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# Numerical modeling of shear strength in a two-layer soil reinforced with geogrid

R. Ziaie Moayed<sup>1</sup>, S.tamassoki<sup>2</sup>

<sup>1</sup>Associate Professor, Civil Engineering Department, Imam Khomeini International University, P.O. Box 34149-16818, Ghazvin; PH (+98281) 3780021; FAX (+98281) 3780084; email: [R\\_ziaie@ikiu.ac.ir](mailto:R_ziaie@ikiu.ac.ir)

<sup>2</sup>M.Sc. Student, Civil Engineering Department, Imam Khomeini International University, Ghazvin; email: [s.tamassoki86@gmail.com](mailto:s.tamassoki86@gmail.com)

## ABSTRACT

The technique of ground improvement using geosynthetics has been developed extensively over the last few decades. Geosynthetics are used to reinforce soils and improve their mechanical characteristics, especially when soft low-bearing capacity soils encountered in civil engineering projects. Particularly, in roads, geosynthetics are placed between the interface of granular materials and soft-soil sub grade to improve the bearing capacity of composite layers. This paper presents the results of the finite element analysis of the two-layer soil (granular base-clayey sub grade) reinforced with geogrid and discusses the effect of the reinforcement on the shear strength. The numerical model was calibrated by comparison with experimental results of Large scale direct shear tests. The results have shown that the shear strength was improved in the two-layer soil reinforced with geogrid. The predictions made by the developed model are found to be in good agreement with experimental data obtained from large scale direct shear tests.

*Keywords:* Two-layer soil, Shear strength, Geogrid, Finite element analysis, Large scale direct shear test.

## 1 INTRODUCTION

In engineering behavioural prediction of engineering structures founded on two layer soil within a certain tolerance, in bridges, road, highway and embankments and cuts is necessary. The shear strength is one of the parameters affecting on the behavior of the soils from the geotechnical engineering point of view. The direct shear test is a very popular test for determining shear strength of soils. Many experimental, analytical and numerical studies have been performed to investigate the shearing behavior of reinforced soils (Bagherzadeh-Khalkhali and Mirghasemi 2009, WookPark and JoonSong 2009).

The Numerical methods enable the determination of material parameters that would have been difficult to measure in the experimental study. The finite element models were also successfully used in back-analyses of experimental results. The development of numerical procedures of calculations caused some important idealizations of the problem. The main ones deal with the following elements: geometry of model; loading conditions; material properties and constitutive models of materials and selection of numerical technique (Burd, and Houlsby 1989, Lizuka et al. 2004, Kazimierowicz-Frankowska 2007, Palmeira 2009, Basudhar 2010). Almost all previous researches in experimental and numerical methods have studied the behavior of geosynthetics in a one layered soil. Although several investigations have been performed in order to find the best depth on embedding the geosynthetics and interaction between soils and geosynthetics (Palmeira 2009, Rajesh and Viswanadham 2010, Nan Liu et al. 2009, Fleming et al. 2006), limited investigations on the interactions of two layered soils and geosynthetics have been carried out. Zhou and Wen (2007) studied a model of sand soil, placed on soft clay which was reinforced by geogrid, using compression test (Zhou and Wen 2007). Also, palmeria (2009) presents some experimental, theoretical and numerical methods evaluation of interaction between soils and geosynthetics (Palmeria 2009), Kazimierowicz-Frankowska (2007) studied the effect of reinforcement on load-settlement characteristics of a two layer subgrade (Kazimierowicz-Frankowska 2007). Sireesh et al. (2008) investigated the bearing capacity of circular footing on geocell-sand mattress overlying clay bed (Sireesh et al. 2008).

This paper presents the results of finite element analysis on a two-layer soil reinforced with geogrid, The numerical model investigated here in this study is the one which experimentally studied by Ziaie and Kamalzare (2010).

## 2 MATERIALS

### 2.1 Soil

In this numerical modeling use two soils, including a clayey soil and a granular soil which has been grained in a manner that satisfied the suggestion of AASHTTO 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 limit mean the maximum and minimum grain size which the AASHTO has suggested. This study used a kind of geogrid (GG) for reinforced soil. Table 2 lists the physical characteristics of this geogrid (Kamalzare and Ziaie moayed 2011).

