ISSN 2303-4521
Periodicals of Engineering and Natural Sciences *Original Research*
Vol. 10, No. 6, December 2022, pp.5-27

The effect of geogrid reinforcement of embankment over soft foundation

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ABSTRACT

This paper deals with the usage of geogrids for soil improvement utilizing the PLAXIS 3D FE program's numerical analysis approach. Because of the low shear strength and instability of soft clay soils, reinforcement has been used to improve clay soils. The reinforcement mechanism was analyzed on the basis of results and output. The results of the program outputs are shown in PLAXIS. The reinforcement has little effect in the case of horizontal displacement and vertical displacement, but only a significant effect on the safety factor. This paper also deals with improving soft clay soil using stone columns. The main objective is to reduce settlement and increase the carrying capacity of the soil and shorten the consolidation period. The work investigates geogrid-reinforced stone columns that improved the behavior of soft clay soils under the influence of loading and construction. Underwent soil the stone columns testing covered with a geogrid and traffic load of 50 kpa. The improved method of using stone columns and PLAXIS 3D was used to create the FE model. The results concluded that the comparison results gave an improvement rate of up to 50 % of the improvement for the stone-column-reinforced clay soil in the construction phase.

Keywords: Reinforced Embankment, Geogrid, Finite element analysis, soft foundation, PLAXIS 3D

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1. Introduction

Soft clay soils are a weak structural material, this type of soil has high compressibility but a low shear strength, sometimes this type of soil has no shear strength to support the embankment, there are several improvement techniques that have been used in the last purpose of increasing soil shear strength [1]. As a product made of geotextiles, geomembranes, geogrid, geocells, and geofoam are the most popular forms of artificial soils, and they are all created by combining polymeric material with soil, rock or other materials that have to do with geotechnical engineering[2]. In this study, geogrids were used to strengthen the embankment. Geogrids have been widely used in road construction due to their high tensile strength, tear resistance, good toughness, safety, and creeping property[3]. Geogrid can effectively improve the construction conditions of the substrate, improve the substrate's shear strength and reduce the unevenness, level the sub-soil, improve the embankment's stability, and control the development of the substrate [4]. To simulate the behavior of the reinforced embankment system under construction and loading, a numerical model was developed using the program PLAXIS 3D 2020 and the finite element method, this program was used to give more accurate results. A brief review of the studies conducted using FEM is presented herein [5-9]. The need for high fidelity and for modeling large three-dimensional (3D) spatial configurations is motivating this direction of research [10] . The finite element method (FEM) consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement [11]. According to Barbour and Krahn [12-15].

Rowe[13] and Rowe and Soderman[14] [15] used a Mohr-column yield criterion to analyze geotextile-reinforced embankments up to failure with undra thein the behavior of the foundation.

Hird and Kwok [16] and Hird [17] researched the impact of full-strength embankments and foundations. Depth on the performance of reinforced embankments with narrow crest width. The Mohr-Column criteria were used to simulate the soil of the embankment. Undrained behavior of the underlying foundation soil was modeled with the Cam-clay model with Modified. the reinforcement was characterized as either linear or bilinear.

Jonathan [18] investigated the geosynthetic tensile reinforcements that improved the efficiency of two test embankments. The reinforcement was handled as a material with linear elastic properties.

Varadarajan et al. [19]] carried out a parametric study of a reinforced embankment using elastoplastic FEA to evaluate the reinforced embankment. For shallower foundations, stiffness, force, and embankment height increased. High-stiffness reinforcement's efficiency depends on the clay-reinforcement interface's shear strength.

Rowe and Soderman [14] examined a geotextile-reinforced embankment built on peat and supported by a firm foundation using a finite element model. With an increase in geotextile modulus, it has been demonstrated that the geotextile's stabilizing impact increases and the stabilizing effect was more significant for shallower deposits.

Qian Jinsong[20] has used ANSYS software to carry out three-dimensional FEA of a geogrid-reinforced embankment. Sensitivity analysis of single factor parameters of geogrid modulus was carried out, and its impact on the reinforced embankment's overall performance was verified.

Hu Youchang[21]] has studied the influence of reinforcement spacing, embankment friction angle, cohesion and other factors on displacement and stress distribution of reinforced embankment by indoor model test and finite element numerical analysis method.

Wang Xiequn[22]] has analyzed the influence law of geogrid type, filler type and compaction degree on the strength characteristics of the geogrid-soil interface by large direct shear test. Most scholars have focused on the analysis of the geogrid characteristics of the built subgrade, and rarely studied the role of geogrid in the process of graded loading. Because of the soil's high settlement force with low shear strength, the consolidation period might be large and extend for a long time after construction. The use of stone columns can help to reduce settling and accelerate the uniformity process. According to numerical studies, stone columns not only improve the carrying capacity of the foundation when set in soft soil but also hasten its consolidation [23] [24].

The usage of stone columns for soil improvement owing to the hardness of the columns permeability top in comparison to the surrounding soi [25-31].

Therefore, due to the absence of lateral support from the soil around it, the usage of stone columns is typically linked with excessive deformation, which results in severe lateral deformation of the column's top. In this study, the influence of stone columns with geogrid reinforcement was utilized by using the finite element method during the construction and loading phases.

Elastic foundation soil parameters and nonlinear elastic behavior are taken into account. As well as the study of the factors affecting the basis of the reinforced embankment, the behavior of the various elements in the study is characterized such as the elastic behavior of reinforcement and the Mohr-Column criterion for the base soil. As for the stone columns, the study aims to achieve a better understanding of the impact of geogrids and stone columns on the performance of clay soil foundations.

2. Numerical analysis

2.1 Geometric modeling

In this study, a reinforced embankment was built on soft clay soil, which is an earthen structure used to raise a height above the surrounding area. The embankment is built 4m high and wide, side slope of 1:1.5, was the foundation soil soft clay layer high 8m, stiff clay layer is 14 m high. Soil simulated using triangular elements 10 Node. The geogrid was simulated using a geogrid with natural hardness but no curvature. Geogrid elements can maintain the tensile forces and there is no pressure. In this study the reinforcement materials were designed as linear elastic elements, the width of the foundation was chosen after a series of model's selection to obtain the model in which the boundary effect is almost equal to zero, model width has been selected. Traffic loads approved are 50 kN/m2. It was a simulation of the embankment's construction. by applying a layer of a geogrid thickness with four layers. The pressure and its effect were not taken into account in the context of this study since it is challenging to ascertain the initial state of the soil before its compaction. All the necessary parameters were made in analyzing the problem of the embankment, which was the study of the embankment situation in Habbaniyah, west of Anbar province, and the parameters that were obtained through experimental work and tests for soil investigations for this project.

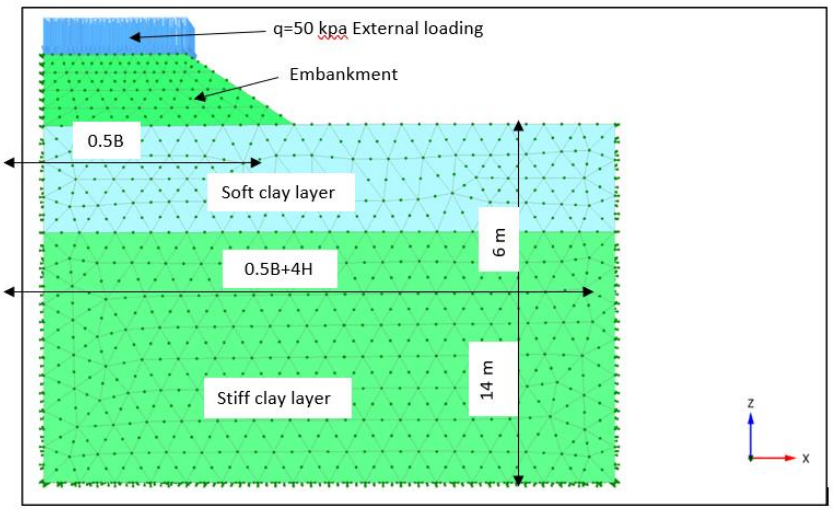

Figure 1. cross-section shows the embankment

2.2 Embankment fill

Parameters of filling embankment/embankment refer to the soil structure used to raise the surrounding area. In this study, the embankment was built on a slope to reinforce the critical point in many locations. The soil components are often compacted in place during the construction of the embankment therefore the soil pressure factor must be significant for stability. Dilatancy Angle, ψ (degree)=0, Unit Weight 19 (kN/m3), Friction Angle φ' (degree) 35, influences the embankment's final height, but the lower the angle of friction. The viscoelastic characteristics of the reinforcing flooring and the viscous properties of the foundation soil determine creep deformations, thus it has minimal effect on time-dependent embankment deformation and reinforcement. Table (1) shows the properties of sand used in the embankment.

Table 1. Properties of sand used in the embankment

Parameter	Embankment Fill
Unit Weight (KN/m3)	19
Young's Modulus(MPa)	35

Parameter	Embankment Fill
Poisson's Ratio,V	0.4
Cohesion, C (Kpa)	0
Friction Angle, ϕ, (degree)	35
Dilatancy Angle, Ψ (degree)	0

2.3 Foundation soil

All structures built on soft soils may face uncontrollable settlement and possibly critical load- bearing capacity. Soil improvement and stability are the keys to these problems. The area of soil stabilization and improvement is wide and may include a variety of techniques. The model was taken with saturated soil. The model was used to simulate the behavior of the embankment soil. Table (2) summarizes the characteristics of the base soil.

