Int. J. of GEOMATE, Sept., 2012, Vol. 3, No. 1 (Sl. No. 5), pp. 308-313
Geotec., Const. Mat. & Env., ISSN:2186-2982(P), 2186-2990(O), Japan

Effect of Soil Reinforcement on Shear Strength and Settlement of Cohesive-Frictional Soil

Bestun J. Nareeman[1] and Mohammed Y. Fattah[2]
[1]Geotechnical Engineering Department, University of Koya, Koya-Erbil, Iraq
[2]Building and Construction Engineering Department, University of Technology, Baghdad, Iraq

ABSTRACT: This study investigates the effect of soil reinforcement using geonet on the shear strength, consolidation and swelling of silty soil. The tests that carried out are classified into two categories: First; tests on soil without reinforcement and second tests on soil with reinforcement. The loading test was conducted on small scale model using different layers of reinforcement. The results showed that the shear strength parameters could be improved by using geonet reinforcement. Moreover, the settlement and swelling of silty soils are decreased by using geonet.

Keywords: Geonet, Soil Improvement, Shear strength, Consolidation, and Swelling.

1. INTRODUCTION

Increase of the bearing capacity of soils due to the application of polymeric reinforcement has been shown for various applications, e.g. reinforced retaining walls, embankments, or base courses. However, there is still a lack of understanding about how geogrids contribute to the observed increase of the load bearing capacity at very low strain levels. Reinforcement is one of the most important functions of geosynthetics. Various kinds of geosynthetics are widely used in civil engineering, water resources and hydropower engineering, environmental engineering, etc. It has been demonstrated that the application of geosynthetics can bring great benefit to a project not only in engineering aspect, but also in economic and environment aspects. In addition, it shows a promising future.

Bergado et al. (1993) [5] studied interaction between cohesive frictional soil and various grid reinforcements. They used 52 large-scale pullout and 24 large-scale direct shear tests. The large-scale direct shear results showed that the interfaces shear stresses between the soil and grid reinforcement could exceed the direct shear resistance of the soil. Moreover, the shear strength parameters obtained from the large-scale direct shear were found to be smaller than the results of the triaxial UU tests.

Lopes and Lopes (1999) [12] investigated the influence of particle size of the soil and geosythetic structure. They concluded that an increase in soil-geogrid interface shear resistance is observed when the soil contained a significant percentage of particles with sizes slightly greater than the thickness of the geogrid bearing members, but smaller than the geogrid apertures.

Kumar et al. (2005) [9] studied pressure–settlement characteristics of rectangular footings on reinforced sand. In their study, they used the model test results conducted by Kumar (1997) [8] on square footing with dimensions of 0.175×0.175 m resting on sand, the model test results conducted by [1] on square footing 0.61 x 0.61m in size, resting on sand and the model test results conducted by Kumar (2003) [11] on square footing 0.20×0.20 m resting on sand reinforced with Tensar SS20 geogrids. In their work, the confining effect of the reinforcement provided in the soil at different layers was incorporated in the analysis by considering the equivalent stresses generated due to friction at the soil– reinforcement interface. It was concluded that the value of settlement may be read directly from pressure–settlement curves for the given pressure intensity. Therefore, the rectangular footing resting on reinforced sand can be proportioned satisfying shear failure and settlement criteria.

Kumar et al. (2007) [10] performed an expermental work on layered sand soil. They used different reinforcement layers to investigate the effect of the reinforcement on bearing capacity of strip footing 0.15 ×1.19 m resting on top strong sand layer underlying weak sand layer. It was concluded that replacing the top layer of soil with a well-graded soil is beneficial, as the mobilization of soil-reinforcement frictional resistance will increase. Kumar et al. (2007) [10] found that the bearing capacity increased 3 to 4 times after replacing the 1 B (foundation width) top layer by a well graded sand layer.

