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Study on the Impact of Sand-Clay Bond in Geo-grid and Geo-Textile on Bearing Capacity

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Abstract

This paper aims to determine the impact of sand-clay bond in geo-grid and geo-textile on bearing capacity. In doing so, we examined clay-geo-synthetics, sand-geo-synthetics and clay-sand-geo-synthetics samples using direct shear tests. The friction between clay and reinforcement was provided by encapsulated-sand system.

This method is used to transfer the tensile force mobilized in geo-synthetics from sand to clay and improve the strength parameters of clay. This study indicated that the provision of a thin layer of sand at both sides of the reinforcement significantly improved the shear strength of clay soil.

Bond coefficient computations indicated that the shear strength of clay-geo-synthetics samples was higher than non-reinforced clay. The increased strength was due to the impact of open meshes of geo-synthetics which provided some degree of resistance bearing. To determine the share of resistance bearing provided by geo-synthetic transverse members in the entire direct shear strength, we conducted a series of tests on geo-synthetics-reinforced samples with and without transverse members. The resistance bearing provided by geo-synthetic transverse members was almost 10% of total shear strength. The results indicated that encapsulated geo-grid and geo-textile sand system increased the bearing capacity of clay, with geo-grid being more efficient than geo-textile.

Keywords: geo-synthetics, tensile force, reinforced soil, transverse members, bond coefficient

1. Introduction

Soft clay soils have low bearing capacity and tend to settle under the influence external loads. In order to prevent excessive settlement, they must be improved before construction process. This paper aims to determine the impact of geo-synthetic coarse-grained reinforcement on bearing capacity of soft clay.

The advantages of grain materials include good drainage, high friction resistance, and good stability against humidity and time [Elias, V., Barry, P. E., & Christopher, R. 1997]. Reinforced-soil structures are often constructed by coarse-grained materials because fine-grained soils have poor drainage and friction resistance and tend to change under the influence of humidity and time [Lin, H., & Atluri, S. N. 2001]. Normally, membranous and confinement impacts are considered in soil reinforcement. In membranous impact, foundation and soil move downward and reinforcement layers (geo-grid and geo-textile) are gradually tensioned. To bear the load, the deformed reinforcement exerts a force upward. The reinforcement under tension needs a specific amount of settlement to mobilize membranous effect. Furthermore, the reinforcement must have sufficient length and stiffness. The upward force is developed at the conjunction of reinforcement and failure surface [Safari, E., Ghazizade, M. J., Abduli, M. A., & Gatmiri, B. 2014; Bhatia, S. K., Khachan, M. M., Stallings, A. M., & Smith, J. L. 2014].

Patra et al. conducted a series of studies on geo-grid reinforced sand with eccentric loading and reported that the increased layers of geo-grid resulted in the increased bearing capacity [Patra, C. R., Das, B. M., Bhoi, M., & Shin, E. C. 2006].

Alawaji conducted a study on settlement and bearing capacity of geo-grid reinforced sand located on weak soil. He reinforced the sand using a geo-grid layer and found that the optimal depth of geo-grid placement for reaching the maximum bearing capacity was 10% of foundation diameter. This result was in line with the studies of other researchers.

Alawaji conducted a series of studies to determine the impact of geo-grid diameter change on load-settlement behavior of samples. He reported that the increased diameter of geo-grid resulted in a significant reduction of settlement in equal capacities [Alawaji, H. A. 2001].

Radhey et al. examined the foundations placed on geo-grid reinforced soil and found that the first layer of reinforcement must be close to foundation with an optimal depth range of 0.5B-2B. They also reported that the length of reinforcement must be between 2B and 8B [harma, R., Chen, Q., Abu-Farsakh, M., & Yoon, S. 2009].

Nazir and Sawwaf conducted a study on the behavior of rectangular foundation located on geo-grid reinforced sand. They reported that the increased soil density resulted in the increased impact of geo-grid layers on bearing capacity [El Sawwaf, M., & Nazir, A. K. 2010].

Basudhar et al. investigated the behavior of circular foundation located on geo-textile reinforced sand. They found that the increased number of geo-textile layers resulted in the increased bearing capacity. They also reported that the increased density of sand led to failure in higher settlements [Basudhar, P. K., Saha, S., & Deb, K. 2007].

This paper aims to determine the impact of sand-clay bond in geo-grid and geo-textile on bearing capacity. In doing so, we conducted a comprehensive study on different parameters of sand and clay in various geo-synthetic layers. This is the first paper to make a comprehensive study on this subject.

2. Research Method

2.1 Shear Strength

The shear strength between reinforcement and soil is provided by 1) the shear strength in the contact area between reinforcement and soil and 2) the shear strength between soils in open meshes of the geo-synthetics.

Equation 1 represents total direct shear strength (F_t) [Sreekantiah, H. R., & Unnikrishnan, N. 1992]:

$$F_t = \sigma_n A[\alpha_{ds} tan(\delta + (1 - \alpha_{ds}) tan\phi) \quad (1)$$

ϕ: Internal friction angle of soil in direct shear

δ: Apparent friction angle of shear surface of reinforcement and soil

α_{ds}: The ratio of shear surface of reinforcement to total shear surface

σ_n: Vertical stress in shear surface and A: total shear surface

Many researchers have recognized bond coefficient as an important parameter in reinforced-soil design [Liu, C. N., Ho, Y. H., & Huang, J. W. 2009; Wang, Z., & Richwien, W. 2002; GHIASIAN, H., & Jahannia, M. 2004]. They have defined bond coefficient as the ratio of soil-soil contact area strength to soil-reinforcement contact area strength. In this definition, soil-soil contact surface strength is the direct shear strength of the soil, provided that shear surface is soil-reinforcement shear surface [Das, B. M., Cook, E. E., Shin, E. C., Yen, S. C., & Puri, V. K. 1993].

