Numerical analysis of the factors that influence geotextile response under pullout condition

Ludma Heliodora Thomé Ferreira
UERJ, Rio de Janeiro, Brazil, ludmathome@gbl.com.br
Ana Cristina Castro Fontenla Sieira
UERJ, Rio de Janeiro, Brazil, sieira@uerj.br
Denise Maria Soares Gerscovich
UERJ, Rio de Janeiro, Brazil, deniseg@uerj.br

Keywords: Numerical simulation, Geotextile, Pullout test

ABSTRACT: The strength parameters of soil-geosynthetic interfaces are mandatory for the design of reinforced soil structures. These parameters are usually defined by laboratory pullout tests. However, there is evidence that the laboratory results are strongly affected by test set up. This paper presents the results of a parametric study on evaluation of the influence of different factors, such as the length and stiffness of the reinforcement, internal lubrication of the test box walls, and roughness of interface soil-geosynthetic. The analyses were performed using a commercially available FEM program. The test set up that was numerically simulated consisted of a 1m long and 0.6m high rigid box, with a geotextile element embedded in a silty-sand soil. In the simulation, vertical stresses were applied on soil surface and constant horizontal loads were applied at the geotextile end, accordingly to the confining stress level. The distributions of load and displacement along the reinforcement were computed for the different test conditions and compared to the experimental data available in the literature. This study revealed that the reinforcement length and the friction mobilization between soil and the rigid test walls are the main factors that affect test results. Besides, numerical simulation proved to be a useful design tool for the prediction of soil-geosynthetic interaction, due its capability to reproduce pullout experimental results under various test conditions.

1 INTRODUCTION

The accurate prediction the behavior of interface between soil and geosynthetics is very important for an appropriate design of reinforced soil masses. The commonly used laboratory tests for obtaining the interface strength parameters are the pullout and direct shear tests. Reinforcements that provide anchorage resistance must be tested under pullout to allow the identification of shear friction and passive resistances (Palmeira and Milligan, 1989).

Pullout test interpretation is subject to the various factors that influence the geosynthetics response under pullout effort; such as: type of reinforcement (geogrid, geotextile, geomembrane, etc.); physical and mechanical properties of the reinforcement (polymer type, geometry, strength and stiffness); soil properties (grain size, nature, soil structure and moisture content); test set up (confining stress device, velocity of the application of the horizontal load, geosynthetic clamping system, size of equipment etc) (Koerner, 2005).

The influence of the stiffness and length of reinforcements was numerically investigated by Sobhi and Wu (1996). The results indicated that the front displacements at failure increased with increasing reinforcement length, and also decrease with increasing stiffness.

The internal roughness of the pullout test box also plays a role in pullout tests interpretation. Palmeira and Milligan (1989) have suggested full lubrication of the internal walls of the test box, in order to reduce their influence on pullout test curves.

The exclusive influence of the front wall roughness was investigated by Sugimoto et al. (2001). The results of pullout tests with geogrids revealed that the higher the roughness of the front walls the higher the forces and displacements at the frontal end of the geogrid.

Dias and Palmeira (2007) carried out numerical simulations to evaluate the influence of full lubrication in comparison to an exclusively lubrication of the front wall. The results revealed higher pullout loads with the increase of the number of lubricated walls.

This paper presents the results of a numerical study aiming to contribute to the interpretation of pullout test on geotextiles. The study is focused on the influence of geotextile length and stiffness, soil-geotextile interface parameters and internal lubrication of test walls. The analyses were performed with a commercially available finite element software (Plaxis®).

2 NUMERICAL ANALYSES

The parametric study addressed different soil-interface conditions and geotextile properties. Test set up (geometry, dimension and load application system) and geomechanical parameters (soil and geotextile properties, shear strength of the interface soil-geosynthetic/test box) were defined according to pullout tests data described in the literature (Ferreira, 2009)

2.1 *Test description*

The geometry of the simulated pullout test is presented in Figure 1. The test box is 0.60m high and 1.0m long and was numerically represented by rigid plates. The 0.80m length geotextile specimen was positioned at the center of the soil mass. To avoid boundary effects, it was kept a distance of 20 cm between the geotextile rear end and the test box (Farrag et al, 1993).

