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SCALE EFFECT ON THE SHEAR STRENGTH OF TWO-LAYER SOIL REINFORCED BY GEOGRID

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Abstract: Geosynthetics are used to reinforce soils and improve their mechanical characteristics, especially when soft low-bearing capacity soils are encountered in civil engineering projects. Particularly, in roads, geosynthetics are placed between the interface of granular materials and soft-soil sub grade to improve composite layers' bearing capacity. This paper presents the results of the finite element analysis of the two-layer soil(granular base-clayey sub grade) reinforced by geogrid and discusses the effect of the reinforcement on the shear strength. As the primary aim of the study, the numerical model was calibrated in comparison with the experimental results of large scale direct shear tests. The results showed that the shear strength improved in the two-layer soil which had been reinforced by geogrid. The predictions made by the developed model were found to be in line with the experimental data obtained from large scale direct shear tests. As another aim of the study, different dimensions of shear box were used for modelling in order to investigate the scale effect on the shear strength of double-layered soil (clay-sand). The results showed that the increase in the dimensions of the reinforced shear box leads to the enhancement of peak shear strength. Moreover, several analyses were conducted on geogrid in shear box with different dimensions in fixed and unfixed states. The results demonstrated that the shear strength of treated geogrid was higher than the shear strength of those in which untreated geogrid was utilized.

Keywords: *Two-layer soil, shear strength, geogrid, finite element analysis, large scale direct shear test.*

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1.0 Introduction

Many experimental, analytical and numerical studies have been performed to investigate the shearing behaviour of reinforced soils [4,5].Numerical methods enable the determination of material parameters that are difficult to be measured in experimental studies. The finite element models have also been successfully used in back-analyses of experimental results. The development of numerical procedures of calculations led to the establishment of some important ideas for problem solving, with the main ones dealing with geometry of model, loading conditions, material properties and constitutive models of materials and selection of numerical technique [2,6,9,13,19].

Almost many previous research studies in experimental and numerical methods have investigated the behavior of geosynthetics in one layered soil. For example, Useche Infante *et al*. [18] investigated the behavior of geogrid reinforced sand under vertical load. Although several investigations have been performed in order to find the best depth for embedding the geosynthetics and the interaction between soils and geosynthetics [11,13,14,17], not a similar degree of attention has been given to the interactions between two layered soils and geosynthetics. Zhou and Wen [20], for example, used a compression test in order to study a model of sand soil, placed on soft clay which was reinforced by geogrid. Similarly, Palmeria[13] presented some experimental, theoretical and numerical methods for evaluating the interaction between soils and geosynthetic. Furthermore, Sharma *et al*. [15]studied the effect of bearing capacity of strip footing on reinforced double layer soil system with fly ash stabilized clayey soil.

On the other hand, one of the most important factors that can affect the results in geotechnical engineering is the impact of dimensions and in general the effect of scale. It is impossible to conduct soil strength tests on the samples that are identical in size to the soil of the site. In addition, the test apparatuses which are available to engineers have limited dimensions. Sobol *et al*. [16] works on scale effect in direct shear tests on recycled concrete aggregate and shown the different result of parameters in medium and large box. Therefore, it is required to observe the effect of test scale when using test data.

This paper presents the results of finite element analysis on shear strength of two-layer soil reinforced with geogrid. The numerical model investigated here is the one which was experimentally studied by ZiaieMoayed and Kamalzare[10].

2.0 Materials

2.1.1 Soil

In this numerical modeling, two types of soil were used: a clayey soil and a granular soil which had been grained in a manner that satisfied the suggestion of AASHTTO [1] for sub base soil of roads. Table 1 lists the physical characteristics of each soil, while Figure 1 shows their grain size distribution curves. It should be noted that in this figure upper and lower limits refer to the maximum and minimum grain sizes which have been suggested by AASHTO [1]. This study used a kind of geogrid (GG) for reinforced soil.

The physical characteristics of this geogrid have been listed in Table 2 (Kamalzare and ZiaieMoayed [10].

