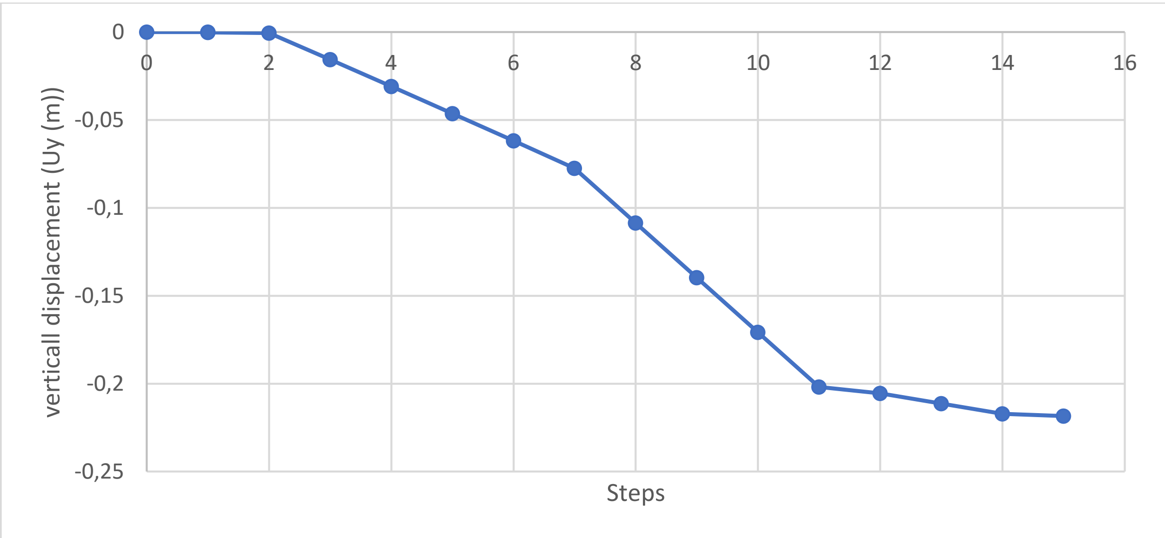

Figure 4.39: Vertical Displacement for Top Embankment Node.

Table 4.22: Vertical Displacement for Face Embankment Node.

Point	Step	Step	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	0.00000000
3	2	2.00	0.00000000
4	3	3.00	-0.00633655
5	4	4.00	-0.01230048
6	5	5.00	-0.01765967
7	6	6.00	-0.02265939
8	7	7.00	-0.02752386
9	8	8.00	-0.03711211
10	9	9.00	-0.04664090
11	10	10.00	-0.05614914
12	11	11.00	-0.06553765
13	12	12.00	-0.06662287
14	13	13.00	-0.06799639
15	14	14.00	-0.06929928
16	15	15.00	-0.06956082

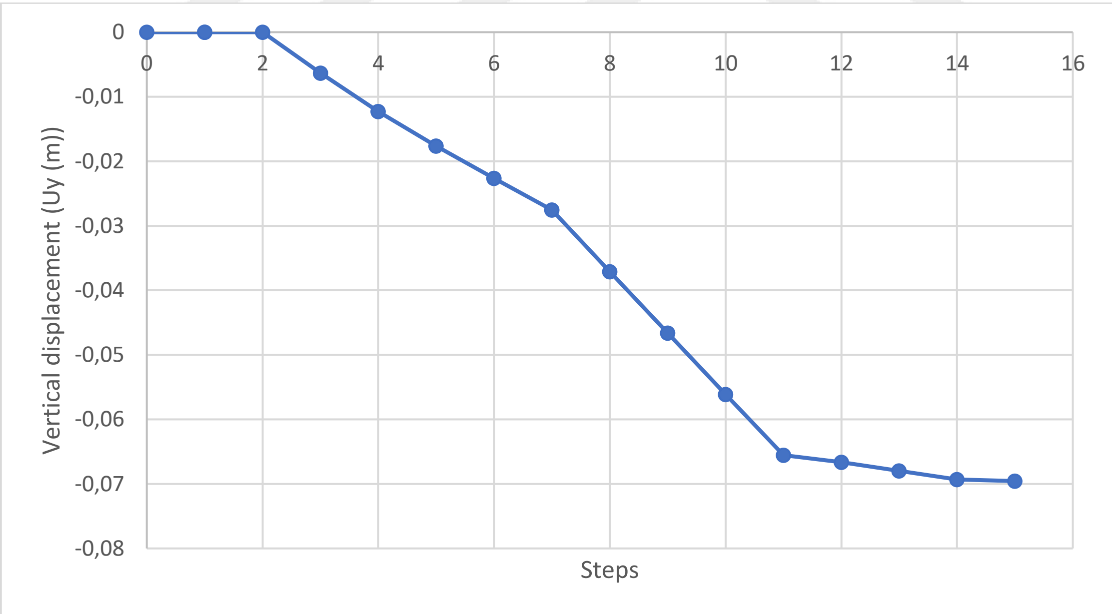

Figure 4.40: Vertical Displacement for Face Embankment Node.