Table 2. Characteristics of the base

Parameter	Soft clay layer	Stiff clay layer
Unit Weight (KN/m^3)	17	17.5
Young's Modulus(MPa)	7.4	15.7
Poisson's Ratio,*V*	0.49	0.49
Cohesion, C (Kpa)	47	116
Friction Angle, ϕ, (degree)	0	0
Dilatancy Angle, Ψ (degree)	0	0

2.4 Geogrid

The embankment was established after adding the geogrid material, within the geogrids linear elastic range, using FE modeling, we compared the impact of geogrid tensile strength on the embankment using three geogrid types with similar elasticity coefficients. The geogrids characteristics were chosen based on the characteristics of the source[32]. As shown in Table (3)

Table 3. shows The properties of the geogrid were selected on the basis of the characteristics of the source [32]

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

3. Properties of granular piles

Soil materials and the stone column were represented by flexible linear plastics by the Mohr-Coulomb model. The form requires input parameters: young modulus (100MPa), stiffness modulus, Poisson's ratio (0.3), Angle of friction (41), and cohesion (0.2 kPa). Table (4) shows the properties of granular [34].

Table 4. Properties of granular piles [34]

Material	Model	Modulus of elasticity (E) MPa	Poisson's ratio (ν)	Permeability (k)m/sec	Dry unit weight (γd) kN/m3	Saturated Unit weight (γsat) kN/m3	Angle of friction (φ) Degrees	Cohesion (c) KPa	Reference
Stone column (crushed stone)	Elastic–Plastic (Mohr-Coulomb)	100	0.3	0.1	16	21	41	0.2	1

4. Method of analysis

Plaxis 3D, a program for 3D analysis, was used to model the foundation; it is based on the finite element approach. Advanced models are used to simulate soil and rock nonlinear, time-dependent, and behavior in geotechnical engineering for deformation and stability. Plaxis 3D simulates the interaction between the geogrid and the soil stages of construction, loads and boundary conditions are determined in particular geometric cross-sections comprising the soil model after soil layers and foundation characteristics are entered (Plaxis 3D), the parameters of the model are weight. The molding E, Poisson's ratio V, and angles φ' were modeled to determine the effect of geogrid on the embankment. Geogrids were added in different types and in many layers 4 layers and their effect on the embankment, as well as the effect of adding stone piles and their effect on the embankment the case adding stone piles in the case of adding geogrids or not adding geogrid, course of analysis of embankment was made, which were built on foundation layers supported by stone columns, then (Plaxis 3D) automatically creates unstructured 3D finite element networks with network improvement options, using facilities its calculation the model will be calculated in (Plaxis 3D), and the results will be made available in the geometric forms (Plaxis 3D 2020) Table (1) shows the parameters utilized in numerical modeling. In order to describe the engineering behind the modeling of stone columns using the final element method. As a part of this study PLAXIS 3D FEA was used to compare the efficiency of an and a stone column under embankment loading (Brinkgreve et al. 2013) [33]. Cross-section of a typical stone column reinforced with geogrids, as shown in Table (5). Figure (2) cross-section shows geogrid reinforced stone columns.

Table 5. Information of a Geosynthetic Reinforced Pile-Supported Embankment

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

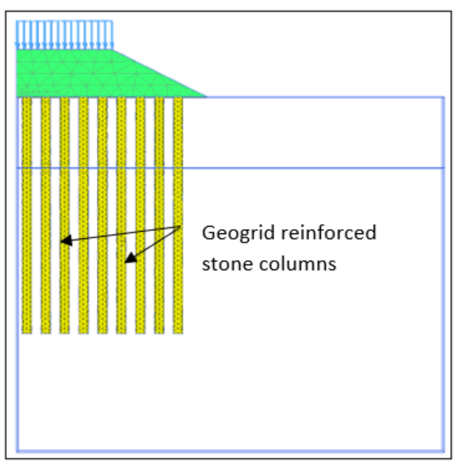

Figure 2. Cross-section shows Geogrid reinforced stone columns

5. Result and discussion

Plaxis outputs of embankment models:

After the completion of the engineering model, Plaxis 3D allows the establishment of an entire geogrid, where the use of finite elements to represent the traffic loads and the layers of the established embankment, represents the outputs of the Plaxis for embankment models, where the horizontal and vertical displacements are in the case of the reinforced and unreinforced embankment. Figure (3) to Figure (8) shows the Plaxis outputs of embankment models.

