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EFFECT OF GEOGRID REINFORCEMENT ON INTERFACE FOR A STRATIFIED EMBANKMENT

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ABSTRACT: Reinforced granular embankments are often placed on soft soil strata for an efficient and economical transfer of superstructure load. This paper describes laboratory tests on circular footing supported on unreinforced and geogrid-reinforced granular soil. Two types of geogrid layer, uniaxial and biaxial geogrid, were placed at the interface of sub-base soil and granular base of an embankment formed on soft ground to support shallow foundations. Load test were conducted with the aim to determine the performance improvement of the circular footing due to the provision of both types of geogrid reinforcement in the soil. Also studied the effect produced by anchoring geogrid layer at the edge of the mold sample. The results showed that the inclusion of a geogrid layer at the interface of sub-base soil and granular base increase the magnitude of the footing bearing capacity and decreases the settlement of the system. The study shows that the type of geogrid used has direct influence on stress-strain behavior of soil-geogrid system and better results occurred when the geogrid was anchored to test mold.

Keywords: Shallow Foundations, Geogrid, Reinforcement, Bearing Capacity Ratio, Settlement

1. INTRODUCTION

A traditional method of soft ground improvement is to replacement part of this low bearing capacity ground by a more competent granular soil. In Cordoba Argentina, the replaced soil generally consists of two layers of compacted granular soil, a base layer formed from crushed stone resting on a sub-base layer formed with fine soil mixed with sand. Fig. 1a shows a typical scheme of distribution of the soil layers under the shallow foundation. For large-area constructions, this type of foundation soil improvement can be very expensive because the volume of material to be replaced is large. An alternative to reduce the volume of soil replacement can be include a geosynthetic layer at the interface of sub-base soil and granular base of an embankment formed (see Fig. 1b).

Many experimental and analytical studies have been performed to investigate the behaviour of shallow foundation resting on reinforced granular beds for different soil types. A number of researchers has been carried out CBR type tests on both reinforced and unreinforced granular soil to establish the improvement by the inclusion of reinforcements in the ground [1]-[5]. Other studies have reported the beneficial effects of reinforcement on the CBR ratio of composite systems such as soil–sand, soil–aggregate and soil-crushed stone [6]-[12]. These investigations showed that the inclusion of geosynthetics reinforcement in the soil mass increases the CBR ratio and therefore increases the strength of the soil.

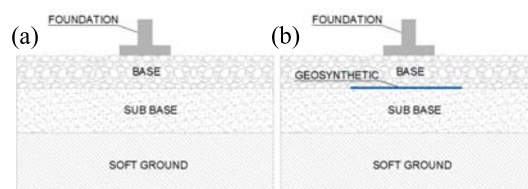

Fig.1 Scheme of embankments under shallow foundations, a) Soft soil replaced with two layers of granular soil, b) Replaced soil improvement with the inclusion of a geogrid layer

Several laboratory model load tests on geosynthetic-reinforced soil have been published in the literature [13]-[17]. These model tests were conducted with model shallow foundations on reinforced soil contained in tanks. The results of these investigations clearly showed that the bearing capacity of the foundation can be significantly improved by the inclusion of reinforcement in the ground. On the other hand, some researchers have presented the theoretical and numerical analyses for determining the bearing capacity of shallow foundations on reinforced soil [18]-[24]. The analytical and numerical methodologies take into account the strength of tension developed in the geosynthetic and presented the design of soil reinforcement procedures.

This paper presents the results of laboratory-load tests on a circular rigid foundation supported by geogrid-reinforced soil layer. A geogrid layer was introduced at the interface of the sub-base soil and base soil as shown in Fig. 1b. In this case, the two layers forming the embankment are studied. Load tests were performed on samples with the base layer and sub-base layer with and without a geogrid layer included between the two layers of soil. The improvement achieved by including uniaxial and biaxial geogrid as reinforcement in the ground is compared. Also is studied the case where the geogrid is anchored to the test mold, in order to reproduce the condition in which the geosynthetic is pressed by compacted ground and a tension force occurs when the geogrid deforms by the application of loads.

