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Numerical Modeling Analysis of the Geogrid Pre-Stress Effects on Granular Soils Parameters by Finite Element Method

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Abstract: This study presents the results of numerical analysis carried out with a new manufacturing method for reinforced soil structures with geosynthetic known as reinforced prestressed soil. The concept of Pre-stressed Reinforced Soil (PRS_i) was developed to increase the load bearing capacity of a reinforced soil structure and introduced to improve its displacement behavior. PRS_i concept was validated by laboratory studies. The positive effects of reinforcement prestressing on the improvement of resistance and reduce the settlement of a reinforced granular beds located on a weak soil was analyzed by a series of bearing capacity at the laboratory scale. The effect of parameters including the resistance of the underlying weak soil, the thickness of the granular bed, presressing force's size, the extension of presressing force, the number of reinforcement layers and geogrid axial stiffness are analyzed. A soil element is taken and its behavior in a place under load is analyzed. The results of this research indicate that the models with geogrid vertical distances of 3, 2, 4 and 1 are in a better condition, respectively and the vertical distance of 3 presents a result better than other distances.

Key words: Pre-stress, granular soil, innovative construction method, weak soil, PRS_i

INTRODUCTION

Nowadays soil reinforcement is used in a variety of ways in terms of form including strip, plate, network, thread or rod, surface roughness including rough or smooth surface and stiffness including high relative stiffness such as steel or low relative stiffness such as polymer textiles. Since, the 80s the synthetic polymers called geosynthetics were used extensively.

The reason may be due to better performance of the products with low relative stiffness which is in better coordination with soil than to metal reinforcement materials with high stiffness. These polymer or synthetic textiles due to relative low stiffness are adapted to soil in terms of deformation. In addition, permeable textiles are strong against corrosion and some of them are stable against bacteria and acid attacks and they are non-toxic. Nowadays in addition to the use of reinforcing materials applied in a certain direction (usually horizontal) in the soil mass, the individual fibers that are randomly distributed in the soil mass are applied. The components of a soil wall reinforced by geosynthetic are as follows:

- Soil: including reinforced fine grained soils and substrate soil under the foundation
- Reinforcement elements: including geogrid or geotextile layer
- Shell: a variety of different, beautiful and strong precast concrete with connection mechanism

Geosynthetic exclusively include products made by synthetic polymer fibers one of the main properties of which is non-rotting against the elements in the soil.

Polymers are produced in granular form in petrochemical complexes. During the next process of production, the material is melted and after being frozen they are shaped into plates, strips and strings. During the melting the additives are added before freezing. These additives are added to improve favorable engineering characteristics of the basic materials particularly to modify their sensitiveness.

End products mainly include (non) woven fabrics, grids, net and composites. Geosynthetics are classified in the following five main groups:

- Geotextiles
- Geogrids
- Geomembranes
- Geonets
- Geocomposite

Geogrids: Geogrids as one of the geosynthetics are polymer products that are usually made in the form of regular grid networks in one or both directions. These

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grids and the holes among them engage soil particles or aggregates and the set of geogrid and surrounding materials have a good interlock. The geogrid used in soil layers act as elements resistant to tension and in the areas that the stresses and tensile deformations appear in the soil, they can inhibit the forces and deformations. Geogrids have numerous applications such as the construction of retaining walls, roof and shallow foundations. Where high tensile stiffness and resistance reinforcement is required, the geogrids are used. Geogrid is widely used to create a pleasant appearance in embankments and retaining walls and play an important role between the blocks and geogrids connection (Shivashankar and Jayaraj, 2014).

Soil reinforcement with geosynthetic is a main method in improving soil in geotechnical science and its being widely used in the world. Recently, the foundational global development discussion in raised abd there is a growing need to land reclamation and the use of soft foundation soils. Placing a granular bed on weak soil is the easiest way to improve land that reduces settlement and increase soil load bearing capacity. The use of Geosynthetic Reinforced Granular Bed (RGB) on weak soil in addition to reducing settlement, increases analytical laboratory studies to examine the behavior of reinforced granular bed for different soil types (Shukla and Chandra, 1994a, b).

