Soil-geocell reinforcement interaction by pullout and direct shear tests

Nazri Mohidin & Marolo C. Alfaro
Department of Civil Engineering- University of Manitoba,Winnipeg, Manitoba, Canada

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ABSTRACT
This paper reports the results of a study to investigate the soil-geocell reinforcement using pullout and direct shear tests. The behaviour of soil-geocell interaction is characterized based on shear stress-displacement behaviour and shear strength properties. The results from pullout tests show strain hardening behaviour of pullout load-displacement curves. In direct shear tests, strain softening behaviour was observed on both reinforced and unreinforced soil where the provision of geocell increased the shear strength of the soil due mainly to higher apparent cohesion and internal friction angle. The degree of interlocking on dense soil and additional friction on the interface between soil and geocell reinforcement may have attributed to increase in shear strength.

RESUMEN
Este artículo presenta los resultados de un estudio para investigar el refuerzo del mecanismo suelo-geocelda ante pruebas de tensión y corte directo. El comportamiento de la interacción entre el suelo y la geocelda es caracterizado en función del comportamiento entre el desplazamiento y el esfuerzo cortante y las propiedades de resistencia del mecanismo suelo-geocelda. Los resultados de las pruebas de tensión demuestran un comportamiento de endurecimiento por deformación en las curvas de carga tensión vs desplazamiento. En pruebas de corte directo, se pudo apreciar un comportamiento de ablandamiento ante la deformación para las condiciones de suelo reforzado y sin refuerzo donde la geocelda incrementó la resistencia al corte del suelo debido principalmente a una mayor cohesión aparente y un incremento en el ángulo de fricción interno. El grado de entrelazado en suelos densos y la fricción adicional en el punto de contacto entre el suelo y el refuerzo de geocelda podría ser atribuido al incremento en la resistencia al corte.

1 INTRODUCTION

Geocell is a geosynthetic product interconnected to form three-dimensional cellular networks. It provides working platform, reduces differential and total settlements, facilitates rapid construction, provide short term and long term slope stability, and increased bearing capacity of embankments (Bush et al. 1990, Cowland and Wong 1993, Krishnaswamy et al. 2000, Madhavi et al. 2006, Madhavi and Rajagopal 2007, Zhou and Wen 2008)

The advantages of using geocell compared with planar types of reinforcements (e.g. geotextiles and geogrids) were reported by Dash et al. (2004). They showed that confinement by geocell allows redistribution of footing loads over a larger area makes a better composite material and reduces settlements. Planar reinforcements resist outward shear stresses induced by embankment fill and provide inward shear stresses to hold back foundation soil from lateral spreading (Jewell 1988). This is also the case for geocell reinforcements. Lateral confinement is due to the three dimensional structure of geocell. Geocell provides vertical confinement in two ways: (i) Friction between the filled soil and geocell walls (ii) geocell acts like mattress minimizing lateral spreading. Zhou and Wen (2008) pointed out that geocell reinforced-base can provide bending resistance, tensile strength and shear strength and intercept the failure plane.

The use of geocell reinforcements is not as popular as planar reinforcements for embankments, shallow foundations and pavement applications. Although successful field applications and researches have been done, lack of understanding of operating mechanisms and influencing factors are the main reasons limiting the use of geocell reinforcements (Yuu et al. 2008). Additional research is needed for establishing design procedure to use geocell as basal reinforcement (Pokharel et al. 2010). The present study aims to investigate the pullout and direct shear interaction behaviour of soil and geocell reinforcements. The soil-geocell interaction is evaluated in terms of shear stress-displacement relationships and shear strengths.

