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Evaluation of Unconfined Compressive Strength of Clayey Soils Typical of the City of Curvelo-MG-Brazil Reinforced with Geogrids and Woven Geotextiles

Juliana REINERT[a,1], Raimundo da Costa LIMA JUNIOR[a],
Tulio Cesar Floripes GONÇALVES[a] and Camilla Cristina Cunha MENEZES[a]
[a] *Civil and Environmental Engineering Department, Federal Center of Technological Education of Minas Gerais (CEFET-MG), Brazil*

Abstract. The main purpose of reinforcement in a soil mass is to limit the development of tensile forces in the soil and geosynthetics are one of the newest materials used for this purpose. It's recommended to use non-cohesive soils in embankments reinforced with geosynthetics, but in the region of Curvelo-MG-Brazil these soils are not easily available at the site construction. This study has as main objective to evaluate the variation of the unconfined compressive strength of a clayey soil typical of the city of Curvelo-MG-Brazil reinforced with geogrids and woven geotextiles. Soil characterization tests and standard Proctor compaction test were performed in soil samples, and uniaxial compression tests were performed on samples of soil without geosynthetics and soil with geogrids and soil with woven geotextile. From the results of the characterization tests it was noticed that the studied soil is a red sandy clay with open graduation and high plasticity, compatible with the type of soil found in the region. The unconfined compressive strength obtained in the uniaxial compression tests were 345.86 kPa for the soil without geosynthetics, 366.47 kPa for the soil with geogrid and 348.87 kPa for the soil with woven geotextile. The coefficient of variation was small in all of them, being the biggest one 7.43. It's important to notice that the samples without geosynthetics and with geogrids had their failure with axial deformations of 3.43% and 4.91%, respectively. However, the unconfined compressive strength of the soil with woven geotextile was obtained with 15% of axial deformation, as it's the test stop criteria. As the results show, the use of geosynthetic reinforcement in clayey soils has a small increase in the unconfined compressive strength. It's recommended to continue this study with bigger samples and with shear strength tests.

Keywords. Geosynthetics, soil reinforcement, unconfined compressive strength.

1. Introduction

Embankments designs are very dependent of the soil deformation and resistance. Some soils don't have the minimum properties required and need reinforcement. One type of

[1] Juliana Reinert, Corresponding author, Department of Civil and Environmental Engineering, CEFET-MG, R. Raymundo Mattoso, 900, Curvelo-MG, Brazil; E-mail: jureinert@cefetmg.br.

material that have been used successfully in civil engineering designs with this purpose are the geosynthetics, mainly because of their versatility and low cost.

Geosynthetics are synthetic polymeric materials that can have unidimensional, bidimensional or tridimensional structures and are used in contact with soil or in composite materials. They absorb and redistribute the forces in the soil, limiting the lateral deformations of reinforced structures and increasing the shear resistance [1].

To analyze the influence of geosynthetics in soil reinforcement, varied laboratory tests can be done. One of them is the unconfined compressive strength, that considers the geosynthetic interaction with the adjacent soil [2].

The mechanical behavior improvement caused by the reinforcement inclusion is only real when the resistance of the reinforcement material is mobilized. This occurs when the soil and the reinforcement material are exposed to relative deformations, causing friction between the two materials and mobilizing the tensile resistance of the reinforcement [3]. Based on this assumption, the idea of this research was to simulate a compacted embankment reinforced with geosynthetics in the laboratory.

In this study, the following laboratory test were done: characterization of the soil, Proctor compaction with standard energy and unconfined compressive strength in samples of natural soil, soil with geogrids and soil with woven geotextiles.

It was proved that the use of geosynthetics increase the shear resistance and decreases the soil deformation, showing that in cohesive soils these properties can still be changed, even in small scale.

2. Materials

Two different type of geosynthetics were used in this research, both manufactured by Huesker Ltd, and one clayey soil typically found in Curvelo/MG-Brazil region.