PROBLEM STATEMENT

With the development of worldwide geotechnical projects in urban areas and observing the dangers of unsafe excavation, the need for study new methods of slope protection of the pit wall is felt more than before. One of the most common methods is to use the soil wall reinforcement system. Changes in pit wall slope, nails' gradient and soil profile (Adhesion and friction coefficient) will change the stability confidence coefficient. Analyzing the numerical effect of pit wall slope, nails' slope, reinforcement design and soil characteristics in confidence coefficient can be used for optimal design. According to the previous studies by reducing the slope of nailed wall, higher confidence coefficient is obtained and improved nail gradient coefficients are increased.

The use of geosynthetics to improve the load carrying capacity and foundation settlement is proven as an effective foundation system. In marginal soil conditions geosynthetic improves the use of shallow foundations instead of deep expensive ones. This is accomplished by the direct reinforcement of cohesive soil or replacing weak soils with beds with stronger grains combined with geosynthetic reinforcement. Today geosynthetic is used for many applications that are not limited to geotechnical engineering. Without the use of geosynthetic reinforcement, many road building projects around the world are not successfully finished (Vinod *et al*., 2009).

In low-lying areas with weak foundation soils, reinforced granular bed with geosynthetic soil can be placed on the weak soil. The resulting mixed soil (reinforced granular bed) improves the bearing capacity of the foundation and provides better pressure distribution above the flattened weak soils. Therefore, we will observe the reduced relevant settlements. During the past 30 years, the use of reinforced soil foundations to keep shallow foundations was significant (Alamshahi and Hataf, 2009).

MODELING AND INTRODUCING THE PARAMETERS

In this study, some of the parameters including model geometry, specific weight (γ), Poisson's ratio (ν), modulus of elasticity (E), adhesion (C) and friction angle (ϕ), geogrid length, the number of geogrids, dilation angle (ψ), geometric boundary conditions, the number of layers of reinforcement, loading and constant mesh are analyzed and geogrid axial stiffness (EA), vertical distance between the geogrid layers and geogrid length are considered as variable.

Hypotheses: The hypotheses are as follows:

- In this study the foundation form is circular with a radius of 5 m. The properties of the soil is that the reinforced soil model includes two layers of the soil including the lower weak soil level with a thickness of 17 m and the upper granular layer with a thickness of 8 m
- The model used in this study has a specific dry and saturated weight of the granular soil as 18 and 19 kN/m^3 and the specific dry and saturated weight of the weak soil are 17 and 17.6 kN/m^3. Poisson's ratio of the soils is equal to 0.3
- Specific friction gravity of soil layer in the weak soil is φ = 12 deg and in granular soil is φ = 13 deg. In this study, R_{inter} is resistance reduction factor is equal with 1
- Dialation angles are assumed to be 0

- Geogrid reinforcement element: geogrid used in research has the axial stiffness EA = 9e+4, 8e+4 and 6e+4 (KN/M) and mass per unit area equal to 730 g/m^2. Geogrid lengths used in geometric model are 5-8 m. Vertical distance above the first layer of reinforcement to below the foundation has the values of 1-4 m
- The number of reinforcement layers (N): in this study, two layers of geogrid reinforcement are used
- The vertical distance between the layers (h): in this study, four different values for modeling the vertical distance between the layers (h) has been considered. Four numbers include 1-4 m. These four values are considered for the vertical distance between the layers (h) at the top granular soil
- The total thickness of the reinforced soil (d): in models studied in this research the reinforcement is done in the top layer granular soil and two reinforcement layers are performed in this soil
- Reinforcement length: in 64 model built in Plaxis finite element software it has four values of 5-8 m as the variable parameter

After modeling and model analysis, results were recorded and analyzed in 128 charts by office software. In order to understand the issue a number of output charts prepared by Plaxis are presented.

According to Fig. 1 that presents the comparison between models 49 and 50 and in order to determine the impact of the change of vertical distance between the geogrid layers on the output of the model which is drown by considering two variable parameters including geogrid axial stiffness (EA) and geogrid length as constant, the effect of vertical distance of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the chart 50 is better than the chart 49 to withstand stress and strain so model 50 has better performance and thus the vertical geogrid distance of 2 m is better than vertical geogrid distance of 1 m.

According to Fig. 2 which presents the comparison between models 61 and 62 and in order to determine the impact of the change of vertical distance between the geogrid layers on the output of the model which is drown by considering two variable parameters including geogrid axial stiffness (EA) and geogrid length as constant, the effect of vertical distance of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the chart 62 is better than the chart 61 to withstand stress and strain so model 62 has better performance and thus the vertical geogrid distance of 2 m is better than vertical geogrid distance of 1 m.