2 TEST PROGRAM

2.1 Test Equipment and Instrumentations

The test apparatus was composed of a box with dimensions of 1200 mm in length, 600mm in width and 410 mm in height. A schematic diagram of the testing equipment and photo used for both pullout and direct shear tests are shown in Figures 1 and 2, respectively. Detailed description of the test equipment is found in Alfaro et al. (2009). The soil thickness above and below the reinforcement were 160 and 250 mm, respectively. A rubber air bag was used to produce a uniformly distributed vertical pressure on top of the soil. The top cover of the equipment containing the rubber air bag was fitted with displacement rods. These rods measure the vertical displacement on top of the soil caused by soil dilation. Extreme care was taken to minimize the interference of tank wall in the pullout test results. Friction between the soil and the side walls of the box was minimized using two layers of thin plastic films lubricated buy silicon grease. In order to avoid front wall effects, a sleeve was fixed to the front wall as recommended by a number of researchers

(Palmeira 2009, Moraci and Recalcati 2006, Farrag et al. 1993).

For the pullout test, the upper and lower parts of the box were bolted together. The bolts were removed while running direct shear tests and the rollers on both sides of the box were engaged (see Alfaro et al. 1995). A load cell was used to measure the pullout/direct shear force. For pullout tests, front displacements, vertical displacements and the displacements along the reinforcement were monitored using linear variable differential transformers (LVDTs). Inextensible stainless wires inside stiff plastic tubings were connected to the designated points along the length of the geocell to measure nodal displacements. The purpose of using stiff plastic tubing was to avoid friction and direct contact with the soil. The stainless wires were always kept tensioned by built-in springs of LDVTs. All instrumentations are linked to a personal computer through an electronic data logger that was programmed to record the measurements at desired time intervals.

2.2 Test Procedure

The soil was compacted in the pullout box by manual tamping, with each layer not exceeding 100 mm to provide adequate and uniform compaction at a relative density of 95%. The compaction process was carried out until the allotted soil is filled into a particular layer. When the lower box was filled completely with soil, the reinforcement specimen was bolted into position to the clamping plates. For direct shear tests, the clamping plates were mounted at the inner face of the rear wall. For the pullout tests, clamping plates were positioned inside the compacted soil and extended behind the sleeve plates. The clamping plates were connected with the pulling rod, which went through the slot in the front face of the box (see Figure 1). After placing sand to the level of underside of reinforcement, the geocell reinforcement was connected to the lubricated clamp. Sand was placed again in layers to form the test specimen. Air pressure was applied from a compressor through a pressure regulator into the top cover containing the rubber air bag. It was applied at least 30 min before running the pullout /direct shear tests to ensure adequate and uniform distribution of pressure to the specimen (Alfaro et al. 1995). For pullout test, displacement instrumentations were attached to the designated points along the reinforcement as shown in Figure 3.

There were four pullout tests conducted with three specimens for performance test and one specimen for element test. The element test is in-isolation test that was conducted to obtain stress-strain relationship of geocell.