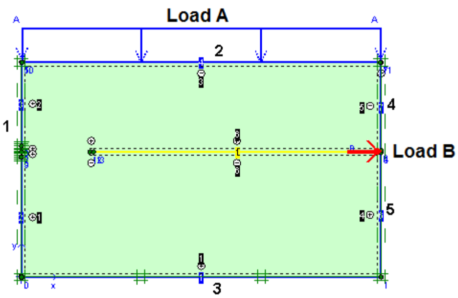


Figure 1. Model geometry.

The confining stress was simulated by a uniformly distributed load on the soil surface (load A). The horizontal load was simulated by single load acting at the frontal end of the geotextile (load B). Load application followed a stress controlled test and, therefore, post peak response was not simulated.

At the mesh boundaries, the horizontal movements were constrained at the vertical plates and no movement was allowed at the horizontal plate. A vertical spacing of 6mm between the two halves of the front wall, allowed free horizontal displacement of the geotextile.

2.2 *Constitutive models and material parameters*

The stress-strain behavior of the soil was modeled using by an elastic-perfectly plastic model and Mohr-Coulomb failure criterion. The geotechnical parameters were compatible with medium compacted sand.

The geotextile specimen was simulated by a flexible elastic element with axial stiffness (EA). The parameters were defined according to typical non-woven geotextile data.

Soil- geotextile interface was simulated by a particular element that incorporates a correction factor (R_{inter}) that minimizes the shear strength parameters of the soil adjacent to the reinforcement; by applying the following rules:

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

and

$$R_{inter} = \frac{\tan\delta}{\tan\phi} \leq 1{,}0$$

where: c_a = interface adhesion; c = soil cohesion; δ = interface friction angle; ϕ = soil friction angle.

Steel material parameters were used to simulate the box walls. Interface elements were also positioned at the contact between the soil and the test front wall to create a lubrication condition. A R_{inter} factor equal to 0.90 as adopted in the standard test, according the recommendation of Dias and Palmeira (2007).

Table 1 summarizes the parameters and constitutive models used in the numerical analyses.

Table 1. Constitutive models and material parameters.

Material	Constitutive model	Parameters
Sand soil	Mohr Coulomb	c' = 0
		ϕ' = 36º
		γ = 19.79kN/m^3
		E = 40MPa
		ν = 0.33
Geotextile	Linear elastic	EA = 500kN/m
		L = 0.8m
Plates	Linear elastic	EA = 210MN/m
		e = 0.002m
		ν = 0.15
Soil-Geotextile interface		R_{inter} = 0.60
Soil-Front wall interface		R_{inter} = 0.90

2.3 *Parametric Analyses*

The analyses were carried to evaluate the influence of reinforcement length and stiffness. The degree of strength mobilization at the interfaces soil-material was also assessed. Table 2 summarizes the parameters variation. The confining stress was considered constant and equal to 25kPa.

Table 2. Parametric analyses.

Parameter	Value		
Geotextile length (m)	0.6	0.8	1.0
Geotextile stiffness (kN/m)	50	500	5000
Soil-Geotextile interface	0.4	0.6	0.9
Soil-Front wall interface	0.4	0.6	0.9

3 RESULTS

3.1 *Influence of the geotextile length and stiffness*

The influence of the reinforcement length was evaluated by carrying out simulations with 0.6 m, 0.8 m and 1.0 m long geotextile specimens. Figure 2 shows the load *vs.* horizontal displacement curves corresponding to a point at the rear face of the reinforcement. The results show that the pullout resistance increases with increasing geotextile length. This response is particularly important in defining the anchorage length for the design of reinforced structures.

The horizontal displacement distributions along the reinforcement length are shown in Figure 3 and reveal that the frontal displacement increases with the increase of geotextile. Pullout test simulations with geogrids provided similar behavior (Dias and Palmeira, 2007).

