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ORIGINAL ARTICLE

Determining the effects of Pre-stressed Reinforcement on granular grounds of poor soil using finite Element method

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ABSTRACT
Soil reinforcement using Geosynthetic is a major technique in improving the soil in Geotechnics during the last three decades. Its function is rapidly increasing throughout the world. The fundamental global development has been lately brought up and there is a need for re-cultivating the grounds and using soft foundation soils. Placing a granular ground on poor soil, is the easiest way of land improvement which leads to land subsiding and augmenting the load carrying capacity of poor soil. In the present research, Plaxis software is used to analyze the interactions between soil and structure in order to model the border area around foundations, candles, retaining walls and common elements. The major objective of this research is to study the benefits of using level soil foundation by numeral analysis method in order to maximize the load carrying capacity and reducing the level foundation subsiding on the soil.
***Keywords**: soil reinforcement method, Geosynthetic, foundation, pre-stressed*

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INTRODUCTION

Today, separate strings with randomly distribution in the soil are used in addition to reinforcing materials which are usually utilized in a horizontally manner in soil mass. In this method, the separate fibers are easily merged into the soil. This is similar to adding cement, lime and other additional materials to the soil. Of the principal benefits of using randomly distributed separate fibers is maintaining the soil cohesion and preventing from formation of potentially poor plates which can occur parallel with directional reinforcing materials. The important subjects of Geosynthetic are Geosynthetic materials, the reason of their production, their function, the various types of Geosynthetic, the causes of soil modification and improving its resistance qualities, technical assessment, the stages of implementing the retaining wall of reinforced soil, its different components, soil interaction mechanism, reinforcement element and at last, the method of designing the aforementioned walls [1].

Due to their considerable solidity, he retaining gravity and semi-gravity walls are categorized into solid walls group. The heaviness and inertia resistance are the main factors of stability of these walls against collapsing.

The traction stress in wall components, especially the wall heels is prevented to occur in design process of these walls. The relatively high solidity of these walls has limited constructing them with considerable heights and implementing these process in area with poor grounds or incompatible soil results in severe structural failure and improving grounds or using deeper foundation will add to the costs significantly. Another group of retaining walls are reinforced soil walls which gain their stability from stressed resistance of their reinforced factor. In these walls, proper accumulation of embankment layers behind them can stabilize the embankment and construct a higher wall [1].

Geosynthetic capabilities has caused more attraction to construction of Geosynthetic wall of reinforced soil, since Geosynthetic reinforced soil wall is known to be more flexible than gravity or concrete retaining walls and has higher capability of absorbing the energy of earthquake and withstanding numerous deformation. So, using it on a poor ground in earthquake-prone areas and in high embankments is more appropriate and cost-effective. Though the wall of reinforced soil with Geosynthetic has unique qualities among retaining walls, but their reliability and sensitivity against changes of design parameters is a vital subject to be discussed.

A review on previous research works

Kurian et al [2] have simulated the reinforced wall system with reinforced horizontal layers using 3-D finite limited particles. The results of numeral analysis were accordant well with obtained results of model experiments.

A model was presented to analyze the granular reinforced ground with several Geosynthetic layers. Granular groundwas modeled by Pasternak and shear and Geosynthetic layers were modeled by elastic membranes. Soft soil is displayed by a series of non-linear springs. A repetitive finite element method is presented in order to display the solutions and result in a dimensionless way [3].

Alamashahi and Hataf [4] have conducted some studies on the effects of anchor networks in geogrid in a sandy steep. They have performed a series of experiments on laboratory models and finite element analysis on a strip foundation of a reinforced sandy steep. They realized that load carrying capacity of solid strip foundation placed on a reinforced steep can be considerably increased through augmenting the reinforced anchor networks .

Madhalivatha and Somwansh [5] performed the laboratory experiments and numeral simulation on a square foundation placed on a reinforced granular ground with several types of Geosynthetic. Studied parameters included the type and resistance of reinforcing material, the depth of reinforcement area, the distance between Geosynthetic layers and the width of reinforcing layer. They found out that configuration of reinforcement material and their state play a vital role in improving the capacity of load carrying, regardless of its reinforcing tensile strength .

Sharma and Chen [6] studied the analysis methods for examining the load carrying capacity of reinforced foundations. They conducted numerous experiments, including the field tests on a reinforced foundation placed on sandy and silt soil. They also analyzed the theory of mechanism failure and present some equations for determining the capacity of load carrying considering the advance of tensile in the reinforcing materials .

The experiments of laboratory models were done to determine the improvement in load carrying capacity and reducing the sand subsiding because of increase in reinforcing strip fibers. The results revealed that the capacity of load carrying can be augmented 6 times and subsiding can be reduced to 90% by introducing the reinforced fibers.

It should be noted that Geosynthetic advantages are only visible after significant subsidence, because the occurrence of strain during the primary subsidence to cause the considerable tensile load in Geosynthetic is insufficient. This is known not to be a favorable characteristic for the foundation of a given structure, since the amounts of subsidence is low. Therefore, a technique is available to allow Geosynthetic to increase the load carrying capacity of the soil, so that a reinforced granular ground can significantly be reduced by a reinforcing Geosynthetic pre-stress.