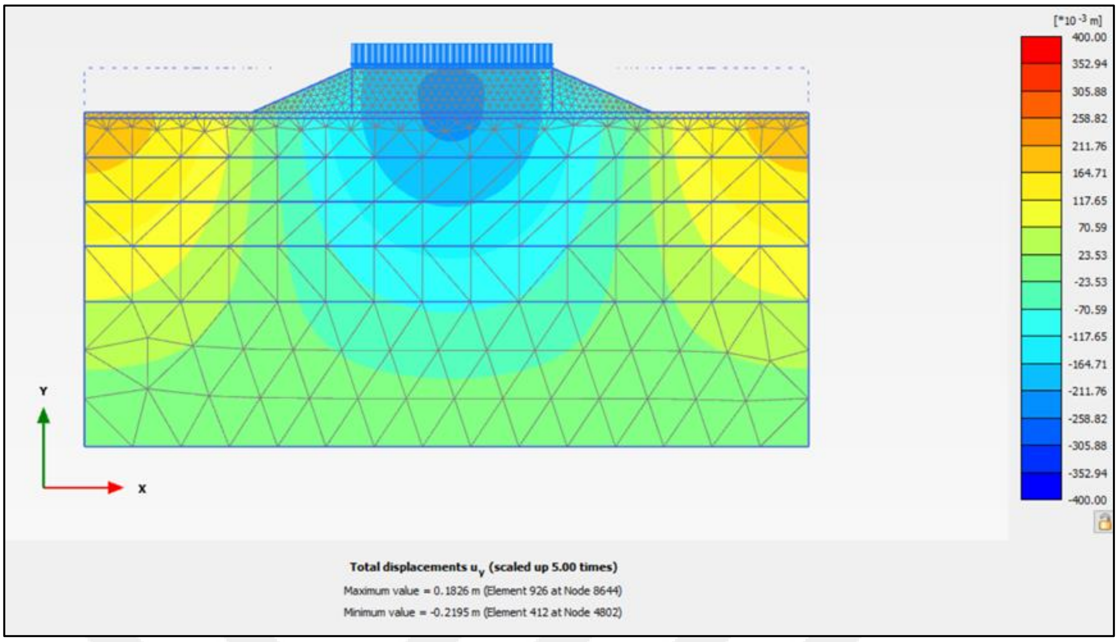

Figure 4.41: Total Vertical Displacement for Model-IV.

4.1.1.5 Model- V (RCA + geogrid)

Stages of Construction

a. Initial Phase

i. Installation of 0.5m concrete layer

ii. Installation of Geogrid on top of the Recycled Concrete layer

iii. Installation of Embankment

iv. Application of cyclic loads (-5.5 kN/m)

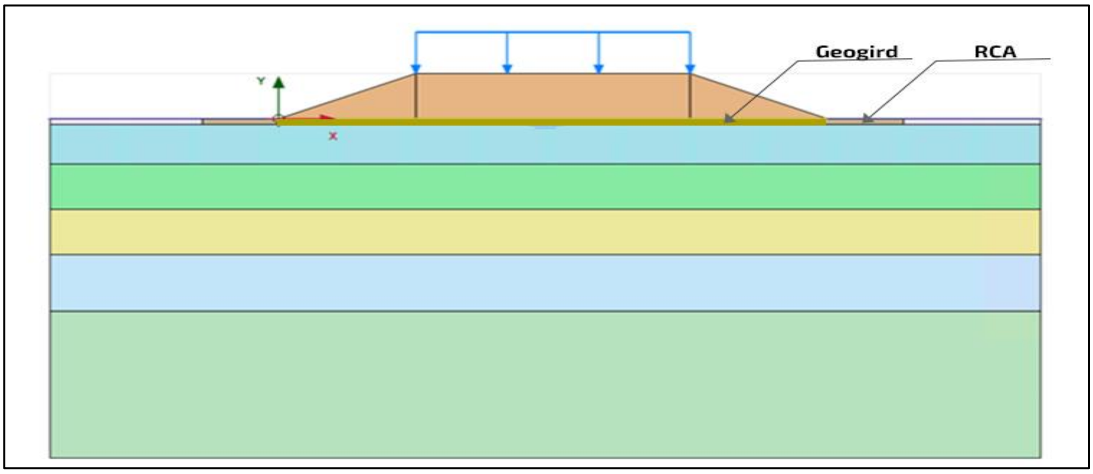

Figure 4.42: Input Construction Stage for Model-V.

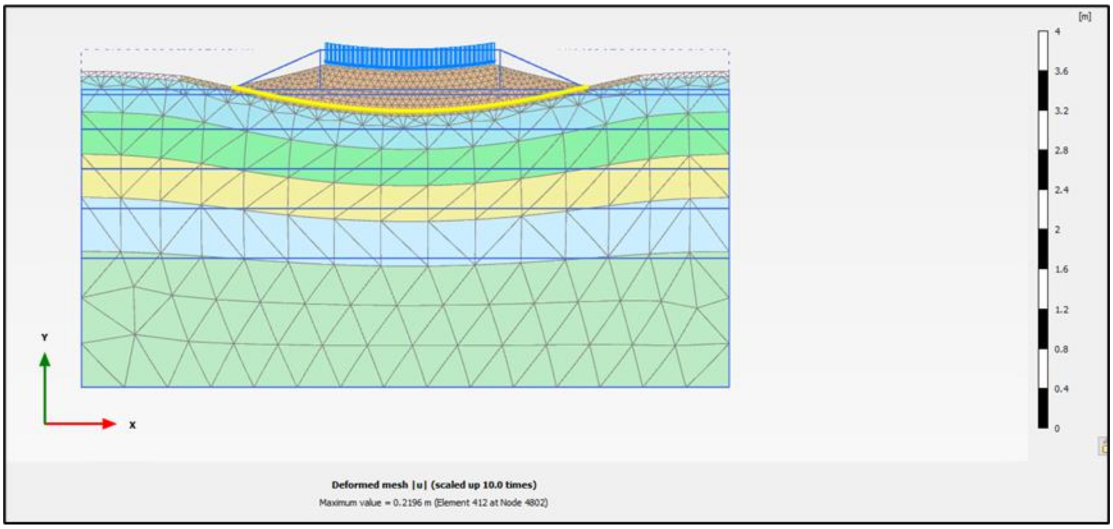

Figure 4.43: Deformed Mesh for Model-V.

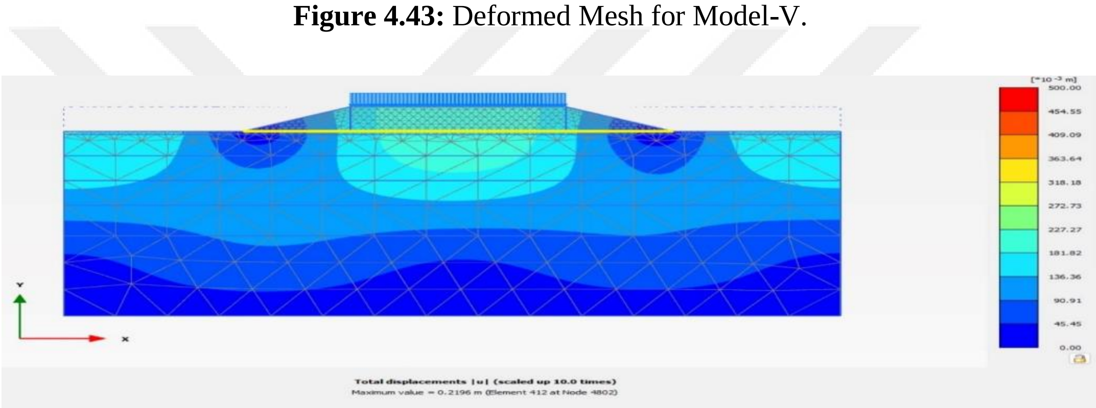

Figure 4.44: Total Displacement for Model-V.

