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Numerical simulation of sand-geosynthetic interaction based on pullout tests

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ABSTRACT
This paper presents a simulation of the sand-geosynthetic interaction based on pullout tests carried out in the Geosynthetics Laboratory of the Sao Carlos School of Engineering of the University of Sao Paulo. With the experimental results, it was determined the pullout strength of a polyester geogrid installed within a poorly graded sand, under confining stresses of 25, 40, 55 and 75 kPa. The simulation was performed in SIGMA/W of GeoStudio and the chosen parameters were selected carefully for representing the real behavior of the interface. In addition, the simulation of the geogrid geometry in this program is only possible in one direction, thus being necessary for an adaptation to consider the real effect of the transversal and the longitudinal elements in its stiffness. Finally, this work showed a good relationship between experimental and numerical results, validating the performed simulation and evidencing that numerical modeling can bring a lot of advantages.

1. INTRODUCTION

When designing and construing any type of engineering work, it is necessary to know the properties and characteristics of the ground where it is going to be performed because of its variability and low tensile strength, which may cause some problems that could affect the safety of the works.

Because of those characteristics, in the last century, it was ever searched the most suitable ground, it means, soils with similar characteristics, more resistant and without the presence of water, even if it meant higher costs (Vertematti 2004). However, the high construction demand, population growth and the scarcity of urban land nowadays, have increased the challenge for designers because they are obliged to build on soils with unfavorable characteristics, it means, with low bearing capacity and surface water table. Thus, there is a need to adopt appropriate geotechnical solutions to improve the ground conditions, making possible the construction of any type of engineering work in those places.

With the passage of time, reinforcement techniques of materials with low tensile strength, such as soil, are still evolving and increasingly being employed in civil works. Thus, since the second half of the twentieth century, steel bands, double-twist hexagonal meshes, and from the '60s, various types of geosynthetics are being used in those applications (Sieira 2003).

Geosynthetics are being increasingly used as reinforcing materials in geotechnical works because of their technical, constructive and economic advantages. In the case of soil reinforcement works with geosynthetics, it is important to note that a high tensile strength does not guarantee the best performance. The most important aspect is its interaction with the surrounding material (DeMerchant et al. 2002). Thus, the test that evaluates the soil-geosynthetic interaction in the best way is the pullout test, where the geosynthetic is subjected to a tensile solicitation until happening adhesion loss with the surrounding material.

Although the pullout tests provide more reliable results of the interaction between the soil and the geosynthetic used as reinforcement material, its implementation involves considerable time and effort. Thus, in this paper, it is shown that numerical simulation can provide similar results to experimental ones, still allowing the modeling and analysis of different situations and problems.

2. MATERIALS AND METHODS

The numerical simulation was carried out based on the material properties used by Campos (2013) in the pullout tests, which were performed in the Geosynthetics Laboratory of the Engineering School of Sao Carlos. As reinforcing material, Campos (2013) used a biaxial polyester geogrid (Table 1) which was inserted into a poorly graded medium sand in a dry state, whose characteristics are shown in Table 2.

2.1 Reinforcement

The reinforcing material used by Campos (2013) corresponds to a biaxial geogrid composed of polyester filaments, which are covered with polyvinyl chloride (PVC). The nominal tensile strength of the geogrid is 40 kN/m, in the longitudinal direction, and 30 kN/m in the transverse direction. Its characterization was performed in the Geosynthetics Laboratory of the Engineering School of Sao Carlos, using the Instron® Universal Testing Machine, whose capacity is 25 tons. Thus, in Table 1 below are shown the characteristics of the reinforcement material.

Table 1. Geogrid properties

Tensile strength [kN/m]	Longitudinal	44.8	
	Transversal	31.7	
Tensile strength [kN/m]	Longitudinal	(ε = 2%)	7.5
		(ε = 5%)	14.4
	Transversal	(ε = 2%)	5.4
		(ε = 5%)	9.7
Stiffness modulus [kN/m]	Longitudinal	229.7	
	Transversal	143.3	
Rupture strain [%]	Longitudinal	11.2	
	Transversal	10.6	
Width of element [mm]	Longitudinal	5.3	
	Transversal	20.4	
Space between elements [mm]	Longitudinal	32.4	
	Transversal	33.4	
Thickness of transversal element [mm]		1.4	

2.2 Surrounding soil

Regarding the soil used as filling material of the pullout box, in the numerical simulation was analyzed the interaction between the poorly graded medium sand used by Campos (2013) and the polyester geogrid, mentioned in the previous item. The fact of Campos (2013) having used this material in a dry state, was more because of avoiding the effect of cohesion and its possible change during the test due to gravimetric water content changes. Thus, in Table 2 below are shown the sand properties, where, some of the parameters required to perform the numerical simulation, were estimated from Marangon (2009), García (2011), França (2012) and Campos (2013).