Analysis of level strain and axial symmetry

Plaxis can be utilized to analyze level strain or axial symmetry. The level strain model is used for structures with stable cross-section, stress state and loading in a relatively long length, orthogonal to the cross section. The model with axial symmetry is used for structure with radius section and even loading around the central axis. The shape changes and stress state in any radius direction are considered equal.

Stone or soil environment

In two-dimensional researches, user can select 6-node or 15-node triangles. 6-node particles provide the second time interpolation and the stiffness matrix of numeral integral is evaluated using three stress points.

Interpolation is in rank 4 for 15-nodes finite elements and numeral integral calculation includes 16 stress pints. 15-node particles are extremely precise two dimensional particles which allow the stresses to be more smoothly distributed in soil and enable the user to predict the failure parameters. Meanwhile, using the mentioned particles will result in occupying higher memory space and prolonging the calculation time.

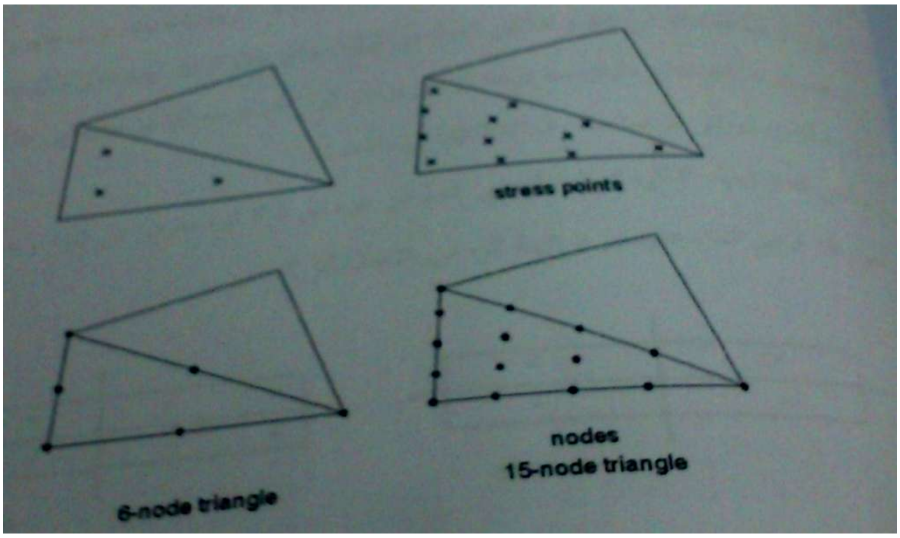

Figure 1: the state of nodes and stress points in various types of soil particles [7]

Beam types
Plaxisis utilized in special elementsforcurving modeling of retaining walls, tunnel grounds and other slim structures.

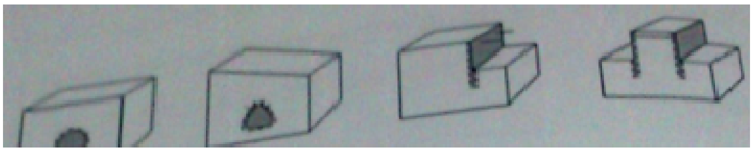

Figure 2: the elements of beams of braces [7]

Although the beams are actually one-dimensional structures, but Plaxis presents the beams such as real papers toward outside of the plate. So, these elements can be used for modeling the walls and plates. The beam elements possess three degrees of freedom in each node: two for moving across Ux and Uy and one for circular movement across(φz)x-y.
When we make use of 6-node elements, each beam element is introduced by three nodes, and the beam elements have 5 nodes when 15-node elements are being utilized.

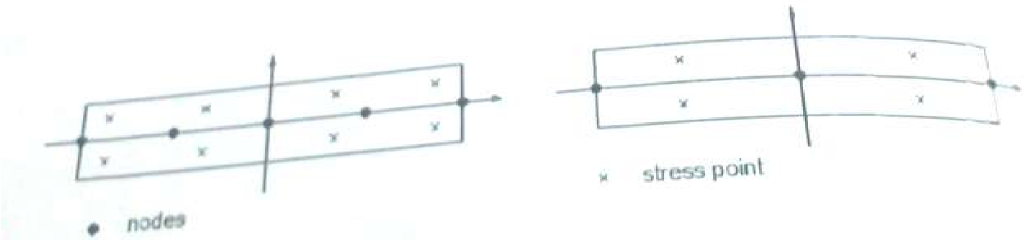

Figure 3: the state of nodes and stress points in 3-node and 5-node beam elements

Bending anchors and axial forces are calculated in stress points. 3-node elements contain two pairs of stress point and 5-node elements have 4 pairs of stress point. Each stress point is located with distance from top and bottom of beam central line. Plaxis considers the deformation due to shear and bending for beams in beam modeling process. The behavior of these elements may be elastic or elastoplastic. The elastic behavior is defined with the use of flexural rigidity and axial rigidity in width unit and with the direction toward the outside of the plate.

