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BEHAVIOR OF GEOGRID REINFORCED SAND UNDER VERTICAL LOAD

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ABSTRACT: In previous works several experimental investigations aimed at establishing the behavior of granular soils reinforced with geosynthetics have been conducted. It has been found that the capacity of the soil improves due to a tensile force given by the geosynthetic that thus provides a soil reinforcement function and therefore allows a better distribution of pressure in the soil. Many of these studies report the use of CBR tests to characterize the behavior of reinforced soil. The CBR test measures the vertical deformation with application of vertical loads, by which it is possible to characterize the stress-strain behavior of the material. In this paper, modified CBR tests are performed on samples of granular soils reinforced with geogrids in order to establish the behavior of reinforced soil at the load application surface from foundations; in this case the displacements are restricted in the cylinder edges of CBR test. The results are compared with those obtained by CBR testing performed without restricting displacements at the edges and without including any type of reinforcement, which were documented in previous work of the authors.

Keywords: Shallow Foundations, Geosynthetics, Reinforced Soil, CBR

1. INTRODUCTION

A considerable amount of literature has been published on improvements achieved by including geosynthetics in the soil mass with shallow foundations: [1]-[3]. These studies concluded that the soil resistance is increased when are included geosynthetics elements. Stress-strain behavior of geogrids reinforced soil, with use of the CBR test, has been studied in [4]. In research presented at [5], the authors conducted an investigation with a modified CBR device to characterize the behavior of soil-geotextile system and the mechanism of reinforced.

In this paper, an experimental study using the CBR test is performed to determine the stress-strain behavior of sand with the inclusion of geosynthetics. In particular the case is studied where the geosynthetic is anchored to the CBR mold, in order to reproduce the condition in which the geosynthetic is pressed by compacted ground and a tension force occurs when the geosynthetic deforms by the application of loads.

Subsequently, the results are compared with samples without anchoring of the geosynthetic to the mold. Therefore, it is possible to establish the improvement achieved in the soil mass by including geosynthetics anchored and unanchored to the mold. Some results for specimens without geosynthetic and geosynthetic layers not anchored to the mold were reported in [6], and are considered in this work to determine the effect of fixing the geosynthetic to the mold in the stress-strain behavior of a soil-geosynthetic system.

The CBR type tests are affected by the small scale of the samples, therefore, the results are not directly applicable to the conditions of shallow foundations in the field. The aim of this study is to determine the relative improvement in the soil strength produced by including a geosynthetic in the sample.

2. MATERIALS

2.1 Sand

In tests, natural sand of Córdoba Argentina is used. This soil is commonly utilized in shallow foundations of structures and embankments bases. The Granulometric distribution of the sand is presented in Fig. 1, the sand is classified by the USCS system as SW (Well graded sand) with uniformity coefficient Cu=8.9 and curvature coefficient Cc=1.7.

Table 1 Mechanical properties of geogrids [7].

Property	Unit	Value
Tensile strength (to def. 5%)	kN/m	35
Functional modulus (def. 5%)	kN/m	700
Strain to break	%	5
Tensile strength (to break)	kN/m	35
Tensile strength to yield for 120 years ≤ 30ºC	kN/m	23
Mesh opening	mmXmm	20X30

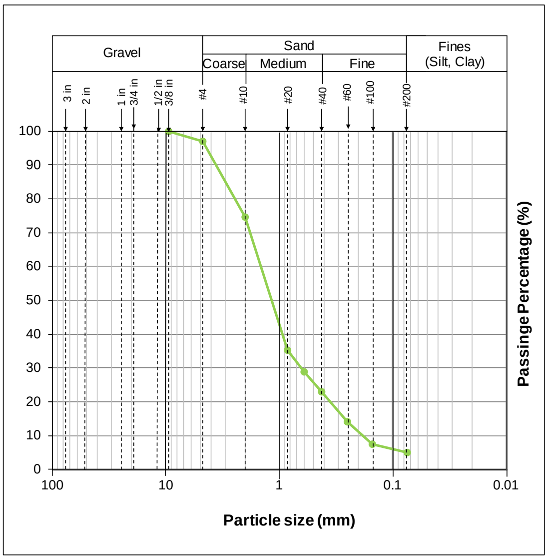

Fig. 1 Granulometric distribution of the sand.