*Table 1: Soil Characteristics (Kamalzare and Ziaie moayed 2011)*

property	Sand	Clay
<b>D<sub>10</sub>, (mm)</b>	0.12	-
<b>D<sub>30</sub>, (mm)</b>	1.20	-
<b>D<sub>60</sub>, (mm)</b>	5.15	-
<b>C<sub>u</sub></b>	42.92	-
<b>C<sub>c</sub></b>	2.33	-
<b>LL</b>	-	13
<b>PL</b>	-	19
<b>Dry unit weight,(kN/m<sup>3</sup>)</b>	-	-
<b>Soil classification(USCS)</b>	SW	CL

*Table 2: Geogrid characteristics (Kamalzare and Ziaie moayed 2011)*

Material	Polyethylene (HDPE)
<b>Aperture size, (mm)</b>	10 × 10
<b>Weight, (g/m<sup>2</sup>)</b>	700
<b>Tensile strength-MD, (kN/m)</b>	7.6
<b>Tensile strength-CD, (kN/m)</b>	7.6
<b>Young's modulus, (MPa)</b>	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 is dried in an oven and after wetting to the optimum water content, compacted to the target unit weight within the shear box. Each soil is compacted in three layers. The compaction of the sand and clay is conducted by using a manual plastic hammer to hit the steel plate, which was placed on top of the soil until reaching the target unit weight. The geogrid is positioned on top of the lower shear box and at the interface of the sand and clay soils. These tests are conducted using normal stresses of 44, 96, and 192 kPa. According to ASTM D5321, a shear rate of 1 mm/min is used in this test program in order to satisfy the undrained failure condition. The direct-shear resistance of the soil/geogrid interface is higher than the soil; and it usually increases the value of the shear resistance of the two-layer soil. This increment is due to the creation of the shear resistance between the soil and surface the opening of the geogrid, and the bearing resistance provided by transverse ribs. These resistances would be created when a relative movement occurs in the soil and geogrid interface (Kamalzare and Ziaie moayed 2011).

## 3 BEHAVIOURAL MODELS OF SOIL IN NUMERICAL MODEL

### 3.1 Drucker-Prager model

A generalization to account for the effects of all principal stresses was suggested by Drucker and Prager by using the invariants of the stress tensor. This generalized criterion can be written as (Desai and Siriwardane 1984):

$$f = \sqrt{J_{2D}} - \alpha J_1 - k \quad (1)$$

Where  $\alpha$  and  $k$  are positive material parameters,  $J_1$  is the first invariant of the stress tensor, and  $J_{2D}$  is the second invariant of the deviatoric stress tensor.

The values of  $\alpha$  and  $k$  can be expressed in terms of angle of internal friction  $\phi$  and cohesion  $c$ . However, the values of  $\phi$  and  $c$  determined by using conventional triaxial compression tests are different from those determined under plane strain conditions. For these conditions the values of  $\alpha$  and  $k$  could be expressed as follows (Desai and Siriwardane 1984):

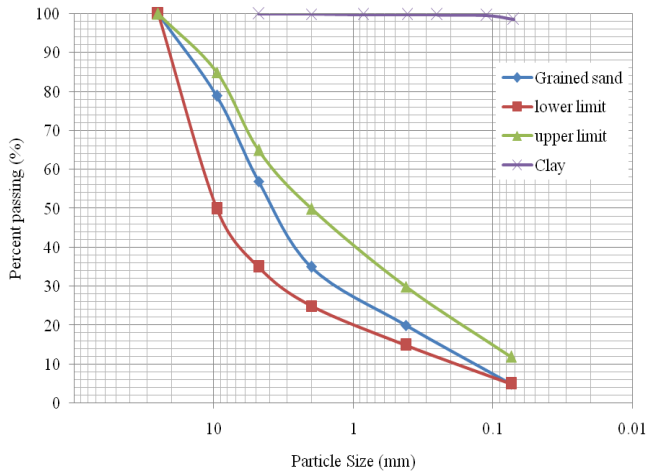


Figure 1. Grain size distribution of two clayey soils (Kamalzare and Ziaie moayed 2011)

