

Pullout Behavior of Geotextiles: Numerical Prediction

Sieira, A. C. C. F.*

*(Structures and Foundations Department, Rio de Janeiro State University, Brasil)

ABSTRACT

The mechanism of soil-geosynthetic interaction is usually complex and depends on the nature of the reinforcement, as well as on the characteristics of the surrounding soil. The strength parameters of the interface are the key for the design of reinforced soil slopes. Usually, these parameters are defined from laboratory pullout tests. The absence of test results implies on conservative assumptions and higher costs. The possibility of using computer programs for analyzing the load transfer mechanism arises as an attractive design tool. This paper presents the numerical simulation of pullout tests, conducted in large equipments. The numerical predictions of the load and displacement distribution along the geosynthetic length were compared to instrumented test results, available in the literature. The analyses revealed to be satisfactory and consistent with the experimental results. Thus, it becomes possible to reduce the uncertainties in the design of the anchorage length for the reinforcement by previously performing studies with computer programs that simulates stress x strain behavior of geotechnical problems.

Keywords - Numerical prediction, Geotextiles, Pullout tests

I. INTRODUCTION

The design of reinforced soil structures requires knowledge of the resistance parameters at the soil-reinforcement interface, usually obtained from field or laboratory pullout tests.

Field pullout tests reproduce more adequately the actual conditions. However, these tests are costly and require a complex infrastructure. Laboratory tests, in turn, are easier to interpret since both envi-ronmental and boundary conditions are fully con-trolled. Nevertheless, they usually require large equipments to overcome scale effects.

Numerical or analytical simulation appears as an attractive approach that combines low cost and speed, allowing the evaluation of different soil-geosynthetics and boundary conditions. Once the model is validated, parameters may be assigned for geotechnical design purposes. Moreover, the simulations are an efficient tool for understanding the stress-strain behavior of geosynthetics.

Many analytical [1-3] and numerical [4-5] studies have been conducted in order to better understand the stress-strain behavior of geosynthetics.

This paper presents the results of numerical simulations of pullout tests carried out in the laboratory in large equipment [6]. The experimental program consisted of a series of pullout tests with 2 types of geotextiles, embedded in sandy soil. The analyses were accomplished with a commercially available finite element program (PLAXIS).

II. LABORATORY TESTS

The pullout tests were carried out at CEDEX Geotechnical Laboratory, in Spain. Two types of geotextiles were used and will be identified

in the present paper as G1 e G2. Both are nowoven needle-punched geotextiles and their main physical and me-chanical properties are presented in Table 1.

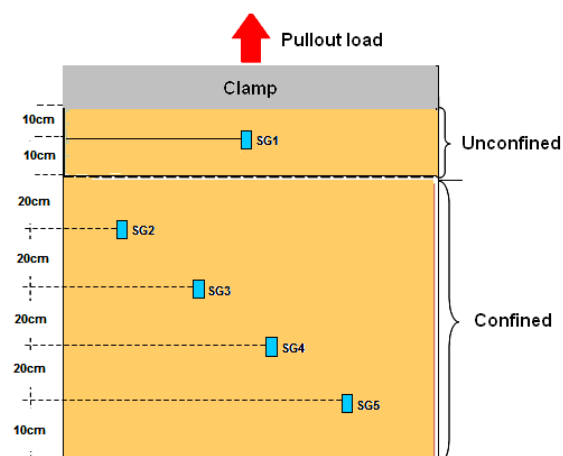
The tests were carried out with silty sand with 10% moisture content and 80% relative density. Characterization tests indicated specific gravity of solids (G) equal to 2.71.

The shear strength parameters were obtained from drained triaxial tests carried out with large di-mension samples (22.9 cm in diameter), under different confining stress levels. The tests provided friction angle (ϕ') and cohesion (c') equal to 37° and 16 kPa, respectively.

Pullout tests were carried out in large dimension equipment (1.0 m x 1.0 m x 0.6 m), under different confining stress levels equal to 12.5; 25 and 50kPa. The geotextile specimens were instrumented with strain gages, installed at 5 different points along the geotextile length. Test set up is shown Figure 1.

Table 1. Geotextile properties [6]

Property	Geotextile G1	Geotextile G2
Longitudinal resistance (kN/m)	50	200
Transverse resistance (kN/m)	14	14
Elongation at failure (%)	12	13
Thickness (mm)	2.3	2.9



Legend: SG = strain-gage

Figure 1. Pullout test instrumentation [6]

III. NUMERICAL MODEL

The geometry, boundary conditions, and load systems, adopted in the numerical analyses, are summarized in Figure 2. The test box is 0.60 m high and 1.0 m long. The box walls were represented by rigid plates. The geotextile length was equal to 0.90m. The confining stress was simulated by a uniformly distributed load (A), acting on the soil surface. The horizontal load was simulated by a point load (B) at the front end of the geotextile specimen. Horizontal movements of the vertical walls were inhibited and no displacement was allowed at the base of the test box. A 6mm vertical spacing between the two halves of the front wall was imposed to allow free move-ment of geotextile.