Fattah et al. (2010) [7] provided a finite element method to model soft cohesive soil, granular trench soil, and the reinforcement material by using a computer program called (SIGMA/W). The behavior of both cohesive and granular soils was simulated by nonlinear elastic soil model (hyperbolic model), while the linear-elastic model was used to simulate the reinforcement material. The angle of friction of trench soil, modulus of elasticity of reinforcement material, depth, width and shape of the granular trench, locations, and number of the reinforcement layers were varied. The sloped granular trench was analyzed in two cases; lined and unlined conditions. The results showed that use of granular trench beneath foundations will increase the bearing capacity and reduce the settlement. Moreover, using of polymers as a reinforcement material has a significant effect on both bearing capacity and settlement. For both reinforced and unreinforced granular trenches, the depth ratio has an important effect on the settlement ratio, which decreases with the increase of depth ratio. The best practical value for the depth ratio was found to be equal to 2. Making a trench with a width (X) larger than the foundation width (B) also decreases the settlement, and the best effect occurs when the width ratio (X/B) equals to 0.75.

In this paper, the behavior of footing resting on soil reinforced by different layers of geonet reinforcement is investigated. In addition, strength and compressibility tests are conducted to determine the strength and compressibility parameters for reinforced and unreinforced samples.

2. EXPERMENTAL WORK

The used soil was collected from Rasty region in Erbil Governorate north of Iraq. Table I shows the physical properties of the soil used in the investigation. According to the Unified Soil Classification System ASTM D-2487, the soil can be classified as silty soil, CL.

Table I: Physical properties of the soil used

Gravel %	Sand %	Silt %	Clay %	Dry Unit Weight (kN/m^3)	LL %	PL %
0	7.7	87.3	5	14.34	36	33

3. TESTING METHOD

A specially manufactured square mould was prepared for this study with dimensions of 25× 25 cm and 30 cm height as shown in Fig. 1.

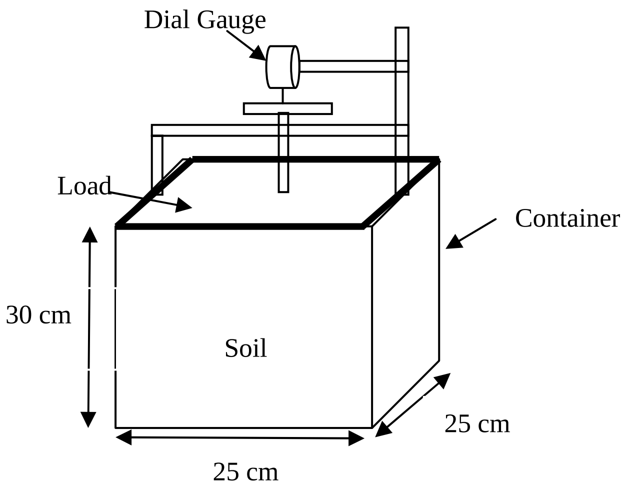

Fig. 1 Special manufactured mold.

A square footing with smooth base made of steel with dimensions of 20 × 20 cm and 5mm thick is placed to carry the applied load. The soil was prepared and compacted at the same density. A dial gauge (0.002 mm/division) is used to read the vertical displacement due to the applied load. Two cases were conducted for study. Firstly, a case study of un-reinforced soil. Secondly, a case study of soil reinforced with geonet with different layers of placement. Different layers of reinforcement were placed in the soil to investigate the effect of number of layers on settlement of the soil. The geonet layers were 1, 2, 3 and 4. The spacing between the layers is equal to 10 cm as shown in Fig. 2.

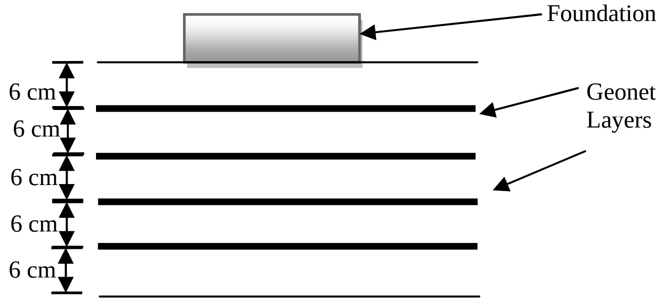

Fig. 2 Typical arrangement for 4 layers of geonet reinforcement.

Many types of Geonet are manufactured such as CE720, CE750 and CE850, as shown in Fig. 3, these types of geonet are designated according to TENAX designation which depend on mass per unit area of each type of geonets. In this study , CE720 has been brought and used.