2. MATERIALS

2.1 Sub-base soil

Sand mixed with fine soil was used for the sub-base soil. As per the Unified Soil Classification System (USCS), the soil can be classified as silty sand (SM). The properties of soil particles are: the mean grain size D_{50}=0.66 mm, size D_{60}=0.95 mm and size D_{30}=0.35 mm.

2.2 Base soil

The base material correspond to a crushed stone with a uniformity coefficient C_u=20.6, coefficient of curvature C_c=1.7, the mean grain size D_{50}=4.47 mm, size D_{60}=6.41 mm, size D_{30}=1.86 mm and size D_{10}=0.31 mm. The crushed stone is classified as a well-graded sand with gravel (SW) according to the Unified Soil Classification System (USCS). This soil showed a 52% of sand and 48% of gravel, so it is classified as well graded sand but has a lot of gravel particles. The particle size distribution for both soils was characterized using the dry sieving method and the results are shown in Fig. 2.

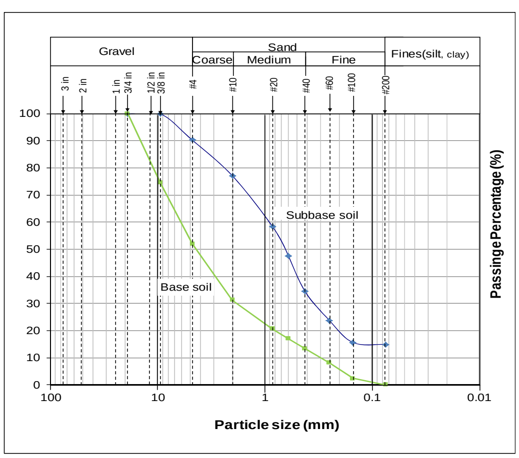

Fig.2 Grain size distribution of the sub-base and base materials used in the study

2.3 Geosynthetic

Two types of geosynthetic were used in the experimental program, uniaxial and biaxial geogrid. These geosynthetics are commercialized by CORIPA S.A, a local company. The uniaxial geogrid is denominated as FORTRAC 35MP (J700). This geogrid is made of polyvinyl alcohol (PVA) yarns. The biaxial geogrid is denominated as FORNIT 20/20 (J400). This geogrid is fabricated of polypropylene (PP) yarns. In Table 1, the mechanical strength parameters of the two types of geogrid used in the tests are shown.

Table 1 Mechanical properties of geogrid

Property	Value for Geogrid Uniaxial	Value for Geogrid Biaxial
Modulus (Long. Direction) (to def. 5%) [kN/m]	630	≥ 360
Modulus (Cross Direction) (to def. 5%) [kN/m]	-	≥ 360
Modulus (Long. Direction) (to def. 2%) [kN/m]	700	≥ 400
Modulus (Cross Direction) (to def. 2%) [kN/m]	-	≥ 400
Mesh opening [mm X mm]	20 x 30	40 x 40

3. EXPERIMENTAL METHODOLOGY

The experimental programme involved a series of laboratory scale load tests on model circular footing resting on two layers of soil. The soil samples were formed by a base layer (well-graded sand with gravel) supported on a layer of sub-base (silty sand). In some samples a geogrid layer was placed at the interface of sub-base soil and base soil and the results are compared with samples without geogrid in order to evaluate the improvement in the soil. A total of 5 load tests were conducted and many of them were repeated to check the consistency of the results. Fig. 3 shows the scheme of the samples tested and Table 2 presents the description of each specimen prepared.

Samples for the laboratory test were compacted according to ASTM D 698 (Method C). The sub-base soil (silty sand) was compacted at 19 kN/m^3 dry density and 4% water content. The base soil (well-graded sand with gravel) was compacted at

21 kN/m^3 dry density and 1% water content. The dry density and the water content of the samples were checked and maintained with a variation of 1 kN/m^3 for dry density and 0.5% for water content in all samples. The sub-base soil was compacted in three layers of 57 blows each and the base soil was compacted in a layer of 73 blows maintaining constant compaction energy in both types of soil. The samples were compacted manually using a rammer of 2.5 kg weight, falling from a height of 30 cm. Fig. 3 shows the geometry of the specimens tested. A cylindrical mold of 15.24 cm diameter was used to contain the ground, the thickness of sub-base layer was 12.5 cm and the thickness of the base layer was 5.0 cm.