The geotextile was simulated by an element presenting tensile resistance only. The axial stiffness (EA) of geotextiles G1 and G2 were defined from tensile tests results. Steel properties were used to compute the stiffness of box walls, considering a wall thickness equal to 2.0 mm.

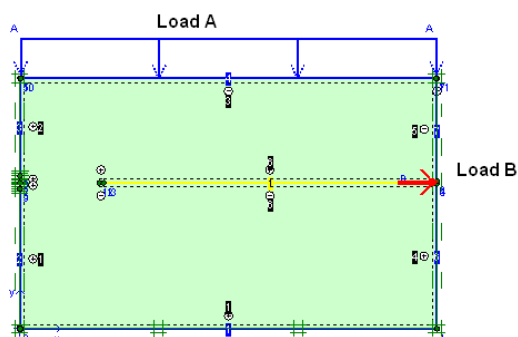


Figure 2. Numerical model [5]

Soil-geotextile behavior was simulated by pre-scribing an interface element above and below the interface contact. This element minimizes the shear strength parameters of the soil adjacent to the

rein-forcement, by applying a correction factor (R_{inter}), according to the following equations:

$$R_{inter} = \frac{c_a}{c} \leq 1,0 \quad (1)$$

$$R_{inter} = \frac{\tan \delta}{\tan \phi} \leq 1,0 \quad (2)$$

In the present study, interface elements were pre-scribed not only at the soil-geotextile contacts but al-so at the front wall contact to simulate internal lubrication. Correction factors (R_{inter}) were defined according to experimental data provided by Espinoza [6]. At the contact between soil sample and front wall, R_{inter} was defined according to reference [7] indicating a light lubrication.

Hardening Soil constitutive model was selected to reproduce the stress-strain behavior of the compacted sandy soil sample. This model allows the variation of the Young modulus with stress level. Table 2 summarizes all parameters and constitutive models adopted in the numerical analyses.

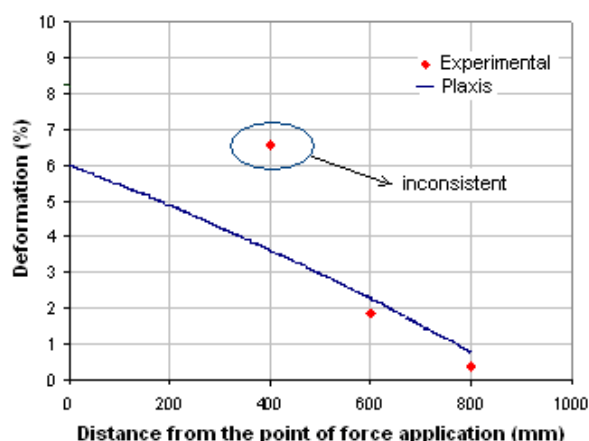
IV. RESULTS DISCUSSION

Figure 3 compares the experimental results with numerical prediction of G1 pullout test, under 25 kPa of confinement. The results (Figure 3a) show a good agreement at the rear end of the geotextile. According to reference [6], the strain-gage located 200 mm from the front edge of the box was damaged during the test and the SG3 (400 mm from the front end) presented malfunction.

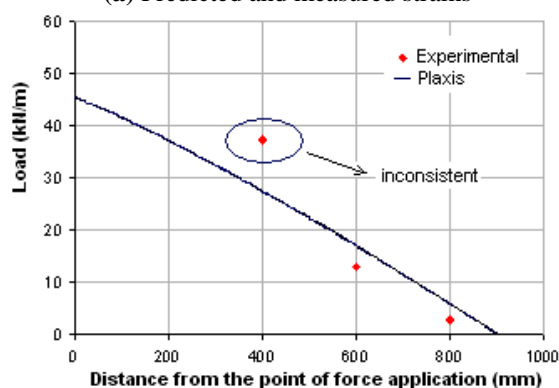
Table 1. Constitutive models and material parameters