2.2 Geosynthetic

In the soil mass uniaxial geogrids are used, commercialized by CORIPA S.A, a local company. Table 1 shows the physical and mechanical properties of the geogrid used. These geogrids are flexible mesh with shaped orthogonal grid made up of woven filaments of polyvinyl alcohol (PVA) covered with a polymeric coating, with high tensile strength, a high stiffness modulus and low susceptibility to yield.

3. LOAD TEST

A modified CBR type tests were conducted on compacted sand samples. The compacted specimens were reinforced and unreinforced by geosynthetic. Some samples were also prepared with geosynthetic anchored to the edge of the mold (Table 2).

The first 4 samples were prepared in the mold used to standard proctor compaction test, preparing samples with 152.4 mm of diameter and 110 mm of height (see [6]). The geogrid was cut into the circular bore size of the mold and introduced into the soil mass as the geometry shown in Figs. 2b, 2c and 2d. For specimens 5 and 6, two rings with 152.4 mm of diameter and 53 mm of height were used in order to press the geosynthetic and thus restrict movement of the geosynthetic on the edge of the mold; for a geosynthetic layer halfway the sample, the height of the specimen after compaction was 106 mm (see Fig. 2e) and for the sample with a geosynthetic layer on the upper third part the height of the specimen after compaction was 82 mm (see Fig. 2f).

Samples for the laboratory test were compacted according to ASTM D 698 (Method C). Compaction of the material was using a 5.5 lb hammer (2.5 kg) with different layers according to the sample volume or the purpose of conserving constant compaction energy as can be seen in Table 2. Load readings of every 0.2 mm piston settlement up to a depth of 20 mm were taken. This was followed by readings every 1 mm until completing a depth of 25 mm, where the trial ends. The piston used to transfer the load to the soil mass had a diameter of 50.8 mm. The dry density of samples γ_d were 19 kN/m^3 with a variation of $\pm$ 1.0 kN/m^3 while the moisture content was 4% with a variation of $\pm$ 1%. A surcharge of 4.5 kg was applied to the samples.

Table 2 Tests conducted.

No. Specimen	Description of the test	Compaction of the sample
1	Without geosynthetics	Three layers, 55 blows each
2	A geosynthetic layer on the upper third part of the sample	Three layers, 55 blows each
3	A geosynthetic layer halfway the sample	Three layers, 55 blows each
4	Two layers of geosynthetics on the upper third part of the sample	Three layers, 55 blows each
5	A geosynthetic layer halfway the sample anchored in the edge of the mold	Two layers 83 blows each
6	A geosynthetic layer on the upper third part of the sample anchored in the edge of the mold	Three layers, 42 blows each

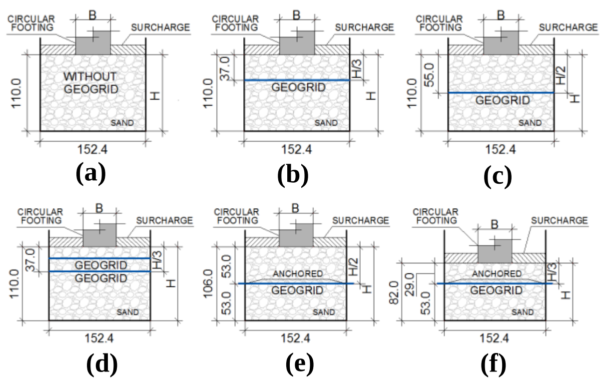

Fig. 2 Scheme of the tests (Dimensions in mm), (a) Specimen No. 1, (b) Specimen No. 2, (c) Specimen No. 3, (d) Specimen No. 4, (e) Specimen No. 5, (f) Specimen No. 6.

4. EXPERIMENT RESULTS

Stress vs. Settlement graphics are performed for each specimen by obtaining values shown in Fig. 3. In these curves different behaviors for small and large deformations were observed. Growth in the slope of the curve is presented from 2.5 mm settlement typical behavior of sands in CBR type tests. From Fig. 4 to Fig. 7 stress-strain behavior for small, medium and high deformations is shown. Subsequently, vertical displacements produced in the geosynthetic for each of the reinforced soil specimens are presented.