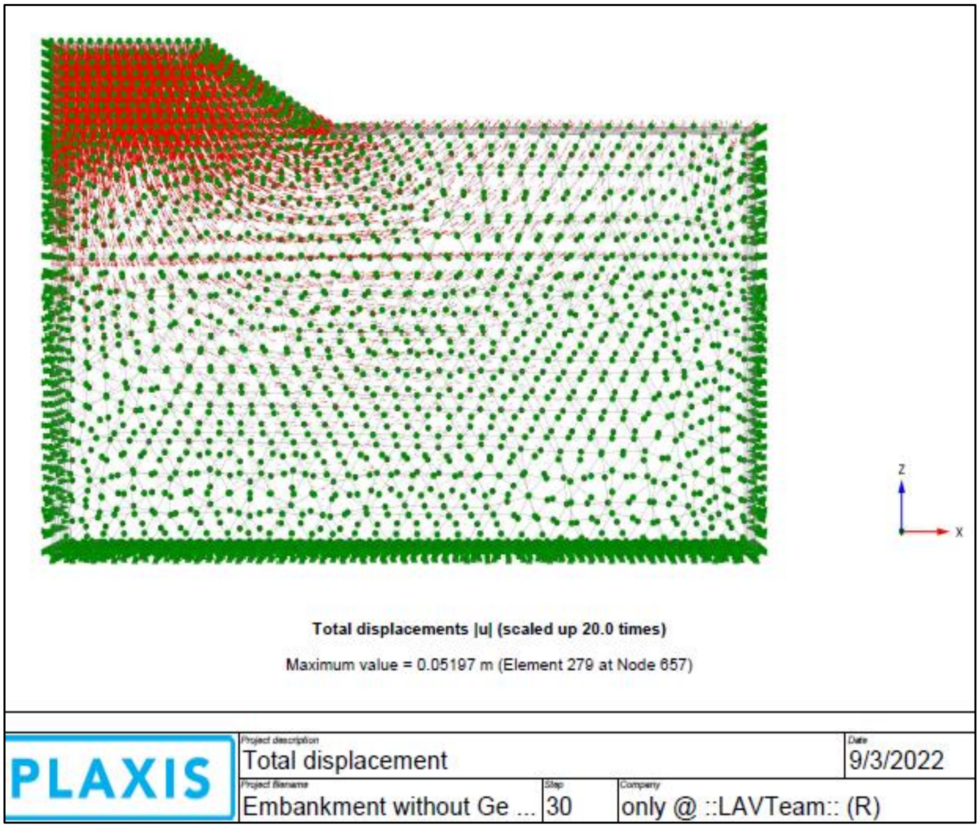

Figure 3. stresses of unreinforced embankment

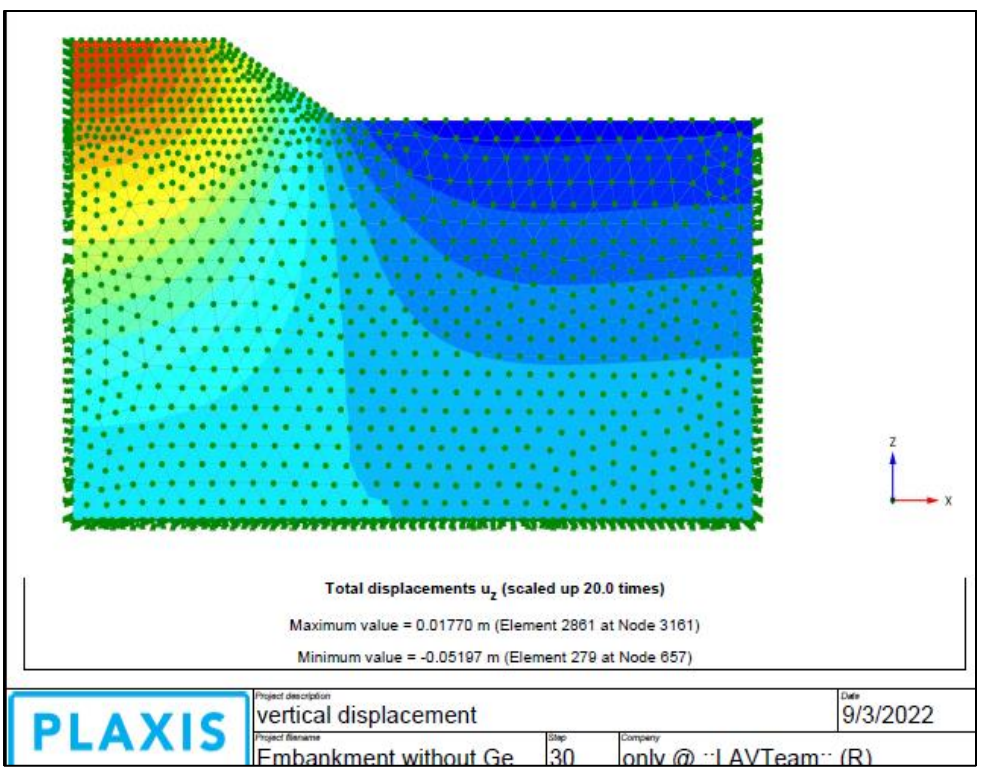

Figure 4. Vertical displacement of unreinforced embankment

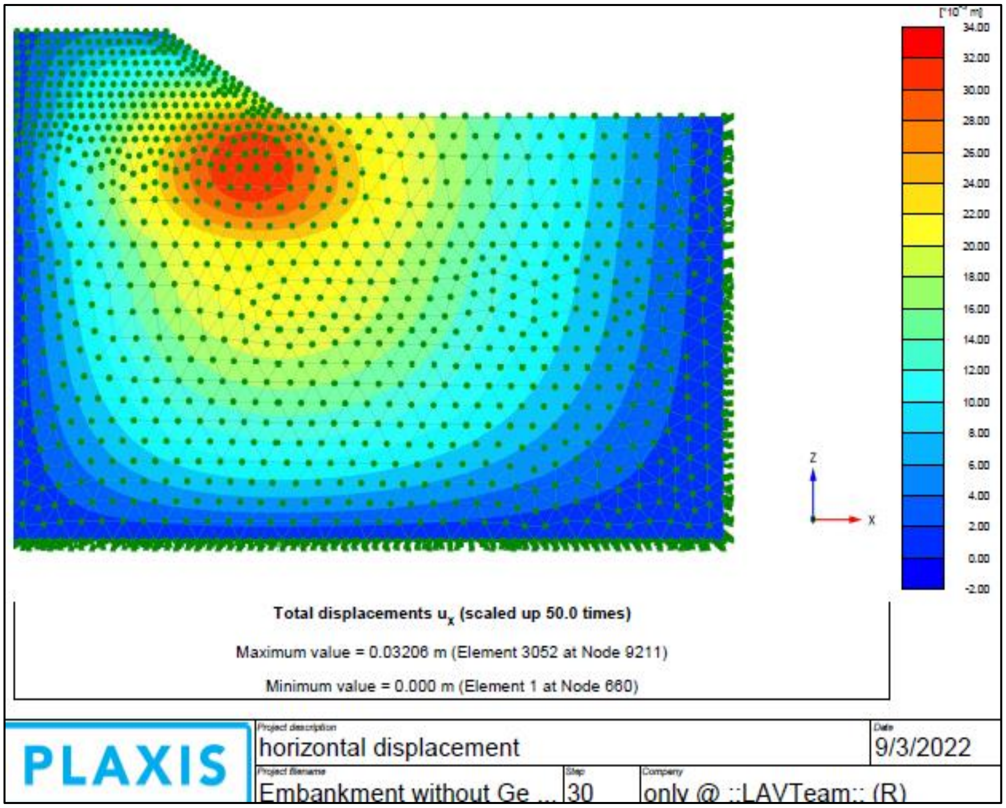

Figure 5. Horizontal displacement of unreinforced embankment

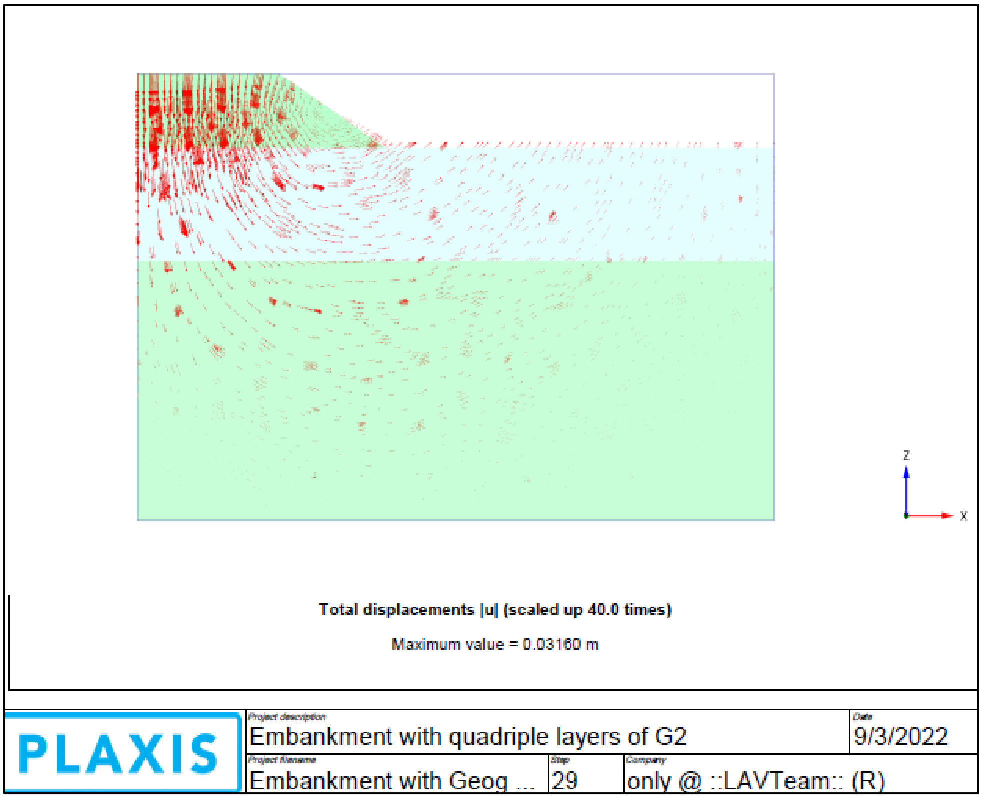

Figure 6. stresses of reinforced embankment

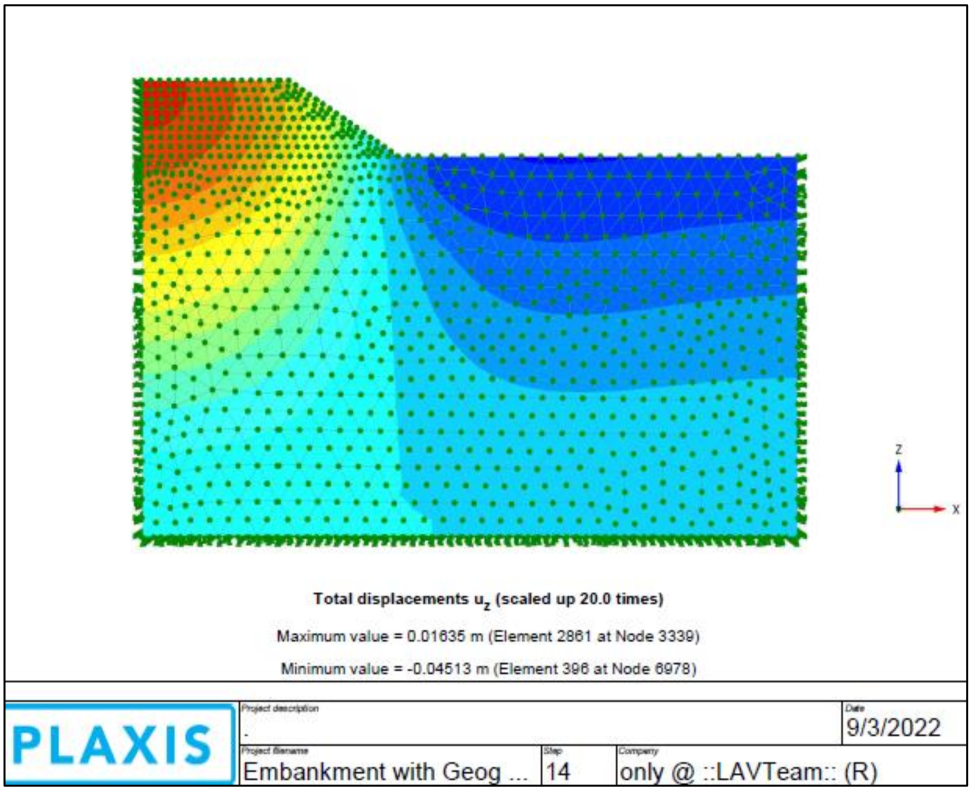

Figure 7. Vertical displacement of reinforced embankment

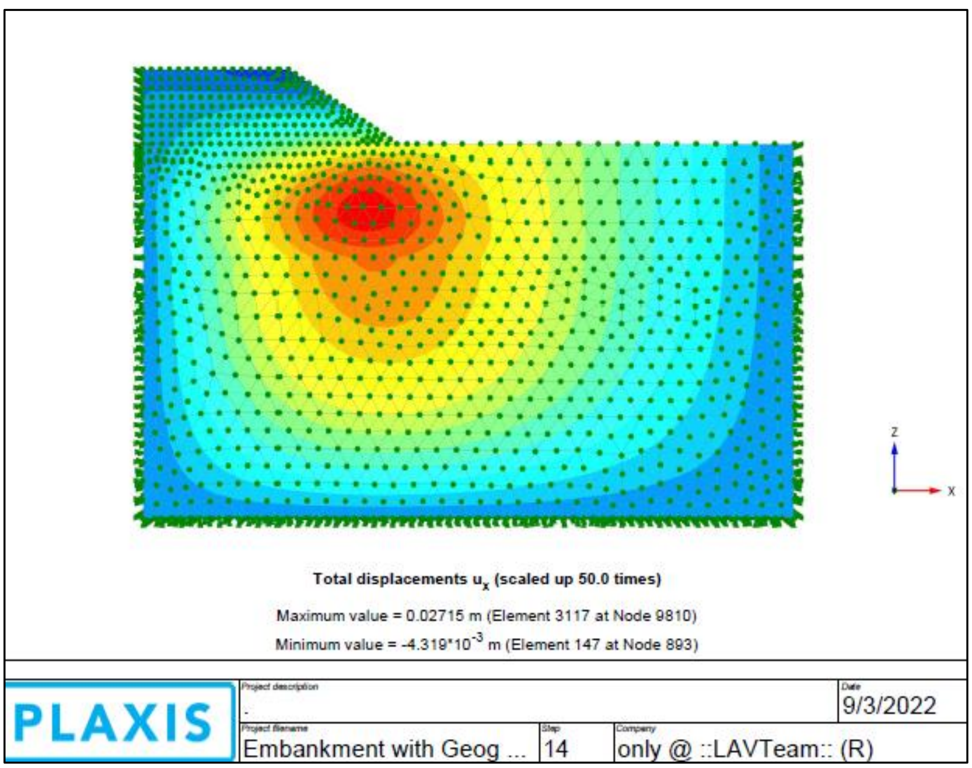

Figure 8. Horizontal displacement of reinforced embankment

6. Parametric study

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

6.1. Effect of geogrid (layers and type)

Considering the impact of geogrid reinforcement on road embankments, in the FE model, the impact of the layer containing the geogrid on the performance of the road embankment is shown by vertical settlement, horizontal displacement, and safety factors. Geogrid is laid on the bottom in single, double, triple, and quadruple layers. The results were obtained for the loading and construction phases. Figure (9) shows layers of geogrid (PLAXIS 3D 2020). Figure (10) show alayer embankment with geogrid.