Table 2 Tests conducted

Specimen	Description of the test
1	Without geogrid
2	A uniaxial geogrid layer at sub base-base interface
3	A biaxial geogrid layer at sub base-base interface
4	A uniaxial geogrid layer at sub base-base interface anchored in the edge of the mold
5	A biaxial geogrid layer at sub base-base interface anchored in the edge of the mold

The geogrid was cut into the circular bore size of the mold (15.24 cm) and introduced at the interface of sub-base soil and base soil (specimens 2 and 3) as shown in Fig. 3-b. For samples 4 and 5 the geogrid was pressed by the mold in order to keep it fixed on the edge and ensure a tensile force in the geogrid, similar to that which takes place when the geogrid is installed in the field and it is pressed by the adjacent compacted soil. (see Fig. 3-c and Fig. 4).

(a) (b) (c)

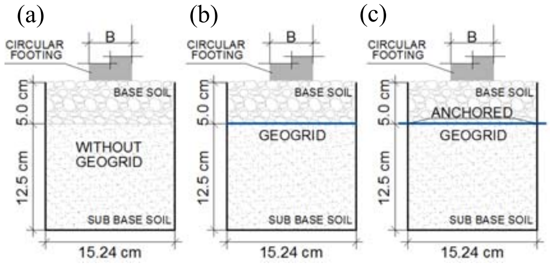

Fig.3 Scheme of the tests described in Table 2, (a) Specimen No. 1 without geogrid, (b) Specimens 2 (uniaxial) and 3 (biaxial) with a geogrid layer at sub base-base interface, (c) Specimens 4 (uniaxial) and 5 (biaxial), with a geogrid layer at sub base-base interface anchored in the edge of the mold

The rigid foundation was modeled by a circular footing made of steel with diameter B=50.8 mm and thickness greater than the diameter (t>B) enough to avoid deformation during testing. The load is applied through a press with a capacity of 50 KN. Load readings of every 0.2 mm foundation settlement up to a depth of 25 mm where the trial ends. The load was recorded by a load cell and the settlements of the foundation were read by a digital dial. Data were acquired using a DTF Datalogger where they are passed directly to the computer for processing.

Fig.4 Preparation of samples with a geogrid layer anchored to the edge of the mold

4. RESULTS AND DISCUSSION

4.1 Stress-settlement response

Stress-settlement curves were performed with the results of load tests. Fig. 5 presents stress-settlement curves for all specimens tested. The primary vertical axis shows the measured values of absolute settlement and the secondary vertical axis shows the values measured of relative settlement (s/B). Fig. 5 shows that by including a layer of geogrid between sub-base layer and base layer improvement occurs in the stress-strain behavior. The samples with biaxial geogrid (Specimens 3 and 5) showed better performance than the samples with uniaxial geogrid (Specimens 2 and 4). Also, the samples in which the geogrid was anchored to the mold (Specimens 4 and 5) performed better stress-settlement than the samples with geogrid unanchored to the mold (Specimens 2 and 3).

Fig. 6 shows the geogrid used in each specimen before and after applying loads to the sample. The uniaxial geogrid presented breaks in the transverse yarns, surrounding the area of influence of the foundation. In the longitudinal yarns not considerable damage was observed although noticeable tension force developed by the geogrid. The biaxial geogrid showed no significant damage to the yarns in any direction, though the wear caused by friction between the soil particles and the yarns of the geogrid is evident.

