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Tension measurements on geogrid-reinforced soil using flexible load

Mesures de tension sur un sol renforcé de géogrilles à l'aide d'une charge flexible

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ABSTRACT: Usually the foundations in low bearing capacity subgrade involves a complex solutions. The geogrid-reinforcement is a modern alternative in situations where shallow foundations would not be recommended. Despite of researches has shown positive results, the use of this technique in engineering practice is still very restricted. This is justified mainly by the lack of understanding of the soil-structure-geosynthetic interaction behaviour. This paper intends to evaluate the geogrid-reinforcement benefits. The tension measurements on subgrade are highlighted. Laboratory-model tests were carried out on simulates the loading of strip footing by sand reinforced with geogrid. Flexible load cells are used for the tension measurement. The ultrafine cell behaves as a variable resistor circuit, which can be easily integrated into small spaces. So, these cells were used in the subgrade of the laboratory-model. It are shown the details of the instrumentation, calibration of the sensors, validation in one-dimensional compression test and results of tests in a laboratory-model simulating the loading of strip footing. The results indicate an increase in the bearing capacity and a significant reduction in settlement with the geogrid-reinforcement.

RÉSUMÉ : Habituellement, les fondations souterraines à faible capacité portante impliquent des solutions complexes. La géogrille de renforcement est une alternative moderne dans les situations où des fondations peu profondes ne seraient pas recommandées. Malgré des recherches qui ont montré des résultats positifs, l'utilisation de cette technique dans la pratique de l'ingénierie est encore très limitée. Ceci se justifie principalement par le manque de compréhension du comportement d'interaction sol-structure-géosynthétique. Cet article vise à évaluer les avantages du renforcement des géogrilles. Les mesures de tension sur le sous-sol sont mises en évidence. Des essais sur modèle en laboratoire ont été réalisés sur des simulateurs de chargement de semelle en bande par du sable renforcé de géogrille. Des cellules de charge flexibles sont utilisées pour la mesure de tension. La cellule ultrafine se comporte comme un circuit de résistance variable, qui peut être facilement intégré dans de petits espaces. Ainsi, ces cellules ont été utilisées dans le sous-sol du modèle de laboratoire. On y montre les détails de l'instrumentation, l'étalonnage des capteurs, la validation dans un essai de compression unidimensionnel et les résultats d'essais dans un modèle de laboratoire simulant le chargement d'une semelle filante. Les résultats indiquent une augmentation de la capacité portante et une réduction significative du tassement avec la géogrille de renforcement.

KEYWORDS: Flexible load cells, pressure increase, geogrid reinforcement

1 INTRODUCTION

Currently, due to urban sprawl, works on soils with low load capacity are increasingly common. These soils present significant deformations when requested, making construction in this location complex in many cases. A modern way of solving this geotechnical problem is the use of special techniques to improve the conditions of the foundation mass.

In this sense, during the last four decades, some methods to improve the behavior of the properties of resistance and deformability of soils were developed in order to obtain more viable solutions than traditional proposals (Marto et al., 2013).

Among the various methods researched, geosynthetics deserve to be highlighted for the results obtained. In the soil-structure-geosynthetic interaction mechanism, the synthetic material, which deforms according to the structure's demand, adds a portion of tensile strength to the soil due to the friction developed. Particularly, in the case of shallow foundations based on subgrades with low load capacity and high compressibility, the introduction of geosynthetics provides an increase in the carrying capacity and a significant reduction of settlements.

Despite recent research, such as Lopes (2019), Elshesheny et al. (2019), El-Soud and Belal (2018), Suku et al. (2017), Roy and Deb (2017), Prasad et al. (2016), Biwas et al. (2015) and Cicek et al. (2015) show positive results, the use of geosynthetics as reinforcement of superficial foundations in engineering practice is still very restricted, especially in Brazil. This is justified, above all, by the lack of understanding of the interaction mechanisms between geosynthetic, soil and foundation structure, which restricts the development of dimensioning methodologies, even at the international level.

Thus, it is concluded that there are still relevant questions to be answered in the case of reinforcement of shallow foundations with geosynthetics. The objective of the article is to study the mechanisms of soil-structure-geosynthetic interaction in shallow foundations reinforced with geogrid in subgrade with low support capacity by means of soil tension measurements. For this, tests will be carried out in a reduced model simulating the loading of a foundation. The model is a strip foundation set on solid sandy soil reinforced with a layer of geogrid. The laws of physical similarity between prototype and model will be considered.