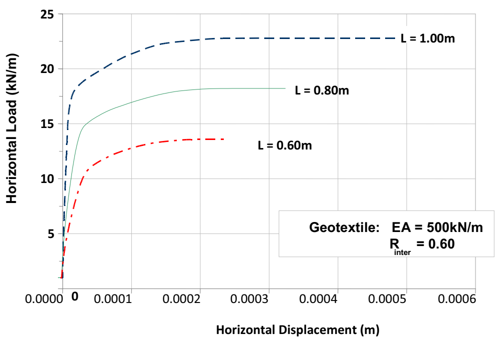


Figure 2. Influence of the geotextile length on the prediction of pullout force.

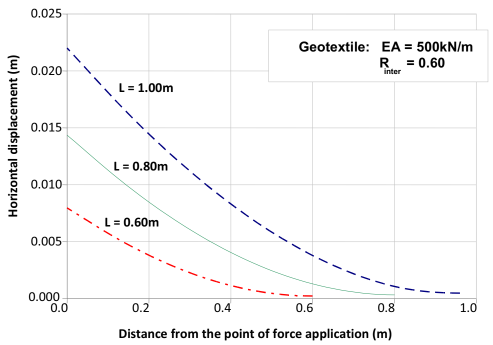


Figure 3. Influence of the geotextile length on the reinforcement displacements.

The influence of geotextile stiffness was evaluated by varying its axial stiffness from 50kN/m to 5000kN/m. Figure 4 shows the horizontal displacement *vs.* distance curves, corresponding to the different stiffness levels. The geotextile strain may be assessed by computing curves tangent. Stiffer reinforcements show lower deformation levels and a greater tendency to move as a rigid body. It is worthwhile to note that the greater the stiffness the lower the displacement needed to cause rupture by tearing (Sobhi and Wu. 1996).

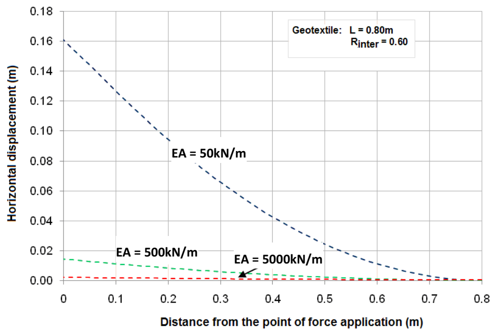


Figure 4. Influence of the geotextile stiffness on the reinforcement displacements.

3.2 *Influence of the Interface Soil-Geotextile*

Figure 5 shows the horizontal displacements along the reinforcement length for three different values of the shear strength reduction factor (R_{inter}). As would be expected, rougher interfaces (R_{inter} = 0.9) require larger geotextile strains to achieve failure.

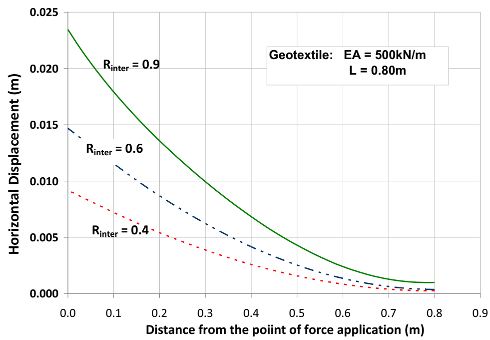


Figure 5. Influence of the degree of interaction between soil and geotextile.

The numerical prediction of the pullout loads, for different degrees of mobilization of the shear resistance at soil-geotextile interface, is shown in Figure 6. Smaller R_{inter} values implies in lower pullout resistances, due to the reduction of strength parameters of the surrounding soil.

3.3 *Influence of the soil-wall interface*

Pullout test results are affected by a number of factors associated to test arrangement. The influence of the test box constraints may be minimized by a complete internal lubrication (Palmeira and Milligan, 1989).

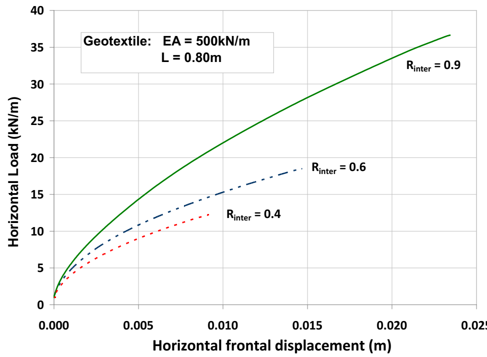


Figure 6. Influence of the soil-geotextile interface interaction on the pullout load.