One of the geosynthethics used was a geogrid Basetrac® Grid, biaxial and flexible, manufactured with polypropylene filaments with high robustness and high tensile strength in conjunction with low strain. This geogrid has nominal mesh size of 25 mm; nominal tensile strength of 30 kN/m and strain at nominal tensile strength equal to 10%.

The other one was a woven geotextile Basetrac® Woven, biaxial, manufactured with polypropylene filaments with increased bearing capacity in all soil conditions and possible use in large panels. This geotextile has nominal tensile strength of 50 kN/m and strain at nominal tensile strength of 15%.

The city of Curvelo/MG-Brazil is in a predominantly geological area of silty-clayey sediments. This soil with high concentration of clay of silty is derived from the original rocks formation that can still be found in the region. The soil used in this research was collected at the Federal Center of Technological Education of Minas Gerais (CEFET-MG) – Unit Curvelo, one meter below the surface.

3. Method

Laboratory tests were done to characterize the soil. Proctor compaction with standard energy and unconfined compressive strength tests were used to analyze the mechanical properties of the natural soil and the reinforcement. All tests were done following the Brazilian Association of Technical Standards (ABNT).

3.1. Soil Characterization Tests

Using the results of the characterization tests is possible to find the parameters that identify the type of soil being used and its behavior.

In this research, the tests performed were: water content (natural and airdry), particle size distribution, dry density, Atterberg limits (plastic and liquid limits).

3.2. Proctor Compaction Test

The compaction test is used to define the relationship between the water content and the dry density of compacted soils.

It was used the dynamic compaction, with standard Proctor energy. The test was conducted without reuse of the material, with soil airdried and a cylinder with volume of 1000 cm^3.

3.3. Unconfined Compressive Strength Test

To analyze the variation of the shear resistance of the reinforced soils, the unconfined compressive strength test was used. The equipment used for this test was the universal testing machine EMIC – Model 23-300.

According to the Brazilian Standard (NBR 12770), the result of this test is a strength vs strain graph that should be obtained with 10 to 15 readings. Because of the machine used, the data acquisition was done every tenth of second, giving ore detailed graphs.

The results were analyzed statistically, using mean, standard deviation and variation coefficient. It was used eight specimens for each type of test (natural compacted soil, natural compacted soil with geogrid and natural compacted soil with woven geotextile), all of them compacted in the optimum water content, with maximum variation of 3%.

3.4. Specimens Preparation

The specimens used in the unconfined compressive strength test were molded using the small proctor compaction cylinder (diameter of 10 cm, height of 12.75 cm and volume of 1000 cm^3).

In the first mold, when extracting the specimens from the cylinder, part of the soil got stuck in the cylinder's walls, creating small cracks in the specimen. To avoid these, before proceeding with the filling, it was applied a release oil inside the cylinder with the purpose of making the extraction of the specimen easier. The oil is a water-repellent, so it didn't alter the water content of the soil.

The compaction was performed in three layers, with 26 rammer blows in each layer, according to the Brazilian Standard (NBR 7182). The excess of material was carefully trimmed with a straightedge tool so the compacted soil is flush with the top of the mold. Right after the extraction of the specimen using a sample ejector, the specimens were covered with plastic bags to avoid losing water content.

The specimens with the geosynthetics were compacted in the same way as the ones only with soil, but circles of geosynthetics were included between each layer.

The use of woven geotextile with the same diameter as the cylinder caused segmentation of the layers in the first attempts. As a result, to avoid this segmentation of the specimen, the sample of woven geotextile used between the layers had diameter of 9 cm instead of 10 cm.

The geogrids samples were cut with 10 cm diameter, since their interaction with the soil is higher than the woven geotextile and the specimens didn't show any signs of segmentation and/or cracks.

4. Results and Discussions

4.1. Soil Characterization

The soil used in this research is a red sandy-clay. It is a gap-graded soil, which means it has one particle size missing. In general, gap-graded soils present low compressive strength after compaction, because their poor grading does not allow the empty voids left by the bigger particles be filled by the smaller ones.

Table 1 presents the summary of the laboratory characterizations tests' results.

Table 1. Summary of results – Soil Characterization.