Diameter of equal (deq) is calculated by the following equation:

$$d_{eq} = \sqrt{12\frac{EI}{EA}}$$

Shear stiffness is calculated by the equation below:

$$\frac{5EA}{12(1+\tau)}$$

The parameters used in the aforementioned equations are as follows:

E: Elastic modulus

I: Moment of inertia

A: Cross-section

The interface elements

Interface elements are necessary for calculating and modeling the soil-structure interaction and are utilized to simulate the shear materials in contact with candles, geogrid, retaining walls, etc. examples of geotechnical structures with mediating elements are presented in figure 14-3.(The dotted lines represent the interface in each direction the soil-structure interaction occurs.)Figure 15-3 shows the connection of interface elements to soil elements.

When using the 6-node soil elements, the corresponding elements of interface are defined by 3 pairs of node, while the corresponding elements of interface for 15-node soil elements are defined with 5 pairs. In figure 15-3, the interface elements have been displayed with a certain diameter, but the elements of each node are equal in finite element formulation, which makes the element diameter 0. Virtual characteristics are attributed to each interface elements to find the interface materials. Stiffness matrix of interface finite elements is obtained by integral points of Newton-Cotes. These points (stress points) are accordant with the state of each pair of node. Therefore, three integral points are used for 6-node interface elements and five Newton-Cotes integral points are used for 15-node interface elements.

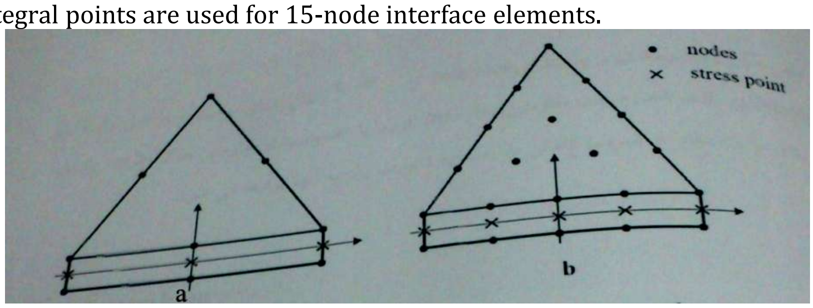

Figure 4: distribution of nodes and stress points in interface elements and connection spot with soil elements [7]

The elastoplastic model (Mohr-Coulomb model) is used to describe the behavior of interface in modeling soil-structure interface.

Mohr-Coulomb criterion is utilized to distinguish between plastic interface and elastic behavior which is characterized by small movements.

Since the interface remains elastic, shear stress should meet the following equation:

3) $|\tau| < \sigma_n \tan\phi_i + C_i$

In case of plastic behavior, shear stress should be accurate in the equation below:

4) $|\tau| = \sigma_n \tan\phi_i + C_i$

$C_i$and Φ_i represent cohesion and friction angle of interface, respectively. σ_z and $\tan_u$ represent normal and shear stresses imposed on interface. The resistance qualities of interface are not necessarily the same as the ones of surrounding soil, but can be related to them using the resistance reduction index as it is shown:

5) $C_i = R_{inter}.C_{Soil}$

6) $\tan\phi_i = R_{inter}.\tan\phi_{Soil}$

7) $\psi_i = \begin{cases} 0 \ddot{} & R_{inter} < 1 \\ \psi_{Soil} \ddot{} & otherwise \end{cases}$

Ψ_i represents dilation angle.

"Tension cutoff" criterion is used for interface in addition to Coulomb criterion of stress.

8) $\sigma_n < \sigma_{t.i} = R_{inter}.\sigma_{t.soil}$

Where $6_{t.soil}$ is the soil tensile strength, so interface strength parameters are obtained by determining R_{inter}.

If R_{inter} = 1, interface has the same qualities as soil except for Poisson index. Generally, the interface element is weaker and more flexible than soil layer in soil-structure real interaction, that is, R<1.

The appropriate amount of R_{inter} in interaction between various types of soils and structure in the soil can be found in scientific literature. In the absence of precise information, it is assumed that R_{inter} is 2.3 for sand-steel connection and 1.2 for clay-steel connection, while interaction with hard concrete requires higher amounts.

R_{inter}>1 is not used. Over-gapping and sliding will occur when the interface is elastic.

The value of the aforementioned movements is calculated through the following equations:

9) Gap displacement Elastic = $\dfrac{\sigma t_i}{E_{oed.i}}$

10)Gap displacement Elastic = $\dfrac{\tau t_i}{G_i}$

Where G_i represents shear modulus, Eoed represents one-dimensional consolidation modulus and tau_i is the virtual diameter of interface. The shear and consolidating modulus is achieved from the equations below:

11) $R_{inter}.G_{soil} < G_{soil} = G_i$

12) $E_{oed} = 2G_i \dfrac{1-\nu_i}{1-2\nu_i}$

In the above equation, Nu_i = 0.45. Considering the aforementioned equation, it is obvious that if elastic parameters are small, the elastic movement may be excessively large and if the elastic parameters are large, numerical ill-conditioning may occur. So, virtual diameter plays a vital role in this matter. This value is determined automatically so that the proper stiffness is achieved (the virtual diameter can be altered by the user).

Also, the interface elements have a permeability index in the vertical direction (K_n) and one in its own linear direction (K_s). One of the simplest applications of interface elements is their function in modeling soil-structure interaction in retaining walls which is useful in embankment beneath foundation. In soil-structure issue, some points require special consideration. The corner points in stiff structures or sudden changes of boundary conditions may result in high peaks in stresses and strains.