The effect of the shear strength mobilization at the front wall was numerically evaluated by reducing the soil-wall interface parameter (R_{inter}) from 0.9 to 0.4; lower R_{inter} values correspond to lower friction mobilization. The results, shown in Figure 7, reveal that the more lubricated the front wall, the greater the required pullout loads. Nonetheless, the differences are less than 10%, and might be considered negligible.

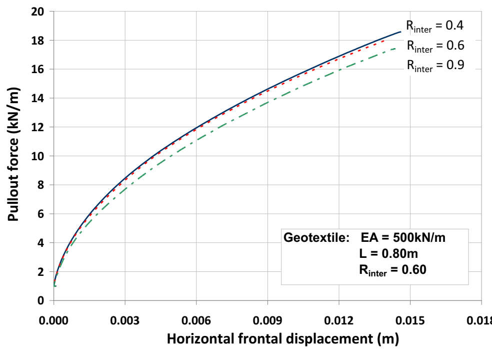
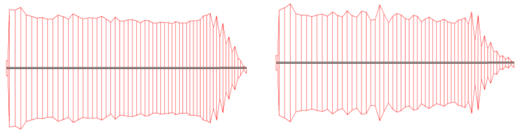


Figure 7. Influence of soil-front wall interface on the pullout load.

The smaller pullout resistance that was observed with a less lubricated box wall (R_{inter} = 0.9) was attributed to a loss of vertical stress due to shear strength mobilization at the soil-box wall interface.

Figure 8 shows the normal stress distribution along the reinforcement length and the corresponding average values, for two interaction conditions. The stress distribution shows small peaks that are attributed to numerical issues. The results support the suggestion that the higher R_{inter} value the lower the vertical stress that is transmitted to the geotextile. Accordingly, low normal stresses produce low pullout resistances, as indicated in Figure 7.



$\overline{\sigma_N}$ = 28.6 kN/m² (a) R_{inter} = 0.4

$\overline{\sigma_N}$ = 26.4kN/m² (b) R_{inter} = 0.9

Figure 8.: Normal stress distribution along geotextile length for different R_{inter} values.

4 CONCLUSIONS

This paper presented a parametric study aiming to discuss some factors that influence pullout tests on geotextiles. The main conclusions are:

- The displacement and the pullout load increases with the reinforcement length;
- Stiffer reinforcements experience less strain and show a tendency to displace as a rigid body;
- The higher the roughness of the front rigid wall the lower the vertical stress transferred to the reinforcement;
- Numerical simulation has shown to be an accurate tool to help engineers estimate pullout resistance for preliminary design of reinforced soil structures. But engineer experience must be exercised for the selection of appropriate parameters.

ACKNOWLEDGEMENTS

The authors gratefully thank the Brazilian research agencies (CNPq, CAPES and FAPERJ) for sponsoring this research project.

REFERENCES

Dias. A.C and Palmeira. E.M. 2007. Experimental and numerical study of the behavior of geogrids on large pullout tests (*in Portuguese*). REGEO. art 49.

Farrag. K.. Acar. Y.B. and Juran. I. 1993. Pullout resistance of geogrids reinforcements. *Geotextiles and Geomembranes*. Vol. 12. pp. 133-159.

Ferreira. L. H. T. 2009. Analytical and numerical models for simulation of pullout tests of geotextiles. (*in Portuguese*). MSc thesis. State University of Rio de Janeiro. 134p.

Koerner. R.M. (2005). Designing with Geosynthetics. New Jersey: Prentice-Hall. 761p.

Palmeira. E.M and Milligan. G.W.E. 1989. Scale and factores affecting the results of pull-out tests of grids buried in sand. *Geotechnique* 39 (3). p 511-524.

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.

Sugimoto. M.. Alagiywanna. A.M.N.. and Kadughi. K. 2001. Influence of rigid and flexible face on geogrid pullout test. *Geotextiles and Geomembranes*. Vol. 19. pp. 257-277.