THE ANALYSIS OF THE RESULTS

The effect of vertical distance between geogrid layers on model outputs: According to Fig. 3 which presents the comparison between models 57 and 58 and in order to determine the impact of the change of vertical distance between the geogrid layers on the output of the model which is drown by considering two variable parameters including geogrid axial stiffness (EA) and geogrid length as constant, the effect of vertical distance of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the chart 58 is better than the chart 57 to with stand stress and strain so model 58 has better performance and thus the vertical geogrid distance of 2 m is better than vertical geogrid distance of 1 m.

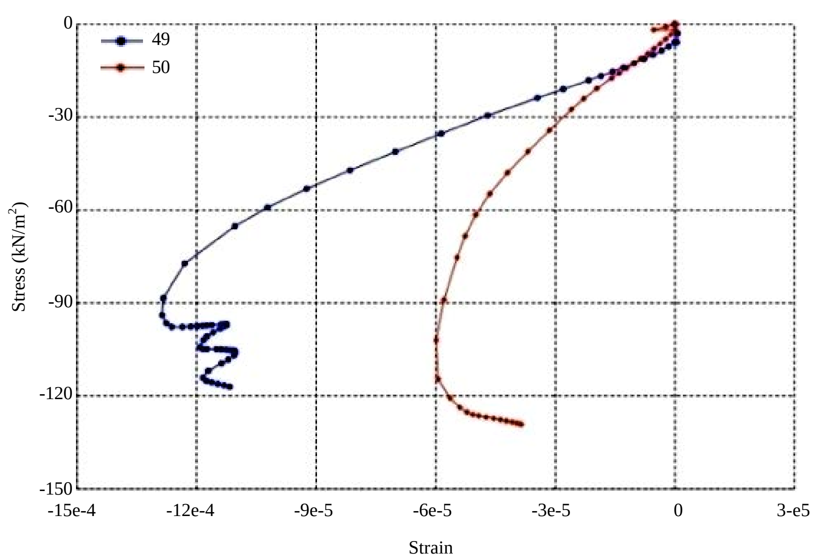

Fig. 1: The stress-strain chart of models 49 and 50

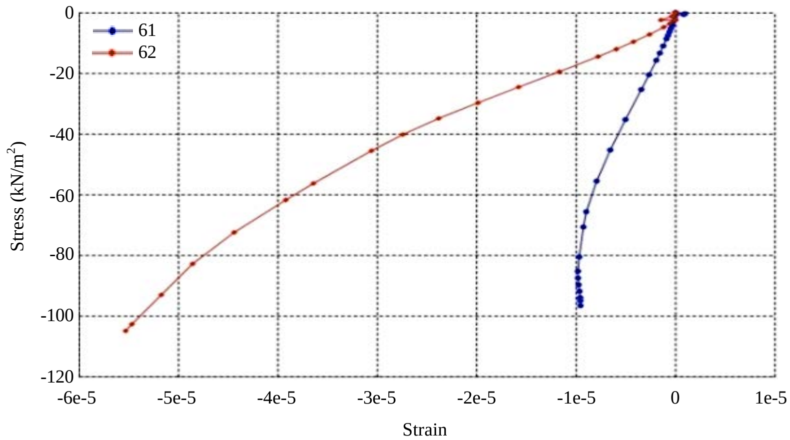

Fig. 2: The stress-strain chart of models 61 and 62

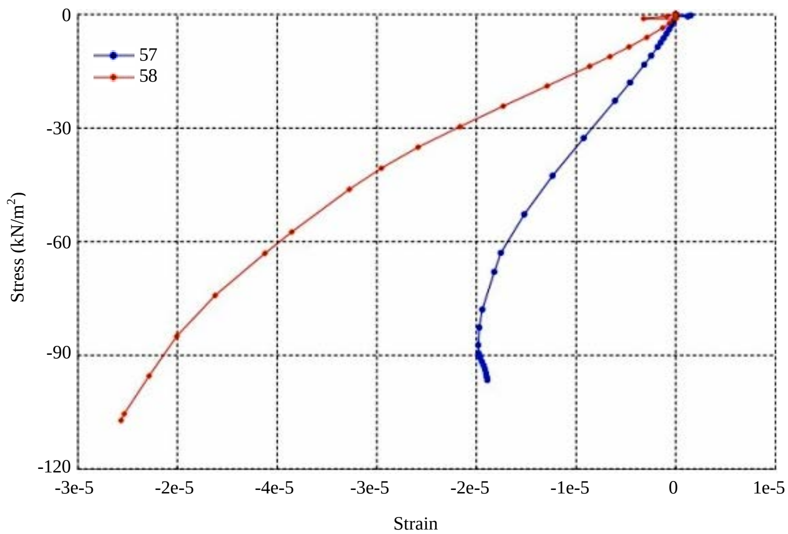

Fig. 3: The stress-strain chart of models 57 and 58

Figure 4 shows the comparison between models 17 and 18 and in order to determine the impact of the change of vertical distance between the geogrid layers on the output of the model which is drown by considering two variable parameters including geogrid axial stiffness (EA) and geogrid length as constant, the effect of vertical distance of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the chart 18 is better than the chart 17 to with stand stress and strain so model 18 has better performance and thus the vertical geogrid distance of 2 m is better than vertical geogrid distance of 1 m.

Figure 5 shows the comparison between models 19 and 20 and in order to determine the impact of the change of vertical distance between the geogrid layers on the output of the model which is drown by considering two variable parameters including geogrid axial stiffness (EA) and geogrid length as constant, the effect of vertical distance of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the chart 19 is better than the chart 20 to withstand stress and strain so model 19 has better performance and thus the vertical geogrid distance of 3 m is better than vertical geogrid distance of 4 m.

Figure 6 shows the comparison between models 17-20 and in order to determine the impact of the change of vertical distance between the geogrid layers on the output of the model which is drown by considering two variable parameters including geogrid axial stiffness (EA) and geogrid length as constant, the effect of vertical distance of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the charts 19-17 have the better performance to withstand stress and strain, respectively so model 19 has the best performance thus the vertical