Table 4.23: Lateral Displacements for Bottom Embankments Node.

Point	Step	Step	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.0000000
2	1	1.00	-0.0000042
3	2	2.00	-0.0000084
4	3	3.00	-0.0000084
5	4	4.00	-0.0000084
6	5	5.00	-0.0001413
7	6	6.00	-0.0002754
8	7	7.00	-0.0004161
9	8	8.00	-0.0005675
10	9	9.00	-0.0007163

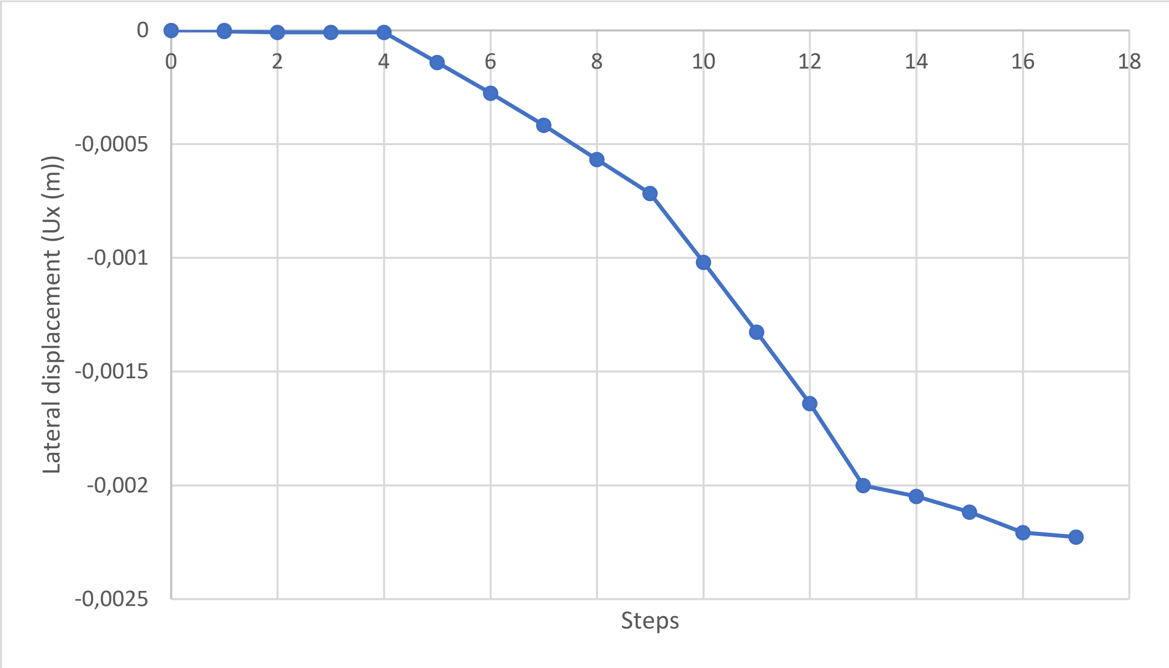

Figure 4.45: Lateral Displacements for Bottom Embankments Node.

Table 4.24: Lateral Displacements for Top Embankments Node.

Point	Step	Step	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	0.00000000
3	2	2.00	0.00000000
4	3	3.00	0.00000000
5	4	4.00	0.00000000
6	5	5.00	-0.00015889
7	6	6.00	-0.00030976
8	7	7.00	-0.00046753
9	8	8.00	-0.00063564
10	9	9.00	-0.00080109

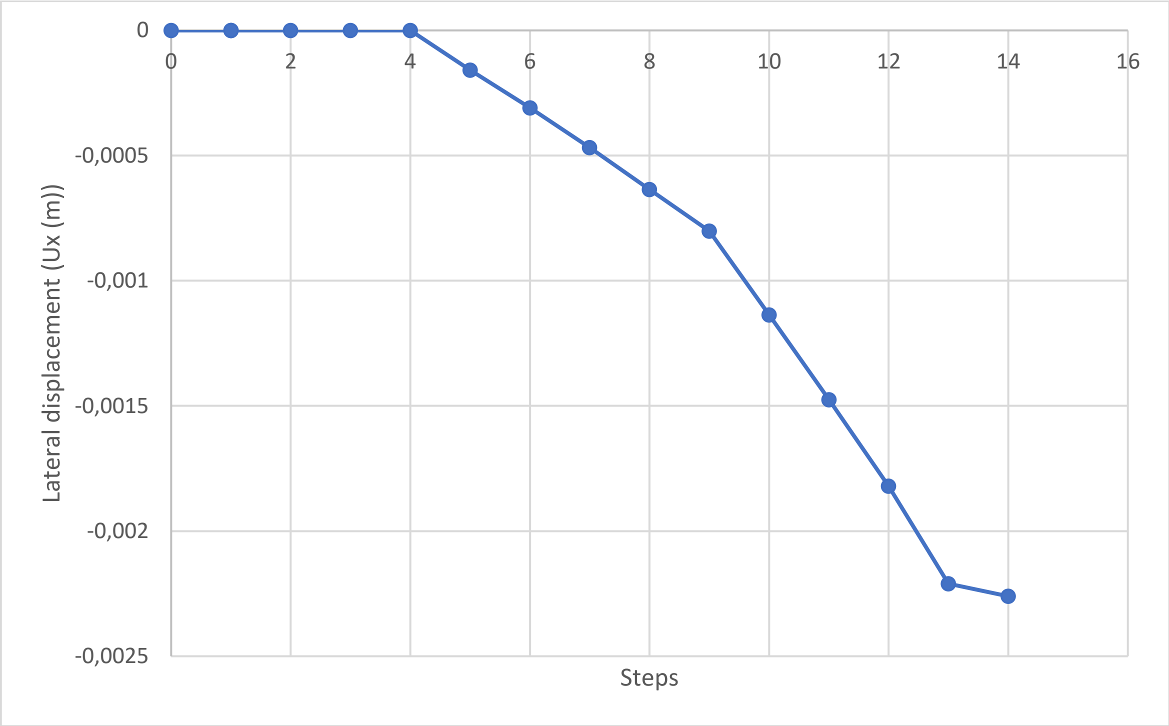

Figure 4.46: Lateral Displacements for Top Embankments Node.