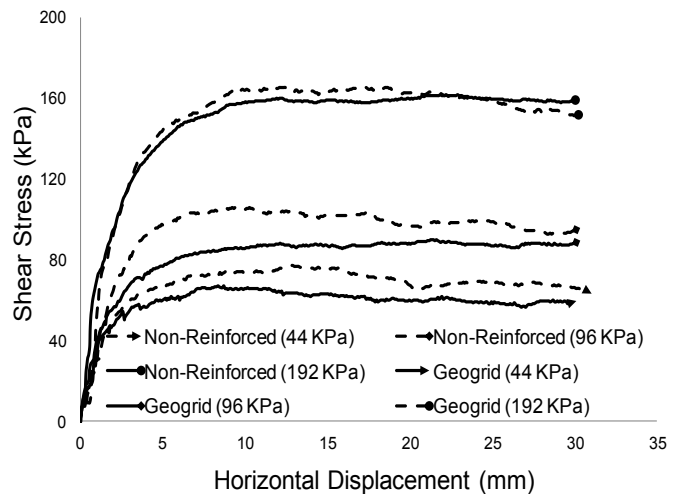


Figure 2. Stress-strain behavior of the reinforced two layer soil by geogrid and non-reinforced (Kamalzare and Ziaie moayed 2011)

$$\alpha = \frac{2\sin\phi}{\sqrt{3}(3 - \sin\phi)} \quad (2)$$

$$k = \frac{6c \sin\phi}{\sqrt{3}(3 - \sin\phi)} \quad (3)$$

### 3.2 Modified Drucker-Prager model

The Drucker-Prager/cap plasticity model has been widely used in finite element analysis programs for a variety of geotechnical engineering applications. The cap model is appropriate to soil behavior because it is capable of considering the effect of stress history, stress path, dilatancy, and the effect of the intermediate principal stress. The onset of plastic behavior is determined by the Drucker-Prager failure surface and the cap yield surface. The Drucker-Prager failure surface is given by (Helwany 2007):

$$F_s = t - p \tan\beta - d = 0 \quad (4)$$

Where  $\beta$  is the soil's angle of friction and  $d$  is its cohesion in the  $p$ - $t$  plane, The Mohr-Coulomb parameters ( $c$ ,  $\phi$ ) can be converted to Drucker-Prager parameters as follows (Helwany 2007):

$$\tan\beta = \frac{6\sin\phi'}{3 - \sin\phi'} \quad (5)$$

$$d = \frac{18c \cos\phi'}{3 - \sin\phi'} \quad (6)$$

In this research, the soils parameters were described by an elastic model. Elastic behavior is modeled as linear elastic using the generalized Hooke's law. Alternatively, an elasticity model in which the bulk elastic stiffness increases as the material undergoes compression can be used to calculate the elastic strains. The plastic parameters of sand were determined by Drucker-Prager model and clay by modified Drucker-Prager model, respectively, using the parameters given in Table 3 and 4. Note that the parameters given in the Table 3 are taken from on Kamalzare and Ziaie (2011) studies.

Table 3: Geotechnical parameters of the studied soil (Kamalzare and Ziaie Moayed 2011)

Property	symbol	Sand	Clay
Dry unit weight, (kN/m <sup>3</sup> )	$\rho$	21.33	18.15
Cohesion, (kPa)	c	-	32
Friction angle, (°)	$\varphi$	47	29.94
Poisson's ratio	$\nu$	0.3	0.25
Young's modulus for 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 the studied soil

Property	symbol	Sand	Clay
Material Cohesion, (kPa)	d	-	200
Friction angle, (°)	$\beta$	62.66	50.13
Cap Eccentricity	R	-	0.2
Initial cap yield surface position	-	-	-
Transition surface radius	$\alpha$	-	0.01
Flow Stress Ratio	K		0.778
Dilation angle for normal stresses 44, 96 and 192 kPa, (°)	$\psi$	4.83, 5.5, 8	-

## 4 FINITE ELEMENT MODELLING AND ANALYSIS

### 4.1 Model geometry

A series of 3D finite element analysis has been conducted to simulate the large-scale direct shear tests using ABAQUS 6.9 application. 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 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 implemented in ABAQUS/Standard. The geogrid was positioned on top of the lower shear box and at the interface of the sand and clay soils. These analysis's are conducted using normal stresses of 44, 96, and 192 kPa. The contact interface is characterized by the coefficient of friction  $\mu$ . 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 Ziaie moayed 2011).