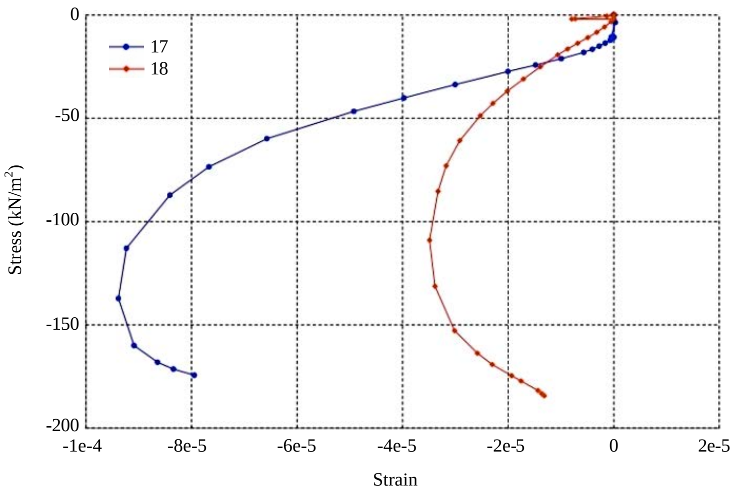

Fig. 4: The stress-strain chart of models 17 and 18

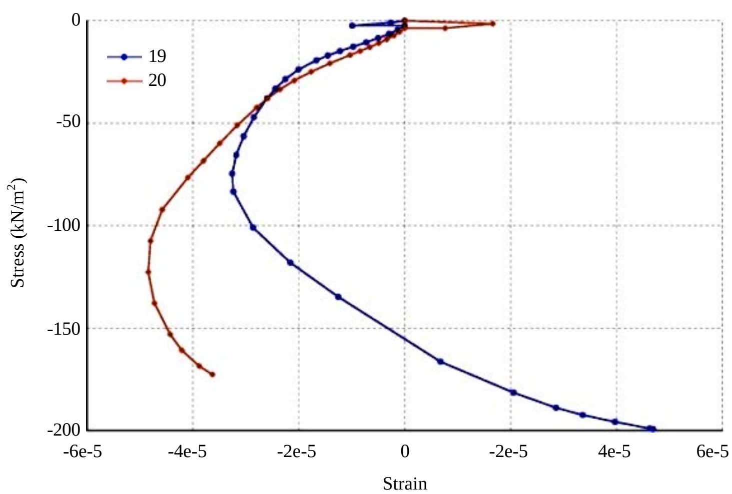

Fig. 5: The stress-strain chart of models 19 and 20

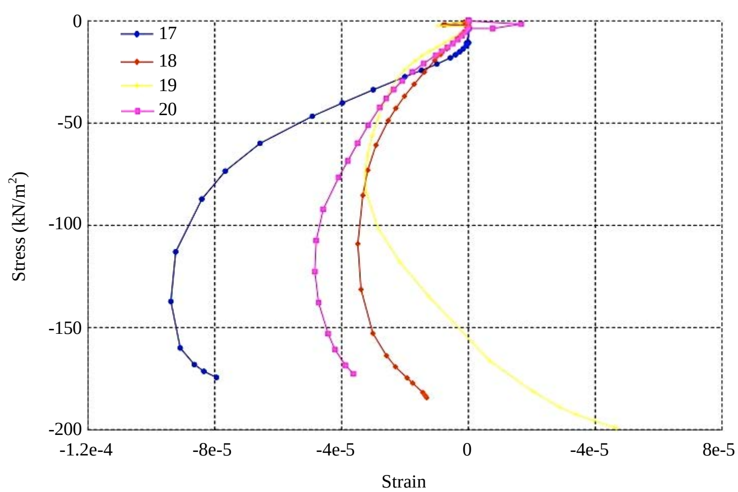

Fig. 6: The stress-strain chart of models 17, 18, 19 and 20