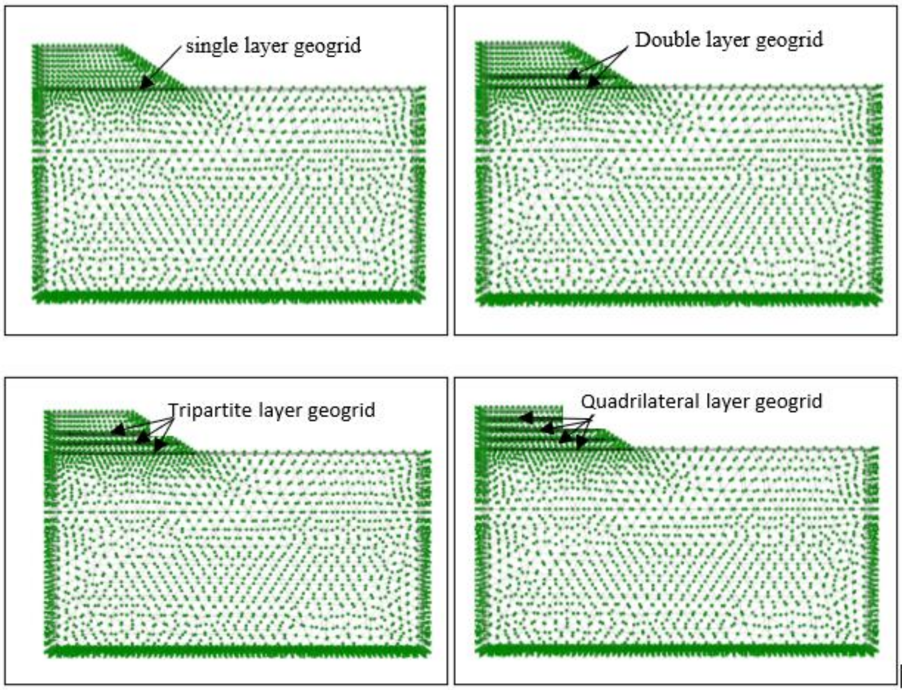

Figure 9. Shows layers of geogrid

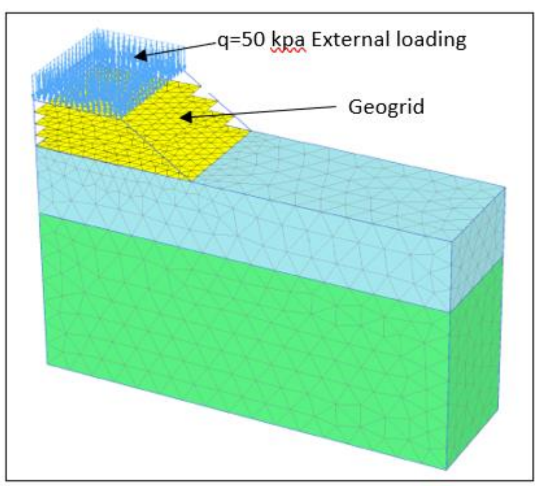

Figure 10. Show layer embankment with geogrid

6.2. Effect of geogrid on embankment deformation

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

A. With respect to vertical displacement

The impact of the placement of the reinforcement on single, double, triple, and quadruple reinforcement's vertical displacement was shown in Figure (9), points have been selected in the (Top center) (Top edge) (Toe center) Figure (11) selection of analysis points ،the result indicates that the value of deformation occurred in the (Top center). The results depended on the program outputs during the loading and constriction. It can be concluded that there is no point in adding more than two layers because the improvement gave the same values. There is a difference in the improvement only when adding the geogrid to the first and second layers. From Figure (13) to Figure (18) vertical displacement of the embankment reinforced with geogrid (GGI) ،(GGII) (GGIII) ،due to layers construction and loading. Figure (12) Vertical displacement of the model (PLAXIS 3D 2020). Table (6) shows the percentage of improvement in the value of Vertical displacement.

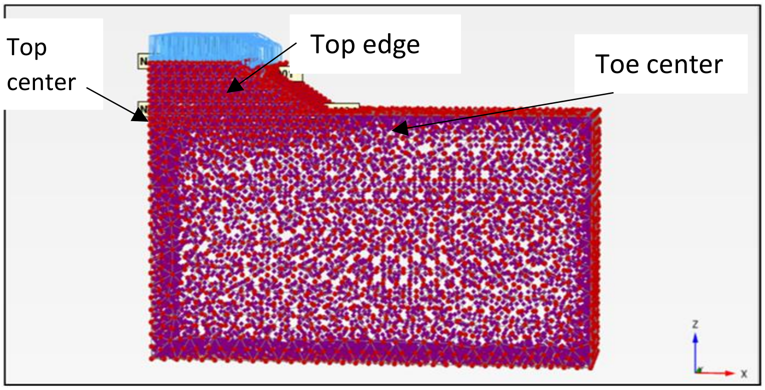

Figure 11. Selection of analysis points

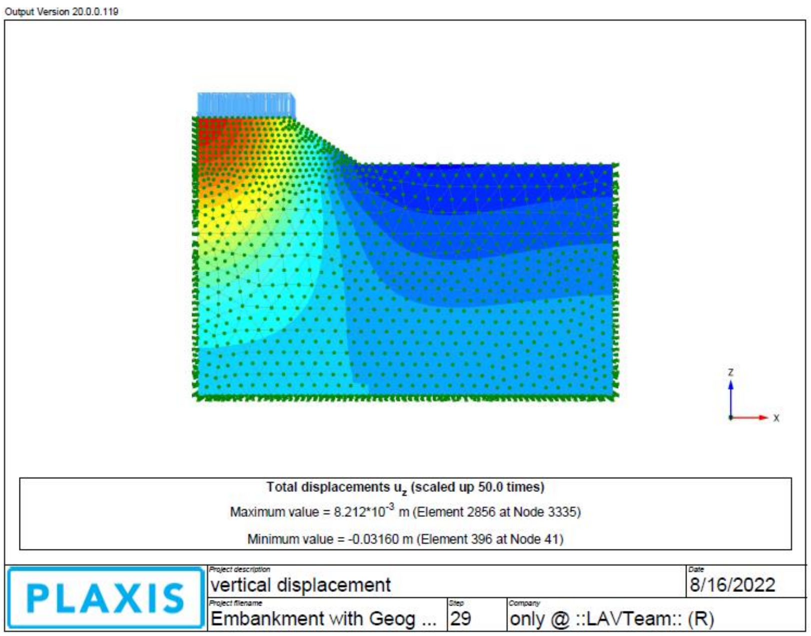

Figure 12. Vertical displacement of the model (PLAXIS 3D 2020)

Table 6. Shows the percentage of improvement in the value of Vertical displacement

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

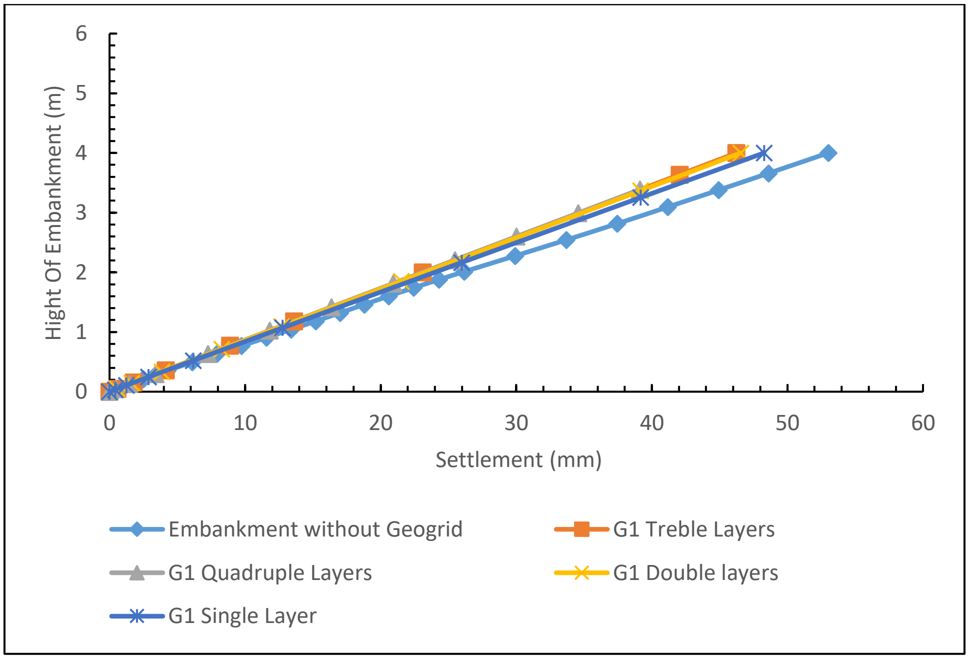

Figure 13. Vertical displacement of the embankment reinforced with geogrid (GGI) due to layer construction

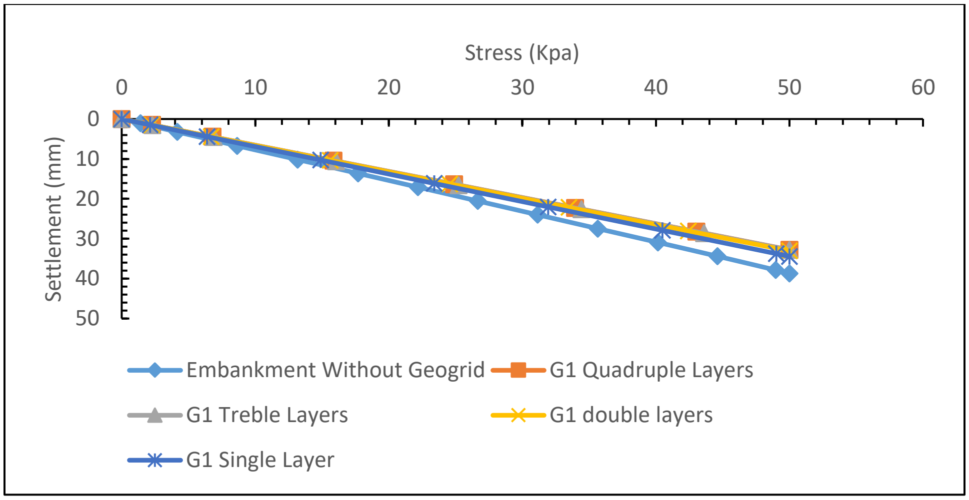

Figure 14. Vertical displacement of the embankment reinforced with geogrid (GGI) due to layer loading