Table 1: Soil characteristics (Kamalzare and ZiaieMoayed [10])

Property	*Sand*	*Clay*
D_{10} (mm)	0.12	-
D_{30} (mm)	1.20	-
D_{60}(mm)	5.15	-
C_u	42.92	-
C_C	2.33	-
LL	-	13
PL	-	19
(USCS)	SW	CL

Table 2: Geogrid characteristics (Kamalzare and ZiaieMoayed [10])

Material	*(HDPE)*
Aperture size, (mm)	10 × 10
Weight, (g/m^2)	700
Tensile strength-MD, (kN/m)	7.6
Tensile strength-CD, (kN/m)	7.6
Young's modulus, (MPa)	10000

The results of the direct-shear tests for reinforced soil and non-reinforced soil are presented in Figure 2. The soil used for the large-scale direct-shear testing (150×150×75 mm) program was dried in an oven. It was then wetted to the optimum water content, followed by compacting to the target unit weight within the shear box. Each soil was compacted in three layers. The compaction of the sand and clay was conducted by using a manual plastic hammer to hit the steel plate, which was placed on top of the soil until the target unit weight was achieved. The geogrid was positioned on top of the lower shear box and at the interface of the sand and clay soils. These tests were conducted using normal stresses of 44, 96 and 192 kPa. According to ASTM D5321[3], a shear rate of 1 mm/min was used in this test program in order to satisfy the undrainedfailure condition.

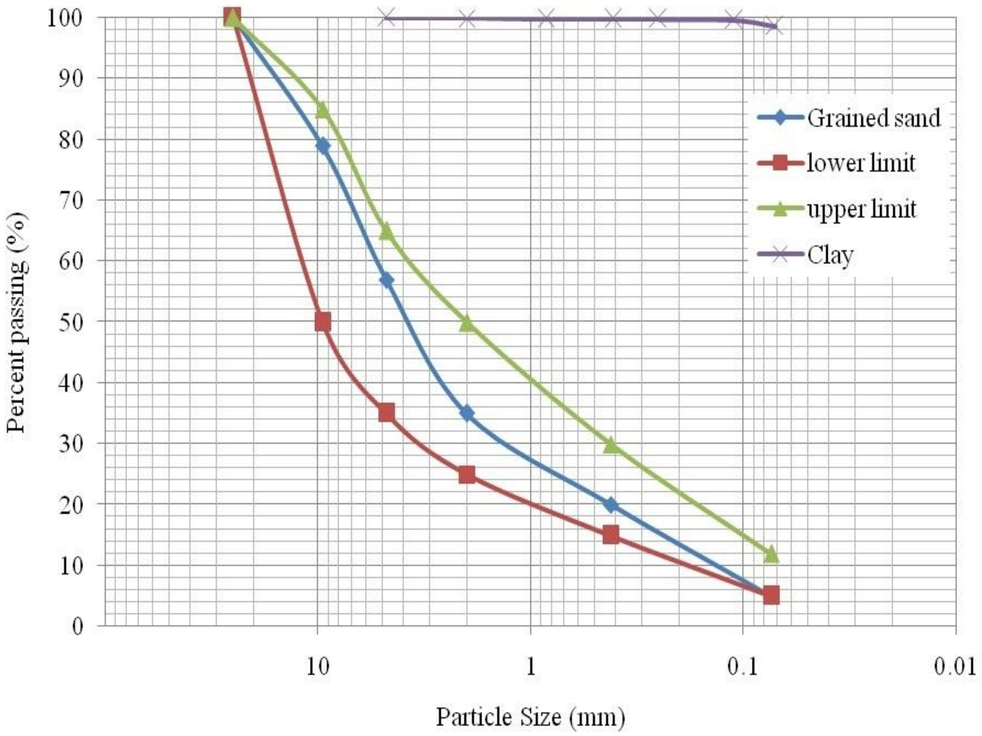


Figure 1: Grain size distribution of tested soils (Kamalzare and ZiaieMoayed[10])

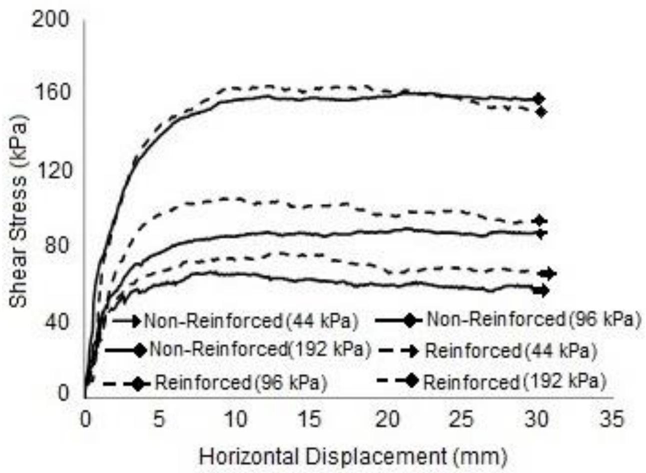


Figure 2: Stress–strain behavior of the reinforced two layer soil by geogrid and non-reinforced (Kamalzare and ZiaieMoayed[10])