If the bond coefficient is bigger than unit number, a powerful bond exists between soil and geo-synthetics and soil-reinforcement contact area strength is higher than soil-soil contact area strength. If it is smaller than 0.5, there is a weak bond between soil and geo-synthetics [Jewell, R. A., & Wroth, C. P. 1987].

2.2 Bond Coefficient

So far, many researchers have studied the friction behavior of soil-geo-synthetics contact area, with an emphasis on the parameters of humidity percentage, soil type and density, geometry, stiffness of geo-synthetics, and vertical stress [Sridharan, A., Murthy, B. S., Bindumadhava, & Revanasiddappa, K. 1991]. They have compared the friction angle mobilized in soil-geo-synthetics contact area with internal friction angle of soil and defined factor C_i (effective bond coefficient) in the form of equation 2:

$$C_i = \frac{C_a + \sigma_n \tan\delta_a}{C + \sigma_n \tan\phi} \quad (2)$$

C_a: Bond between soil and geo-synthetics

δ_a: Apparent friction angle of contact area

C: Soil bond

ϕ: Internal friction angle of soil

σ_n: Vertical stress

If the tested soil is sand, bond coefficient is simplified as follows:

$$C_i = \frac{\tan\delta_a}{\tan\phi} \quad (3)$$

Bond coefficient of the reinforcement depends on geo-synthetic surface, bearing capacity of transverse members, bearing capacity of surrounding soil, type of soil, and the length of buried sample. In soil-reinforcement direct shear bond mechanism, the shear strength of contact area is a combination of soil-soil direct shear strength and soil-reinforcement direct shear strength. If bond coefficient is smaller than 0.5, a weak bond exists between soil and geo-synthetics. If it is bigger than 1, a strong bond exists between soil and geo-synthetics.

2.3 Materials

We carried out the tests using kaolinite clay and silica sand. The sand was a mixture of three types of uniform sand with grain sizes of 0.7-1.2, 1-2 and 2-4 mm. Figure 1 illustrates the information of clay-sand mixture based on ASTM standards. Based on unified soil classification system (USCS), clay is classified in CL group (clay with low plastic property) and sand is classified in SW group (finely grained sand). The tests were carried out using a large direct shear device with some modifications for connecting the geo-synthetics to lower shear box by clamp (according to D5321 ASTM) [Unnikrishnan, N., Rajagopal, K., & Krishnaswamy, N. R. 2002]. Figure 2 illustrates the compaction curves.