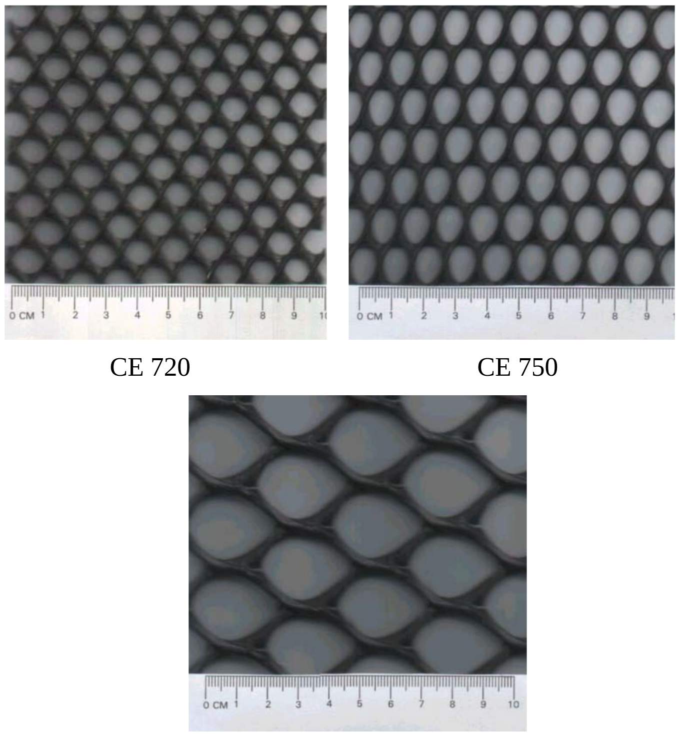

Fig. 3 Three different types of geonets [13].

4. LOADING TEST

It can be noticed from Fig. 4 that the soil was improved by using geonet. It is clear that for reinforced soil, settlement is less than for the unreinforced soil. The most striking feature in this figure is that the settlement is reduced from about 1 cm at 10 kPa for unreinforced soil to around 0.4 cm for reinforced soil. Consequently, the settlement is reduced by about 60%. It is beneficial to say that reinforcing by geonet will help decrease settlement of such types of soils.

Another comparison can be made between the number of layers of reinforcement. From Fig. 4, it is clear that for each case: one-layer, two layers, three layers and four layers of reinforcement, the results are so close. This is due to the small dimensions of the mold used. The results might become different if another mold with larger dimensions is used. Anyway, the effect of number of reinforcement layers becomes clear at high stresses.

5. SHEAR STRESS TEST RESULTS

Direct shear test, performed according to ASTM D3080, provides shear strength properties of soils under conditions of drained loading, which is required for assessing the stability of earth slopes and bearing capacity of foundations. The shear resistance of soil is changed by reinforcement. Direct shear test is conducted for soil without geonet, for soil with geonet layer placed horizontally and for soil with geonet layer placed inclined at 45 degrees. The results of reinforced and unreinforced soil can be seen in Table II below.

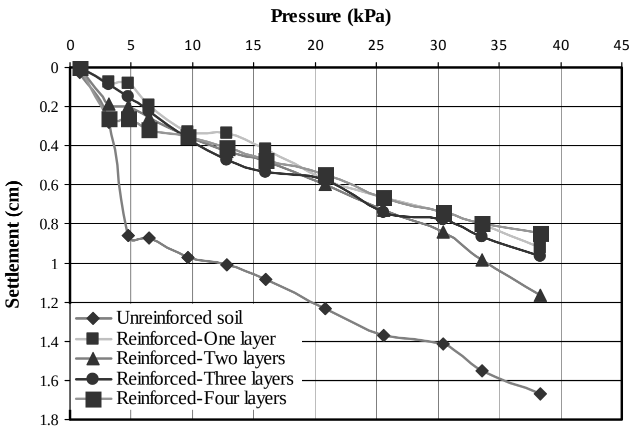

Fig. 4 Pressure - settlement relationship for reinforced and unreinforced soils.