Material	Constitutive model	Parameters
Silty Sand soil	Hardening Soil	$c' = 16 \text{ kPa}$
		$\phi' = 37^\circ$
		$\gamma = 19.79 \text{ kN}/\mu^3$
		$E_{50}^{ref} = 35 \text{ MPa}$
		$\mu = 0.5$
		$\nu = 0.33$
Geotextile	Linear elastic	$EA = 500 \text{ kN}/\mu$ $\Lambda = 0.8 \mu$
Plates	Linear elastic	$EA = 210 \text{ MN}/\mu$ $\epsilon = 0.002 \mu$ $\nu = 0.15$
Soil-Geotextile G1 interface		$P_{I_{VTEO}} = 0.71$
Soil-Geotextile G2 interface		$P_{I_{VTEO}} = 0.93$
Soil-Frontal wall interface		$P_{I_{VTEO}} = 0.90$

Note: c' = cohesion; ϕ' = friction angle; γ = specific weight; E_{50}^{ref} = deformability modulus corresponding to 50% failure; m = HS model exponent parameter; ν = Poisson coefficient; EA = axial stiffness; e = thickness.



(a) Predicted and measured strains

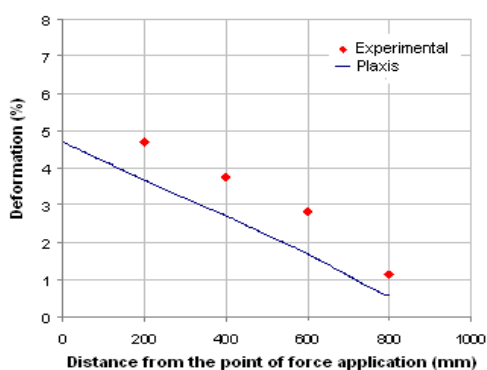


(b) Predicted and computed horizontal loads

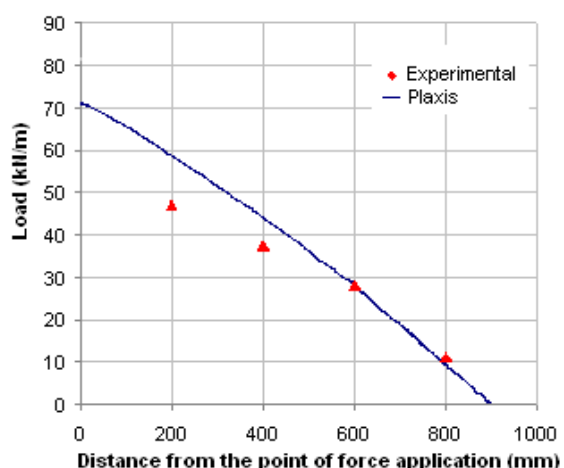
Figure 3. Geotextile G1 pullout response at failure, confining stress = 25 kPa

Based on the load and strain curve provided by the tensile tests, the axial loads were predicted and compared to the experimental data. The results, shown in Figure 3b, followed a similar trend observed in Figure 3a.

The results of the geotextile G2 test, under 50kPa of confinement, are presented in Figure 4. The predicted deformation is slightly lower (maximum difference of 1%) than the experimental data (Figure 4a). On the other hand, the axial loads showed a better agreement, particularly at the rear end of the reinforcement (Figure 4b).



(a) Predicted and measured strains



(b) Predicted and computed horizontal loads

Figure 4. Geotextile G2 pullout response at failure, confining stress = 50 kPa

It is worthwhile to mention that the geotextile is simulated by a linear and elastic element. Figure 5 compares the curve obtained in tensile tests with GA and the curve adopted by Plaxis. It is expected that for higher strain levels the program provides higher values of tensile load. The same behavior is expected in the simulations with the geotextile G2. Additionally, the linear and elastic constitutive model does not incorporate an ultimate load.

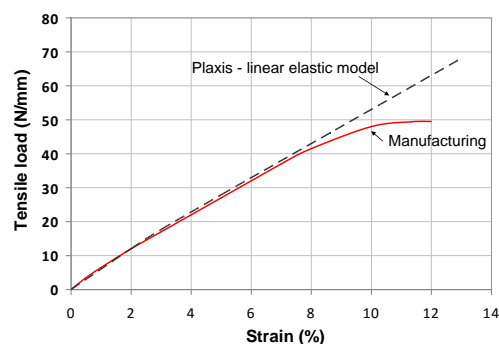


Figure 5. Difference among the constitutive models

Geotextiles G1 and G2 show a significant difference of axial stiffness, which definitely influences the comparison of the pullout responses. Figure 6 presents experimental and numerical results, at failure, for the specimens under 50 kPa of confinement. It is interesting to note that experimental data with geotextile G1 shows higher strains at the front end of the reinforcement and a sharp reduction along the geotextile length; at the rear end the strain is quite negligible. This behavior is typical of low stiffness geotextiles. Due to the linearity of F vs. ϵ curve and, hence, the constant relationship between F and ϵ the numerical results

yield a more uniform strain reduction along the geotextile length.