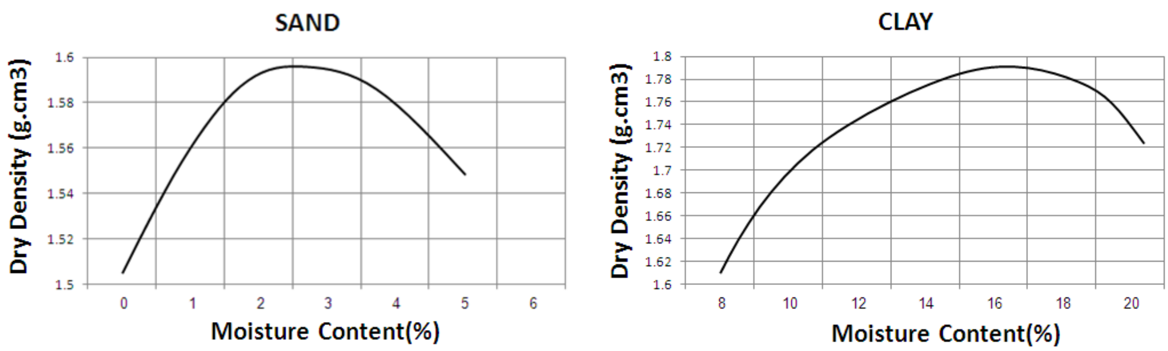

Figure 1. Clay-sand compaction curve

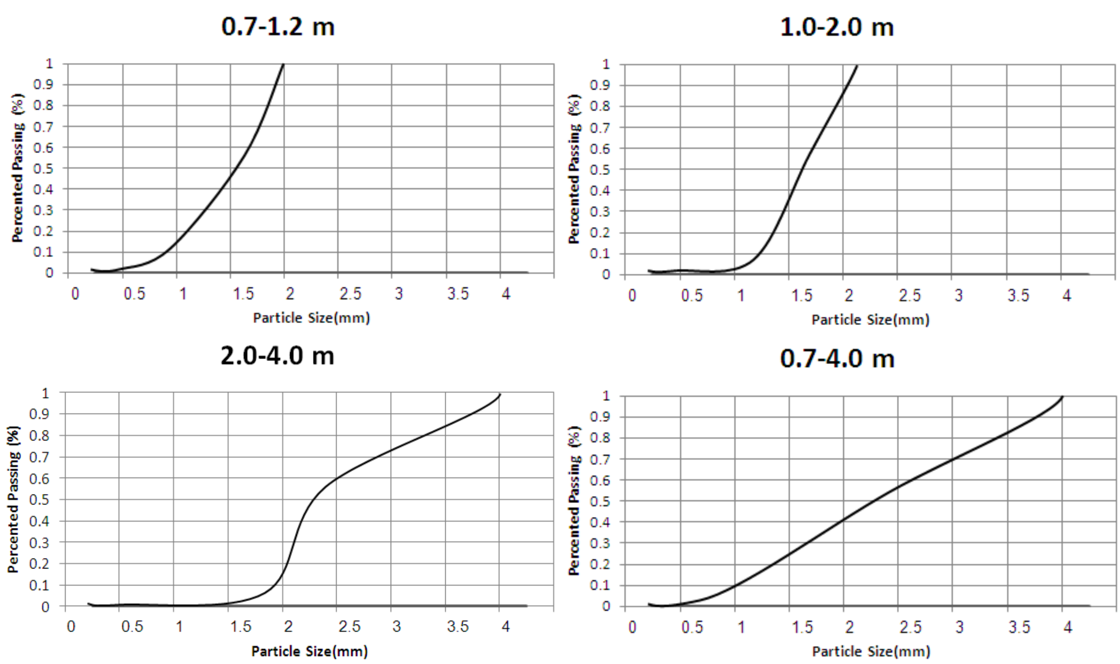

Figure 2. Sand gradation curve

2.4 Direct Shear Test

We performed soil compaction test inside the shear box using a hammer designed for this purpose. The test was carried out with and without transverse members. The samples were prepared as follows:

We completely mixed the clay and sand in the needed amount with optimal moisture content. Then we divided the mixture into two equal parts to fill the lower and upper parts of the shear box. The first part was poured in the lower shear box until reaching the maximum density obtained from proctor standard density [Mohiuddin, A. 2003; Biswas, A., Ansari, M. A., Dash, S. K., & Krishna, A. M. 2015; Bhat, S., & Thomas, J. 2015]. The number of required blows for reaching the intended density was determined by trial and error method and preliminary tests. The thickness of clay in lower box was 10 cm minus half of the sand layer for covering geo-synthetics at the middle of shear box. The needed sand was divided into two parts based on the required thickness. One part was poured into the lower shear box and the other part was poured into the upper shear box. The clamp was connected to the lower part of the shear box and was fixed by screws. After placing the geo-synthetics at the shared boundary of the box, we poured the remaining sand over the geo-synthetics at the upper box. The upper shear box was filled and compressed with the clay just like the lower shear box. After placing the loading plate on the sample, we let the force be equally distributed for 20 minutes. The test was started with the shear force rate of 1mm/min.

2.5 Test Method

We carried out direct shear tests to simulate the bond mechanism between soil and geo-synthetic reinforcement in contact area. In order to match other researches, we selected vertical stresses of 25, 50 and 75 kilopascal and shear force rate of 1mm/min [Zhang, C., Jiang, G., Liu, X., & Buzzi, O. 2016].

All tests were performed by strain control method according to ASTM D5321. We measured the shear force by load cell ($LVDT_s$) and measured vertical and horizontal displacements by a transducer connected to computer. Next, we depicted the curves based on shear stress and displacement and determined shear strength parameters. After completing each test, the shear box soil was sampled to control moisture content and dry weight of the samples.

2.6 Layering Method

For this purpose, we used three types of geo-grid and two types of geo-textile with the dimensions of 300×300 mm. The geo-grids and geo-textiles were placed at the middle of sand layer and at the shared boundary between two layers of soft clay and sand (Table 1). To prepare the clay, we increased its moisture content to 26% by adding water. The uniaxial resistance of clay in moisture content of 26% was 0.21 kg/cm^2, which is in the range of soft clay. The thickness of clay in test box was 15 cm, which was compressed by hand and compactor in three 5 cm layers after being fully mixed. The sand was placed on the clay in one 5 cm layer and was compressed by compactor and plastic hammer to reach the density of 55%. The geo-grid and geo-textile layers were used in three modes: 1) between two layers of sand and clay, 2) at the middle of sand layer, and 3) at both places [Demir, A., Yildiz, A., Laman, M., & Ornek, M. 2014; Wang, Z., Jacobs, F., & Ziegler, M. 2014].

After preparing the sample in test box, we placed the box in the device and put the loading plate exactly at the middle of sand surface. The force speed was set on 1.27 mm/min and the amount of force and settlement was measured by two gauges. The final settlement value was 25 mm and 50 readings were recorded. As the basic test, we tested a clay layer with the thickness of 20 cm. Next, we performed a few other tests. In one test, we placed a non-reinforced sand layer with the thickness of 5 cm on a clay bed. In another test, we used a reinforced sand layer with three types of geo-grid and two types of geo-textile.