Table II: Direct shear test results for reinforced and unreinforced soils

Unreinforced Soil	Angle of internal friction, ϕ (degrees)	34
	Cohesion, c (kN/m²)	38
Soil Reinforced by Geonet (placed horizontally)	Angle of internal friction, ϕ (degrees)	38
	Cohesion, c (kN/m²)	16
Soil Reinforced by Geonet (placed at 45°)	Angle of internal friction, ϕ (degrees)	44
	Cohesion, c (kN/m²)	32

It is clear from Table II that the angle of internal friction increased from 34^o for unreinforced soil to 38 ^{o} for soil reinforced horizontally by a geonet layer and to 44 ^{o} for soil reinforced by a geonet layer placed at 45^o inclination. This leads to the fact that geonet increases the friction between the soil and surface of the geonet. Hence, the angle of internal friction increased. On the other hand, cohesion decreased from 38 kPa for unreinforced soil to 16 kPa and 32 kPa, for soil reinforced with a horizontal layer and inclined reinforcement layer, respectively. This might be caused by the two different materials (soil and the polymer). The improvement in the values of the angle of friction is better in case of inclined reinforcement since the geonet intersects the failure surface which is almost horizontal.

For unreinforced soil, three trails with normal stresses of 75, 150 and 300 kPa are conducted for direct shear test. Horizontal displacement versus shear stress is drawn in Fig. 5. It can be noticed that the shear stress increased with normal stress.

Fig. 6 shows horizontal displacement versus vertical displacement. It is clear that for the highest normal stress, the highest vertical displacement is recorded. Small normal stresses induced compression, while dilation was recorded under high normal stress (300 kPa).

Fig. 7 presents the relationship between normal and shear stresses.

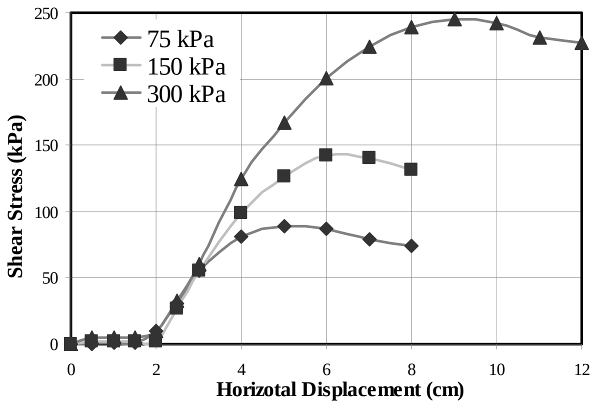

Fig. 5 Shear stress versus horizontal displacement for unreinforced soil.

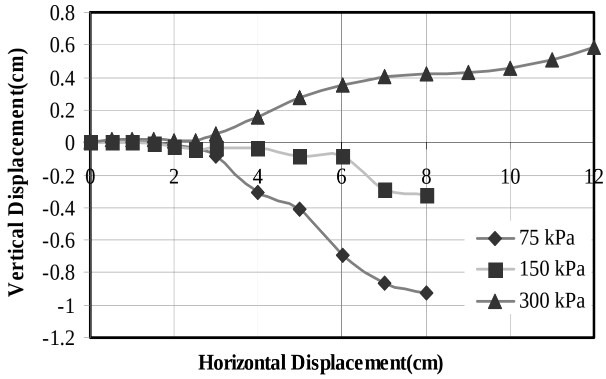

Fig. 6 Horizontal versus vertical displacement for unreinforced soil.

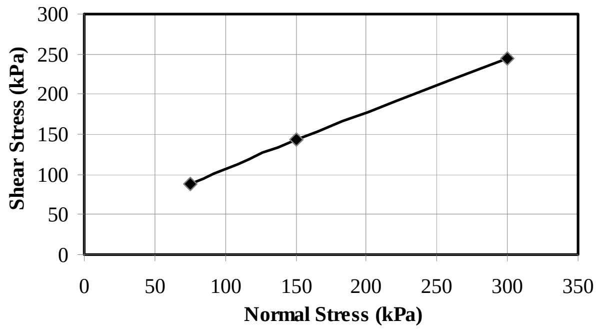

Fig. 7 Shear stress versus normal stress for unreinforced soil.

Figs. 8 to 10 show direct shear test results for soil reinforced by a geonet layer placed horizontally. By comparing Figs. 4 and 8, it can be easily noted that the shear stress increased for soil reinforced by horizontal geonet layer, while the vertical displacement decreased. This is because the geonet layer works as a reinforcement layer that strengthens the soil and tends to increase shear strength of the soil. It can be seen that both compression and dilation of the soil are decreased by adding reinforcement layers.