Characteristics	Results
Natural water content	26.7%
Hygroscopic water content	9.6%
Dry density	2.997 g/cm^3
Liquid limit	56%
Plastic limit	44%
Plasticity Index	12%
Gravel (>2,00 mm)	0,89%
Sand (0,06 - 2,00 mm)	33,88%
Silt (0,002 - 0,06 mm)	8,50%
Clay (<0,002 mm)	56,74%

According to Casagrande plasticity chart, this soil is classified as a MH (high-plasticity silt). This chart refers to the expected behavior of the soil – in this case it reflects the impact of the sand in the soil, but the high-plasticity still commands its deformation.

It is possible to notice that the tested soil presented, in all tests, results that are compatible to clayey soils.

4.2. Compaction Test

Using the proctor compaction curve for the soil, it was obtained an optimum water content of 30.7% and a maximum dry density of 1.4 g/cm^3. Tropical clayey soils generally have high optimum water contents, around 30%, and low dry density, varying from 1.4-1.5 g/cm^3 [4]. Therefore, the results obtained are according to the expected.

4.3. Unconfined Compressive Strength

4.3.1. Natural Compacted Soil

The unconfined compressive strength obtained for the natural compacted soils was 346 kPa with strain of 4.46% and shear resistance of 173 kPa. The specimens tested presented uniform water content, void ratio near to 1.15 and degree of saturation equals to 83%. Figure 1 shows the strength vs strain curve for the tests without geosynthetics.

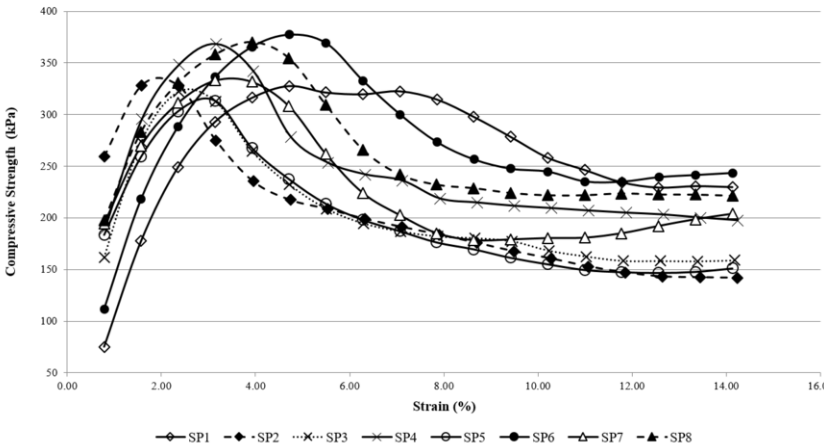

Figure 1. Strength vs Strain curve for the natural compacted soil.

4.3.2. Soil Reinforced with Geogrid

The strength vs strain curve for the tests with geogrids, as shown in Figure 2, presented similar behavior and the rupture of the specimens occurred between 345 and 400 kPa.

The mean of the unconfined compressive strength was 367 kPa, the mean strain was 4.91% and the mean shear resistance was 183 kPa. The same way as happened in the natural compacted soil, the water content was uniform among the specimens, the void ratio was 1.15 and the degree of saturation was around 80%.

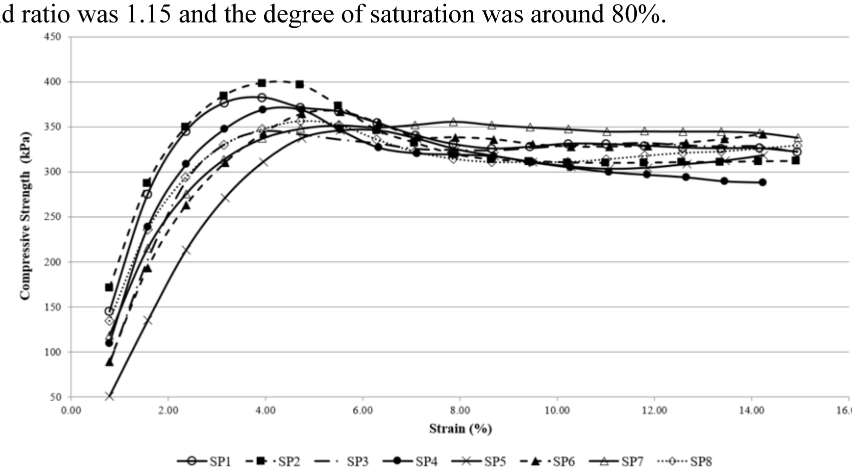

Figure 2. Strength vs Strain curve for the soil reinforced with geogrid.