Ordinary finite elements do not have the re-distribution of these hard peaks, so they will produce non-physical stress fluctuations. This problem can be worked out with the assist of interface elements, shown in figures 16-3 and 17-3.

Interface elements increase the flexibility of finite elements mashes and prevent from occurrence of unreasonable results (in terms of physical understanding of the problems). However, it should be considered that the existence of interface element should not create unreal poor points in soil.

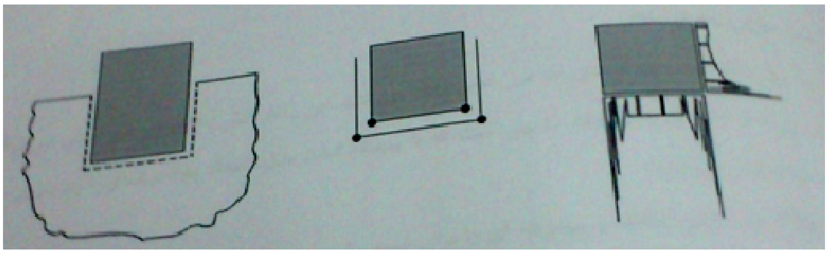

Figure 5: rigid lateral points which induces unreasonable results in value of stresses

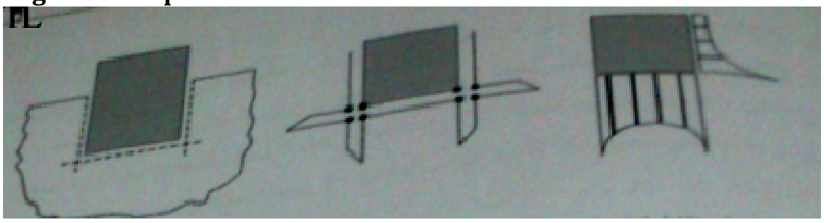

Figure 6: flexible lateral points which causes improvement in results and stress values