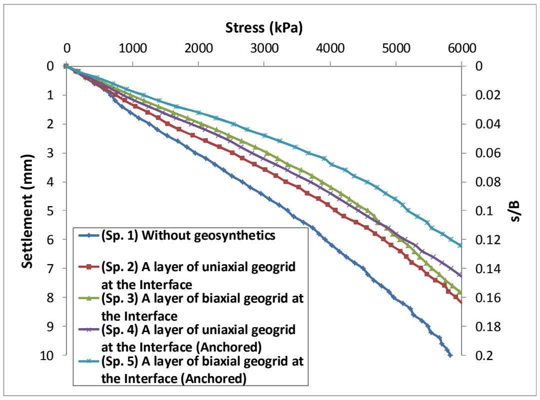

Fig.5 Stress vs. Settlement for the specimens tested

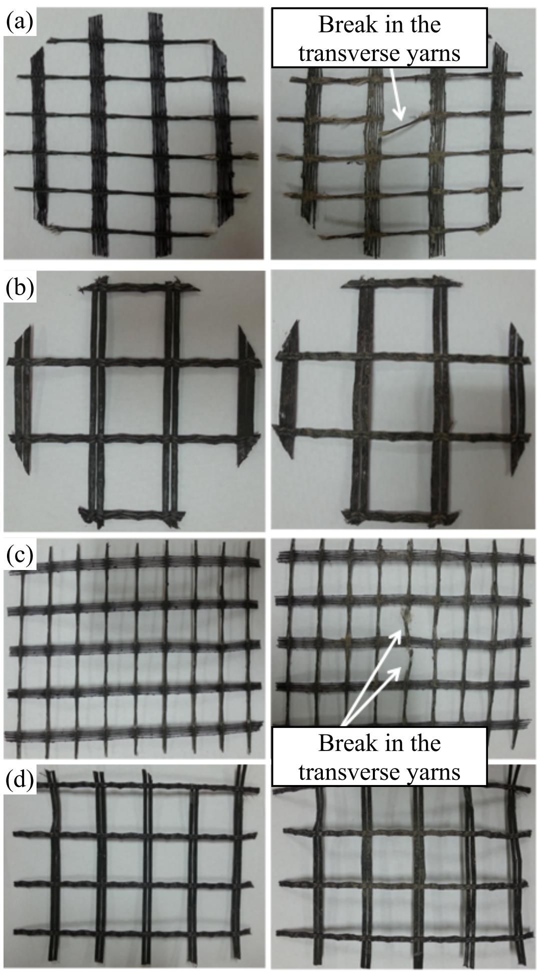

Fig.6 Geogrid before and after the test load, (a) Sp. 2 with a uniaxial geogrid layer at sub base-base interface, (b) Sp. 3 with a biaxial geogrid layer at sub base-base interface, (c) Sp. 4 with a uniaxial geogrid layer at sub base-base interface anchored in the edge of the mold, (d) Sp. 5 with a biaxial geogrid layer at sub base-base interface anchored in the edge of the mold

4.2 Bearing capacity behavior

In order to estimate the improvement of the soil produced by the inclusion of geogrids, the BCR (Bearing Capacity Ratio) is calculated for each of the samples tested. The BCR was defined in Adams and Collin [14] as the ratio of the bearing load capacity of reinforced soil and bearing load capacity of unreinforced soil. In this paper, the ratio is performed for vertical load between reinforced and unreinforced samples at the same settlement. This value is calculated for each value of measured load and is defined as:

$$BCR = \frac{q_{(R)}}{q_{(U)}} \qquad (1)$$

where $q_{(U)}$ and $q_{(R)}$ are bearing load capacity values for unreinforced and reinforced foundations, respectively, at the same settlement. Fig. 7 provides the BCRs versus the relation (s/B) for all specimens, where improvement occurred in the bearing load capacity when the geogrid is included in the soil is observed.

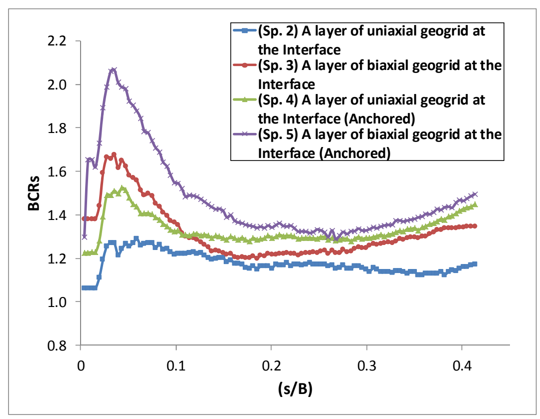

Fig.7 Variations of BCRs with (S/B)