Comparing the results obtained without any reinforcement, it is possible to see an increase of the compressive strength and an increase of the strain at the maximum strength.

4.3.3. Soil Reinforced with Woven Geotextile

When reinforced with woven geotextiles, the specimens had a mean compressive strength of 349 kPa and mean shear resistance of 175 kPa. The results of the void ratio and degree of saturation followed the same tendency of the above presented.

The strength vs strain curve, as shown in Figure 3, did not present a peak and the test was stopped when the strain got to 15%, as the standard recommends. Because of the excessive deformation, the specimens had big damages in their lateral walls.

Comparing the results of the natural compacted soil, it can be noticed that there is a small increase of the compressive strength, mainly when compared with the results of the soil reinforced with geogrids. As expected, the strain at the maximum strength also increased.

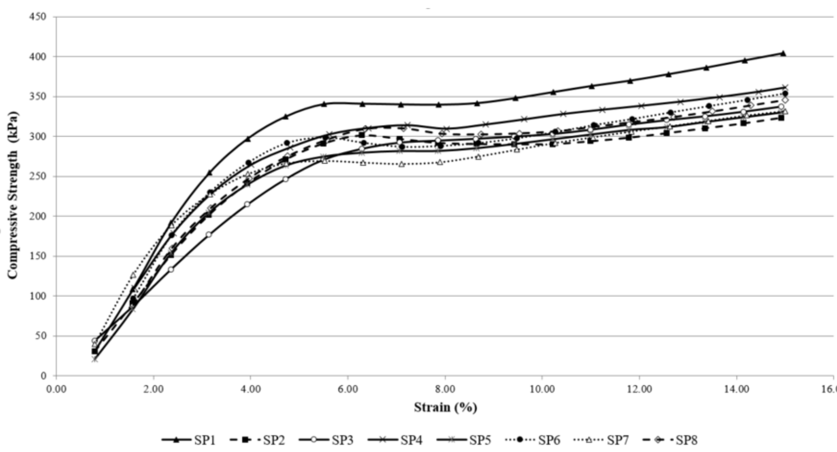

Figure 3. Strength vs Strain curve for the soil reinforced with woven geotextile.

Table 2 and Figure 4 stablish a comparation among the means of the unconfined compressive strength and strain at the maximum strength for the three tests done (natural compacted soil, soil reinforced with geogrid and soil reinforced with woven geotextile). Besides that, table 2 also presents the standard deviation and coefficient of variation (COV) obtained in each test.

Table 2. Summary of results – unconfined compressive strength tests.

Results		Natural Soil	Geogrid	Geotextile
Strength (kPa)	Average	345,86	366,47	348,87
	Std Deviation	23,24	18,58	25,93
	COV	6,72	5,07	7,43
Strain (%)	Average	3,46	4,91	15,00
	Std Deviation	1,04	0,94	0,01
	COV	30,13	19,17	0,05