The effect of parameter index of soil-Geosynthetic (R_{inter})on model output

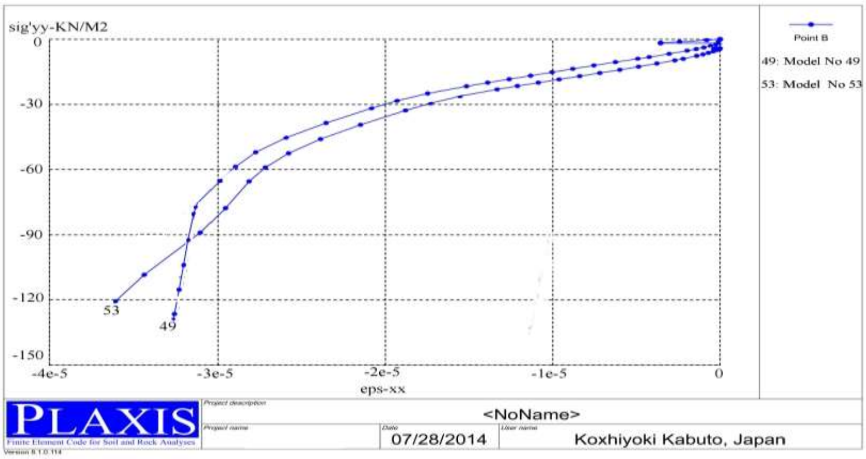

Figure 7- the diagram of stress-strain for models No. 49 and No. 53

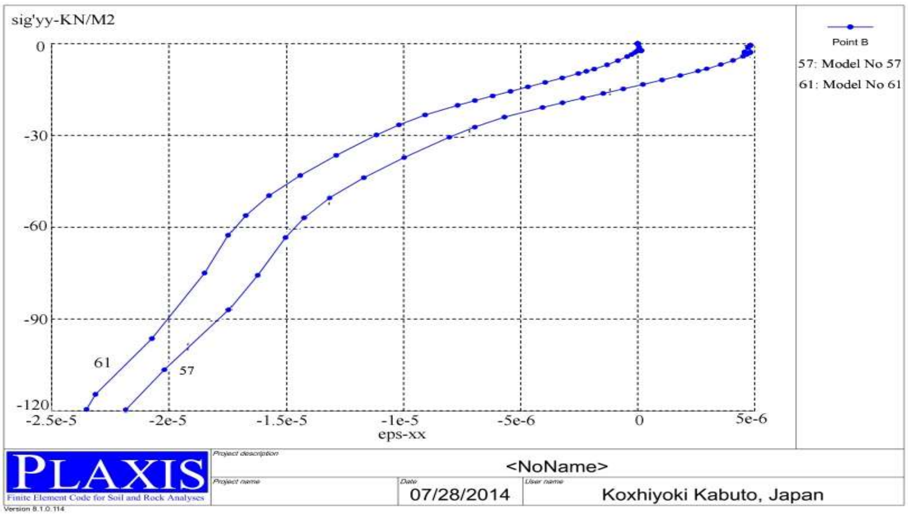

Figure 8- the diagram of stress-strain for models No. 57 and No. 61

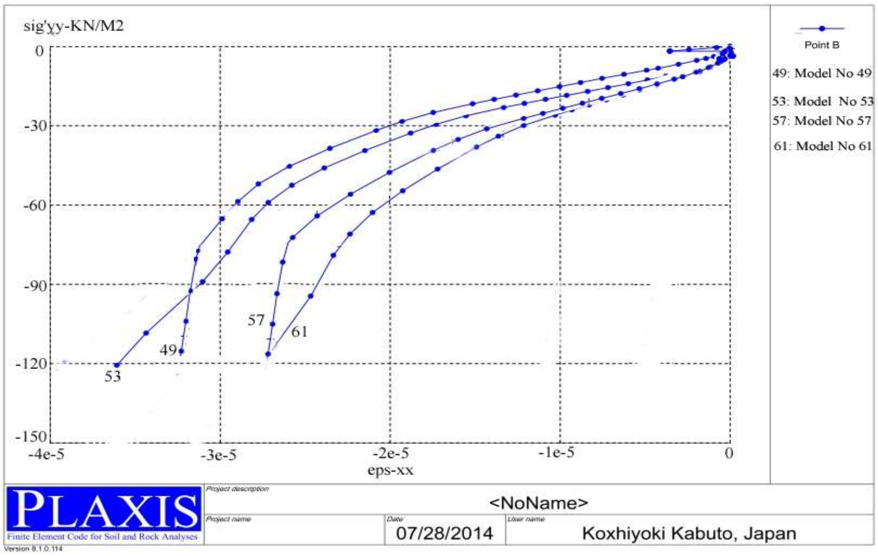

Figure 9- the diagram of stress-strain for models No. 49, No. 53, No. 57 and No. 61

As it was previously mentioned and can be seen in the resultant of 4 diagrams shown in figure 9, the effect of soil-Geosynthetic interaction on the stress and strain values of soil is that R_{inter} values with0.8, 1, 0.9 and 0.85 have the largest effects respectively.

The effect of pre-stressed force on model output

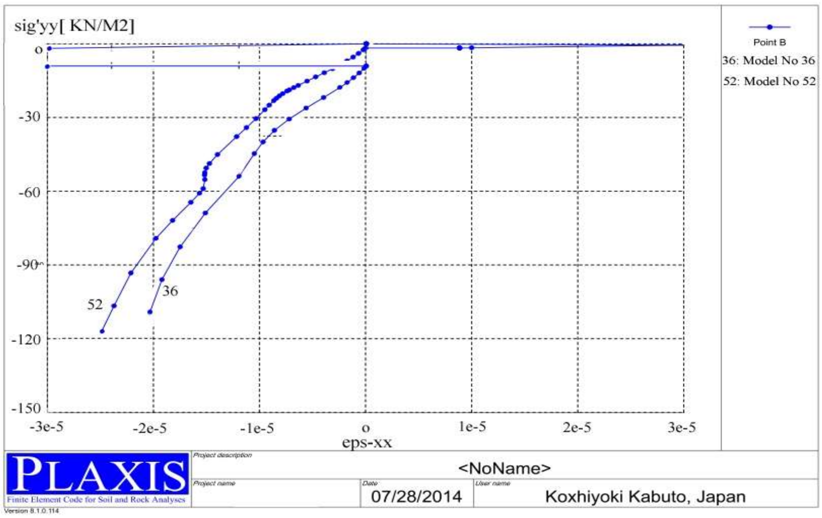

Figure 10- the diagram of stress-strain for models No. 36 and No. 52

As it is visible, the diagram of model 52 indicates that the orthogonal effective stress of this model have more tolerance with pre-stress force of 0.31 KN/M in comparison with model 36 with pre-stressed force of 0.23 KN/M. But the tolerable horizontal strain of model 36 is higher than model 52.In figure 11, we will depict the overall comparison of four diagrams (4, 20, 36, 52) with the geogrid orthogonal distance and same soil- Geosynthetic interaction index, as the only changing factor is the pre-stressed force.