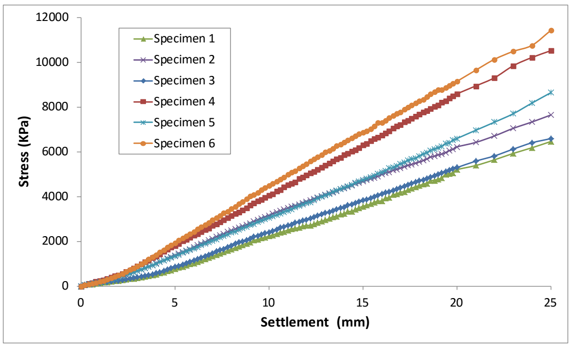

Fig. 3 Stress vs. Settlement for the specimens tested.

The values obtained for deformations below 1 mm are shown in Fig. 4. There can be seen some erratic data and in some specimens improvement is achieved. It is also shown no significant improvement for specimen 3 corresponding to the geosynthetic layer halfway. In Fig. 5, deformation behavior between 1 mm and 5 mm is presented. The data trend is shown and the improvement is seen with the inclusion of geosynthetics, except when a layer of geosynthetic is used halfway the sample (Specimen No. 3). However, when the geosynthetic was anchored to the mold (Specimen 5), an evident increase was presented in soil strength. From 2.5 mm settlement an accelerated growth curve is shown, marking stiffening.

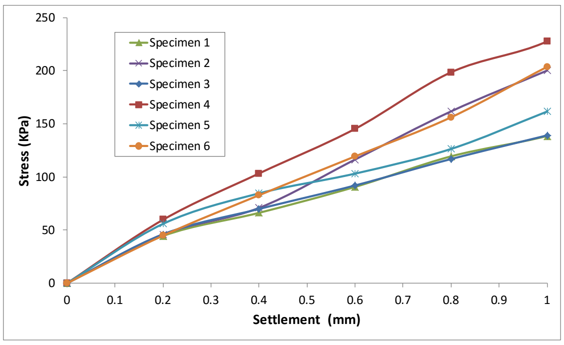

Fig. 4 Stress vs. Settlement for the specimens tested to lower strains than 1 mm.

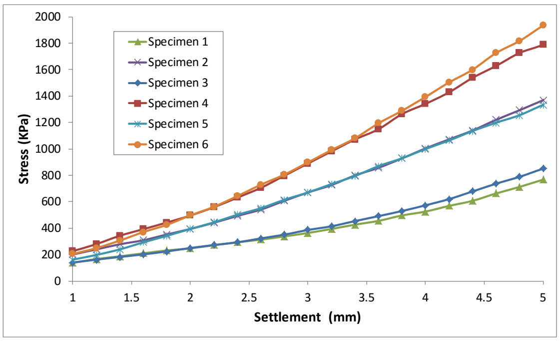

Fig. 5 Stress vs. Settlement for the specimens tested to strains between 1 and 5 mm.

In Fig. 6, the curves for deformation between 5 mm and 15 mm can be seen, the growth shown from 2.5 mm settlement remains. A small improvement is shown for specimen 3 (geosynthetic used halfway the sample unanchored to the mold), which had shown no increase with small deformations. Fig. 7 shows the results for high strains, namely strains from 15 mm to 25 mm; in this case the linear trend of the data is maintained. The best results were obtained for the sample with a geosynthetic layer on the upper third part of the sample anchored in the edge of the test mold (Specimen 6), for deformations between 5 and 25 mm.

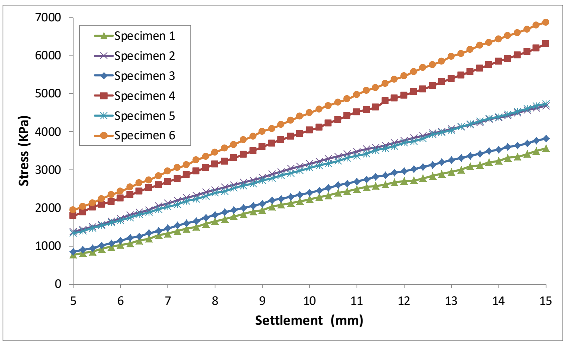

Fig. 6 Stress vs. Settlement for the specimens tested to strains between 5 and 15 mm.