Table 4.25: Lateral Displacements for Face Embankments Node.

Point	Step	Step	u_x [m]
0	0	0.00	N/A
1	1	1.00	0.000000
2	1	1.00	0.000000
3	2	2.00	0.000000
4	3	3.00	0.000000
5	4	4.00	0.000000
6	5	5.00	-0.002782
7	6	6.00	-0.005507
8	7	7.00	-0.008406
9	8	8.00	-0.011439
10	9	9.00	-0.014490

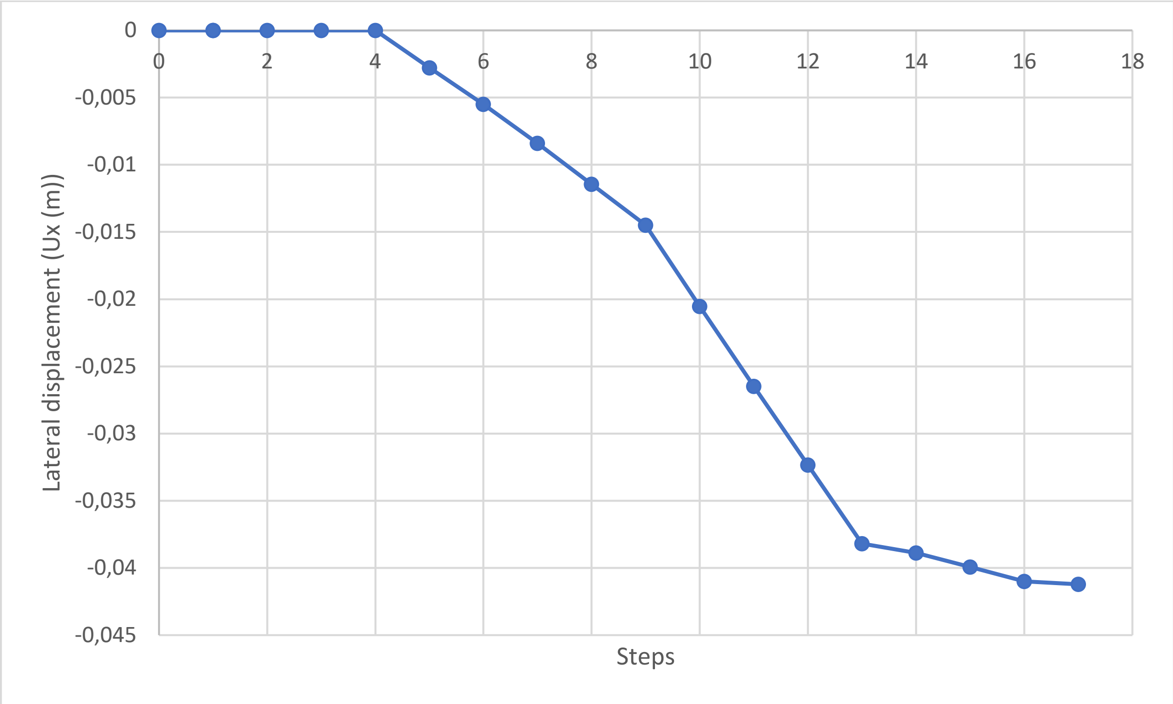

Figure 4.47: Lateral Displacements for Face Embankments Node.

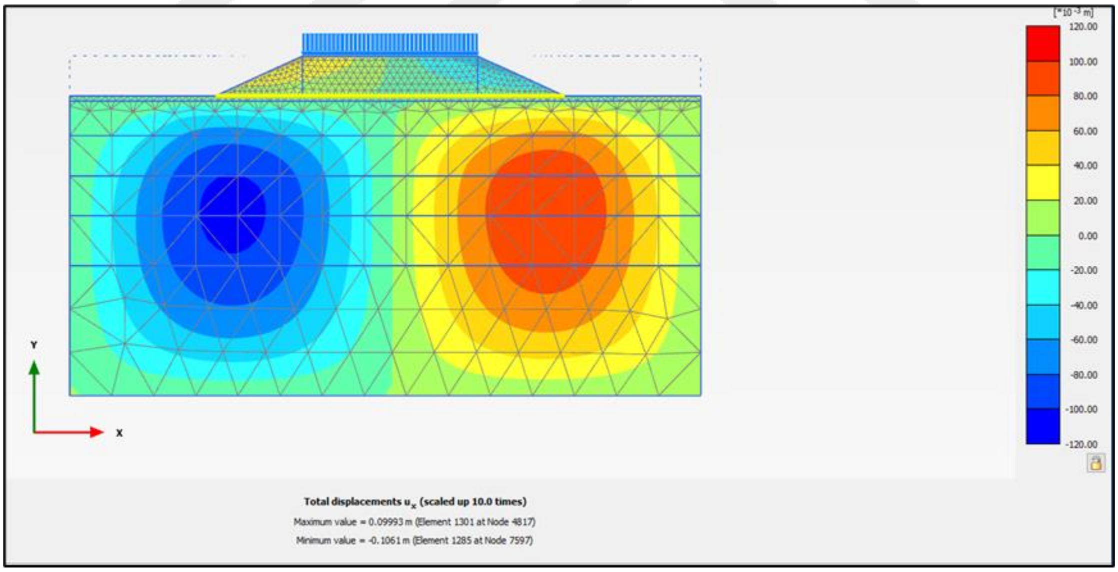

Figure 4.48: Total Lateral Displacement for Model-V.

Table 4.26: Vertical Displacements for Bottom Embankments Node.