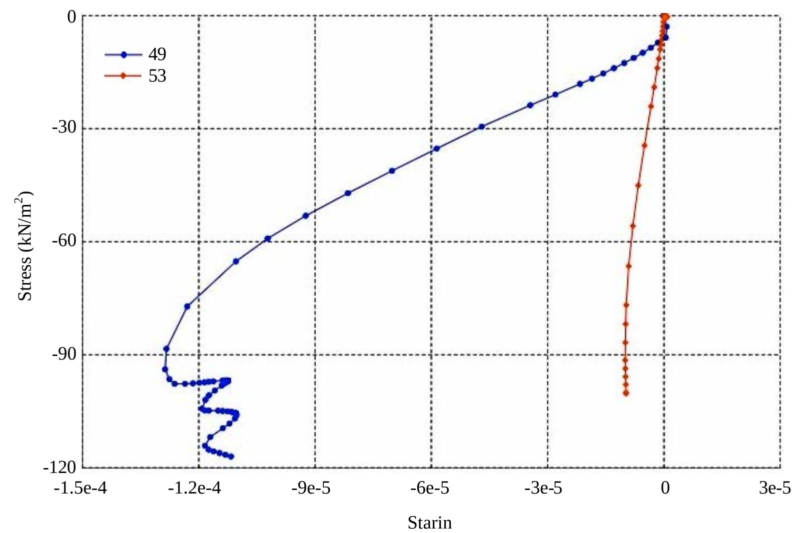

Fig. 7: The stress-strain chart of models 49 and 53

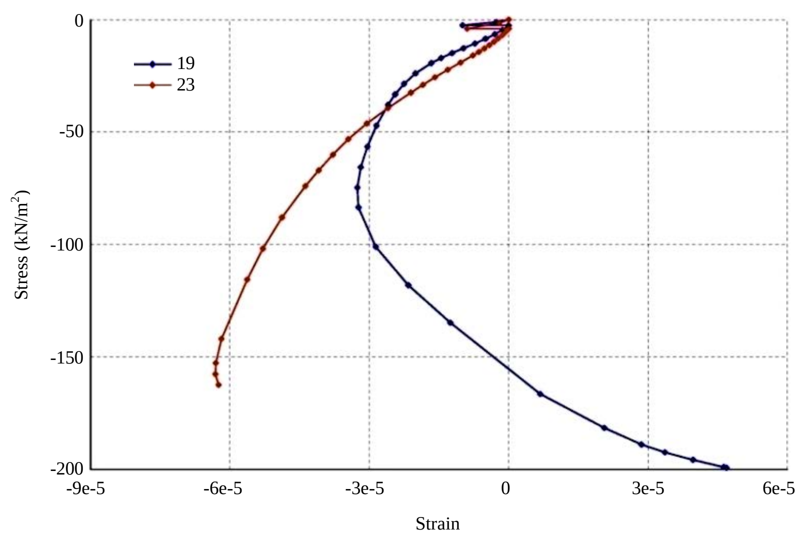

Fig. 8: The stress-strain chart of models 19 and 23

geogrid distances of 3, 2, 4 and 1 m are in a better condition, respectively and the vertical geogrid distance of 3 m has the best result.