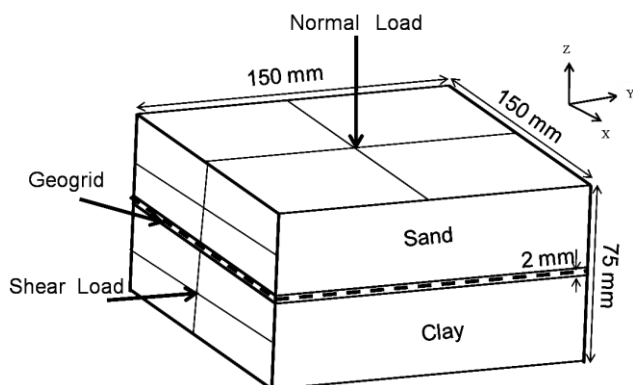


Figure 3. Model geometry (According to ASTM-D5321)

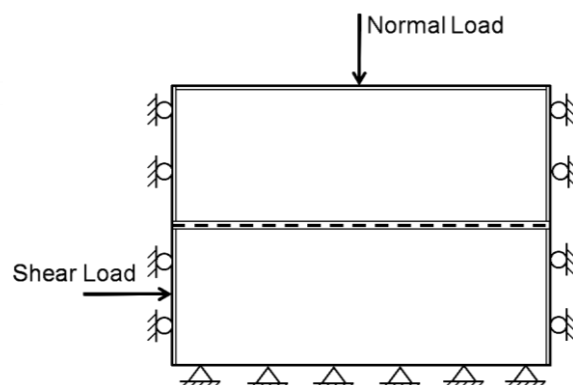


Figure 4. Boundary conditions of model

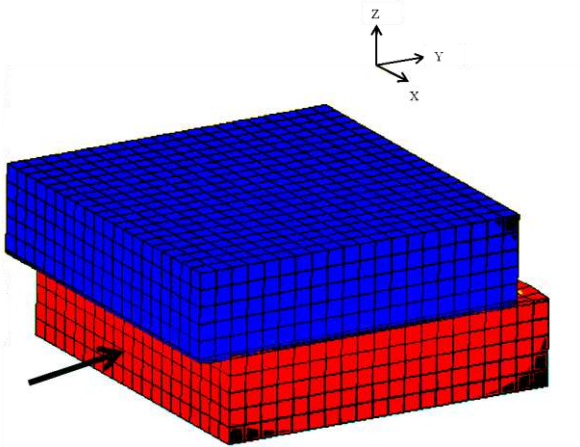


Figure 5. Horizontal displacement of direct shear box

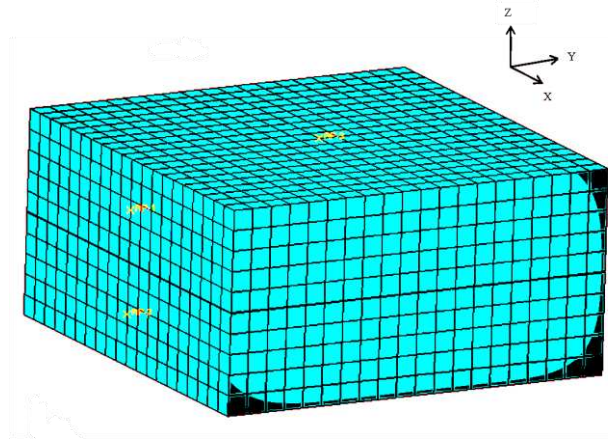


Figure 6. 3D mesh of modelling of direct shear test

## 4.2 Boundary condition

Figure 4 shows the boundary condition of the occupied model. The bottom of the model is restrained in x and z direction. In the initial and first step, the upper box is restrained in x, y direction and The lateral walls of upper and lower boxes are restrained against in movements in x, y and z. In the second step, the lateral walls of upper box are restrained in x, y and z, however the beneath box is restrained in x, z and a horizontal displacement of about 30 mm is applied to the lower box in y direction (figure 5). The FE mesh of the model is shown in the 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 occupied here in this work.