Table 1. The used symbols

CLAY						
Flow limit%	Plasticity limit%	Plasticity index %	Optimal moisture%	Maximum dry density (g/cm3)	Bond (kPa)	Internal friction angle°
26.5	4.5	22	17	1.78	11.7	22.5

SNAD				
Curvature coefficient (Cc)	Optimal moisture%	Maximum dry density (g/cm3)	Bond (kPa)	Internal friction angle°
1.69	4	1.6	12.1	33.7

GeoGrid								
	Weight (kg/m2)	Thickness (mm)	Mesh shape	Color	Tensile strength (KN/m)	Material	Mesh size (mm)	Product name
GEO_GRID_1	0.73	2.2	Square	Black	8.2	HDPE	8×8	CE121
GEO_GRID_2	0.7	2.2	Square	Black	7.6	HDPE	10×10	CE161
GEO_GRID_3	0.42	2.4	Square	Orange	5.5	HDPE	15×15	SQ15L

Geotextile				
	Permeability (cm/sec)	Tensile strength (KN/m)	Thickness (mm)	Weight (gr/cm3)
GEO_TEXTILE_1	0.23	18	2.6	300
GEO_TEXTILE_2	0.28	35	4.5	600

Location of geo-synthetic layers	
SAND_CENTER	Middle of sand layer
SAND_CLAY_MID	Between two layers of sand and clay
SAND_CLAY_CENTER_MID	At the middle and between two layers of sand and clay

3. Results

3.1 Clay

Figure 3 illustrates the shear stress-displacement curves obtained from direct shear tests for non-reinforced and geo-synthetic reinforced clay. As you can see, non-reinforced and reinforced clays have shown stiffening behaviors. Shear surface was formed more quickly due to deformation of compressed soil. Moreover, reinforced clay curves indicate that shear failure has been formed more quickly in the reinforced samples. This behavior denotes that large-scale direct shear test is much more efficient for geo-technical structures of the reinforced soils [Ze, L., & Yong, L. 2014; Infante, D. U., Martinez, G. A., Arrúa, P., & Eberhardt, M. 2016; Liu, C. N., Yang, K. H., & Nguyen, M. D. 2014]. The curves indicate that shear strength in geo-synthetic-soil contact area is higher than in soil-soil contact area. This is probably due to the impact of geo-synthetic transverse elements which have provided some degree of resistance bearing along the shear surface.

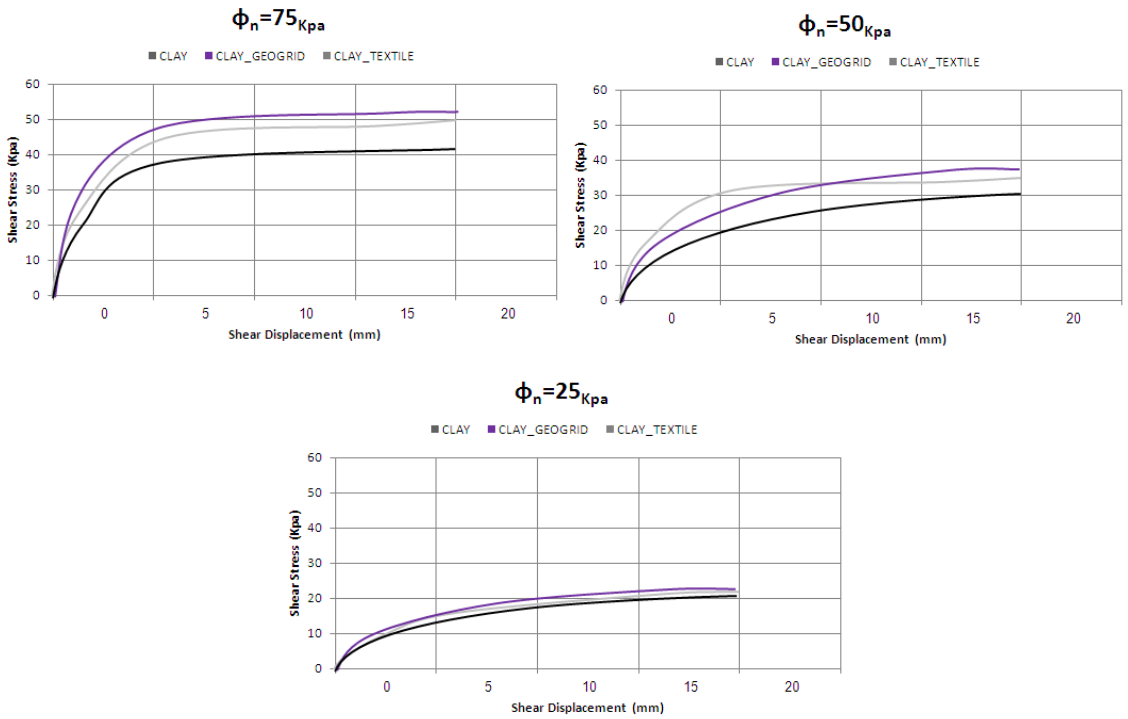

Figure 3. Shear stress curves – shear displacement of clay samples

3.2 Sand

Figure 4 illustrates the results of direct shear tests for non-reinforced and geo-synthetic-reinforced sand. As you can see, geo-synthetic reinforcement has increased the shear strength of the sand. The shear strength of both reinforced and non-reinforced sands has significantly and linearly increased after slight increase of displacement (1 mm). After reaching the maximum shear strength with a displacement of about 3 mm, shear strength has declined. In high horizontal displacements (about 4 mm), shear strength has become stable. Both reinforced and non-reinforced sands showed similar behaviors, with slight difference in the amount of shear strength. As you can see in the figure, the tensile strength of geo-synthetics has not been fully mobilized.