Fig. 7 shows that the biaxial geogrid present a greater improvement in bearing load capacity than the uniaxial geogrid. Likewise, samples with the geogrid anchored in the edge of the mold showed higher values in the BCRs compared to samples with no anchored geogrid. These results have the same pattern as those reported by Useche Infante et al. [5] for samples of geogrid-reinforced sand where the anchoring effect produced increased in the bearing load capacity. A peak value can also be seen for BCRs when the ratio (s/B) is closer to 0.05, namely when settlement reaches foundation 2.5 mm, an asymptotic behavior occurs in the BCRs, which (s/B) >0.1.

4.3 Stress Ratio Index

This index was calculated to verify the improvement achieved in reinforced soil for settlements of 2.5 mm and 5.0 mm. Load values obtained for these settlements are compared to standard values of stress. The calculation is performed for all specimens tested as follows:

$$\mathrm{SR} = \frac{\boldsymbol{Stress\ (kPa)}}{\boldsymbol{Standard\ Stress\ (kPa)}} * 100 \qquad (2)$$

where standard stress corresponds to the values adopted in the CBR test for 2.5 mm and 5.0 mm of penetration. These standard stress are 1000 psi (6900 kPa) and 1500 psi (10300 kPa) respectively. Fig. 8 shows the results of SR obtained for the specimens tested. It can be seen that the inclusion of geogrid at the interface of sub-base soil and granular base increased soil resistance to 2.5 mm and 5.0 mm settlement of the foundation. The improvement was greater when the geogrid was anchored to the mold as seen in SR values reached by the specimens 4 and 5. The stress-strain behavior shown by the specimens with geogrid including at this level of settlements corresponds to some research which report increases in CBR value for samples of two soil layers with the inclusion of different types of geosynthetic [6]-[12].

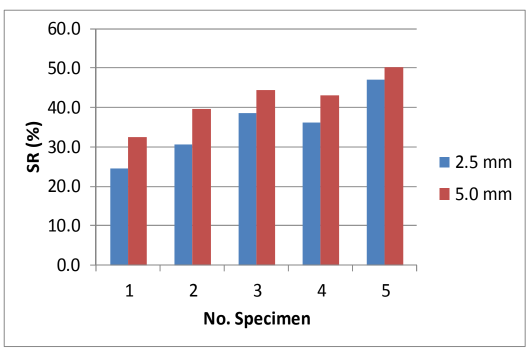

Fig.8 SR for the specimens tested

4.4 Settlement Reduction Factor

The settlement reduction factor (SRF) is defined by Abu-Farsakh et al. [13] as the ratio of the measured settlement on a foundation resting on reinforced soil and measured settlement on a foundation resting on the ground without reinforcement, for the same value of load applied. This factor is calculated as follows:

$$SRF = \frac{S_{(R)}}{S} \qquad (3)$$

where $S_{(R)}$ is the settlement measured in reinforced soil and S is the settlement measured in soil without reinforcement. The results of SRF for different loads applied in the tests are plotted in Fig. 9. It can be seen from these curves that the reduction in the settlement is greater for samples in which the geogrid is anchored to the test mold. Likewise, biaxial geogrid specimens showed greater reduction in the settlement compared to specimens with uniaxial geogrid included. This is consistent with results of other indices calculated so far in this paper.