## 5 RESULTS AND DISCUSSION

### 5.1 Model calibration

The analysis carried out for each three normal stress 44, 96 and 192 kPa in FE model. The results are in a good agreement with experimental data obtained from the case study which mentioned before (Kamalzare and Ziaie moayed 2011), the results of numerical modeling are shown in Figure 7 and 8. In comparison to experimental results of large scale direct shear tests.

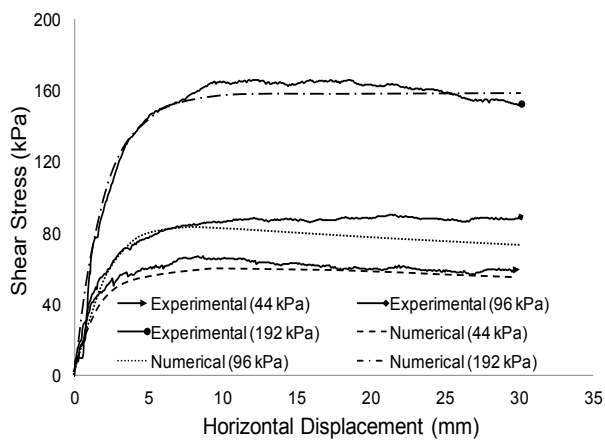


Figure 7. Comparison of experimental and numerical modelling of direct shear test on non-reinforced two layer soil

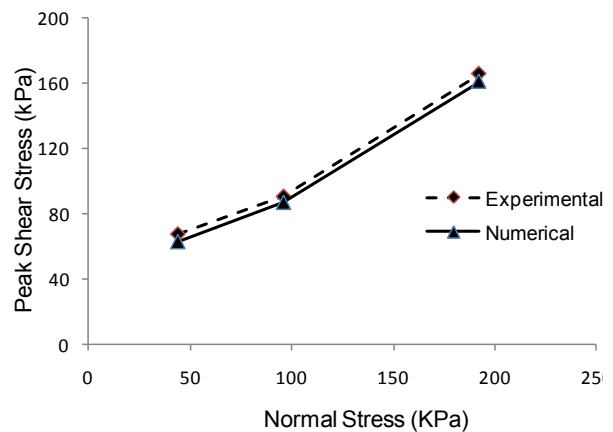


Figure 8. Peak shear strength versus normal stress for the non-reinforced two layer soil

## 5.2 Two-layer soil reinforced with geogrid

To discuss the stress-strain behavior of the soil/geogrid interface, the results of numerical modeling are presented in Figure 9. The results of the peak shear stress versus the normal stress are shown in Figure 10. The result show that there is a good agreement with experimental data obtained from the case study which mentioned before (Kamalzare and Ziaie moayed 2011) the results of numerical modeling In comparison to experimental results of large scale direct shear tests.

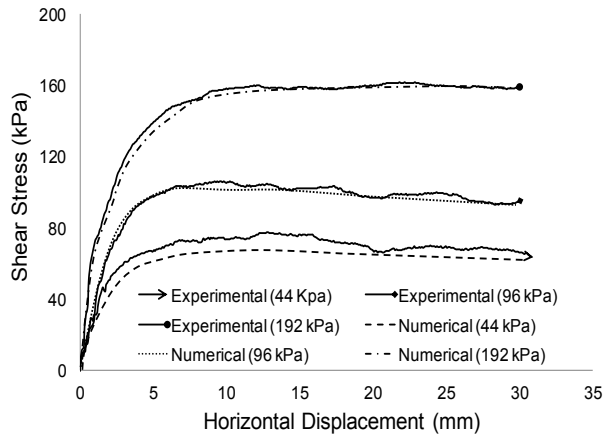


Figure 9. Comparison of experimental and numerical modeling of direct shear test on two layer soil reinforced by geogrid