2 LABORATORY MODEL TEST

2.1 *Material Characterization*

The subgrade in the tests simulating the loading of a shallow foundation was represented by fine sand with an average grain diameter between 0.06 to 0.7 mm. This value was determined considering the similarity laws between prototype and reduced model. The reference sand of the study was extracted from the Paraíba do Sul River, in the region of the city of Campos dos Goyacazes - RJ. Considering a scale factor (λ) of the prototype and model equal to 7.5 and that the sand fraction has a soil diameter between 0.06 mm and 2.0 mm, the sand used in the reduced model must have, by the similarity laws , mean diameter between 0.06 mm, lower limit of the sand fraction, and 0.27 mm. The physical and resistance properties of the soil are shown in Table 1.

The characterization of the soil consists of obtaining the physical, strength and compressibility properties. In relation to the physical properties, granulometric tests, real grain density and determination of the maximum and minimum specific weight were carried out. For the strength and compressibility parameters, direct shear and confined compression tests were performed.

Table 1. Properties of sand used for model test.

Parameter	Value
Effective particle size, D10	0.12
Uniformity coefficient, Cu	1.92
Coefficient of curvature, Cc	1.17
Maximum dry unit weight, (γ max)	15.2 kN/m³
Minimum dry unit weight, (γ min)	12.7 kN/m³
Angle of internal friction at 20% RD	30º
Angle of internal friction at 90% RD	35º

The geogrid used in the tests was made taking into account the scale factor of the similarity laws. The geometric and resistance characteristics are shown in Table 2. The reference geogrid was provided by the company Huesker in the sense of mutual collaboration.

Table 2. Properties of geogrid.

Parameter	Value
Aperture size	3.3 x 3.3 mm
Thickness	0.3 mm
Ultimate tensile strength	5.1 kN/m
Tensile strength for %2 strain	112.9 kN/m
Tensile strength for %3 strain	109.9 kN/m
Tensile strength for %5 strain	99.6 kN/m

2.2 *Experimental set-up*

The tests simulating the loading of a shallow foundation were carried out in the one-dimensional compression equipment available at the Civil Engineering Laboratory of UENF. The test chamber has internal dimensions equal to 72.5 x 72.5 x 48 cm. The strip foundation, with dimensions equal to 72.5 x 8 cm, was made with a PVC profile and filled with reinforced concrete. The load cell was attached to the shoe to measure the load applied to the foundation. To ensure a rough surface between the structure and the ground, sandpaper was attached to the base of the shoe. The testing apparatus is depicted schematically in Figure 1.

In the physical similarity analysis, the reduced model with a foundation with a width equal to 8 cm presents a scale factor (λ) equal to 7.5 to represent a prototype of a foundation with a width of 60 cm.

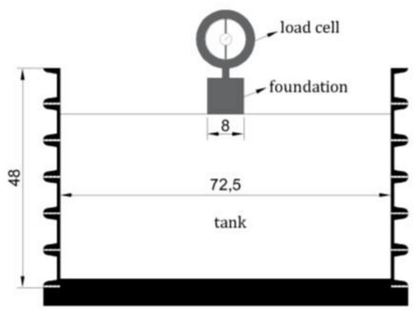
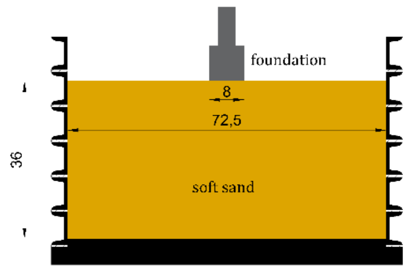


Figure 1. The schematic representation of the testing apparatus

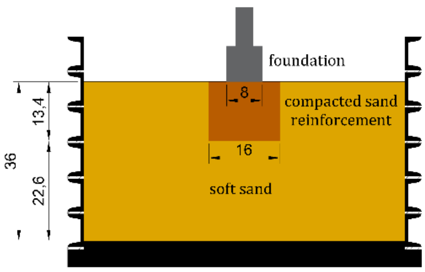
2.3 *Test Program*

The experimental program evaluated the benefits of including the reinforcement with the geogrid highlighting stress measurements in the soil through tests simulating the loading of a strip foundation. The tests were carried out in three different configurations: test on soft soil mass, test with compacted sand reinforcement layer overlying the soft soil and geogrid reinforcement in the compacted sand layer overlying the soft soil.