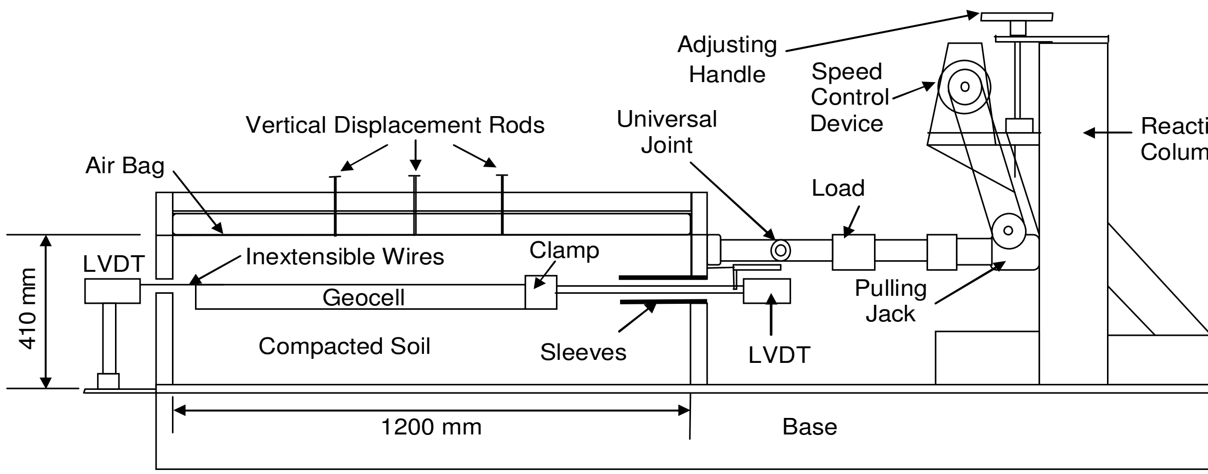

Figure 1. Schematic diagram of the testing equipment used for both pullout and direct shear tests.

Figure 2. Photograph of a typical setup.

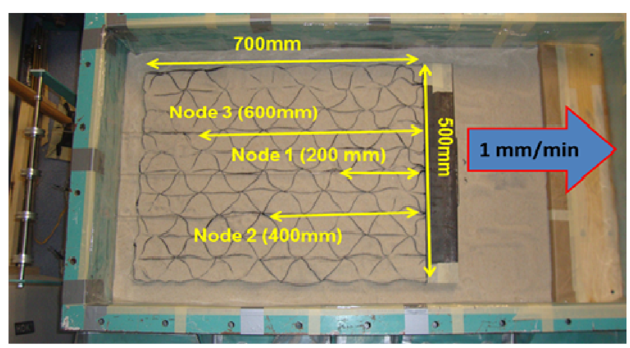

Figure 3. Pullout test set-up showing locations of nodal displacement measurements.

This relationship is important to determine the pullout distribution and resistance along the reinforcement (see Ochiai et al. 1996, Alfaro et al. 1995). The dimensions of all geocell reinforcements used in pullout test are 700 mm x 500 mm x 50 mm (LxWxH). Figure 3 shows the geocell specimen inside the pullout box and the location of nodes where displacements along the reinforcement are measured. The clamp use to grip the geocell is located inside the soil to minimize strain localization in the reinforcement near the point of load application. Consequently, pullout tests on the clamp plate were performed so that the resistance at various normal pressures can be subtracted from the results of pullout tests of geocells. This method was used by previous researchers to account resistance of the internal clamping system in the test results (Moraci and Recalti 2006, Khedkar and Mandal 2009, Farrag et al. 1993).

Two types of direct shear tests were conducted: 1) soil-soil test and 2) soil-geocell tests where the soil and top of geocell specimen coincides the predetermined sliding surface. The length and width for the top box and bottom box were 600 mm x 600mm and 800mm x 600 mm, respectively. The advantage of this set up is that there is no need to reduce the shear area with shear displacements. All pullout and large direct shear tests were conducted at a displacement rate of 1 mm/min.

2.3 Testing Materials

2.4.1 Soil Properties

The soil used in this study was poorly graded fine quartz sand with the following particle size properties: average particle size d_{50} = 0.65 mm; coefficient of curvature of gradation curve, C_c = 0.9; and coefficient of uniformity, C_u = 1.8. The maximum and minimum unit weights were 18 kN/m^3 and 16 kN/m^3, respectively. The grain distribution curve is shown in Figure 4. The shear strength of the sand was determined by performing conventional square direct shear. Peak and critical internal friction angles of the compacted soil determined from direct shear tests was 40° and 34°, respectively.

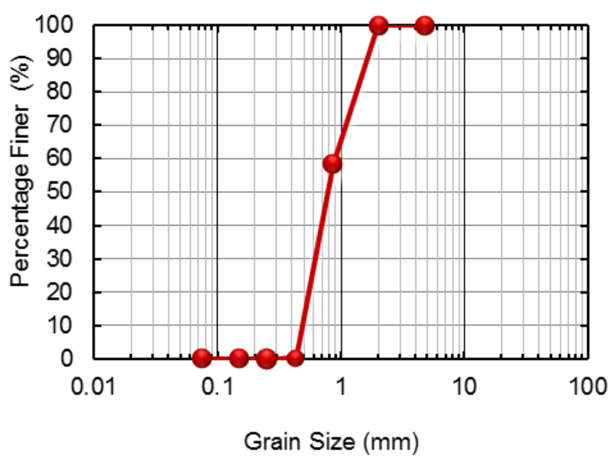

Figure 4. Grain distribution of backfill soil.