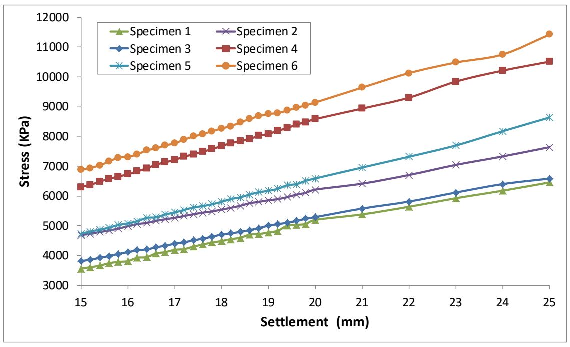

Fig. 7 Stress vs. Settlement for the specimens tested to strains between 15 and 25 mm.

Furthermore, vertical relative deformations in the geosynthetic were measured. These measurements were made from the upper horizontal plane of the specimen, every 2 cm from the central axis considering the directions shown in Fig 8. Before measuring, the soil above the layer of geosynthetic in the specimen was removed. Vertical profiles were performed along the coordinate axes for each layer of geosynthetic, obtaining the resulting deformation in the geogrid at the end of the test. The results of these measurements show some small initial deformations caused by soil compaction, these are located at different points of geogrid and are most evident in the samples in which the geosynthetic is not anchored to the mold. The vertical profiles for the different layers of geosynthetic according to the different geometric configurations (see Fig. 2 and Table 2) can be seen in Fig. 9 and Fig. 10.

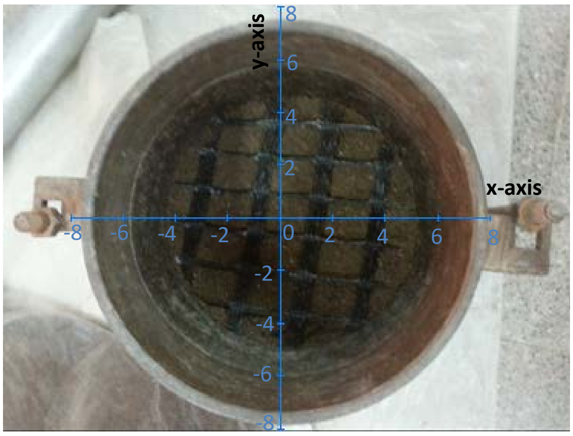

Fig. 8 Axes (Unit: cm) used to measure the vertical displacements in the geosynthetic.

The vertical displacements along the x-axis for the specimens with geosynthetics can be seen in Fig. 9 and the displacements along the y-axis are shown in Fig. 10. In these curves, greater deformation can be observed in specimen 6, in which the displacements of geosynthetic are restricted in the edges, where the geogrid layer presses the mold. The top layer of the specimen 4 (where two layers of geosynthetic are used in the upper third part of the sample) also shows greater deformations than 1.5 cm, proving that a tensile force occurs in the geosynthetic that results in an improvement in soil behavior.

It is to be noted that the vertical deformation measurements in the geogrid were greater in the samples with the layer of geogrid anchored to test mold (Specimens 5 and 6), these correspond to the specimens that showed a greater increase in the soil strength. The maximum vertical deformation in the geosynthetic was measured around the center axis and the value was 1.5cm approximately.

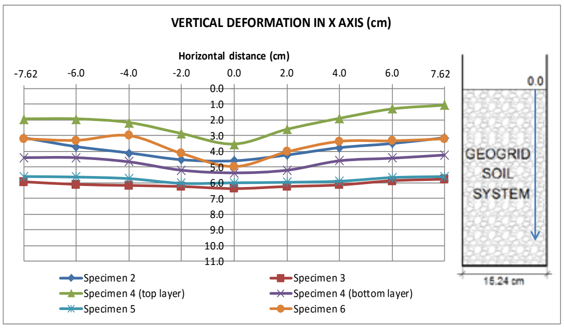

Fig. 9 Geosynthetic vertical displacement (x-axis).