3.0 Finite Element Modelling and Analysis

3.1 Soil parameters

In this research, the plastic parameters of sand and clay were determined by Drucker-Prager model and modified Drucker-Prager model, respectively, using the parameters given in Tables 3-4.

Table 3: Geotechnical parameters of studied soils (Kamalzare and ZiaieMoayed[10])

Property	*Symbol*	*Sand*	*Clay*
Dry unit weight, (kN/m^3)	γ_d	21.3	18.2
Cohesion, (kPa)	*C*	0	32
Friction angle, (˚)	*Φ*	47	30
Poisson's ratio	*ν*	0.3	0.25
Young's modulusfor normal stresses 44, 96 and 192 kPa, (MPa)	*E*	35,36 and 38	7, 8 and 8.5

Table 4: Equivalent Drucker-Prager parameters of studied soils

Property	*symbol*	*Sand*	*Clay*
Cohesion, (kPa)	*d*	-	200
Friction angle, (˚)	*β*	62.6	50.1
Cap eccentricity	*R*	-	0.2
Transition surface radius	*α*	-	0.01
Flow stress ratio	*K*		0.778
Dilation angle for normal stresses 44, 96, 192 kPa, (˚)	*ψ*	4.8, 5.5, 8	-

3.2 Model Geometry and Boundary Conditions

A series of 3D finite element analyses were conducted to simulate the large-scale direct shear tests using ABAQUS software. The model geometry is shown in Figure 3. The metal box of the direct shear apparatus was modeled by rigid surfaces in the numerical model. The soils were modeled as an elastic–plastic material and the geogrid was assumed as a linear elastic material. The interface between the soil and the walls of the box was modeled using tie constraint by discretization method surface-to-surface capability. The geogrid was positioned on the top of the lower shear box and at the interface of the sand and clay soils. These analyses were conducted using normal stresses of 44, 96 and 192 kPa. The contact interface was characterized by the coefficient of frictionμ. In the numerical model, the coefficient of friction was assumed to be 1.19 for contact interfaces between sand and geogrid - clay and geogrid (Kamalzare and ZiaieMoayed[10]).

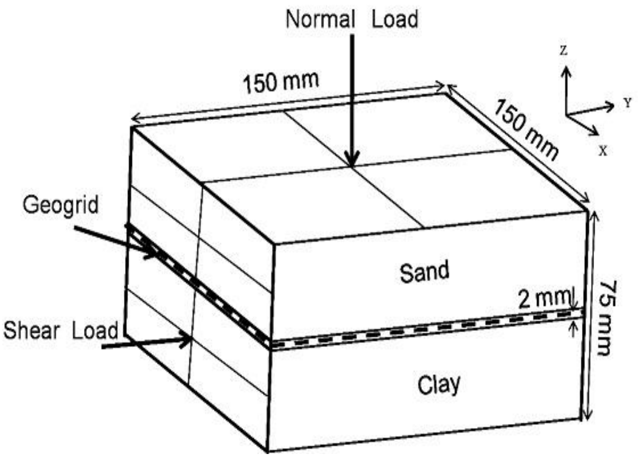


Figure 3: Model geometry (According to ASTM-D5321[3])

Figure 4 shows the boundary condition of the occupied model. The bottom of the model was restrained in x and z direction. In the initial step, the upper box was restrained in x, y direction and the lateral walls of upper and lower boxes were restrained against movements in x, y and z. In the second step, the lateral walls of upper box were restrained in x, y and z; however, the lower box was restrained in x and z. At the same time, a horizontal displacement of about 30 mm was applied to the lower box in y direction (see Figure 5,). The FE (finite element) mesh of the model is shown in Figure 6. Because of the composite geometry of the problem, the mesh was implemented using “structured mesh” technique in ABAQUS application. The sand, clay and geogrid were modeled by C3D8R (8-node linear brick, reduced integration, hourglass control) elements. Dynamic analysis was applied at this stage of the study.