2.4.2 Geocell Specimen

All geocell specimens used for this study are made from Mirafi HP270, which is a woven type of geotextile, formed in diamond patterns. Diamond patterns have a similar performance and same efficiency as chevron pattern (Krishnaswamy et al. 2000). Furthermore, diamond patterns have less number of joints, and thus the failure for single joints during test is minimized. The geocell with pocket dimensions (DxH) of 100 mm x 50 mm was used for all tests. The aspect ratio (height to diameter ratio) of 0.5 was used and was based on optimum aspect ratio recommended by other researches (Krishnaswamy et al. 2000, Mhaiskar and Mandal 1996). The overall geocell reinforcement dimensions for pullout test were 500mm x 700mm x 50mm (WxLxH), while for large direct shear test the dimensions are 600mm x 600mm x 50mm. Three normal loads were applied in direct shear test: 50, 75 and 100 kPa. The normal loads applied in pullout test were 25, 50 and 100 kPa. The joints in the geocell were made from commercially available 20 gauges hardware wire. This allows a customized geocell that has size reasonable for the pullout and direct shear test equipment used in this study.

3 EXPERIMENTAL RESULTS AND DISSCUSIONS

3.1 Pullout Test

Figure 5 shows the pullout load against front junction displacements under the normal pressures of 25 kPa, 50 kPa and 100 kPa. As expected, the pullout resistance increases with increasing normal pressures. Besides, the pullout load shows ductile behaviour that has no clear peak value even pullout displacements up to 50 mm. This may be attributed to the extensibility of geocell as it is being pulled out from the soil (shown in Figure 6). The initial slope of the pullout curves is steeper as normal pressure increases, consistent with the results reported by Khedkar and Mandal (2009).

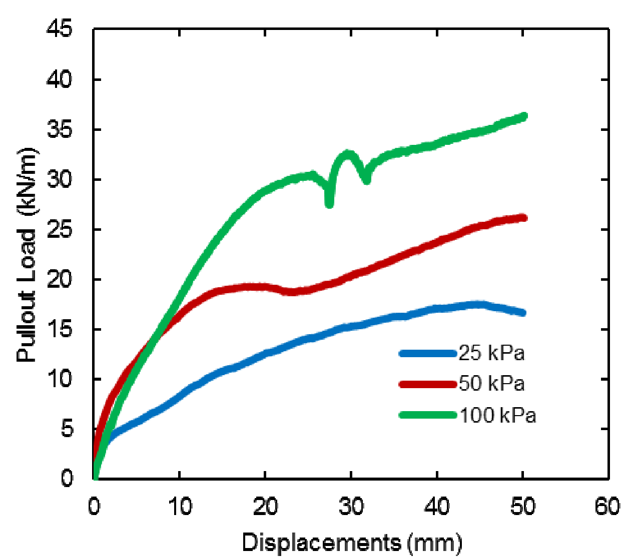

Figure 5. Typical pullout load–displacement relationships of geocell at various normal pressures.

The variations of displacements at the end of the test for four different locations along the reinforcements are shown in Figure 6. The locations of nodal displacements are also shown in the inset of Figure 6. Apparently the mobilizations of the displacements are non-uniform due to the extensibility of geocell, reducing with distance from the point of pullout load application. The results show that progressive mobilization of shear resistance along the reinforcement. Figure 7 shows the geocell strains calculated from nodal displacements in Figure 6. Higher strains were found near the point of pullout load application for higher normal pressures. The strains reduce with increasing distance, with higher normal pressures producing lower strains closer to the end of reinforcement. Higher normal pressures limit the displacements, and therefore strains towards the end of reinforcement.