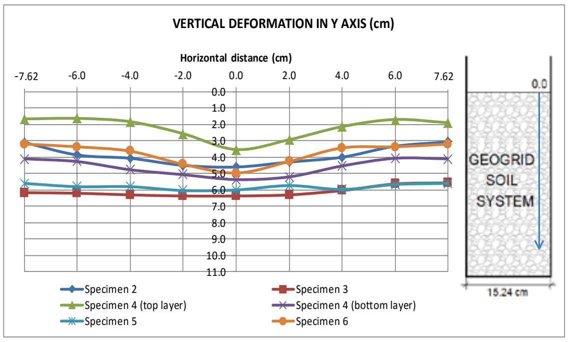

Fig. 10 Geosynthetic vertical displacement (y-axis).

5. ANALYSES AND DISCUSSION

In order to estimate the improvement of the soil produced by the inclusion of geogrids, a modified BCR (Bearing Capacity Ratio), the SRF (Settlement Reduction Factor) as well as the index SR (Stress Ratio) are calculated for each of the samples tested.

5.1 BCR (modified Bearing Capacity Ratio)

With the results of the experiment the BCR (modified Bearing Capacity Ratio) was calculated and the data obtained from the samples anchored and unanchored to the mold were compared. As can be seen when the geosynthetic is pressed by the mold, a tension force occurs in the geosynthetic achieving a much greater improvement in the soil. The BCR was defined in [8] as the ratio of the ultimate bearing capacity of reinforced soil and ultimate bearing capacity of unreinforced soil. In the present study, the ratio is performed for vertical load between reinforced and unreinforced samples at the same settlement. So, we defined it as modified BCR as follows:

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

where $q_{(R)}$ and $q_{(U)}$ are the values of the applied load during the test for reinforced and unreinforced soil respectively for the same settlement value.

The modified BCR is plotted against the ratio of settlement (s) and the width of the foundation (B) for the purpose determining the improvement in soil produced for different values of (s/B).

Fig. 11 provides the BCR versus the relation (s/B) for specimens 2 and 6 with a geosynthetic layer included in the upper third part of the sample unanchored (2) and anchored (6) to the mold (see Table 2). Evidently, a further increase in the BCR occurs when the geosynthetic is pressed by the mold (Specimen 6). A peak value can also be seen for BCR when the ratio (s/B) is closer to 0.08, namely when Settlement reaches piston 4 mm. The BCR peak grows from 1.9 (Specimen 2) to 2.7 (Specimen 6) to anchor the geosynthetic layer of the test mold.

The results, for the specimens with a geosynthetic layer halfway the sample, are presented in Fig. 12. In this case can be seen that when the geogrid is included in the soil without being anchored to the mold edges, no significant increase occurs in the BCR, however when the geosynthetic is anchored to the mold, this value increases reaching a maximum value when the ratio (s/B) is near to 0.08 as occurs in the samples with a geosynthetic layer in the upper third part. The maximum BCR was 1.9 for the specimen 5 while this value was 1.1 for the specimen 3.

Fig. 13 shows the curve for specimen 4 in which two layers of geosynthetic in the upper third part of the sample are included without any anchor. It shows similar behavior to the other specimens tested with a peak in the value of the BCR when the value of the ratio (s/B) is close to 0.08. The sample in which a larger value of BCR is reached corresponds to specimen 6, with a geosynthetic layer on the upper third part of the sample anchored to the mold (see Fig. 2 and Fig. 11). The BCR peak was 2.6 for two layers of geosynthetics.