Table 2. Sand properties

Parameter			Specification
Specific mass of solids	ρ_s [g/cm³]	2.66	ABNT NBR 6508
Particle size fraction	Fine sand [%]	15	ABNT MB 32
	Medium sand [%]	55	
	Coarse sand [%]	30	
Classification	SUCS	SP	ASTM D2488
Specific weight	γ [kN/m³]	16.7	
Strength parameters	φ [°]	34.5	
	c [kPa]	0	
Modulus of elasticity	E [MPa]	13.1	
Poisson's ratio	ν	0.35	
Dilatancy angle	$\Psi = \varphi - 30$ [°]	4.5	

3. LABORATORY PULLOUT TESTS

According to Teixeira (2003), the monotonic pullout test was developed in order to evaluate the behavior of inclusions embedded in soil when subjected to a tensile solicitation until taking them to the adhesion loss with the surrounding material. This test is considered the most appropriate for assessing the soil-geogrid interaction because it considers the surface friction portions and the passive strength that the cross members provide, as shown in Figure 1 below.

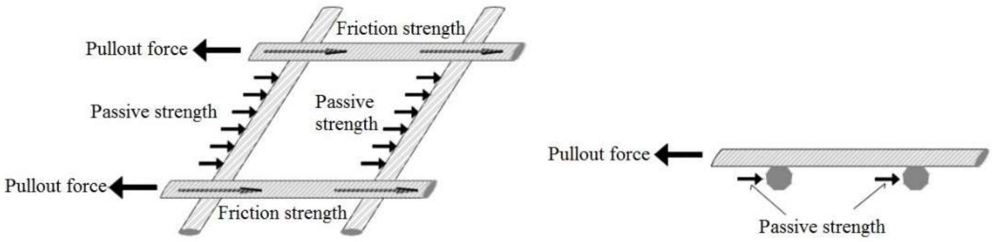

Figure 1. Soil-geogrid interaction (Voottipruex *et al.* 2000)

The pullout tests results are generally used, not only to clarify the soil-geosynthetic interaction but also for the behavior analysis of real reinforced soil structures. Because of this, the realization conditions of these tests are so important for determining the desired parameters. Thus, depending on the conditions of the project or the required purpose, the pullout tests can be performed in a laboratory or in the field (Kakuda 2005).

For tests performed in the laboratory, typical pullout equipment is formed by a rigid steel box with a rectangular cross-section, which is filled with properly compacted material containing the reinforcement inclusion that will be pulled by a hydraulic piston. The tensile force in the reinforcing element is applied by a hydraulic system, whose speed can be controlled during the test, and the confining stress on the filling material is generally applied by a compressed airbag (Kakuda 2005).

The equipment used by Campos (2013) has 1.50 m long, 0.70 m wide and 0.48 m height (Figure 2), thus corresponding to large dimensions one since it reaches the minimum specifications required by ASTM D6706 (0.61 m long, 0.46 m wide and 0.305 m height).

Figure 2. Pullout test equipment (Campos 2013)

Concerning the results obtained by Campos (2013), the pullout strength values were obtained for four confining stresses (25, 40, 55 and 75 kPa), as well as the behavior of the sand-geogrid interaction. In the execution of the tests, Campos (2013) used a pullout speed of 3.6 mm/min, which was equivalent to a rate of 1% deformation per minute. Thus, in Figure 3 are shown the experimental results obtained for the four confining stresses.