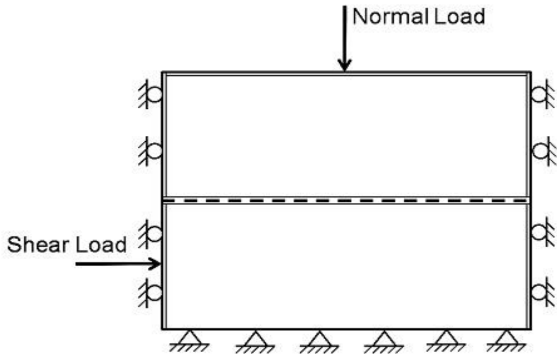


Figure 4: Boundary conditions of model

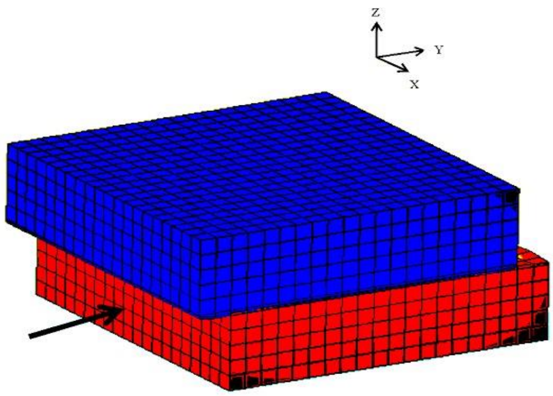


Figure 5: Horizontal displacement of direct shear box

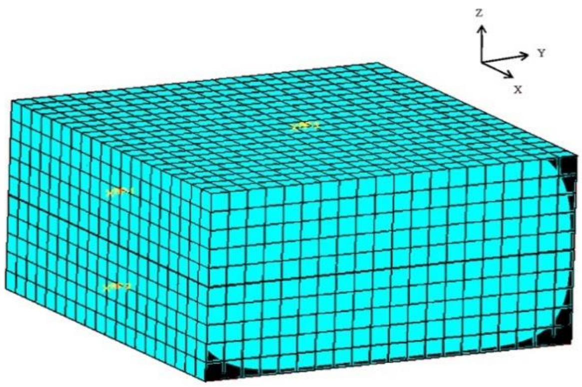


Figure 6: 3D mesh of modeling of direct shear test

In order to study the effect of dimensions on the shear strength of double-layered (clay-sand) soils, different dimensions of shear box were considered. Table 5, illustrates different dimensions used for modeling.

Table 5: Dimensions of direct shear box in modeling

Dimensions of shear box(mm)
75 × 150 × 150
150 × 300 × 300
300 × 600 × 600
300 × 900 × 900

4.0 Results and Discussion

4.1 Model Calibration

The analysis was carried out for each of the three normal stresses of 44, 96 and 192 kPa in FE model. The results were in good agreement with experimental data obtained from the aforementioned case study (Kamalzare and ZiaieMoayed[10]). The results of numerical modeling are shown in Figs. 7-8, in comparison to the experimental results of large scale direct shear tests.

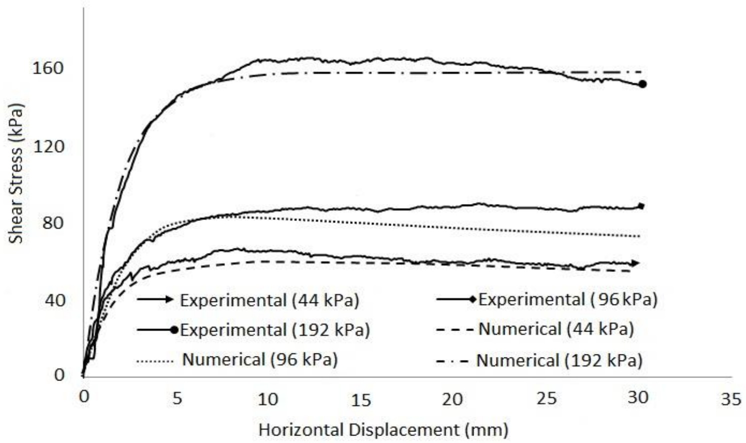


Figure 7: Comparison of experimental and numerical modeling of direct shear test on non-reinforced two layer soil

Figure 7 indicates the comparison of experimental and numerical modeling of direct shear test on non-reinforced two layers soil. As it can be seen in figure 7, experimental and numerical data have experienced an acceptable adaptation. Overall, although after 25 mm displacement experimental data reduced and have been less then numerical data but in all other cases the numerical data was less than experimental ones. In more details, as shear stress has been increased the adaption has been reduced during the horizontal displacement.