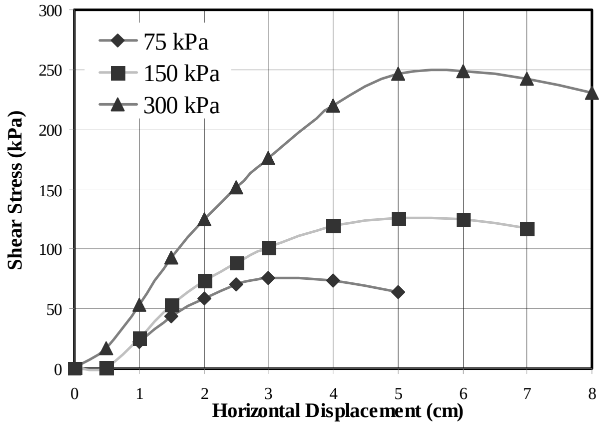

Fig. 8 Horizontal displacement versus shear stress for soil reinforced by geonet layer placed horizontally.

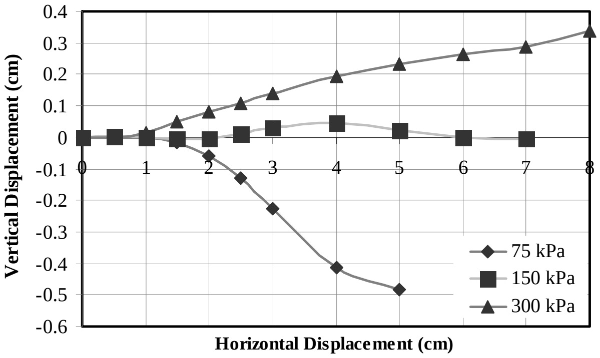

Fig. 9 Horizontal displacement versus shear stress for a soil reinforced by geonet layer placed horizontally.

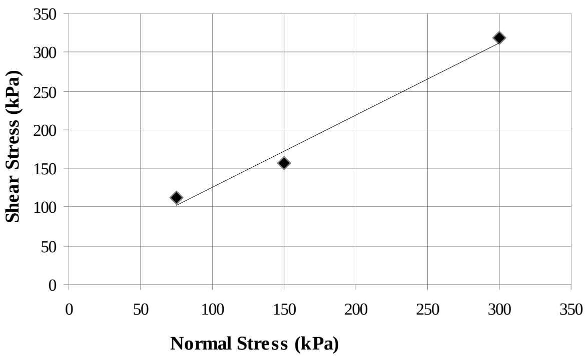

Fig. 10 Shear stress versus normal stress for a soil reinforced by geonet layer placed horizontally.

Figs. 11 to 13 show direct shear test results for a soil reinforced by geonet layer placed at inclination of 45°. It can be noticed that the angle of internal friction increased by using geonet especially for a soil reinforced with a geonet layer placed at 45°. Furthermore, the shear stress and vertical displacement of the soil are improved.

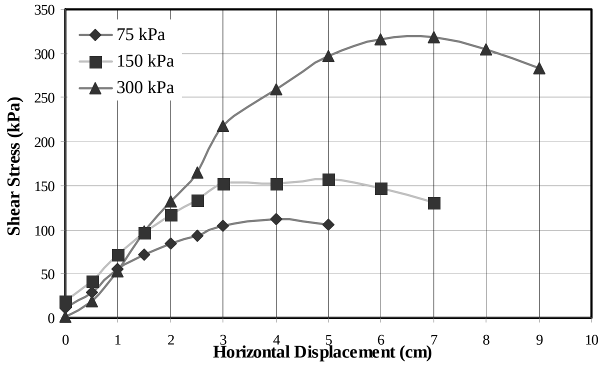

Fig. 11 Horizontal displacement versus shear stress for a soil reinforced with geonet layer placed at inclination of 45°.

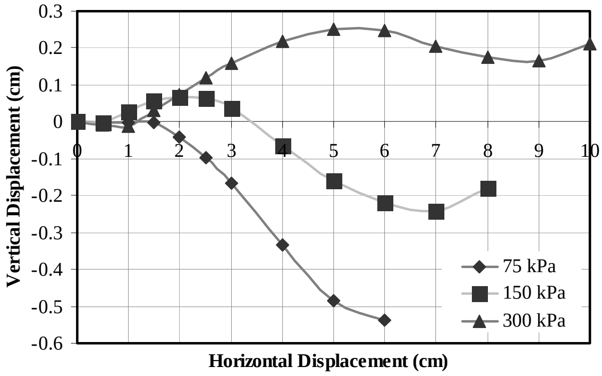

Fig. 12 Horizontal displacement versus vertical displacement for a soil reinforced with geonet layer placed at inclination of 45°.