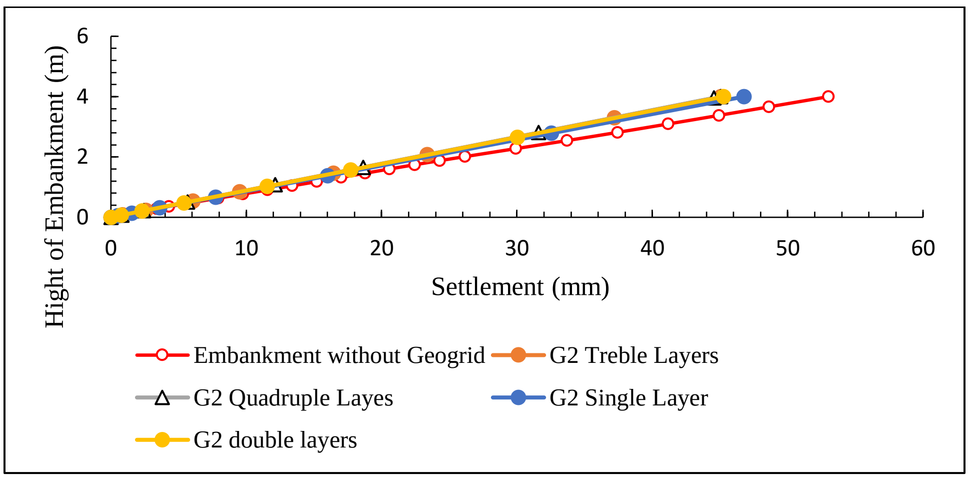

Figure 15. Vertical displacement of the embankment reinforced with geogrid (GGII) due to layer construction

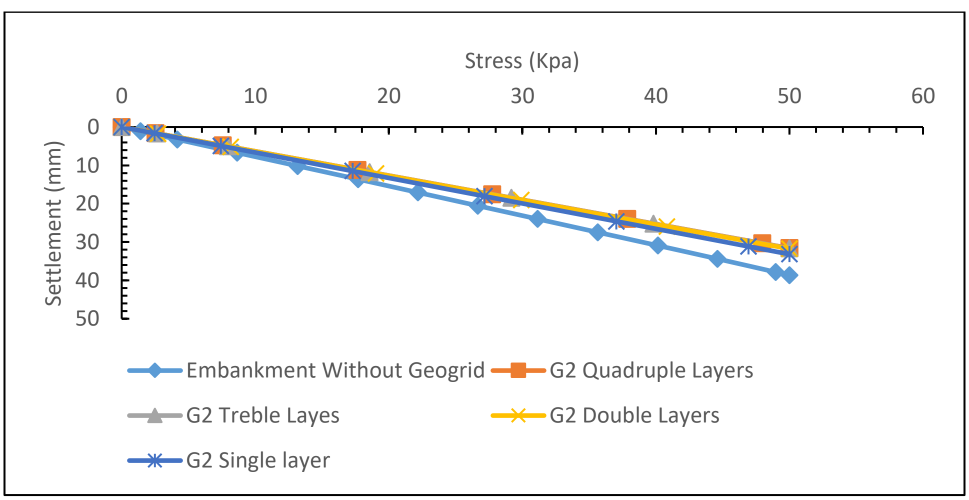

Figure 16. Vertical displacement of the embankment reinforced with geogrid (GGII) due to layer loading

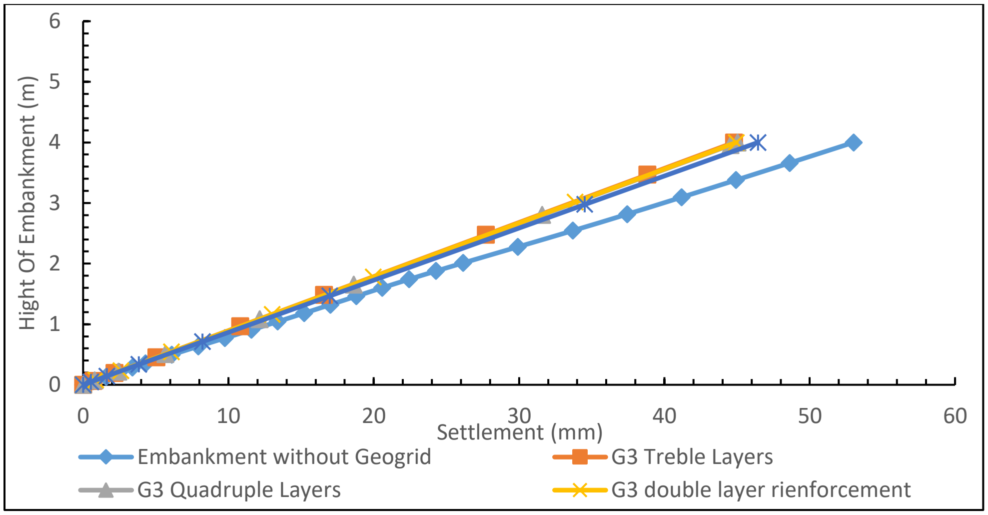

Figure 17. Vertical displacement of the embankment reinforced with geogrid (GGIII) due to layer construction

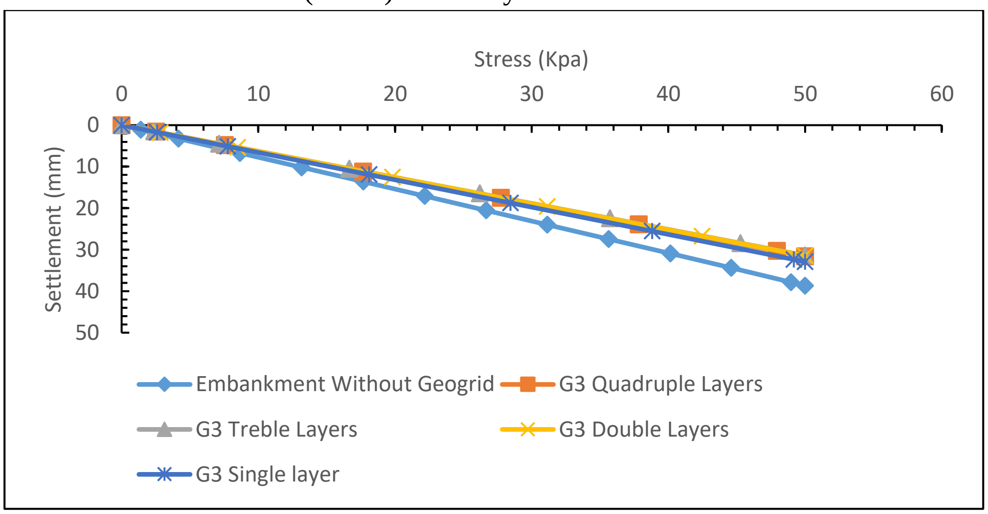

Figure 18. Vertical displacement of the embankment reinforced with geogrid (GGIII) due to layer loading

B. With respect to horizontal displacement

The four reinforcing layers' effects of geogrid were applied to model an embankment ،points have been selected in the (Top center) (Top edge) (Toe center) Figure (11) selection of analysis points ،to know the values of deformations and draw deformation curves for the embankment. reinforcement by single-layer, double-layer, three-layer, and four-layer. It should be noted that when the number of layers and geogrid type change, the displacement value decreases, the deformations decrease and there is an improvement in the value of lateral displacement from the unreinforced soil. The third and fourth layers. It can be noted that there is no noticeable difference in the reduction of deformation. The results indicate that the reinforcement with four layers (Toe center) and the type of geogrid (GGIII) may reduce the horizontal displacement more than the reinforcement of the rest of the layers. Table (7) shows the percentage of improvement in the amount of horizontal displacement when it relates to reinforced soil and non-reinforced soil in the construction and loading phase. Figure (19) horizontal displacement of the model (PLAXIS 3D 2020). From Figure (20) to Figure (25) horizontal displacement of the embankment reinforced with geogrid (GGI) ،(GGII) (،GGIII) ،due to layers construction and loading. Table (8) shows the percentage of improvement in the value of horizontal displacement.