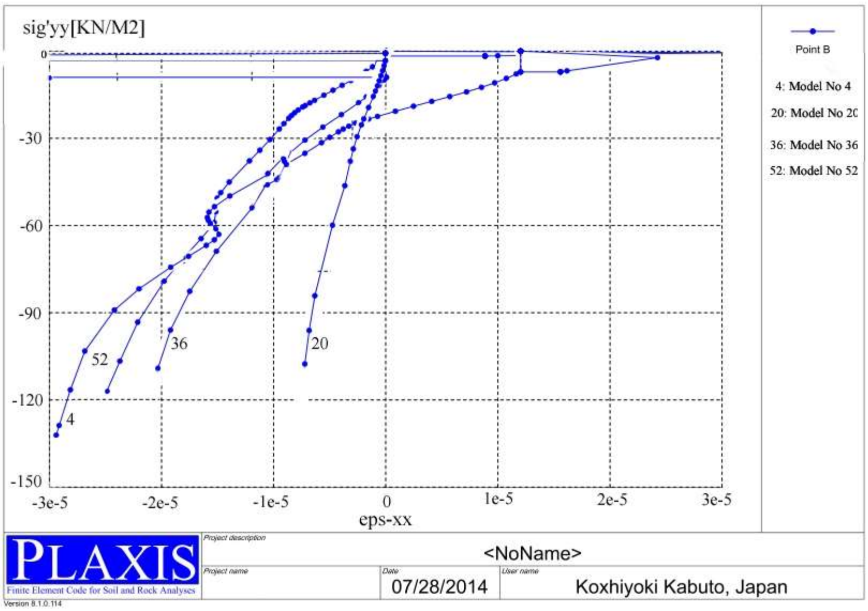

Figure 11- stress-strain diagram for models No. 4, No. 20, No. 36 and No. 52

The above diagram illustrates the models No. 4, 20, 36 and 52 with the pre-stress force of 0.077, 0.154, 0.23, and 0.31 KN/M respectively. What can be realized from this diagram is that the model 4 with pre-stress force of 0.077 KN/M has the highest rate of tolerable stress and Models 20, 36, and 52 are in the next ranks of tolerance with pre-stress forces of 0.31, 0.23, and 0.154 respectively. To make a second comparison and become assured of the obtained result, we analyze the diagrams of stress-strain of the depicted 4 models which had the same geogrid distances and soil-Geosynthetic interaction index.

The indices of soil-Geosynthetic interaction are 0.8 and the orthogonal geogrid distance is 2 meters.

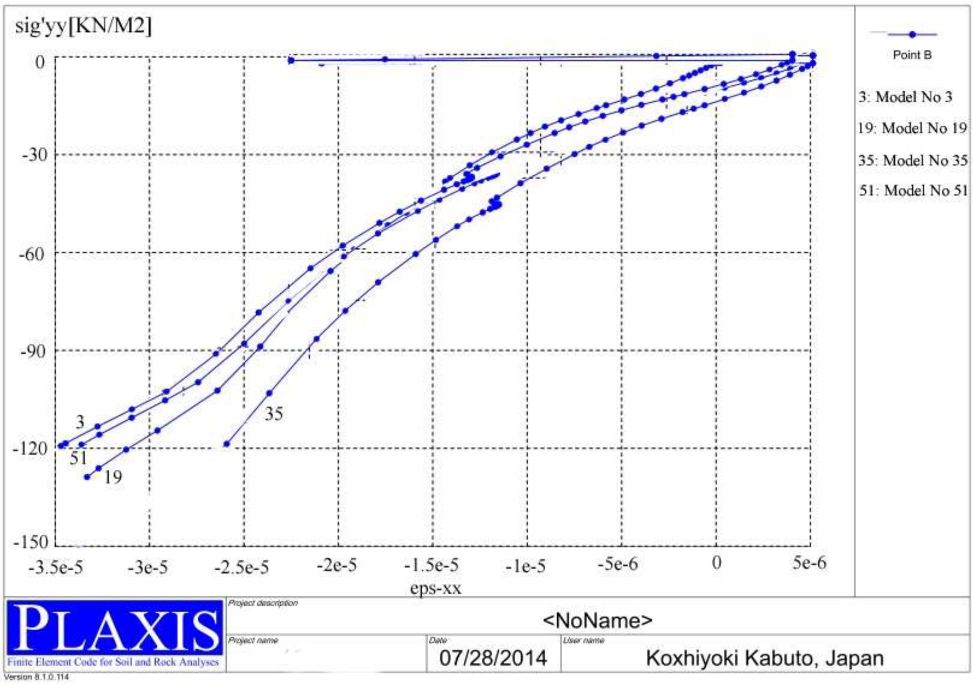

Figure 12 diagram of stress-strain for models No.3, No. 19, No.35 and No.51

The above diagram illustrates the models No. 3, 19, 35 and 51 with the pre-stress force of 0.077, 0.154, 0.23, and 0.31 KN/M respectively. What can be realized from this diagram is that the model 4 with pre-stress force of 0.077 KN/M has the highest rate of tolerable stress and

Models 20, 36, and 52 are in the next ranks of tolerance with pre-stress forces of 0.31, 0.23, and 0.154 respectively. To make a second comparison and become assured of the obtained result, we analyze the diagrams of stress-strain of the depicted 4 models which had the same geogrid distances and soil-Geosynthetic interaction index.

The effect of numbers of reinforcement layers on model output

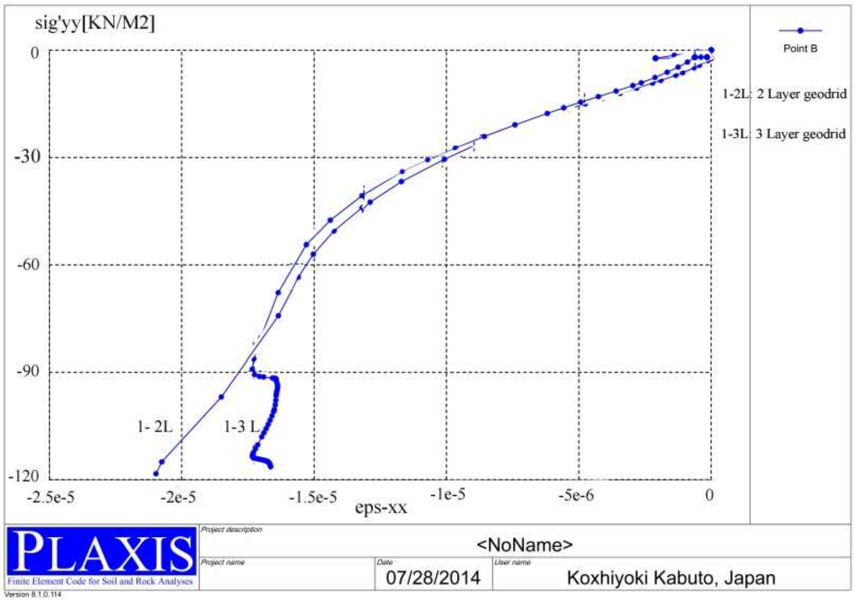

Figure 13. Diagram of stress-strain of model No. 1 with 2 and 3 layers of reinforcement