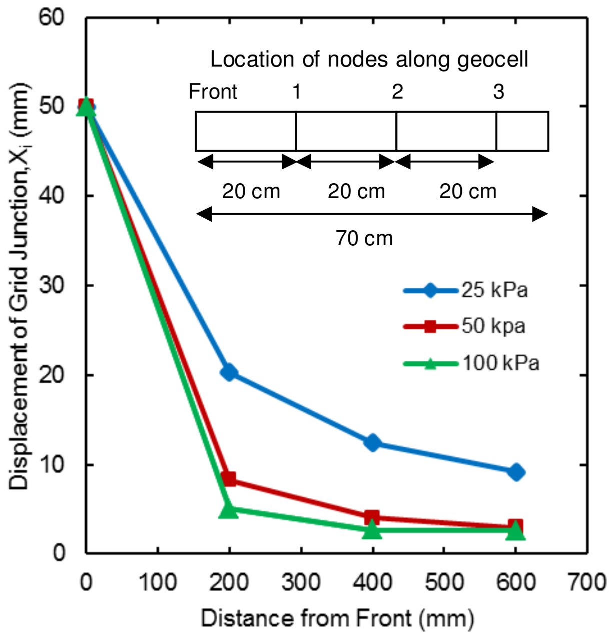

Figure 6. Distributions of nodal displacements along the geocell reinforcement at the end of test.

The strain distributions along the reinforcement length shown in Figure 7 can be used to estimate the average pullout resistance of geocell reinforcement. Subsequently, the interface shear properties can be determined using the effective area method proposed by Ochiai et al. (1996) for planar reinforcements. The average interface shear resistance, τ_A between soil and geocell reinforcement can be expressed as:

$$\tau_A = \frac{F_{Tmax} - F_r}{2\,BL_e} \qquad [1]$$

where, L_e = effective length of the geocell, B = width of the geocell reinforcement, F_{Tmax} = maximum value of pullout force, F_r = force at effective length of geocell. Figure 8 shows distribution of pullout force versus distance from point of load application. The pullout resistance is estimated from the in-isolation pullout force-strain relationship of geocell but with soil fill (considered index tests) was used to estimate the load distribution along the geocell. Table 1 shows the values of L_e, F_{Tmax}, F_r, and the corresponding τ_A for different normal pressures. The interface shear properties deduced from the evaluation of average resistance is shown in Figure 9. The friction angle and apparent cohesion at pullout interface obtained in this study were 45° and 22 kPa, respectively. The interface shear strength appears to be attributed to the apparent cohesion and additional friction angle provided by the geocell. The interface friction angle is higher compared to friction angle of unreinforced soil.

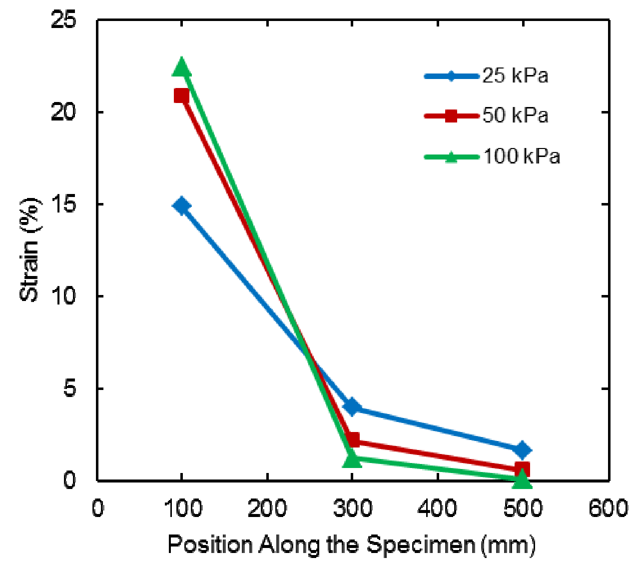

Figure 7. Strain versus position along the specimen for various normal loads.