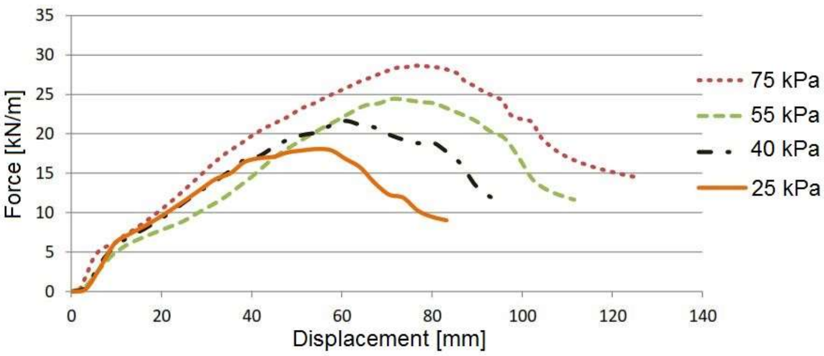

Figure 3. Experimental pullout test results in the sand (Campos, 2013)

4. NUMERICAL SIMULATION AND RESULTS

In order to validate the experimental results obtained by Campos (2013), the numerical simulation with finite element method was performed with SIGMA/W of GeoStudio packet, using the same equipment dimensions and similar boundary conditions to those presented during the tests. In this work, the pullout tests realized by Campos (2013) in the sand were modeled as two-dimensional plane strain problems, whose results were later processed to 0.70 m width, corresponding to the size of the equipment used in the execution of the tests.

The model shown in Figure 4 was assembled based on the criteria adopted by Sugimoto and Alagiyawanna (2003). Regarding the simulation of the filling material, four regions were created, one for the interface and the others for the sand above, below and on the left side of the interface. Subsequently, the finite element mesh was created with 1766 nodes and 1852 elements, having a greater detail in central regions as shown in Figure 4.

Due to the inability to simulate the three-dimensional structure of the geogrid, an equivalent two-dimensional model was created, where the cross-section of the element, corresponded to the total cross-section of all longitudinal members in a meter of wide of the geogrid (Peng et al. 2000). Thus, its simulation was done using a structural beam element, specifying its modulus of elasticity according to the characterization realized by Campos (2013), defining a unitary cross-section area value and disabling the compressive strength option.

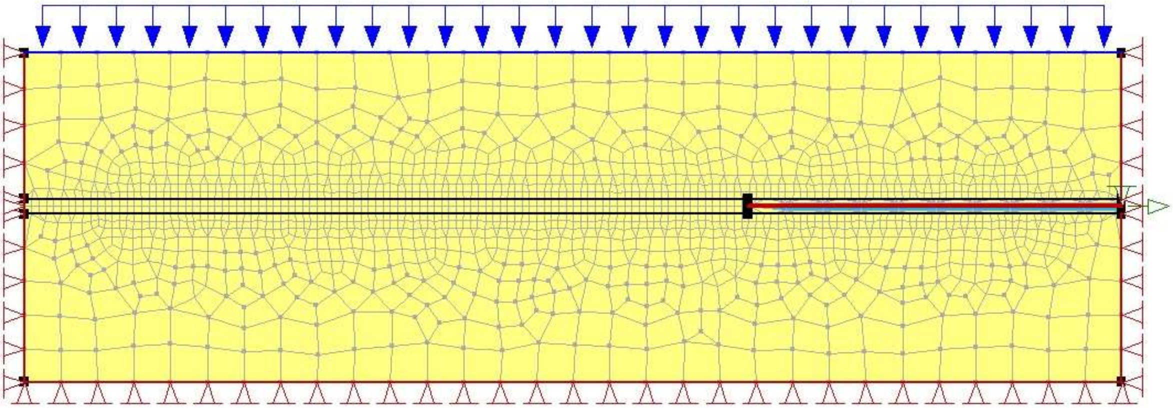

Figure 4. Finite element model

To simulate the boundary conditions, there were placed supports with horizontal displacement constraints along the lateral borders, except in the front face opening where the geogrid was pulled. In addition, there were also placed supports with vertical displacement constraints along the inferior border. Subsequently, it was applied the confining stress on the finite element mesh corresponding to the sand, and after that, it was applied the pullout force in the geogrid under a constant displacement rate based on the pullout speed used by Campos (2013) in the experimental phase, which was 3.6 mm/min.