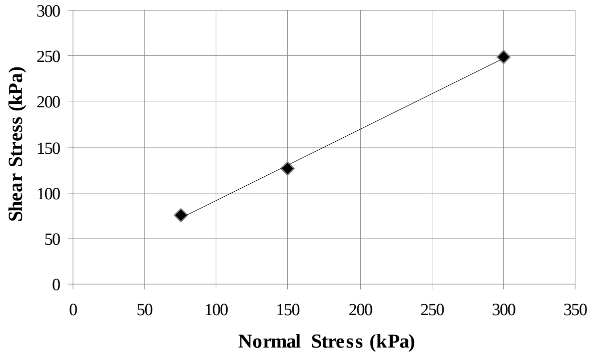

Fig. 13 Normal stress versus shear stress for a soil reinforced with geonet layer placed at inclination of 45°.

It can be noticed that the shear strength parameter (angle of internal friction) increased by using geonet especially for geonet layer placed at inclination of 45°. On the other hand, the cohesion is affected by the direction of reinforcement.

6. SWELLING TEST RESULTS

Swelling, which is increase in volume for the soil after contacting with water, is one of the problems in geotechnical engineering. The soil used in this work is classified as being of low swelling potential based on plasticity index as outlined by Day (2006) [6] and Table III.

Table III: Relation between swelling potential and plasticity index (Day, 2006) [6].

Plasticity Index I_p (%)	0 -10	10-15	15-25	25-35	> 35
Swelling potential	Very low	Low	Medium	High	Very high

Swelling test is conducted according to ASTM D 4546–03 for unreinforced and soils reinforced by geonet. A geonet layer is placed horizontally in the oedometer ring. A comparison between the results for the two cases is performed to show the effect of the reinforcement and how the soil can be improved. Table IV shows swelling pressure for the two selected soils: unreinforced and reinforced soils.

Table IV: Swelling test results.

Swelling Pressure of Unreinforced Soil (kPa)	Swelling Pressure of Reinforced Soil (kPa)
2.52	2.88

Fig. 14 shows swelling test results for unreinforced and reinforced soils. It is clear from the figure that there is a gradual increase in swelling with time. Moreover, swelling for reinforced soil is less than that for unreinforced soil. Consequently, the soil is improved by using geonet.

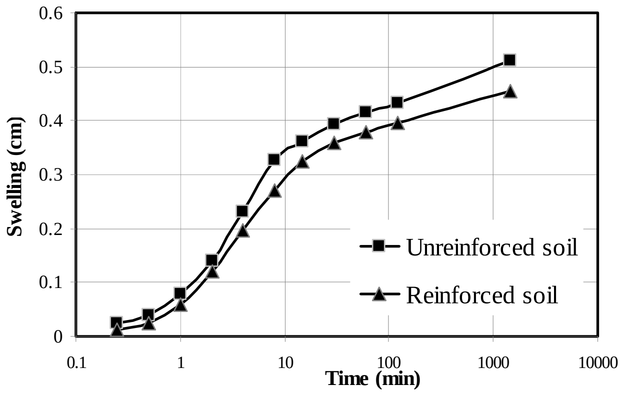

Fig. 14 Swelling test results for unreinforced and reinforced soils.

7. CONSOLIDATION TEST RESULTS OF UNREINFORCED AND REINFORCED SOIL

The results of consolidation test are presented in Fig. 15. Table V shows values of the compression and swelling (expansion) indices for each unreinforced and reinforced soils obtained from consolidation test.

Table V: Compression and swelling index for unreinforced and reinforced soils.

Index	Unreinforced Soil	Reinforced Soil
Compression index Cc	0.123	0.05232
Swelling Index Cr	0.0227	0.00361

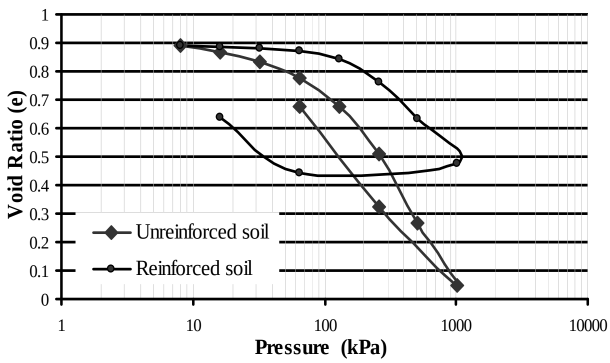

Fig. 15 Void ratio versus pressure for unreinforced and soil reinforced by geonet.