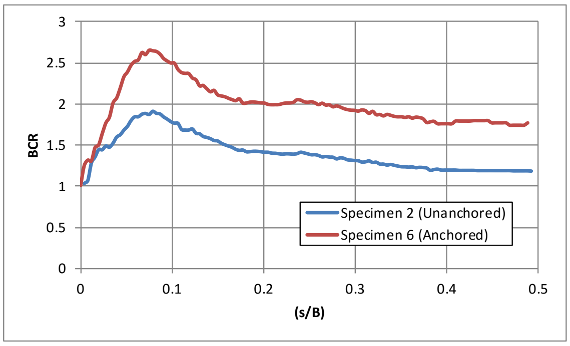

Fig. 11 BCR vs. (s/B) for a geosynthetic layer included in the upper third part of the sample; with geogrid unanchored (Specimen 2) and with geogrid anchored (Specimen 6).

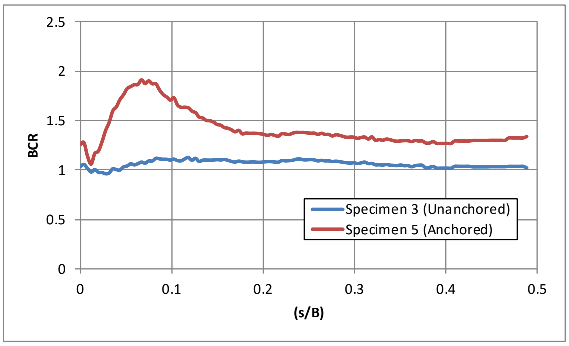

Fig. 12 BCR vs. (s/B) for samples with a layer of geosynthetic in halfway; with geogrid unanchored (Specimen 3) and with geogrid anchored (Specimen 5).

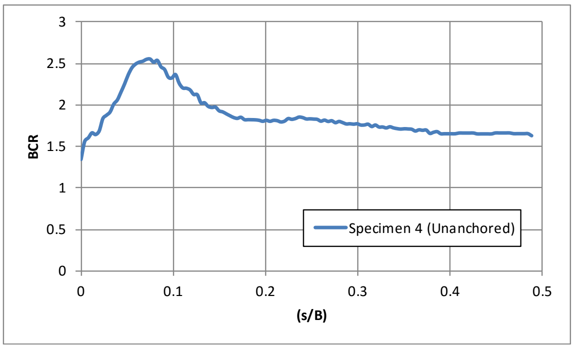

Fig. 13 BCR vs. (s/B) for the specimen 4, with two layers of geosynthetic in the upper third part of the sample unanchored to the mold.

5.2 SRF (Settlement Reduction Factor)

The settlement reduction factor (SRF) is defined by Abu-Farsakh et al. [9] 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:

$$SRF = \frac{S_{(R)}}{S} \qquad (2)$$

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. 14. It can be seen from these curves that the reduction in the settlement is greater for sample with a geosynthetic layer on the upper third part of the sample anchored in the edge of the mold; the settlement was reduced 0.45 times on average for specimen 6. The least reduction in the settlement was for specimen 3, where the settlement was reduced 0.08 times on average.

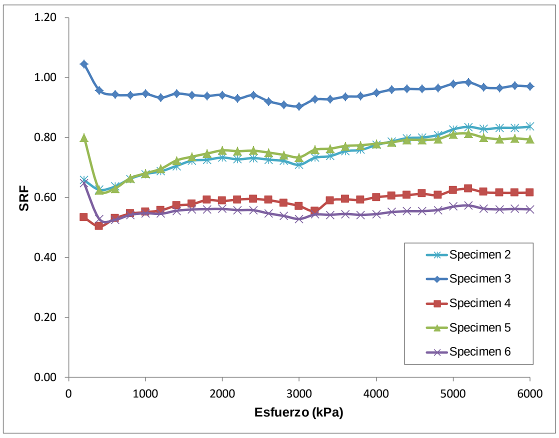

Fig.14 SRF versus applied footing pressure

5.3 Index calculation SR (Stress Ratio)

The SR (Stress Ratio) index relates the stress values obtained in load tests with standard values to the same deformation. It was calculated for each specimen as follows:

$$SR = \frac{\text{Stress}}{\text{Standard Stress(kPa)}} * 100 \qquad (3)$$

This index is calculated for stress values corresponding to 2.5 mm and 5.0 mm of settlement obtained from stress-settlement curves, which are divided between CBR test standard stress of 1000 Psi (6900 kPa) and 1500 psi (10300 kPa) respectively. In other words, with this analysis small deformations are measured.