The effect of geogrid axial stiffness (EA) on the outputs of the model: The chart presented in Fig. 7 shows the comparison between models 49 and 53 and in order to determine the impact of geogrid axial stiffness (EA) on the output of the model which is drown by considering two variable parameters including vertical geogrid distance and geogrid size as constant, the effect of axial stiffness of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the chart 49 is better than the chart 53 to withstand stress and strain so model 49 has better performance and thus geogrid axial stiffness (EA) with the value 6e+4 (kN/M) is better than geogrid axial stiffness (EA) with the value 7e+4 (kN/M).

The chart presented in Fig. 8 shows the comparison between models 19 and 23 and in order to determine the impact of geogrid axial stiffness (EA) on the output of the model which is drown by considering two variable parameters including vertical geogrid distance and geogrid size as constant, the effect of axial stiffness of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the chart 19 is better than the chart 23 to withstand stress and strain so model 19 has better performance and thus geogrid axial stiffness (EA) with the value 6e+4 (kN/M) is better than geogrid axial stiffness (EA) with the value 7e+4 (kN/M).

The chart presented in Fig. 9 shows the comparison between models 57 and 61 and in order to determine the impact of geogrid axial stiffness (EA) on the output of the model which is drown by considering two variable parameters including vertical geogrid distance and geogrid size as constant, the effect of axial stiffness of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the chart 61 is better than the chart 57 to withstand stress and strain so model 61 has better performance and thus geogrid axial stiffness (EA) with the value 9e+4 (kN/M) is better than geogrid axial stiffness (EA) with the value 8e+4 (kN/M).

The chart presented in Fig. 10 shows the comparison between models 49, 53, 57 and 61 and in order to determine the impact of geogrid axial stiffness (EA) on the output of the model which is drown by considering two variable parameters including vertical geogrid distance and geogrid size as constant, the effect of axial stiffness of the geogrid layers on the stress and strain tolerable by the reinforced soil is that the charts 49, 53, 61 and 57 with geogrid axial stiffness 6e+4, 7e+4, 9e+4 and 8e+4 (kN/M) are in better conditions to withstand stress and strain, respectively so model 49 has the best performance so the geogrid axial stiffness of 6e+4 (kN/M) is the optimal geogrid axial stiffness (EA) compared with the other models.

The effect of geogrid length on the outputs of the model: The chart presented in Fig. 11 shows the comparison between models 4 and 20 and in order to determine the