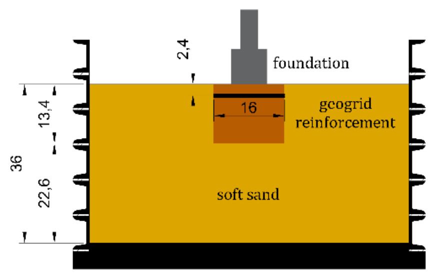
According to Lopes (2019), there is mobilization of the subgrade to a depth equal to 3.5B. Thus, considering a safety margin, the usable height of the test was adopted at 4.5B, that is, 36 cm. The thickness of the sand reinforcement layer was specified as 1.67 cm, which corresponds to 13.4 cm. This measure was defined according to the studies by Biwas et al. (2015). The geogrid settlement depth (u) was adopted at 0.2B, which represents 2.4 cm. It is noteworthy that only one layer of reinforcement of the synthetic material will be used in the tests (N=1). The geogrid width was set at 2.0B, that is, 16 cm, according to the recommendations of the Brazilian Geosynthetic Manual. Figure 2 shows the geometry of the tests in a reduced model in the three different configurations with dimensions.



a)Test with soft subgrade



b) Test with compacted sand reinforcement layer overlying soft soil



c) Test with geogrid reinforcement in the layer of compacted sand overlying the soft soil

Figure 2. Test set up

3 TEST INSTRUMENTATION

To analyze the voltage distribution inside the subgrade, all flexible load cells were applied (Figure 3) with data acquisition by arduino. These sensors function as variable pressure resistances and can be easily integrated into space-constrained applications. Figure 4 shows the location of the flexible cells in the reduced model assay. These electronic components have the possibility to measure the force between the two surfaces and are resistant enough to connect the stresses inside the subgrade.

The acquisition of the readings of the sensors was made by means of two arduinos that were connected to the computer. For this, it was necessary to produce an electrical circuit in accordance with the load cell manufacturer's recommendations. The adopted model is composed of resistor, capacitor, integrated circuit and a single power supply. Regarding the data, the acquisition of two readings per second was programmed simultaneously in the load cells.

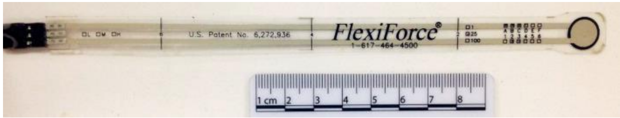


Figure 3. Flexible load cells

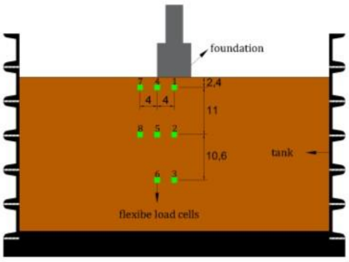


Figure 4. Location of flexible cells in the reduced model assay

In order to ensure accurate readings, the flexible load cells were calibrated according to the expected stress values in tests simulating the loading of a surface foundation. Following the manufacturer's recommendations, the calibration of the sensors was performed with the same configuration used in the tests and followed the following steps: adjustment of the sensor's sensitivity with the application of voltage and variation of the circuit resistance until the instrument's output voltage is close at 5V; charging and discharging 120% of the sensor's maximum voltage with charge holding for 10 seconds; charging in stages to full load by reading the applied voltage and the sensor output voltage. Calibration was done at four load stages in two load and unload cycles to test the repeatability of the flexible load cell. Figure 5 shows the structure used to calibrate the sensors and Table 3 shows the constants resulting from the calibration of each flexible load cell.

After calibration, the effectiveness of the flexible load cells was confirmed by means of a confined compression test. Sand from the reduced model in the dense condition and the traditional oedometric compaction equipment were used. The sensor was placed in the middle of the specimen, which has a diameter equal to 2 cm and a height equal to 4.8 cm. Figures 6 and 7 show, respectively, the assay setup and the result of the validation of the flexible load cells.