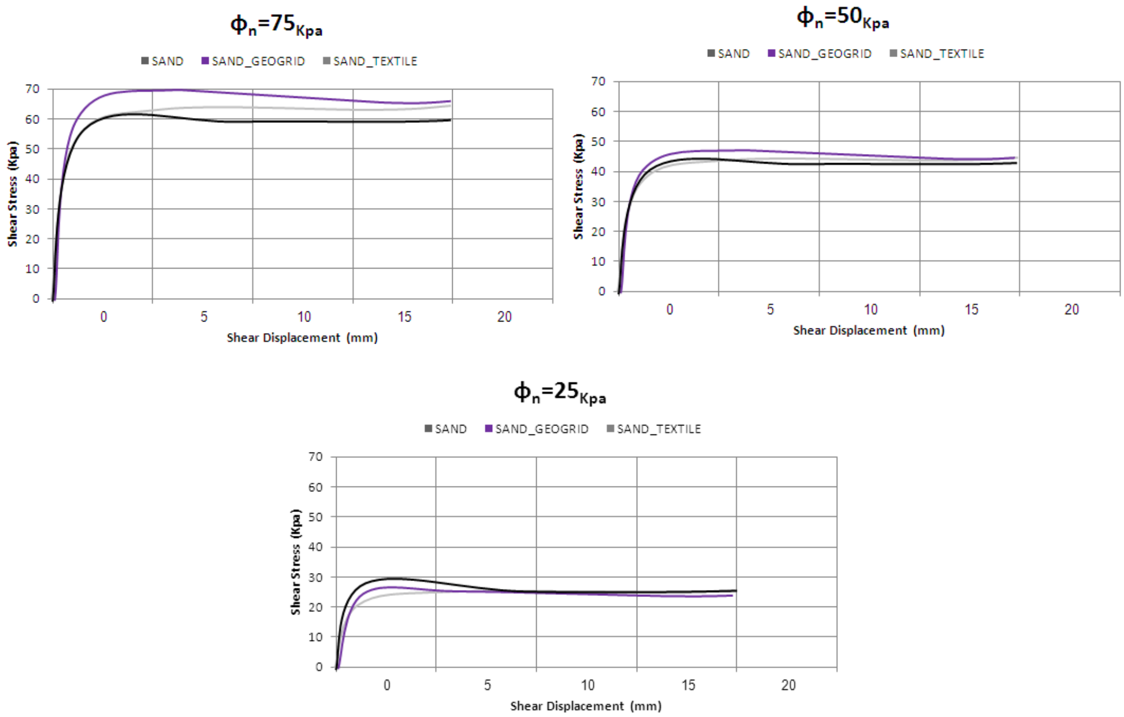

Figure 4. Shear stress-displacement curves of sand samples

3.3 Rupture Envelope

Table 2 contains the rupture envelope for non-reinforced and geo-synthetic-reinforced clay. As you can see, geo-synthetic reinforcement has increased the bond and slightly reduced the friction angle in contact area.

Table 2 contains the rupture envelope for non-reinforced and geo-synthetic-reinforced sand. As you can see, geo-synthetic reinforcement has significantly increased the apparent friction angle, but apparent bond has not changed. The increased apparent friction angle of the reinforced sand may be explained by the locking of sand particles in open meshes of geo-synthetics.

Table 2 represents the rupture envelopes of geo-synthetics-reinforced samples with and without transverse members. As you can see, geo-synthetic transverse members have increased the apparent bond, but have not significantly affected the apparent friction angle.

Table 2. Rupture envelopes

	Shear Strengh (Kpa)									
normal stress (Kpa)	SAND	SAND_GEOGRID	SAND_TEXTILE	CLAY	CLAY_GEOGRID	CLAY_TEXTILE	CLAY_SAND_GEOGRID with transverse members	CLAY_SAND_GEOGRID without transverse members	CLAY_SAND_TEXTILE without transverse members	CLAY_SAND_TEXTILE without transverse members
25	28	29	28	18	20	19	25	22	24	22
50	42	44	43	30	34	39	49	40	47	39

3.4 Transverse Members

To determine the impact of geo-synthetic transverse members in the entire direct shear strength of contact area, we carried out a series of tests on geo-synthetics-reinforced clay samples with and without transverse members. You can see the results in figure 5. Figure 6 illustrates the results for contact area. The results indicated that geo-synthetic transverse members increased the resistance bearing by about 10%.