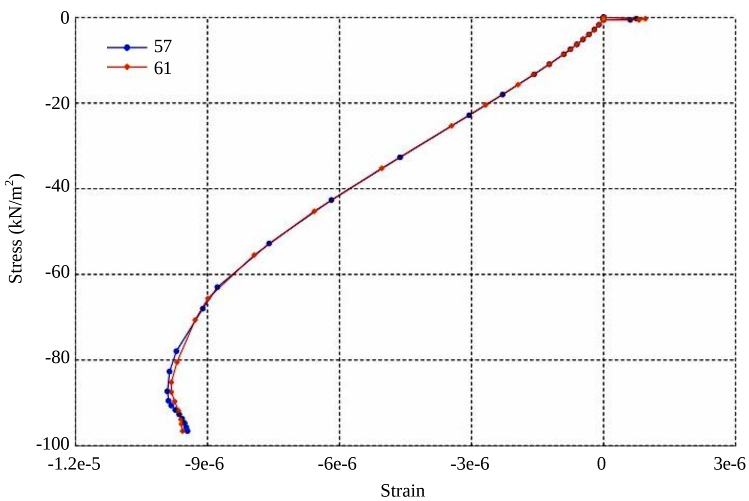

Fig. 9: The stress-strain chart of models 57 and 61

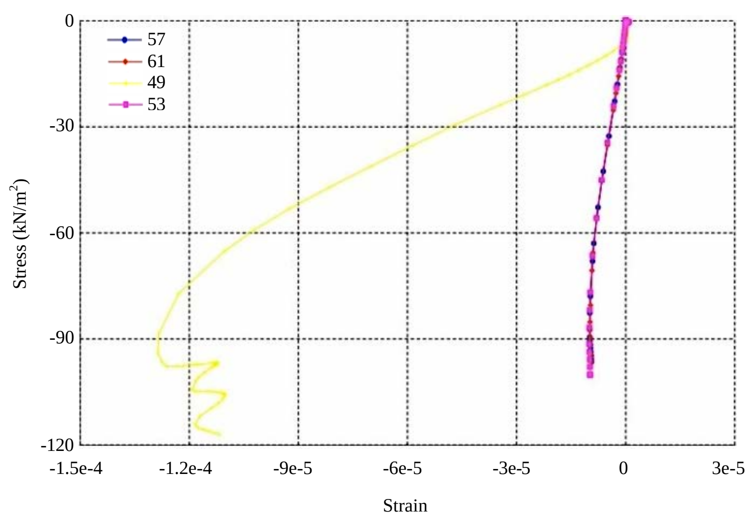

Fig. 10: The stress-strain chart of models 49, 53, 57 and 61

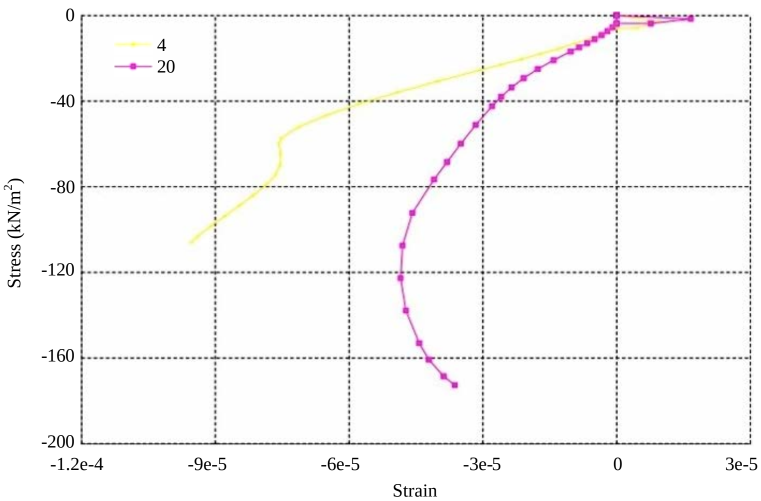

Fig. 11: The stress-strain chart of models 4 and 20

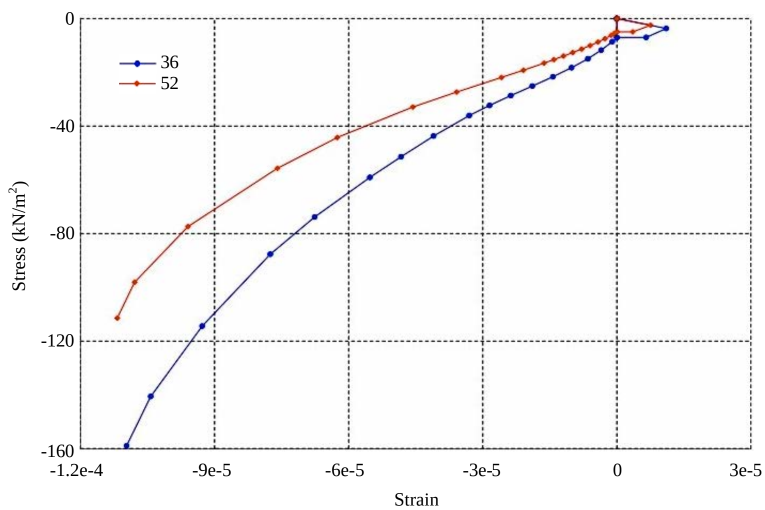

Fig. 12: The stress-strain chart of models 36 and 52

impact of geogrid length on the output of the model which is drown by considering two variable parameters including vertical geogrid distance and geogrid axial stiffness (EA) as constant, the effect of geogrid length layers on stress and strain tolerable by the reinforced soil is that the chart 20 is better than the chart 4 to withstand stress and strain so model 20 has better performance and thus geogrid length of 6 m is better than geogrid length 5 m.

The chart presented in Fig. 12 shows the comparison between models 36 and 52 and in order to determine the impact of geogrid length on the output of the model which is drown by considering two variable parameters including vertical geogrid distance and geogrid axial stiffness (EA) as constant, the effect of geogrid length layers on stress and strain tolerable by the reinforced soil is that the chart 36 is better than the chart 52 to withstand stress and strain so model 36 has better performance and thus geogrid length of 7 m is better than geogrid length 8 m.