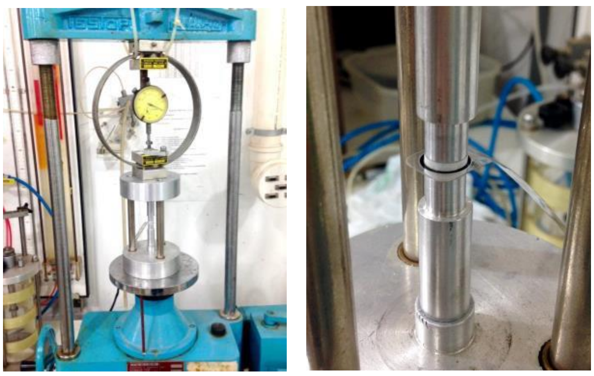


Figure 5. Structure used to calibrate the sensors

Table 3. Load cell constant

Flexibe load cells	Constant (kPa/V)
1	142.358
2	136.467
3	144.912
4	128.626
5	127.309
6	116.120
7	121.927
8	132.924

The test demonstrated the effectiveness of the instrument in measuring tension inside the subgrade. The voltage measured by the sensor is slightly lower than that applied to the top of the sample, the difference being greater at the start of loading and decreasing with the increase in load. This is likely due to the boundary conditions of the test and the mobilization of resistance along the specimen.

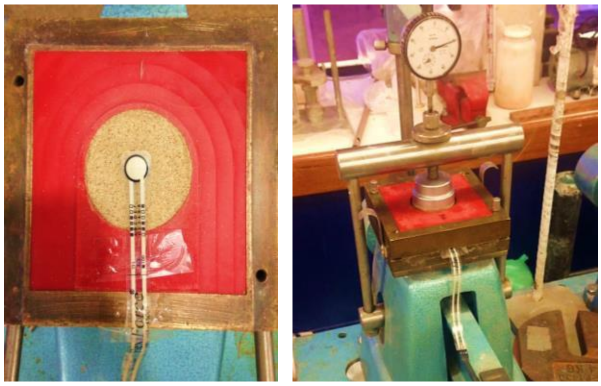


Figure 6. Assembly of the validation test of flexible load cells

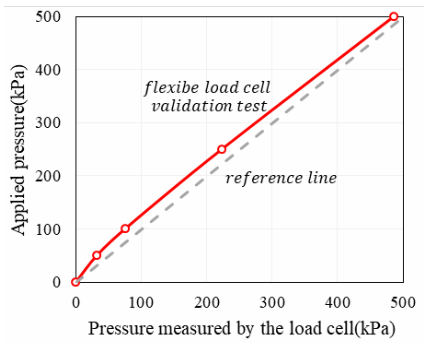


Figure 7. Instrumentation validation result with flexible load cells

4 RESULTS AND DISCUSSION

The stress distribution inside the subragde was obtained by reading the eight flexible load cells during the loading of the surface foundation. Figure 8 shows the voltage addition in the three different test configurations. There is a greater subgrade rigidity of the reinforced models when compared to the unreinforced models. For the same levels of settlement, there is an increase in the increase in vertical tension with the introduction of reinforced compacted sand and synthetic material. This is justified by the portion of resistance that the reinforcement, especially of the synthetic material, adds to the foundation mass.

Comparing the results obtained with the different sensors, it is possible to notice a decrease in the increase in voltage with the increase in the depth of the sensors and the concentration of stresses in the load symmetry axis, which decrease as they move horizontally away.The flexible load cells 1 and 4, which are closest to the surface and the axis of symmetry, showed the highest values of tension, while sensors 3, 6 and 7 showed the lowest values.