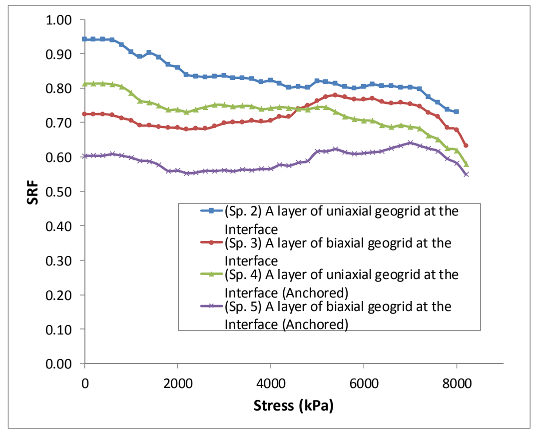

Fig.9 SRF versus applied footing pressure

4.5 Vertical Deformation

The values of vertical deformation on the geogrid layers were measured from the upper horizontal plane of each specimen as shown in Fig. 10. Vertical deformation measurements were taken every two centimeters along the axes shown at the end of load tests. The initial vertical distance measure from the same horizontal plane shown in Fig. 10 is subtracted from the final deformation measured the geogrid getting the relative vertical deformation in the geogrid. For tested samples the geogrid was placed at the interface of sub-base soil and base soil (see Fig. 3), so that the initial vertical distance for each specimen was 5 cm, corresponding to the thickness of the soil layer base.

In Fig. 11 vertical deformation values are presented for all samples. The vertical relative displacements in the geogrid layers along the x-axis for the different samples are shown in Fig. 11a. The curves show that the geogrid more deformed when it was anchored to the test mold. The type of geogrid showed no a significant effect on the vertical deformation, the curves for uniaxial and biaxial geogrid showed no significant difference. The values along the y-axis (Fig. 11b) showed similar results to the values along the x axis, curves similar to the two types of geogrid used and a substantial increase in the vertical deformation when the geogrid is anchored to the test mold. The samples that had greater vertical strain in the geogrid (Specimens 4 and 5) correspond to samples that showed greater improvement in bearing load capacity and greater reduction in the settlement of the foundation.

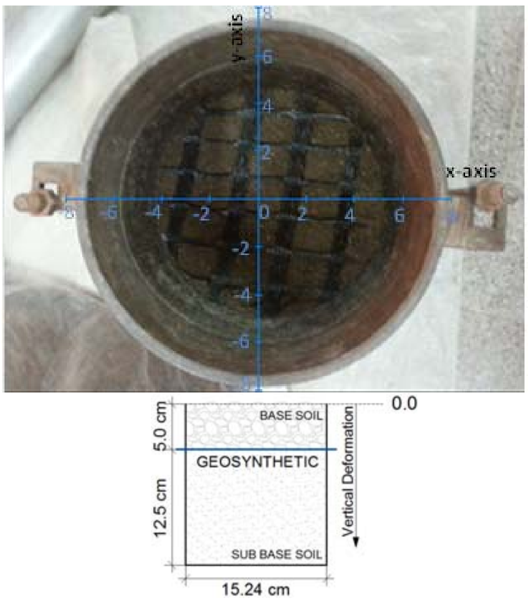

Fig.10 Axes (Unit: cm) used to measure the vertical displacements in the geogrid

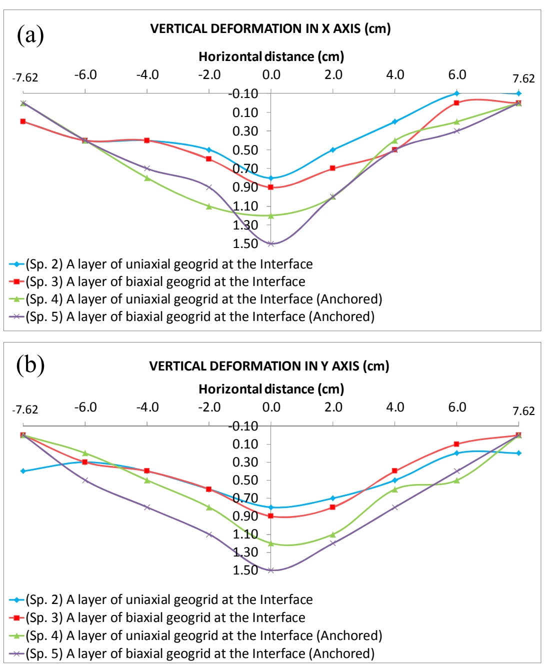

Fig.11 Vertical deformation for different samples tested, (a) In x axis, (b) In y axis

5. CONCLUSIONS

In this paper, the results of an experimental program conducted with the aim of establishing the improvement achieved in the bearing capacity and settlement of a circular foundation resting on geogrid reinforced soil is presented. Based on the results and discussions presented in the previous section, the following conclusions can be drawn:

The type of geogrid included in the ground has direct effect on the stress-strain behavior of soil, biaxial geogrid samples showed higher values of bearing load capacity than uniaxial geogrid samples. For specimens with geogrid anchored to the edge of the test mold, the BCR value increases from 1.6 with uniaxial geogrid to 2.1 with biaxial geogrid for maximum improvement, for specimens with geogrid unanchored to the test mold the BCR value increases from 1.3 with uniaxial geogrid to 1.6 with biaxial geogrid. The settlement in the foundation was lower in the biaxial geogrid samples. The test here shows that the settlement reduction factor was 0.6 and 0.7 on average for the samples with biaxial geogrid anchored and unanchored to the test mold respectively, while these values were 0.75 and 0.85 on average for the samples with uniaxial geogrid anchored and unanchored to the test mold.The layers of uniaxial geogrid showed breakage in the transverse yarns that do not provide to the ground reinforcing function. It remains to establish with future larger trials and tests of friction between soil and geogrid if rupture of these yarns has influence on the behavior of reinforced soil.

Specimens with the geogrid anchored to the test mold showed higher improvement in relation to the specimens with the geogrid unanchored to the test mold. When the layer of geogrid is pressed by the adjacent ground develops a greater tension force that occurs in the geogrid unanchored. Determine longitude of geogrid to which the soil adjacent exert adequate pressure on the geogrid to the tensile strength occurs is essential for the improvement occurred in the soil is optimal. The optimal length of the geogrid should be verified with larger trials.

In general, the use of geogrid between the sub-base layer and the base layer showed a significant improvement in the stress-strain behavior of foundation soil. BCRs values showed a peak for deformations close to 2.5 mm, after the curve tends to asymptotic values for major deformations, this may be caused by loss of friction between soil particles and the yarns of the geogrid. It will be necessary to conduct a study of the interaction between soil particles and the yarns of the geogrid with direct shear tests to establish the relationship between friction and increasing the bearing load capacity of reinforced soil.

The vertical deformation measurements in the geogrid were greater in the samples with the layer of geogrid anchored to test mold (between 0.15 and 0.6 cm on average), these correspond to the specimens that showed a greater increase in the bearing load capacity and decrease in the settlements of the foundation. This corresponds to that reported by Sharma et al. [21], who suggest that the tension force developed by the geosynthetic is directly related to the settlement occurred in the foundation, where if the settlement of the foundation is increased a greater tensile strength is developed in the geosynthetic, which translates into an improvement in the stress-strain behavior of reinforced soil.

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7. REFERENCES

[1] Adams CA, Apraku E, Opoku-Boahen R, “Effect of triaxial geogrid reinforcement on CBR strength of natural gravel soil for road pavements”, Journal of Civil Engineering Research, Vol. 5, No. 2, 2015, pp. 45–51.

[2] Duncan Williams E, Attoh Okine NO, “Efect of geogrid in granular base strength - an experimental investigation”, Construction and Building Materials, Vol. 22, 2008, pp. 2180-2184.

[3] Elvidge CB, Raymond GP, “Laboratory survivability of nonwoven geotextiles on open-graded crushed aggregate”, Geosynthetics International, Vol. 6, No. 2, 1999, pp. 93-117.

[4] Naeini SA, Mirzakhanlari N, “The effect of geotextile and grading on the bearing ratio of granular soils”, Electronic Journal of Geotechnical Engineering, Vol. 13, 2008, pp. 1-10.

[5] Useche Infante DJ, Aiassa Martinez G, Arrúa P, Eberhardt M, “Stress-Strain Behavior of Geosynthetic Reinforced Soil Using a Modified CBR Test”. Fifth International Conference on Geotechnique, Construction Materials and Environment, Osaka, Japan, Nov. 16-18, 2015.

[6] Bergado DT; Youwai S; Hai CN, Voottipruex P, “Interaction of nonwoven needle-punched geotextiles under axisymmetric loading conditions”, Geotextiles and Geomembranes, Vol. 19, No. 5, 2001, pp. 299-328.