It can be noticed that both compression and swelling indices for reinforced soil are much less than those for unreinforced soil. As a result, consolidation settlement decreases in the reinforced soil. This is because that geonet layer works as reinforcement layer to improve the soil compressibility and prohibits soil movement.

8. CONCLUSIONS

It can be concluded from the tests conducted that:

1. Settlement result for soil reinforced by geonet is lower than that for unreinforced soil because the geonet layer strengthen the soil.
2. The shear strength of the soil reinforced with a geonet layer placed at inclination of 45 ^{o} is improved more than the soil reinforced with horizontal geonet layer especially in the angle of internal friction.
3. The swelling for reinforced soil is less than that of unreinforced soil. This means that geonet could be used as improving material to decrease swelling of the soil for geotechnical engineering applications.
4. The compression and swelling indices for reinforced soil are much less than for those for unreinforced soil.

9. REFERENCES

1. Adams, M. T. and Collins, J. G. “Large Model Spread Footing Load Tests on Geosynthetic Reinforced Soil Foundations”. J. Geotech. Geoenviron. Eng., ASCE, Vol 123, No. 1. 1997, pp 66-72.
2. ASTM, D3080-98. “Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions”, Aerican Society for Testing and Materials.

Philadelphia, PA: American Society for Testing and Materials, 1998.

3. ASTM D 4546-03. “Standard Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils”. Aerican Society for Testing and Materials. Philadelphia, PA: American Society for Testing and Materials, 2004.
4. ASTM, **D 2487**-83. “Standard Test Method for Unified Classification System”, American Society for Testing and Materials. Philadelphia, PA: American Society for Testing and Materials, 1983.
5. Bergado, D.T., Chai, J. C., Abiera, H.O., Alfaro, M.C. and Balasubramaniam, A.S. “Interaction between Cohesive-Frictional Soil and Various Grid Reinforcement”. Geotextiles and Geomembrances, Volume 12, 1993, pp. 327-349.
6. Day, R. W. “Foundation Engineering Handbook”, McGraw-Hill Companies, Inc, 2006.
7. Fattah, M. Y., Al-Baghdadi, W., Omar, M., Shanableh, A. “Analysis of Strip Footings Resting on Reinforced Granular Trench by the Finite Element Method”, International Journal for Geotechnical Engineering, Vol. 4, Issue 4, October, 2010, pp. 471-482.J. Ross Publishing, Inc.
8. Kumar, A. “Interaction of Footings on Reinforced Earth Slab”. PhD. Thesis, University of Roorkee (UP), India, 1997.
9. Kumar, A, Walia, B.S and Saran, Swami. “Pressure – Settlement Characteristics of Rectangular Footings on Reinforced Sand”. Geotechnical and Geological Engineering, Vol. 23, 2005, pp. 469-481.
10. Kumar, A, Ohri, M.L and Bansal, R.K. “Bearing Capacity Tests of Strip Footings on Reinforced Layered Soil”. Geotechnical and Geological Engineering, Vol. 25, 2007, pp. 139- 150.
11. Kumar, S. “Eccentrically and Obliquely Loaded Footings on Reinforced Earth Slab”. PhD. Thesis, IIT University of Roorkee (UA), India, 2003.
12. Lopes, M.J. and Lopes, M.L. “Soil and Seosynthetic Interaction Influence of Soil Particle Size on Soil-Geosynthetic”. Geosynthetics International , Vol. 6, 1999, pp. 261-282.
13. TENAX, Geosynthetics company, 2012, http://www.tenax.net/index.php.

International Journal of GEOMATE , Sept., 2012, Vol. 3, No. 1 (Sl. No. 5), pp. 308-313
MS No. 1263 received May 14, 2012, and reviewed under GEOMATE publication policies.

Pertinent discussion including authors’ closure, if any, will be published in the Sept. 2013 if the discussion is received by March, 2013.
Corresponding Author: Bestun J. Nareeman