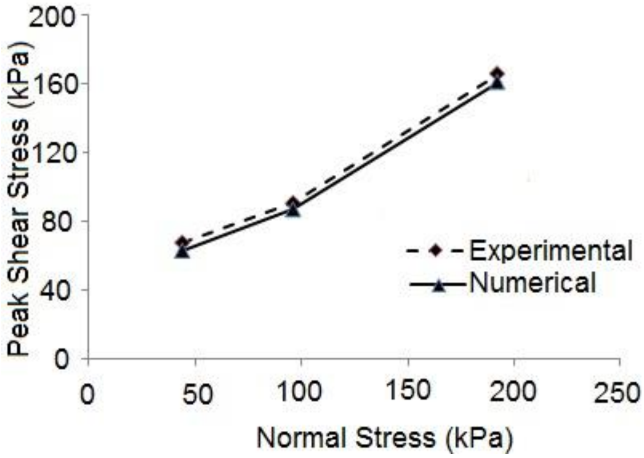


Figure 8: Peak shear strength versus normal stress for the non-reinforced two layer soil

Figure 8 shows the comparison of peak shear strength and normal stress for the non-reinforced two layers soil. The experimental and numerical collected data match almost well in different locations. The trend for both numerical and experimental condition, have been experienced a sharper and slight increase at 100 kPa normal stress.

4.2 Two-Layer Soil Reinforced With Geogrid

To evaluate the stress-strain behavior of the soil-geogrid interface, the results of numerical modeling are presented in Figure 9.Also; the results of the peak shear stress versus the normal stress are shown in Figure 10. The results obtained from the numerical modelling of large scale direct shear test are in line with those of the laboratory study conducted by Kamalzare and ZiaieMoayed[10].

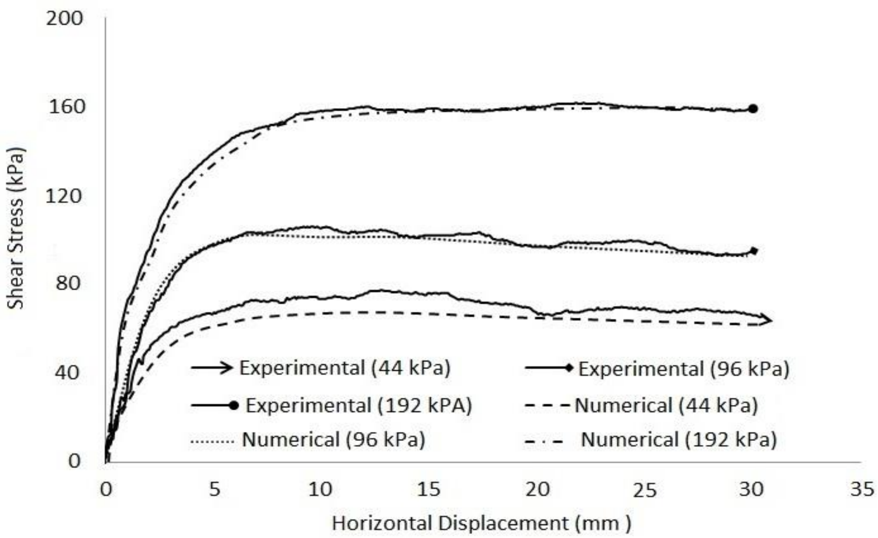


Figure 9: Comparison of experimental and numerical modeling of direct shear test on two layer soil reinforced by geogrid

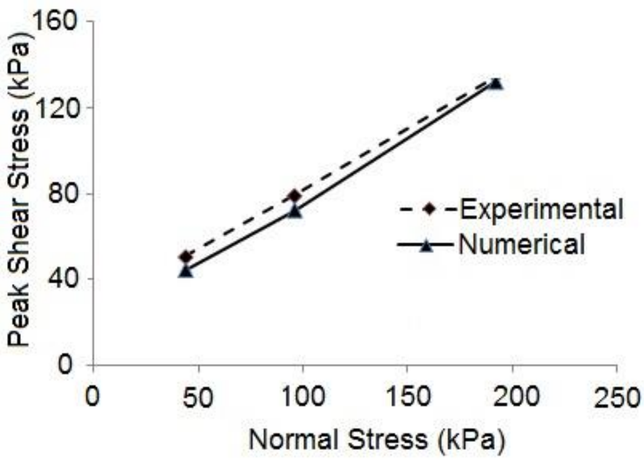


Figure 10: Peak shear strength versus normal stress for the two layer soil reinforced by geogrid