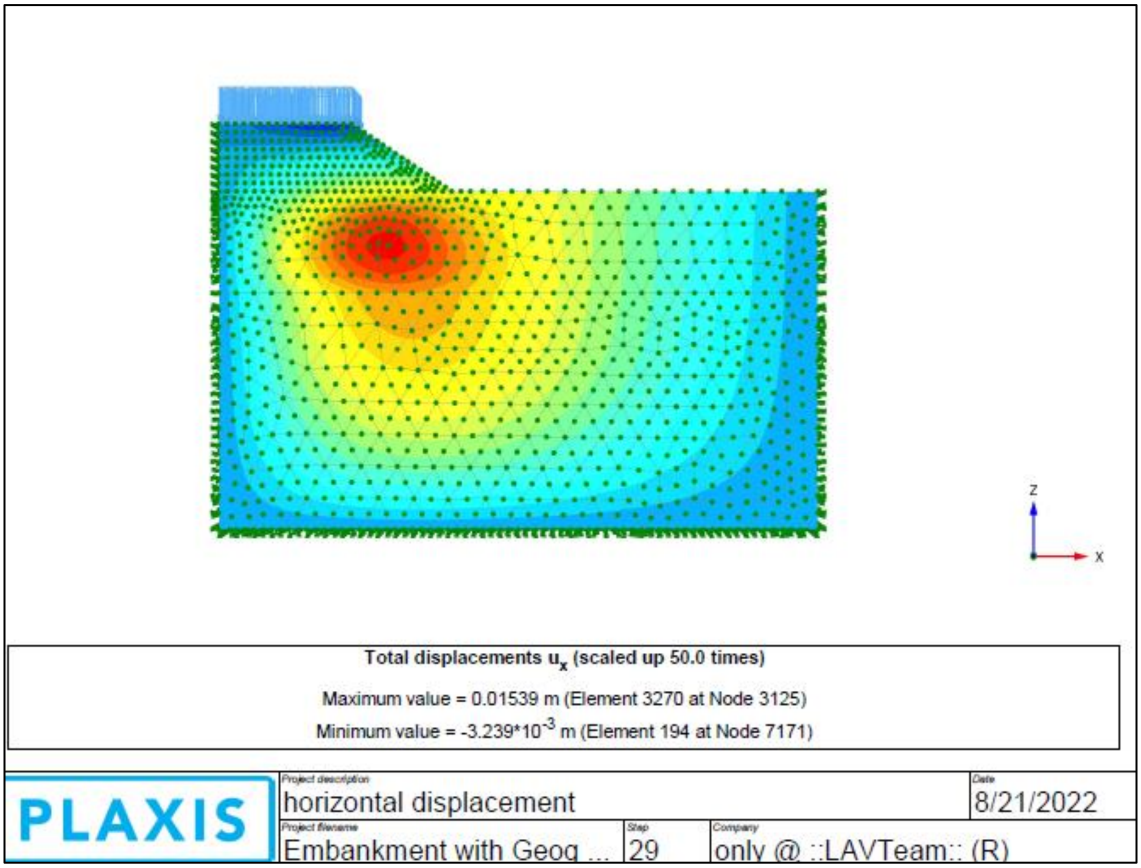

Figure 19. Horizontal displacement of the model (PLAXIS 3D 2020)

Table 7. Shows the percentage of improvement in the value of horizontal displacement

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

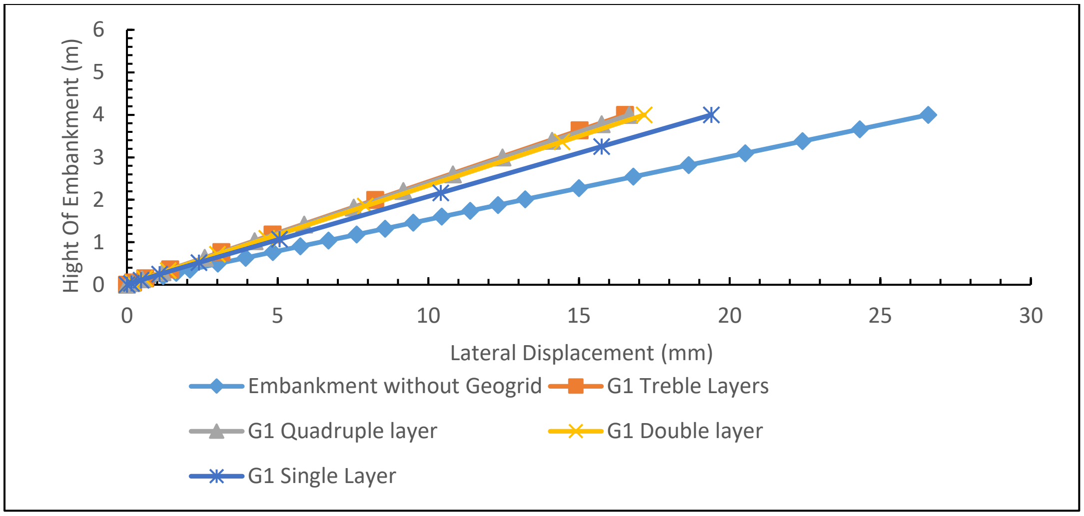

Figure 20. Horizontal displacement of the embankment reinforced with geogrid (GGI) due to layer construction

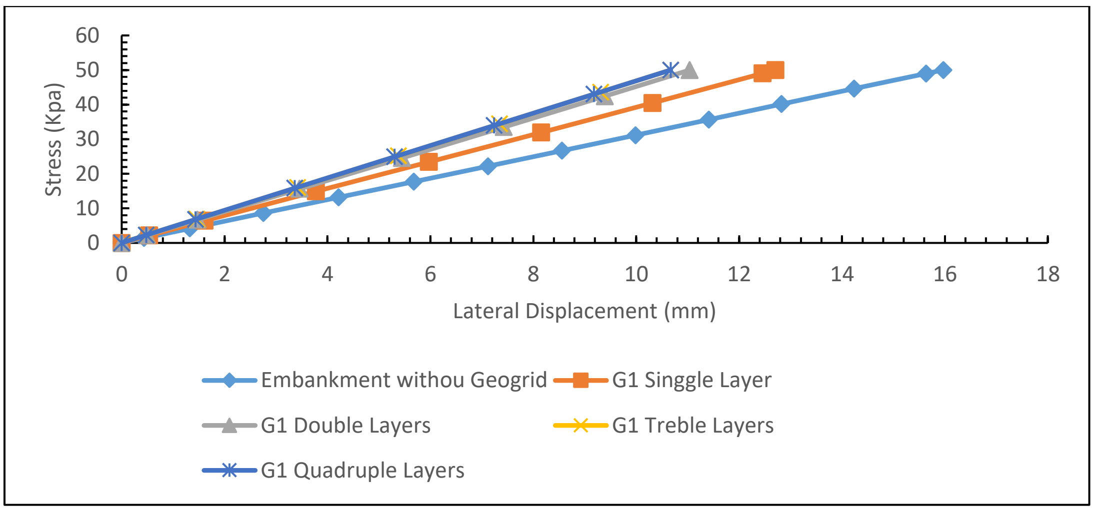

Figure 21. Horizontal displacement of the embankment reinforced with geogrid (GGI) due to layer loading

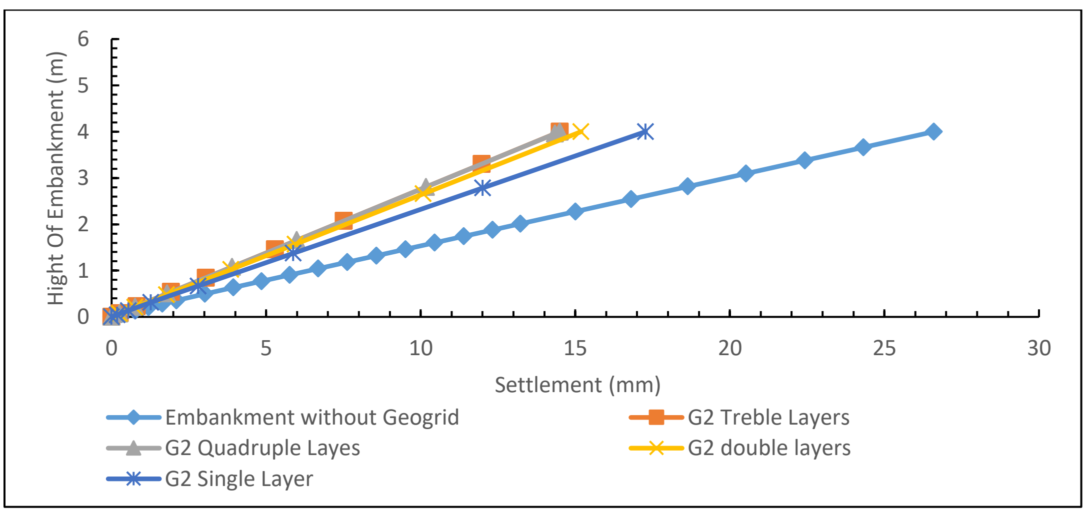

Figure 22. Horizontal displacement of the embankment reinforced with geogrid (GGII) due to layer construction

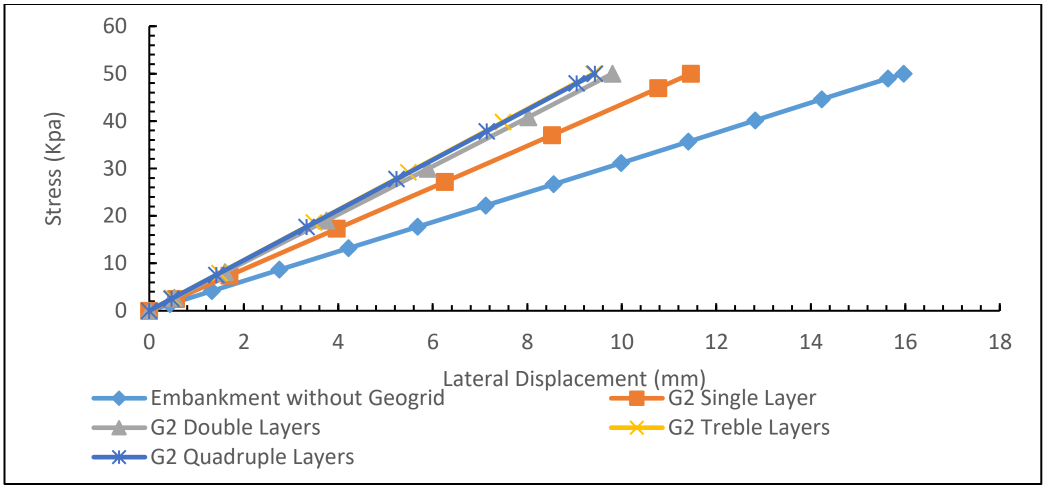

Figure 23. Horizontal displacement of the embankment reinforced with geogrid (GGII) due to layers loading