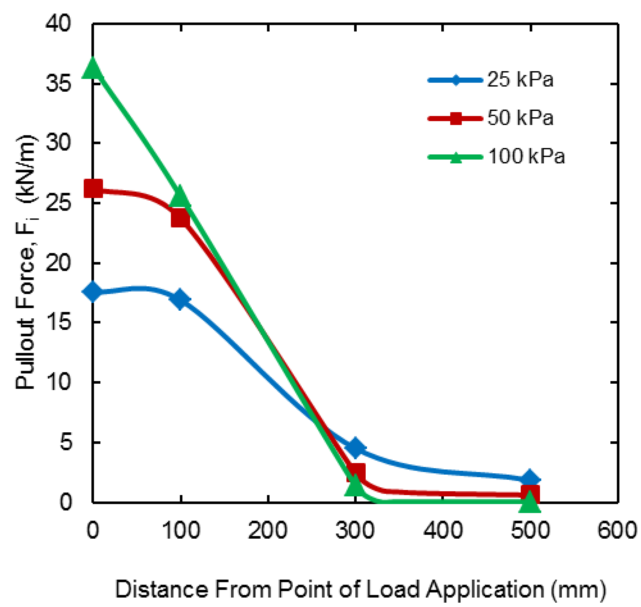

Figure 8. Distribution of tensile forces along the geocell.

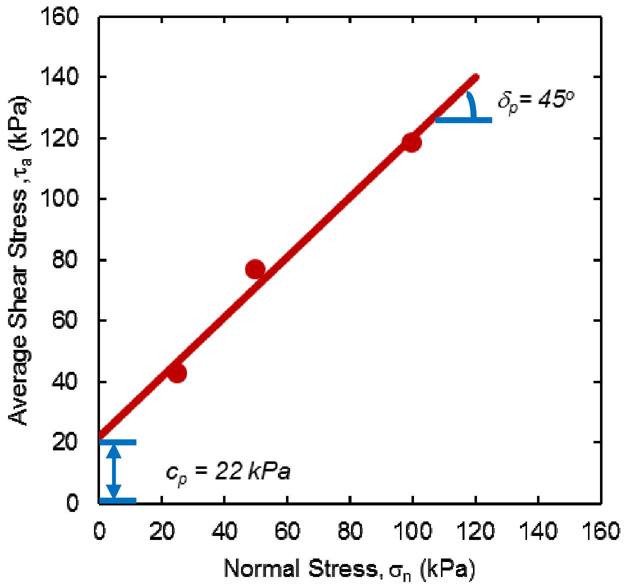

Figure 9. Average shear resistance at soil–geocell reinforcement interface deduced from pullout test results.

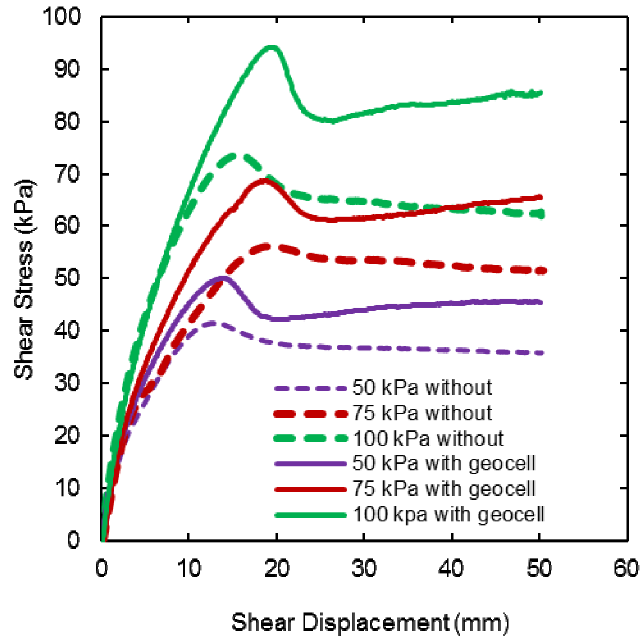

Figure 10. Shear stress–shear displacements behaviour for large direct shear with and without geocell reinforcements.