The chart presented in Fig. 13 shows the comparison between models 4, 20, 36 and 52 and in order to determine the impact of geogrid length on the output of the model which is drown by considering two variable parameters including vertical geogrid distance and geogrid axial stiffness (EA) as constant, the effect of geogrid length layers on stress and strain tolerable by the reinforced soil is that the charts 20, 36, 52 and 4 with geogrid lengths of 6, 7, 8 and 5 m have better performance to withstand stress and strain respectively, so model 20 has the best performance and geogrid length of 6 m is in better condition than the rest of geogrid lengths.

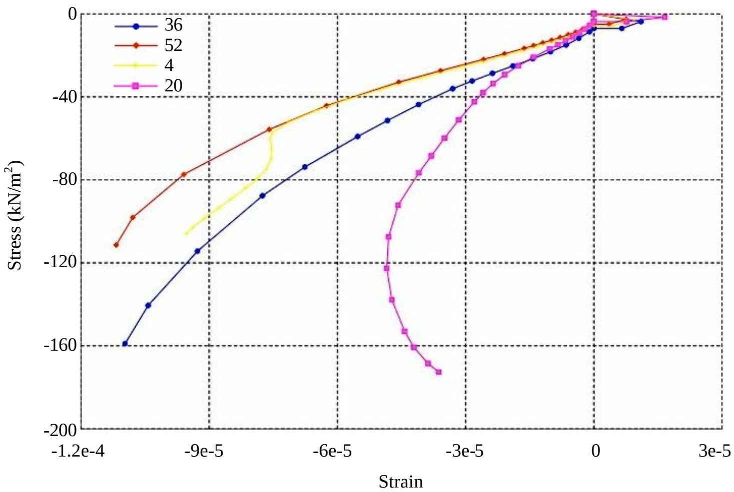

Fig. 13: The stress-strain chart of models 4, 20, 36 and 52

CONCLUSION

The results of numerous studies and analyses regarding prestressing of the reinforcements in reinforced granular soil beds are as follows:

- The effect of vertical distance between geogrid layers on tolerable stress and strain is that the models with vertical distance between geogrid layers of 2 m have higher vertical effective stress and load bearing and horizontal strain than the vertical distance between geogrid layers of 1 m
- The effect of vertical distance between geogrid layers on tolerable stress and strain is that the models with vertical distance between geogrid layers of 3 m have higher vertical effective stress and horizontal strain and load bearing than the vertical distance between geogrid layers of 4 m
- The effect of vertical distance between geogrid layers on tolerable stress and strain is that the models with vertical distance between geogrid layers of 3, 2, 4 and 1 m are in a better condition and the vertical distance between geogrid layers of 3 m has the best result in design
- The effect of axial stiffness (EA) and on tolerable stress and strain by the reinforced soil is that the models with axial stiffness of 6e+4 (kN/M) have higher tolerable vertical effective stress and horizontal strain and load bearing than the axial stiffness of 7e+4 (kN/M)
- The effect of axial stiffness (EA) and on tolerable stress and strain by the reinforced soil is that the models with axial stiffness of 9e+4 (kN/M) have higher tolerable vertical effective stress and horizontal strain and load bearing than the axial stiffness of 8e+4 (kN/M)
- The effect of axial stiffness (EA) and on tolerable stress and strain by the reinforced soil is that the models with axial stiffness of 6e+4, 7e+4, 9e+4 and 8e+4 (kN/M) are in a better condition and the axial stiffness (EA) of 6e+4 (kN/M) has the best result in design compared to other three values
- According to the charts of chapter 5 it is inferred that based on different modes of optimal reinforcement depth the values 3, 2, 4 and 1 m have the performance and the optimized reinforcement depth is 3 m
- The effect of geogrid layers length on tolerable stress and strain by the reinforced soil is that the models with geogrid length of 6 m have higher tolerable vertical effective stress and load bearing and horizontal strain than the geogrid length of 5 m
- The effect of geogrid layers length on tolerable stress and strain by the reinforced soil is that the models with geogrid length of 7 m have higher tolerable vertical effective stress and load bearing and horizontal strain than the geogrid length of 8 m
- The effect of geogrid layers length on tolerable stress and strain by the reinforced soil is that the models with geogrid length of 6, 7, 8 and 5 m are in a better condition and the geogrid length of 6 m has the best result in design compared to other three values

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