Point	Step	Step	u_y [m]
0	0	0.0	N/A
1	1	1.0	0.00000000
2	1	1.0	-0.00028739
3	2	2.0	-0.00057477
4	3	3.0	-0.00057477
5	4	4.0	-0.00057477
6	5	5.0	-0.01574832
7	6	6.0	-0.03102946
8	7	7.0	-0.04644009
9	8	8.0	-0.06193371
10	9	9.0	-0.07745828

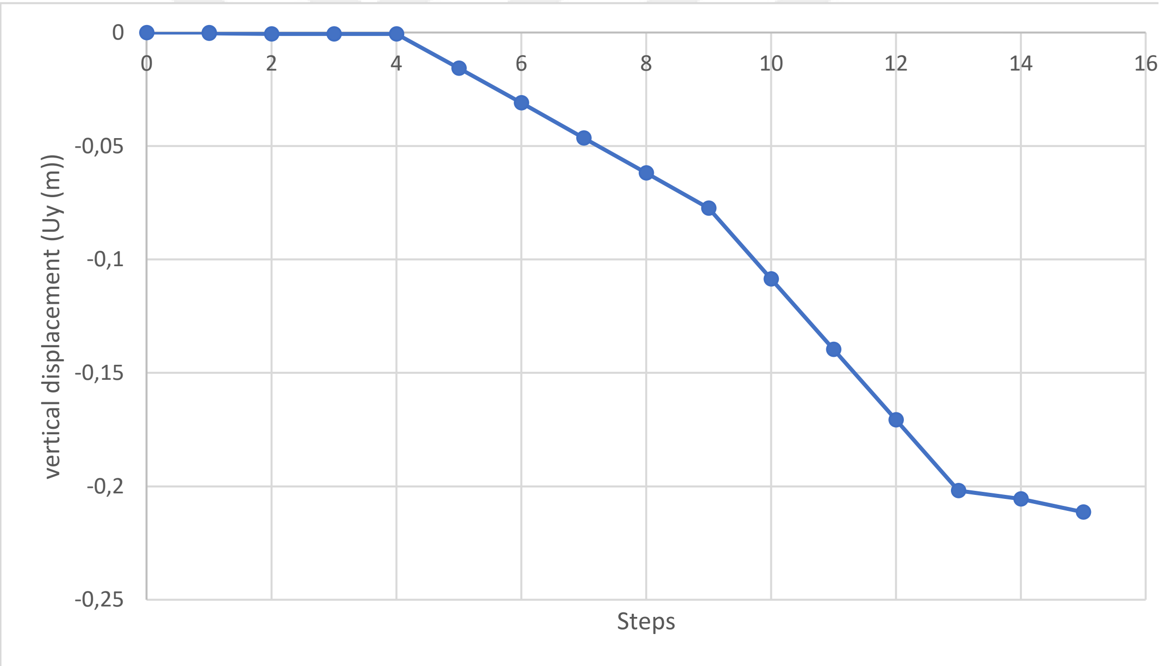

Figure 4.49: Vertical Displacements for Bottom Embankments Node.

Table 4.27: Vertical Displacements for Top Embankments Node.

Point	Step	Step	u_y [m]
0	0	0.00	N/A
1	1	1.00	0.00000000
2	1	1.00	0.00000000
3	2	2.00	0.00000000
4	3	3.00	0.00000000
5	4	4.00	0.00000000
6	5	5.00	-0.01583596
7	6	6.00	-0.03120845
8	7	7.00	-0.04670216
9	8	8.00	-0.06227039
10	9	9.00	-0.07786514
11	10	10.00	-0.10905869

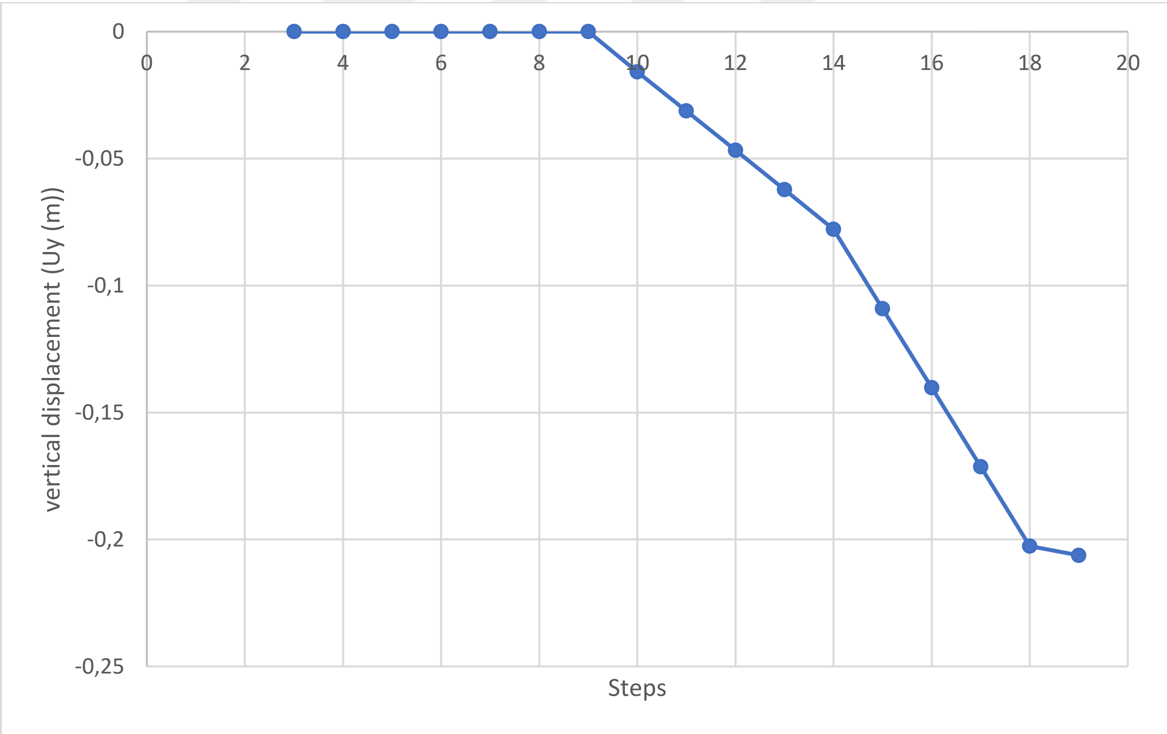

Figure 4.50: Vertical Displacements for Top Embankments Node.