4.3 *Effect of Dimensions*

Figure11 shows the changes in shear stress-displacement curves in different dimensions when the shear box was reinforced by geogrid. As this figure illustrates, the increase in dimensions of reinforced shear box led to an increase in the maximum shear strength. This is due to the fact that geogrid which was employed in smaller dimensions was not able to interlock with and be fixed to soil due to slight strains during shear force employment. As a result, the strength of geogrid was not employed completely. However, as bigger dimensions made it possible to have more displacements in the sample, the geogrid is able to be fixed to soil, leading to an increase in the shear strength of soil.

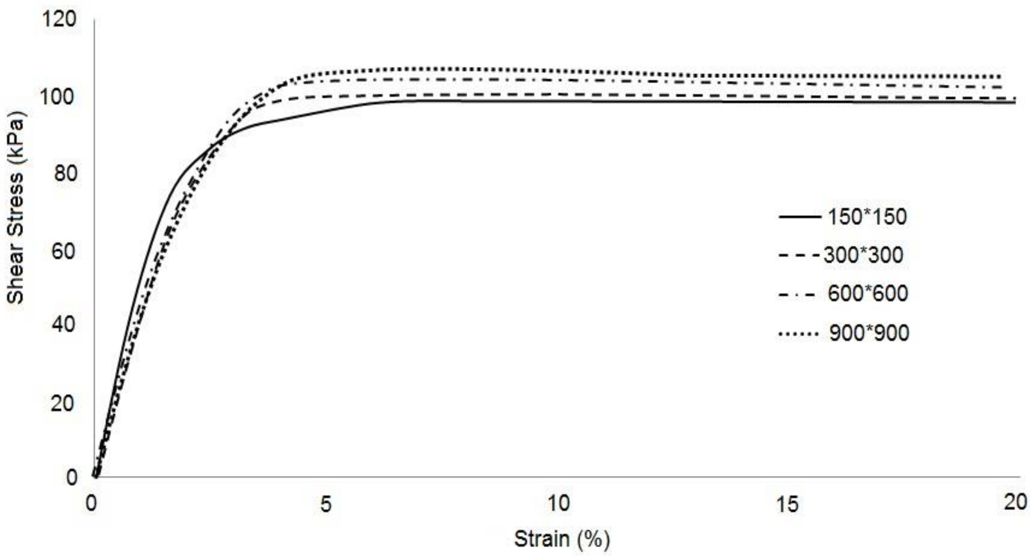
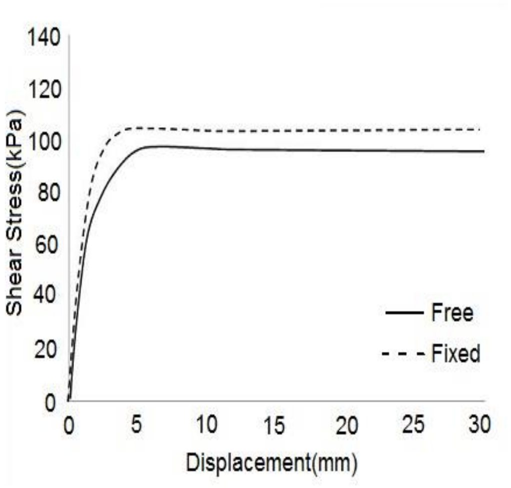


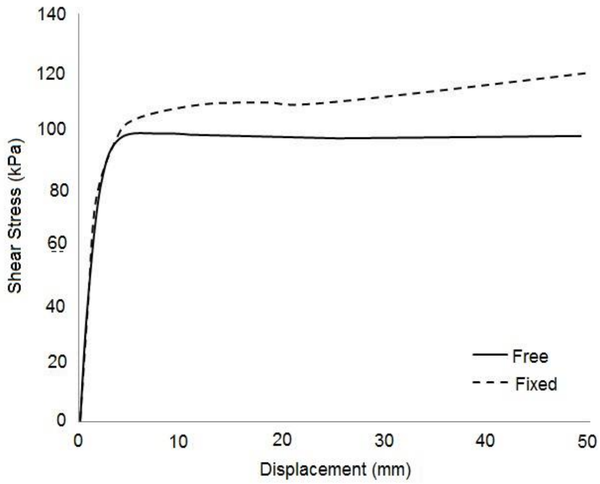
Figure 11: Effect of dimensions on stress–strain for two layer soil reinforced by geogrid (σ= 96 kPa)