One of the very important parameters in designing thee reinforced soil is the number of reinforcement layers which is also vital in terms of economy. As it is obvious, the above diagram depicts model 1 which possesses two and three layers of reinforcement. It is observed that soil in two-layer state has higher effective orthogonal stress and horizontal strain than 3-layer state. So it is considered optimized to use two layers of reinforcement.

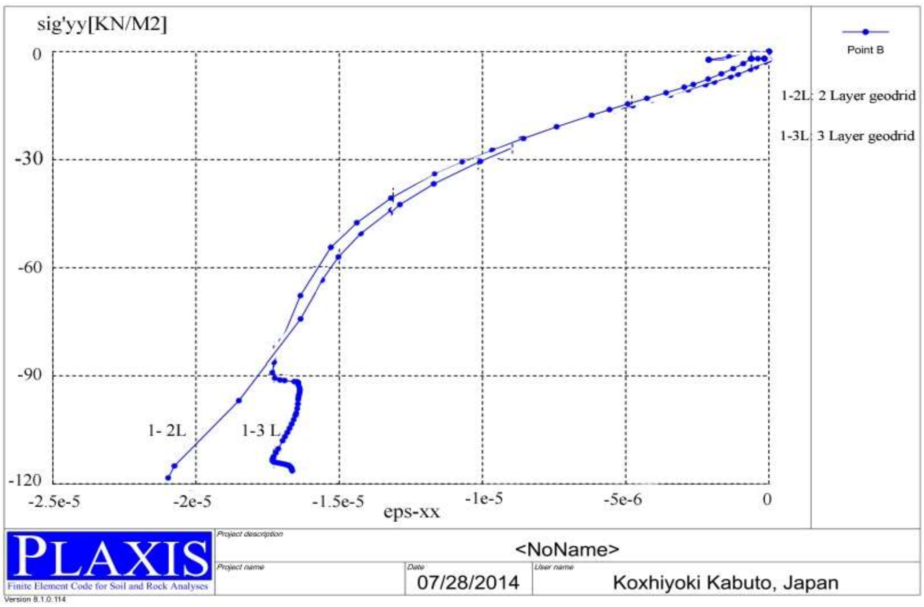

Figure 14- the diagram of load-strain of model No.1 with 2 and 3 reinforcement layers

As it is obvious, the above diagram depicts model 1 which possesses two and three layers of reinforcement. It is observed that soil in two-layer state has slightly higher load carrying capacity and horizontal strain than 3-layer state. So it is considered optimized to use two layers of reinforcement.

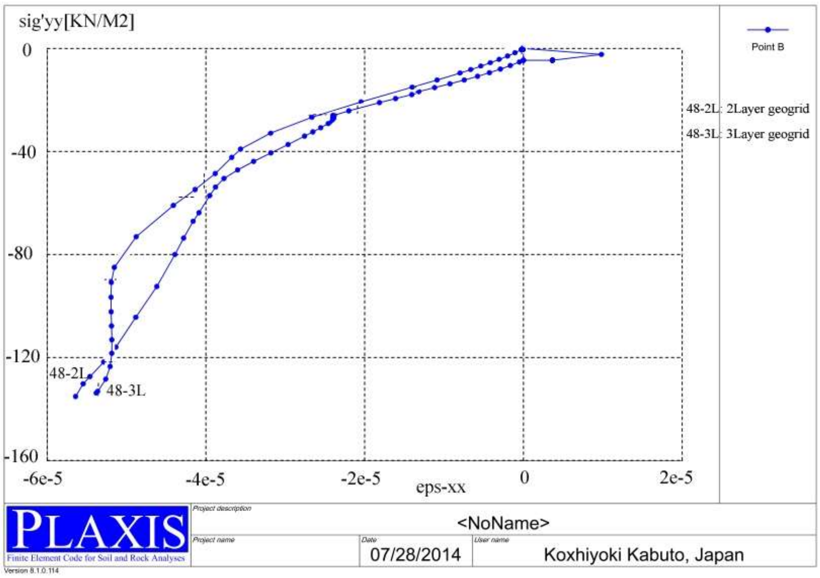

Figure 15- the diagram of stress-strain of model No. 48 with two and three reinforcement layers

As it is obvious, the above diagram depicts model 48 which possesses two and three layers of reinforcement. It is observed that soil in two-layer state has higher effective orthogonal stress and horizontal strain than 3-layer state. So it is considered optimized to use two layers of reinforcement.