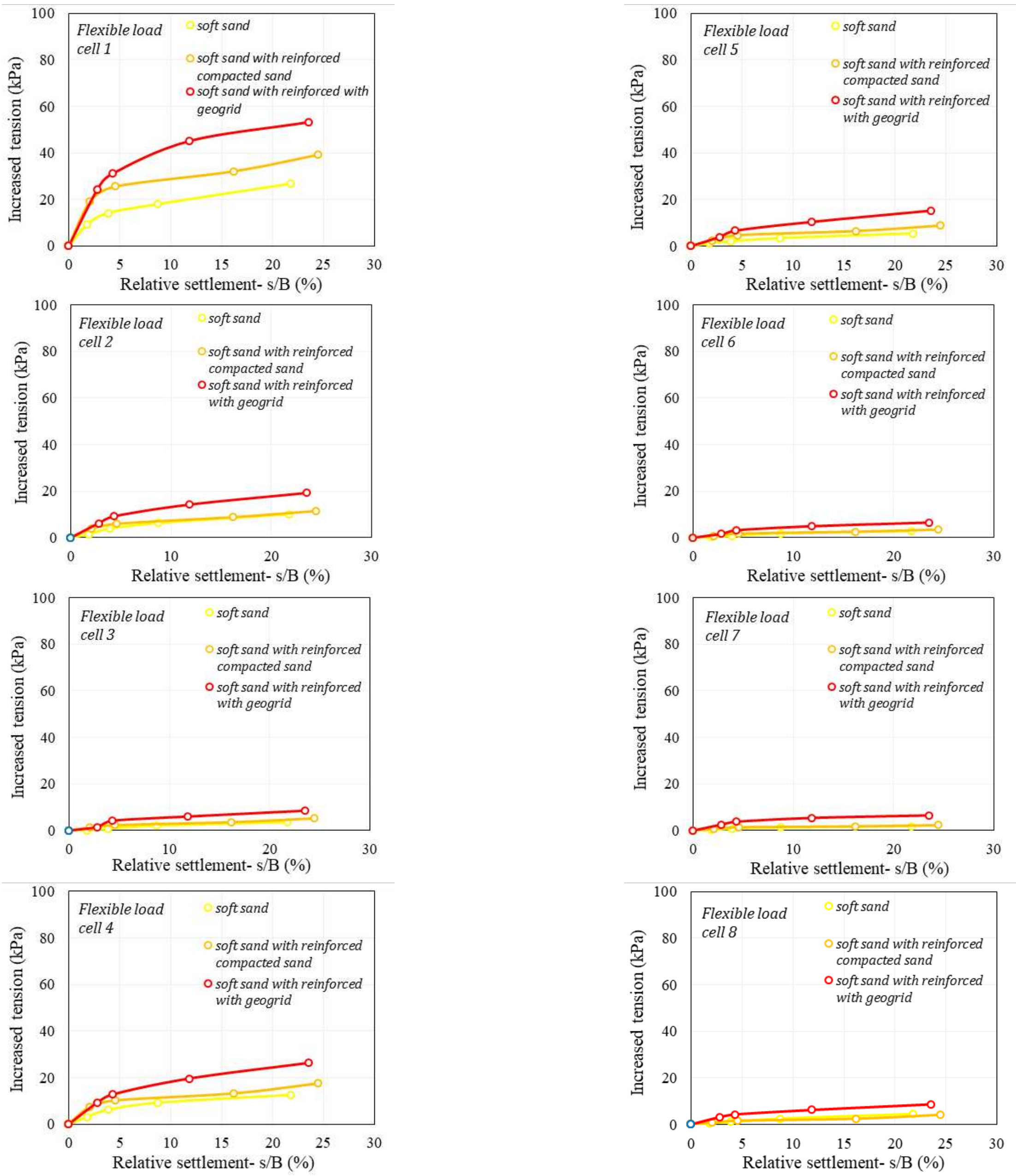


Figure 8. Increased voltage in the five different test configurations

5 CONCLUSIONS

The article aimed to study the soil-structure-geosynthetic interaction mechanism and evaluate the benefits of using geogrid reinforcement through tests in a reduced model simulating strip foudation loading. For comparison, tests were carried out in three different configurations: soft sand, soft sand with reinforcement of compacted sand and soft sand with reinforcement and geogrid. Throughout the process, the similarity laws were respected.

In the tests, the voltage increase distribution was evaluated through eight flexible load cells connected to an arduino and a computer. It was necessary to assemble an electrical circuit according to the recommendations of the load cell manufacturer, which collected two readings per second on each of the sensors.

Instrumentation with flexible load cells measures soil tension with adequate precision, helping to interpret resistance mobilization and rupture mechanisms. There is a greater subgrade rigidity of the reinforced models in relation to the subgrade rigidity of the reinforced models in relation to the unreinforced model. For the same levels of settlement, there is an increase in the increase in vertical tension with the introduction of reinforced compacted sand and synthetic material. This shows that the reinforcement of compacted sand and synthetic material in the subgrade in the soft condition increases the limit depth of tension mobilization in relation to the unreinforced soil fundation.

With the results generated, it was also possible to conclude a stress concentration on the subgrade surface and on the symmetry axis of the load application.

6 ACKNOWLEDGEMENTS

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