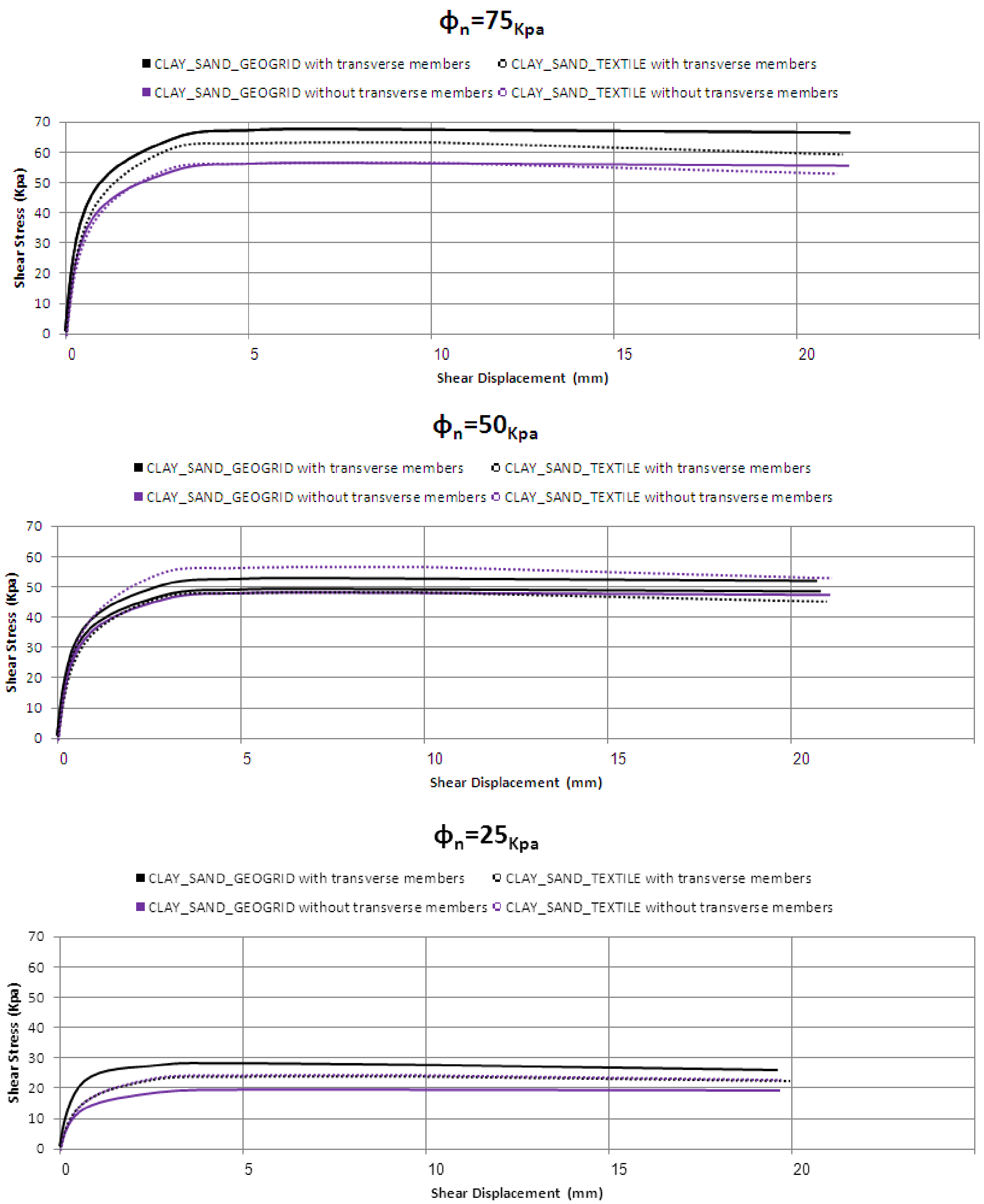

Figure 5. Shear stress-displacement curves for clay-sand-geo-synthetics samples without and without transverse members

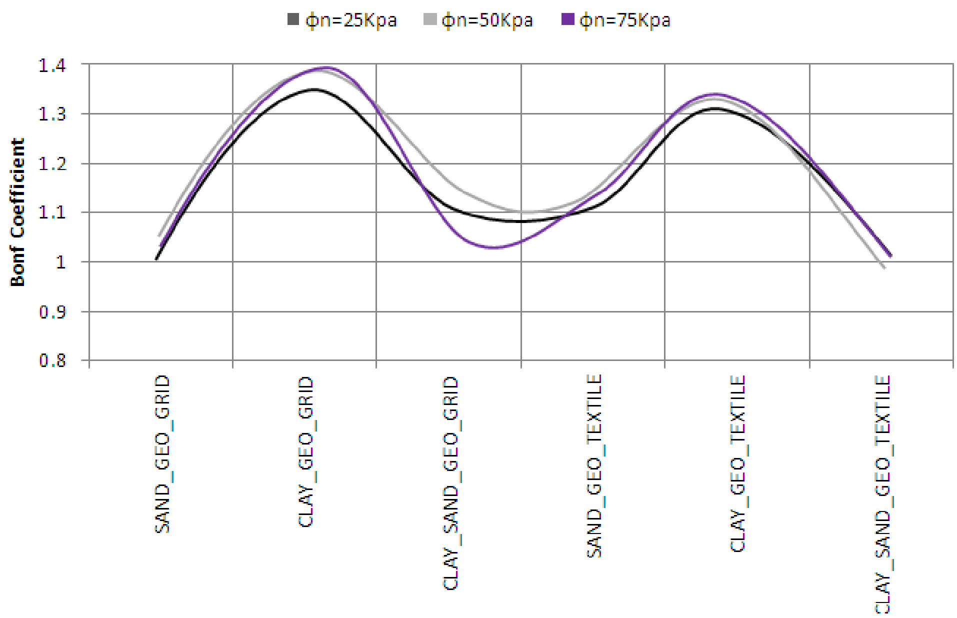

Figure 6. Bond coefficient changes of geo-synthetics compared to vertical stress

3.5 Layering

Figure 7 illustrates pressure-settlement diagram for clay samples with geo-synthetics-reinforced sand layer. The diagrams indicate that the sand layer with one geo-grid or geo-textile layer increases the bearing capacity and reduces the settlement. The use of two geo-grid or geo-textile layers at below and middle of sand layer increases the bearing capacity more than when only one geo-grid or geo-textile layer is used. It should be noted that the increased bearing capacity is more visible in high settlements, because geo-grid and geo-textile strengths are fully mobilized and the settlement is prevented [Keskin, M. S. 2015; Moreira, A., Vieira, C. S., das Neves, L., & Lopes, M. L. 2016; Aldeeky, H., Al Hattamleh, O., & Alfoul, B. A. 2016].