Likewise, it was necessary to adopt parameters for the sand-geogrid interface simulation based on the experimental results obtained by Sugimoto and Alagiyawanna (2003), García (2011), França (2012) and Campos (2013). Thus, in Table 3 below are shown the parameters that were adopted for the interface modeling.

Table 3. Parameters of interface modeling

Parameter	Value
Modulus of elasticity - E [kPa]	1310
Internal friction angle - φ [°]	24.6
Cohesion - c [kPa]	0
Dilatancy angle – Ψ [°]	2.3
Specific weight - ɣ [kN/m³]	16.7

Figure 5 shows the pullout strength values for each confining stress, coming from the experimental results obtained by Campos (2013) and the numerical results obtained in SIGMA/W of GeoStudio. Through the envelopes shown in Figure 5, it can be concluded that the adopted numerical model provided satisfactory results. Still, it was found that the interface parameters have significant relevance, especially the dilatancy angle, as well as Sugimoto and Alagiyawanna (2003) showed.

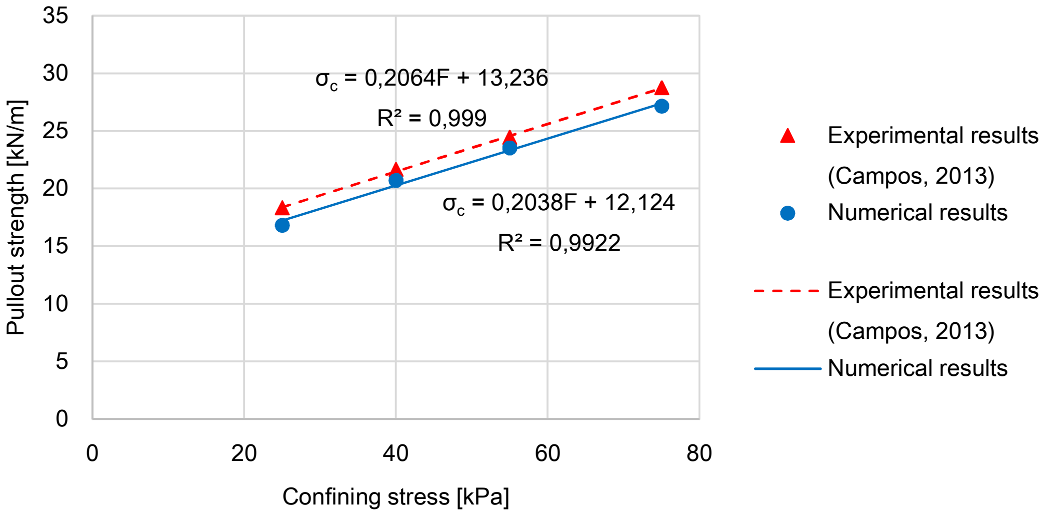

Figure 5. Experimental pullout results *versus* numerical pullout results

From the calibration between the experimental and numerical results, it was also observed the variation of the displacement along the geogrid (Figure 6). As already anticipated, it was verified that as greater the confining stress, the displacement along the geogrid was higher. In addition, that behavior was also confirmed in the closest positions of the pullout force application region.