Table 4.28: Vertical Displacements for Face Embankments Node.

Point	Step	Step	u_y [m]
0	0	0.0	N/A
1	1	1.0	0.000000000
2	1	1.0	0.000000000
3	2	2.0	0.000000000
4	3	3.0	0.000000000
5	4	4.0	0.000000000
6	5	5.0	-0.006337618
7	6	6.0	-0.012302565
8	7	7.0	-0.017662514
9	8	8.0	-0.022663032
10	9	9.0	-0.027528348

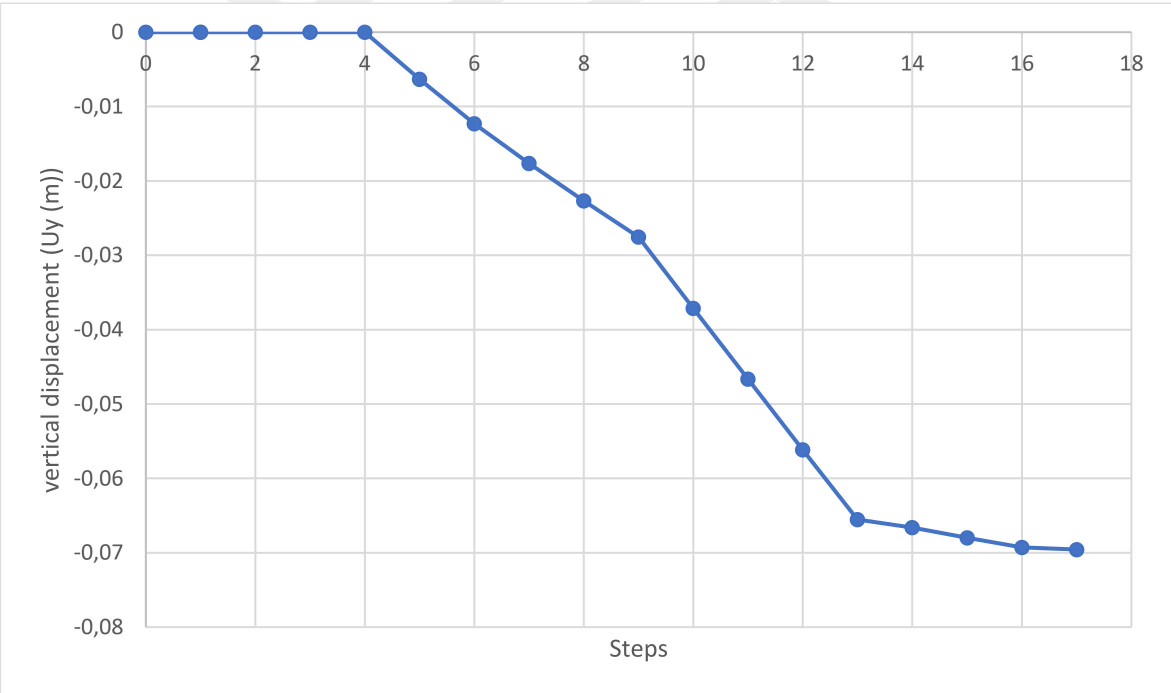

Figure 4.51: Vertical Displacements for Face Embankments Node.

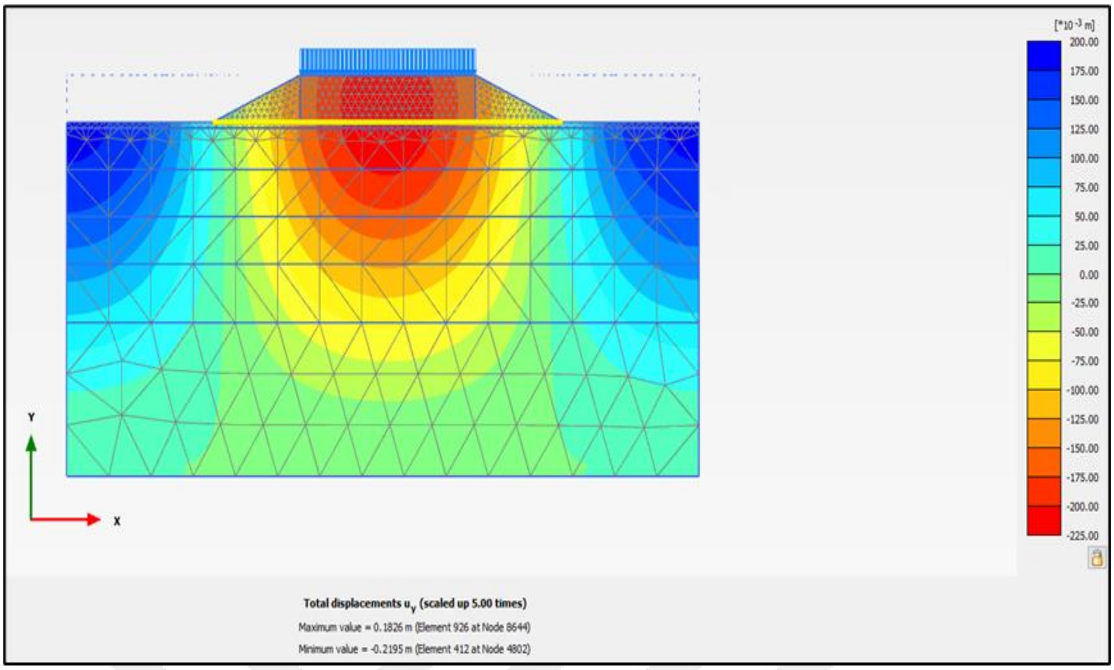

Figure 4.52: Total Vertical Displacement for Model-V.