When load is applied, the circular plate and the reinforced soil move downward and the reinforcement layers (geo-grid and geo-textile) located in the sand are gradually tensioned. Consequently, the reinforcements are deformed due to their stiffness and exert a force upward to bear the load. Therefore, a specific amount of settlement is needed to mobilize the membranous impact in the reinforcement under tension [Shirlal, K. G., & Mallidi, R. R. 2015].

The comparison of pressure-settlement diagrams for different geo-grids indicated that the better coarsely-grained particles are locked in geo-grid meshes, the less settlement will occur. Since the coarse-grained particles are sand, the mesh size of 8×8 mm would be more efficient than the mesh size of 15×15 mm. It should also be noted that the tensile strength of GEO_GRID_1is higher than GEO_GRID_3. Therefore, geo-grid is more efficient than geo-textile in the improvement of bearing capacity. Where the reinforcement layers are located at the middle of the sand, the type of geo-grid or geo-textile does not affect the bearing capacity. The best mode is the use of two reinforcement layers at the middle and below the sand layer. The worst mode is the use of one reinforcement layer below the sand layer.

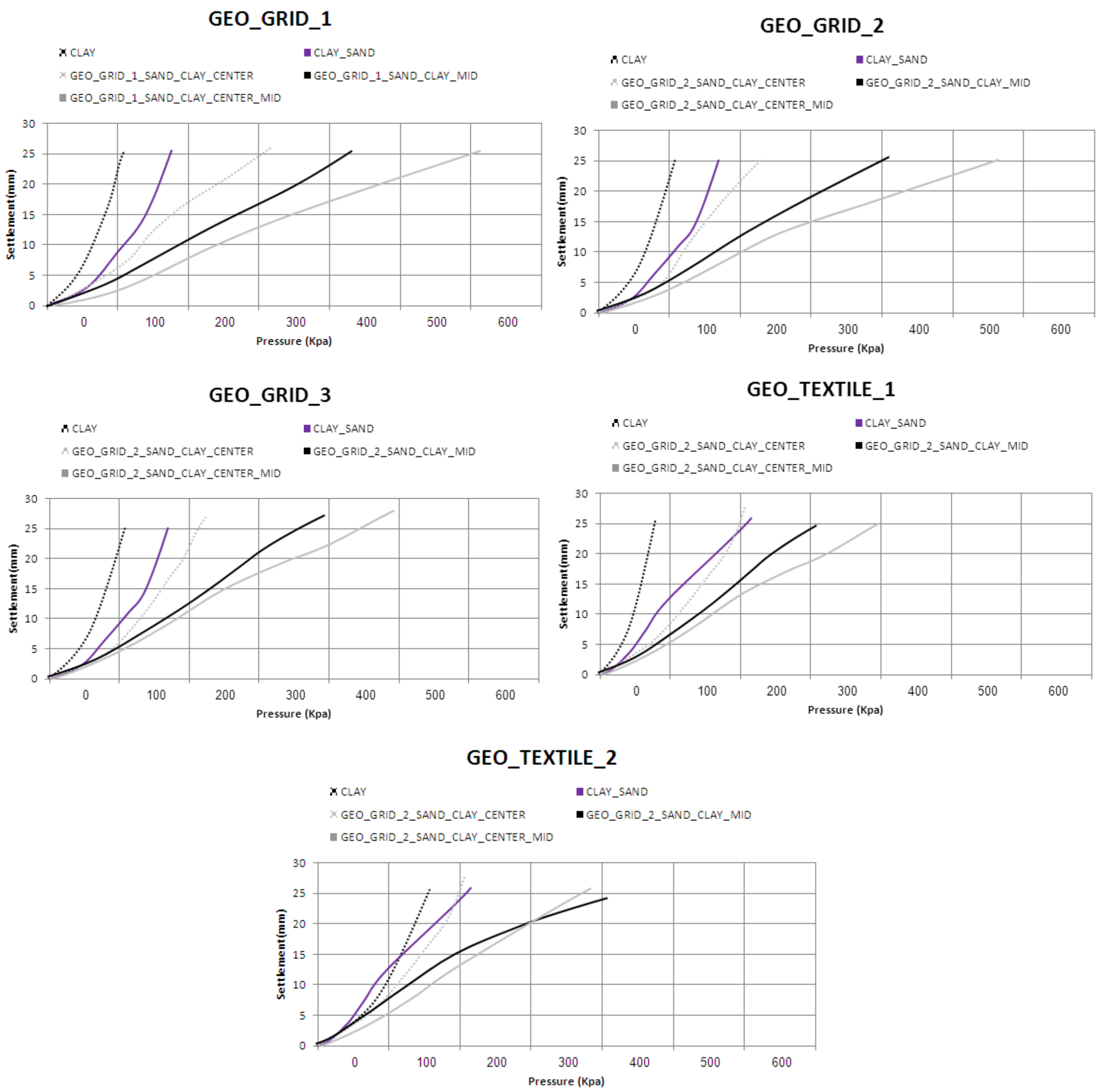

Figure 7. Pressure-settlement diagram for the reinforced samples

Figure 8 illustrates the pressure changes in settlement percentages of 5 and 50 for all modes (the ratio of settlement to loading plate diameter). In low settlement percentages, sand layer increases the bearing capacity by about two times. In high settlement percentages, since the clay bed is gradually more tensioned, the bearing capacity is declined by 1.6 times in settlement percentage of 50% compared to where no sand layer exists. In other words, the clay bed bears more pressure in higher settlement percentages. As you can see, geo-textile negatively affects the bearing capacity in low settlement percentages, because geo-textile is tensioned more slowly in low settlement percentages and increases the settlement due to its thickness. According to Figure 8, when geo-textile is located below the sand layer (B), the bearing capacity is negatively affected until the settlements of 20-25 mm.