4.4 *Effect of Fixation*

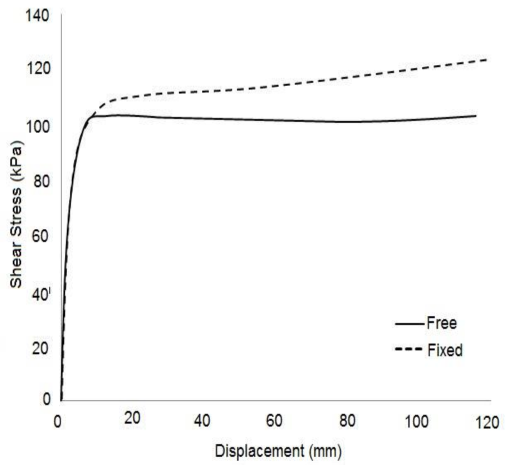
In numerical modelling of direct shear test, attempts are made to simulate laboratory conditions as much as possible. In direct shear tests (Kamalzare and ZiaieMoayed[10]), geogrid is freely located between two layers of clay and sand. Considering that the geogrids are elongated up to 30 meters during the field construction process, it seems to be more realistic to fix geogrids in modelling. In this phase, the results of the modelling of the direct shear test of reinforced double-layered soil using fixed and unfixed geogrids in different dimensions are reported. As shown in Figure 12, the fixation of geogrid in numerical modelling increased shear strength since the fixation of geogrid improved the strength of geogrid. On the other hand, an unfixed geogrid was like a plate between two layers of soil that could be moved freely along the shear plane. As it was expected, the increase in dimension was due to more changes in the shear points; the shear strength of the sample with fixed geogrid was higher than that of the sample with unfixed condition.



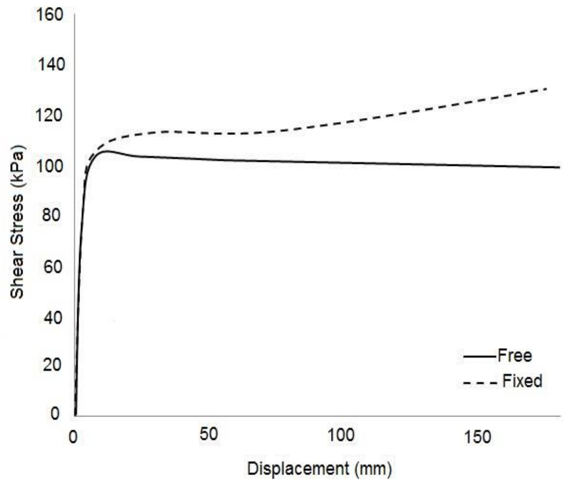
(a) 150 mm shear box



(b)300 mm shear box



(c)600 mm shear box



(d)900 mm shear box

Figure 12: Effect of fixation of geogrid on stress-strain for two layer soil reinforced by geogrid (σ = 96 kPa)

Figure 13 shows the shear stress-displacement diagram depicted based on the results of the modelling of the double-layered soil reinforced with geogrid in different dimensions (σ = 96 kPa). Figure 14 indicates the changes in dimension–maximum shear strength when fixed and unfixed geogrid were employed. As shown, by the increase in dimensions, the shear strength of the fixed geogrid went higher than that of the unfixed geogrid. The increases in the maximum shear strength of the double-layered soil reinforced with fixed geogrid in the dimensions of 150, 300, 600 and 900 mm are 73.6%, 18%, 23.15% and 32%, respectively. This is a considerable increase in comparison to the unfixed state.