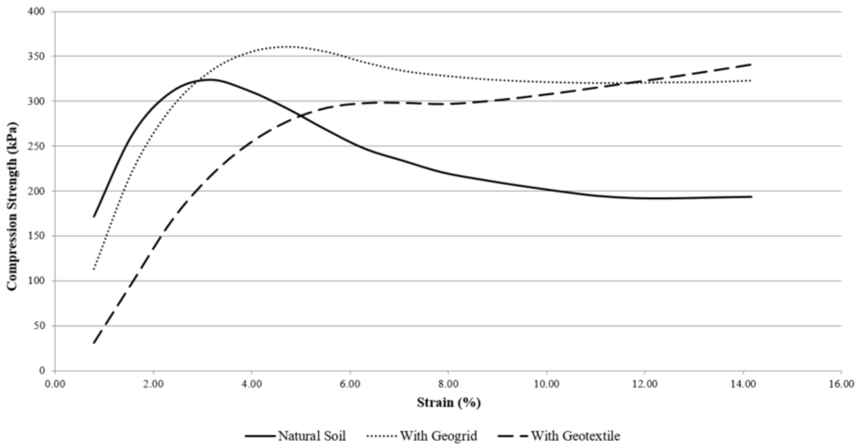

Figure 4. Strength vs Strain – comparative curve.

The statistical analysis of the results was based mainly on the coefficient of variation, that relate the standard deviation with the average value. In all of the performed tests the coefficient of variation was relatively low when compared to the natural variability of the soil [5].

A soil collapses when, in one defined plan, the active shear stress is bigger than the mobilized shear resistance. When the soil is reinforced, there is an increase in the shear resistance. This increment can be understood as an apparent cohesion assigned to the set soil-reinforcement and the effect of the inclusion of reinforcement in the soil can be considered similar to an increase in the confining stress [6].

The unconfined compressive strength test applies an axial load in the specimen. This load mobilizes the shear resistance in the soil-geosynthetic interface and, as consequence, mobilizes the tensile strength in the geosynthetic [2].

In this research, it was noticed that the tensile strength of the geosynthetic was mobilized even without the confining of the specimen, increasing the compressive strength of the natural soil.

Soil mechanics critical conditions can be divided in two main groups: stability and elasticity. Stability problems analyze the equilibrium condition of an ideal soil immediately before its collapse by plastic flow, while elasticity problems treat the deformations caused by soil weight or external forces, e.g. building weight [4].

In geotechnical engineering, strength and strain of soils must always be considered. As an example, when an embankment is being designed sometimes the soil has the required strength but it collapses with a very low deformation. In this case, the insertion of reinforcement elements, like geosynthetics, increases the embankment capacity of tolerate deformations, avoiding the collapse. It is important to notice that the deformation in soils is usually bigger than in structural materials and, if excessive, can take the construction to a collapse.

In this research it was verified that the insertion of geosynthetics in the soil as a reinforcement material allowed the soil to deform more before the collapse. In other words, while the natural compacted soil is going to collapse with a small deformation, the reinforced soil only will collapse with bigger deformations. This is important in engineering because it enables more flexible and deformable structures.

5. Conclusion

Knowing the correct properties and characteristics of a soil is extremely important in any engineering design, because the stability of the structure will totally depend on its soil's behavior. This study includes characterization tests, proctor compaction tests and unconfined compressive strength test in soil samples from Curvelo, Minas Gerais, Brazil.

The characterization tests results showed that the soil is a red sandy clay, with liquid limit of 56% and plasticity index of 12%, and its classified as high plasticity silt by Casagrande plasticity chart. In the proctor compaction test, the maximum dry density was 1.4 g/cm^3 and optimum water content was 30.7%.

It is possible to notice by the unconfined compressive strength test results that the insertion of geosynthetics increased the strength and the strain at the break. Reinforced soils tend to collapse with bigger deformations, mainly because of the properties of the geosynthetics.

In general, specimens of natural compacted soil collapsed with unconfined compressive strength of 346 kPa, soil reinforced with geogrids with 367 kPa and soil reinforced with woven geotextiles with 349 kPa.

The coefficient of variation obtained in the tests were small, showing that the data set is reasonably similar. Geotechnical tests involve uncertainties due to the soil's natural variability and coefficient of variation around 40% are expected for laboratory tests.

The results of this research constitute valuable reflections about reinforced soils with geosynthetics in cohesive soils. However, it is necessary to determine comparison patterns and analysis with respect to efficiency of this technique. As next steps, it is recommended to execute unconfined compressive strength test in specimens with bigger diameter, avoiding scale factor in geogrids. In addition, it is suggested more laboratory tests, like pullout test and direct shear strength, with the purpose of measuring the interface resistance inside the reinforced soil.

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