Table 1. Summary of average interface shear resistance values for different normal pressures.

Normal Pressure (kPa)	L_e (m)	F_{Tmax} (kN/m)	F_r (kN/m)	τ_A (kN/m^2)
25	0.33	19.6	3.6	48.4
50	0.31	26.2	2.4	76.7
100	0.29	36.3	2.0	118.4

3.2 Large Direct Shear Test

Figure 10 shows the results of soil-geocell reinforcement direct shear tests together with the results for soil-soil tests. Both show strain softening behaviour. It can be seen that the shear resistance with geocell is generally higher than that of the soil-soil test. Wang et al. (2008) attributed this higher shear resistance to the confinement of dense soil within the geocell and additional friction on the interface between soil and geocell reinforcement.

The failure envelopes for tests with and without geocell are shown in Figure 11. Comparing the cohesion of unreinforced with that of geocell reinforced soil, no increase was found at critical state strength but increases by 5 kPa at peak strength. The friction angle is increased for both critical and peak states. The increases of internal friction angle values are 5° and 6° for critical and peak strengths, respectively. The increase on direct shear strength with the presence of geocell is consistent with what was observed by Madhavi et al. (2000).

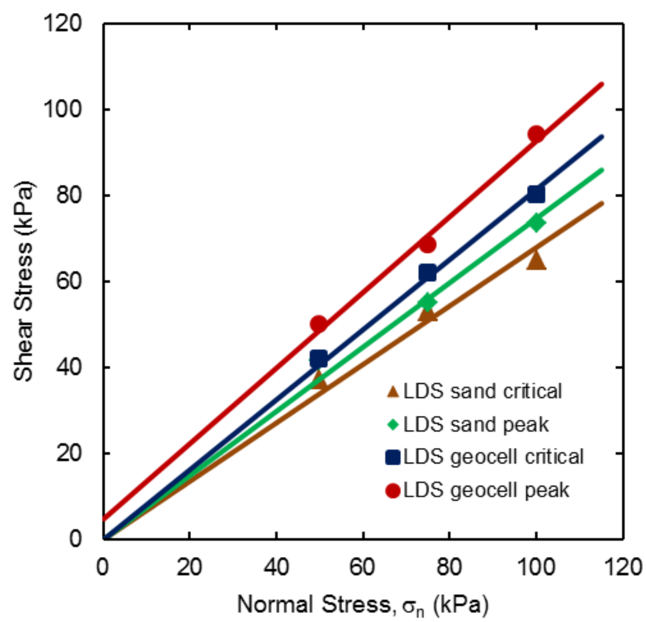

Figure 11. Mohr Column failure envelope envelops for reinforced and unreinforced large direct shear tests.

4 CONCLUSIONS

Large scale laboratory pullout and direct shear tests were conducted to investigate the interaction behaviour of soil and geocell reinforcement. Strain hardening behaviour of pullout load-displacement curves was observed. The non-uniform straining of geocell during pullout results to progressive mobilization of shear resistance along the reinforcement. The interface shear strength appears to be attributed to the apparent cohesion and additional friction angle provided by the geocell.

In direct shear tests, strain softening behaviour was observed on both reinforced and unreinforced soil where the provision of geocell increased the shear resistance. No increase of cohesion component was found at critical state strength but increases by 5 kPa at peak strength. The presence of geocell increased the critical and peak friction angles by 5° and 6°, respectively.