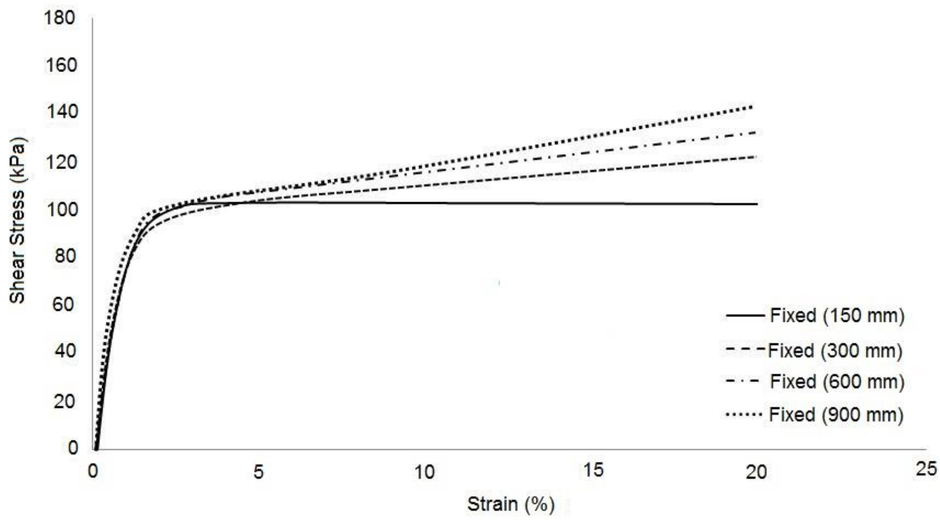


Figure 13: The effect of increase of dimensions in fixed state on shear stress (σ = 96 kPa)

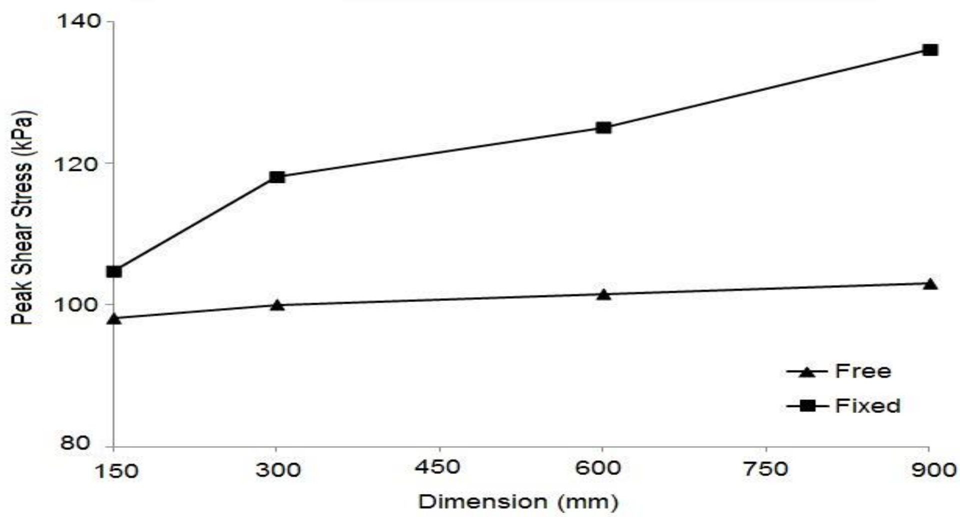


Figure 14: Peak shear strenght in different dimensions in fixed and free state of geogrid (σ = 96 kPa)

5.0 Conclusion

This paper presented the results of simulation analysis of large direct shear test which was carried out on the non-reinforced and reinforced two layer soil. The following conclusions could be drawn.

- The predictions made by the developed numerical model were found to be in good agreement with experimental data obtained from large scale direct shear tests on a non-reinforced and reinforced two layer soil by geogrid. Peak shear stress in the reinforced two layer soil and non-reinforced was almost identical in numerical and experimental results.

- The increase in dimensions of reinforced shear box led to the increase in the maximum shear strength of reinforced specimens. As it was expected, during the increase in dimensions, which was due to more changes in shear points, the shear strength of the samples with fixed geogrids was higher than that of the samples with free geogrids.

- Fixation of geogrids in numerical modeling increased the shear strength. It is recommended that in the direct shear tests conducted on the soils reinforced by geo-synthetics, the geo-synthetic material be fixed to actualize the laboratory results.

- The numerical model showed that the shear strength improved in the two-layer soil reinforced by geogrid.

- With the increase in normal load, the magnitude of shear strength was enhanced in the non-reinforced and reinforced two layer soil.

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