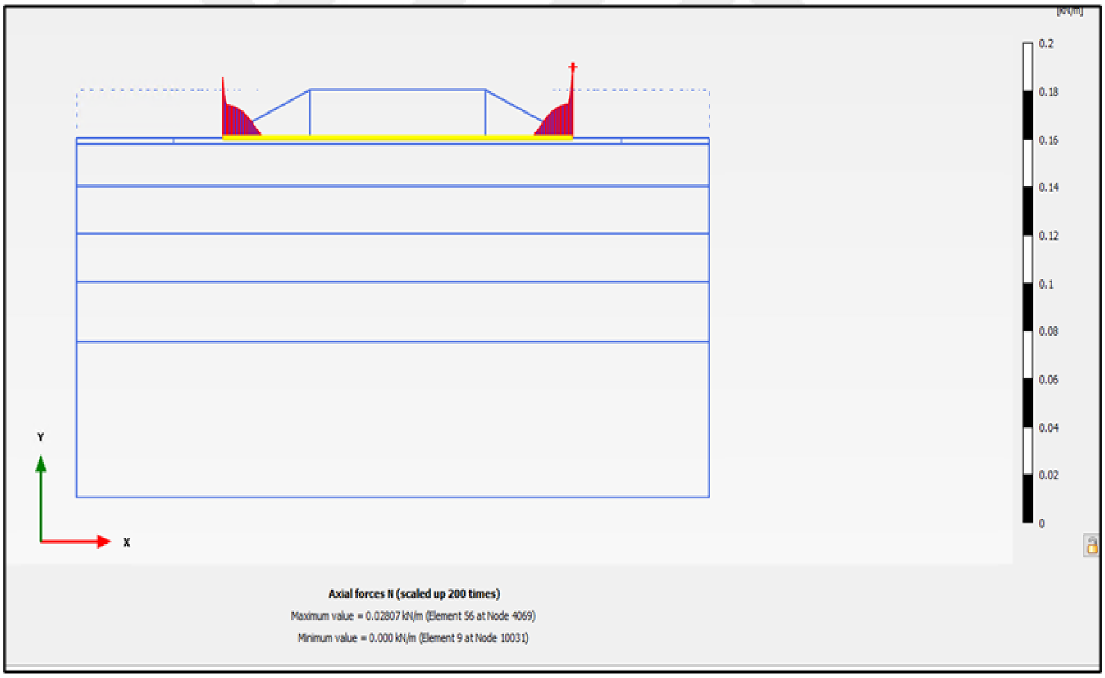

Figure 4.53: Axial Forces in the Geogrid.

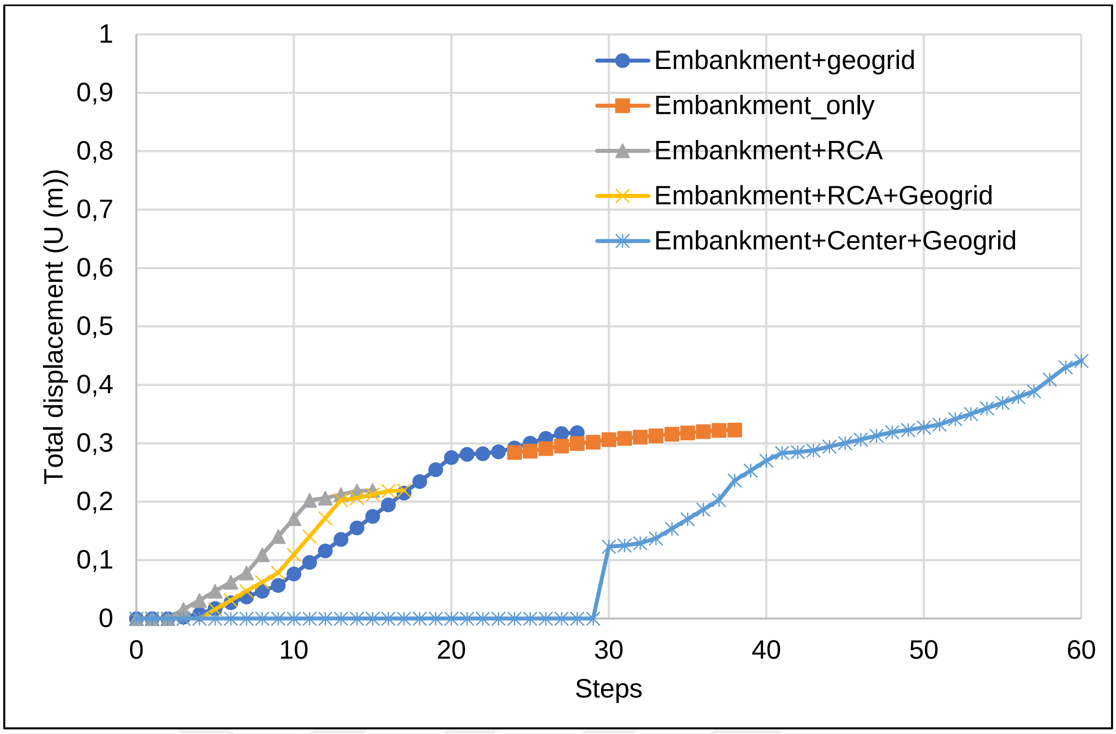

Figure 4.54: Comparison of Results Total Displacement.