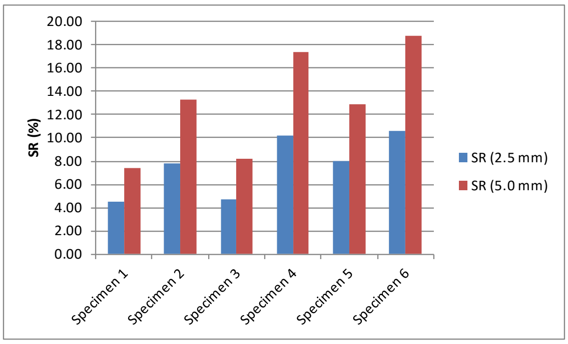

Fig. 15 SR for the specimens tested.

In Fig. 15, SR results are shown for each of the samples tested. It can be seen that no appreciable increase occurs in the SR rate for specimen 3. This means that including a geogrid layer halfway the sample produced no improvement in the soil, although when the geogrid layer is pressed by the mold (the displacements are restricted in the edge of the mold) a considerable increase occurs in the SR. This value grew from 4.7% for specimen 3 to 8.0% for the specimen 5 (for deformations of 2.5 mm) and the SR grew from 8.2% for specimen 3 to 12.9% for the specimen 5(for deformations of 5.0 mm). The results for the other samples show a significant increase in the SR using geogrid, especially when they are anchored to the edge of the mold. These results are similar to those achieved calculating the modified BCR.

6. CONCLUSIONS

In this paper, modified CBR test was performed on compacted sand samples in order to determine the effect of the geosynthetic inclusion on the behavior of soil-geosynthetic systems. From the experimental results, the following can be concluded:

For settlements, s/B, around 8%, results show a significant increase when geosynthetics are included in the soil mass. The calculated values of modified BCR show that for deformations near to 4 mm a peak value occurs in the BCR, which results in an appreciable improvement in soil behavior.

The calculated values of SRF show that including geosynthetics in the soil, foundation settlements are reduced significantly. On the other hand, the values of SR (Stress Ratio) show a significant increase particularly when the geosynthetic is anchored to the mold, the SR maximum in all trials was 10.6% and 18.8% for 2.5 mm and 5.0 mm of deformation respectively, for specimen 6. Improvement factors calculated in this paper show that the increase in soil strength is influenced by the number of geosynthetic layers and the distance between the base of the foundation and the first layer of reinforcement.

The improvement obtained when the geosynthetic layer is boundary anchored by the mold, is better than when it is left unanchored. The tension force developed by the geogrid when it is anchored to the mold can clearly be seen, therefore it is important to establish a sufficient anchorage length in geosynthetic, enough to ensure that this force occurs. In the present tests, a size of geogrid three times the width of the foundation (3B) was used.

For large settlements (s/B > 10%), the results showed that although the improvement that occurs is below the peak, an asymptotic behavior occurs in the BCR, which is >1 (see Figs. 11, 12 and 13). The behavior of modified BCR vs. s/B presents a curve with two differentiated zones denominated as pre-peak and post-peak. It is estimated that this can be provisionally explained as follows: (1) First, the development of tension in the geosynthetic, and friction interaction sand-geogrid, during the first settlements produces an increased in modified BCR reaching a maximum at optimum combination between compacted soil and geosynthetic effect, (2) then the curve drops to stabilize at a given value of BCR, higher than one (asymptote) where, possibly, have been reaching a residual friction interaction sand-geogrid. However, it will be necessary to increase the experimental study and numerical analysis of the behavior, in order to confirm this explanation. For this, direct shear tests are planning, where sand-geogrid interaction can be studied.

In addition, larger scale tests are planned in order to validate the present results and establish the optimum value of the anchorage length as well as the overlapping layers.

Furthermore, other variables such as soil moisture, shape and size of the foundation should be considered. Also experiments with biaxial geogrids should be considered, as well as different forms of geometric configuration of the soil-geosynthetic system.

7. ACKNOWLEDGEMENTS

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