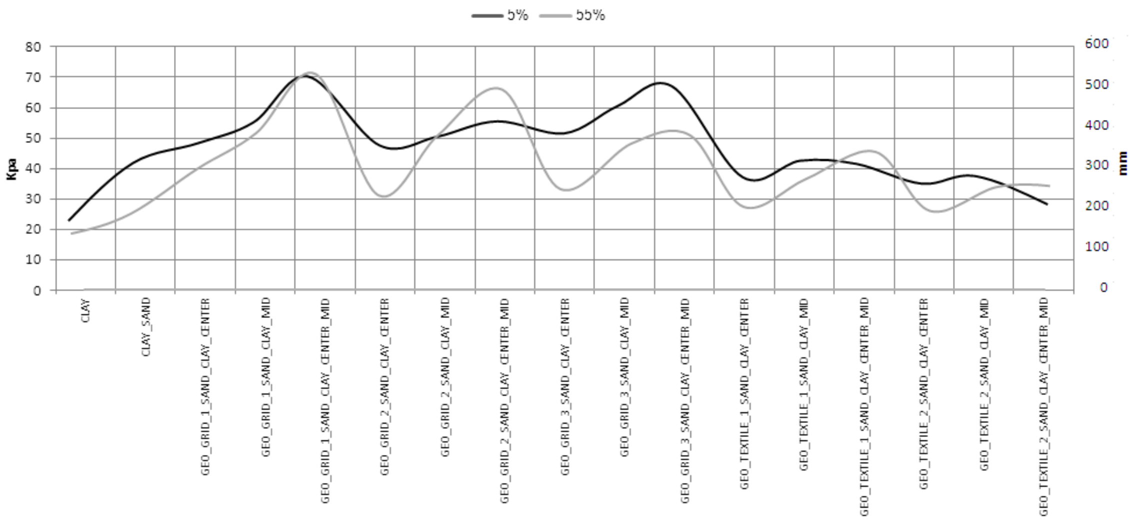

Figure 8. Comparison of the pressures (S/D=5% and S/D=55%)

4. Conclusion

We examined the bond between clay-geo-synthetics, sand-geo-synthetics and clay-sand-geo-synthetics using large-scale direct shear tests. In order to determine the impact of geo-synthetic transverse members on total strength of contact area, we repeated the tests without the transverse members. Studies on geo-synthetic surface friction indicated that the friction of contact area between soil and geo-synthetic materials may be smaller than internal friction angle of the same soil. This is likely to develop a weak surface along the contact area between geo-synthetic and soil. Figure 6 illustrates the changes of bond coefficient. As you can see, the shear strength of total contact area of the reinforced soil is higher than that of non-reinforced soil. The comparison of curves indicates that bond coefficient of sandwich method is higher than reinforced clay and reinforced sand. The reinforced sand shows the increased vertical stress, the reinforced clay shows the reduced vertical stress, and clay-geo-synthetic-sand sample shows an ascending trend [Deb, K., & Konai, S. 2014; Yang, K. H., Yalew, W. M., & Nguyen, M. D. 2015].

We reached the following conclusions based on test results:

Geo-synthetic reinforcement of clay increases the shear strength, which is mainly explained by the impact of open meshes of geo-synthetics. The reinforcement significantly improved the bond, but its impact on apparent friction angle was not significant. Geo-synthetic reinforcement of sand increased the shear strength of contact area, with a significant impact on internal friction angle. The provision of a thin layer of sand at both sides of the reinforcement significantly improved the apparent friction angle of the clay soil. The geo-synthetic transverse members developed the resistance bearing and constituted about 10% of total shear strength.

Test results indicated that shear surface of the reinforced soil is formed more quickly and its total strength remains unchanged after displacements of 2-4 mm. The bond coefficient was 1.10 for clay, 1.04 for sand and 1.11 for clay-sand-geo-synthetics sample. The increased coefficient denotes the significant impact of burying the geo-synthetics in thin layers of sand as clay reinforcement.

The placement of a sand layer on soft clay bed increases the bearing capacity and reduces the settlement. In low settlements, the sand layer bears almost half of the pressure. As the load and settlement increase, soft clay bed bears more load than sand layer does. The reinforcement of sand layer by geo-grid and geo-textile increases the bearing capacity. The use of two reinforcement layers at the middle and below the sand layer is more efficient than the use of one reinforcement layer.

As regards the bearing capacity, the placement of reinforcement at the middle of the sand layer is more efficient than when it is placed below the sand layer. Also, geo-grid is more efficient than geo-textile in the improvement of bearing capacity, because the soil below the circular plate moves downward in high settlement percentages and the reinforcement layers (geo-grid and geo-textile) are gradually tensioned. Consequently, geo-grid and geo-textile strength is fully mobilized and prevents the settlement.

In low settlement percentages, geo-textile negatively affects the bearing capacity because geo-textile is tensioned more slowly than geo-grid and increases the settlement due to its thickness. In all settlement percentages, the highest bearing capacity belongs to the sample in which two GEO_GRID_1 layers have been used at the middle and below the sand layer.

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