Accordingly, both numerical and experimental results with geotextile G 2 present lower strains due to its higher stiffness. Moreover, it is observed a good agreement between both approaches.

Figure 7 compares the pullout loads computed at the strain gage (SG2), located 20 cm from the front wall with the tensile resistance provided by the manufacturer. The geotextile G2, which is stiffer and more resistant, is less mobilized than geotextile G2. In engineering practice, the design with geotextile G2 would be conservative and, hence, economically inappropriate.

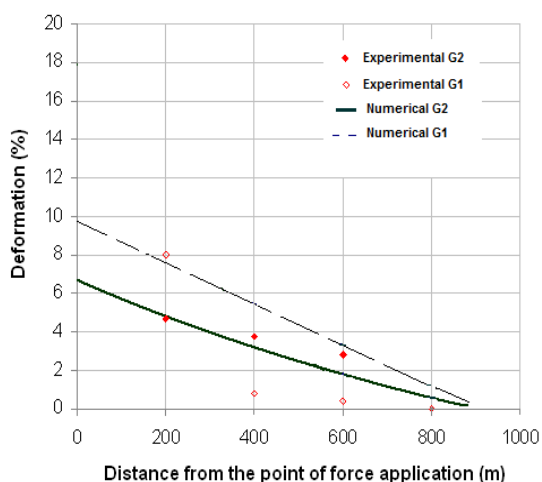


Figure 6. Predicted and measured strains at failure, under 50 kPa of confinement

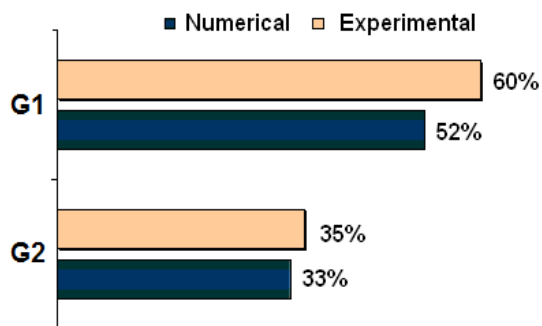


Figure 7. Geotextiles G1 and G2: Pullout loads under 50 kPa of confinement

V. CONCLUSION

This paper presented the results of numerical simulations of pullout tests with geotextiles. The numerical analysis was performed with PLAXIS software. The analyses were compared to experimental results of instrumented pullout tests, available in the literature.

The numerical results are in agreement with the experimental tests response and, therefore, imply

in considering the numerical analysis as a powerful tool to simulate pullout tests on geotextiles. Besides they may be used as a design tool to help engineers to reduce the uncertainties in defining the anchorage length of geotextiles.

The geotextile G2, which is stiffer and more resistant, is less mobilized than geotextile G1. In engineering practice, the design with geotextile G2 would be conservative and, hence, economically inappropriate.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support for this work provided by the Brazilian Science Foundation's CAPES, CNPq and FAPERJ.

REFERENCES

- [1] Beech, J. F., (1987). Importance of stress-strain relationships in reinforced soil system designs. In: Geosynthetics 87 Conference. Vol.1, pp. 133-144.
- [2] Ochiai, H.; Hayaschic, S.; Ogisako, E.; Sakau, A. (1988). Analysis of polymer grid: reinforced soil retaining wall. International Conference on Numerical Methods in Geomechanics, 6. Innsbruck. Balkema, Rotterdam. Vol. 2, pp. 1449-1454.
- [3] Sieira, A.C.C.F, Gerscovich, D.M.S and Sayão, A.S.F.J. (2009). Displacement and Load Transfer Mechanisms of Geogrids under Pullout Condition. Geotextiles and Geomembranes. 27, pp. 241-253.
- [4] Sobhi, S. and Wu, J.T.H. 1996. An interface pullout formula for extensible sheet reinforcement. Geosynthetics International, Vol. 3, n. 5, pp. 565-582.
- [5] Ferreira, L. H. T. 2009. Analytical and numerical models for simulation of pullout tests with geotextiles. (in Portuguese). MSc thesis. State University of Rio de Janeiro. 134p.
- [6] Espinoza, M.E.D. (2000). Study of the stress-strain behavior of geosynthetics under pullout condition with respect to the design of reinforced soil structures. PhD thesis. Polytechnic University of Madrid, 350p.
- [7] Palmeira, E.M. and Dias, A.C 2007. Experimental and numerical study of the behavior of geogrids on large pullout tests (in Portuguese). REGEO. V. 1, pp. 1-8.