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REFERENCES

Alfaro, M.C., Miura N., and Bergado, D.T. 1995. Soil-geogrid reinforcement interaction by pullout and direct shear tests. *American Testing Journal, ASTM* 18 (2): 157-167.

Alfaro, M.C., Blatz, J.A., Abdulrazaq, W.F., and Kim, C.S. 2009. Evaluating shear mobilization in rockfill columns used for riverbank stabilization. *Canadian Geotechnical Jounal* 46: 976–986

Bush, D. I., Jenner, C. G., and Bassett, R. H. 1990. The design and construction of geocell foundation mattress supporting embankments over soft ground. *Geotextiles and Geomembranes* 9: 83–98.

Cowland, J.W., Wong, S.C.K. 1993. Performance of a road embankment on soft clay supported on a geocell mattress foundation. *Geotextiles and Geomembranes* 12 :687–705

Dash, S.K., Rajagopal, K., Krishnawamy, N.R. 2004. Performance of different geosynthetic reinforcement materials in sand foundations. *Geosynthetics International* 11(1) : 35-42

Farrag, K., Acar, Y.B., Juran, I. 1993. Pull-out resistance of geogrid reinforcements. *Geotextiles and Geomembranes* 12: 133–159.

Jewell, R.A. 1988. The mechanics of reinforced embankments on soft soils. *Geotextiles and Geomembranes 7*: 237-273

Krishnaswamy, N.R., Rajagopal, K., Madhavi Latha, G., 2000. Model studies on geocell supported embankments constructed over soft clay foundation. *Geotechnical Testing Journal, ASTM* 23: 45–54.

Khedkar, M.S. and Mandal, J.N. 2009. Pullout behaviour of cellular reinforcements. *Geotextiles and Geomembranes* 27: 262-271

Madhavi Latha, G., and Rajagopal, K. 2007. Parametric finite element analyses of geocell supported embankments. *Canadian Geotechnical Journal*, 44(8) : 917–927

Madhavi, L.G., Rajagopal, K. and Krishnaswamy, N.R. 2006. Experimental and theoretical investigations on geocell supported embankments. *International Journal of Geomechanics* 6 (1): 30–35.

Madhavi, L.G., Rajagopal, K. and Krishnaswamy N.R., 2000. Interfacial friction characteristics of geocell reinforced soil. *Proceeding of International Conference GEOENG2000,* Melbourne, Australia.

Mhaiskar, S.Y. and Mandal, J.N. 1996. Investigations on soft clay subgrade strengthening using geocells. *Construction and Building Material Journal* 10 (4):281-286

Moraci N. and Recalcati P. 2006. Factors affecting the pullout behaviour of extruded geogrids embedded in a compacted granular soil. *Geotextiles and Geomembranes* 24 : 220–242

Ochiai, H., Otani, J., Hayashic, S. and Hirai, T. 1996.The pull-out resistance of geogrids in reinforced soil. *Geotextiles and Geomembranes* 14:19-42

Palmeira, E.M. 2009. Soil–geosynthetic interaction: Modelling and analysis. *Geotextiles and Geomembranes* 27: 368-390.

Pokharel, S.K., Han, J., Leshchinsky D., Parson R. L., and Halahmi I. 2010. Investigation of factor influencing behaviour of single geocell-reinforced bases under static loading. *Geotextiles and Geomembranes* 28: 570-578

Wang, Y.M., Chen, Y.K., Wang, C.S., and Hou, Z.X. 2008. Large direct shear testing of geocell reinforced soil. *Advances in Transportation Geotechnics : 759-764*

Yuu, J., Han, J., Rosen, A., Parson R., Leshchinsky D. 2008. Technical review of geocell-reinforced base courses over weak subgrade. *In. Proceeding of First Pan American Geosynthetics Conference and Exhibition*, Cancun, Mexico : 1022-1030

Zhou, H.B. and Wen X.J. 2008. Model studies on on geogrid-or– geocell-reinforced sand cushion on soft soil. *Geotextiles and Geomembranes* 26: 231-238