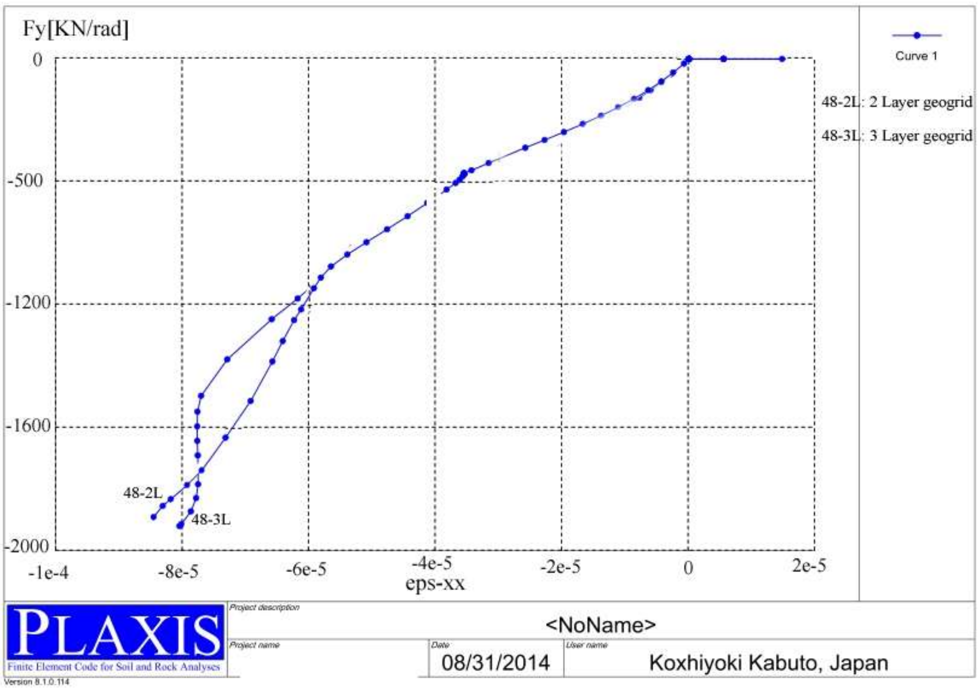

Figure 16- diagram of load-strain of model No. 48 with 2 and 3 reinforcement layers

As it is obvious, the above diagram depicts model 1 which possesses two and three layers of reinforcement. It is observed that soil in two-layer state has slightly higher load carrying capacity and horizontal strain than 3-layer state. So it is considered optimized to use two layers of reinforcement.

Overall, one can conclude that using two layers of reinforcement in comparison with three layers leads to effective orthogonal stress, load carrying capacity and more tolerablehorizontal strain.

CONCLUSION

The results of several studies and researches on the pre-stress effect of reinforcements in granular ground of reinforced soil can be summarized as follows:

1. The effect of soil-Geosynthetic index, R_{inter}, on the tolerable stress and strain of reinforced soil are described with indices equal to 0.8, 1, 0.9 and 0.85 respectively, which shows the highest amount of effect.
2. The effects of pre-stress forces on tolerable stress-strain for reinforced soil with the values 0.077, 0.31, 0.23 and 0.154, induces the highest amount of tolerable stress respectively.
3. The effect of geogrid orthogonal distance on tolerable stress-strain for reinforced soil shows that the distances of 2, 0.625, 2.5 and 1.25 meters causes the highest amount of tolerable orthogonal stress respectively, and the optimized depth of reinforcement is 2 meters.
4. Through studying the 8 diagrams of stress-strain and load-strain, we conclude that the tolerance of two reinforcement layers in the soil on orthogonal stress and horizontal load and strain will be enhanced in comparison with three-layer state, so it is considered optimized to use two layers of reinforcement in the soil.
5. The effect of upper to lower reinforcement layers depth on tolerable stress-strain value can be exemplified by the higher effective orthogonal stress and horizontal in 2.5 meters distance from upper reinforcement section to lower surface in comparison to other distance values.
6. Changing any of pre-stress force variables (orthogonal geogrid distance and the interaction index of soil-Geosynthetic) has no effect on orthogonal subsidence. The reason is the fixed soil specific weight and elastic modulus in all 64 models.
7. Lengthening the reinforcement materials will result in effective stress reduction, but will induce no change on orthogonal subsidence and horizontal movement.

SUGGESTIONS FOR FUTURE RESEARCH WORKS

1. Due to the limitation of time and space to elaborate the different shapes of foundations, it is recommended that more researchers discuss and analyze the extended, strip and square foundations.
2. In the present research, the pre-stress force parameters, the orthogonal distance of geogrid layers and the interaction index of soil-Geosynthetic (Rinter) are considered as changing parameters.
3. It is suggested that elastic modulus parameters of soil, soil permeability index, the extension of pre-stress force, the number of reinforcement layers, the length of reinforcement materials, the total diameter of reinforced soil and dilation angle (ψi) be examined as changing parameters.
4. The effects of alterations of ground water surface in various levels.
5. In this research, the loading was performed in the form of pre-described displacement. It is suggested that exhaustive loading be applied as the imposed load on model geometry.
6. It is suggested that the change effect of geogrid parameters such as geogrid axial stiffness and geogrid length on model outputs be evaluated precisely.

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