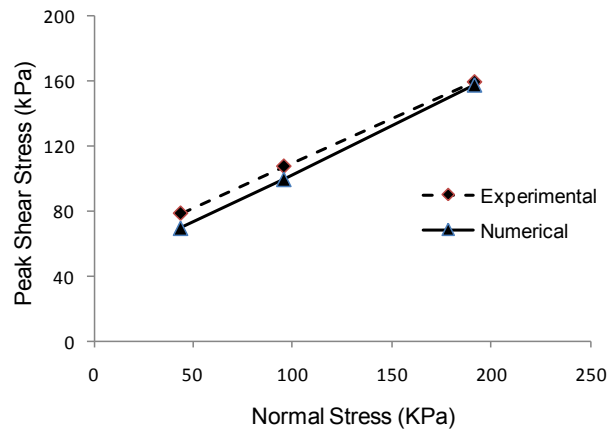


Figure 10. Peak shear strength versus normal stress for the two layer soil reinforced by geogrid

## 5.3 Effect of friction angle

The effect of friction angle of sand on shear strength is illustrated in Figure 11 and 12. As shown in these figures, the shear strength of soil was increased with increase in friction angle in normal stress 96 kPa. Increments in the friction angle of sand lead to increase the interlocking between soil particles and hence increasing the shear strength of two layer soil reinforced by geogrid.

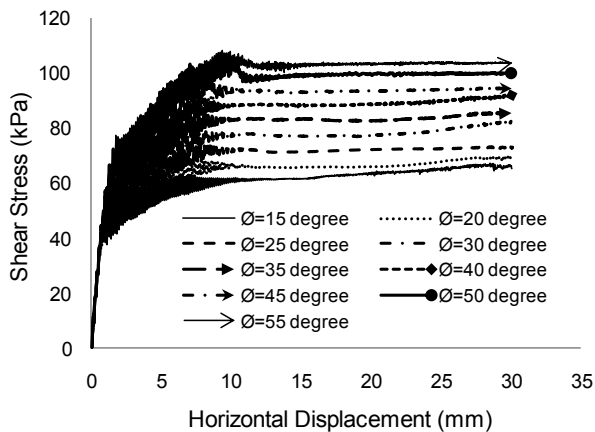


Figure 11. Effect of different friction angle of sand on curves Shear Stress–Displacement for two layer soil reinforced by geogrid

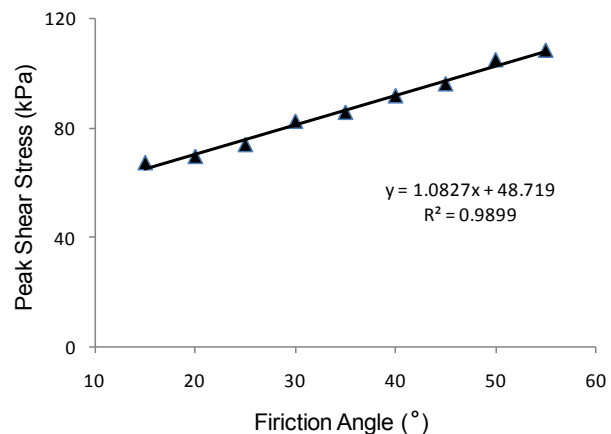


Figure 12. Peak shear strength versus friction angle for two layer soil reinforced by geogrid

## 6 CONCLUSION

The present study shows simulation 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 model are 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 is almost identical in numerical and experimental results.
- The numerical model shows that the shear strength improved in the two-layer soil reinforced by geogrid.
- With increase normal load, the magnitude of shear strength was increased in the non-reinforced and reinforced two layer soil
- With increase in friction angle sand at normal stress of 96 kPa, the magnitude of shear strength two layer soil reinforced by geogrid was increased.

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