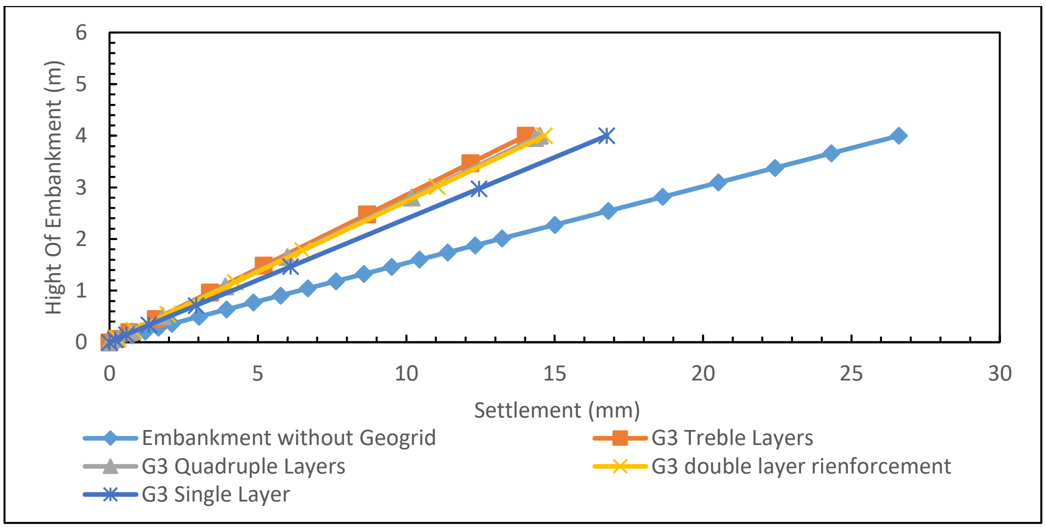

Figure 24. Horizontal displacement of the embankment reinforced with geogrid (GGIII) due to layers construction

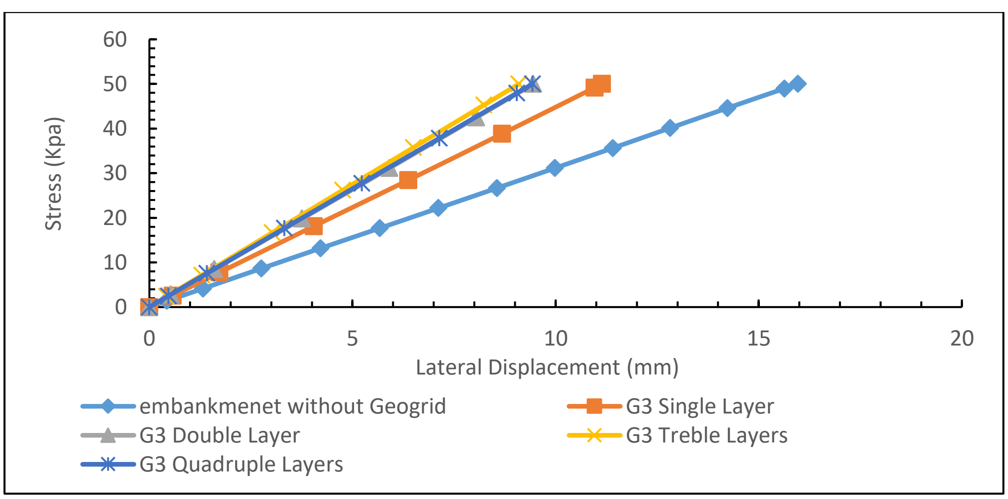

Figure 25. Horizontal displacement of the embankment reinforced with geogrid (GGIII) due to layer loading

6.3. Effect of geogrid reinforcement on the safety factor

The safety factor against slipping is calculated to prevent failure from happening. The influence of reinforcing layers and type on safety factors for different cases of single, double, triple, and quadruple reinforcement is shown in Figures (26) to Figure (28). This illustrates how the geogrid works when it is used at the base of an embankment. (Over clay soils) may affect the performance of the road embankment. It can be noted that the value of the safety factor has no effect in the case of one layer in the reinforcement soil on the non-reinforced soil. When the four-layer geogrid is applied ،it increases the safety factor and has an impact on the performance of the road embankment. It can be concluded that the type of geogrid does not affect the safety factor, but its effect appears when the number of geogrid layers is increased. It can be noted that the safety factor improvement increased by (50) % in the unreinforced embankment layer. Table (8) shows the value of safety factors.

Table 8. Values of safety factor

Reinforcement	Reinforcement layer	the safety factor
unreinforcement	**-**	1.4
GGI	Single	1.4
	Double	1.5
	Tripartite	1.7
	Quadrilateral	2.16
GGII	Single	1.4
	Double	1.5
	Tripartite	1.7
	Quadrilateral	2.16
GGIII	Single	1.4
	Double	1.5
	Tripartite	1.7
	Quadrilateral	2.16

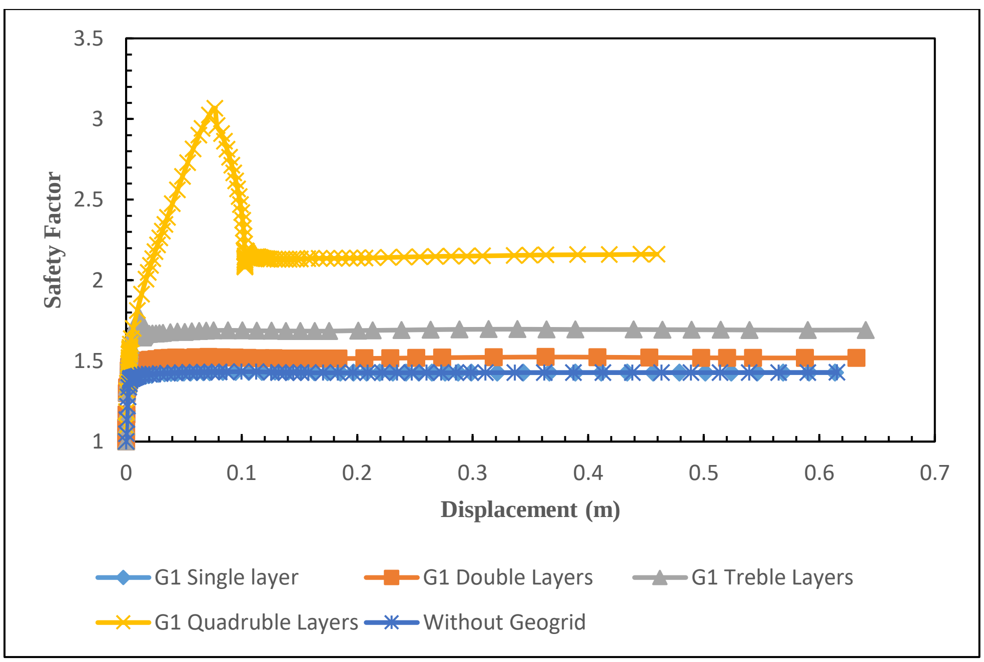

Figure 26. Show effect of geogrid type (GGI) on the safety factor

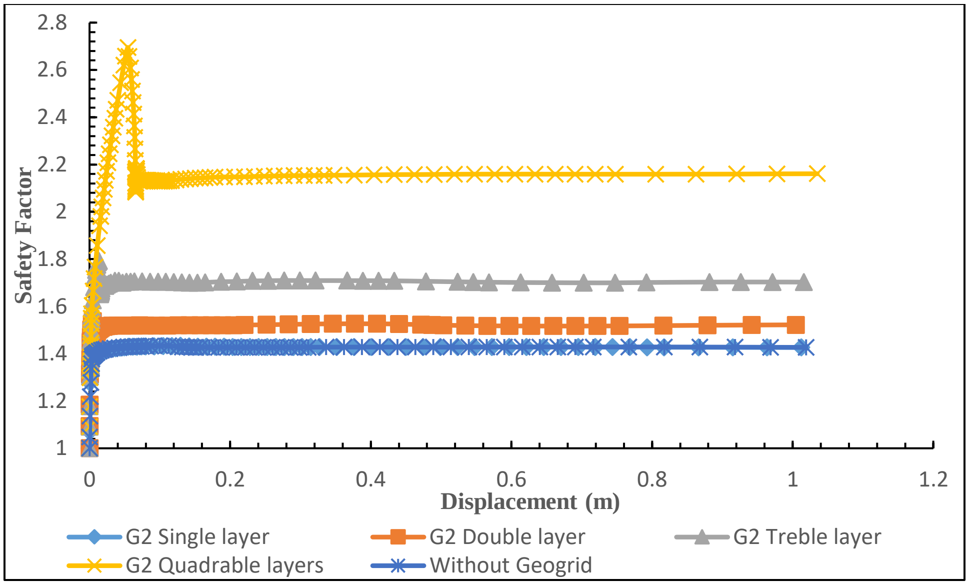

Figure 27. Shows effect of geogrid type (GGII)on the safety factor

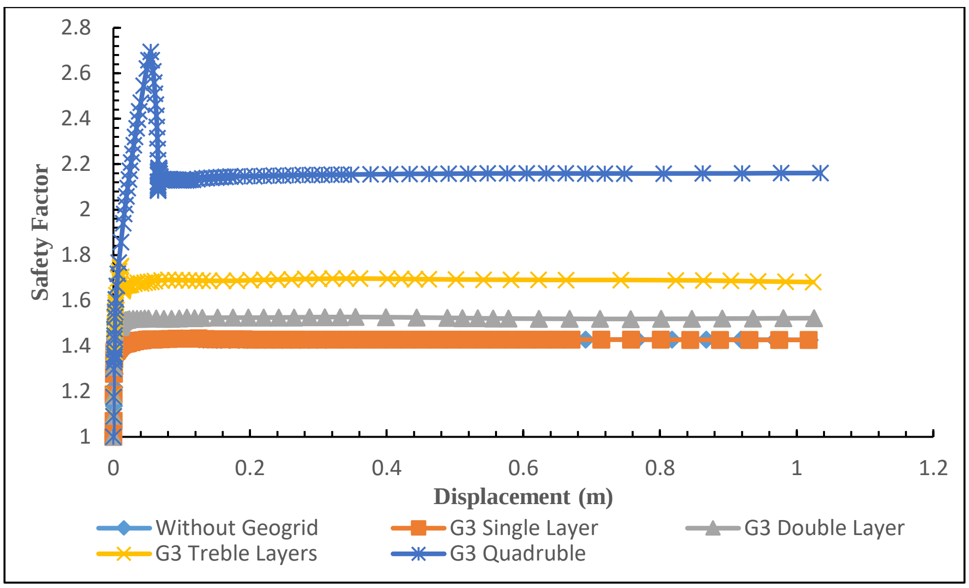

Figure 28. Shows effect of geogrid type (GGIII) on the safety

7. Results of stone column

Since it is necessary to compare the results of numerical analysis, Figure (31) and Figure (32) show the final result of the PLAXIS 3D model embankment with stone Colum. A lower settlement can be observed for soil reinforced with stone Column reinforced geogrids compared to untreated soil. From these values, it can be funded that the stone Column reduces the stability value and can be used as a means to improve the foundation soil. The results were compared in the case of loads and construction. Settlement embankment without stone Colum in loading 44mm.Settlement embankment with a stone column for loading 17mm, Settlement embankment without a stone column for construction 60 mm, Settlement embankment with a stone column for construction 29.6 mm, improving was 60% percent for loading, for in the case of construction the improvement value was 50 %. Figure (29) and Figure (30) shows a settlement in the stone Colum in phase loading and constriction.