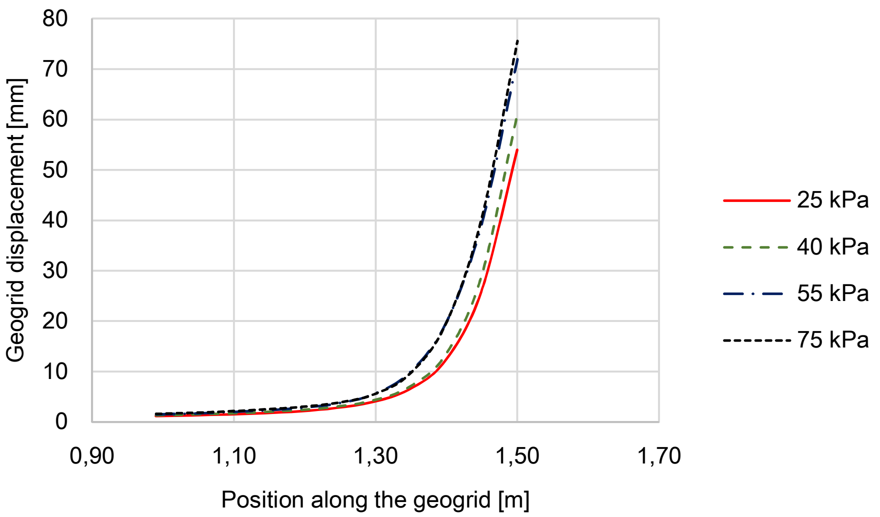

Figure 6. Displacement along the geogrid

5. CONCLUSION

From the monotonic pullout results obtained by Campos (2013) in the sand, it was performed a numerical simulation in SIGMA/W of GeoStudio, based on the finite element method. The numerical model provided compatible monotonic pullout strength values with the experimental ones, for all confining stresses tested by Campos (2013). Besides, it was evaluated the variation of the displacement along the geogrid, showing satisfactory results according to the expected behavior.

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REFERENCES

ASTM D6706, (2007). Standard test method for measuring geosynthetic pullout resistance in soil. *American Society for Testing and Materials*, USA.

Campos, M. V. W., (2013). *Avaliação da interação solo-reforço por meio de ensaios de cisalhamento cíclico de interface*. Dissertação de Mestrado – Escola de Engenharia de São Carlos, Universidade de São Paulo. São Carlos, Brasil. (in portuguese).

DeMerchant, M. R.; Valsangkar, A. J.; Schriver, A. B., (2002). Plate load tests on geogrid-reinforced expanded shale lightweight aggregate. *Geotextiles and Geomembranes*, University of New Brunswick. Fredericton, Canada, n. 20, p. 173-190.

França, F. A. N., (2012). *Novo equipamento para realização de ensaios confinados e acelerados de fluência em geossintéticos*. Tese de Doutorado – Escola de Engenharia de São Carlos, Universidade de São Paulo. São Carlos, Brasil. (in portuguese).

García, G. F. N., (2011). *Implementação de ensaios de arrancamento cíclico de geossintéticos*. Dissertação de Mestrado – Escola de Engenharia de São Carlos, Universidade de São Paulo. São Carlos, Brasil. (in portuguese).

Kakuda, F. M., (2005). *Estudo de ensaios de arrancamento de geogrelha com utilização de um equipamento reduzido*. Dissertação de Mestrado – Escola de Engenharia de São Carlos, Universidade de São Paulo. São Carlos, Brasil. (in portuguese).

Marangon, M., (2009). *Geotecnia de fundações – Parâmetros dos solos para cálculo de fundações*. Universidade Federal de Juiz de Fora, Vol. 1, Unidade 3, p. 83. Juiz de Fora - MG, Brasil. (in portuguese).

Peng, F. -L.; Kotake, N.; Tatsuoka, F.; Hirakawa, D.; Tanaka, T., (2000). Plane strain compression behavior of geogrid-reinforced sand and its numerical analysis. *Soils and Foundations*, Vol. 40, No. 3, p. 55-74.

Sieira, A. C. C. F., (2003). *Estudo experimental dos mecanismos de interação solo-geogrelha*. Tese de Doutorado – Pontifícia Universidade Católica do Rio de Janeiro. Rio de Janeiro, Brasil. (in portuguese).

Sugimoto, M.; Alagiyawanna, A. M. N., (2003). Pullout behavior of geogrid by test and numerical analysis. *Journal of Geotechnical and Geoenvironmental Engineering* © ASCE, Vol. 129, No. 4, p. 361-371.

Teixeira, S. H. C., (2003). *Estudo da interação solo-geogrelha em testes de arrancamento e a sua aplicação na análise e dimensionamento de maciços reforçados*. Tese de Doutorado – Escola de Engenharia de São Carlos, Universidade de São Paulo. São Carlos, Brasil. (in portuguese).

Vertematti, J. C./Coordenador, (2004). *Manual brasileiro de geossintéticos*. Ed. Blucher. São Paulo, Brasil. (in portuguese).

Voottipruex, P.; Bergado, D. T.; Ounjaichon, P., (2000). Pullout and direct shear resistance of hexagonal wire mesh reinforcement in weathered Bangkok clay. *Geotechnical Engineering Journal*, Vol. 31, p. 43-62.