[7] Chakravarthi VK, Jyotshna B, “Efficacy of overlying coarse aggregate and geosynthetic separator on CBR value for soft subgrade of varying plasticity - a lab study”. Int. J. of Research in Engineering and Technology, Vol. 2, No. 12, 2013, pp. 749–755.

[8] Chegenizadeh A, Nikraz H, “CBR test on fibre reinforced silty sand”, Int. J. of Structural and Civil Engineering, Vol. 1, No. 3, 2012, pp. 1–9.

[9] Elshakankery MH, Almetwally AA, Tawfik KA, “Experimental Study of Bearing Capacity for Egyptian Soils Reinforced by Geotextiles”, Journal of Applied Sciences Research, Vol. 9, No. 3, 2013, pp. 2378-2385.

[10] Nair AM, Latha GM, “Bearing resistance of reinforced soil–aggregate systems”, Ground Improvement, Vol. 164, No. GI2, 2011, pp. 83-95.

[11] Senthil Kumar P, Rajkumar R, “Effect of geotextile on CBR strength of unpaved road with soft subgrade”, Electronic Journal of Geotechnical Engineering, Vol. 17, 2012, 1355-1363.

[12] Yetimoglu T, Inanir M, Inanir OE, “A study on bearing capacity of randomly distributed fiber-reinforced sand fills overlying soft clay”, Geotextiles and Geomembranes, Vol. 23, 2005, pp. 174–183.

[13] Abu-Farsakh M, Chen Q, Sharma R, “An experimental evaluation of the behavior of footings on geosynthetic-reinforced sand”, Soils and Foundations, Vol. 53, No. 2, 2013, pp. 335–348.

[14] Adams TM, Collin JG, “Large model spread footing load tests on geosynthetic reinforced soil foundations”, J. of Geotechnical and Geoenvironmental Engineering, Vol. 123, No. 1, 1997, pp. 66–72.

[15] Dash SK, Rajagopal K, Krishnaswamy NR, “Behaviour of geocell-reinforced sand beds under strip loading”, Canadian Geotechnical Journal, Vol. 44, 2007, pp. 905–916.

[16] Demir A, Yildiz A, Laman M, Ornek M, “Experimental and numerical analyses of circular footing on geogrid-reinforced granular fill underlain by soft clay”, Acta Geotechnica, Vol. 9, 2014, pp. 711–723.

[17] Kumar, S.; Solanki, C.H. and Pandey, B.K. “Behaviour of prestressed geotextile-reinforced fine sand bed supporting an embedded square footing” Int. J. of GEOMATE. Vol. 8, No. 2, 2015, pp. 1257-1262.

[18] Bhandari A, Han J, Parsons RL, “Two-dimensional DEM analysis of behavior of geogrid-reinforced uniform granular bases under a vertical cyclic load”, Acta Geotechnica, Vol. 10, 2015, pp. 469–480.

[19] Latha GM, Somwanshi A, Reddy KH, "A multiple regression equation for prediction of bearing capacity of geosynthetic reinforced sand beds". Indian Geotechnical Journal, Vol. 43, No. 4, 2013, pp. 331-343.
[20] Michalowski RL, "Limit loads on reinforced foundation soils". J. of Geotechnical and Geoenvironmental Engineering, Vol. 130, No. 4, 2004, pp. 381-390.
[21] Sharma R, Chen Q, Abu-Farsakh M, Yoon S, "Analytical modeling of geogrid reinforced soil foundation", Geotextiles and Geomembranes, Vol. 27, 2009, pp. 63-72.
[22] Stahl M, Konietzky H, Kamp L, Jas H, "Discrete element simulation of geogrid-stabilised soil", Acta Geotechnica, Vol. 9, 2014, 1073–1084.
[23] Yang X, Han J, Leshchinsky D, Parsons RL, "A three-dimensional mechanistic-empirical model for geocell-reinforced unpaved roads", Acta Geotechnica, Vol. 8, 2013, pp.201–213.
[24] Zidan AF, "Numerical study of behavior of circular footing on geogrid-reinforced sand under static and dynamic loading", Geotechnical and Geological Engineering, 2012, Vol. 30, pp. 499–510.

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