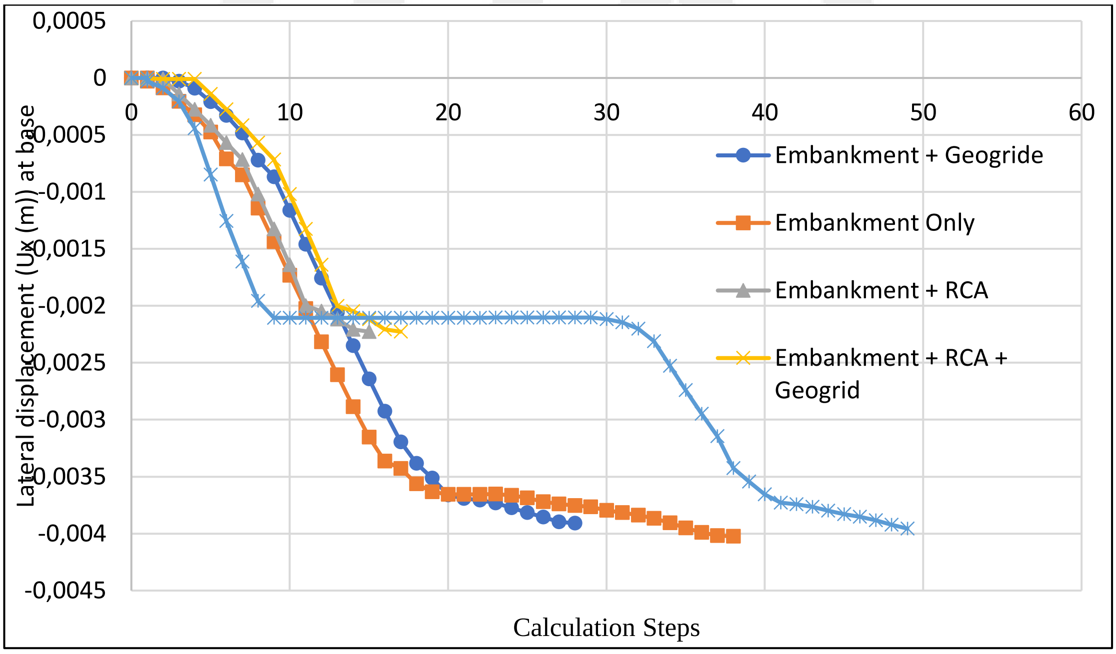

Figure 4.55: Comparison of Results Lateral Displacement.

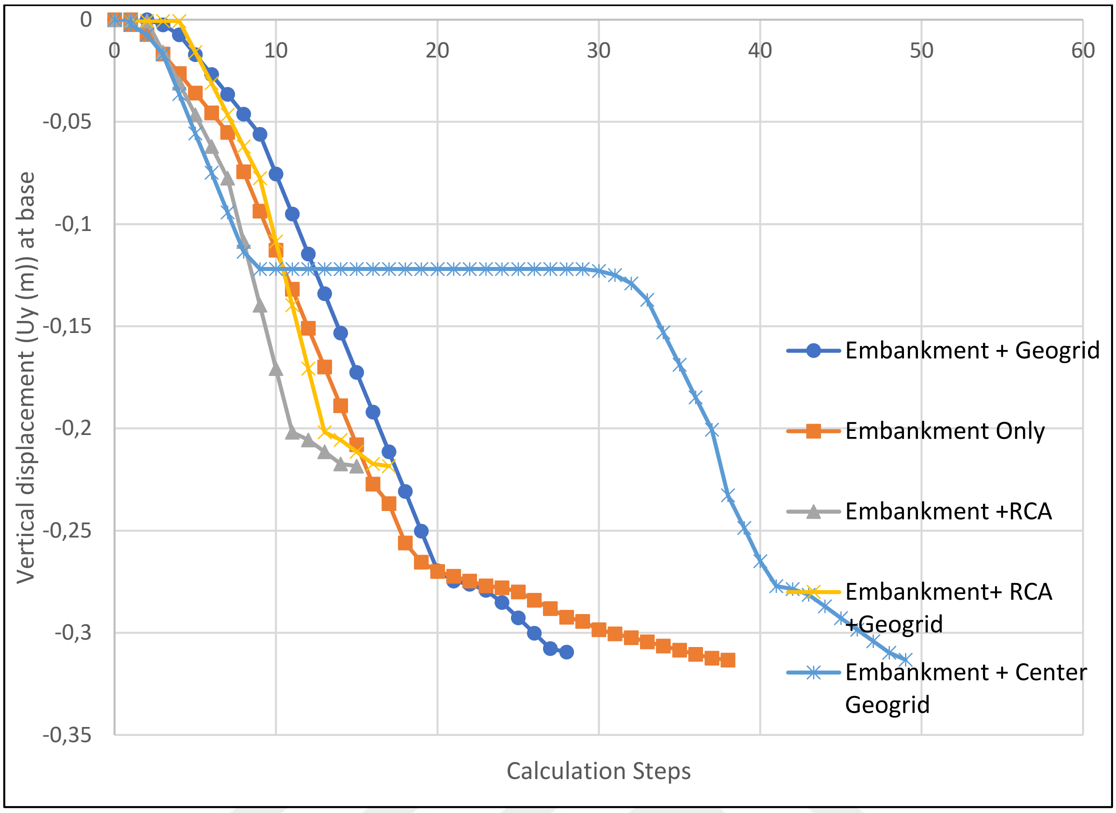

Figure 4.56: Comparison of Results Vertical Displacement.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Geogrids are increasingly or use RCA with geogrid or as an alternative used as reinforcement in road embankments in soft soils. The aim of this study is to determine the optimum strength of embankment with or without geogrid and the placement of multilayer geogrid for least deformation, taking into account the permissible displacement and load. It was carried out with the finite element method using PLAXIS 2D. Based on the data analysis and the results obtained in this study of slope improvement methods at a natural slope, the following conclusions were drawn:

An examination of current data reveals that most road embankments collapse due to excessive settlement and slope stability (via traffic loading). from the lateral and vertical displacement graphs, the Recycled concrete aggregated, and geogrid models showed lower displacement than other models. The model with geogrid in the center and only Embankment showed the worst behavior. The effect of using the geogrid does not depict much change. Settlements have occurred within the embankment materials as a result of some of the embankments not being appropriately compacted utilizing locally available inadequate materials. This problem may have been prevented if the necessary compaction specifications and designed materials had been used. If the roadside materials contain peat or organic soil, it is advised that material from other sites be used in their place. Prior to building national and regional highway embankments, subsurface analysis should be done in order to execute the proper corrective actions to reduce potential residual settlement and enhance bearing capacity. However, subsoil research and testing are more expensive for less important roadways, including district roads.

Along with the aforementioned problems, improper management of soft verges leads to water buildup and slope failure because of water seepage through tension cracks that inevitably form. As a result, maintaining effective surface water drainage is necessary for maintaining the integrity of embankment slopes and controlling pavement deterioration.

5.2 FUTURE WORKS AND RECOMMENDATIONS

Several recommendations can enhance the study of the slope improvement methods for natural slopes. The recommendations are as follows.[69]

a. Record the features of the soil layers in the existing embankments, such as shear strength values and settlement qualities, by conducting additional field experiments.
b. Look into how vegetation affects shear strength and stability.
c. Examine the shear strength of stabilized soils, including dredging sand.
d. Conduct field trials to investigate the efficacy and applicability of various ground improvement approaches documented in the literature.
e. Similar to this, carry out field testing to determine the suitability of various geo-reinforcement types to increase the bearing capacity of the foundation and the resistance to shearing of the embankment.

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