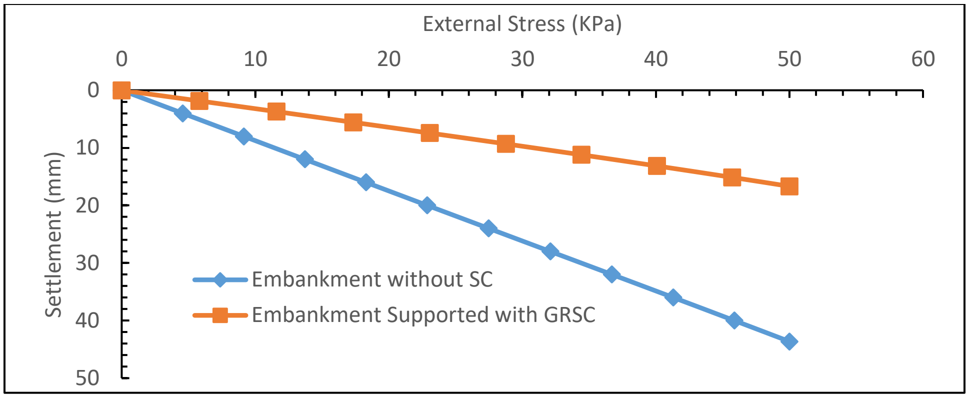

Figure 29. Shows settlement in stone Column in case loading

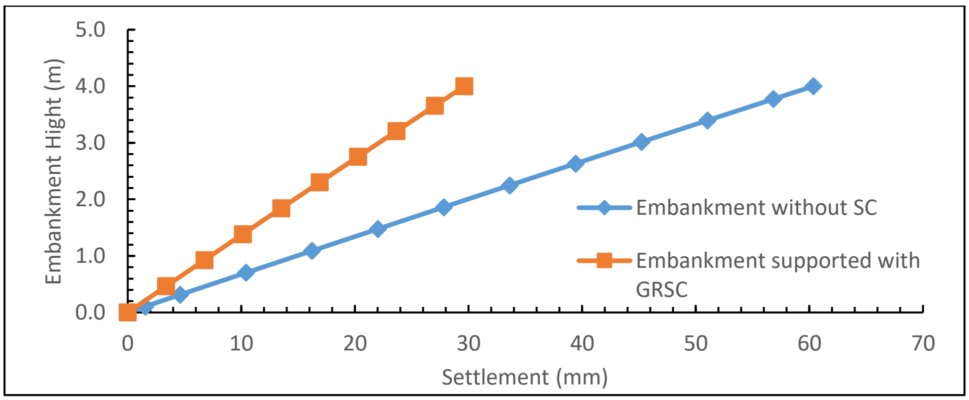

Figure 30. Shows settlement in stone Column in case of embankment constriction

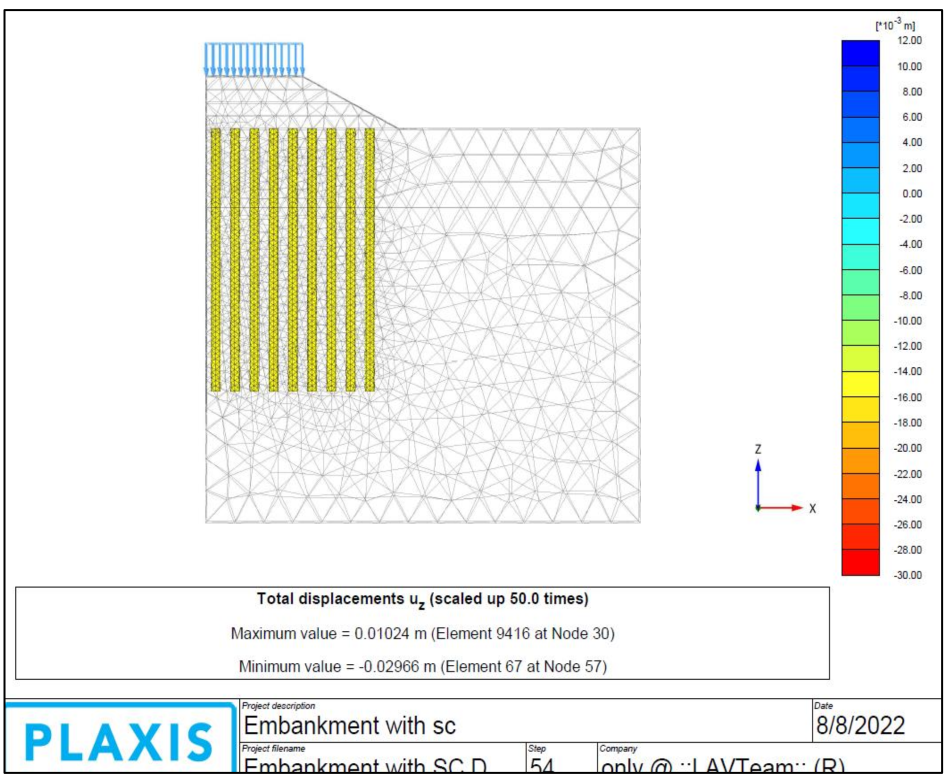

Figure 31. Show embankment with stone Column

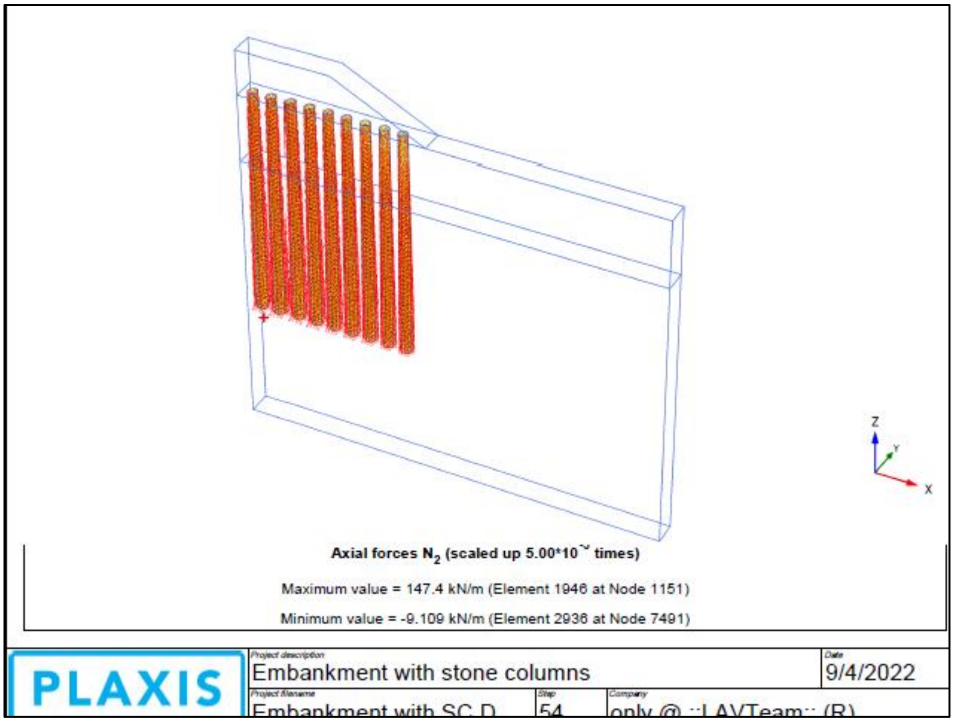

Figure 32. Show embankment with stone Column

8. Conclusion

The following conclusions were drawn after this study's findings were analyzed:

- The embankment's stability analysis using the finite element method (Plexus 3D 2020) gives acceptable results that can simulate the construction stages.
- Geogrids-reinforced slopes are safer and yield better results than embankment slopes without reinforcements.
- The insertion of geogrid reinforcement layers in the right place improves the filling of the embankment.
- Geogrids can help to reduce embankment instability, and the geogrids can complement low soils, and the depth of the foundation has a great effect on determining the effect of the strength of the reinforcement.
- The geogrid laid on the foundation soil substantially reduces the embankment's lateral displacement, although the effect on vertical displacement is low.
- The multi-layer geogrids are better than one layer, it is also affected by the type of geogrid and the location of the reinforcement, that is the closer the reinforcement position is to the base soil, the better the effect.
- The reinforcement has a significant impact on increasing the safety factor.
- The geogrids stone column encapsulation helps reduce instability.

Nomenclature

q External loading kpa

(0.5B+4H) width the modeling

(E) Young's Modulus(MPa)

V Poisson's Ratio

C Cohesion (Kpa)

ϕ (degree) Friction Angle

Ψ (degree) Dilatancy Angle
(k) Permeability m/sec
γd Dry unit weight KN/m3
γsat Saturated unit weight KN/m3

Abbreviations
FEA finite element analysis
FEM finite element method
GGI Geogrid Type I**
GGII Geogrid Type II**
GGIII Geogrid Type III**

Declaration of Competing Interest
The authors declare that they have no recognized non-financial or financial competing interests in any materials conversed in the current work.

Funding
No funding was gained from any financial organization for conducting the current work.

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